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MDOT Hydraulics Unit
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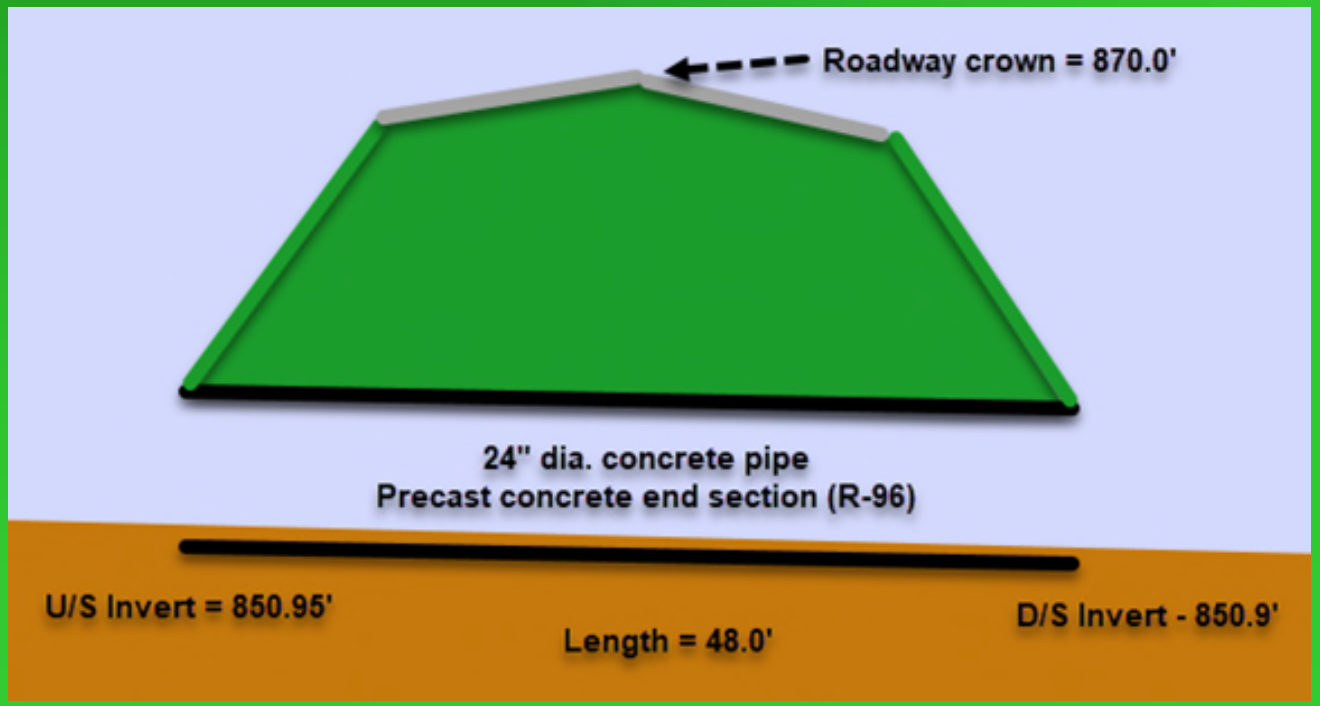
Culvert Example

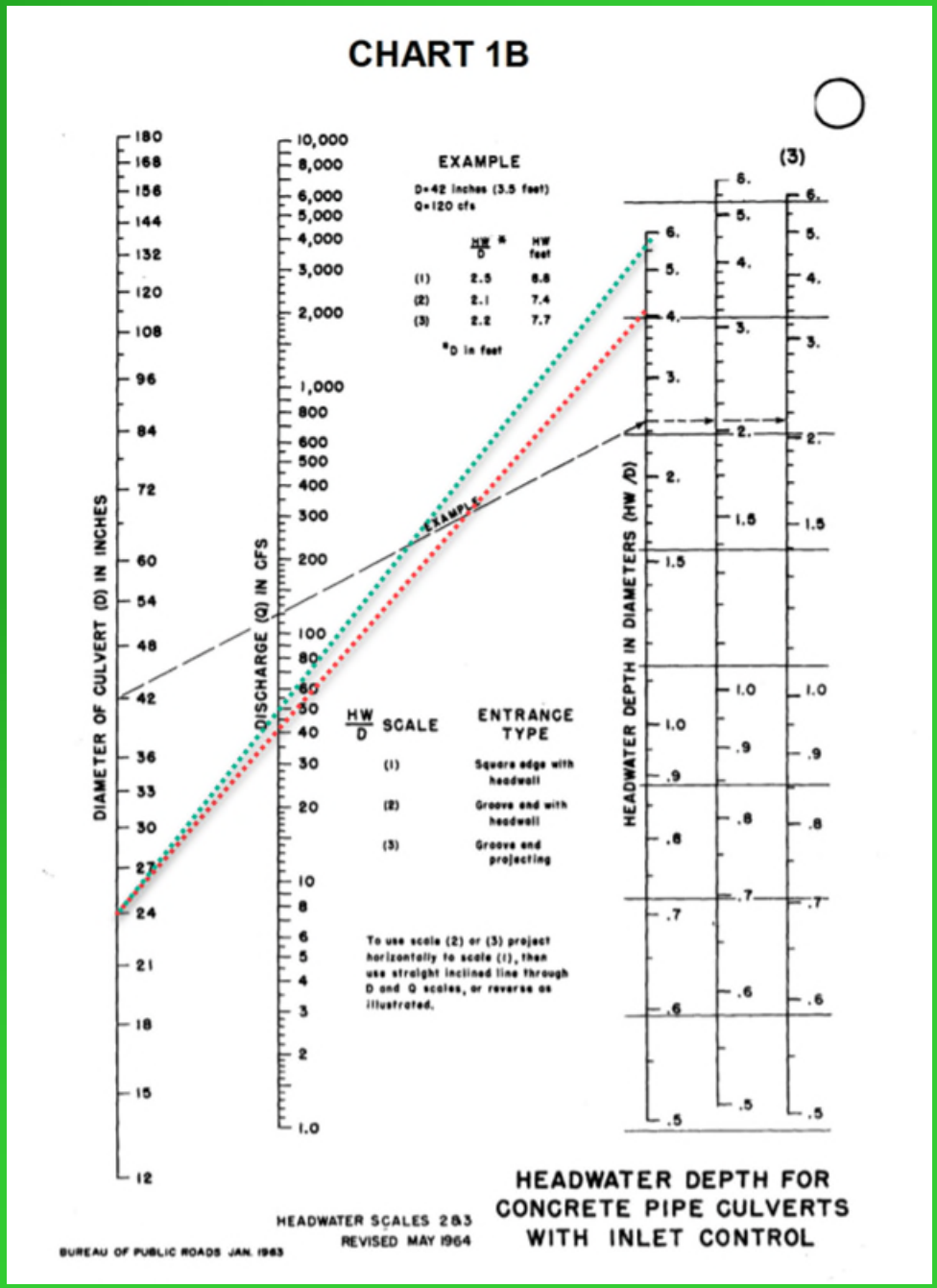
Existing Culvert

- 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:

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

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

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

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

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

Existing Culvert

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

$$V_{full} = Q / A_{full}$$

$$= 40 \text{ cfs} / 3.14 \text{ sft.} = 12.74 \text{ ft/s}$$

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

$$= (1 + 0.5 + 29 * (0.012)^2 * 48') / (0.5^{1.33}) * (12.74 \text{ ft/s})^2 / (2 * 32.2 \text{ ft/s}^2)$$

$$= 5.05 \text{ ft.}$$

Existing Culvert

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

$$V_{full} = Q / A_{full}$$

$$= 50 \text{ cfs} / 3.14 \text{ sft.} = 15.92 \text{ ft/s}$$

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

$$= (1 + 0.5 + 29 * (0.012)^2 * 48' / (0.5^{1.33})) * (15.92 \text{ ft/s})^2 / (2 * 32.2 \text{ ft/s}^2)$$

$$= 7.89 \text{ ft.}$$

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’)

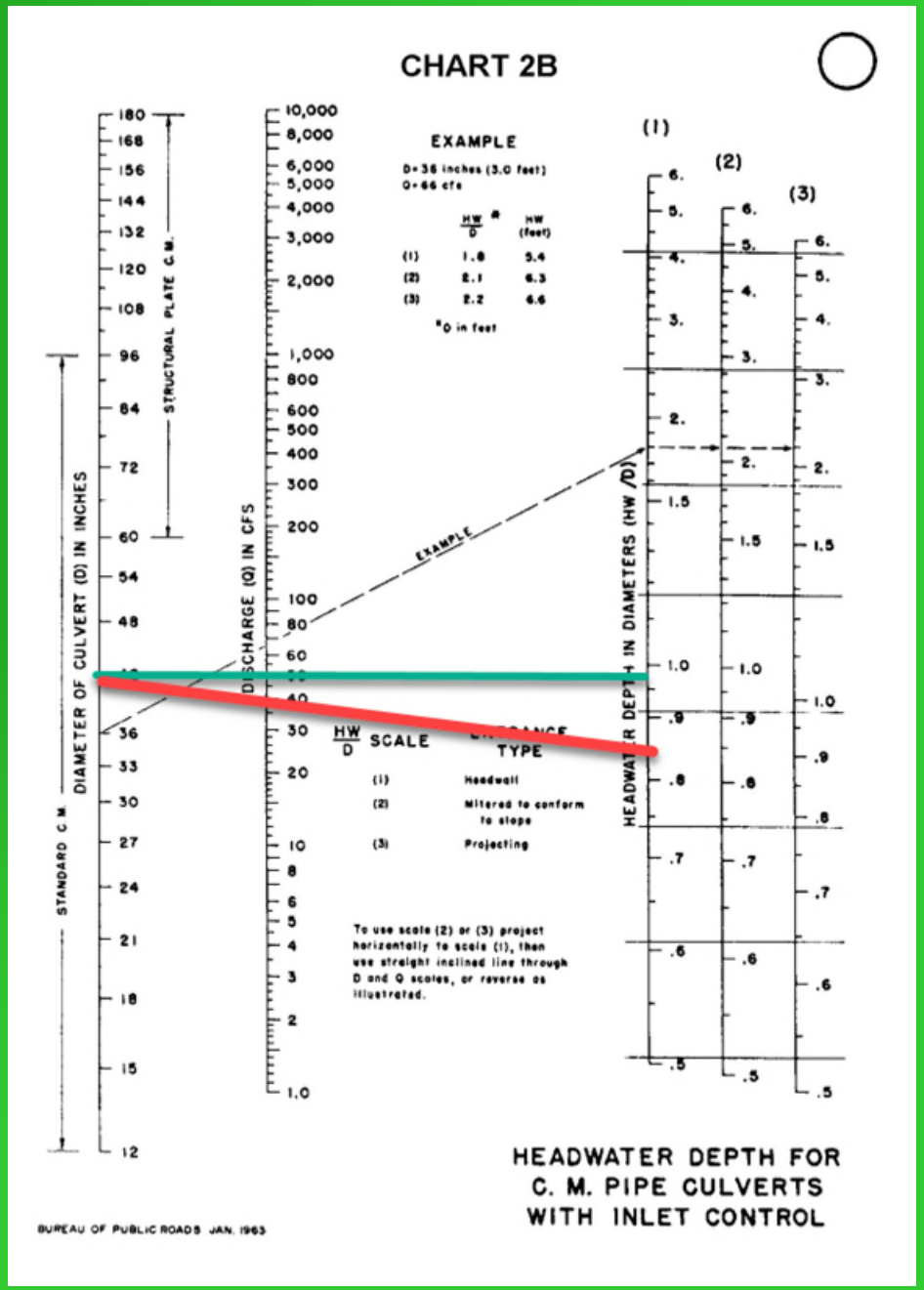
- Because we cannot pick material, assume CMP as worst case (n = 0.024)
- Lower inverts 6”, per Drainage Manual 5.3.4

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:

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

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

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

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

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

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

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

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

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

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

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

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

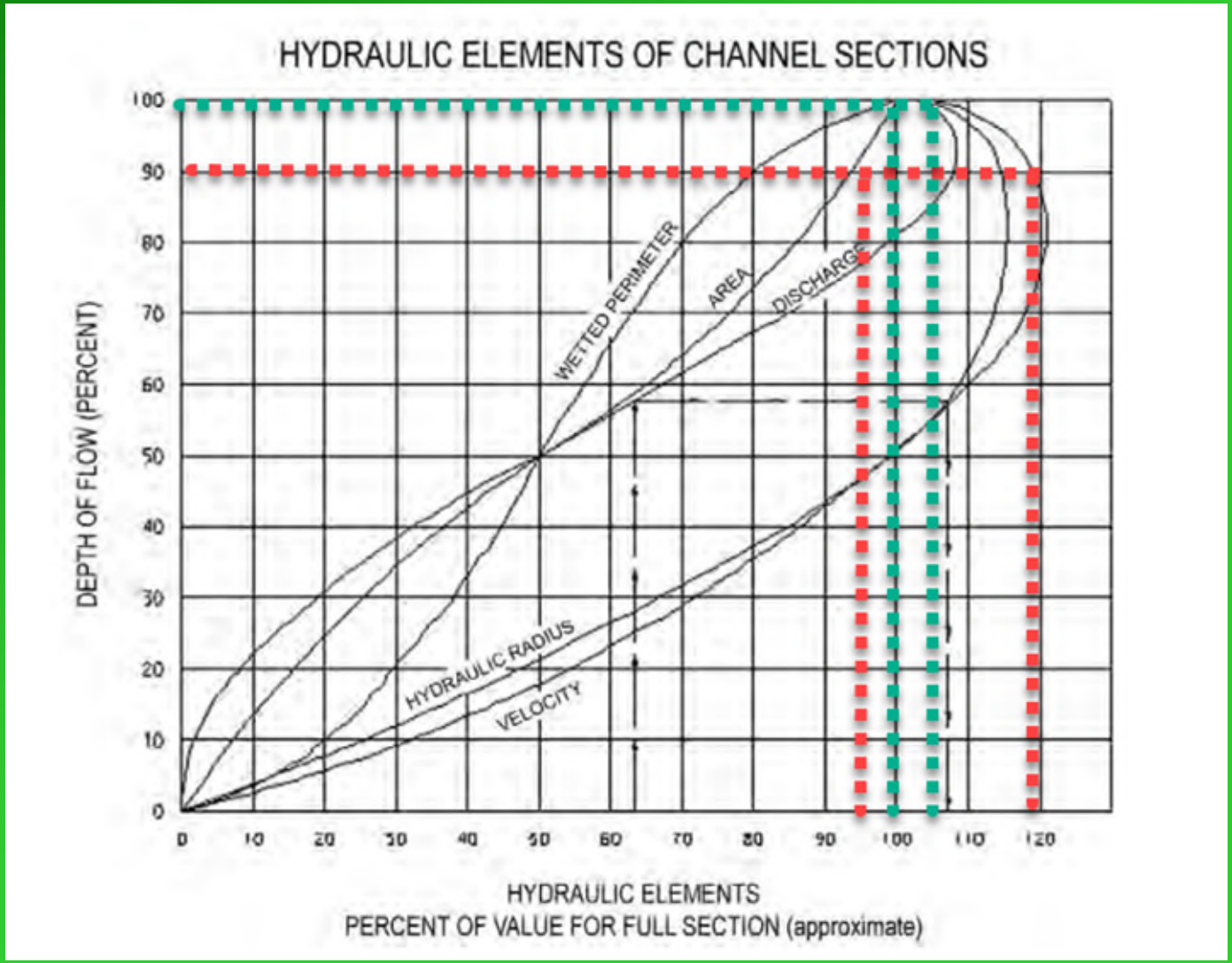
$A_{part} = 0.98 * A_{full} = 0.98 * 9.62 \text{ sft.} = 9.52 \text{ sft.}$

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

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

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

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:

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

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

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

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

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

Proposed Culvert

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

Q_{50}:

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

$$= (1 + 0.5 + (29 * (0.024)^2 * 48\ ft) / (1.04\ ft)^{1.33}) * (4.38\ ft/s)^2 / (2 * 32.2\ ft/s^2)$$

$$= \underline{\mathbf{0.68\ ft.}}$$

Q_{100}:

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

$$= (1 + 0.5 + (29 * (0.024)^2 * 48\ ft) / (0.92\ ft)^{1.33}) * (5.25\ ft/s)^2 / (2 * 32.2\ ft/s^2)$$

$$= \underline{\mathbf{1.03\ ft.}}$$

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’ = **<u>854.24’</u>**
    - Q_{100}:

      HW_{oc} = 853.84’ + 1.03’ = **<u>854.87’</u>**
  - Determine controlling headwater (HW_c) for proposed culvert:
    - Q_{50}:

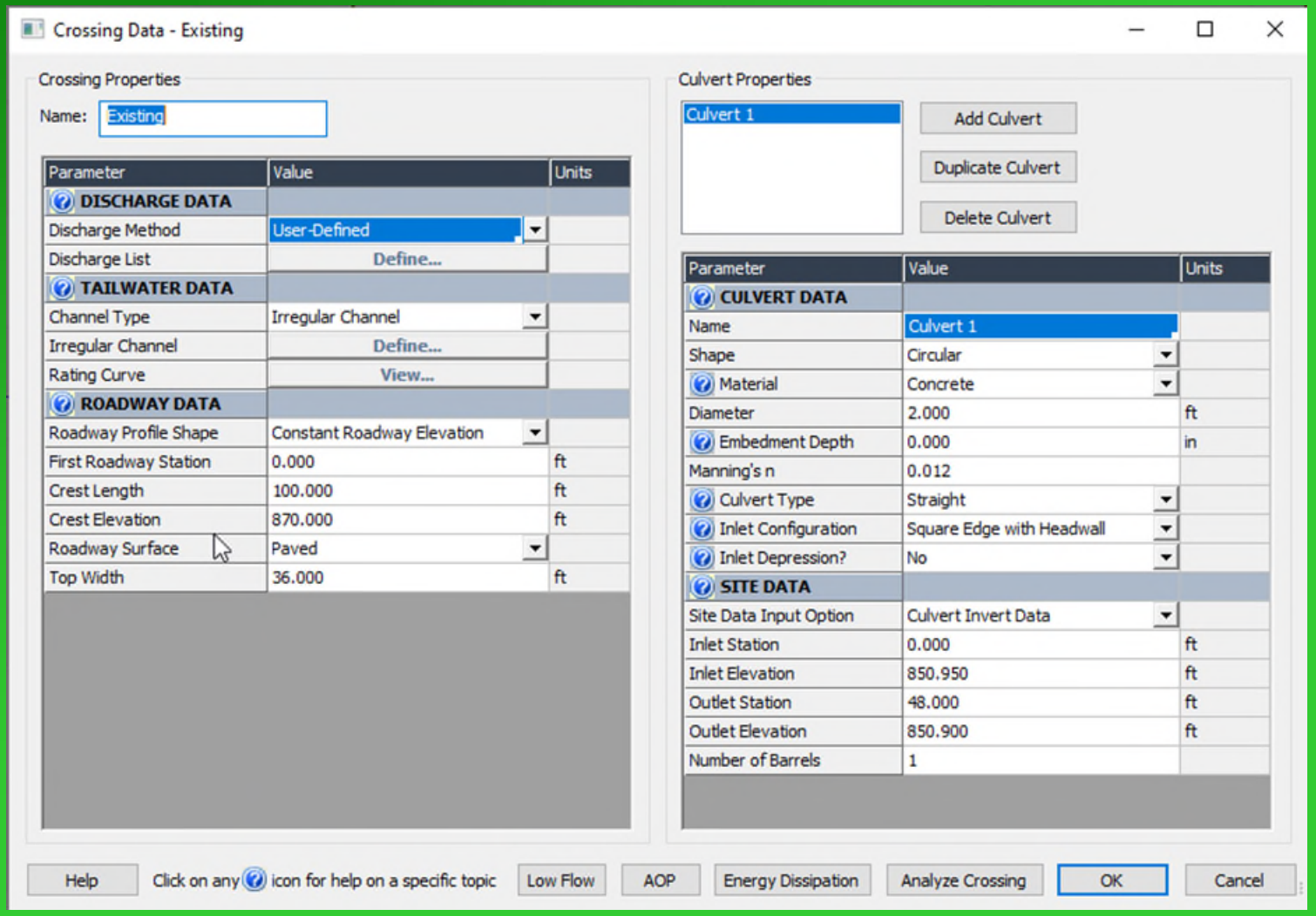
      $HW_{ic} < HW_{oc}$??

      HW_c = **<u>854.24’</u>** (outlet control)
    - Q_{100}:

      $HW_{ic} < HW_{oc}$??

      HW_c = **<u>854.87</u>**’ (outlet control)

HY-8 Analysis - existing

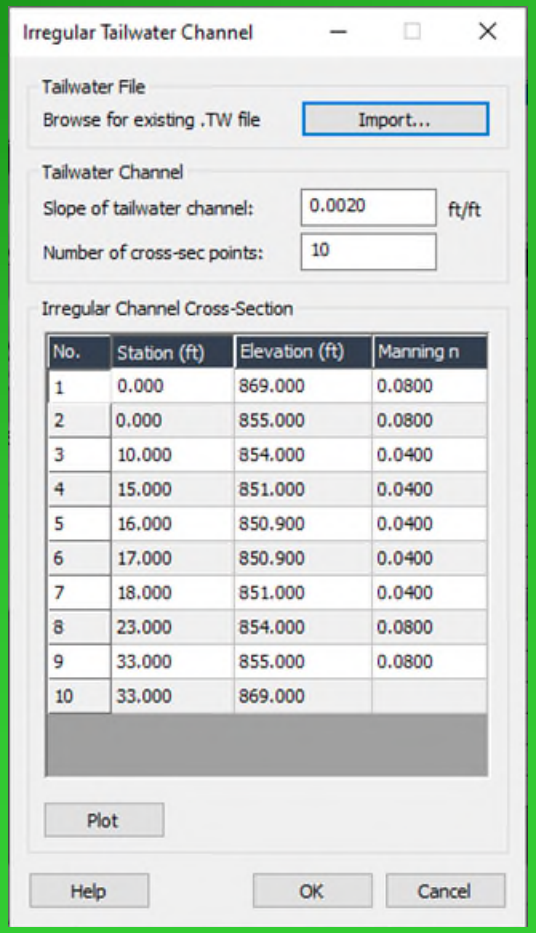


HY-8 Analysis - existing

- 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

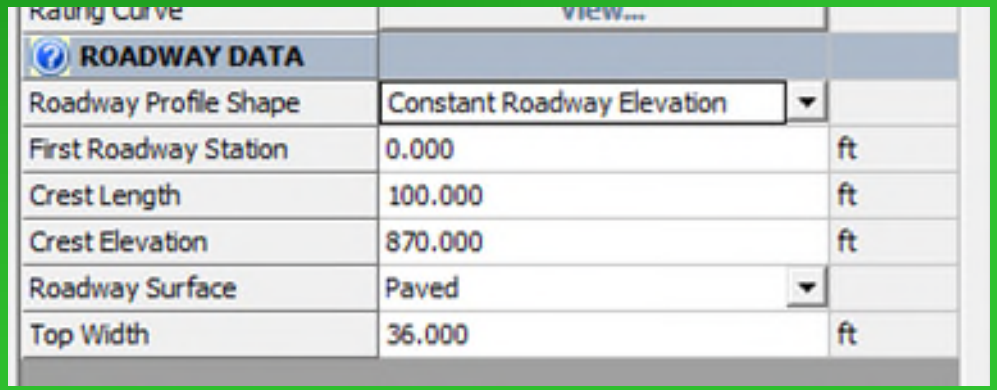
HY-8 Analysis - existing

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



HY-8 Analysis - existing

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



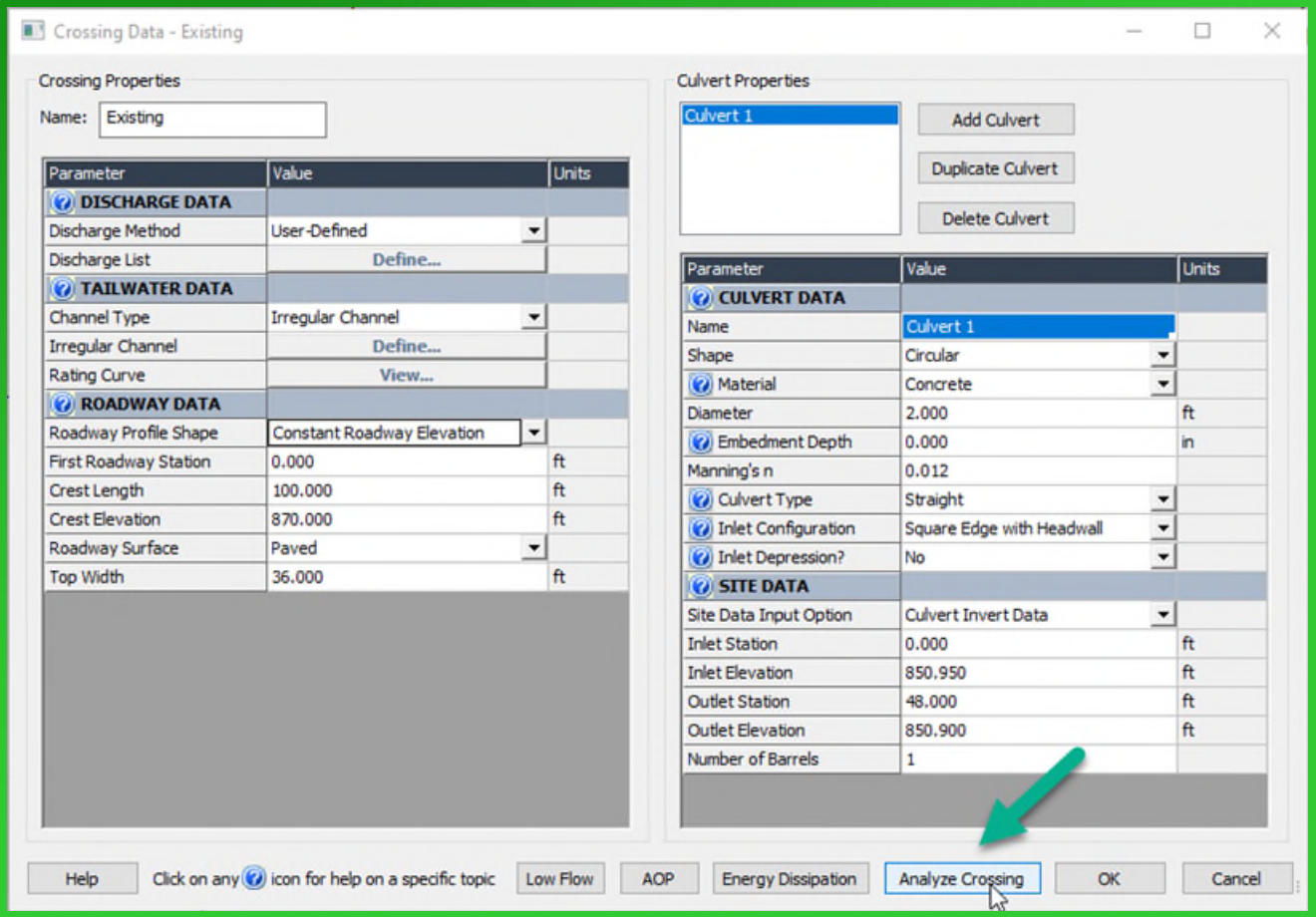
HY-8 Analysis - existing

- 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	

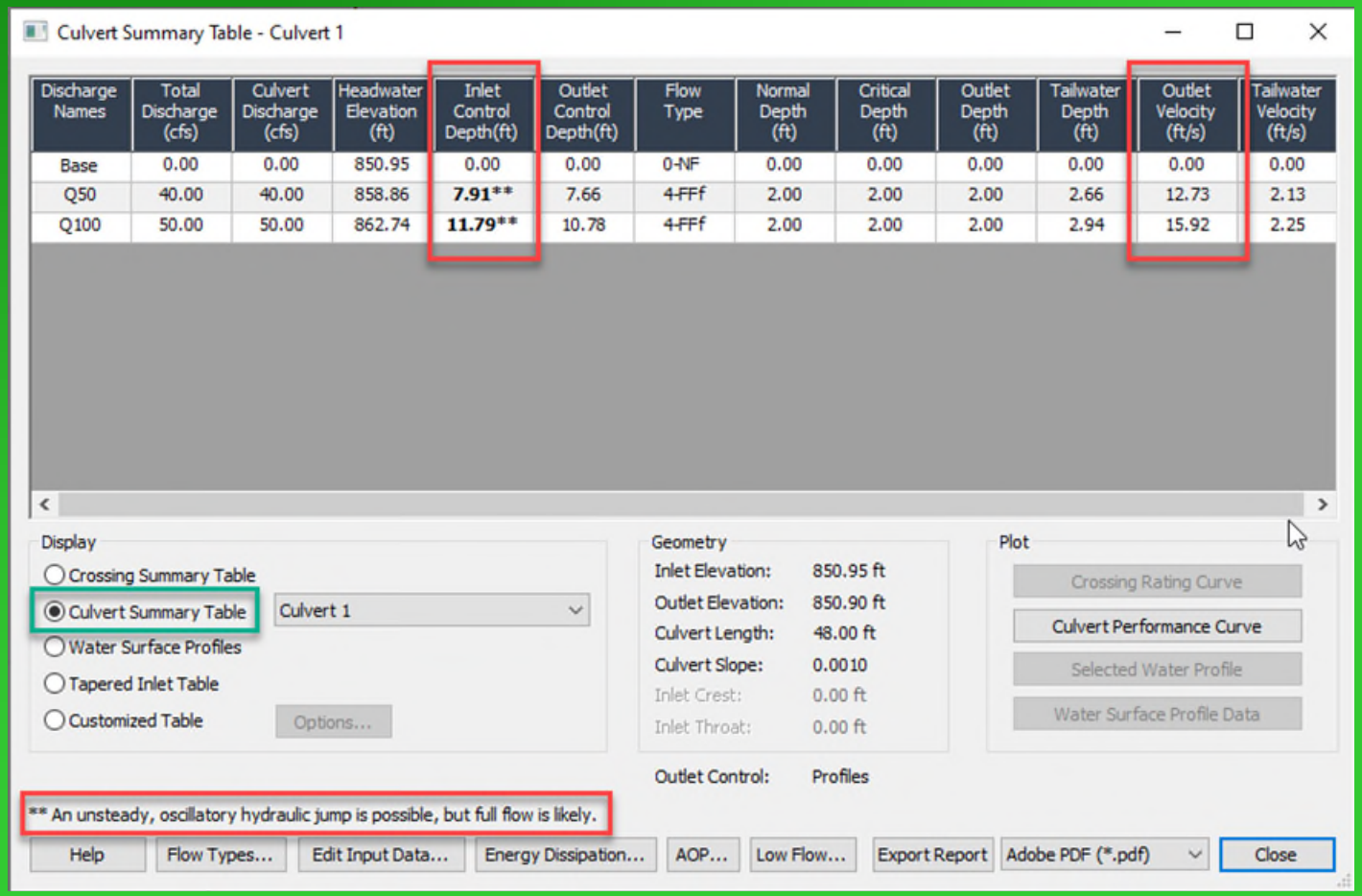
HY-8 Analysis - existing

- Analyze crossing

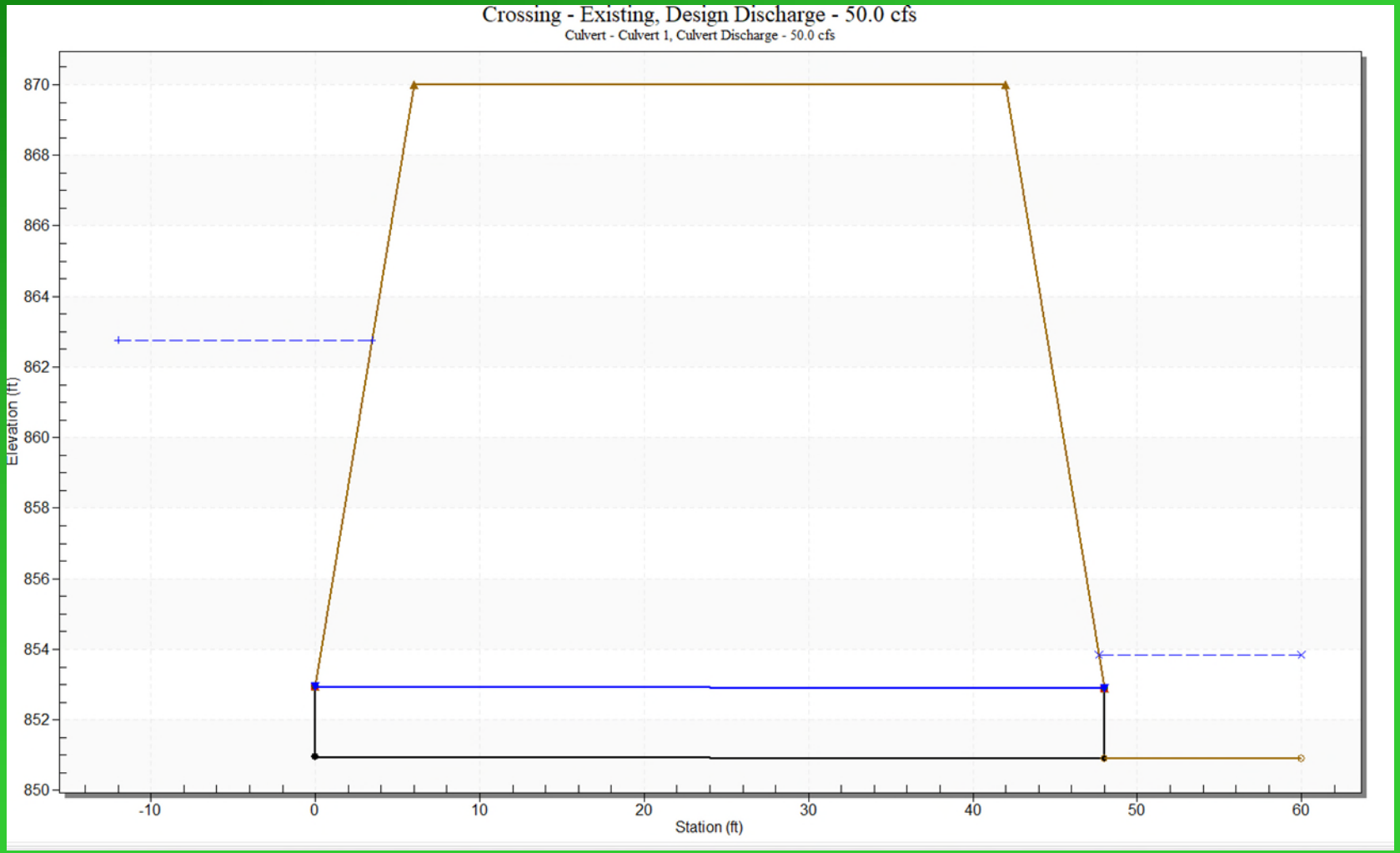


HY-8 Analysis - existing

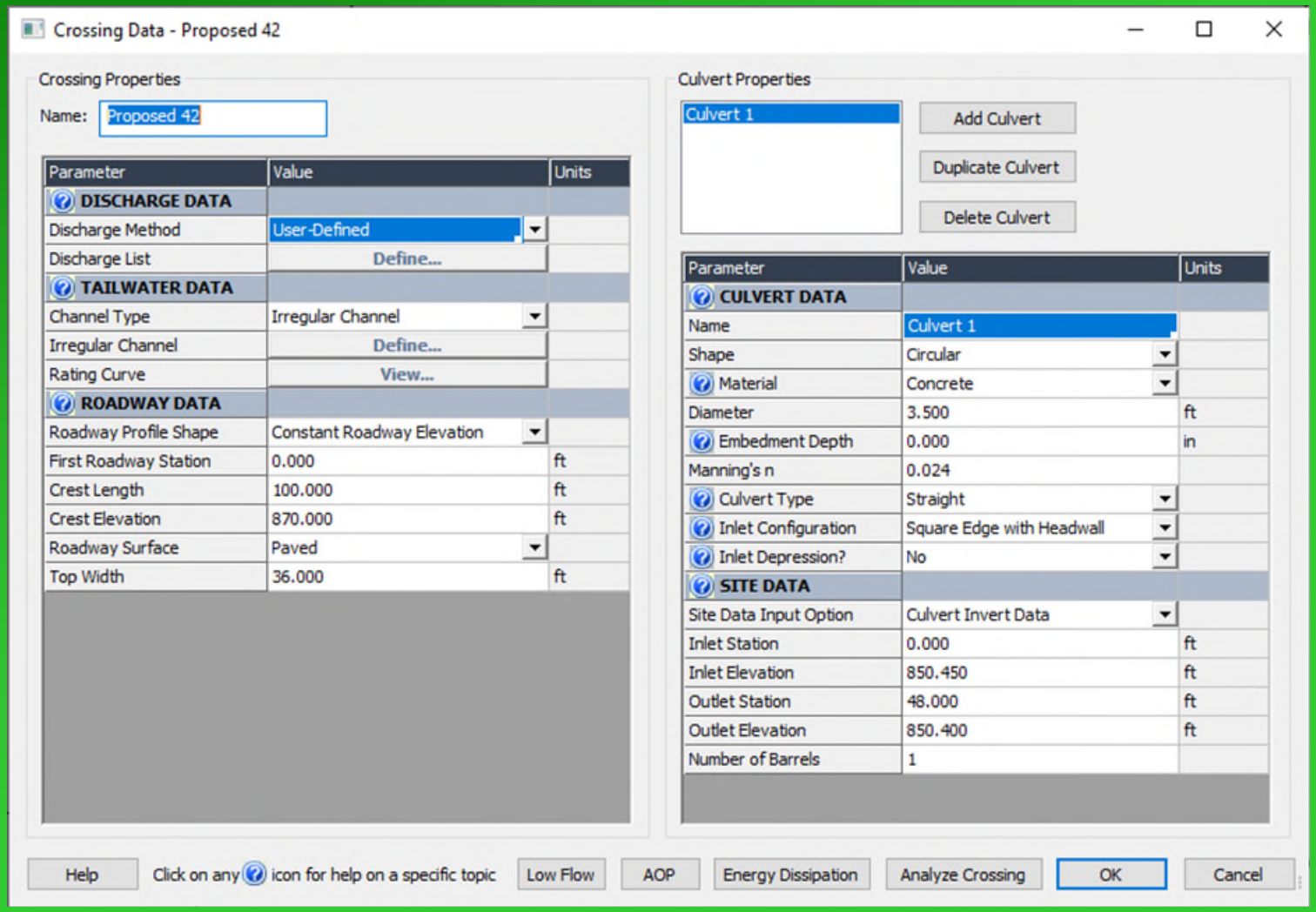
- Analyze crossing



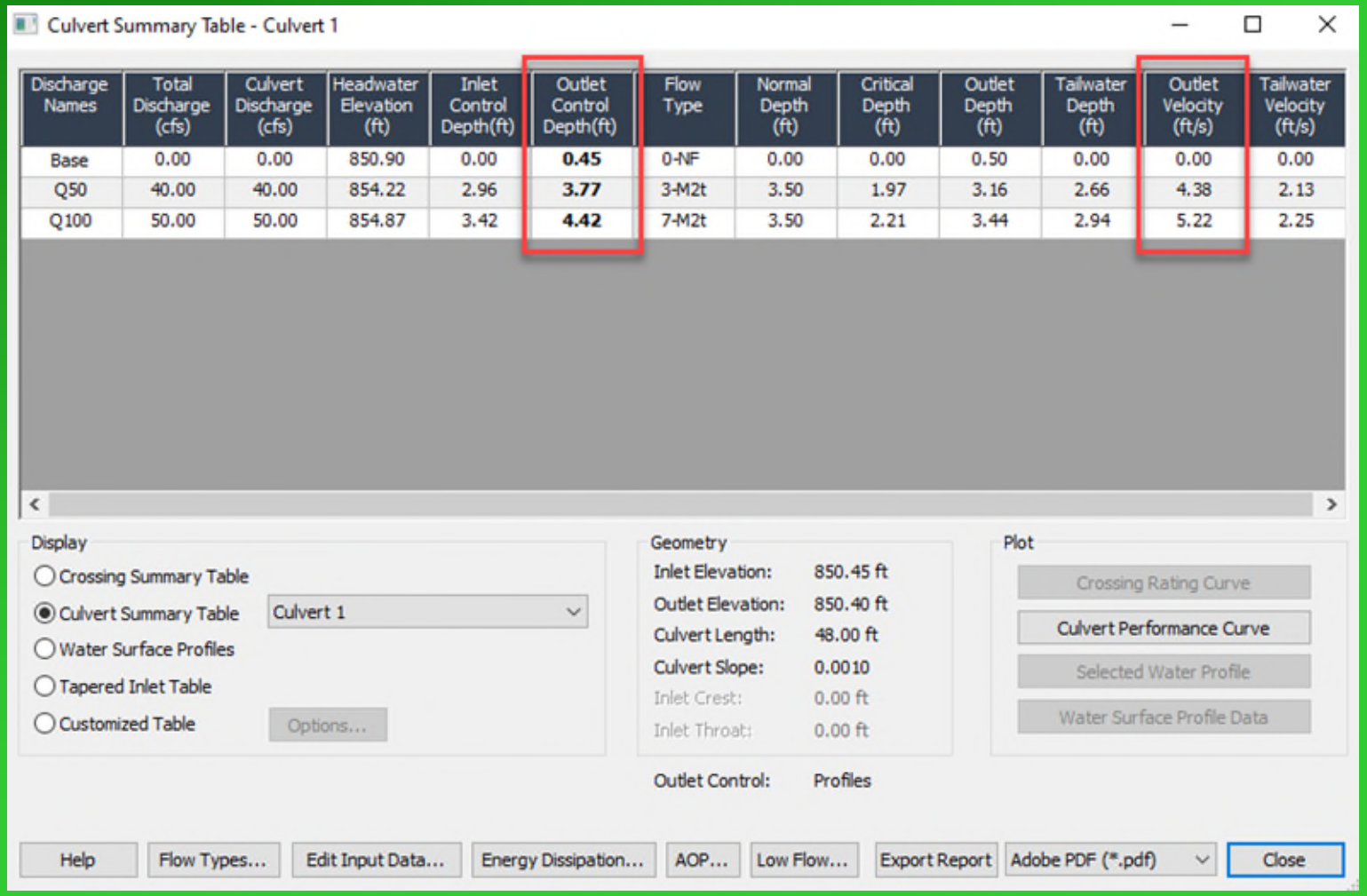
HY-8 Analysis - existing



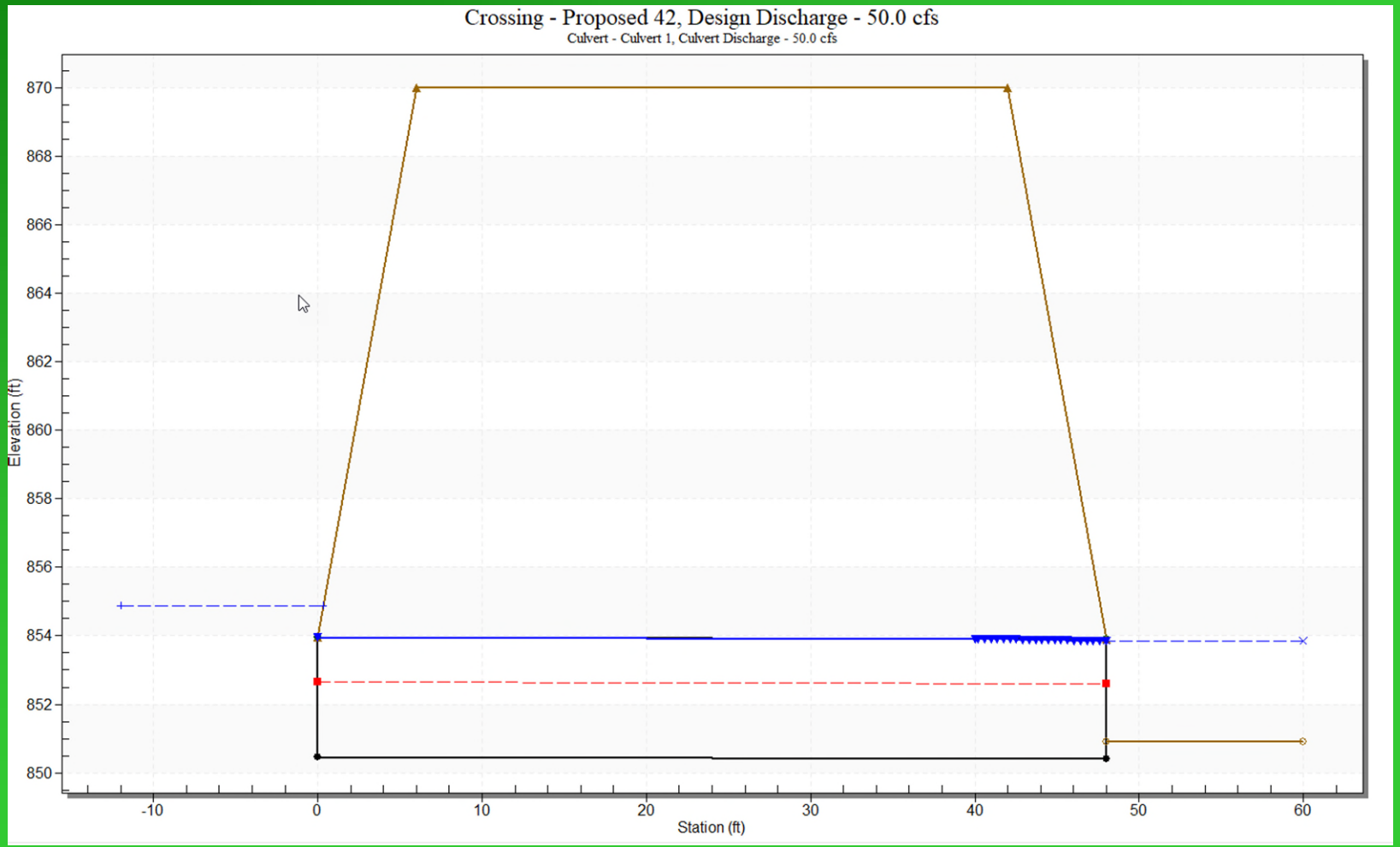
HY-8 Analysis - proposed



HY-8 Analysis - proposed



HY-8 Analysis - proposed



Questions?