Section 3-04
Culvert Design

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APPENDIX A

GLOSSARY OF TERMS

TERMS	DESCRIPTION
alignment (culvert)	Placement of the culvert with respect to the streambed and roadway.
allowable headwater depth (AHW)	Allowable depth of water upstream of a culvert, measured from the invert up to the allowable height of the water. AHW is established as a design control feature not to be exceeded during the design flood event. Can be set to reduce or avoid property flood damage, risk of life, or both.
allowable headwater elevation (AHE)	The water surface elevation that corresponds to the allowed headwater depth.
beveled end	A flare on the inlet end of a culvert to improve efficiency or capacity of the culvert. Beveled ends have a reduced inlet coefficient K_e.
capacity (hydraulic)	The effective carrying ability of a drainage structure. Measure of volume per time.
coefficient of runoff	Percentage of gross rainfall that appears as runoff. Used in the rational method for computing design runoff.
corrugated metal pipe (CMP)	Galvanized or aluminum sheet metal fabricated into a finished pipe shape.
critical depth (d_c)	The flow depth at which specific energy is minimum for a given flow rate. Flow at critical depth has a Froude number (Fr) = 1, a condition where flow is at the critical stage of changing from *tranquil* flow to *rapid* or *shooting* flow.
critical flow	Critical flow occurs when the water is flowing at critical depth, a condition where the Froude number (Fr) = 1. It defines the characteristics of flow as: 1. When the Fr is < 1, the flow is considered to be *subcritical,* also described as *slow* or *tranquil*. 2. When the Fr is > 1, the flow is considered to be *supercritical*, also described as *rapid* or *shooting*.
critical slope	Slope of channel or culvert where flow depth equals critical depth. Also described as where flow changes from *tranquil* to *rapid* or *shooting*.
critical velocity	Mean water velocity at critical depth.
design discharge	The discharge that a structure is designed to accommodate.
design flood	The peak discharge and total volume of flood associated with the probability of recurrence for a given drainage basin and culvert crossing.
design frequency	The recurrence of a storm event used for design purposes. Example, a design frequency of 50 years means a storm of a given magnitude has a 2 percent (1/50) chance of being equaled or exceeded in one year.
design storm	A storm event, with a specified probability of occurrence in any given year expressed in years or percentage, used as a design parameter. A particular storm that generates a design runoff, depth, duration, or frequency.

diameter (D)	Inside diameter of the culvert.
discharge	The volumetric rate of water flowing past a given point. Also, flow rate.
energy gradeline (EGL)	The line that represents the total amount of energy available at any point along a culvert. It is the potential energy expressed as the water surface elevation referenced to a datum and the kinetic energy, usually expressed as velocity head, at points along the streambed or culvert profile.
energy head	The sum of the hydraulic grade line at any section plus the velocity head of the mean velocity of the water in that section.
entrance loss	The head loss in eddies, contraction and friction at the inlet of the culvert.
flood frequency	Recurrence interval or return period of a given storm event. The percentage chance of occurrence is the reciprocal of flood frequency, e.g., a 2 percent chance of occurrence is the reciprocal for a 50-year flood event (1/50).
flow area	Cross-sectional area of flow calculated using the inside diameter of the culvert or channel cross-sectional area.
flow rate	Volume of water flowing per unit of time. Usually expressed as ft^3/sec or cfs.
Froude number	For rectangular or wide channels, $F = V/(gy_h)^{0.5}$ where F is the Froude number, a dimensionless number used to determine flow behavior. V is the average velocity of flow, g is gravitational accelerationand y_h is the hydraulic depth. If F is > 1.0, the flow is supercritical and is characterized as swift. If F is < 1.0, the flow is subcritical and is characterized as smooth and tranquil. If F = 1.0, the flow is said to be critical.
head (static)	The height of water above the datum.
headwater	The height of water at the inlet of the culvert.
height of cover	Distance from the crown (top) of the culvert to the road surface (including embankment and surfacing).
hydraulic capacity	The maximum flow of water that a culvert can continuously pass.
hydraulic grade line (HGL)	A line representing the total potential energy, a combination of energy from the height of the water and internal pressure. In open channels, this corresponds to the water surface profile.
hydraulic jump	A sudden transition from supercritical flow to subcritical flow.
hydraulic radius	The ratio of flow area to wetted perimeter.
hydrograph	A graph of the stage discharge over time.
inlet control	Culvert flow capacity determined by inlet shape characteristics and headwater depth.
invert	The flowline at the inside lowest point of a culvert cross section.
Manning equation $V = 1.49/n \times S^{1/2} \times R^{2/3}$	An empirical equation used to estimate friction loss and discharge in culvert design. Incorporates channel roughness, hydraulic radius and cross-sectional area of flow. Assumes uniform flow or gradually varied flow.

Manning's n	An empirical coefficient relating the effect of channel boundary or culvert roughness to energy loss in flowing water.
rational method	A method to estimate the rate of storm runoff based on an intensity-runoff relationship: Q = CIA. C is the coefficient of runoff of an area, I is the rainfall intensity during the time of concentration and A is the drainage area.
runoff	Precipitation and snowmelt runoff flow.
scour	Degradation of channel at the culvert outlet as a result of erosive velocities.
skew (culvert)	Culverts that are set perpendicular (90°) to the roadway centerline are considered normal crossings with no skew angle. The acute angle formed between a line that is perpendicular to the roadway centerline and the centerline of the culvert is the skew angle of the culvert.
slope	(1) The gradient of a stream; (2) inclination of the face of an embankment, expressed as the ratio of the vertical to horizontal (V:H) projection.
subcritical flow	Flow at velocities less than critical, with a Froude number less than 1.0. Gravity forces are more pronounced than inertial forces. Flow has a lower velocity and is often described as steady, tranquil, or streaming.
supercritical flow	Flow at velocities greater than critical, with Froude number greater than 1.0. Inertial forces are dominant, so flow has a higher velocity and is usually described as rapid or shooting.
tailwater depth	Depth of water immediately downstream from the culvert, measured from the culvert outlet invert.
tailwater elevation	The water surface elevation immediately downstream from the culvert, measured from a datum.
time of concentration	Time required for storm runoff to flow from the most remote point of a drainage area to the point of concentration. It is usually associated with a design storm.
wetted perimeter	The cross-sectional length of wetted contact between the water prism and the culvert or channel bottom.

SECTION 1 - INTRODUCTION

General: This chapter provides the fundamental principles for designing roadway culverts, channel changes and storm sewers in accordance with WYDOT's operating policies. The overview **DOES NOT** cover all the principles of coding or running software design programs. Designers are referred to WYDOT's Culvert Design System (CDS) software manual and to standard hydraulics and hydrology textbooks for more detailed information.

Operating Policy 18-6, Drainage Design for Highway Systems, provides the procedures and defines the program responsibilities for the design of drainage structures on the highway system. The process is implemented through the technical practices and procedures provided by the Bridge Program, Hydraulics Section and Project Development. The Hydraulics Section performs the hydrology and determines the drainage classification and structure type for all drainage basins.

SECTION 2 - DESIGN RESPONSIBILITIES

General: Project Development designs Type 1 structures, which are defined as "culverts having comparatively low construction and maintenance costs." The responsibilities are further defined based on Operating Policy 18-6, Drainage Design for Highway Systems, for Class I, II, III and IV Designs, as follows:

Storm Sewer Design:
- Class I Designs: The Hydraulics Section develops and details the initial storm sewer design, which includes the basin hydrology, pipe hydraulics, pipe sizes, inlet locations, etc., for Project Development's use in developing the final plans. Project Development completes the storm sewer details which includes determining the location of manholes, inlet boxes, laterals, trunklines, plan quantities, summaries, etc. If it is necessary to change or modify the initial storm sewer layout due to utility conflicts or other design constants, the Hydraulics Section will update the storm sewer model based on the plan changes. Project Development would include any resulting changes in pipe sizes, etc., in the plans.

Culvert Design:
- Class II Designs: The Hydraulics Section is responsible for sizing and determining the structure type when the structure opening is equal to or greater than 35 ft^2 [3.25 m^2]. When the structure type is determined to be a commercial culvert, Project Development is responsible for the final plan details including a pipe cross-section, culvert length, grade, plan quantities, summaries, etc.

- Class III Designs: Project Development is responsible for the design of commercial culverts with openings of less than 35 ft^2 [3.25 m^2].

- Class IV Designs: Project Development is responsible for designing culverts at locations where the District requests or accepts a single barrel 24-inch [610 mm] round pipe (or equivalent).

Basin Hydrology: The Hydraulics Section provides the basin hydrology analysis and discharge (Q) for all drainage crossings. Project Development is responsible for initiating the request for the project basin hydrology by compiling a listing of the project drainage sites in the form of an Excel spread sheet as indicated in Exhibit 1. After completing the drainage site information, Project Development should e-mail the Excel spread sheet to the District (if needed) and Hydraulics Section, requesting them to provide the corresponding hydrology data.

REQUEST FOR HYDROLOGY DATA
PROJECT NO: 252140 & 252153,   NAME: EL RANCHO SECTION, R. M. 94.18 - R. M. 100.82

						INFORMATION PROVIDED BY						
	PROJECT DEVELOPMENT			DISTRICT*	BRIDGE-HYDRAULICS SECTION							
Station	Existing Size and Type	Drainage, Irrigation, or Unknown	Remarks	Water Right Discharge ft³/sec	Hydrologic Region	Drainage Area Acres	Basin Slope	Q50	Q100	V50	V100	Drainage Area sq mile
567+99.17			South Bear Creek structure (NBL)		1988 Plains	2820	500	1039.55	1366.31	129.84	129.84	4.406
567+99.59			South Bear Creek structure (SBL)		1988 Plains	2820	500	1039.55	1366.31	129.84	129.84	4.406
578+16.64	54 in CMP	Drainage			1988 Plains	559	500	432.18	568.03	38.70	38.70	0.873
582+61.88	36 in RCP	Drainage	Inlet West of SBL outlet median		1988 Plains	36.1	500	68.20	89.64	4.98	4.98	0.056
582+62.96	36 in RCP	Drainage	Inlet median outlet East of NBL		1988 Plains	39.4	500	72.91	95.82	5.32	5.32	0.062
590+99.86			Cassa Interchange structrure (NBL)		1988 Plains	30.2	500	59.42	78.10	4.36	4.36	0.047
590+99.94			Cassa Interchange structrure (SBL)		1988 Plains	26.5	500	53.63	70.49	3.96	3.96	0.041
594+23.92	30 in RCP	Drainage	Inlet median outlet East of NBL		1988 Plains	82.8	500	125.72	165.23	9.27	9.27	0.129
594+75.93	30 in RCP	Drainage	Inlet West of SBL outlet median		1988 Plains	81.5	500	124.32	163.39	9.17	9.17	0.127
598+96.65	24 in RCP	Drainage	Inlet median outlet West side SBL		1988 Plains	2.8	500	7.50	9.85	0.74	0.74	0.004

*Provide Water Right information for all listed irrigation crossings.

Average Basin Slope use Geographic Factor=1

P/D file path: k\025140\Summary\Hydrology_data.xls

EXHIBIT 1
REQUEST FOR HYDROLOGY DATA

SECTION 3 - CRITERIA FOR DRAINAGE DESIGN
General: There are several items that must be considered in addition to determining culvert sizes. Culvert design requires that the overall configuration of roadway and culvert elements be set to convey the design runoff with the highest efficiency possible in terms of alignment, grade, size of culvert, fill cover, headwater depth, tailwater depth, flood routing, velocities, erosion control, corrosion protection, flood impact, construction/maintenance costs, etc.

Drainage design generally begins with the issuance of Preliminary Plans, which includes the project mapping, preliminary roadway alignment, earthwork and cross-sectional elements. The basic criteria required for culvert design includes the following items:

1. Corrosion resistance number and type of culvert required,

2. Flood frequency for design and review,

3. Minimum and maximum cover,

4. Culvert shapes, type and end treatments,

5. Culvert alignment,

6. Culvert cross-sections,

7. Culvert plan elements,

8. Culvert hydrology,

9. Culvert hydraulics,

10. Flood routing with CDS,

11. Channel change design,

12. Storm sewer layout and details, and

13. Erosion protection.

Corrosion Resistance: Soil samples are taken at each culvert crossing or storm sewer location and submitted to the Materials Program where alkali tests are run to determine the soil's corrosion classification number (CR1 through CR9). Higher CR numbers are more corrosive and require the use of corrosion resistant pipe.

The *Standard Specifications for Road and Bridge Construction* provides a "Corrosion Resistance Acceptability" table that indicates by a "Yes" or "No" if a culvert is suitable for installation in soil with a particular CR number. For example, CR1 indicates a low corrosive soil that would permit the use of any type of pipe, but a CR6 number is a highly corrosive soil that would require the installation of a concrete pipe manufactured with alkali resistant cement or coating. The Materials Program provides a report listing the CR numbers to Project Development. The CR numbers are included in the Culvert, Storm Sewer, and Structural Plate Pipe Summaries. When using Structural Plate Pipe, contact the Materials Program for special requirements that may apply such as bituminous coatings, increased gage thickness and use of granular backfill material.

The Contractor is required to supply pipe of the specified type that meets or exceeds the CR number given in the summaries.

Flood Frequency: In general terms, flood frequency is the probability that a particular flood event will occur during any given year. The greater the flood, the higher the frequence value but the less probability of occurrence. The recurrence interval (or return periods) is the average interval of time, expressed in years, within which the given flood will be equaled or exceeded at a particular location. *Thus, a flood having a return period of 100 years (or a 100-year flood) has a 1 percent probability of happening in any given year.* It is a statistical computation and does not mean that a flood of this magnitude will happen only once every 100 years. The occurrence of a flood in a given return period does not affect the probability of such a flood occurring again the next year.

Exhibit 2 is a list of the typical flood frequencies used for drainage design and property flood analysis.

FLOOD FREQUENCY IN YEARS	% OF PROBABILITY IN ANY GIVEN YEAR
2	50%
5	20%
10	10%
25	4%
50	2%
100	1%

EXHIBIT 2
FLOOD FREQUENCY

The flood frequencies used by WYDOT are based on risk assessment of costs associated with injury, loss of life, property damage, etc, and vary according to the following highway classifications, structure type and traffic volumes:

- Urban arterials and collectors,
- Rural arterials,
- Rural collectors,
- Structure Type 1 or 2, and
- Traffic Volumes - ADT >750 or ADT <750.

The design engineer must select the appropriate ***Flood Frequency Year*** to be used from the tables in Operating Policy 18-6, Drainage Design for Highway Systems. The flood frequency year is used to determine the drainage area runoff in cubic feet per second (cfs) [m^3/sec] and total volume in acre-feet (ac-ft) [m^3]. Higher flood frequencies produce higher drainage runoff volumes. For example, Exhibit 3 is a listing of the flows and volumes produced by the hydrology portion of CDS for the 5, 10, 25, 50, and 100 year flood frequencies, when applied to the same drainage basin:

BASIN CRITERIA	CDS FLOW AND VOLUME		
	Flood Frequency	cfs	ac-ft
• High Desert Region • Drainage Area = 19.2 acres • Annual Precipitation =14 inches • Geographic Factor = 0.8	5	8.1	1.48
	10	13.9	1.94
	25	26.2	2.60
	50	37.7	3.11
	100	52.8	3.64

EXHIBIT 3
CDS FLOOD FREQUENCY FLOWS & VOLUMES

Minimum and Maximum Cover: Culvert failure can be caused by too much or not enough overlaying material. Therefore, it is necessary to design each culvert crossing to meet the minimum and maximum fill height requirements specified for the type of culvert being used. WYDOT Standard Plans give allowable fill heights for various types of culverts.

When a culvert has less than minimum cover, the applied load is not spread over a large enough area and the culvert can fail structurally due to concentrated live loads. If the maximum fill height is exceeded, a culvert can fail structurally by collapsing due to the weight of the overlaying embankment and surfacing materials.

The designer must check the actual minimum and maximum cover at each pipe section to make sure the allowable fill heights are not violated. The fill height measurements include the surfacing material, as shown in Exhibit 4.
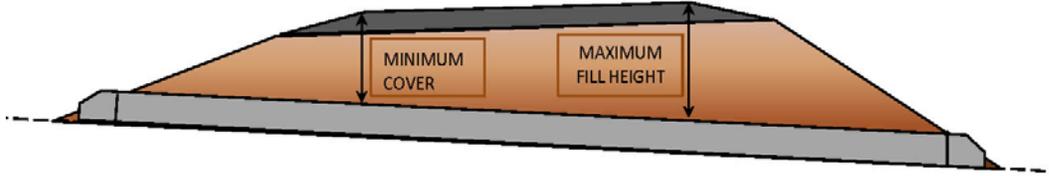
EXHIBIT 4
MINIMUM AND MAXIMUM COVER

The maximum fill height measurement (ft) or [m] is shown in the Culvert Summary. The contractor must supply a culvert type from the Standard Plans that has an allowable fill height greater than or equal to the maximum fill height given in the Culvert Summary. Therefore, the designer must make sure that a "solution is possible," i.e., that some culvert of the specified type and size has an allowable fill height greater than or equal to the maximum fill height given in the Culvert Summary. *Minimum fill heights are not given in the Culvert Summary, but the designer is responsible for ensuring that minimum cover requirements are met for all culverts.*

The allowable minimum cover and maximum fill height requirements for CMP are shown below in Exhibit 5 as an example only. The designer should use the appropriate tables provided in the Standard Plans:

ROUND CORRUGATED STEEL PIPE								
2 2/3 IN X 1/2 IN CORRUGATIONS								
RIVETED, WELDED, OR HELICAL FABRICATION								
PIPE DIAMETER	WATERWAY AREA	TOP OF PIPE TO TOP OF SURFACING	RIVET PATTERN *	PLATE THICKNESS				
				0.064 IN	0.079 IN	0.109 IN	0.138 IN	0.168 IN
				16 GA.	14 GA.	12 GA.	10 GA.	8 GA.
IN	FT^2	IN	RIVETS PER FT.	MAX. FILL HEIGHT ABOVE TOP OF PIPE (FT)				
15	1.2	21	4.5	74	81	100	100	100
18	1.8	21	4.5	62	67	87	91	95
24	3.1	21	4.5	46	51	65	68	71
30	4.9	21	4.5	37	40	52	54	57
36	7.1	21	4.5	31	34	43	45	47
42	9.6	21	9	34	47	74	78	81
48	12.6	21	9	30	41	65	68	71
54	15.9	21	9	-	37	58	60	63
60	19.6	21	9	-	-	52	54	57
66	23.8	21	9	-	-	-	49	52
72	28.3	21	9	-	-	-	45	48
78	33.2	21	9	-	-	-	-	44
84	38.5	21	9	-	-	-	-	41

*FOR 14 AND 16 GAGE THICKNESS; USE 5/16 IN RIVETS.

FOR 8, 10 AND 12 GAGE THICKNESS; USE 3/8 IN RIVETS.

FOR 15 IN THRU 36 IN DIA.; USE SINGLE RIVETS.

FOR 42 IN THRU 84 IN DIA.; USE DOUBLE RIVETS. (TABLE VALUE INCLUDES BOTH ROWS)

NOTES FOR STEEL AND ALUMINUM PIPE

DO NOT EXCEED MAXIMUM OR MINIMUM COVER REQUIREMENTS.

FOR APPROACHES ONLY, MINIMUM COVER FOR 15 IN [375] THROUGH 24 IN [600] DIAMETER PIPE MAY BE 1 FT [300].

EXHIBIT 5

CMP - MINIMUM AND MAXIMUM ALLOWABLE FILL HEIGHTS

SECTION 4 - CULVERT SHAPE, TYPE AND END TREATMENT

General: There are numerous cross-sectional shapes available for culverts and end treatments. Commonly used shapes and end treatments are shown in Exhibit 6.

EXHIBIT 6
CULVERT SHAPES AND END TREATMENTS
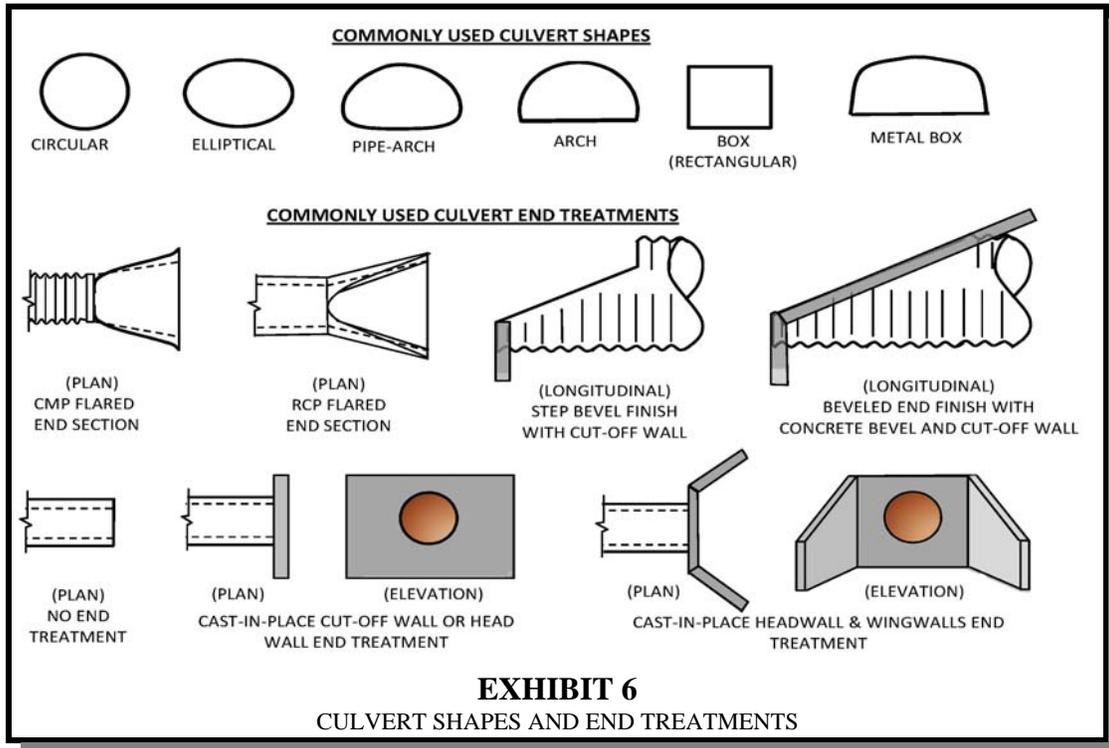
Type of Culvert: Selecting the shape and type of culvert depends on several factors, such as the corrosiveness of the soil at the culvert site, maximum depth or minimum fill cover, limitation of upstream water surface elevation, hydraulic performance, etc. Common types of rigid and flexible culvert used by WYDOT include the following:

Rigid: Reinforced concrete pipe (RCP)
                   Horizontal elliptical reinforced concrete pipe (HERCP)
                   Reinforced concrete box (RCB)
                   Reinforced concrete pipe arch (RCP arch) - Used in special cases
                   Structural plate pipe (SPP) - Typically used for stock passage

Flexible: Corrugated steel pipe (CSP)
                   Corrugated aluminum alloy pipe (CAP)
                   Corrugated metal pipe (CMP)
                   CSP arch, CAP arch, or CMP arch - Used in special cases

The most widely used types of commercial culverts are the CMP and RCP. These types of culvert installations are made up of a series of tubular sections (normally supplied in even 2 ft [610 mm] increments) laid end to end. CMP sections are connected with bands that encircle the joints and the RCP sections have tongue and groove joints.

At locations where very large diameter culverts are required for large flows or stock passage, a structural plate pipe (SPP) would typically be used. The SPP is made up of curved corrugated metal plates that are bolted together.

Unless site conditions require the installation of a particular type of pipe, *WYDOT bids all culverts as a generic "Pipe" bid item, as long as all requirements given in the plans are met.* This allows the Contractor to supply any type of culvert (CMP or RCP) having a CR number that meets or exceeds the CR number given in the Culvert Summary. For example, if a particular site requires a corrosion resistance acceptability of CR4, then the Contractor would have to provide and install one of the acceptable options provided in the *Standard Specifications for Road and Bridge Construction*. In this case, the Contractor would most likely provide an RCP (Type II cement) culvert.

Culvert End Treatments: Selection of an appropriate end treatment can reduce erosion, undercutting and improve hydraulic efficiency.

Commercial flared end sections are used on most culverts. They improve inlet and outlet loss by smoothly funneling the flow into and out of the culvert. In some cases, use of an improved culvert inlet can actually reduce the culvert size. When commercial flared ends are not available or there is a particular site requirement, other types of end treatment can be used such as the following:

-      <u>Concrete Head/Wing Wall</u>: Typically used for larger single or multiple installations to retain the roadway embankment and provide a vertical face at the culvert ends where there is not room for tapered end sections or to prevent undercutting or piping at the inlet and outlet ends.

-      <u>Cut-Off Wall</u>: Typically used on metal pipe with step bevel or bevel end finishes to retain slopes and prevent undercutting or piping at the inlet and outlet ends.

Each end treatment and type of pipe has different head losses that influence the hydraulic efficiency of the culvert. CDS software allows the designer to select coefficients based on the type of end treatment and pipe being used. See the CDS user's manual for **entrance and culvert type coefficients**. Exhibit 7 shows the typical "Inlet Codes" for corrugated circular culverts.

CORRUGATED CIRCULAR CULVERT INLET CODES					
INLET TYPE	**RIVETED**	**RIVETED 25% PAVED**	**STRUCTURAL PLATE**	**STRUCTURAL PLATE 25% PAVED**	**ENTRANCE COEFFICIENT**
Projecting	21	22	23	24	0.9
Headwall	41	42	43	44	0.5
End Section	51	42	53	54	0.5
Bevel (A) R/D = 0.067	61	62	63	64	0.2
Bevel (B) R/D = 0.033	71	72	73	74	0.2
Mitered	81	82	83	84	0.7
Manning's N	0.024	0.021	0.032	0.026	----

EXHIBIT 7
PIPE AND INLET CODES

Standard designs for cut-off walls and beveled finishes are given in the Standard Plans. End treatment with wingwalls are typically designed by the Bridge Program.

SECTION 5 - CULVERT ALIGNMENT

General: Determining the culvert alignment is critical to the function of the culvert and drainage channel. If possible, the inlet and outlet of the culvert should be located in the channel where the roadway fill slopes intersect the natural channel bottom. In cases where the crossing is severely skewed (from a 90° crossing), an alternate alignment with channel changes can be used to reduce the skew angle and culvert length. When selecting an alignment, try to avoid sharp upstream or downstream bends in the channel.

Locating the culvert outside of the natural drainage channel often increases the potential for erosion or silting problems. Construction cost savings by minimizing the length of the culvert is typically offset by the cost of ongoing maintenance.

The intersecting point of the culvert alignment and roadway centerline station is the station of the culvert location. Culverts are installed on a straight line. The station of the culvert may not be at the same location where the drainage channel crosses the roadway centerline. Exhibit 8 shows some preferred options for culvert alignments.

CULVERTS LOCATED IN NATURAL CHANNEL
(RECOMMENDED)

CULVERTS WITH CHANNEL CHANGES

EXHIBIT 8
PREFERRED CULVERT ALIGNMENT
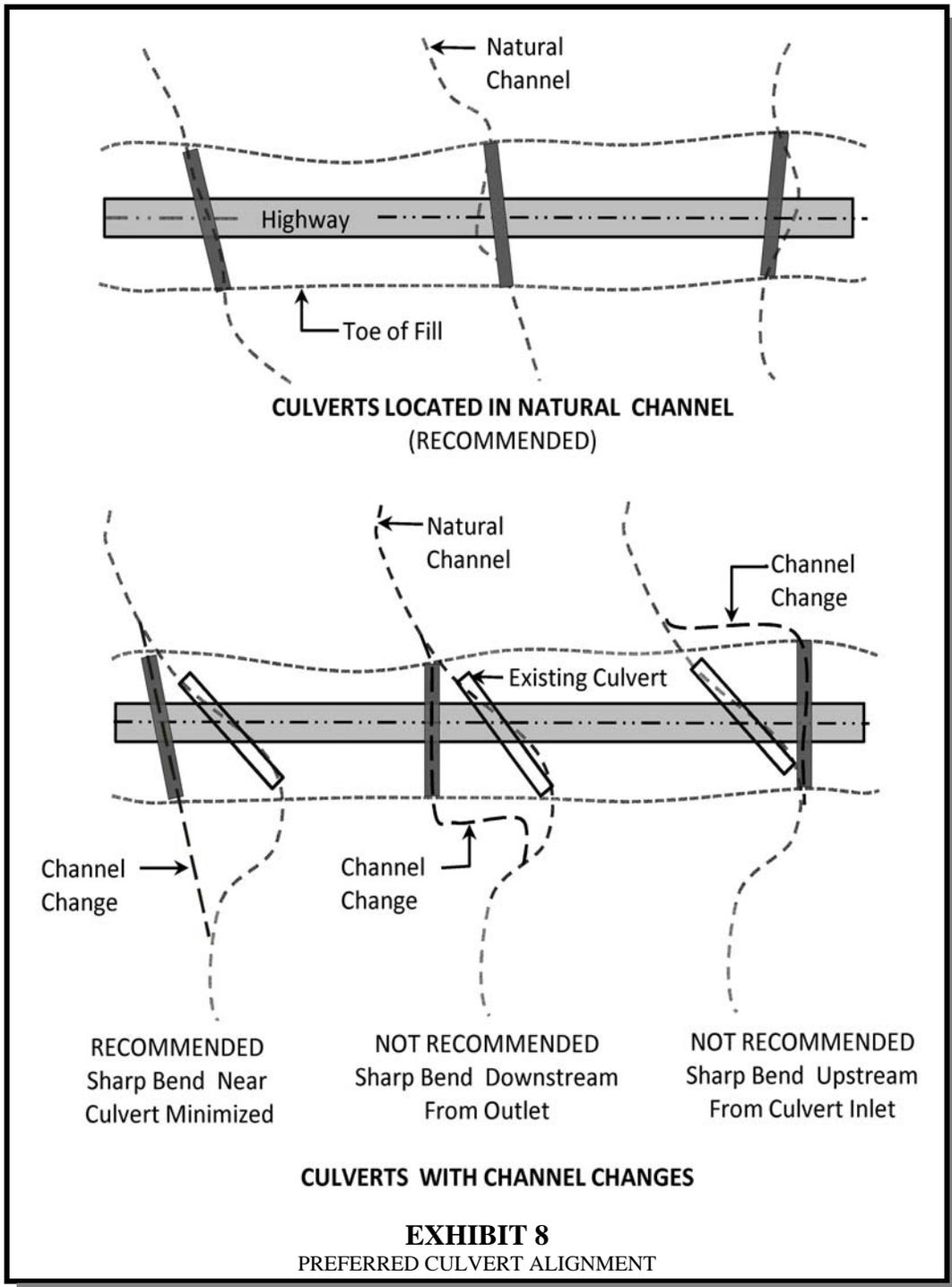
Most culverts can be located in the natural channel without channel changes. When setting the culvert alignment, do not rely on the graphical intersection of the fill slope lines with the channel alignment. The fill slope lines shown in plan view are straight

line approximations drawn between the slope stake catch points that are located at each regular cross-section interval. Additional cross-sections will have to be added perpendicular to the alignment that intersects the channel bottom to calculate the correct catch points, culvert length and flowline elevations. Exhibit 9 illustrates the need for additional perpendicular and skewed cross-sections to determine the correct culvert alignment.

EXHIBIT 9
ADDITIONAL PIPE CROSS-SECTIONS
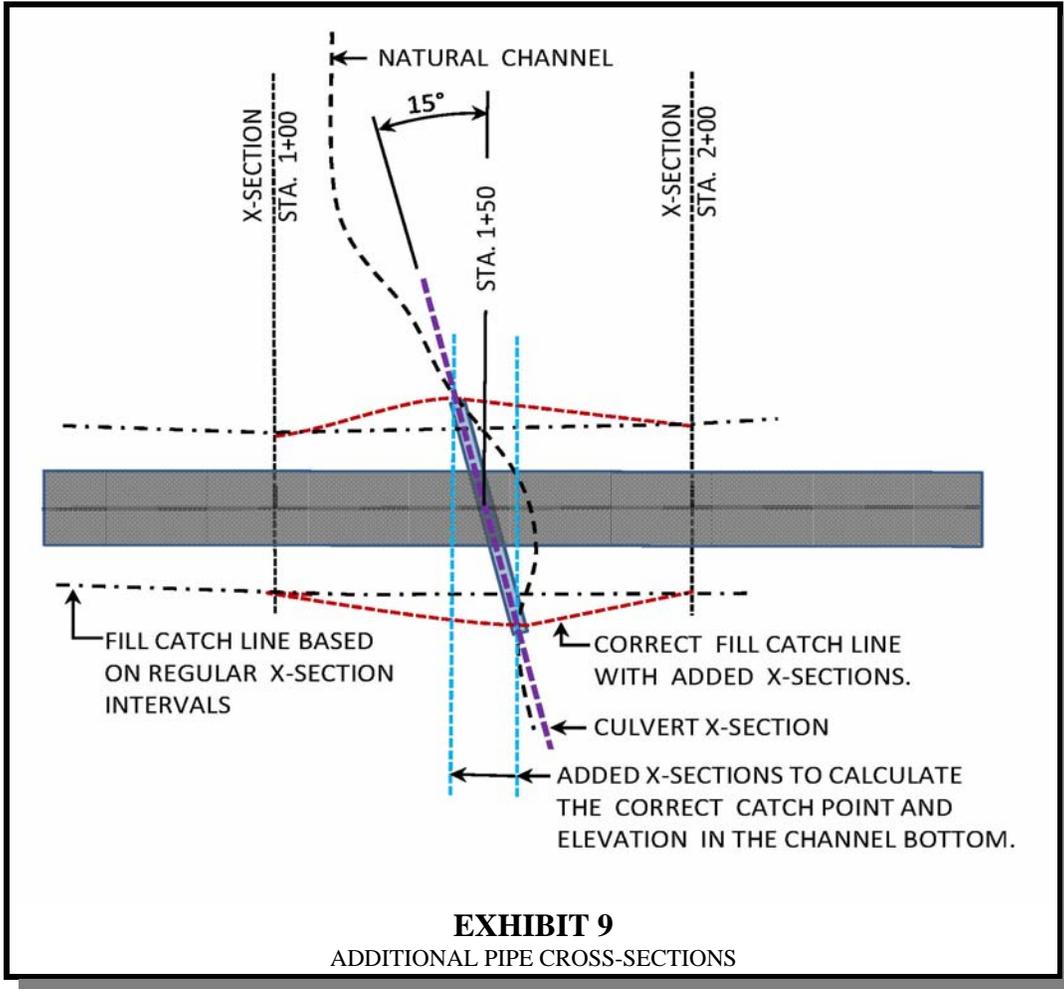
Minor channel changes for small drainage areas with intermittent flows are acceptable providing there is not an excessive increase in channel slope or velocities that disrupt channel stability. Channel changes on large drainage areas or live streams should be avoided when possible to minimize the impacts that could damage wetlands or fish habitat, reduce the stream side environment, or increase flow velocities, etc.

SECTION 6 - PIPE CROSS-SECTIONS

General: A detailed pipe cross-section is developed for drainage crossings that require new culvert installations or pipe extensions. Collectively, these sections are referred to as the "pipe cross-sections."

The pipe cross-section is used to determine initial culvert length, inlet/outlet elevations, slope (S) and allowable headwater (AHW) elevation, which are key input elements used in calculating the culvert diameter.

After the culvert diameter has been determined, the pipe cross-section is completed. The actual culvert and end treatment are shown on the cross-section (to scale) along with other applicable information, such as culvert subexcavation, fill height, size, length, final pay quantities, etc. When drawing the actual culvert, set the end treatment to fit the roadway fill slopes and round the final culvert length up to the nearest 2 ft [610 mm] increment. The total number of pipe cross-section sheets is shown in the Index of Sheets on the plan title sheet. Minimum typical data to be included on the pipe cross-section sheets includes the following:

Data Typical to Each Sheet:

•   Sheet heading: Wyoming Department of Transportation,
•   Project No., Sheet No., date and scale. Shown in upper right corner,
•   Project name;
•   Scale: Show horizontal scale (ft) [m] across bottom of each sheet,
•   Scale: Show vertical scale elevation (ft) [m] along both sides of each section.

Data Typical to Each Pipe Cross-Section:

•   Centerline station and profile grade elevation,
•   Skew angle,
•   Cross-section embankment slope,
•   Pipe grade slope in ft/ft [m/m],
•   Fill height (maximum or minimum cover over the top of pipe including surfacing),
•   Length and diameter of pipe (round length up to nearest 2 ft [610 mm] increment),
•   End treatment type and size,
•   Applicable quantities, such as culvert excavation, erosion control (riprap), subexcavation, etc., and
•   Outlet and inlet flow line elevations, offset distance to centerline and coordinates (N, E) when requested by the Resident Engineer.

During the bidding process, copies of the pipe cross-sections are made available for purchase when requested by the bidder.

Exhibit 10 shows an example of a typical pipe cross-section that is developed for each drainage crossing.

EXHIBIT 10
TYPICAL PIPE CROSS-SECTION
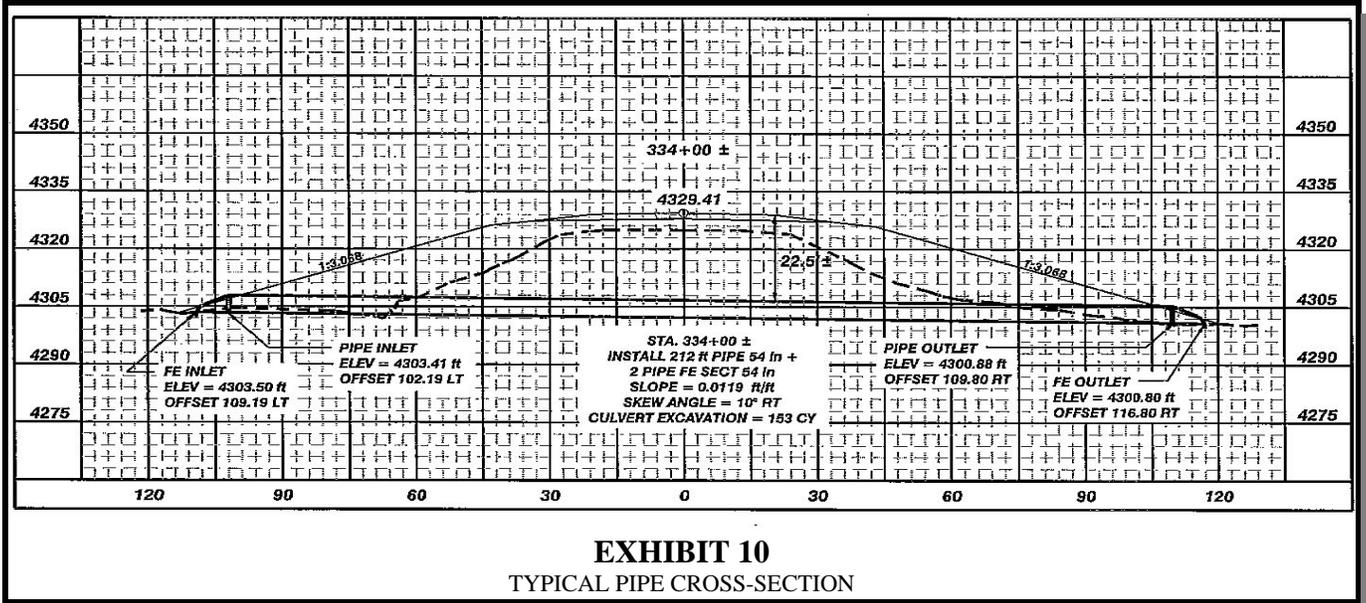
Once the culvert diameter is known, the length is set to fit the roadway fill slopes. The guidelines provided in Exhibit 10A can be use to determine the final culvert length in most cases. However, sites with large culverts, step beveled ends, excessive skew angles, very flat roadway slopes and steep pipe grades will require the designer to custom set the culvert length to best fit the conditions.

EXHIBIT 10A
GUIDELINES FOR DETERMINING PIPE LENGTH
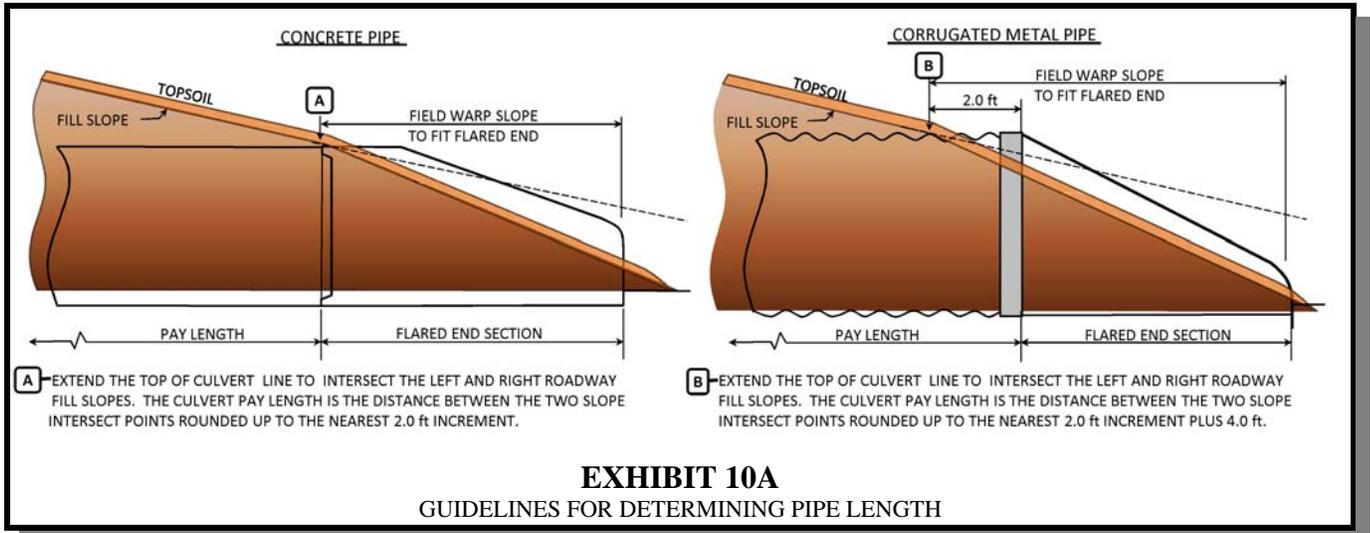
SECTION 7 - CULVERT PLAN ELEMENTS

Once the culvert design is completed, show the typical culvert geometry, station, culvert size, etc., on the plan and profile sheets for each crossing, as shown in Exhibit 11.

EXHIBIT 11
PLAN & PROFILE SHEET CULVERT DATA
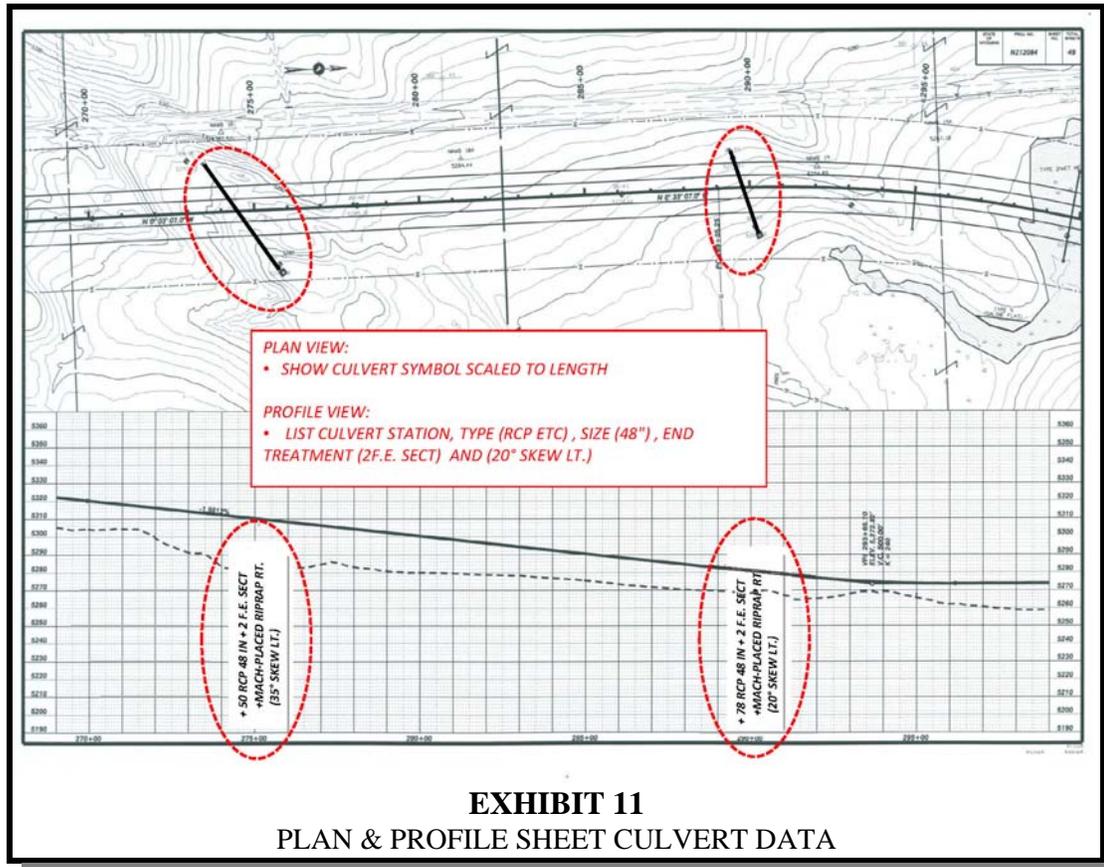
SECTION 8 - BASIN AND CULVERT HYDROLOGY

General: Project hydrology is the flood frequency relationship applicable to a given drainage area and culvert crossing. The principles of hydrology are used to determine the flow, based on the design frequency, that a culvert must carry.

For any given drainage basin, the peak flow due to naturally occurring rainfall events vary from event to event, year to year, etc. The variation of rainfall events are expressed in terms of a recurrence interval or a flood frequency as defined in SECTION 3 - CRITERIA FOR DRAINAGE DESIGN, Flood Frequency. Culvert design is based on a specific flood frequency year of 5, 10, 25, 50, 100, etc., per Operating Policy 18-6. The design process includes the hydrology for the drainage basin flow as well as the flow through the culvert system:

• The **Basin Hydrology** requires the determination of the basin area and peak flow for the given design flood frequency.

• The **Culvert Design** requires sizing of the culvert to carry the basin flow.

Basin Size and Peak Flow: This section is an overview of the process that the Hydraulics Section performs when calculating the basin size and peak flow. Determining the basin size is the first step in culvert design. Any scaled contour mapping with sufficient coverage can be used to determine the basin size. In most cases, USGS contour mapping is used when the project mapping is not adequate. Exhibit 12 shows a typical drainage delineation.

EXHIBIT 12
DRAINAGE BASIN DELINEATION
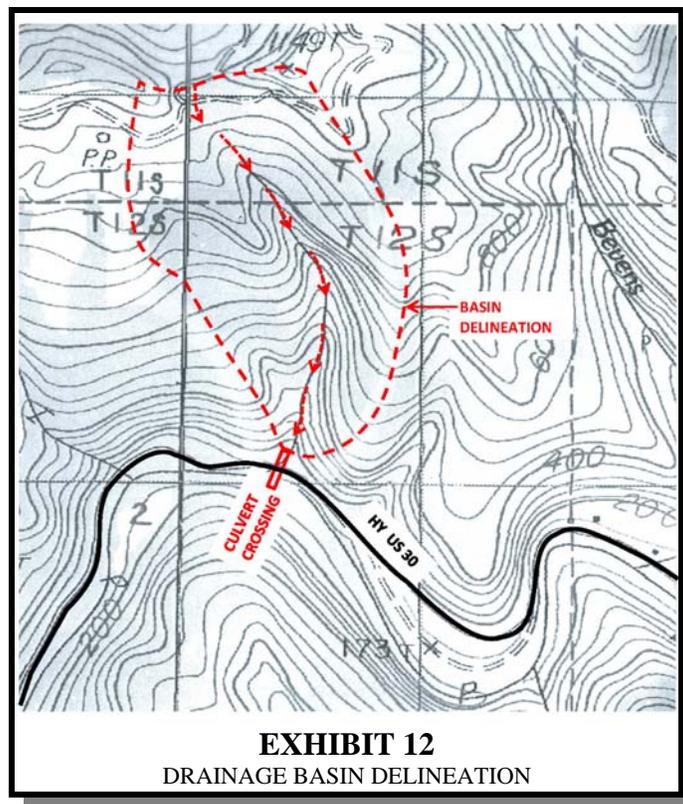
Drainage basin boundaries are established for each culvert crossing by tracing along the contour ridge lines of the basin. The area within the basin boundary is calculated in acres or square miles. When electronic mapping is available, the basin boundary and area can be developed on the computer. When electronic mapping is not available, the basin boundaries are hand traced on the mapping and the area is determined by using a planimeter. Once the area is determined, the basin flow can be calculated by using regression equations.

Regression Equations: Using statistical methods of actual stream flow data, basin characteristics and regional relations, the U.S. Geological Survey (USGS) has developed several sets of regional equations to predict the peak flow (cfs) and total runoff volumes (acre-ft) for drainage basins within Wyoming. USGS equation sets developed in 1988 and 2003 are contained in WYDOT'S CDS computer program. The following is an example of the regression equation set for a <u>High Desert Region</u> (USGS Report 1988-4045):

$$P_{10} = 13.8 \times A^{0.55 \times A^{-0.03}} \times PR^{0.90} \times G_f$$

$$P_{25} = 19.4 \times A^{0.53 \times A^{-0.03}} \times PR^{0.98} \times G_f$$

$$P_{50} = 24.2 \times A^{0.52 \times A^{-0.03}} \times PR^{1.02} \times G_f$$

$$P_{100} = 30.1 \times A^{0.51 \times A^{-0.03}} \times PR^{1.05} \times G_f$$

Where:
P_t = *annual peak flow in cfs (Q), subscript t designates the recurrence interval*
A = *contributing drainage area, in square miles*
PR = *average annual precipitation, in inches*
G_f = *geographic factor*

For example, if a drainage basin is determined to have the following characteristics or CDS input items:

- High desert region = 2
- Drainage area = 19.2 acres
- Annual precipitation = 14 inches
- Geographic factor = 0.8
- Design flood frequency = 25 years

Then CDS would determine the basin hydrology for a 25-year flood frequency and generate the following peak flow and total runoff volume.

- Peak flow = 26.2 cfs
- Total runoff volume = 2.60 acre-ft

The runoff volume is equal to the total area under the basin hydrograph.

The following example shows the manual calculation of equation P_{25}:

Convert 19.2 acres to square miles: $A = \dfrac{19.2 acres}{640 acres \big/ sqmiles} = 0.03 sqmiles$

Using Equation: $P_{25} = 19.4 \times A^{0.53 \times A^{-0.03}} \times PR^{0.98} \times G_f$

$P_{25} = 19.4 \times 0.03^{0.53 \times 0.03^{-0.03}} \times 14^{0.98} \times 0.8$

$P_{25} = 19.4 \times 0.1269 \times 13.280 \times 0.8 = 26.2 cfs$

The Hydraulics Section will select either the 1988 or 2003 equation sets based on the project's location and how the basin region is divided.

Project Development is responsible for requesting the basin hydrology information as defined in SECTION 2 - DESIGN RESPONSIBILITIES, Basin Hydrology. The Hydraulics Section develops all the project-related basin hydrology and the District field offices provide irrigation water right flow information. After receiving the basin hydrology, Project Development uses the information to design the culvert crossing.

Culvert Hydrology: Sources of water flowing through culverts include:

1.   Basin flow from thunderstorms,
2.   Flow from snow melt,
3.   Irrigation flow (design for double the water right), and
4.   Year-around flow in a stream or river channel.

Project Development designs culverts with flow sources 1, 2, and 3. There are two types of culvert design: ***hydrograph design*** and ***peak flow design***, depending on the source of water flowing through the culvert.

Hydrograph Design (Stage-Storage Design): Use when the design flow through a culvert is due to a rainfall event, where the flow varies with time, starting at zero, increasing to a peak (Q_{peak}) and decreasing to zero flow.

- The Q versus Time flow relationship is known as a hydrograph.
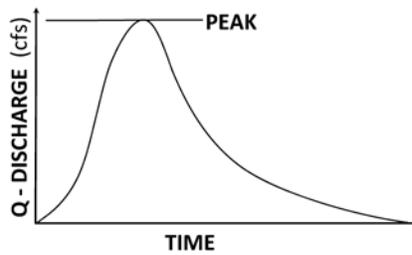
EXHIBIT 13
HYDROGRAPH

- Total volume (usually expressed in acre-ft) of flow through the culvert is equal to the area under the discharge hydrograph.

- Due to the flow being time related, the culvert can be sized to take advantage of the upstream storage to decrease the peak flow through the culvert, which is known as "flood routing," " hydrograph design" or "stage-storage design".

- USGS has developed a synthetic, dimensionless hydrograph for small watersheds (< 15 square miles) in Wyoming–See Exhibit 14. CDS uses this hydrograph to calculate and scale the actual basin hydrograph that is used for flood routing.

DIMENSIONLESS HYDROGRAPH	
TIME UNITS	FLOW UNITS
0	0
3	5.6
5	13
7	25
10	49
11	57
12	60
13	59
14	55
18	38
23	23
30	12
40	5.2
50	2
60	0.5
70	0
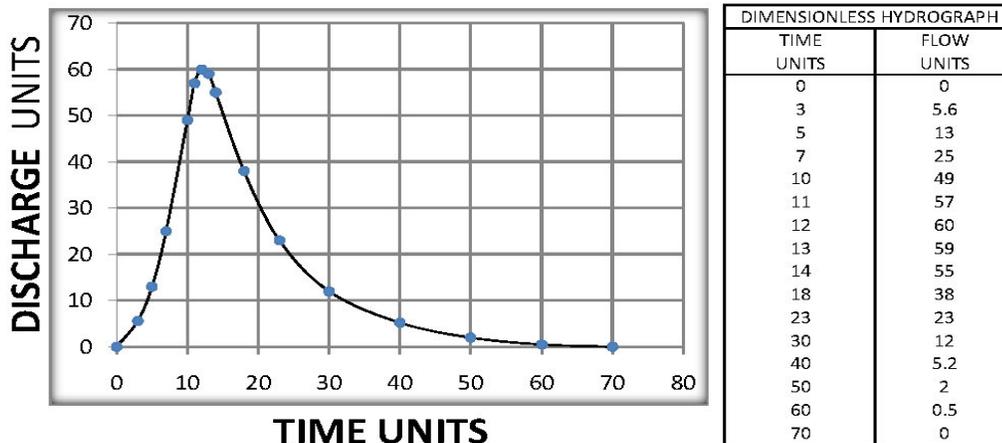
EXHIBIT 14
USGS DIMENSIONLESS HYDROGRAPH

- The unit hydrograph shape is a function of peak discharge Q_P and time T. Relationship equations developed by USGS are used to calculate *scale factors* that can be applied to the unit *hydrograph* to create a real time and discharge *basin hydrograph*. Relationship equations are:

$$MinutesperTimeUnit = \frac{726 \times (V \div 970)}{Q_P \div 60} = TimeScaleFactor$$

$$\frac{Q_P}{FlowUnit} = \frac{Q_P}{60} = FlowScaleFactor$$

Where: *V = basin flow volume in ac-ft*
                           Q_p= basin peak flow in cfs
                           60 = peak unit flow

- CDS uses the value of the basin peak flow (cfs) and the total runoff volume in acre-feet to "scale" the unit hydrograph so that it represents the actual *inflow v. time* relationship for a particular drainage basin.

- The "scaled" hydrograph is used by CDS for hydrograph culvert design, i.e., for flood routing situations where upstream storage is used to decrease the peak flow through the culvert.

- Example: The calculation process to determine the basin hydrograph for a particular drainage basin with a peak discharge of 26.2 cfs and a total volume V of 2.6 ac-ft is illustrated in the following equations and Excel spreadsheet shown in Exhibit 15:

$$MinutesperTimeUnit = \frac{726 \times (2.6 \div 970)}{26.2 \div 60} = 4.5 TimeScaleFactor$$

$$\frac{Q_P}{FlowUnit} = \frac{26.2}{60} = 0.4366 FlowScaleFactor$$

DIMENSIONLESS HYDROGRAPH TIME UNITS	×	MINUTES PER TIME UNIT	=	BASIN HYDROGRAPH TIME IN MINUTES	DIMENSIONLESS HYDROGRAPH FLOW UNITS	×	FLOW UNIT FACTOR	=	BASIN HYDROGRAPH Q in cfs
0				0					0
3		4.5		13.5	5.6		0.4366		2.4
5		4.5		22.5	13		0.4366		5.7
7		4.5		31.5	25		0.4366		10.9
10		4.5		45.0	49		0.4366		21.4
11		4.5		49.5	57		0.4366		24.9
12		4.5		54.0	60		0.4366		26.2
13		4.5		58.5	59		0.4366		25.8
14		4.5		63.0	55		0.4366		24.0
18		4.5		81.0	38		0.4366		16.6
23		4.5		103.5	23		0.4366		10.0
30		4.5		135.0	12		0.4366		5.2
40		4.5		180.0	5.2		0.4366		2.3
50		4.5		225.0	2		0.4366		0.9
60		4.5		270.0	0.5		0.4366		0.2
70		4.5		315.0	0				0
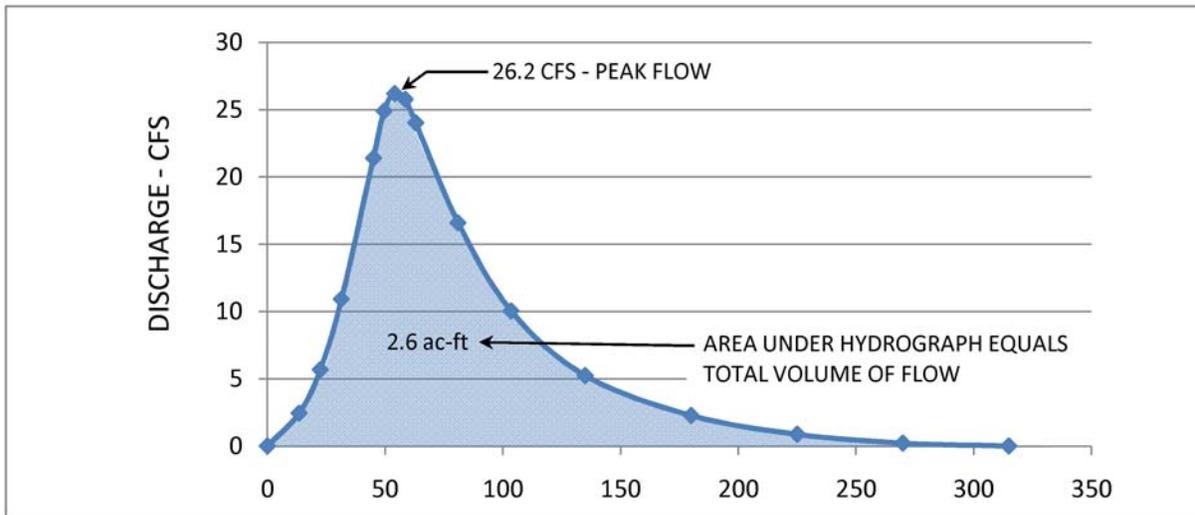
EXHIBIT 15
SPREADSHEET CALCULATION FOR A BASIN HYDROGRAPH

When the flood routing data is coded into CDS, the program automatically calculates and stores the basin hydrograph for use in determining *flood routing* for culvert design. Refer to the CDS user's manual for other hydrograph input options.

Peak Design: Use when the design flow through the culvert is due to snowmelt or irrigation.

- Flow into the culvert (Q_{peak} in cfs or [m^3/sec]) is constant for a long period of time.

- Total volume of flow (acre-ft) or [m^3] through the culvert is very large.

- Peak flow is constant over long periods of time and cannot be reduced to take advantage of upstream storage.

SECTION 9 - CULVERT HYDRAULIC (Culvert Sizing)

General: Culvert sizing is the hydraulic analysis of surface water flow to determine the culvert diameter that will convey the stormwater runoff under the roadway embankment. The primary purpose of a culvert is to convey surface water, but properly designed it may also be used to restrict flow and reduce downstream peak flows, etc. In addition to the hydraulic function, a culvert must be designed to protect adjacent property owners from flood hazard to the extent practicable.

This section provides guidance for determining the culvert size. The designer should refer to SECTION 3 - CRITERIA FOR DRAINAGE DESIGN, General, for other elements associated with the design of culverts such as the following:

- Corrosion resistance number and type of culvert required,
- Flood frequency for design and review,
- Minimum and maximum cover,
- Culverts shapes, type, and end treatments,
- Culvert alignment,
- Culvert cross-sections,
- Culvert plan elements,
- Culvert hydrology,
- Channel change design, and
- Erosion protection.

To provide an overall understanding of culvert hydraulics, two processes are presented: the manual use of inlet and outlet control nomographs and the use of the CDS computer software program. Both methods are based on the same hydraulic principals.

Nomographs and Computer Software: Nomographs were used before computers. The process requires a trial and error solution that is still a reliable method for sizing culverts. Determining velocity, flood routing, roadway overtopping, outlet scour, etc., requires additional computations beyond what the nomographs provide. For example, see APPENDIX A - SECTION A - CULVERT DESIGN (Using Nomographs).

CDS software also uses a trial and error process for sizing culverts, but it can also evaluate improved inlets, flood routing hydrographs, overtopping, outlet scour, etc., which makes culvert design much easier than manually using nomographs.

Culvert Hydraulics: The process is a complex analysis of the stormwater flow system that includes the upstream channel, culvert section, and downstream channel. Flow through the system is controlled by the culvert size and the inlet and outlet flow control conditions. There are two general types of flow conditions for culverts: "inlet control" and "outlet control," as shown in Exhibit 16.

INLET CONTROL FLOW CONDITIONS OUTLET CONTROL FLOW CONDITIONS

HW - Headwater
TW - Tailwater
d_c - Critical Depth
H - Losses Through Culvert

A. Submerged

B. Unsubmerged
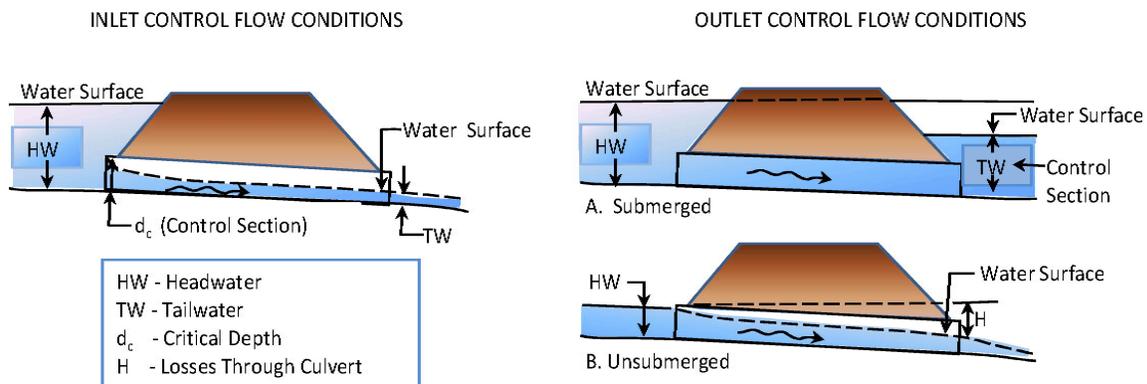
EXHIBIT 16
CULVERT FLOW CONDITIONS

Inlet control flow occurs when the culvert barrel is capable of conveying more flow than the culvert inlet will accept. This typically happens when a culvert is operating on a steep slope. The control section (critical depth d_c) of the culvert is located just inside the entrance.

Outlet control flow occurs when the culvert barrel is not capable of conveying as much flow as the inlet opening will accept. When this occurs, the control section in the culvert flow system is located at the barrel exit or further downstream. Either subcritical or pressure flow exists in the culvert barrel under these conditions.

Culvert Flow Equations:
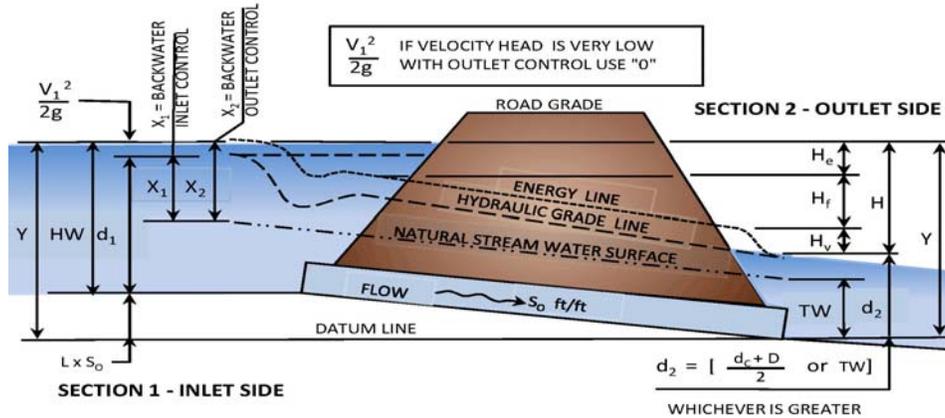
EXHIBIT 17
CULVERT FLOW CRITERIA

E x   h i bit 17 shows the energy grade line and the hydraulic grade line for full flow in a culvert. The energy grade line represents the total energy at any point along the culvert. The hydraulic grade line is the depth to which water would rise in tubes if connected to the culvert. In full flow conditions, the energy grade line and the hydraulic grade line are parallel straight lines separated by the velocity head lines, except in the vicinity of the inlet where the flow passes through a contraction.

The headwater (HW) and tailwater (TW) conditions, as well as the entrance losses, are also shown in Exhibit 17. **Equating the total energy (Y) between the inlet side and outlet side of culvert results in the following equations:**

$$HW + \frac{V1^2}{2g} = TW + \frac{V1^2}{2g} + H$$

Where :   H = the sum of all losses = $H_e + H_f + H_v$;

$$H = \left[1 + Ke + \frac{29 \times n^2 \times L}{R^{1.33}}\right] \times \frac{V^2}{2g}$$

Where :   V = the mean or average velocity in the culvert in ft/sec
                        TW = tailwater depth in ft,
                        g = acceleration of gravity ft (32.2 ft/sec)
                        K_e = inlet loss coefficient
                        R = hydraulic radius (R = flow area ÷ wetted perimeter)

$$H_e = \text{entrance head loss} = Ke \times \frac{V^2}{2g}$$

$$H_f = \text{culvert friction head loss} = \left[\frac{29 \times n^2 \times L}{R^{1.33}} \right] \times \frac{V^2}{2g}$$

$$H_v = \text{velocity head loss} = \frac{V^2}{2g}$$

Culvert Flow Control: Culvert design is based on a constant discharge considering inlet and outlet control. Generally the hydraulic control in a culvert will be at the culvert outlet if the culvert is operating on a mild slope. Inlet control usually occurs if the culvert is operating on a steep slope with velocities in the range of 30 ft/sec [9.14 m/sec].

Inlet Control: When the control is at the culvert upstream end, only the headwater and inlet configuration affect the culvert performance. The headwater depth is measured from the invert of the culvert inlet to the surface of the upstream flow or pool. The inlet is the cross-sectional area of the culvert unless there is an improved inlet, in which case the face area of the improved inlet is the control section.

Example of Inlet Control: The type of flow depends on the submergence of the inlet and outlet ends of the culvert. Depending on the tailwater, a hydraulic jump may occur downstream of the inlet. The following are examples of inlet control flow:

• Exhibit 18 shows a condition where neither the inlet nor the outlet ends of the culvert are submerged. The flow passes through critical depth just downstream of the culvert entrance, and the flow in the barrel is supercritical. The culvert is partly full over its length and the flow approaches normal depth at the outlet end.
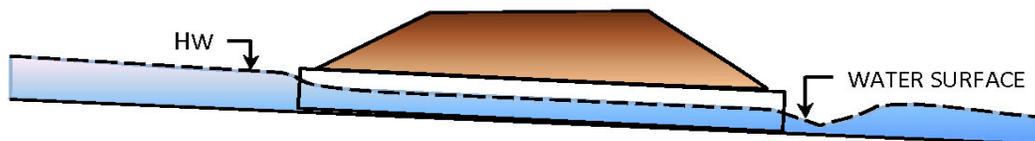
EXHIBIT 18
INLET & OUTLET UNSUBMERGED

• Exhibit 19 shows that submergence of the outlet end does not assure outlet control. In this case, the flow just downstream of the inlet is supercritical and a hydraulic jump forms in the culvert.
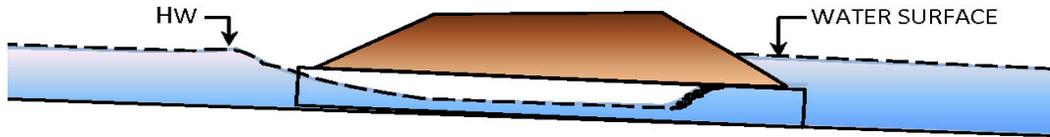
EXHIBIT 19
OUTLET SUBMERGED & INLET UNSUBMERGED

• Exhibit 20 shows a more typical situation. The inlet end is submerged and the outlet end flows freely. Flow is supercritical and the culvert flows partly full over its length. Critical depth is located just downstream of the culvert entrance and the flow is approaching normal depth at the downstream end of the culvert.
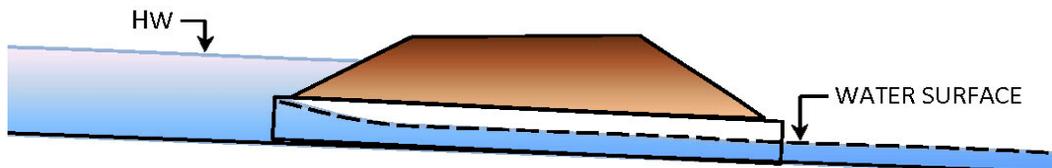
EXHIBIT 20
SUBMERGED INLET

• Exhibit 21 is an unusual condition illustrating that submergence of both the inlet and outlet ends of the culvert does not assure that the culvert will flow full. In this case, a hydraulic jump will form in the culvert due to the median inlet providing ventilation. If the culvert was not vented, a sub-atmospheric pressure could develop unstable conditions that cause the culvert to alternate between full flow and partly full flow.
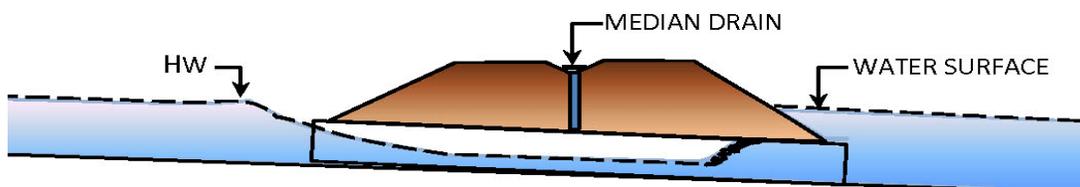
EXHIBIT 21
SPECIAL CONDITION WITH MEDIAN DRAIN

Outlet Control: Factors that influence outlet control are the culvert roughness, shape, length and tailwater depth, as well as the same factors that influence inlet control.

The culvert roughness is a function of the material used to fabricate the pipe. Typical materials include concrete, corrugated metal, and structural plates. The roughness coefficient is the hydraulic resistance to flow, which is defined by Manning's n. For n values, see APPENDIX A - SECTION B - TABLE OF MANNING's n-VALUES.

The pipe length is the total length from the entrance to the exit of the culvert. Because the design height of the culvert and the slope influence the actual culvert length, an approximation of the culvert length, based on the culvert cross-section, is necessary to begin the design process. The slope is the actual slope of the culvert, which is often the same slope as the natural channel.

The tailwater elevation is based on the downstream water surface elevation. A typical downstream control cross-section should be used to determine tailwater depth.

Outlet control conditions can be calculated based on energy balance. The total energy H_L required to pass the flow through the culvert is made up of the entrance loss H_c, the friction loss through the culvert H_f and the exit loss H_o. Losses at junctions H_j and losses at gates H_g are included when applicable.

- Exhibit 22 represents the classic full flow condition with both inlet and outlet submerged. Typically, this condition seldom exists.
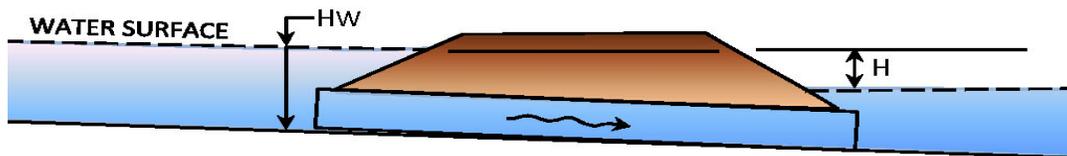
EXHIBIT 22
INLET & OUTLET SUBMERGED

- Exhibit 23 shows the outlet submerged and the inlet unsubmerged. In this case, the headwater is shallow and the top of the culvert crown is exposed due to the flow contracting as it enters the culvert.
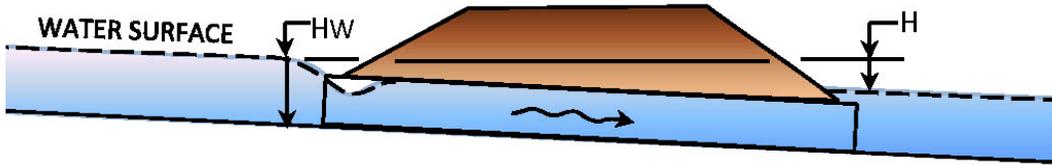
EXHIBIT 23
OUTLET SUBMERGED - INLET UNSUBMERGED

•   Exhibit 24 shows a rare condition where the entrance is submerged to such a degree that the culvert flows full throughout its entire length while the outlet is unsubmerged. It requires an extremely high headwater to maintain full barrel flow with no tailwater. The outlet velocities are usually high under this condition.
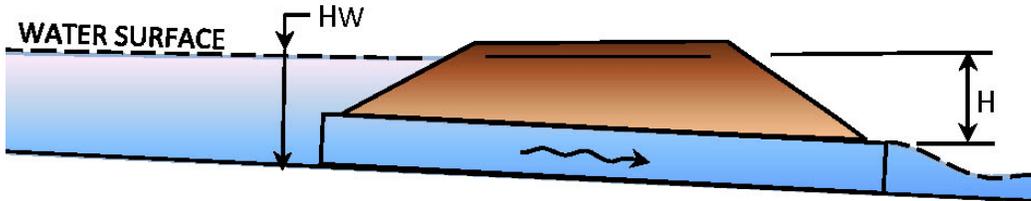
EXHIBIT 24
INLET SUBMERGED - OUTLET UNSUBMERGED

•   Exhibit 25 is a typical condition where the culvert entrance is submerged by the headwater and the outlet end flows freely with a low tailwater. For this condition, the culvert flows partly full over at least part of its length (subcritical flow) and then the flow passes through critical depth just upstream from the outlet.
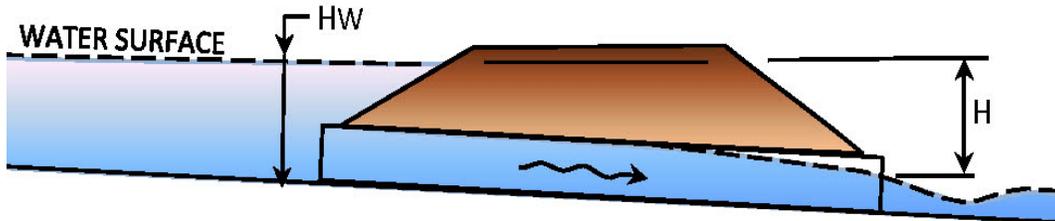
EXHIBIT 25
INLET SUBMERGED - OUTLET PARTIALLY SUBMERGED

August, 2011

• Exhibit 26 is also a typical condition where neither the inlet nor outlet ends of the culvert are submerged. The culvert flows partly full over the entire length and the flow profile is subcritical.
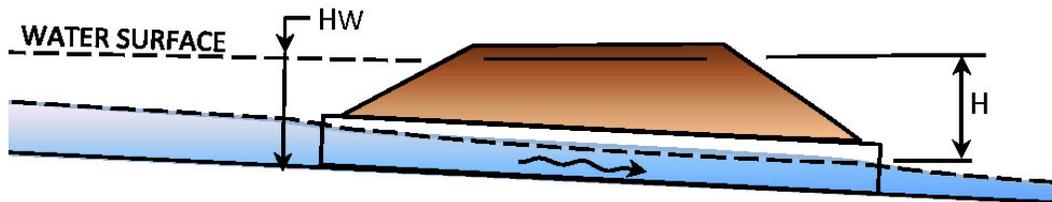
EXHIBIT 26
INLET & OUTLET UNSUBMERGED

CDS computer software uses the same basic hydraulic principle of equating the total energy (Y) between the inlet side and outlet side to determine the culvert size.

SECTION 10 - ALLOWABLE HEADWATER (AHW)

General: The headwater depth is the difference between the culvert inlet elevation and the upstream allowable water surface elevation. It is recommended not to use an AHW depth that exceeds 15 ft [4.6 m] without consulting the Hydraulics Section.

Determining the maximum AHW is a very important designer-specified input parameter. There are several configurations of roadway grades combined with existing terrain and property improvements that must be reviewed to determine this elevation. Exhibit 35 provides general examples of different case conditions that control the AHW elevation, such as the ditch grade elevation adjacent to either side of the culvert crossing, limiting fill height over the culvert, avoidance of property damage, etc.

The AHW depth is the maximum depth of upstream storage allowed in designing a culvert for the project-specified design frequency. However, the designer should always review the culvert site for the 100-year design Q to make sure that there is no significant property damage, as shown in Exhibit 27, Case-4. In this case, to avoid significant damage, the culvert should be sized for the Basic Flood (Q_{100}), as specified in Operating Policy 18-6. By using the Q_{100}, CDS would upsize the culvert to maintain the AHW and the property would be protected from flood damage for storms that are $\leq$ the Basic Flood (Q_{100}). Flood protection is not required for storms greater than Q_{100}.

EXHIBIT 27
CRITERIA FOR DETERMINING AHW DEPTH
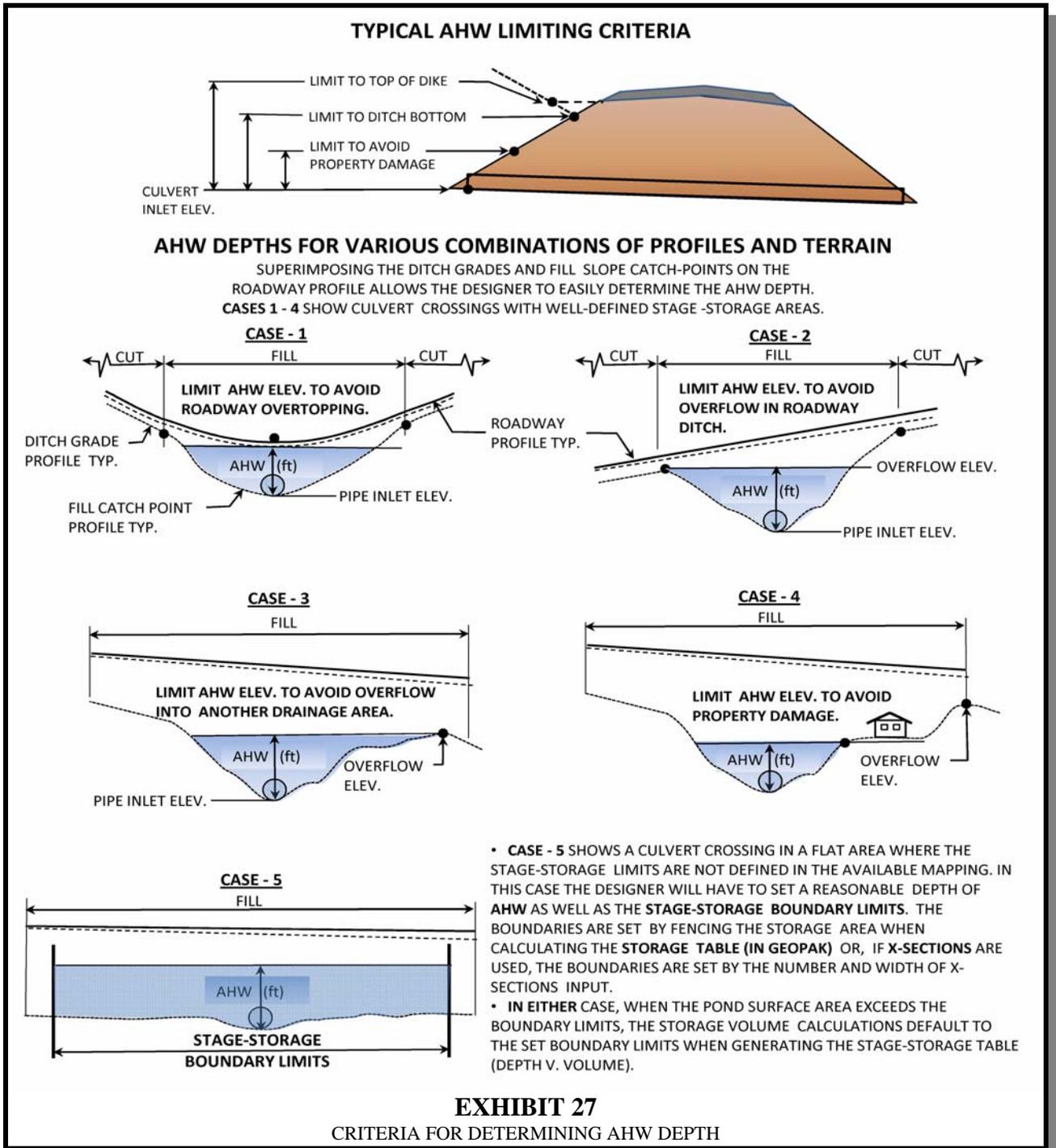
The first step in culvert design is to merge the design file with mapping tin so that the contours show the proposed improvements. It is critical that the designer use the merged mapping file when determining the AHW and for culvert design in general.

A quick review of the contour elevations, roadway profile, adjacent ditch grades, cross-section, improvement impacts, etc., will allow the designer to determine the correct AHW elevation.

GEOPAK Option For Determining AHW Depth: In addition to manually reviewing the mapping, the designer can also use GEOPAK to visually look at upstream water surface areas for various pond depths to determine or verify the AHW elevation and roadway overtopping areas. By using GEOPAK's "Plane to TIN" feature located on the DTM menu bar, the designer can quickly change the input to view several different pond depths. Exhibit 28 shows three screen prints along with the "Elevation Differences" dialog box used for input data.

EXHIBIT 28
WATER SURFACE VIEWS OF INCREASING WATER DEPTH
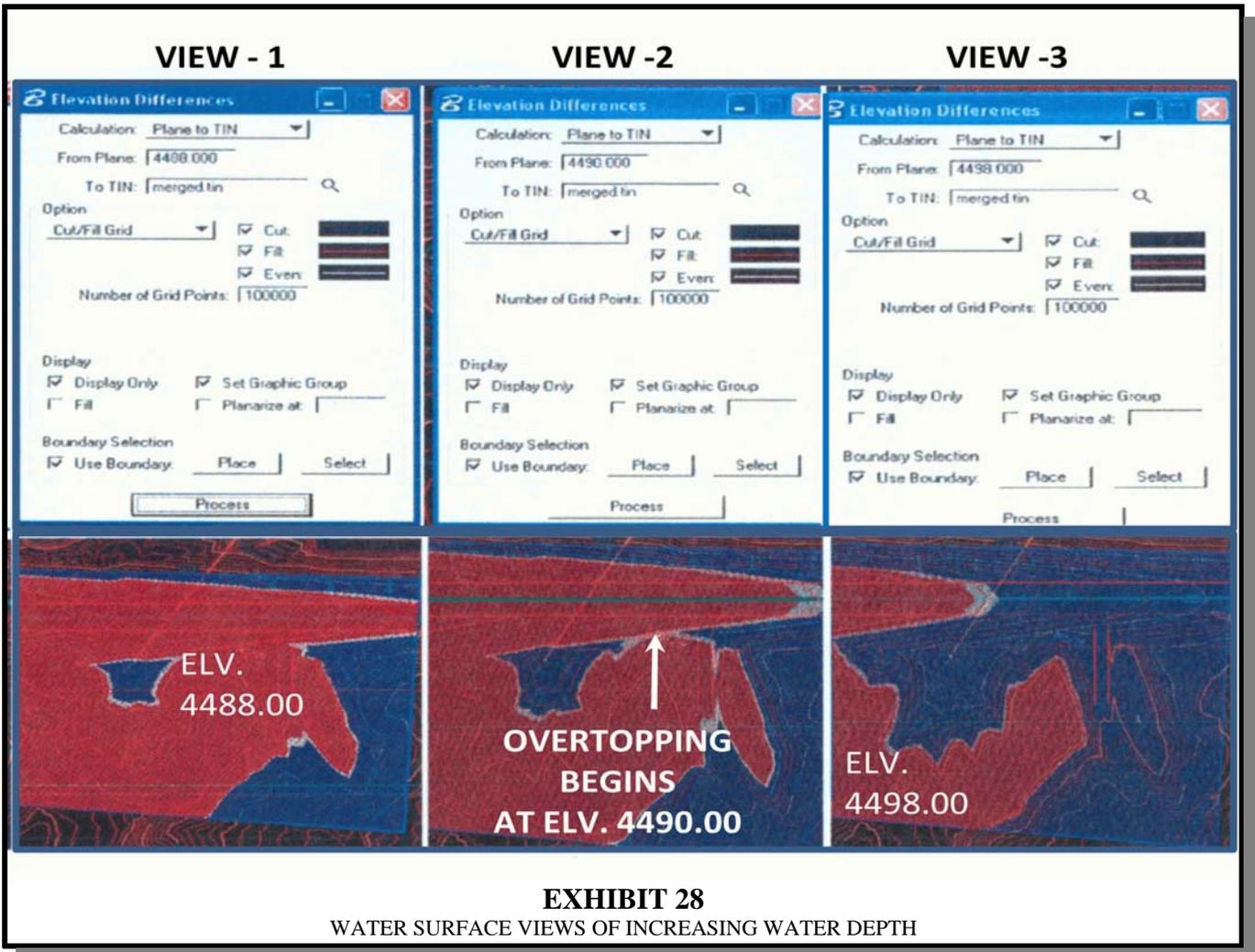
The inlet elevation for this culvert crossing is 4483.40 and the plane elevation coded is considered the water surface elevation that you want to view. The blue area indicates the contours that are below the water surface and the red areas indicate contours that

are above the water surface. For this process, the default boundary limits (fenced area) should be set to include the upstream storage area and a portion of the downstream mapping so that both the pond area and overtopping area can be viewed.

Multiple surface areas can quickly be viewed by changing the pond depth, which is equal to the plane elevation that is coded in the "From Plane" box located on the dialog box shown in Exhibit 28. To show that water is accumulating in the pond, the plane elevation must be higher than the culvert inlet elevation.

View Examples:

• **View - 1:** Shows a pond surface area at elevation 4488.00 (depth of 4.6 ft), which is still below the AHW elevation.

• **View - 2:** Shows a pond surface area at elevation 4490.00 (depth of 6.6 ft). This graphic view identifies that overtopping begins at elevation 4490.00.

• **View - 3:** Shows a pond surface area at elevation 4498.00 (depth of 14.6 ft). At this depth, overtopping is occurring. In this case, the designer could use elevation 4498.00 as the top elevation of the stage-storage table to ensure that the stage-storage table extends high enough above the AHW so that CDS can correctly analyze overtopping.

SECTION 11 - FLOOD ROUTING DESIGN WITH CDS

General: This process utilizes upstream storage to reduce the culvert size and downstream flows. It is also known as stage-storage discharge or hydrograph design.

Storm water runoff due to a rainfall event can be quantified in a flood hydrograph of discharge-versus-time for a given flood frequency as shown in Exhibit 29.
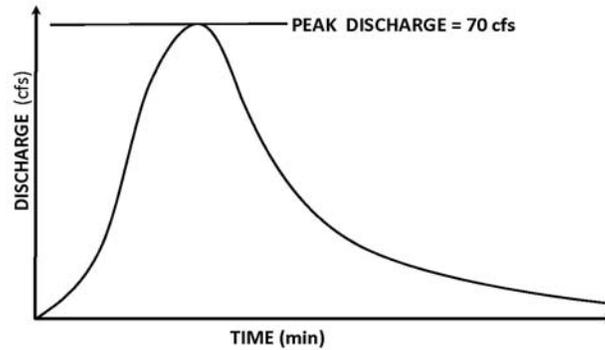
EXHIBIT 29
TYPICAL STORM HYDROGRAPH

Exhibit 30 shows a culvert flow hydrograph superimposed over a storm basin hydrograph with a peak discharge of 70 cfs [2 m^3/sec]. Using hydrograph design to calculate the effect of the upstream storage will allow the culvert size and flow rate to be reduced. The difference in the two hydrographs is the volume of upstream storage.
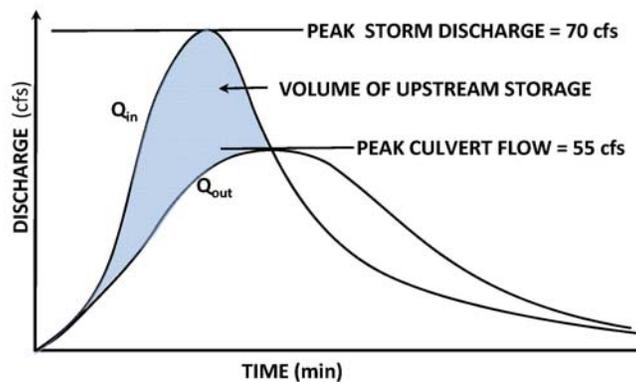
EXHIBIT 30
STORM & PIPE FLOW HYDROGRAPH

Exhibit 31 shows the different systems of flows analyzed in the hydrograph design process for a typical culvert with upstream storage. Flow in the system is controlled by the size of the culvert.

EXHIBIT 31
TYPICAL CULVERT CROSSING WITH UPSTREAM STORAGE
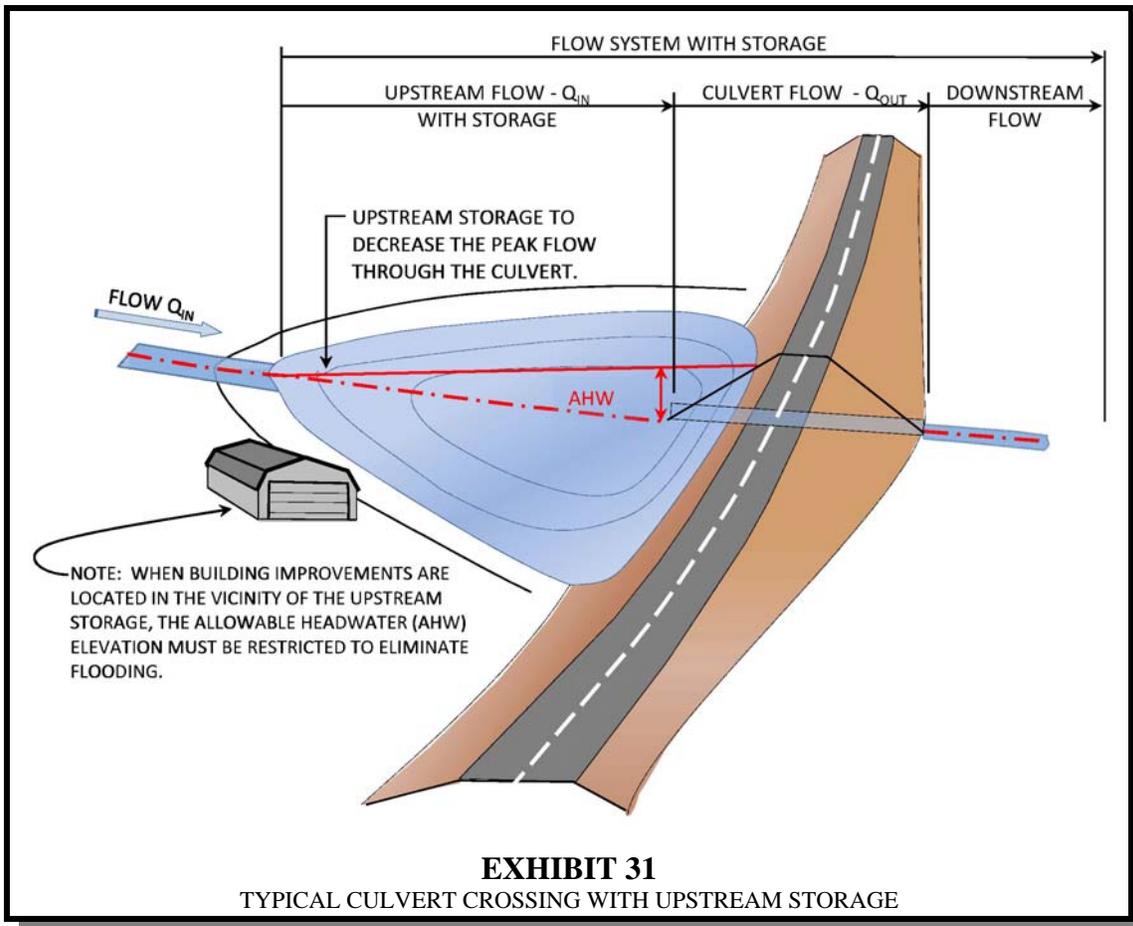
Hydrograph design can be used when the design flow is due to a rainfall event, providing the terrain and local development will allow upstream storage. Since the total volume of flow through the culvert is infinite, upstream storage can be utilized where:

- Over some interval of time (T), between times t_1 and t_2, the average flow rate into the system via the upstream channel Q_{IN} can be obtained from the inflow hydrograph. See SECTION 8 - BASIN AND CULVERT HYDROLOGY, Culvert Hydrology and Hydrograph Design (Stage-Storage Design) for information on inflow hydrographs.

- The volume of water entering the system during this time period (V_{IN}) is:
  $V_{IN} (\text{ft}^3) = Q_{IN} (\text{cfs}) \times T(\text{sec})$

- During this time period, the average flow rate out of the system via the culvert and the downstream channel is Q_{OUT}.

- The volume of water (V_{OUT}) exiting the system during this time is:
  $V_{OUT} = Q_{OUT} \times T$

- The amount of water stored (S) upstream of the culvert during this time period is given by the basic flood routing equation: $S = V_{IN} - V_{OUT}$

- The amount of water stored upstream of the culvert (S) is determined by the configuration of the upstream storage basin terrain and the difference between the headwater depths at time t_1 and t_2.

- For each time interval T, CDS uses an iterative process to determine the combination of headwater depth in the upstream basin and depth of flow in the downstream channel that satisfies the basic flood routing equation.

- CDS then considers the next increment of time, from t_2 to t_3, and repeats the same process of determining the headwater depth in the upstream storage basin at each stage.

  The process is repeated for sequential increments of time until the allowable depth specified by the user is exceeded, in which case the culvert size is increased and the entire analysis is repeated starting at time zero on the inflow hydrograph.

  When the process finds a culvert of sufficient size to carry a Q_{OUT} that restricts the pond storage to a depth of $\leq$ the AHW, the process is satisfied and culvert size is accepted as having adequate capacity. The use of storage allows the culverts peak flow rate to be reduced, which results in smaller culvert sizes.

- CDS begins the flood routing analysis by generating a **stage-discharge table** of *depth v. flow* for the downstream channel and a **stage-storage table** of *depth v. stored volume* for the upstream storage basin.

- For a particular flow depth (d) in the downstream channel, the associated flow rate (Q) is determined from Manning's equation based on a downstream cross-section:

$$Q = VA = \left[\frac{1.49}{n} \times S^{1/2} \times R^{2/3} \right] \times A$$

Where: V = Velocity
                  A = Cross sectional area of channel
                  n = Manning's friction coefficient
                  R = Hydraulic radius (area ÷ wetted perimeter)
                  S = Channel slope

Higher Manning's n-values (for rough channels) produce a lower flow rate than a "smooth" channel with a lower n-value. See APPENDIX A - SECTION B - TABLE OF MANNING's n-VALUES.

CDS requires a downstream cross-section to calculate the ***stage-discharge table***. The cross-section should be placed far enough downstream of the pipe outlet so that the section represents the natural channel flow.

SECTION 12 - CDS STAGE-STORAGE TABLES

General: The designer has the option of having CDS determine the stage-storage table by inputting upstream cross-sections or by inputting a pre-calculated stage-storage table. When upstream cross-sections are provided, CDS uses the end area method (same process as calculating earthwork quantities) to calculate a storage table in depth v. volume. However, it is more accurate and is the ***preferred option*** to use GEOPAK and the project mapping to calculate the stage-storage table as a direct input item to CDS.

In either case, the designer should review the project mapping at each drainage site to identify the following key elements needed to calculate the stage-storage table or layout of cross-sections:

- Determine AHW - See SECTION 10 - ALLOWABLE HEADWATER (AHW),
- Identify flow ridge line, if possible,
- Identify overtopping points (elevation),
- Identify stage-storage limits based on AHW depth,
- Identify stage-storage limits for flood review based on overtopping elevation and
- Set default-boundary fence.

Site conditions will be encountered where the storage area is well-defined and where the storage area is not defined within the available project mapping file.

Calculating Stage-Storage Table With GEOPAK: Exhibit 32 shows the mapping file at a typical culvert crossing where the design and mapping tin have been merged together. In this example, the storage area is well-defined within the mapping boundaries.

EXHIBIT 32
DATA FOR STAGE- STORAGE TABLE CALCULATIONS
(FOR A WELL-DEFINED AREA)

Key Elements: By reviewing the mapping contour elevations, the key elements required for culvert design can easily be identified and noted on the mapping for use in calculating the stage-storage table and the stage-discharge table.

The following are key elements in Exhibit 32:

(1)   Note the contour elevations along the roadway centerline, culvert inlet elevation (4483.40) and overflow elevation (4490.00).

(2)   Trace out the ridge-line, if possible.

(3)   Calculate the AHW depth: AHW = (Overflow Elev. - Freeboard Depth - Inlet Elev.) Freeboard depth was not used in this example but, if needed, generally 2 ft to 3 ft is acceptable. See SECTION 10 - ALLOWABLE HEADWATER (AHW).

AHW = (4490.00 - 0) - (4483.40) = 6.6 ft.
In this case, CDS will limit the maximum pond depth to Elev. 4490.00.

- •   Use CDS code **HD** to input *AHW* .

(4)   Tracing along contour line 4490 delineates the maximum area of the stage-storage pond that will be used for designing the culvert.

(5)   Set the top elevation of the stage-storage table at 4 ft to 8 ft above the overtopping elevation of 4490 ft. This will provide enough storage depth to properly analyze the 100-year overtopping event. In this case, an additional 8 ft is used. The top elevation of the stage-storage table is: 4490 + 8 = 4498. Trace along contour line 4498 to delineate where overtopping will occur. Make sure there are no flood impacts to residential or commercial properties.

- •   Use CDS code **SEV** to input the GEOPAK *file name* and CDS will automatically import and use the stage-storage table for culvert design.

(6)   Use GEOPAK to set a boundary fence around the stage-storage area that is defined by contour elevation 4498.00. The boundary fence identifies the location within the mapping file and sets the default limits for the stage-storage calculations.

(7)   Locate and generate a downstream cross-section (using GEOPAK). This cross-section will be used by CDS to calculate the stage-discharge table *depth v. flow* in the downstream channel. Also, determine the average downstream channel slope (0.0732 ft/ft).

- •   Use CDS codes **SEC** and **XS** to input the downstream cross-section: Code **SEC** inputs the *x-sec. file name* and CDS automatically imports the *x-sec. file* and calculates the stage-storage table. Code **XS** inputs *distance, skew (optional), and average downstream slope*.

(8)   Set the overtopping alignment and profile.
   •   Use CDS code **GR** to input data station and elevation.
(9)   Use GEOPAK to create the pipe cross-section alignment, profile, pipe length, pipe grade, etc.

Once the above data has been compiled, the stage-storage area is calculated in GEOPAK using the *plane to tin* calculation. Exhibit 33 shows a screen print of the "DTM" menu bar with the dialog boxes and input data used for this example.

EXHIBIT 33
GEOPAK DIALOG BOXES REQUIRED
(TO CALCULATE THE STAGE-STORAGE TABLE)

The following are key elements in Exhibit 33:

{1}   **Elevation Differences Dialog Box:** Generates a plan view of the plane elevation coded and no volumes are calculated. The plane elevation coded is equal to the top elevation of the storage table previously determined as elevation 4498.00. GEOPAK provides a view of the plane elevation (item {4}).

Coding elements:
*   **Calculation:** Activate the "Plane to TIN" tab.

*   **From Plane:** Input the top elevation (4498.00) of the stage-storage table. This should be 4 ft to 8 ft above the overtopping elevation.

*   **To Tin:** Use a tin file created by merging the existing ground tin with the design tin for culvert design.

*   **Option:** Select the "Cut/Fill Grid" or "Cut/Fill Contours" tab.

*   **Cut, Fill & Even:** ✓ all boxes and select different colors for Cut, Fill & Even.

*   **Number of Grid Points:** Input the number of grids. This should be a value large enough to give an adequate view of the storage area. The higher the value, the clearer the picture.

*   **Display:** Allows the visual grid or contours to be drawn. Either "Display Only" or "Set Graphic Group" must be activated. *"Display Only" will disappear when the screen is updated, whereas "Set Graphic Group" will remain activated until deleted.*

*   **Boundary Selection:** ✓ "Use Boundary" box. *Once the boundary is placed, it must be "Selected" to unghost the "Process" button. When the "Process" button is selected, the area within the boundary will be filled with the colors chosen within the "Option" section.*

    Set the boundary fence somewhat larger than the top elevation of the stage-storage area (elevation 4498). The boundary can be placed using a combination of lines converted into a complex shape or with a shape command button in MicroStation.

{2}   **Volume Calculations Dialog Box:** Inputs stage-storage volume calculation criteria.

Coding elements:
*   **Calculation Method:** Select "Prismoidal" option.

*   **Calculation Options:** Activate the "Plane to TIN" tab.

*   **From Plane:** Input the top elevation (4498.00) of the stage-storage table. This should be 4 ft to 8 ft above the overtopping elevation.

*   **To TIN:** Input "merged tin" in this box. *Use a tin file created by merging the existing ground tin with the design tin for culvert design.*

*   ✓ "Use Range" box.

*   **Volume Calculations:** ✓ "Use Factor" box and code in 1.00 in both the <u>Cut</u> and <u>Fill</u> boxes.

*   **Output:** ✓ "Output To ASCll File" box. Name the file with the culvert station and place it in the same directory as the culvert input file. The dialog box shows the "storage.vol" file name.

*   **Boundary Selection:** ✓ "Use Boundary" box.

*   **Volume Polygons:** ✓ "Display Only" box.

{3}   **Volume Elevation Range Dialog Box:**

Coding elements:
*   **Range:** Activate the "Auto Range Increment" tab.

*   **Range Increment:** Code a value into this box. The number of increments cannot exceed 50. Therefore, the depth of the stage-storage pond must be divided by the increment value to make sure the number of increments do not exceed 50. In this example, the pond depth of 14.6 ft divided by the increment depth of 0.5 ft equals 29.2 increments, which is less than 50. Typically, an increment depth of 0.5 ft should be used unless the total number of increments exceeds 50. Then, increase the increment depth to reduce the number of increments below 50.

*   **Minimum Elevation:** Code the culvert inlet elevation (4483.40), which is also the bottom of the stage-storage pond, into this box.

- **Maximum Elevation:** Code the tin elevation (4498.00), which is also the top of the stage-storage pond, into the box.

- Select the "Set Range" box.

- Once the range is set and all previously described areas are populated or boxes checked, activate the "Select" button in the "Volume Calculations" ({2}) dialog box under the Boundary Selection to highlight the data within the boundary area.

- Activate the "Process" tab.

- The volume file can be viewed by selecting the "View" tab under the file name or with Notepad/Wordpad.

Exhibit 34 shows the "Plane To TIN Report" and a cross-section of the storage area to demonstrate how the quantities are calculated.
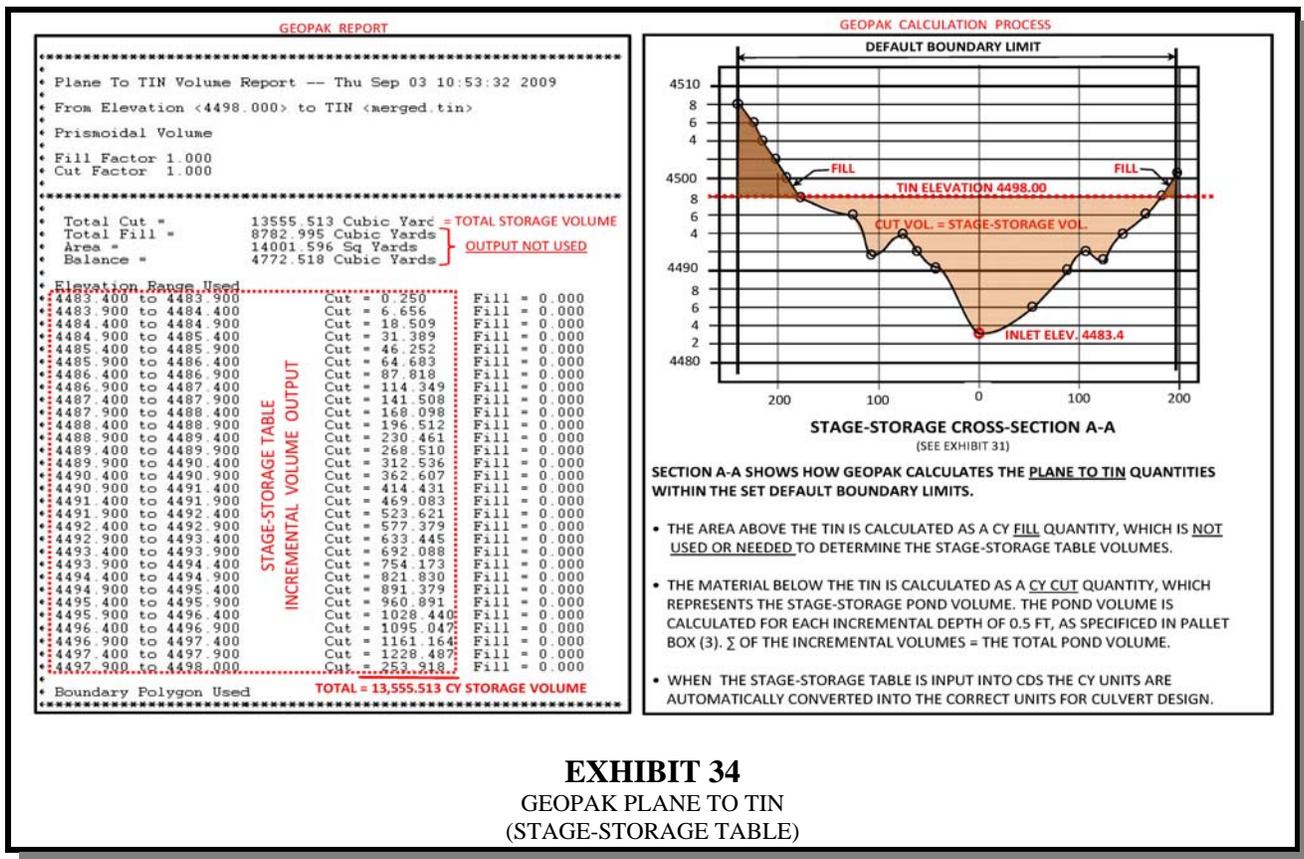
EXHIBIT 34
GEOPAK PLANE TO TIN
(STAGE-STORAGE TABLE)

Calculating Stage-Storage Using Cross-Sections: CDS allows up to 30 input cross-sections that are identified with stationing. The alignment and cross-sections should be set to accurately calculate the available storage area. The cross-section stationing can begin with any given station, such as 0, 10, 100, etc., starting with the first downstream cross-section so that the stationing increases in the upstream direction.

Typically, for small culvert design, only one downstream cross-section is needed and the designer can use up to 29 upstream cross-sections to cover the storage area. Exhibit 35 shows a typical layout of cross-sections and stationing with the alignment along the stream bottom**.**

EXHIBIT 35
TYPICAL CROSS-SECTION LAYOUT FOR STAGE-STORAGE VOLUMES
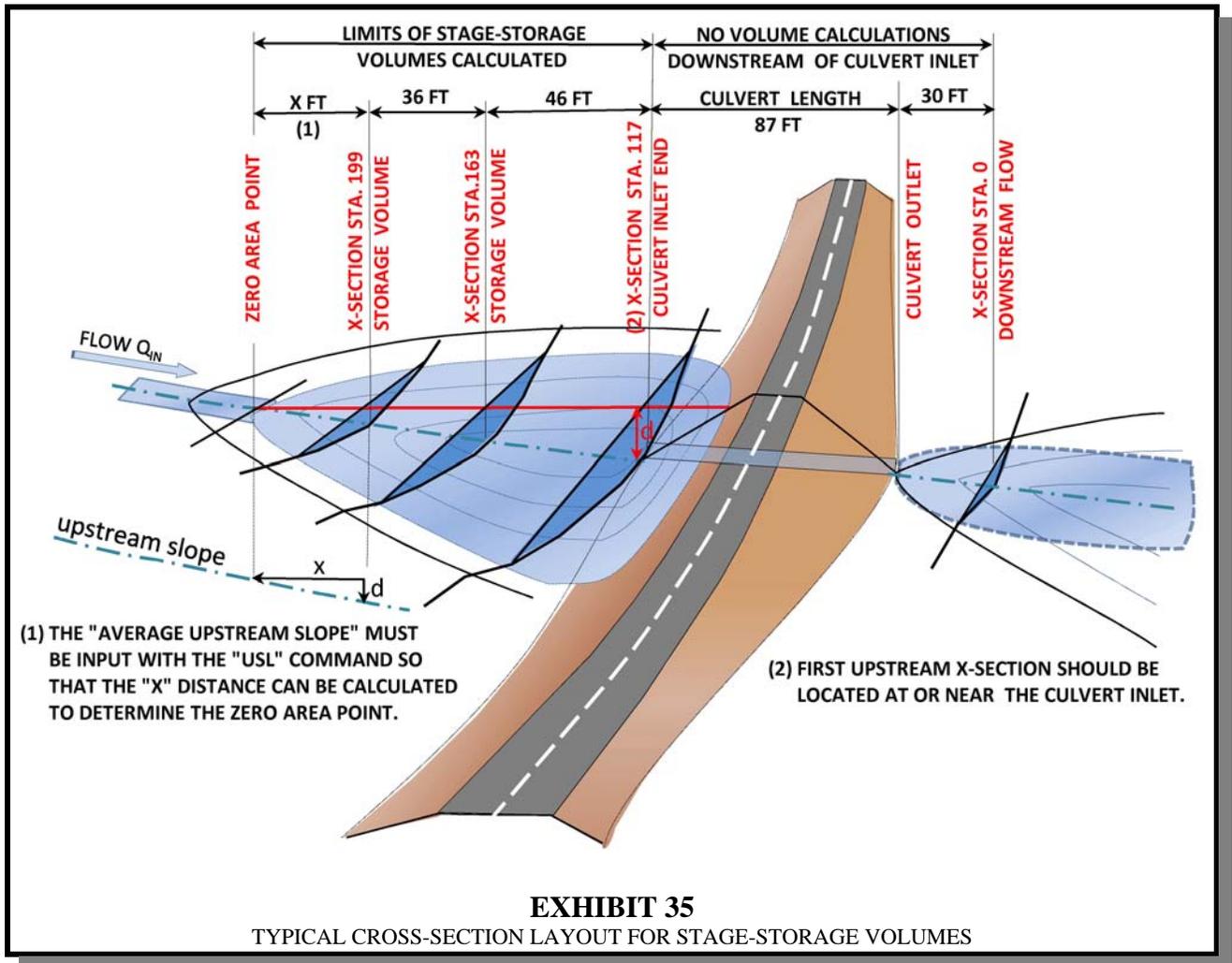
Cross-Section Alignment and Spacing: Setting the alignment and placement of the cross-sections is a critical step in correctly calculating the stage-storage volume. The first step is to review the mapping. If stage-storage is possible, identify the general limits of the storage area. Once the storage limits are identified, the alignment and cross-section configuration should be set.

EXHIBIT 36
PIPE CROSS-SECTION LAYOUT
TO BEST CALCULATE STORAGE
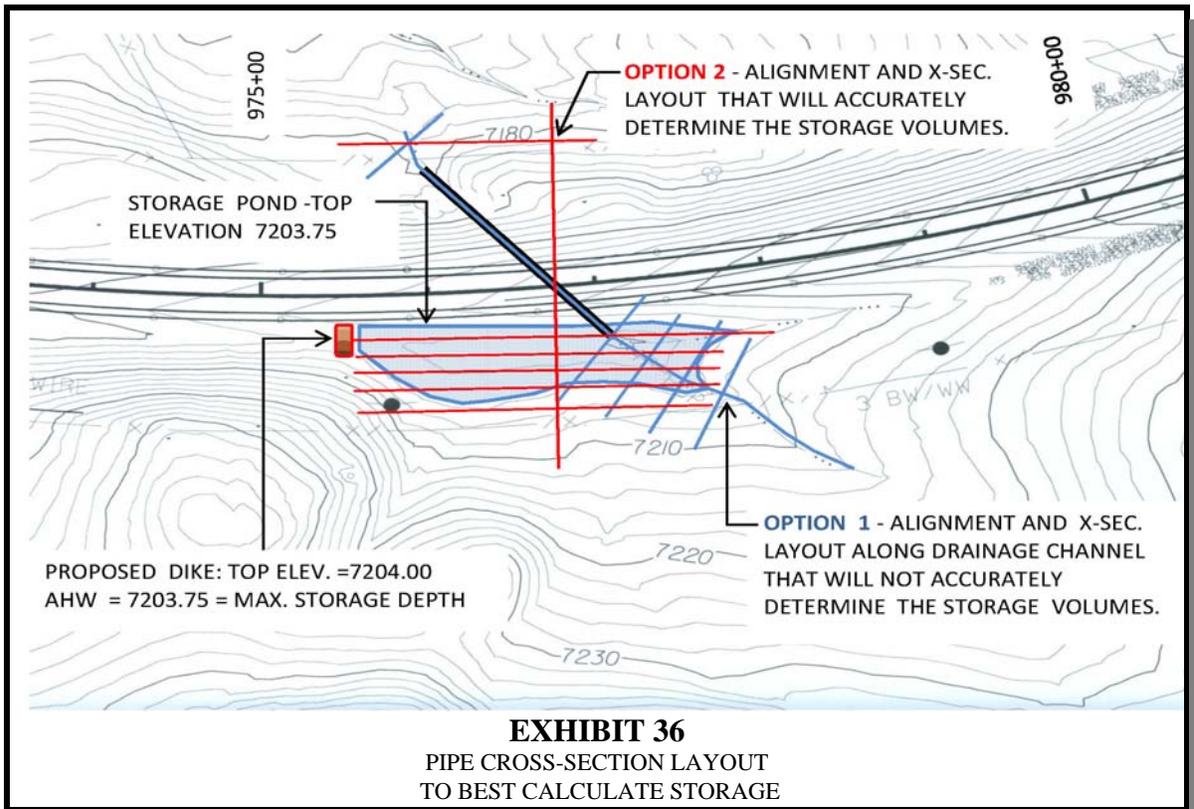
Drainage basins come in different sizes and shapes that dictate the alignment of cross-sections to best calculate the storage volume.

Exhibit 36 shows two options that demonstrate why the designer should always review the mapping to determine the maximum AHW and the shape of the storage area before laying out the stage-storage cross-sections.

If Option 1 cross-sections were used, CDS would calculate the culvert size, but it would not be correct because the cross-sections only cover approximately one-third of the total available storage. However, if the cross-sections are spaced through the entire pond area as shown in Option 2, the designer achieves the best results because CDS would use all of the available storage volume to determine the smallest possible culvert size.

Default Storage Area Limits: Both the cross-section and GEOPAK methods of calculating stage-storage volumes require default limits. With the cross-section method, the number and width of cross-sections used will set the default limits. When GEOPAK is used, the default limits are set by placing a fence around the stage-storage area.

In most cases where the mapping does not define all of the storage area, it is not practical to have the mapping extended for small pipe design. In this case, the designer has the option to set default limits at a reasonable width that extends to the edge of the mapping. This will require some judgment on the part of the designer. If the design Q is large or if it's not clear as to what default limits should be used, the designer should consult with the Hydraulics Section.

SECTION 13 - CODING CDS SOFTWARE

General: CDS is capable of analyzing complex drainage functions beyond what Project Development requires for small culvert design. It is powerful in the sense that it can accommodate several different user-specified combinations of input codes. Contact the Hydraulics Section for the latest version of CDS.

This section provides Project Development with supplemental guidance of the basic CDS commands and coding required for small culvert design. It is not intended to replace the CDS manual or the need for the designer to refer to the CDS manual for guidance.

The minimum size drainage culvert allowed is 24 in [610 mm] for interstate, primary, secondary and county highways. The minimum size culvert allowed for approaches is 18 in [450 mm].

Key Steps to Complete Before Coding CDS:
- Request the project basin hydrology from the Hydraulics Section, as indicated in the SECTION 2 - DESIGN RESPONSIBILITIES - Basin Hydrology. The basin hydrology information received from the Hydraulics Section is needed input for culvert design.

- Create a file of the design tin merged with the mapping tin. Use the merged tin file to calculate the stage-storage data table (Exhibit 32) that will be used for the flood routing analysis. Calculate the table in GEOPAK using the surface -to-tin calculation process to create a file of the stage-storage table. This data table can be directly input into CDS using the **SEV** command to input the filename.

- Review the merged mapping to determine if peak design or stage-storage design will be used:

  > **Peak Design:** Use if the flow is from irrigation water, snow melt, or normal storm runoff conditions where there is no storage available.

  > **Stage - Storage Design (Flood Routing):** Use when upstream storage is available.

- Create an alignment and pipe cross-section that includes the downstream channel and upstream channel. The pipe cross-section should include both the existing and design criteria. Once the basic pipe cross-section is completed, determine the culvert flow-line (bottom of pipe) inlet/outlet elevations, culvert length (distance between the inlet/outlet elevation), culvert grade and the average upstream and downstream grade slope. This information will be used to code the input data for CDS, as well as become the final pipe cross-section

that shows culvert size, length, pay quantities, etc. Refer to SECTION 6 - PIPE CROSS-SECTIONS for guidance.

File Structure: A standardized file structure for culvert design should be used to track the multiple profiles, alignment, cross-sections, input coding, output reports, etc. It is recommended that the general file structure shown in Exhibit 37 be used.

EXHIBIT 37
TYPICAL FILE STRUCTURE
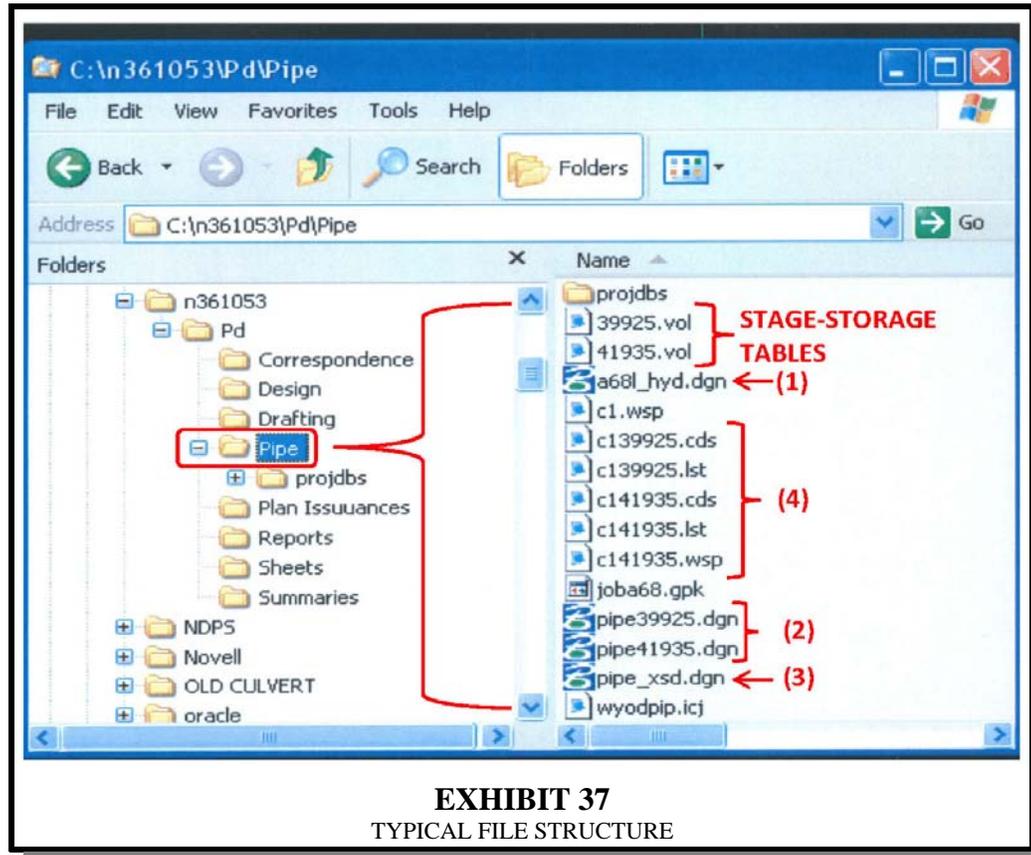
(1)   **File xxxx_hyd.dgn where xxxx is the job number:** Input the GEOPAK roadway plan view mapping into this file and draw the drainage channel alignment and pipe cross-section pattern lines for each culvert location to generate the individual pipexxxx.dgn files shown in Item (2).

(2)   **Files pipe39925.dgn, pipe41935.dgn, etc.:** Individual culvert files in which the number portion of the file name is the pipe crossing station without the plus (+) sign.

(3)   **File pipe_xsd.dgn:** Pipe cross-sections.

(4)   **File c139925.cds or dat:** CDS input file. Generated in Notepad or Wordpad.
        File c139925.lst or rpt: CDS output reports.

Listing of CDS Code Descriptions: The following is a condensed list of the CDS code descriptions that Project Development would typically use for small culvert design.

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single-line, multiple data entries be separated by <u>one or more bar spaces</u> or a <u>tab space</u>.
	HEADER COMMANDS

JOB	*Project No. and Name etc:* *1.* *Use to input the project number. Project name, etc., is input below the JOB code line as a comment.*
	Example Coding | *Remarks*
	JOB N331021 | *Input project number*
	� **Thermopolis - Meeteetse** | ✳ *Input Comment can be used anywhere in the input list.*

JOB	*Project No. and Name etc:* *1.* *Use to input the project number. Project name, etc., is input below the JOB code line as a comment.*	
	Example Coding	*Remarks*
	JOB N331021	*Input project number*
	✳ **Thermopolis - Meeteetse**	✳ *Input Comment can be used anywhere in the input list.*
SI	*Input: Working Units English or metric input and output.* *2.* *If SI code is not used the program will default to metric input and output* *3.* *Use one of the four options given in the example.*	
	Example Coding	*Remarks*
	SI 0 0	*Option 1-Metric input and output. Coded as 0 space 0.*
	SI 1 0	*Option 2-English input and Metric output. Coded 1 bar space 0.*
	SI 1 1	*Option 3-English input and output. Coded as 1 bar space 1.*
	SI 0 1	*Option 4-Metric input & English output. Coded as 0 bar space 1.*

PRT	*Input: Print Command -* <u>*sd, ss, ro, cul, & 0*</u>
	sd - Code 1 prints the Stage-Discharge Table.
	ss - Code 1 prints the Stage-Storage x-sections and table.
	ro - Code 1 to print the Roadway Overflow analysis.
	cul - Code one of three options:
	    1 - prints Hydrograph Summary.
	    2 - prints Hydrograph detail output (every time step).
	    3 - print a brief output.
	0 - Always code a 0 if you do not want to print the option.
	Code the print options in sequential order form left to right.	

	Example Coding	*Remarks.*
	PRT **1 0 1 3**	*sd: Code 1 prints the Stage-Discharge Table.* *ss: Code 0 does not print the Stage-Storage x-sections and table.* *ro: Code 1 will print the Roadway Overflow analysis* *cul: Code 3 will print the brief output*
RUN & END	*Example Coding- Executes the CDS analysis*	
	RUN	*This command is used multiple times within the input coding to run or process a specific section of the input.*
	END	*This command is always placed at the end of the input coding.*

CONTINUED ON NEXT PAGE

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.
	STAGE-DISCHARGE COMMANDS

XS	*Inputs: <u>distance, skew, & slope</u>. Use to input the <u>negative</u> distance between the downstream x-sec to culvert outlet.*

Example Coding	*Remarks*
XS -200 0 0.002	<u>*Distance*</u> *- is a negative length between the culvert outlet & the downstream x-sec.* <u>*Skew*</u> *- (optional) angle of x-sec. normal to the channel (degrees)* <u>*Average Downstream Slope*</u> *- Average channel slope in ft/ft*

GR	*Inputs: <u>x-sec. X, Y coordinate data</u>. Can be used to input x-sec. for either stage-discharge or stage-storage. Note: This command would not be used when the SEC- <u>stream x-sec. file name</u> command is used. The SEC command allows CDS to import x-sec. directly from the GEOPAK files, which eliminates the need for inputting the x-sec. with the GR command.*

Example Coding	*Remarks*
GR -100 5000 -50 4095 -10 4094 0 4094	*Y - x-sec point horizontal distance increasing to the right.*
GR 10 4093 50 4095 200 5000	*X - x-sec vertical elevation.*

SA & N	*Input: <u>SA & n</u> - SA is channel subsection data when more than one Manning's n value is required to define the discharge channel flow characteristics. <u>n</u> input is Manning's n, and values are input from left to right. Coding SA is not required when the channel has only one Manning's n value.*

Example Coding	
SA -30 22	STAGE DISCHARGE DOWNSTREAM X-SECTION SECTION DATA (SA) & MANNING'S (N) VALUES SA = -30 SA = 22 N = 0.04 N = 0.035 N = 0.045 -100 -50 0 50 100
N 0.04 0.035 0.045	

SDC	*Inputs a stage- discharge rating table, see CDS manual if used. Generally not used by Project Development.*
HTW	*Allows culverts to be modeled in series, see CDS manual if used. Generally not used by Project Development.*

STW	*Input: <u>station & slope</u>, sets the location of the stream section to be used in the tailwater analysis. Must be used with the SEC command and it <u>must</u> proceed the SEC command. Generally not used by Project Development.*

Example Coding	*Remarks*
STW 100 0.002	*100 is the stream channel <u>station</u> & 0.002 is the average downstream <u>channel slope</u>.*

SEC	*Input: <u>x-sec. file name</u>, which allows CDS to load the x-sec. data from GEOPAK WSPRO formatted files - *.WSP or *.dat or *.sec. This is an optional command that can be used instead of the XS & GR commands to input x-sec. data into CDS. The file can be edited to provide the Manning's numbers using the N & SA if a given section in the file is to be used for the stage-discharge tailwater analysis.*

Example Coding	*Remarks*
SEC filename	*Input the x-sec. file name.*
Note: The files must be in WSPRO format to be read by CDS.	

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CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	STAGE-STORAGE COMMANDS	
XS	*Input: <u>distance, skew, & slope</u>. Use to input the <u>positive</u> distance between the upstream x-sec and culvert inlet .*	
	Example Coding	*Remarks*
	XS 200 0 0.002	*<u>Distance</u> - is a positive length between the culvert inlet & the first upstream x-sec. If the designer places the first upstream x-sec. at the inlet pipe end, then this command is not needed.* <u>Skew</u> - (optional) angle of x-sec. normal to the channel (degrees) *<u>Average Upstream Slope</u> - channel slope in ft/f from inlet to first x-sec..*
GR	*Input: <u>x-sec. X, Y coordinate data</u>. Can be used to input x-sec. for either stage-discharge or stage-storage. Note: This command would not be used when the SEC- <u>stream x-sec. file name</u> command is used. The SEC command allows CDS to import x-sec. directly from the GEOPAK files, which eliminates the need for inputting the x-sec. with the GR command. Typically Project Development would use the SEV command to input stage-storage data.*	
	Example Coding	*Remarks*
	GR -100 5000 -50 4095 -10 4094 0 4094	*Y - x-sec point horizontal distance increasing to the right.*
	GR 10 4093 50 4095 200 5000	*X - x-sec point vertical elevation.*
STW	*Input: <u>station & slope</u>. This sets the location of the stream section to be used in the tailwater analysis. It must be used when the SEC command is used and it <u>must</u> precede the SEC command.*	
	Example Coding	*Remarks*
	STW 100 0.002	*100 is the stream channel <u>station</u> & 0.002 is the <u>channel slope</u>.*
SEC	*Input: <u>x-sec. file name</u>. This allows CDS to load the x-sec. data from GEOPAK WSPRO formatted files - *.WSP or *.dat or *.sec. This is an optional command that can be used instead of the XS & GR commands to input x-sec. data into CDS. The file can be edited to provide the Manning's numbers using the N & SA if a given section in the file is to be used for the stage-discharge tailwater analysis. This command must be used with the STW command.*	
	Example Coding	*Remarks*
	SEC filename	*Input the x-sec. file name.*
	Note: The x-sec. files must be in WSPRO format to be read by CDS.	
SSC	*This is the input command for a stage-storage data table, used for flood routing analysis. Data to be input as <u>depth, volume, and area</u> or as <u>elevation, volume, and area</u> . Typically Project Development would not use this Command. See CDS manual if used.*	
SSA	*This is the input command for a stage-storage data table, used for flood routing analysis. Data to be input as <u>depth, volume</u> or <u>elevation, volume.</u> Typically Project Development would not use this Command. See CDS manual if used.*	
SEV	*This is the input command for a stage-storage data table, used for flood routing analysis. Data input as <u>elevation, area, volume</u> or <u>filename</u>. Project Development would typically use this command to input a stage-storage table calculated in GEOPAK by inputting the stage-storage <u>filename (xxxx.vol)</u>. If this command is used, the XS & GR commands would not be used.*	
	Example Coding	*Remarks*
	SSE filename	*In this case the designer would calculate the storage volume table with GEOPAK by using the <u>plane to tin</u> criteria.*

CONTINUED ON NEXT PAGE

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	## STAGE-STORAGE COMMANDS ### (CONTINUED)	
SAE	*This is the input command for a stage-storage data table, used for flood routing analysis. Data input as <u>elevation and area</u> or <u>filename</u>. Project Development would typically not use this Command. See CDS manual if used.*	
USL	*Input: Optional - <u>upstream slope from last x-section</u>. Use when upstream x-sections are input for calculating the stage storage volumes. This command would be used with the SEC, XS, & GR commands. Typically Project Development would use the SEV command to input stage-storage data, in which case the USL command would not be used.*	
	Example Coding	*Remarks*
	USL 0.005	*Average channel slope in ft/ft that extends upstream from the last upstream x-sec.*
STC	*Input: <u>stream station of culvert inlet</u>. Use with the XS, GR or SEC commands.*	
	Example Coding	*Remarks*
	STC 256.2	
XT	*Input: <u>template location data.- distance, skew, & slope</u>. This command must be followed by the GR command to supply the template section X, Y coordinates. Generally not used by Project Development. See CDS manual if used.*	
GT	*Input: <u>template x-section</u>. The command must follow a XS command to use a template x-section at the station specified on the XS command. It replaces the GR command for a given XS command. Typically Project Development would not use this Command. See CDS manual if used.*	

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	## OVERTOPPING / OVERFLOW COMMANDS ### (ROADWAY OVERTOPPING OR OVERFLOW DIVERSION)	
XR	*Input: <u>station, width, ipav, usercf, & skew</u>. Data to identify the roadway.* *Station - is the station of the roadway stream crossing, based on the same datum as the stream x-sections.* *Width - is the pavement width.* *ipav - designates the pavement type: 1 = pavement, 2 = gravel, 0 = no adjustment for width.* *usercf - coefficient (If not coded CDS defaults to 3.0) (Typically only used by Hydraulics Section)* *skew - Roadway skew angle in degrees. (Typically only used by Hydraulics Section)*	
	Example Coding	*Remarks*
	XR 155 46 1 2.5 12	*155 - the station, 46 - is the pavement width,* *1 - designates the pavement type, 2.5 - is the coefficient,* *12 - is the roadway skew angle from 90° to the channel align.*
GR	*Input: <u>sta. / elev, sta. / elev.....etc., of the roadway profile</u>. Up to 50 sta / elev entries can be input. Reference SL command for initial overtopping depth parameter. In this case the roadway profile is input as a x-sec. with GR x-sec. command .*	
	Example Coding	*Remarks*
	GR 100 4042 200 4018 300 4017 400 4018	*Sta & Elev in ft.*
	GR 500 4042	
SOC	*Input: <u>depth / discharge, depth / discharge...... etc</u>, for overtopping or overflow table. It allows the user to input a rating curve from another source such as a weir, culvert overflow, or ditch rating. Can be used to simulate an overflow relief structure located above the culvert or to divert overflow down a borrow ditch. Typically Project Development would not use this Command. See CDS manual if used.*	

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	ANALYSIS COMMANDS	
HD	*This is a hydrograph design option that allows the designer to input <u>AHW, GVD, velocity, HW/D, pond size</u>.* *AHW - Allowable headwater depth above flowline of culvert.* *GVD - Greatest vertical culvert height. Allows user to limit culvert height to meet fill height and cover limitations.* *Velocity - (optional) this limits the culvert outflow to a maximum velocity. If the velocity is exceeded, then CDS will increase culvert size to reduce the outlet velocity. This feature only works well if the culvert is flowing full.* *HW / D - Headwater / Culvert Diameter ratio (optional). If this ratio is exceeded CDS will increase the culvert size.* *Pond Size - (optional) This limits the pond size for the design discharge (acres). If this value is exceeded, CDS will increase the culvert size which will lower the HW depth and reduce the area of inundation.* *Note: For best results, use only one of the above input parameters for a particular CDS run, otherwise a no solution may result.*	
	Example Coding	*Remarks*
	HD 10.0 8.0 12.0 1.5 25.0	*This coding shows all commands.*
	HD 10.0	*Coding shows AHW input only. Typically Project Development would use this command to input the AHW.*
HR **or** **PR**	*Input: <u>No. of culvert barrels, width, & height of existing culverts or RC Boxes</u>. This command is used for reviewing an existing culvert size.*	
	Example Coding	*Remarks*
	HR 2 4.0 4.0	*Coding to review 2-48" culverts*
	PR 3 5.0 4.0	*Coding to review a 3-barrel x 5.0 ft x 4.0 ft. RC Box Culvert.*
PD	*Input - <u>AHW, GVD, velocity, & HW/D</u>.* *AHW - Allowable headwater depth above flowline of culvert.* *GVD - Greatest vertical culvert height. Allows user to limit culvert height to meet fill height and cover limitations.* *Velocity - (optional) This limits the culvert outflow to a maximum velocity. If the velocity is exceeded, then CDS will increase culvert size to reduce the outlet velocity. This feature only works well if the culvert is flowing full. If used, it may not find a solution. Project Development would typically not use this command.* *HW / D - Headwater / Culvert Diameter ratio (optional). If this ratio is exceeded CDS will increase the culvert size.*	
	Example Coding	*Remarks*
	PD 10 8.0 12.0 1.5	*10 ft. = AHW, 8.0 ft = GVD , 12.0 = velocity, 1.5 = HW/D ratio.*
	PD 10 8.0	*Coding shows AHW & GVD only. Typically Project Development would use these two input commands.*

CONTINUED ON NEXT PAGE

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	CULVERT GEOMETRY COMMANDS **(FOR DESIGN AND REVIEW)**	
STA	*Inputs the roadway station of the culvert crossing. Not used in computations, only for identifying the culvert location on the output.*	
	Example Coding	*Remarks*
	STA 10100	*Do not code as typical station with a + sign (101+00). Code the station without the + sign as shown in the example.*
SL	*Inputs culvert parameters - <u>slope, length, inlet elevation, outlet elevation, oh,</u>* *Slope - culvert slope in ft / ft (slope value must be positive).* *Length - culvert length in ft.* *Inlet Elevation - This elevation is very important as it links the stage-storage data to the datum. If not input, then CDS will use the lowest elevation of the stage-storage x-sections if x-sections are used.* *Outlet Elevation - (optional) The outlet elevation sets the tailwater depth datum for the culvert capacity computations. If not input, then CDS uses the slope to compute the outlet elevation.* *oh - This input is the water depth where overflow initially begins, which may be overflow down the adjacent roadway section or overflow of the roadway. Depth is measured from the inlet elevation to the lowest overflow point in ft.*	
	Example Coding	*Remarks*
	SL 0.005 102 4602.3 4602.81 6.75	*0.005 ft / ft - culvert slope, 102 ft - culvert length,* *4602.3 - inlet elevation, 4602.81 - outlet elevation,* *6.75 ft - overtopping depth from inlet elevation*
RCP **CMP** **ECP** **CPA** **MPA** **ECP** **RCB**	*Input for various culvert types and inlet types - <u>RCP, CMP, etc., ic, mn, & Ke</u>* *RCP, CMP....etc. - inputs the culvert type.* *ic - inputs the culvert inlet code. (must code)* *mn - inputs Manning's n number (optional)* *Ke - inputs the inlet coefficient (optional)* *Note: If the optional commands are not input, CDS will use default values.* *See tables 1.7.6, 1.7.7 & 1.7.8 in CDS manual for inlet codes, Manning's n number, & entrance loss coefficients.* *RCP - Round concrete culvert type & inlet code* *CMP - Round corrugated metal culvert type & inlet code* *CPA - Concrete arch culvert type & inlet code* *MPA - Corrugated metal arch culvert type & inlet code* *ECP - Concrete elliptical culvert type & inlet code* *RCB - Concrete box culvert type & inlet code* *Note: The designer should always code all the various culvert types for each culvert site being designed. This will allow a review culvert size based on available culvert materials.*	
	Example Coding	*Remarks*
	RCP 11	*RC Pipe - inlet code 11 = socket end projecting.*
	RCP 51 0.013 0.2	*RC Pipe - 51= ic, 0.013 mn, & 0.2 =Ke*
SCR	*Inputs soil codes for outlet scour analysis. This command requires the input of the soil type at the culvert outlet.* *<u>SOIL TYPE & CODE</u> Uniform Sand - 1, Graded Sand - 2, Uniform Gravel - 3, Graded Gravel - 4, Cohesive Soil - 5* *Note: CDS has other equation options that can be used for scour analysis, however Project Development would generally use the soil type codes given above. See CDS manual if other options are used.*	
	Example Coding	*Remarks*
	SCR 2	*Code 2 = Graded Sand*

<div align="center">CONTINUED ON NEXT PAGE</div>

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	HYDROLOGY COMMANDS **(DISCHARGE AND FLOOD DATA)**	
Q	*Inputs the design or review discharge Q in cfs. A total of six discharges can be input per line. However, the command can be repeated to allow the use of additional discharges. For the design mode, the first entry would be the design discharge followed by review discharges. If the Q command is used, then the V command should also be coded. This is an optional command to be used when drainage area is not calculated by the WHY or GS3 command. Typically Project Development would use either the WHY or GS3 as provided by the Hydraulics Section, in which case the Q and V commands would not be used.*	
	Example Coding	*Remarks*
	Q 1000 1500 2000 2500 3000 3500 **RUN** **Q 4000 4500 5000**	*1000 = design discharge & 1500 through 5000 are review discharges. Note an additional Q command was used to input additional discharges 4000 through 5000.*
V	*Inputs the flood volume data for a CDS internally computed hydrograph. It is used in the computation of the default hydrograph. This command is used with the Q command.*	
	Example Coding	*Remarks*
	V 25 30 100	*Up to six flood volumes can be input.*
RPD	*Inputs the frequency data command. It identifies the frequencies data to be applied to the Q and V commands for printing purposes only.*	
	Example Coding	*Remarks*
	RPD 25 2 5 10 50 100	*25 - is the frequency of the first Q entry coded in the Q command.*
WHY1988 Eq. **or** **GS3 2003 Eq.**	*Note: CDS contains two sets of regional hydrology regression equations (WHY-1998 & GS3-2003) that were developed by the USGS for culvert design in Wyoming. The Hydraulics Section will determine the equation set and input data that Project Development will use for calculating the basin Q and V. Note: Project Development must request the basin information from the Hydraulics Section as outlined in SECTION 2 - DESIGN RESPONSIBILITIES, Basin Hydrology.*	
	<u>*Equation set WHY 1988 input data for region 1, 2, &3:*</u> **Area - Drainage area in acres.** **GF - Geographic factor.** **PI - Precipitation regional index (1or 2).** **SB - Basin slope for region 3 in ft/mile.** **Elevation - (Optional for region 1) ft.** **W - (Optional channel geometry for regions 1, 2, or 3 ft.** **ivlo - Volume equation 0 = f area, 1 = f discharge.**	*Equation set GS3 input data for regions 1, 2, 3, 4, 5,& 6:* *Input Data:* *SI - Soil index* *Lat - Latitude in degrees* *Mar - March precipitation* *Jan - January precipitation* *Lng - Longitude degrees* *BFD - basin development factor* *ivlo - Volume equation 0 = f area, 1 = f discharge.* *Input Data by Regional Equations:* *Reg1 Eq - Area, Elevation, LNG (longitude degrees)* *Reg 2 Eq - Area, BFD* *Reg 3 Eq - Area, SI, BDF, ivol* *Reg 4 Eq - Area, Mar, Lat* *Reg 5 Eq - Area, Jan* *Reg 6 Eq - Area, Lat, BDF, ivol*
	Example Coding	*Remarks*
	WHY 1 2 1.1 0	*Where 1 = region, 2 = area, GF = 1.1, PI = 0*
	GS3 1 2 7500 109	*Where 1 = region, 2 = drainage area, 7500 = elev, 109 = LNG*

CDS CODES	DESCRIPTION OF CODE INPUT CRITERIA Note: CDS requires that all single line multiple data entries be separated by a <u>single bar space</u> or <u>comma</u>.	
	HYDROLOGY COMMANDS **(DISCHARGE AND FLOOD DATA)** **(CONTINUED)**	
HYE	*Inputs a storm hydrograph to compute the SCS unit hydrograph method. Input includes <u>step in min, intensity in in/hr</u>. Use with SCS command. Typically Project Development would not use this command. See CDS manual.*	
HYD (Option 1)	*Input: Hydrograph file name - <u>HYD test.hyd</u>. The file name must be DOS compatible and is an ASCII file. Typically Project Development would not use this command. See CDS manual.*	
	Example Coding	*Remarks*
	HYD test.hyd	*File name.*
HYD (Option 2)	*Input: Hydrograph data for hydrographic analysis - <u>time, discharge...time, discharge... etc.</u> Up to 200 discharges can be input. Typically Project Development would not use this command. See CDS Manual.* *Time - Time of discharge in minutes.* *Discharge - Discharge in cfs.*	
	Example Coding	*Remarks*
	HYD 5 20 10.2 30 15 40 20 50 25 100 30 200 **HYD 35 150 40 120**	*In this case, 8 times and 8 discharges were input.*
SCS	*Inputs data to compute a hydrograph using the SCS unit hydrgraph method. The HYE command must be used to provide the hydrograph for the analysis. Input includes <u>area, length, slope, CN, Tc, & print option,</u>* *Area - drainage area in square miles.* *Length - overland flow length (ft) used to compute the time of concentration; if 0, then TC will be used.* *Slope - basin slope (ft)/ft) used to compute time of concentration, if 0 then TC is used.* *CN - SCS curve number; See CDS manual for value.* *TC - input time of concentration.* *Print - input print option: 0 = no printout; 1= print peak, volume and time of concentration; 2 = print SCS hydrograph.*	
	Example Coding	*Remarks*
	SCS 1 1000 0.005 75 0	*1 = area in square miles, 1000 = basin overland flow length in ft.* *0.005 = basin slope, 75 = SCS curve number .* *0 = print option.*
	FLOW DISTRIBUTION COMMANDS	
FD	*Input: <u>p1, p2, p3....etc</u>. Typically Project Development would not use this command. See CDS manual.* *p1, p2, p3.....etc = <u>discharge -Q</u> or <u>surface water elevation</u> in section.* *This command is not required for culvert analysis. It is used to analyze the flow distribution of a single section. The output provides tractive shear, velocity, momentum, and discharge distributions for a channel section that is coded for stage-discharge using XS, GT, N, & SA commands that must proceed the FD command. The flow distribution may be coded as either a discharge or elevation.*	
	Example Coding	*Remarks*
	FD -300 -400	*Where -300 & -400 = Q1, Q2 etc.*
	FD 5010.2 5012.2	*Where 5010.2 5012.2 = Elev 1, Elev 2 etc.*
	FD -300 -400 5010.2 5012.2	*Where both Q & Elevation are coded.*

CDS Coding & Output Examples: These examples are based on the culvert crossing criteria given in Exhibit 32, which demonstrates the process of calculating the upstream stage-storage table. The drainage site is located in region 3 and the basin size is 30 acres. Coding and output examples are included for both stage-storage and peak design. Comments in red provide additional guidance.

Stage-Storage Design - CDS Coding Example: Exhibit 38.

c139925.cds

CDS CODES	CDS CODE INPUT CRITERIA

JOB	Sta. 399+25 Worland &Worland East 0N36-01(053) - 0.047 Mi² (30 ac) — — (CULVERT STATION, PROJECT NO. & DRAINAGE AREA INPUT)
*	**Stage-Storage Design**
SI	1 1 ———————————(WORKING UNITS: 1 1 = ENGLISH INPUT & OUTPUT)
*	
PRT	1 1 1 3 ————————(PRINT COMMANDS - SEE CDS CODE CRITERIA FOR OPTIONS)
*	(STAGE- DISCHARGE X-SEC. STA. & SLOPE: 1068 = STA. & 0.0732 = CHANNEL SLOPE FT/FT)
STW	1068 0.0732 THIS COMMAND MUST ALWAYS PROCEED THE SEC COMMAND - SEE CODE INPUT CRITERIA)
SEC	c1.wsp ——————————(DOWNSTREAM STAGE- DISCHARGE X-SECTION - FILE
*	(1000 = STATION....NOT USED IN CALCULATIONS BUT MUST BE ENTERED TO RUN
XR	39925 24 2 —— - 24 = ROADWAY WIDTH & 2 = PAVEMENT TYPE)
GR	0,4500 85,4498 170,4496 235,4495
GR	285,4490 315,4492 330,4494 335,4496 — (OVERTOPPING X-SECTION OR PROFILE:
GR	345,4498 385,4500 0,4500 = DIST. & ELEV......................ETC.)
*	
SEV	39925.vol ——————————(STAGE-STORAGE DISCHARGE GEOPAK TABLE - FILE NAME.....SEE EXHIBIT 34)
*	
*	
STA	39925 ——————————————————(CULVERT STATION)
SL	0.0547 318 4483.40 —————(CULVERT - SLOPE, LENGTH & INLET ELEVATION)
HD	6.6 5 ———————————————(AHW & GREATEST VERTICAL CULVERT DIAMETER -GVD)
CMP	51 ————————————————(CMP END TREATMENT CODE: 51 = 0.5 COEFFICIENT) - SEE CDS MANUAL
RCP	51 ————————————————(RCP END TREATMENT CODE: 51 = 0.5 COEFFICIENT) - SEE CDS MANUAL
RPD	25 100 ——————————(DESIGN FREQUENCE : 25 YEAR & 100 YEAR)
WHY	3 30 1 178 ——————(WHY 1988 INPUT EQUATION DATA FOR BASIN Q & V CALCULATION)
SCR	2 —————— •3 = REGION AREA, 30 =ACRES, 1, PRECIPITATION INDEX
RUN	& 178 = BASIN SLOPE FOR REGION 3 IN FT/MILE.
*	(SOIL TYPE CODE INPUT FOR SCOUR ANALYSIS -SEE CDS MANUAL)
*	(RUNS SECTION)
*	
STA	39925 ——————————————(CULVERT STATION)
SL	0.0547 318 4483.40 —————(CULVERT - SLOPE, LENGTH & INLET ELEVATION)
HR	1 2 2 ——————————(1=NO. CULVERTS, 2 = CULVERT HEIGHT,& 2 = CULVERT WIDTH)
CMP	51 ————————————————(CMP END TREATMENT CODE: 51 = 0.2 COEFFICIENT) - SEE CDS MANUAL
RPD	25 100 ——————————(DESIGN FREQUENCE : 25 YEAR & 100 YEAR)
WHY	3 30 1 178 ——————(WHY 1988 INPUT EQUATION DATA FOR BASIN Q & V CALCULATION)
SCR	2 —————— •3 = REGION AREA, 30 DRAINAGE AREA IN ACRES, 1 = PRECIPITATION
RUN	INDEX & 178 = BASIN SLOPE FOR REGION 3 IN FT/MILE.
*	(SOIL TYPE CODE INPUT FOR CALCULATING SCOUR ANALYSIS)
*	(RUNS SECTION)
STA	39925 ——————————————(CULVERT STATION)
SL	0.0547 318 4483.40 —————(CULVERT - SLOPE, LENGTH & INLET ELEVATION)
HR	1 2 2 ——————————(1=NO. CULVERTS, 2 = CULVERT HEIGHT, & 2 = CULVERT WIDTH)
RCP	51 ————————————————(CMP END TREATMENT CODE: 51 = 0.5 COEFFICIENT)-SEE CDS MANUAL
RPD	25 100 ——————————(DESIGN FREQUENCE : 25 YEAR & 100 YEAR)
WHY	3 30 1 178 ——————(WHY 1988 INPUT EQUATION DATA FOR BASIN Q & V CALCULATION)
SCR	2 —————— •3 = REGION AREA, 30 DRAINAGE AREA IN ACRES, 1 = PRECIPITATION
RUN	(SOIL TYPE CODE INPUT FOR CALCULATING SCOUR ANALYSIS)
END	(RUNS SECTION)
	(ENDS INPUT CODING: MUST ALWAYS BE PLACED AT THE END OF CODING)

Labels in left margin:
- OVER-TOPPING CRITERIA
- CULVERT DESIGN FOR RCP & CMP
- CULVERT REVIEW FOR CMP
- CULVERT REVIEW FOR RCP

EXHIBIT 38
CDS CODING EXAMPLE - Sta. 399+25
STAGE-STORAGE DESIGN

Stage-Storage Design - CDS Output Report, Exhibit 39.

```
STATION:  39925.00  DESIGN OUTPUT FOR ROUND CONCRETE - F.E.
   CULVERT SIZE: 1-  18.0 in X  18.0 in ---------------------------- CALCULATED SIZE
   ROUND CONCRETE/  ROUND CONCRETE, COMMERCIAL END(FE) INLET
   Manning N :    .0130  Inlet Loss Coef. :    .5000 -------------- INPUT DATA
   Discharge Q:   35.4796 cfs FREQ:   25 YR ----------------------- CALCULATED CFS

ANALYSIS TYPE: HYDROGRAPH DESIGN Print Option  3

   DESIGN CRITERIA
   Allowable  Greatest  Maximum  Maximum  Maximum  Incipient
   Headwater  Culvert   Pond     HW/D     Outlet   Overtopping
   Depth      Height    Size     Ratio    Velocity Depth
    ft         ft        ac                fps      ft                   INPUT
   6.60       5.00       .00      .00       .00     6.60                 DATA
                                        Flowline Elev.      Overtopping Elev
   BARREL GEOMETRY: LENGTH    SLOPE    Inlet    Outlet
                      ft        %       ft       ft          ft
                     318.0    5.47000  4483.40  4466.01    4490.00
```

```
* * * * * * * *  C U L V E R T    P E R F O R M A N C E * * * * * * * * * * * *
```

Freq yr	Peak Discharges			Headwater		Outlet			Flow	Pond
	Inflow cfs	Outflow cfs	Over cfs	Depth ft	Elev ft	Vel fps	Depth ft	Fr no	Type	Area ac
25	35.5	21.2	.0	6.3	4489.7	15.6	1.1	2.66	IS2	0.
100	72.4	49.3	25.0	7.9	4491.3	15.9	1.2	2.55	IS2	1.

CALCULATED FLOW CRITERIA

```
****DOWNSTREAM CHANNEL PERFORMANCE****
```

Freq yr	Culvert Outflow cfs	Depth ft	velocity		Scour Analysis				Cutoff wall	
			ave fps	max fps	Depth ft	Wid. ft	Leng. ft	Vol. cy	Depth ft	Width ft
25	21.2	.5	.0	.0	1.4	12.	15.	0.	.9	7.3
100	24.3	.7	5.6	6.5	1.5	13.	16.	0.	.9	7.9

```
STATION:  39925.00  DESIGN OUTPUT FOR ROUND METAL - F.E.
   CULVERT SIZE: 1-  24.0 in X  24.0 in
   ROUND METAL   RIVETED)/ UNPAVED /
   ROUND METAL,  COMMERCIAL END(FE) INLET
   Manning N :    .0240  Inlet Loss Coef. :    .5000
   Discharge Q:   35.4796 cfs FREQ:   25 YR

ANALYSIS TYPE: HYDROGRAPH DESIGN Print Option  3

   DESIGN CRITERIA
   Allowable  Greatest  Maximum  Maximum  Maximum  Incipient
   Headwater  Culvert   Pond     HW/D     Outlet   Overtopping
   Depth      Height    Size     Ratio    Velocity Depth
    ft         ft        ac                fps      ft
   6.60       5.00       .00      .00       .00     6.60
                                        Flowline Elev.      Overtopping Elev
   BARREL GEOMETRY: LENGTH    SLOPE    Inlet    Outlet
                      ft        %       ft       ft          ft
                     318.0    5.47000  4483.40  4466.01    4490.00
```

```
* * * * * * * *  C U L V E R T    P E R F O R M A N C E * * * * * * * * * * * *
```

Freq yr	Peak Discharges			Headwater		Outlet			Flow	Pond
	Inflow cfs	Outflow cfs	Over cfs	Depth ft	Elev ft	Vel fps	Depth ft	Fr no	Type	Area ac
25	35.5	29.2	.0	4.6	4488.0	10.3	1.7	1.40	IS2	0.
100	72.4	43.7	9.4	7.5	4490.9	11.0	2.0	1.39	OM2F	0.

```
****DOWNSTREAM CHANNEL PERFORMANCE****
```

Freq yr	Culvert Outflow cfs	Depth ft	velocity		Scour Analysis				Cutoff wall	
			ave fps	max fps	Depth ft	Wid. ft	Leng. ft	Vol. cy	Depth ft	Width ft
25	27.2	.5	.0	.0	1.6	12.	17.	0.	1.1	7.2
100	34.3	.6	5.5	6.3	1.8	13.	19.	0.	1.2	8.0

EXHIBIT 39
CDS OUTPUT REPORT Sta. 399+25
STAGE-STORAGE DESIGN

A general review of the design performance criteria should be made to make sure the values calculated are reasonable. For example, a review of the round concrete pipe criteria in Exhibit 39 would include the following:

<u>Input Data</u>: Make sure all the Design Criteria and Barrel Geometry input data is correct.

<u>Peak Discharge</u>: The peak flow of 35.5 cfs that is generated by the drainage basin looks reasonable. The culvert flow of 21.2 cfs also looks reasonable and should be less than the basin flow for stage-storage design.

<u>Headwater</u>: The headwater depth of 6.3 ft is less than the AHW depth of 6.6 ft and for the 100-year flood shows that 1.3 ft of overtopping will occur, which is reasonable because most of the flow will not overtop the roadway.

<u>Velocity</u>: Compare values for outlet velocity (15.6 cfs), channel velocity (5.6 cfs), and scour length-width-depth to make sure there is no need for erosion control riprap or cutoff walls.

Peak Design CDS Coding Example: Exhibit 40. This example is also based on the same culvert site that was used for the stage-storage design example. It shows that storage design is more economical than peak design because the upstream storage reduces the culvert size. In this case storage design requires an 18-inch diameter culvert and peak design requires a 24-inch diameter culvert.

Peak Design - CDS Coding Example: Exhibit 40.

EXHIBIT 40
CDS CODING EXAMPLE - Sta. 399+25
PEAK DESIGN

Peak Design - CDS Output Report: Exhibit 41.

```
STATION:  39925.00  DESIGN OUTPUT FOR ROUND CONCRETE -F.E.
  CULVERT SIZE: 1-  24.0 in X  24.0 in
  ROUND CONCRETE/  ROUND CONCRETE, COMMERCIAL END(FE) INLET
  Manning N :    .0130  Inlet Loss Coef. :    .5000
Discharge Q:   35.4796 cfs FREQ:   25 YR


ANALYSIS TYPE: PEAK DESIGN    Print Option  3

  DESIGN CRITERIA
  Allowable  Greatest  Maximum  Maximum  Maximum  Incipient
  Headwater  Culvert   Pond     HW/D     Outlet   Overtopping
  Depth      Height    Size     Ratio    Velocity Depth
    ft         ft       ac               fps       ft
   6.60       5.00      .00      .00      .00      6.60
                                     Flowline Elev.      Overtopping Elev
  BARREL GEOMETRY: LENGTH     SLOPE     Inlet    Outlet
                     ft         %         ft       ft           ft
                    318.0    5.47000   4483.40  4466.01      4490.00


  * * * * * * * *  C U L V E R T    P E R F O R M A N C E * * * * * * * * * *

        |  Peak Discharges     |Headwater |   Outlet      |  Flow|   Pond |
  Freq  Inflow  Outflow  Over  |Depth Elev  Vel  Depth  Fr Type    Area
   yr    cfs     cfs     cfs    ft    ft    fps   ft    no          ac
  ----------------------------------------------------------------------
   25    35.5    35.5     .0    6.1  4489.5 18.1  1.2  2.91 IS2      0.
  100    72.4    72.4    29.9   8.0  4491.4 18.9  1.4  2.86 IS2      0.

        ****DOWNSTREAM CHANNEL PERFORMANCE****

        |Culvert|          Velocity  | Scour Analysis      |Cutoff Wall |
  Freq  Outflow |Depth   ave   max   Depth Wid. Leng. Vol. Depth  Width
   yr    cfs      ft     fps   fps    ft    ft    ft    cy    ft     ft
  ----------------------------------------------------------------------
   25    35.5    .6      5.2   6.0    1.6   15.   18.   0.   1.0    8.9
  100    42.5    .8      6.2   7.2    1.8   16.   20.   0.   1.1    9.8
```

```
STATION:  39925.00  DESIGN OUTPUT FOR ROUND METAL -F.E.
  CULVERT SIZE: 1-  30.0 in X  30.0 in
  ROUND METAL    RIVETED)/ UNPAVED /
  ROUND METAL,   COMMERCIAL END(FE) INLET
  Manning N :    .0240  Inlet Loss Coef. :    .5000
Discharge Q:   35.4796 cfs FREQ:   25 YR


ANALYSIS TYPE: PEAK DESIGN    Print Option  3

  DESIGN CRITERIA
  Allowable  Greatest  Maximum  Maximum  Maximum  Incipient
  Headwater  Culvert   Pond     HW/D     Outlet   Overtopping
  Depth      Height    Size     Ratio    Velocity Depth
    ft         ft       ac               fps       ft
   6.60       5.00      .00      .00      .00      6.60
                                     Flowline Elev.      Overtopping Elev
  BARREL GEOMETRY: LENGTH     SLOPE     Inlet    Outlet
                     ft         %         ft       ft           ft
                    318.0    5.47000   4483.40  4466.01      4490.00

  * * * * * * * *  C U L V E R T    P E R F O R M A N C E * * * * * * * * * *

        |  Peak Discharges     |Headwater |   Outlet      |  Flow|   Pond |
  Freq  Inflow  Outflow  Over  |Depth Elev  Vel  Depth  Fr Type    Area
   yr    cfs     cfs     cfs    ft    ft    fps   ft    no          ac
  ----------------------------------------------------------------------
   25    35.5    35.5     .0    3.6  4487.0 11.4  1.5  1.63 IS2      0.
  100    72.4    72.4    10.8   7.6  4491.0 12.6  2.5  1.42OM2F      0.

        ****DOWNSTREAM CHANNEL PERFORMANCE****

        |Culvert|          Velocity  | Scour Analysis      |Cutoff Wall |
  Freq  Outflow |Depth   ave   max   Depth Wid. Leng. Vol. Depth  Width
   yr    cfs      ft     fps   fps    ft    ft    ft    cy    ft     ft
  ----------------------------------------------------------------------
   25    35.5    .6      5.2   6.0    1.7   12.   18.   0.   1.2    7.5
  100    61.7    .8      6.2   7.2    2.2   17.   24.   0.   1.5   10.3
```

EXHIBIT 41
CDS OUTPUT REPORT - Sta. 399+25
PEAK DESIGN

SECTION 14 - CHANNEL CHANGE DESIGN

General: Project Development designs low-volume, intermittent-flow channel changes associated with small culverts. Higher volume channel changes with large flows or continuous flow can be very complex and involve elements such as water surface profile, sediment transportation, erosion, environmental impact issues and will be analyzed by the Hydraulics Section.

Minor channel shaping within ±20 ft [6 m] of the pipe inlet or outlet is generally not analyzed or designed as a channel change. If a longer channel change is needed, then it must be designed or checked for capacity, depth of flow, velocity, erosion protection, etc.

When investigating options for the realignment of a natural channel, the designer should always consider the following fundamental rules:

• 	If possible, avoid changing the natural channel.

• 	If a channel change is necessary, keep the realignment length and slope as close to the natural channel length and slope as possible.

• 	Avoid sharp bends.

• 	Match the proposed channel cross-section shape to natural channel shape as close as possible.

Exhibit 42 shows elements of a trapezoidal channel.
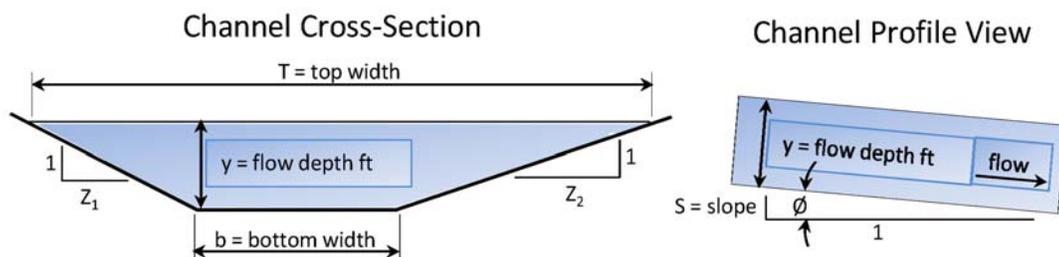
EXHIBIT 42
TRAPEZOID CHANNEL ELEMENTS

Channel Flow Equations:

Most channel changes associated with small pipe design are trapezoidal in shape and can be designed using the following equations to calculate unknown channel criteria such as velocity, discharge, depth of flow, flow area, wetted perimeter, hydraulic radius, froude number, etc.:

$$Q = V \times A \qquad\qquad V = \frac{1.49}{n} \times S^{1/2} \times R^{2/3} \qquad\qquad A = \frac{y}{2}(b + T)$$

$$WP = b + y\left[\sqrt{1 + Z_1{}^2} + \sqrt{1 + Z_2{}^2}\right] \qquad T = b + \left[y \times (Z_1 + Z_2)\right]$$

$$Froude\,No. = V \times \sqrt{\frac{T}{gA \times \cos\phi}} \qquad\qquad \phi = Tan^{-1} of\,(S) \qquad\qquad R = \frac{A}{WP}$$

Where:

Q   = Discharge or flowrate (ft^3/sec).
V   = Average velocity of the water (ft/sec).
A   = Flow cross-sectional area (ft^2).
n   = Manning friction coefficient (non-dimensional). n is a function of the channel material such as grass, concrete, earth, etc. A rough channel with a higher Manning's n-value would have a lower flow rate than a smooth channel with a lower n-value.
S   = Slope of the channel bottom or grade (ft/ft).
R   = Hydraulic radius of the flow cross-section (ft) R= A ÷ WP.
WP = Wetted perimeter (ft). Contact length between the water and the channel bottom and sides.
b   = Channel bottom width (ft).
y   = Water depth (ft).
T   = Top width of the water (ft).
Z$_1$ = Left side of channel. Horizontal distance Z_1.
Z$_2$ = Right side of channel. Horizontal distance Z_2.
F   = Froude number (non-dimensional). F is a parameter ratio of the inertial to gravity forces in the flow. F<1 are low velocity flows called subcritical. F>1 are high velocity flows called supercritical. Subcritical flows are controlled by downstream obstructions, while supercritical flows are affected by upstream controls. F=1 flows are called critical. If flows exceed F=1, a hydraulic jump will occur.
g   = acceleration due to gravity = 32.2 ft./sec^2. g is used in the equation for the Froude number.
∅   = Angle formed by S.

Manning's *n-Values*: Standard tables for Manning's *n-values* are available for various types of channels, closed conduits, mountain streams, floodplains, etc. The normal *n-value* that applies to "Excavated Channels" is 0.027. See APPENDIX A - SECTION B - TABLE OF MANNING's n-VALUES.

Channel Design: Example: Assume a culvert crossing in a rural area that carries an intermittent design flow rate of 50 cfs. Site conditions require the construction of a 150-foot long channel change to direct flow from the culvert outlet back into the natural channel. The slope has been determined to be 0.0015 ft/ft and the natural channel bottom width is ±5.5 ft.

At this point there are several unknowns about the channel that will have to be set to analyze the channel's flow properties such as y, R, F, V, etc. The process may require the designer to analyze additional channel configurations to find a shape with acceptable flow properties. Typically, the proposed channel should be configured to match the natural channel shape as near as possible.

Step 1:   **Analyze Natural Channel Conditions:** The project is located in a rural area and the natural channel is covered with short prairie grass. There is little or no sign of erosion within the channel bottom width of ±5.5 ft and the channel has uniform side slopes. The culvert analysis determined the natural channel tailwater depth to be in the range of 2.0 ft for a flow rate of 50 cfs.

Step 2:   **Proposed Channel Shape:** Based on the natural channel condition, a graded trapezoid channel with uniform side slopes is a good choice for the proposed channel. For a first trial channel shape, the side slopes are set at 1V:3H to allow for easy topsoil placement and seeding. The bottom width is set at 6 ft to approximate the natural channel bottom width of ±5.5 ft.

Step 3:   **Manning's *n-value*:** An *n-value* of **0.027** is selected based on an excavated channel with established channel cover of short grasses.

The proposed channel shape now has enough known elements to analyze the flow properties:

Known elements: Q = 50 cfs
                    S = 0.0015 ft/ft
                    n = 0.027
                    Z_1 & Z_2 = 3 ft
                    b = 6 ft

Unknown element: T = top width (ft)
                    A = flow area (ft^2)
                    WP = wetted perimeter (ft)
                    R = hydraulic radius (ft)
                    V = average velocity (ft/sec)
                    y = depth of flow (ft)

Calculate Unknown Channel Elements: The Excel spreadsheet shown in Exhibit 43 is used to demonstrate how the equations are applied to calculate the unknown elements of the proposed channel change shape. The spreadsheet is set up to calculate values based on 0.1-foot incremental depths of flow starting with **y** = 1.0 ft and ending with **y** = 2.1 ft. From the calculated results, the channel flow rate of Q = 50 cfs falls between the flow depths of 1.8 ft and 1.9 ft. By interpolation, the flow depth for 50 cfs is calculated to be 1.819 ft. This depth is added to the spread sheet as shown in the highlighted row and calculations are completed for a channel flow of 50 cfs.

PROPOSED GRADED CHANNEL

LENGTH = 150 ft
SLOPE = .015 ft/ft
Q = 50 cfs
n = .027
S = .0015 ft/ft

FLOW DEPTH	T=b+(y)×(Z₁+Z₂) T=Top Width	A=(y/2)×(b+T) A=AREA	WP=b+(y)×[(1+Z₁²)^0.5+(1+Z₂²)^0.5] WP=Wetted Perimeter	R= A ÷ WP R=Hy. Radius	GRADE	V=1.49 ÷ N × S^(1/2) × R^(2/3)				Q= V×A Flow
						1.49 ÷ n				
y	T	A	WP	R	s	n=.027	S^(1/2)	R^(2/3)	V	CFS
1.0	12.0	9.00	12.32	0.7302	0.0015	55.19	0.039	0.811	1.73	15.6
1.1	12.6	10.23	12.96	0.7895	0.0015	55.19	0.039	0.854	1.83	18.7
1.2	13.2	11.52	13.59	0.8477	0.0015	55.19	0.039	0.896	1.91	22.1
1.3	13.8	12.87	14.22	0.9049	0.0015	55.19	0.039	0.936	2.00	25.7
1.4	14.4	14.28	14.85	0.9613	0.0015	55.19	0.039	0.974	2.08	29.7
1.5	15.0	15.75	15.49	1.0170	0.0015	55.19	0.039	1.011	2.16	34.0
1.6	15.6	17.28	16.12	1.0720	0.0015	55.19	0.039	1.047	2.24	38.7
1.7	16.2	18.87	16.75	1.1264	0.0015	55.19	0.039	1.083	2.31	43.7
1.8	16.8	20.52	17.38	1.1804	0.0015	55.19	0.039	1.117	2.39	49.0
1.819	16.9	20.84	17.50	1.1906	0.0015	55.19	0.039	1.123	2.40	50.0
1.9	17.4	22.23	18.02	1.2339	0.0015	55.19	0.039	1.150	2.46	54.7
2.0	18.0	24.00	18.65	1.2869	0.0015	55.19	0.039	1.183	2.53	60.7
2.1	18.6	25.83	19.28	1.3396	0.0015	55.19	0.039	1.215	2.60	67.1

EXHIBIT 43
OPEN CHANNEL FLOW COMPUTATIONS

The *Froude number* is determined using the calculated channel elements:

$$\phi = Tan^{-1}of\,(S) \qquad\qquad \phi = 0.08593° \qquad\qquad \cos\phi = 0.99$$

$$F = V \times \sqrt{\frac{T}{gA \times \cos\phi}} \qquad = 2.40 \times \sqrt{\frac{16.9}{32.2 \times 20.84 \times 0.99}} \quad F = 0.38106$$

The *Froude number* indicates that the flow is subcritical. The velocity of 2.40 ft/sec is reasonable and erosion mitigation is not required. Typically, the flow velocity can be in the range of 5 ft/sec to 6 ft/sec before erosion starts to occur, and when the velocity reaches or exceeds 10.0 ft/sec, erosion protection should be considered.

In this example, the analysis has shown the proposed channel change to be an acceptable design. If the design was marginal or unacceptable due to channel slope, shape, alignment, etc., other channel configurations would have to be investigated.

Optional Design Software: The spreadsheet example in Exhibit 43 was provided to demonstrate how the equations relate to the open channel flow elements, but there are more efficient tools available that make the process of channel design fast and easy.

The FHWA has a free tools program called "Visual Urban (HY-22) Urban Drainage Design" that allows the designer to quickly analyze channel flow. The Open Channel Hydraulic portion of the program uses seven variable input options. The user must always enter variables 3 and 4, plus any four of the remaining five input variables to compute the output results.

VARIABLES	INPUT DATA
1. Channel Slope (ft/ft)	0.0015
2. Channel Bottom Width (ft)	6.0
3. Left Side Slope (Horizontal to 1)	3.0
4. Right Side Slope (Horizontal to 1)	3.0
5. Manning's Coefficient	0.027
6. Discharge (cfs)	50
7. Depth of Flow (ft)	?

OUTPUT RESULTS:

Cross-Section Area	20.84 ft^2
Average Velocity	2.40 ft/sec
Top Width	16.92 ft
Hydraulic Radius	1.19 ft
Froude Number	0.38
Depth of Flow	1.82 ft

The Visual Urban (HY-22) Urban Drainage Design Program performs the following in metric or English units:
- Drainage of highway pavements,
- Open channel flow characteristics,
- Critical depth calculations,
- Development of stage-storage relationships, and
- Reservoir routing .

The procedures are described in FHWA *Hydraulic Engineering Circular (HEC-22) Urban Drainage Design Manual* and the program can be downloaded at no cost from the following site:
http://www.fhwa.dot.gov/engineering/hydraulics/software/softwaredetail.cfm

SECTION 15-STORM SEWER LAYOUT AND DETAILS

General: The Hydraulics Section develops and details the initial storm sewer system including the basin hydrology, system hydraulics, plan view and profile layout. Project Development uses the initial design to complete the final storm sewer plan details which includes determining the final location of manholes, inlet boxes, laterals, trunklines, grades, plan quantities, summaries, etc.

The design evolves with the initial storm sewer layout being included in the Grading Plans and the final storm sewer design being included in the Right-of-Way and Utility Plans. Throughout the process it is generally necessary to modify the initial storm sewer layout due to utility conflicts or other design constraints. When significant modifications are made, notify the Hydraulics Section so that the storm sewer model can be updated, if needed. Any resulting changes in pipe sizes, etc., are to be included in the final plan details. Have the Hydraulics Section review and approve the final storm sewer plan.

Key Elements: Criteria to be considered when developing the final storm sewer layout and details are:

1. **Utilities:** All existing underground utilities must be shown on the storm sewer plan and profile sheets. A cross-sectional elevation view of each utility should be drawn as near to scale as possible on the trunkline and lateral profiles.

    - Buried utilities such as electrical power, telephone, waterlines, etc., are drawn at the approximate buried depth provided by the utility company or owner. For sanitary sewer crossings the designer should calculate the actual grade elevation where it crosses the storm sewer. The utility survey should include sewer manhole invert elevations on both sides of the crossing.

    - For major utility crossings such as buried gas and oil lines, electrical power, etc., it may be necessary to pothole the utility so that the exact location and elevation can be determined.

    - Typically, small buried utilities such as electrical power, waterline, gas and oil lines, telephone (non-fiber optics), etc., can be adjusted to avoid conflicts with the storm sewer system. However, when there are conflicts with a sanitary sewer or other major utilities such as a large high pressure gas, fiber optics telephone, etc., the storm sewer should be modified to avoid the conflict, if possible.

2.   **Trunkline and Manhole Location:** If possible, set the trunkline alignment so that the manhole lids are not located in the traffic lane wheel path. Install manholes at changes in pipe grades, alignment changes, pipe intersections and at intervals less than 300 ft [91 m] or at the interval required by municipal standards. Factors to consider when setting grade and elevation are: pipe size, cover requirements, minimum slope, lateral connections and vertical clearance to avoid obstructions (utilities, etc.).

3.   **Alignment:** Avoid angle changes in the pipe alignment between connecting manholes/inlet boxes to minimize hydraulic losses, if possible. This is most critical for the main trunkline. Curved alignment is permissible when supplier-furnished bends are used, providing that the radius specified matches the standard available bends for the type of conduit being used.

4.   **Pipe Slope:** Typically, a uniform slope is maintained between structures, unless it is unavoidable. In most cases storm sewers are designed with slopes that develop a self-cleaning velocity of 3 ft/sec [0.91 m/sec] or greater. If possible, maintain a minimum slope of 1 percent for CMP and 0.5 percent for RCP. Where flatter grades are needed to meet the outfall elevation, etc., use RCP and calculate the minimum slope using the following form of Manning's equation:

$$S = K_s \left(\frac{nV}{D^{0.67}} \right)^2$$

Where:
S = minimum slope, ft/ft
K_s = constant, 2.88
n = Manning's coefficient,
V = average pipe velocity, 3ft/s
D = pipe diameter, ft

Minimum RCP Slopes for Storm Sewers

Pipe Diameter (in.)	Slope (ft/ft)
18	0.0026
24	0.0017
30	0.0013
36	0.0010
42	0.0008
48	0.0007
54	0.0006
60	0.0005
66	0.0005

Note: When there is a need to use flatter slopes, notify the Hydraulics Section so that the storm sewer model can be updated. Flatter slopes may require a larger pipe diameter.

5.   **Curb and Gutter Grades:** A minimum gutter gradient of 0.20 percent (0.30 percent desirable) is recommended. When lesser slopes are encountered, the gutter shall be warped to provide the minimum slope. A continuous inlet system such as a slotted or trench drain may be used in sag or low gradient gutter sections.

      For new construction in flat terrain, the designer can maintain minimum grades by using a rolling centerline profile.

6.   **Manholes - Size, Invert Elevations and Type:** Ensure that the diameter of each manhole is large enough to accommodate the intersecting pipe sizes. Check by drawing a scaled plan view of the manhole and intersecting pipe diameters as shown in Exhibit 44. For RCP add wall thickness to scaled drawing.

      If possible, the manhole invert elevations should be set so that the trunkline outlet elevation is a minimum of 0.1 ft [30.48 mm] lower than the trunkline inlet elevation. The lateral pipe inlet elevation should be set a minimum of 0.1 ft [30.48 mm] above the trunkline inlet elevation as shown in Exhibit 45.

EXHIBIT 44
MANHOLE SHOWING
INTERSECTING PIPE CLEARANCE

EXHIBIT 45
MANHOLE INVERT CRITERIA
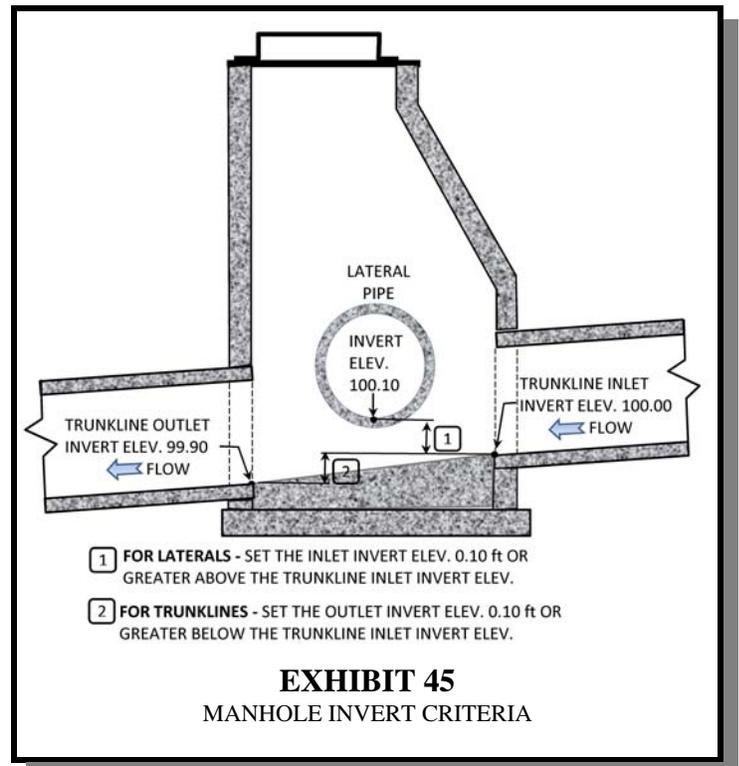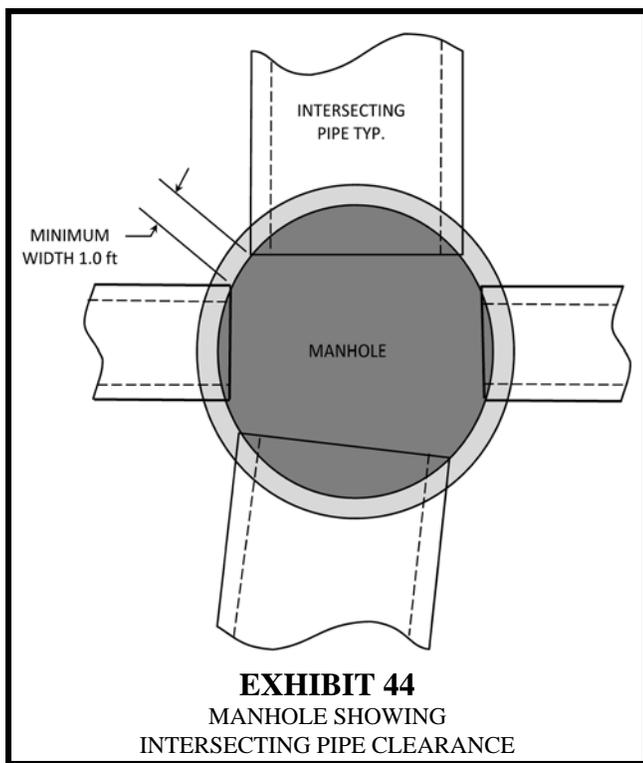
There are two standard manhole options that can be use for storm sewer design listed below: (See WYDOT Standard Plans for details)

- Type A - Eccentric Manhole: Typically used for most storm sewers.

- Type C - Straight Manhole With Slab Cover: Typically used for shallow depth manholes.

7. **Pollution Control:** Meet federal and local municipal standards for storm sewer pollution control to the extent possible. Precast Concrete Stormceptor or other approved pollution separators may be used to separate pollutants from the storm water.

8. **Side Ditches:**
    In some cases it may be necessary to collect water into the storm sewer system from side ditches.

9. **Plan and Profile Details:** Separate plan and profile sheets are required for the trunkline and lateral details:

    - **Trunkline Sheet Details:** On the plan view, detail the entire storm sewer system including the trunkline, laterals, inlet boxes and grates, manholes, etc. In the profile view, detail the trunkline and manholes only.

    - **Lateral Details:** Provide separate plan and profile sheets that detail lateral piping between the inlets and manholes.

10. **Labeling:** Include references that tie the lateral detail sheets to the trunkline sheets. Typical labeling and references include flowline elevations, grades, pipe lengths, pipe diameters, manhole diameters, manhole rim elevation, utility type and size, inlet type and size, etc., as shown in Exhibits 46 and 47.

THE CHURCH OF CHRIST
SCALE: 1"=50'

NEBRASKA AVE
PENNSYLVANIA AVE
IOWA AVE

21+00 22+00 23+00 24+00 25+00 26+00 27+00

COMBINATION GUY ANCHOR COMPANY

GRASS GRASS GRASS GRASS GRASS GRASS

MH 2049
TYPE D MANHOLE (66")
STA 20+49.39

2174L
TYPE U INLET
STA 21+74.07

MH 2364
TYPE D MANHOLE (60")
STA 23+63.89

MH 2400
TYPE D MANHOLE (60")
STA 23+99.85

MH 2483
TYPE D MANHOLE (96")
STA 24+83.16

2523L
TYPE U INLET
STA 25+23.24

MH 2745
TYPE C MANHOLE (48")
STA 27+45.42

N 89° 20' 01.5" E   N 89° 20' 01.5" E

30'-SLOTTED DRAIN 18"

2048R
TYPE T INLET
STA 20+47.56

2174R
TYPE A INLET
STA 21+74.07

POWER GUY ANCHOR

2364R
TYPE C INLET
STA 23+63.86

2401R
TYPE T INLET
STA 24+01.30

2452R
TYPE V INLET
STA 24+51.83

2483R
TYPE A INLET
STA 24+83.16

2741R
TYPE V INLET
STA 27+40.92

2745R
TYPE A INLET
STA 27+45.40

MH 2174
TYPE D MANHOLE (60")
STA 21+74.07

2046/18
TYPE A INLET
STA 20+46.18

18" NEENAH
R-4999 L9
TRENCH DRAIN

FIRST SOUTHERN BAPTIST

2399R
TYPE A INLET
STA 23+98.54

18" NEENAH
R-4999 L9
TRENCH DRAIN

ALBERTSONS

FIRE HYDRANT

NOTE: PIPE LENGTHS SHOWN ARE SLOPE DISTANCES.

(F) = SEE STORM SEWER DETAIL "F"
(G) = SEE STORM SEWER DETAIL "G"
(H) = SEE STORM SEWER DETAIL "H"
(I) = SEE STORM SEWER DETAIL "I"
(J) = SEE STORM SEWER DETAIL "J"
(K) = SEE STORM SEWER DETAIL "K"

RIM = 5205.87
MH2745

RIM = 5200.80
MH2483

RIM = 5196.98
MH2400

WATER

24" X 25' RCP
2.63 %

EXISTING GAS

RIM = 5195.46
MH2364

WATER

IE = 5196.61

IE = 5196.31

IE = 5192.05

SCALE: (H) 1"=50'
(V) 1"=10'

RIM = 5195.30
MH2174

30" X 7' RCP
9.49 %

IE = 5191.56

SANITARY SEWER

40" X 31" RCP
0.52 %

IE = 5184.25

IE = 5184.15

RIM = 5179.42
MH2048

30" X 185' RCP
1.77 %

WATER

IE = 5181.10

IE = 5181.20

30" X 120' RCP
5.19 %

IE = 5177.82

IE = 5177.73

27+00

IE = 5171.50

5208 5204 5200 5196 5192 5188 5184 5180 5176 5172 5168

21+00 22+00 23+00 24+00 25+00 26+00

STORM SEWER TRUNKLINE

EXHIBIT 46

TYPICAL STORM SEWER SHEET

Panel I

MH2400
TYPE D MANHOLE (60")
STA 23+99.85

24+00

SCALE 1" = 20'

18" NEENAH R - 4990 L9
TRENCH DRAIN

2401R
TYPE T INLET
STA 24+01.30

2399R
TYPE A INLET
STA 23+99.54

PROFILE: RIM = 5195.86 MH2399; TBC = 5199.46 INLET 2401R; TBC = 5200.05 INLET 2399R
IE(E) = 5184.25; IE(W) = 5184.15; IE = 5187.62; 18" X 52' RCP; 7.63%; IE = 5191.69; 90%; IE = 5191.88; IE = 5191.79; 18" X 10' RCP
PROFILE SCALE: (H) 1" = 20'; (V) 1" = 10'
NOTE: PIPE LENGTHS SHOWN ARE SLOPE DISTANCES.

Panel J

SCALE 1" = 20'

2483R TYPE A INLET STA 24+83.16
2523L TYPE U INLET STA 25+23.24
2452R TYPE V INLET STA 24+51.83
MH2483 96" TYPE D MANHOLE STA 24+83.16
25+25

PROFILE: TBC = 5201.01 INLET 2523L; RIM = 5200.50 MH2483; TBC = 5199.72 INLET 2483R
18" X 50' RCP; 0.56%; IE = 5182.69; IE = 5192.58; 5.33%; IE(E) = 5192.06; IE(W) = 5191.56; IE = 5192.56; IE = 5193.04; 18" X 9' RCP
ENCASE WATERLINE
PROFILE SCALE: (H) 1" = 20'; (V) 1" = 10'
NOTE: PIPE LENGTHS SHOWN ARE SLOPE DISTANCES.

Panel K

MH2745
TYPE C MANHOLE (48")
STA 27+45.42

2745R TYPE A INLET STA 27+45.40
2741R TYPE V INLET STA 27+40.92

27+50
SCALE 1" = 20'

PROFILE: RIM = 5205.87 MH2745; TBC = 5206.09 INLET 2745R
18" X 9' RCP; 3.13%; IE(E) = 5199.31; IE(W) = 5198.81; IE = 5199.31; IE = 5199.56
PROFILE SCALE: (H) 1" = 20'; (V) 1" = 10'
NOTE: PIPE LENGTHS SHOWN ARE SLOPE DISTANCES.

Panel L

MH2826
TYPE C MANHOLE (48")
STA 28+27.83

2826L TYPE U INLET STA 28+27.76

28+25
SCALE 1" = 20'

PROFILE: TBC = 5208.33 INLET 2826L; RIM = 5208.46 MH2826
18" X 46' RCP; 0.55%; IE = 5201.34; IE = 5201.09; IE(E) = 5201.09; IE(W) = 5200.99
PROFILE SCALE: (H) 1" = 20'; (V) 1" = 10'
NOTE: PIPE LENGTHS SHOWN ARE SLOPE DISTANCES.

STORM SEWER LATERAL DETAILS I, J, K, L

EXHIBIT 47

TYPICAL LATERAL PLAN & PROFILE
DETAILS

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SECTION 16-EROSION PROTECTION AT CULVERTS

General: Erosion control is required to protect drainage structures, embankments, channels and environmentally sensitive streams where there is a need to control turbidity. This overview provides basic guidelines that are limited to erosion protection associated with small culvert design. Designers should contact the Hydraulics Section for assistance with the design of erosion protection for larger culverts and major channel changes with higher flows.

Erosion control should be considered when the existing culverts are extended or replaced and at new drainage crossings. The process for designing erosion control depends on if the site is <u>existing</u> or <u>new</u>. At new sites the design of erosion control is based solely on CDS predictions for scour, soil stress, riprap, etc. At existing sites the design of erosion control is based on CDS predictions and the erosion history at the site:

- <u>Culvert Extensions</u>: When culvert extensions are installed on minor widening projects without any hydraulics analysis the design of erosion protection is based solely on engineering judgement and the existing erosion conditions. However, if longer extensions are needed, then the culvert hydraulics should be run and erosion protection is determined as if the installation was a culvert replacement.

- <u>Culvert Replacement</u>: The design of erosion control is based on CDS predictions for scour, soil stresses, riprap, etc., and existing conditions. Where the existing condition shows significant differences than what CDS predicts, use engineering judgement to adjust the erosion control limits to best fit the existing condition.

- <u>New Construction</u>: At a new site where there is no erosion history the design of erosion control is based solely on CDS calculated predictions for scour and soil stresses due to flow conditions.

There is no technical basis for selecting the design frequency for erosion protection. Generally, the design for urban or rural areas is based on the same frequency that is used for the culvert or channel design. However, a reduced frequency may be considered in rural areas if material costs are unreasonably high when compared to maintenance costs.

Erosion associated with culverts normally shows up as a scour hole near the inlet or outlet of the culvert. Scouring at the outlet may also include head cutting as shown in Exhibit 48.

NOTE:

1. HEAD CUTTING IS NOT A FREQUENT OCCURRENCE, BUT IT CAN BE CAUSED BY LOCAL SCOUR OR BY CHANNEL DEGRADATION.

2. SCOUR MOUNDING CAN FORM DURING THE SCOURING PROCESS. HOWEVER, IF THE SCOUR HOLE BECOMES STABLE, THE MOUND MAY BE ERODED AWAY OVER TIME.

3. CULVERTS FLOWS CAN BE TURBULENT WITH EDDIES AND SOIL SHEAR STRESSES THAT CREATE SCOUR HOLES.

EXHIBIT 48
TYPICAL EROSION AT CULVERTS

Inlet Scour: The culvert cross-sectional area is normally smaller than the cross-sectional area in the natural channel, so the flow will contract and accelerate as it enters the culvert. Water vortexes and higher velocities have the potential to scour away the embankment next to the culvert. Scour holes in the channel bottom may also form upstream of the culvert inlet due to the acceleration of flow as it enters the culvert.

Outlet Scour: The restricted shape of the culvert can generate flows with greater energies that have the potential to create a scour hole with downstream mounding near the outlet end, as shown in Exhibit 48. If the scour hole becomes stable, the mound may erode away over time. In rural areas, small scour holes (0 - 2 ft deep) that are stable normally would not need protection.

Channel Degradation: Flowing water naturally degrades the channel by carrying erodible soil from steeper areas and depositing the material in the flatter reaches of the channel. It naturally reduces the channel slope over time. The process continues to work its way upstream and can occur uniformly over long reaches of the channel or may show up as one or more abrupt drops known as head cutting.

Site Inspections: Determining the need for and design of erosion control can be a subjective process that requires the use of good engineering judgement to evaluate the various combinations of channel configuration, slope, volume flow, peak discharge flow, soil type, ground cover, rural or urban location, cost, etc., that influence the need for erosion control. Knowing what the existing conditions are at each crossing site is important to the process:

•   Most drainage crossings have existing culverts that show actual scour holes or erosion conditions which provide key information in determining the need for protective coverings.

•   A field inspection is required to observe and photograph each site. Describe the scoured material and measure the approximate dimensions (length, width and depth) of any scour hole or erosion damage. Note the area land use (rural or urban) and drainage environmental value (fishery, stream classification, etc.) that might influence the design or need for erosion protection.

•   When available, compare the existing scour hole size (length/width) with the design dimensions of the proposed protective aprons. If there is a significant difference, use engineering judgment to adjust the design dimensions to approximate the existing scour size.

Erosion Protection Materials: Knowing the shear stress in pounds per square foot that flowing water imposes on the soil is a key element in determining the need for erosion protection and the type of protective material to be used. Common coverings used to retard erosion include grass, jute netting, synthetic mat, geotextile fabrics, gravel or rock riprap, wire-enclosed riprap, concrete liners and soil cement.

Cover material used should have a permissible shear stress equal or greater than what is generated by the culvert or channel flow. Exhibit 49 shows a listing of typical materials and their permissible unit shear stress. Comparing the computed shear stress generated by the culvert flow with the shear stress values in Exhibit 49 provides the designer guidance when selecting the type of protective covering needed, such as grasses, riprap, gabions, etc. CDS will calculate the culvert flow shear stress and riprap rock size.

RETARDATION PROTECTIVE COVERINGS	PERMISSIBLE UNIT SHEAR STRESS lbs/sq ft
Jute netting	0.45
Buffalo grass Grass - legume mixture Italian ryegrass	0.60
Gravel, D_{50} = 2.0in	0.80
Grass - legume mixture Orchard redtop, Italian ryegrass - Irr. or wet meadow Kentucky bluegrass	1.00
Straw w/netting	1.45
Curled wood mat	1.55
Synthetic mat	2.00
Bermuda grass Native grass mixture Little bluestem, bluestem, blue Gamma, short & long Alfalfa	3.00
Rock,Riprap	3.00 - 5.00
Armorflex w/out grass	12.0 - 20.0
Armorflex w/longitudinal & lateral cables, no grass	>34.0
Gabions, 6.0in rock or Wire-enclosed riprap	35.0

EXHIBIT 49
PERMISSIBLE UNIT SHEAR STRESS

A simple cutoff wall for most rural sites on draws that are not environmentally sensitive is adequate to protect the culvert installation. The formation of scour holes may be tolerable if it does not significantly endanger the culvert or roadway embankment and does not adversely impact adjacent land use.

Determining Need and Protection Type: Exhibit 50 provides basic flow chart guidelines for determining the need and type of protection at new and existing sites. It should be used only for small culvert designs.

EXHIBIT 50
EROSION PROTECTION FLOW CHART
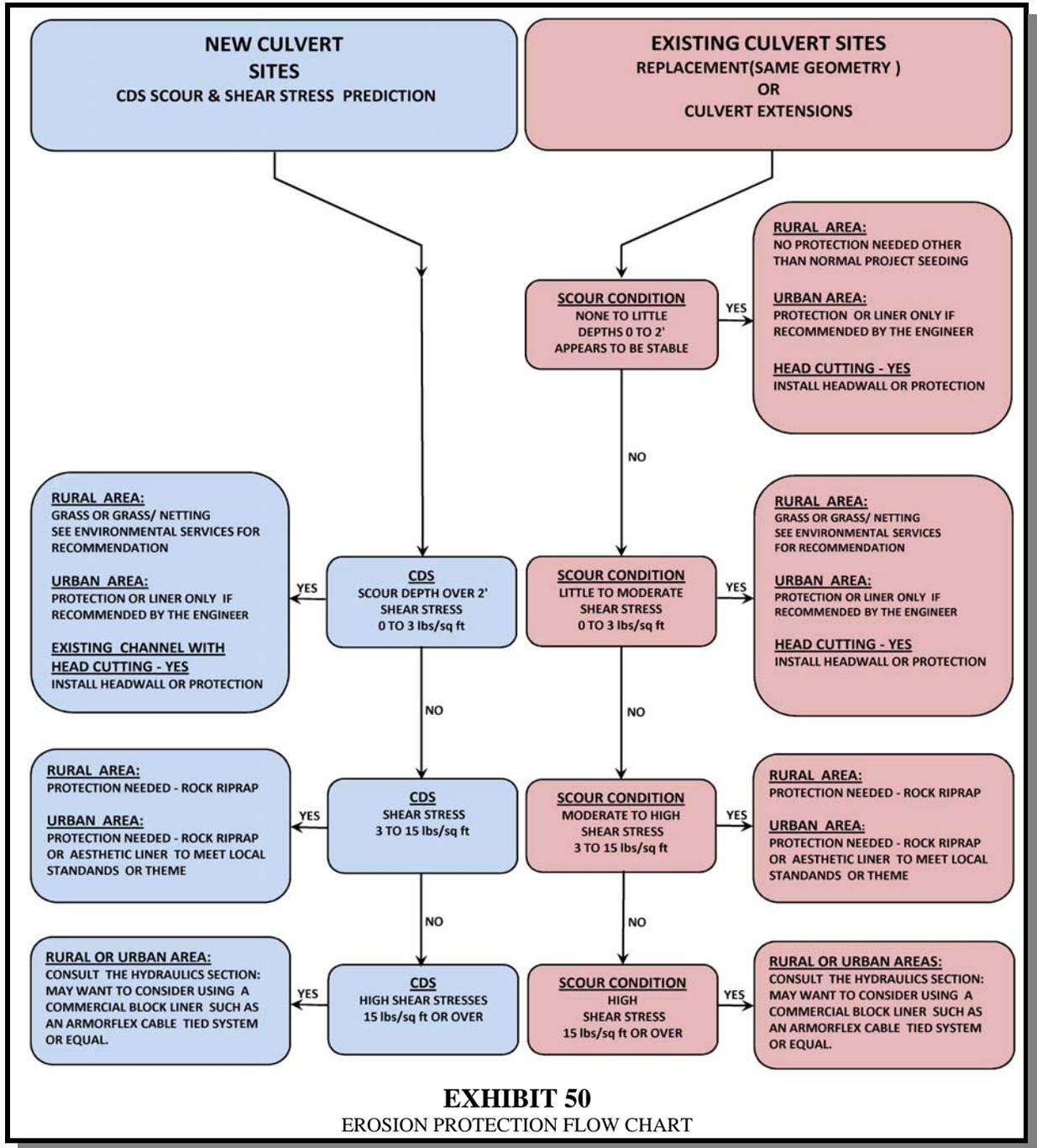
Rock Riprap Outlet Protection: Exhibit 51 provides basic guidelines for placing rock riprap.

FOR CULVERT DIAMETERS 18 in to 72 in, THE PROTECTIVE APRON LENGTH CAN BE ESTIMATED WITH THE FOLLOWING EQUATION:

$$L = [D \times (Q \div D^{2.5})] + 8$$

L = LENGTH (FT), D = CULVERT DIAMETER (FT) AND Q = DISCHARGE (CFS). CDS WILL ALSO CALCULATE THE APRON LENGTH.

IF THE COMPUTED SIZE (LENGTH AND WIDTH) DIFFERS FROM THE EXISTING FIELD SCOUR LIMITS, ADJUST THE APRON SIZE TO BEST FIT THE FIELD CONDITION.

THE MINIMUM APRON THICKNESS IS 1.5 TIMES THE MAXIMUM SIZE STONE.

EXHIBIT 51
ROCK RIPRAP
(MACHINE OR HAND PLACED)

Example: The following example demonstrates the process of determining the type of protection covering and placement of rock riprap:

KNOWN INFORMATION	
CDS OUTPUT	**EXISTING SITE CONDITIONS**
Scour: length - 17 ft, depth - 2 ft, width - 8 ft	Scour: none to little.
Soil Shear: 1.10 lbs/ft^2	Site supports good grass cover.
Riprap: Size 3.0 inches, Length = 43.0 ft	Defined channel with no existing erosion
Culvert Diameter: 24 inches or 2.0 ft	
Q = 33.6 cfs	

Determining an acceptable erosion protection covering:

Step 1.   Compare the CDS calculated soil shear stress value with the Permissible Shear Stresses given in Exhibit 49. In this case, the likely protective covering that would resist a 1.10 lbs/ft^2 shear stress would be a grass-legume mixture.

Step 2.   Compare the use of a grass mixture with the existing conditions by using Exhibit 50 - Erosion Protection Flow Chart.

Case 1 Findings: If the existing condition shows little or no scour, then a grass mixture is an acceptable protective covering and no further investigation is needed. In this case, contact Environmental Services for seeding recommendations.

Case 2 - Findings: If the existing condition shows a moderate amount of scour (say 18 ft length - 3.0 ft depth - 10.0 ft width) then special grasses or rock riprap are both options for erosion protection.

Select one of the follow options base on engineering judgement:

•   If the existing site supports good grass cover, then grading and seeding the area may be an acceptable option if Environmental Services concurs that grass seed or grass seeding with netting will control erosion.

•   If the existing site does not support good grass cover, then rock riprap should be used to control the erosion.

If rock riprap is selected then proceed with Step 3 and 4.

Rock riprap placement per Exhibit 51:

Step 3.   Determine the width of placement for a defined channel. Typically the width should be equal to $3 \times$ Pipe Diameter. Make sure this width is wide enough to contain the depth of flow. If needed, adjust the width to a wider dimension to contain the flow.

Step 4.   Calculating the length (L) using the following formula:

$$L = \left[D \times \left(Q \div D^{2.5} \right) \right] + 8$$

Where:
L = Length, ft
D = Culvert Diameter   , ft
Q = Discharge, ft³/sec

$$L = \left[2.0 \times \left(33.6 \div 2.0^{2.5} \right) \right] + 8 = 19.9 \, feet$$

Compare this length the CDS scour length of 17.0 feet and riprap length of 43.0 ft. Use engineering judgement to choose the length that best fits the conditions.

Case 1 Findings: Because the existing condition shows little or no scour the best option would be to use the shortest of the three lengths which is 17.0 ft.

Case 2 Findings: If the existing condition shows a moderate amount of scour (say 25.0 ft length - 3.0 ft depth - 10.0 ft width), then the best option would be to use the existing scour length which is 25.0 ft.

Rock Sizing: CDS will calculate the rock size based on the Class II, III and IV gradations for riprap as shown in Exhibit 52.

Nominal Riprap Class by Median Particle Diameter		d_{15}		d_{50}		d_{85}		d_{100}
Class	Size	Min.	Max.	Min.	Max.	Min.	Max.	Max.
I	6 in	3.7	5.2	5.7	6.9	7.8	9.2	12.0
II	9 in	5.5	7.8	8.5	10.5	11.5	14.0	18.0
III	12 in	7.3	10.5	11.5	14.0	15.5	18.5	24.0
IV	15 in	9.2	13.0	14.5	17.5	19.5	23.0	30.0
V	18 in	11.0	15.5	17.0	20.5	23.5	27.5	36.0
VI	21 in	13.0	18.5	32.0	24.0	27.5	32.5	42.0
VII	24 in	14.5	21.0	23.0	27.5	31.0	37.0	48.0
VIII	30 in	18.5	26.0	28.5	34.5	39.0	46.0	60.0
IX	36 in	22.0	31.5	34.0	41.5	47.0	55.5	72.0
X	42 in	25.5	36.5	40.0	48.5	54.5	64.5	84.0

Note: Only Classes II, III and IV are suitable for use in partial grading applications.

EXHIBIT 52
STANDARD CLASSES OF RIPRAP
(BY PARTICLE DIAMETER)

Typically the designer will use the rock size given in the standard specification for Machine Placed Riprap or Hand Placed Riprap. In cases where the designer would want to use a riprap size calculated by CDS then the appropriate class size given in Exhibit 52 would have to be included in the plan details or in a special provision.

Appendix A

SECTION A - CULVERT DESIGN (Using Nomographs)

General: The following example demonstrates the trial-and-error process of culvert design using nomographs to size culverts for peak design flow. It applies the same basic logic used by CDS. Flood routing design, roadway overtopping, and outlet scour analysis would require additional calculations beyond what is included in this example.

Basic Procedure: Culvert design with inlet and outlet nomographs includes the following steps:

Step 1:   Required design data:

- Q = discharge (cfs)
- L = culvert length (ft)
- S = culvert slope (ft/ft)
- Ke = inlet coefficient
- V = velocity (ft/sec)
- TW = tailwater depth (ft)
- HW = allowable headwater depth (ft)

Step 2:   Determine a trial size by assuming a velocity of 5 ft/sec to 7 ft/sec and computing the culvert area, $A = Q \div V$, to determine the culvert diameter (D) in inches.

Step 3:   Determine the actual HW for the trial-size culvert for inlet and outlet control using the nomographs.

         a.   For inlet control, enter the inlet nomograph Exhibit A-1 with D and Q to find the ratio of HW/D for the proper entrance type. Compute the HW and, if too small, try another culvert size before computing HW for outlet control.

         b.   For outlet control, enter the outlet control nomograph with the culvert length, inlet coefficient, and trial size culvert diameter. See Exhibit A-2.

                 To determine the HW, connect the pipe length in the scale for the type of entrance condition and culvert diameter scale with a straight line that crosses the pivot turning line. Then

draw a straight line from the design discharge through the turning point to the head loss scale H. Compute the headwater elevation HW from the following equation:

$HW = (H + h_o) - LS$
where $h_o = \frac{1}{2}$ (critical depth + D) or tailwater depth, whichever is greater.

Step 4:   Compare the computed headwater and use the higher HW nomograph to determine if the culvert is under inlet or outlet control. If outlet control governs and HW is unacceptable, select a larger trial size and find another HW with outlet control nomograph. Because the smaller trial size culvert had been determined to operate under outlet control, the inlet control for the larger pipe need not be checked.

Step 5:   Calculate the exit velocity and streambed scour to determine if an energy dissipater is needed. The stream degradation may be a pre-existing condition and the reasons and rate of degradation need to be determined. A performance curve for any culvert can be obtained from the nomographs by repeating the steps outlined above for a range of discharges that are of interest for a particular culvert design. A graph is then plotted of headwater versus discharge with sufficient points so that a curve can be drawn through the range of interest. These curves are applicable through a range of headwater, velocities, and scour depths versus discharges for the length of the culvert. Curves with length intervals of 25 ft to 50 ft are usually satisfactory for design purposes. Such computations are made much easier by the CDS program.

Culvert Design Example:

Step 1:   Input Data:
- Q = 70 cfs - 10-year flood
- Q = 176 cfs - 100-year flood
- Allowable HW = 4.5 ft - 10-year discharge
- Allowable HW = 7.0 ft - 100-year discharge
- Length of culvert L = 100 ft (from culvert cross-section).
- Invert elevations: inlet =15.50 ft, outlet = 15.35 ft
- Culvert slope S = 0.0015 ft/ft
- Tailwater depth TW = 3.0 ft* - 10-year discharge
- Tailwater depth TW = 4.0 ft* - 100-year discharge
- End treatment = groove end with headwall
- Type of culvert = concrete

* Tailwater depth is the flow depth, based on the given design year flow rate, in the normal downstream channel.

Step 2:   Assume a velocity in the range of 5.0 ft/sec to 7.0 ft/sec. Use 5.0 ft/sec with a Q = 70 cfs (10-year discharge).

$A = Q \div V$
$A = 70 \div 5.0 = 14.0 \text{ ft}^2$

Calculate the corresponding culvert diameter of a round culvert with an area of 14.0 ft^2, using the following equation:

$D = [(A \times 4) \div \pi]^{0.5}$
$D = [(14.0 \times 4) \div (3.14)]^{0.5} = 4.2 \text{ ft (50.4 in)}$
Try a 48-inch or 4.0 ft diameter concrete pipe.

Step 3a: **Check for *Inlet Control*:** End treatment selected for design is a grooved end with a headwall. Using the inlet control nomograph, Exhibit A-1, draw a straight line from a 48-inch pipe through a 70 cfs discharge to the H/D graph (1). Then extend a horizontal line through graph (2) and read the H/D value of 0.93 from graph (2), which is scaled for a grooved end with headwall.

The depth of H = (0.93) × (4) = 3.72 ft, which is less than the allowable headwater of 4.5 ft.

Step 3b: **Check for *Outlet Control*:** Use the outlet control nomograph, Exhibit A-2. To establish the turning line point on the graph, draw a straight line from the inlet coefficient scale $K_e = 0.20$ for a culvert length of 100 ft to a pipe diameter of 48 in. Then draw a straight line from the 70 cfs discharge point through the turning line point to the "Head (H) In Feet" scale where H is determined to be 0.77 ft. The headwater for outlet control is computed by equation:

$HW = (H + h_o) - (L \times S)$

For the tailwater depths that are lower than the top of the culvert, $h_o = T_w$ or ½ (critical flow depth d_c + D), whichever is greater. Critical depth flow $d_c = 2.55$ ft as determined from Exhibit A-3.

Therefore, use the greater value of:

$h_o = 3.0$ ft or

$h_o = \frac{1}{2} (2.55 + 4) = $ **3.28 ft, controlling h_o**

$HW = (0.77 + 3.28) - (100 \times .0015) = $ **3.90 ft, controlling HW**

Step 4:   In this case, ***outlet control governs*** the culvert design because the HW for outlet control is greater than the HW for inlet control. Thus, the maximum headwater expected for a 10-year recurrence flood is 3.90 ft, which is less than the allowable headwater of 4.5 ft.

Check the culvert performance for the 100-year discharge using the same process. The allowable headwater for a 100-year discharge is 7 ft; critical depth in the 48-inch diameter culvert for the 100-year discharge is determined to be 3.95 ft from Exhibit A-4. For outlet control, an H value of 5.2 ft is read from the outlet control nomograph.

The maximum headwater for outlet control is calculated using the following equation:

$HW = (H + h_o) - (L \times S)$

$HW = (5.2 + 4.0) - (100 \times 0.0015) = $ **9.05 ft**

This depth is greater than the allowable depth of 7.0 ft; thus, a larger size culvert is needed. Repeat steps 3 - 4 trying a 54-inch culvert.

Try a 54-inch or 4.5-foot diameter culvert for a 10-year 70 cfs flow:

Inlet control: $H/D = 0.77$ from Exhibit A-1
$H = 0.77 \times 4.5 = $ **3.47 ft**

Outlet control: $H = 0.46$ ft from Exhibit A-2
$HW = H + h_o - (L \times S)$
$h_0 = T_W$ or $\frac{1}{2} (d_c + D)$, whichever is greater
$T_W = 3.0$ ft; $d_c = 2.45$ ft - from Exhibit A-4
$h_o = \frac{1}{2} (2.45 + 4.5) = $ **3.48 ft, controlling h_o**
$HW = 0.46 + 3.48 - 0.15 = $ **3.79 ft, controlling HW**

Try a 54-inch or 4.5-foot diameter culvert for a 100-year 176 cfs flow:

Inlet control: $H/D = 1.50$ - from Exhibit A-1
$H = 1.50 \times 4.5 = $ **6.75 ft**

<u>Outlet control</u>: H = 2.90 ft - from Exhibit A-2
HW = H + h_o - (L×S)
h_o = T_W or ½ (d_c +D), whichever is greater
T_W = 4.0 ft; d_c = 3.95 ft - from Exhibit A-4
h_o = ½ (3.95 + 4.5) = **4.22 ft, controlling h_o**
HW = 2.90 + 4.22 - 0.15 = **6.97 ft, controlling HW**

The 54-inch diameter culvert is found to have a maximum headwater depth of 3.79 ft for the 10-year discharge and 6.97 ft for the 100-year discharge. These values are acceptable; therefore, the 54-inch culvert is an acceptable size.

Step 5:   Estimate outlet velocity. Using the 100-year discharge of 176 cfs and the area of a 54-inch or 4.5-foot diameter culvert, the exit velocity is calculated using the equation Q = (V × A) or V= (Q ÷ A).

Therefore:

$V = Q ÷ [(\pi × D^2) ÷ 4]$

$V= 176 ÷ [(3.14 × 4.5^2) ÷ 4] = 11.1$ ft/sec

This velocity may require energy dissipation or downstream bank protection. CDS would calculate a scour analysis.

The designer should check minimum velocities for low-flows if the larger storm event (100-year) controls culvert design.

EXHIBIT A-1
INLET CONTROL NOMOGRAPH

EXHIBIT A-2
OUTLET CONTROL NOMOGRAPH

EXHIBIT A-3
CRITICAL DEPTH GRAPH - 0 to 100 cfs

EXHIBIT A-4
CRITICAL DEPTH GRAPH - 0 to 1000 cfs
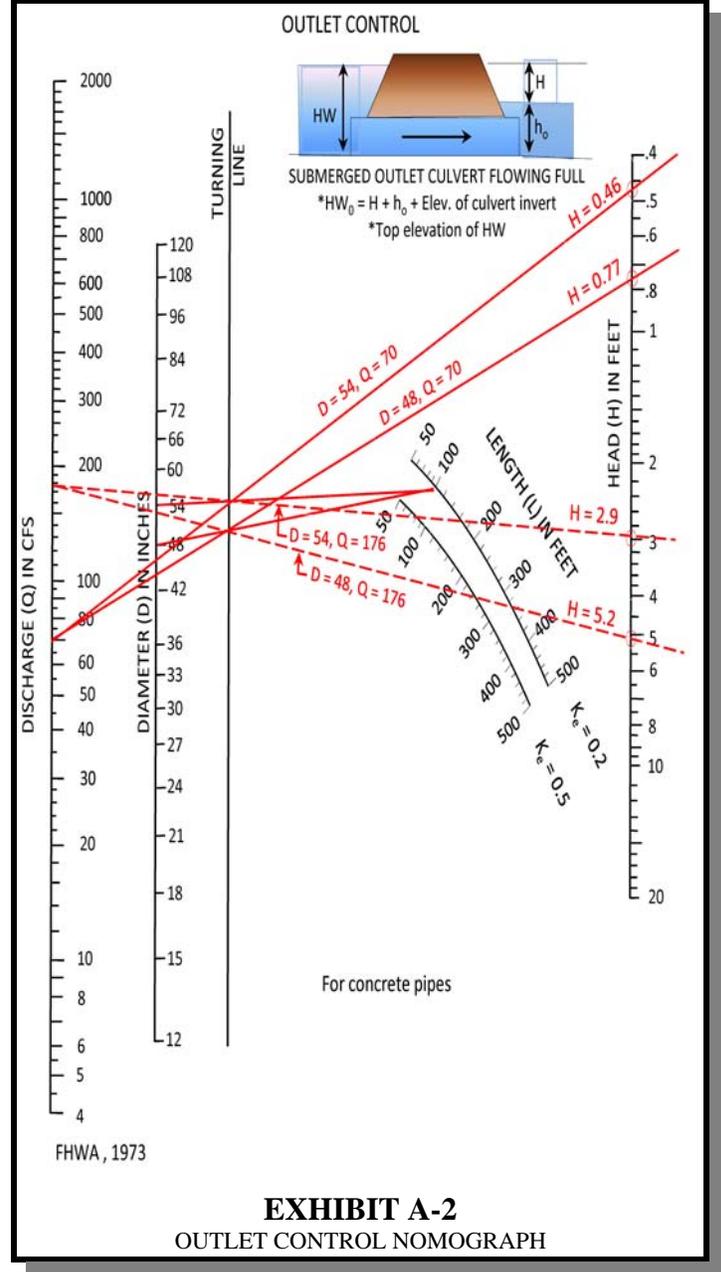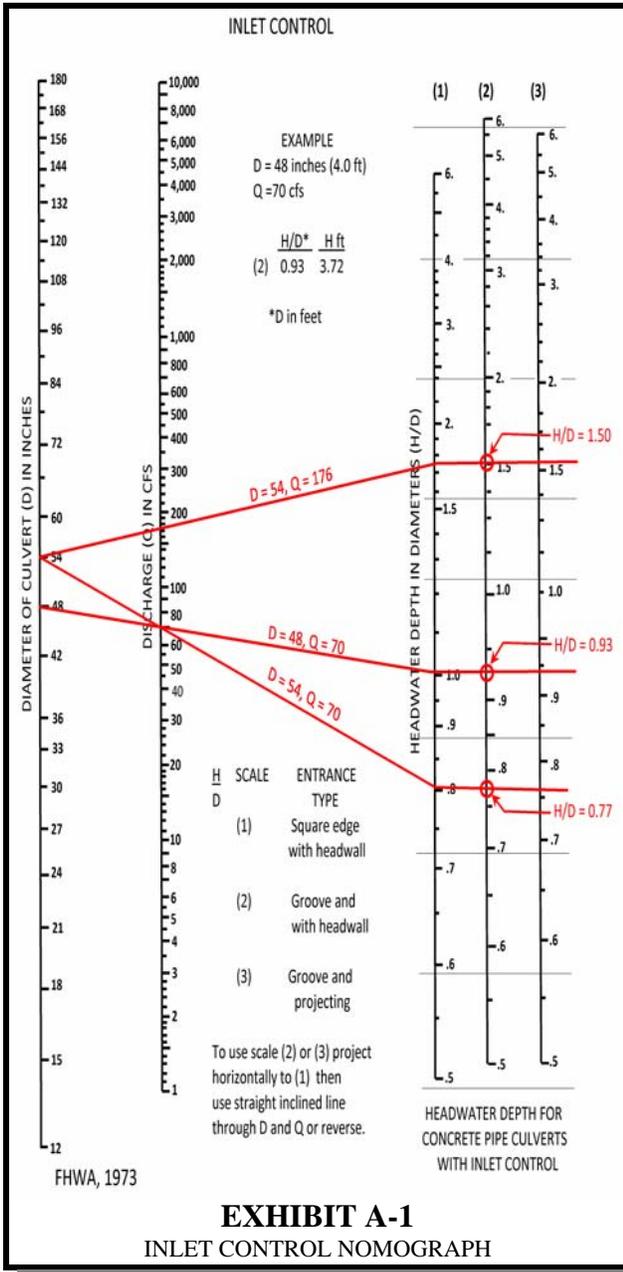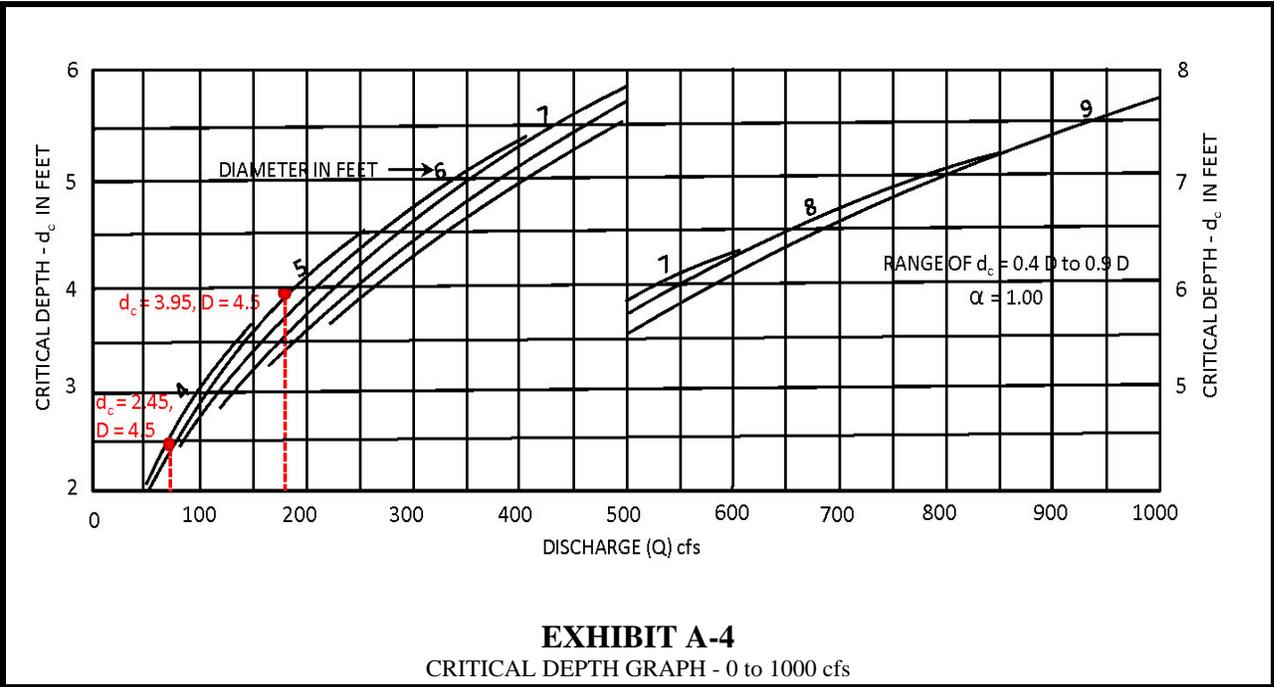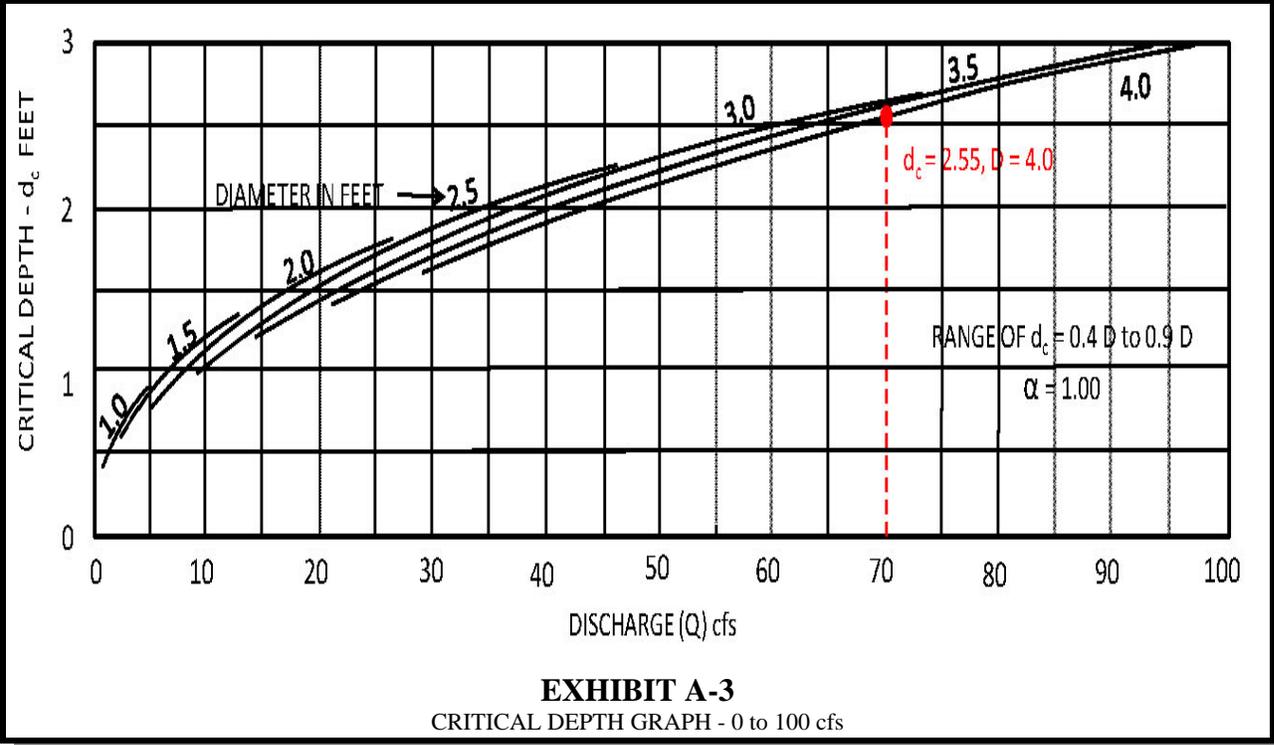
SECTION B - TABLE OF MANNING's n-VALUES

General: Manning's n-values define the coefficient of roughness that is used to calculate the flow in various pipes and open channels. There are several sets of published values that can be used for specific types of channel soil, vegetation and pipe roughness. The reference table below was developed by Chow in 1959.

Manning's n-values:

FOR OPEN CHANNELS (Chow, 1959)	Minimum	Normal	Maximum
1. Main channels			
a. clean straight, full stage, no rifts or deep pools	0.025	0.030	0.033
b. same as above, but more stones and weeds	0.030	0.035	0.040
c. clean, winding, some pools and shoals	0.033	0.040	0.045
d. same as above, but some weeds and stones	0.035	0.045	0.050
e. same as above, lower stages, more ineffective slope & sections	0.040	0.048	0.055
f. same as (d) with more stones	0.045	0.050	0.060
g. sluggish reaches, weedy, deep pools	0.050	0.070	0.080
h. very weedy reaches, deep pools, or heavy timber/underbrush	0.075	0.100	0.150
2. Mountain streams, no vegetation in channel, banks usually steep, trees and brush along banks submerged at high stage.			
a. bottom: gravels, cobbles, and few boulders	0.030	0.040	0.050
b. bottom: cobbles and large boulders	0.040	0.050	0.070
3. Floodplans			
a. Pasture, no bush:			
1. short grass	0.025	0.030	0.035
2. high grass	0.030	0.035	0.050
b. Cultivated areas:			
1. no crop	0.020	0.030	0.040
2. mature row crops	0.025	0.035	0.045
3. mature field crops	0.030	0.040	0.050
c. Brush:			
1. scattered brush, heavy weeds	0.035	0.050	0.070
2. light brush and trees, in winter	0.035	0.050	0.060
3. light brush and trees, in summer	0.040	0.060	0.080
4. medium to dense brush, in winter	0.045	0.070	0.110
5. Medium to dense brush, in summer	0.070	0.100	0.160
d. Trees:			
1. dense willows, summer, straight	0.110	0.150	0.200
2. clear land with trees stumps, no sprouts	0.030	0.040	0.050
3. same as above, but with heavy growth of sprouts	0.050	0.060	0.080
4. heavy timber, few down trees, little undergrowth, flood stage below branches	0.080	0.100	0.120

4. Excavated or dredged channels			
a. Earth, straight, and uniform:			
1. clean, recently completed	0.016	0.018	0.020
2. clean, after weathering	0.018	0.022	0.025
3. gravel, inform section, clean	0.022	0.025	0.030
4. with short grass, few weeds	0.022	0.027	0.033
b. Earth winding and sluggish:			
1. no vegetation	0.023	0.025	0.030
2. grass, some weeds	0.025	0.030	0.033
3. dense weeds or aquatic plants in deep channels	0.030	0.035	0.040
4. earth bottom and rubble sides	0.028	0.030	0.035
5. stony bottom and weedy banks	0.025	0.035	0.040
6. cobble bottom and clean sides	0.030	0.040	0.050
c. Dragline-excavated or dredged:			
1. no vegetation	0.025	0.028	0.033
2. light brush on banks	0.035	0.050	0.033
d. Rock cuts:			
1. smooth and uniform	0.025	0.035	0.040
2. jagged and irregular	0.035	0.040	0.050
e. Channels not maintained, weeds and brush uncut			
1. dense weeds, high as flow depth	0.050	0.080	0.120
2. clean bottom, brush on sides	0.040	0.050	0.080
3. same as above, highest stage of flow	0.045	0.070	0.110
4. dense brush, high stage	0.080	0.100	0.140
5. Lined or constructed channels			
a. Cement:			
1. neat surface	0.010	0.011	0.013
2. mortar	0.011	0.013	0.015
b. Wood:			
1. planed, untreated	0.010	0.012	0.014
2. planed, creosoted	0.011	0.012	0.015
3. unplaned	0.011	0.013	0.015
4. plank with battens	0.012	0.015	0.018
5. lined with roofing paper	0.010	0.014	0.017
c. Concrete:			
1. trowel finish	0.011	0.013	0.015
2. float finish	0.013	0.015	0.016
3. finished, with gravel bottom	0.015	0.017	0.020
4. unfinished	0.014	0.017	0.020
5. gunite, good section	0.016	0.019	0.023
6. gunite, wavy section	0.018	0.022	0.025

	Minimum	Normal	Maximum
7. on good rock excavated rock	0.017	0.020	
8. on irregular excavated rock	0.022	0.027	
d. Concrete bottom float finish with sides of:			
1. dressed stone in mortar	0.015	0.017	0.020
2. random stone in mortar	0.017	0.020	0.024
3. cement rubble masonry, plastered	0.016	0.020	0.024
4. cement rubble masonry	0.020	0.025	0.030
5. dry rubble or riprap	0.020	0.030	0.035
e. Gravel bottom with sides of:			
1. formed concrete	0.017	0.020	0.025
2. random stone mortar	0.020	0.023	0.026
3. dry rubble or riprap	0.023	0.033	0.036
CLOSED CONDUITS FLOWING PARTLY FULL (Chow, 1959)	**Minimum**	**Normal**	**Maximum**
a. Brass, smooth	0.009	0.010	0.013
b. Steel:			
1. lockbar and welded	0.010	0.012	0.014
2. riveted and spiral	0.013	0.016	0.017
c. Cast iron:			
1. coated	0.010	0.013	0.014
2. uncoated	0.011	0.014	0.016
d. Wrought Iron:			
1. black	0.012	0.014	0.015
2. galvanized	0.013	0.016	0.017
e. Corrugated Metal:			
1. Subdrain	0.017	0.019	0.021
2. Stormdrain	0.021	0.024	0.030
f. Concrete:			
1. culvert, straight and free of debris	0.010	0.011	0.013
2. culvert with bends, connections, and some debris	0.011	0.013	0.014
3. storm sewer with manholes, inlet, etc., straight	0.013	0.015	0.017