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MDOT Hydraulics Unit

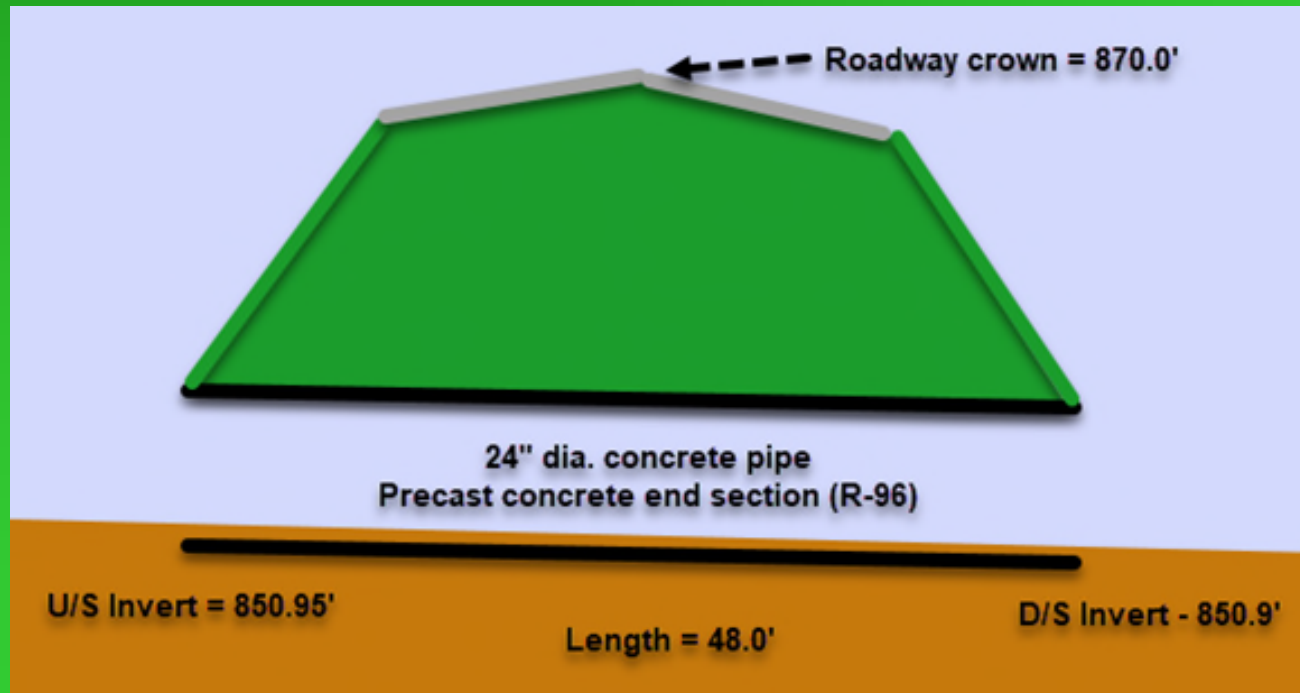
July 2022

Culvert Example



Existing Culvert

- Determine headwater and outlet velocity for the existing culvert
 - $Q_{50} = 40$ cfs
 - $Q_{100} = 50$ cfs
 - $TW_{50} = 853.56'$
 - $TW_{100} = 853.84'$

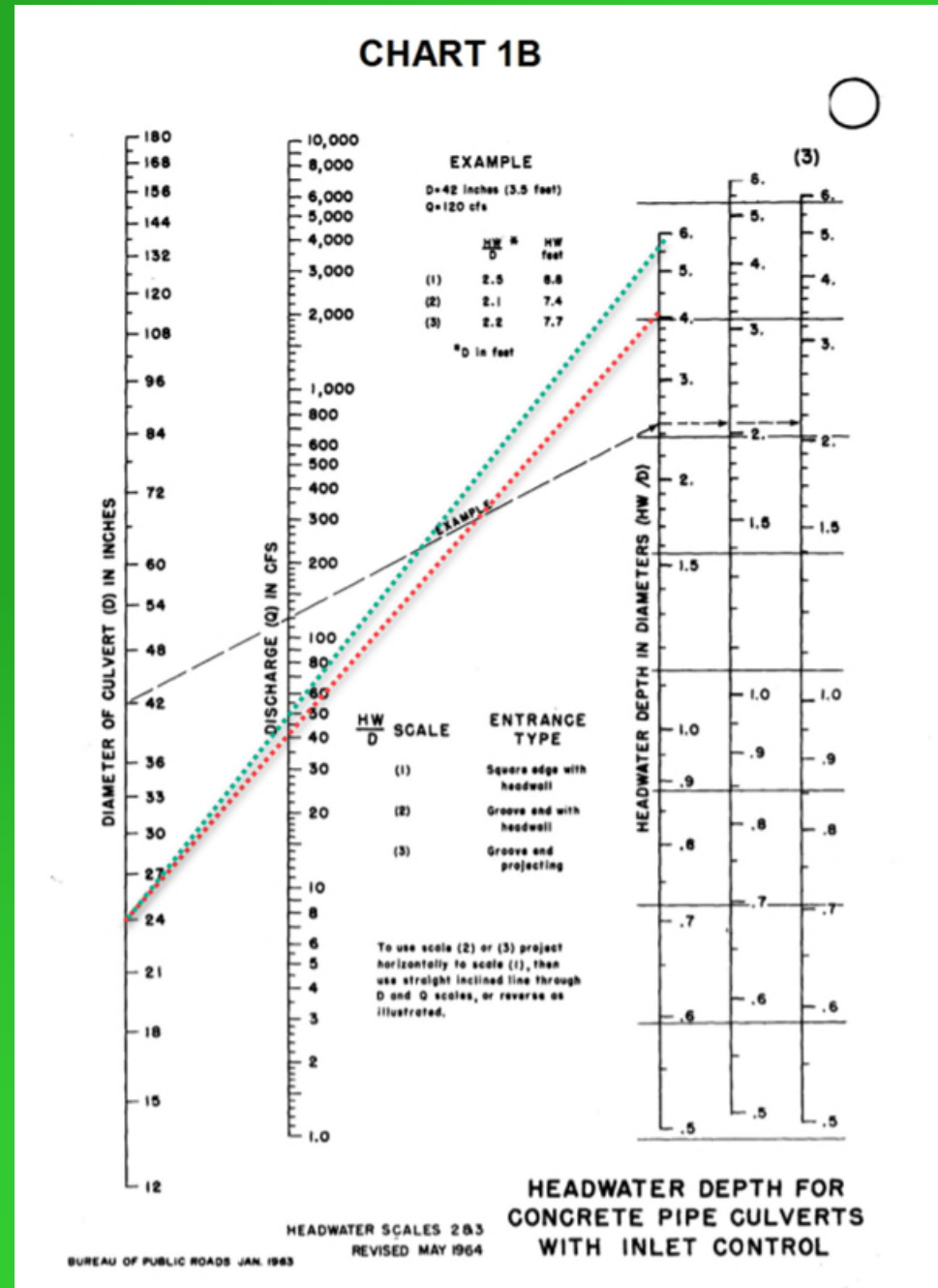


Existing Culvert

- Determine inlet control headwater (Chart 1B):

- Q_{50}
 - $HW / D = 4$
 - $HW = 4 * D = 4 * 2' = 8.0'$
 - $HW_{ic} = U/S_{invert} + HW = 850.95' + 8.0' = 858.95'$

- Q_{100}
 - $HW / D = 5.8$
 - $HW = 5.8 * D = 5.8 * 2' = 11.6'$
 - $HW_{ic} = U/S_{invert} + HW = 850.95' + 11.6' = 862.55'$



Existing Culvert

- Determine outlet control headwater:
 - $TW_{50} = 853.56'$
 - $TW_{100} = 853.84'$
 - $k_e = 0.5$ (squared edge with headwall)
 - $n = 0.012$ (concrete)
- Determine headloss:

$$H_L = (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g$$

$$\text{Full barrel area} = A_{\text{full}} = \pi D^2 / 4$$

$$= \pi (2 \text{ ft.})^2 / 4 = \underline{\mathbf{3.14 \text{ sft}}}$$

$$\text{Full barrel hydraulic radius} = R = A_{\text{full}} / P_{\text{full}} = (\pi D^2 / 4) / (\pi D)$$

$$= D / 4 = 2 \text{ ft.} / 4 = \underline{\mathbf{0.5 \text{ ft.}}}$$

Existing Culvert

- Determine outlet control headwater (cont.):
 - Determine headloss (cont.):
 - Is the downstream crown submerged?
 - Q_{50} :

$$V_{\text{full}} = Q / A_{\text{full}} \\ = 40 \text{ cfs} / 3.14 \text{ sft.} = 12.74 \text{ ft/s}$$

$$H_L = (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g \\ = (1 + 0.5 + 29 * (0.012)^2 * 48') / (0.5^{1.33}) * (12.74 \text{ ft/s})^2 / (2 * 32.2 \text{ ft/s}^2) \\ = 5.05 \text{ ft.}$$

Existing Culvert

- Determine outlet control headwater (cont.):
 - Determine headloss (cont.):
 - Is the downstream crown submerged?
 - Q_{100} :

$$V_{\text{full}} = Q / A_{\text{full}} \\ = 50 \text{ cfs} / 3.14 \text{ sft.} = \mathbf{15.92 \text{ ft/s}}$$

$$H_L = (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g \\ = (1 + 0.5 + 29 * (0.012)^2 * 48' / (0.5^{1.33})) * (\mathbf{15.92 \text{ ft/s}})^2 / (2 * 32.2 \text{ ft/s}^2) \\ = \mathbf{7.89 \text{ ft.}}$$

Existing Culvert

- Determine outlet control headwater (cont.):
 - Determine outlet control headwater:
 - $HW_{oc} = TW + h_L$ (Assume $V_u \approx V_d$)
 - Q_{50} :
 $HW_{oc} = 853.56' + 5.05' = 858.61'$
 - Q_{100} :
 $HW_{oc} = 853.84' + 7.89' = 861.73'$
 - Determine controlling headwater (HW_c) for existing culvert:
 - Q_{50} :
 $HW_{ic} > HW_{oc} ??$
 $HW_c = 858.95'$
 - Q_{100} :
 $HW_{ic} > HW_{oc} ??$
 $HW_c = 862.55'$

Proposed Culvert

Try D = 42 inches (3.5')

- Because we cannot pick material, assume CMP as worst case (n = 0.024)
- Lower inverts 6", per Drainage Manual 5.3.4

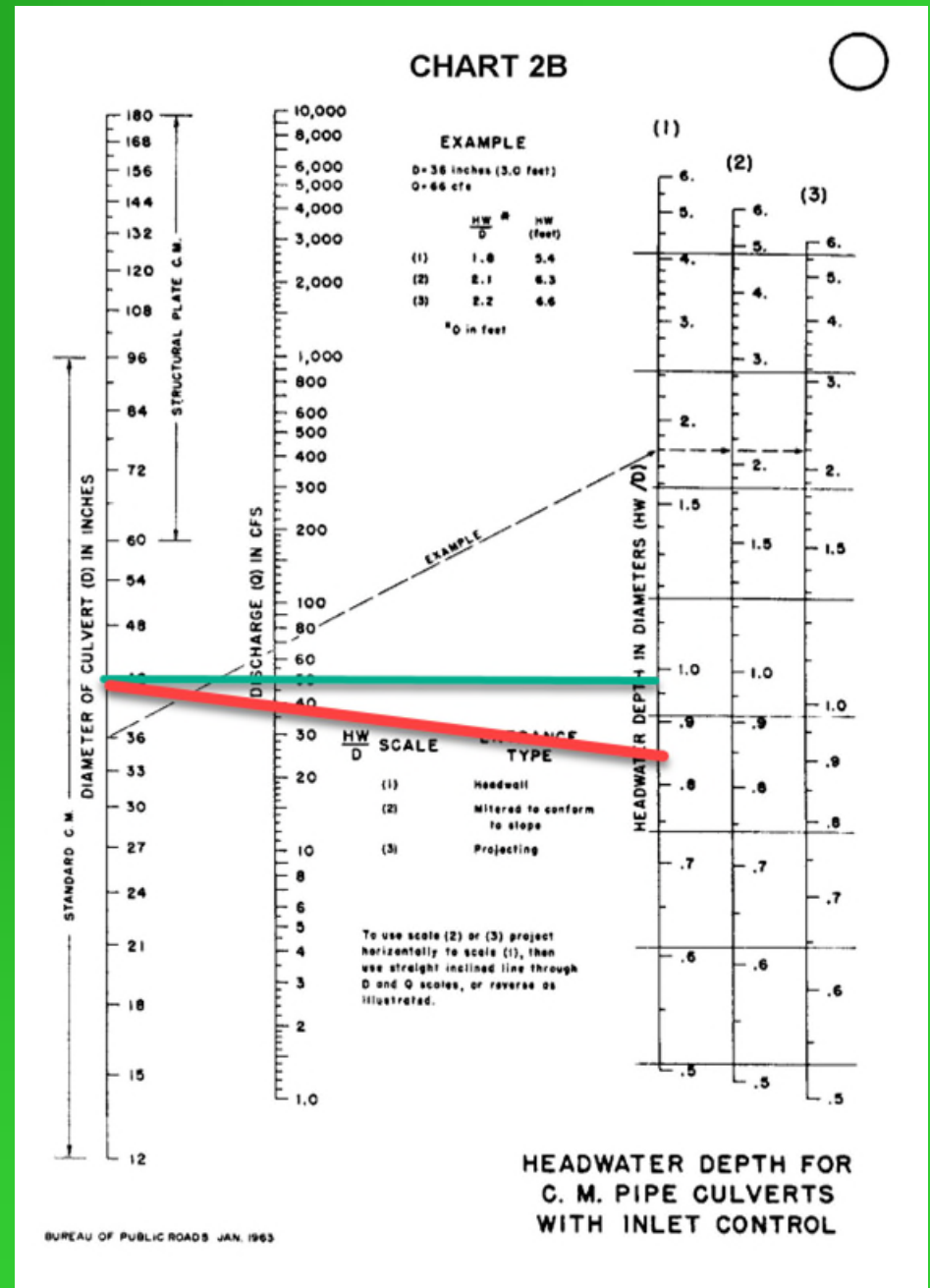
Proposed Culvert

DETERMINE PROPOSED SIZE

Proposed Culvert

- Determine inlet control headwater (Chart 2B):

- Q_{50}
 - $HW / D = 0.84$
 - $HW = 0.84 * D = 0.84 * 3.5' = 2.94'$
 - $HW_{ic} = U/S_{invert} + HW = 850.45' + 2.94' = 853.39'$
 - Q_{100}
 - $HW / D = 0.97$
 - $HW = 0.97 * D = 0.97 * 3.5' = 3.40'$
 - $HW_{ic} = U/S_{invert} + HW = 850.45' + 3.40' = 853.85'$



Proposed Culvert

- Determine outlet control headwater:
 - $TW_{50} = 853.56'$ (same as existing)
 - $TW_{100} = 853.84'$ (same as existing)
 - $k_e = 0.5$ (squared edge with headwall)
 - $n = 0.024$ (assume worst case, CMP)
- Determine headloss:

$$H_L = (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g$$

$$\text{Full barrel area} = A_{\text{full}} = \pi D^2 / 4$$

$$= \pi (3.5 \text{ ft.})^2 / 4 = \mathbf{9.62 \text{ sft}}$$

$$\text{Full barrel hydraulic radius} = R = A_{\text{full}} / P_{\text{full}} = (\pi D^2 / 4) / (\pi D)$$

$$= D / 4 = 3.5 \text{ ft.} / 4 = \mathbf{0.875 \text{ ft.}}$$

Proposed Culvert

- Determine outlet control headwater (cont.):
 - Determine headloss (cont.):
 - Use partial elements to determine V_{part} and R_{part} :
 - Q_{50} :

$$TW_{50} / D = (2.66 \text{ ft.} + 0.5 \text{ ft.}) / 3.5 \text{ ft.} = 0.9$$

Based on partial elements

$$A_{\text{part}} / A_{\text{full}} = 0.95$$

$$A_{\text{part}} = 0.95 * A_{\text{full}} = 0.95 * 9.62 \text{ sft.} = 9.14 \text{ sft.}$$

$$V_{\text{part}} = Q / A_{\text{full}} = 40 \text{ cfs} / 9.14 \text{ sft.} = \underline{\underline{4.38 \text{ ft/s}}}$$

$$R_{\text{part}} / R_{\text{full}} = 1.19$$

$$R_{\text{part}} = 1.19 * R_{\text{full}} = 1.19 * 0.875 \text{ ft.} = 1.04 \text{ ft.}$$

Proposed Culvert

- Determine outlet control headwater (cont.):
 - Determine headloss (cont.):
 - Use partial elements to determine V_{part} and R_{part} :
 - Q_{100} :

$$TW_{100} / D = (2.94 \text{ ft.} + 0.5 \text{ ft.}) / 3.5 \text{ ft.} = 0.98$$

Based on partial elements

$$A_{\text{part}} / A_{\text{full}} = 0.98$$

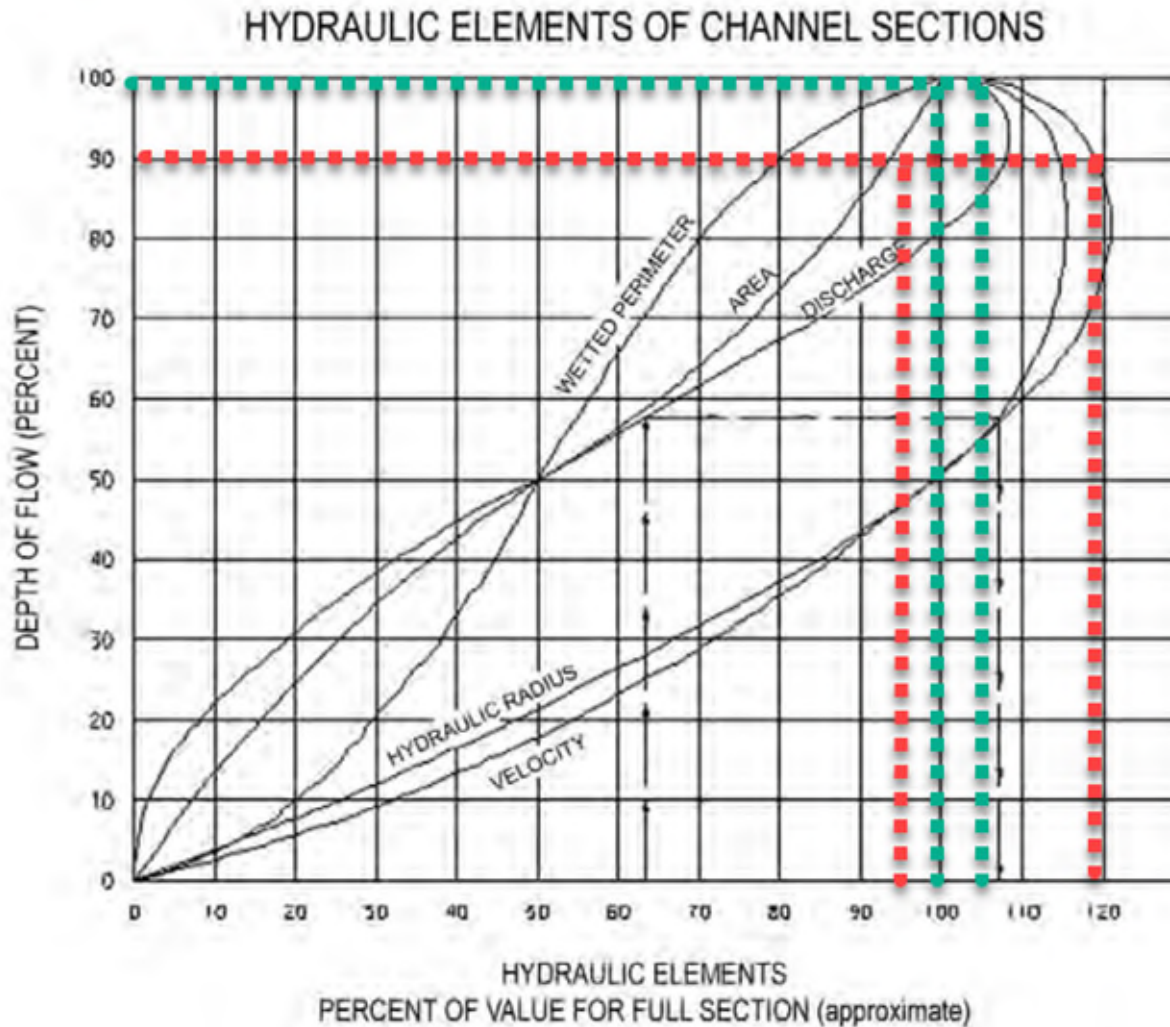
$$A_{\text{part}} = 0.98 * A_{\text{full}} = 0.98 * 9.62 \text{ sft.} = 9.52 \text{ sft.}$$

$$V_{\text{part}} = Q / A_{\text{part}} = 50 \text{ cfs} / 9.52 \text{ sft.} = \underline{\underline{5.25 \text{ ft/s}}}$$

$$R_{\text{part}} / R_{\text{full}} = 1.05$$

$$R_{\text{part}} = 1.05 * R_{\text{full}} = 1.05 * 0.875 \text{ ft.} = 0.92 \text{ ft.}$$

Proposed Culvert



Proposed Culvert

- Determine outlet control headwater:
 - $TW_{50} = 853.56'$ (same as existing)
 - $TW_{100} = 853.84'$ (same as existing)
 - $k_e = 0.5$ (squared edge with headwall)
 - $n = 0.024$ (assume worst case, CMP)
- Determine headloss:

$$H_L = (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g$$

$$\text{Full barrel area} = A_{\text{full}} = \pi D^2 / 4$$

$$= \pi (3.5 \text{ ft.})^2 / 4 = \mathbf{9.62 \text{ sft}}$$

$$\text{Full barrel hydraulic radius} = R = A_{\text{full}} / P_{\text{full}} = (\pi D^2 / 4) / (\pi D)$$

$$= D / 4 = 3.5 \text{ ft.} / 4 = \mathbf{0.875 \text{ ft.}}$$

Proposed Culvert

- Determine outlet control headwater (cont.):
 - Determine headloss (cont.):

Q_{50} :

$$\begin{aligned}H_L &= (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g \\&= (1 + 0.5 + (29 * (0.024)^2 * 48 \text{ ft}) / (1.04 \text{ ft})^{1.33}) * (4.38 \text{ ft/s})^2 / (2 \\&\quad * 32.2 \text{ ft/s}^2) \\&= \underline{\mathbf{0.68 \text{ ft.}}}\end{aligned}$$

Q_{100} :

$$\begin{aligned}H_L &= (1 + K_e + 29 n^2 L / R^{1.33}) * V^2 / 2g \\&= (1 + 0.5 + (29 * (0.024)^2 * 48 \text{ ft}) / (0.92 \text{ ft})^{1.33}) * (5.25 \text{ ft/s})^2 / (2 \\&\quad * 32.2 \text{ ft/s}^2) \\&= \underline{\mathbf{1.03 \text{ ft.}}}\end{aligned}$$

Proposed Culvert

- Determine outlet control headwater (cont.):
 - Determine outlet control headwater:
 - $HW_{oc} = TW + h_L$ (Assume $V_u \approx V_d$)
 - Q_{50} :
 $HW_{oc} = 853.56' + 0.68' = \underline{\underline{854.24'}}$
 - Q_{100} :
 $HW_{oc} = 853.84' + 1.03' = \underline{\underline{854.87'}}$
 - Determine controlling headwater (HW_c) for proposed culvert:
 - Q_{50} :
 $HW_{ic} < HW_{oc} ??$
 $HW_c = \underline{\underline{854.24'}}$ (outlet control)
 - Q_{100} :
 $HW_{ic} < HW_{oc} ??$
 $HW_c = \underline{\underline{854.87'}}$ (outlet control)

HY-8 Analysis - existing

Crossing Data - Existing

Crossing Properties

Name: Existing

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	User-Defined	
Discharge List	Define...	
TAILWATER DATA		
Channel Type	Irregular Channel	
Irregular Channel	Define...	
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	100.000	ft
Crest Elevation	870.000	ft
Roadway Surface	Paved	
Top Width	36.000	ft

Culvert Properties

Culvert 1

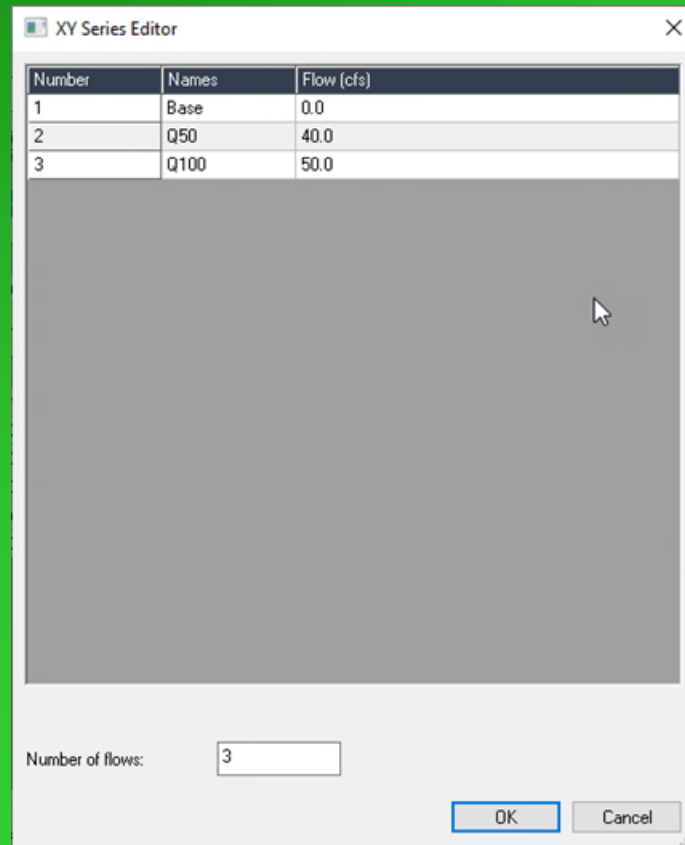
Add Culvert
Duplicate Culvert
Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Circular	
Material	Concrete	
Diameter	2.000	ft
Embedment Depth	0.000	in
Manning's n	0.012	
Culvert Type	Straight	
Inlet Configuration	Square Edge with Headwall	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	850.950	ft
Outlet Station	48.000	ft
Outlet Elevation	850.900	ft
Number of Barrels	1	

Help Click on any icon for help on a specific topic Low Flow AOP Energy Dissipation Analyze Crossing OK Cancel

HY-8 Analysis - existing

- Enter hydrologic information (Discharge Data)
 - Example problem uses “User-Defined” for Q_{50} , Q_{100}
 - Use “Minimum, Design, and Maximum” when using rating curve spreadsheet



The screenshot shows the 'XY Series Editor' dialog box. It contains a table with the following data:

Number	Names	Flow (cfs)
1	Base	0.0
2	Q50	40.0
3	Q100	50.0

Below the table, there is a 'Number of flows:' label and a text input field containing the value '3'. At the bottom right, there are 'OK' and 'Cancel' buttons.

HY-8 Analysis - existing

- Enter tailwater information (Tailwater Data)
 - Example problem uses “Irregular Channel” for surveyed cross section
 - Use “Enter Rating curve” when using rating curve spreadsheet

Irregular Tailwater Channel

Tailwater File
Browse for existing .TW file


Tailwater Channel
Slope of tailwater channel: ft/ft
Number of cross-sec points:

Irregular Channel Cross-Section

No.	Station (ft)	Elevation (ft)	Manning n
1	0.000	869.000	0.0800
2	0.000	855.000	0.0800
3	10.000	854.000	0.0400
4	15.000	851.000	0.0400
5	16.000	850.900	0.0400
6	17.000	850.900	0.0400
7	18.000	851.000	0.0400
8	23.000	854.000	0.0800
9	33.000	855.000	0.0800
10	33.000	869.000	

HY-8 Analysis - existing

- Enter roadway information (Roadway Data)
 - Example problem uses “Constant Roadway Elevation” but could enter road profile (“Irregular”).

Rating Curve	VIEW...	
 ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	100.000	ft
Crest Elevation	870.000	ft
Roadway Surface	Paved	
Top Width	36.000	ft

HY-8 Analysis - existing

- Enter culvert information (Culvert and Site Data)

Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Circular	
Material	Concrete	
Diameter	2.000	ft
Embedment Depth	0.000	in
Manning's n	0.012	
Culvert Type	Straight	
Inlet Configuration	Square Edge with Headwall	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	850.950	ft
Outlet Station	48.000	ft
Outlet Elevation	850.900	ft
Number of Barrels	1	

HY-8 Analysis - existing

- Analyze crossing

Crossing Data - Existing

Crossing Properties

Name: Existing

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	User-Defined	
Discharge List	Define...	
TAILWATER DATA		
Channel Type	Irregular Channel	
Irregular Channel	Define...	
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	100.000	ft
Crest Elevation	870.000	ft
Roadway Surface	Paved	
Top Width	36.000	ft


Culvert Properties

Culvert 1

Add Culvert
Duplicate Culvert
Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Circular	
Material	Concrete	
Diameter	2.000	ft
Embedment Depth	0.000	in
Manning's n	0.012	
Culvert Type	Straight	
Inlet Configuration	Square Edge with Headwall	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	850.950	ft
Outlet Station	48.000	ft
Outlet Elevation	850.900	ft
Number of Barrels	1	

Help Click on any icon for help on a specific topic Low Flow AOP Energy Dissipation Analyze Crossing OK Cancel



HY-8 Analysis - existing

- Analyze crossing

Culvert Summary Table - Culvert 1

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Base	0.00	0.00	850.95	0.00	0.00	0-NF	0.00	0.00	0.00	0.00	0.00	0.00
Q50	40.00	40.00	858.86	7.91**	7.66	4-FFF	2.00	2.00	2.00	2.66	12.73	2.13
Q100	50.00	50.00	862.74	11.79**	10.78	4-FFF	2.00	2.00	2.00	2.94	15.92	2.25

Display

Crossing Summary Table

Culvert Summary Table Culvert 1

Water Surface Profiles

Tapered Inlet Table

Customized Table Options...

Geometry

Inlet Elevation: 850.95 ft

Outlet Elevation: 850.90 ft

Culvert Length: 48.00 ft

Culvert Slope: 0.0010

Inlet Crest: 0.00 ft

Inlet Throat: 0.00 ft

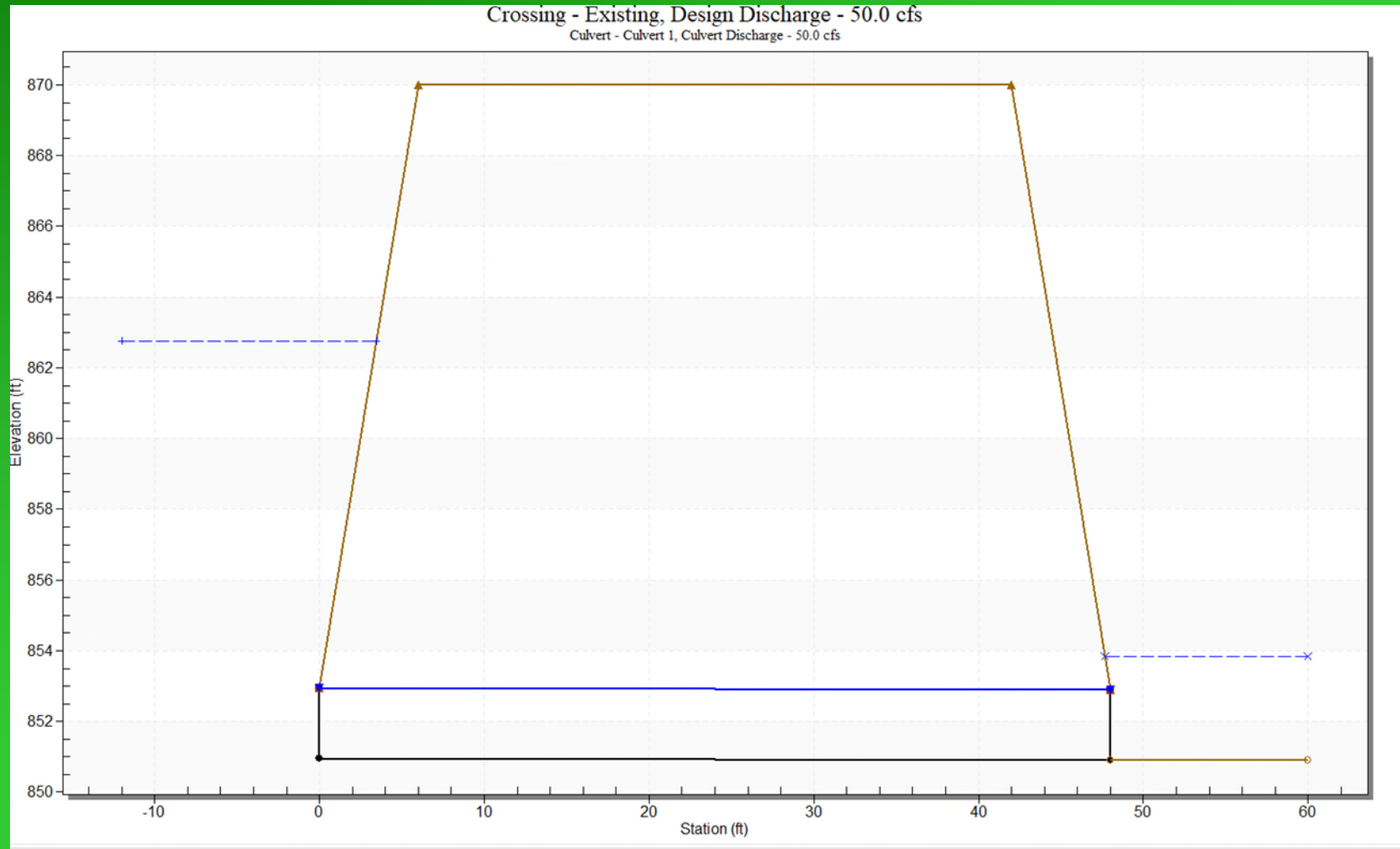
Outlet Control: Profiles

Plot

**** An unsteady, oscillatory hydraulic jump is possible, but full flow is likely.**

Help Flow Types... Edit Input Data... Energy Dissipation... AOP... Low Flow... Export Report Adobe PDF (*.pdf) Close

HY-8 Analysis - existing



HY-8 Analysis - proposed

Crossing Data - Proposed 42

Crossing Properties

Name:

Parameter	Value	Units
DISCHARGE DATA		
Discharge Method	User-Defined	
Discharge List	Define...	
TAILWATER DATA		
Channel Type	Irregular Channel	
Irregular Channel	Define...	
Rating Curve	View...	
ROADWAY DATA		
Roadway Profile Shape	Constant Roadway Elevation	
First Roadway Station	0.000	ft
Crest Length	100.000	ft
Crest Elevation	870.000	ft
Roadway Surface	Paved	
Top Width	36.000	ft

Culvert Properties


Culvert 1

Add Culvert

Duplicate Culvert

Delete Culvert

Parameter	Value	Units
CULVERT DATA		
Name	Culvert 1	
Shape	Circular	
Material	Concrete	
Diameter	3.500	ft
Embedment Depth	0.000	in
Manning's n	0.024	
Culvert Type	Straight	
Inlet Configuration	Square Edge with Headwall	
Inlet Depression?	No	
SITE DATA		
Site Data Input Option	Culvert Invert Data	
Inlet Station	0.000	ft
Inlet Elevation	850.450	ft
Outlet Station	48.000	ft
Outlet Elevation	850.400	ft
Number of Barrels	1	

Help Click on any  icon for help on a specific topic Low Flow AOP Energy Dissipation Analyze Crossing

HY-8 Analysis - proposed

Culvert Summary Table - Culvert 1

Discharge Names	Total Discharge (cfs)	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth(ft)	Outlet Control Depth(ft)	Flow Type	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Base	0.00	0.00	850.90	0.00	0.45	0-NF	0.00	0.00	0.50	0.00	0.00	0.00
Q50	40.00	40.00	854.22	2.96	3.77	3-M2t	3.50	1.97	3.16	2.66	4.38	2.13
Q100	50.00	50.00	854.87	3.42	4.42	7-M2t	3.50	2.21	3.44	2.94	5.22	2.25

Display

Crossing Summary Table

Culvert Summary Table Culvert 1

Water Surface Profiles

Tapered Inlet Table

Customized Table Options...

Geometry

Inlet Elevation: 850.45 ft

Outlet Elevation: 850.40 ft

Culvert Length: 48.00 ft

Culvert Slope: 0.0010

Inlet Crest: 0.00 ft

Inlet Throat: 0.00 ft

Outlet Control: Profiles

Plot

Crossing Rating Curve

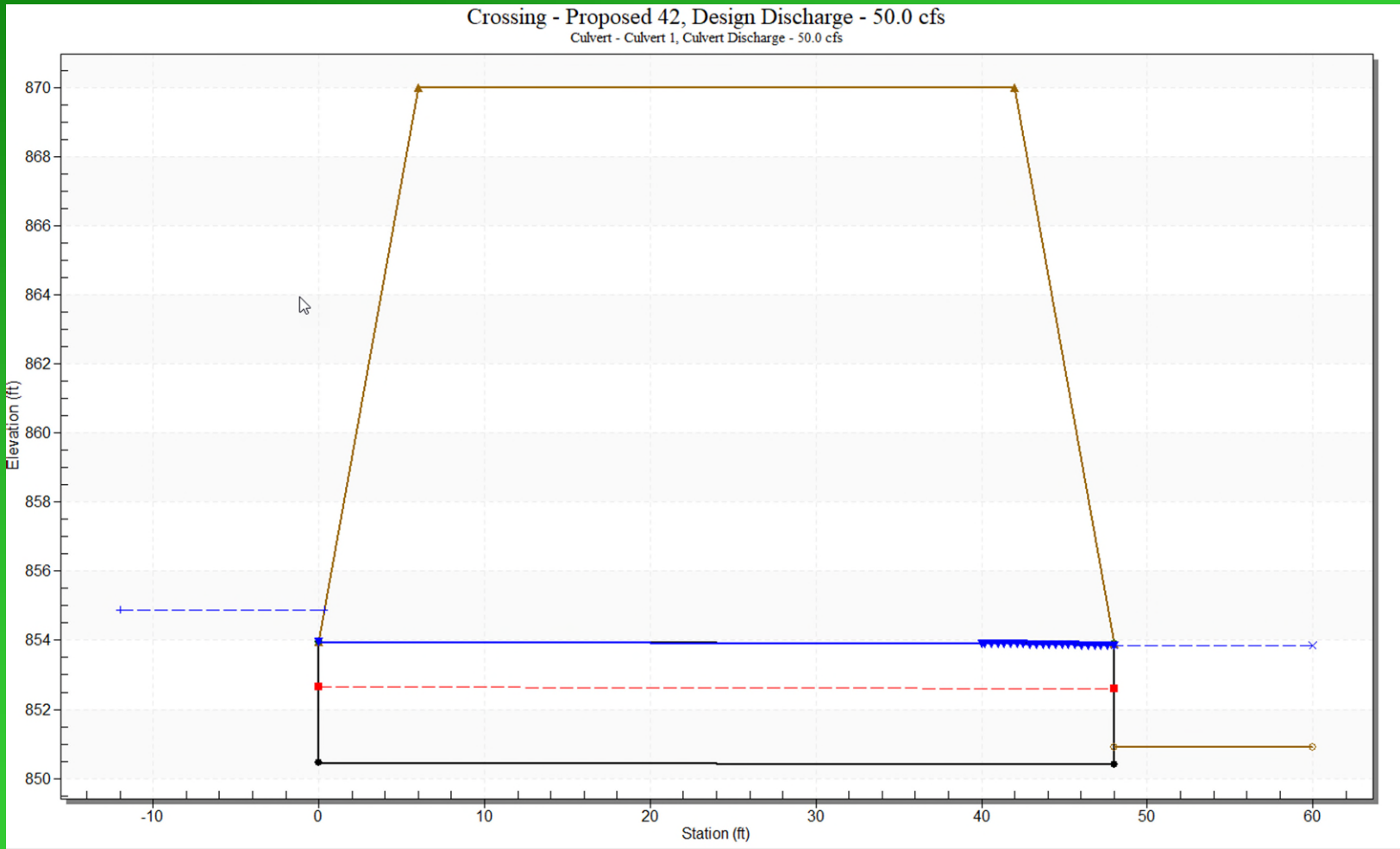
Culvert Performance Curve

Selected Water Profile

Water Surface Profile Data

Help Flow Types... Edit Input Data... Energy Dissipation... AOP... Low Flow... Export Report Adobe PDF (*.pdf) Close

HY-8 Analysis - proposed



Questions?

