INDIANA LTAP

ROAD SCHOLAR CORE COURSE #10

CULVERT DRAINAGE

Presented by

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OBJECTIVES

- Review culvert shapes, end sections, and materials
- Types of culvert flow conditions
- Steps to determine culvert size
  - HY-8
- Examine culvert material and shape selection

CULVERT FLOW

Conditions

- Full flow (flow under pressure)
- Partially full (free surface)
- Combination

VARIABLES

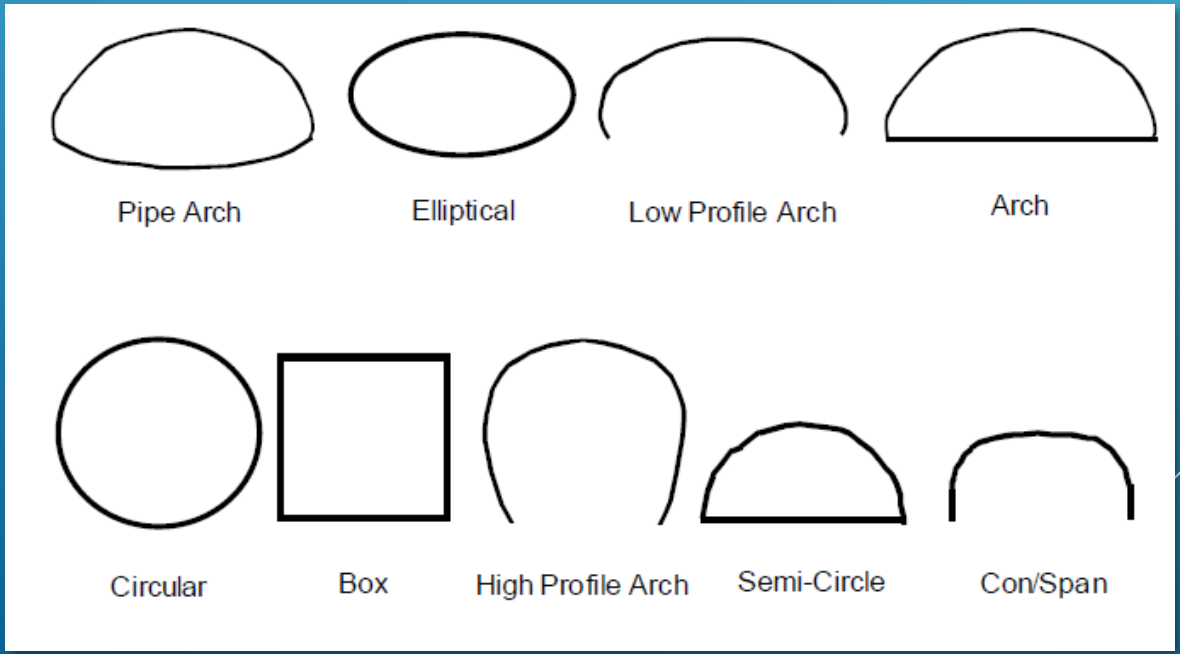
Flow is dependent upon:

- Inlet geometry
- Roughness
- Slope
- Pipe Diameter
- Length
- Headwater (approach) or tailwater conditions

CULVERT SHAPES AND MATERIALS

Typical Materials:

- Corrugated Metal Pipe
- Concrete
- Polyvinyl Chloride (PVC) Pipe
- High-Density Polyethylene
- Ductile Iron Pipe (DIP)
- Clay



CONCRETE

Concrete Arch

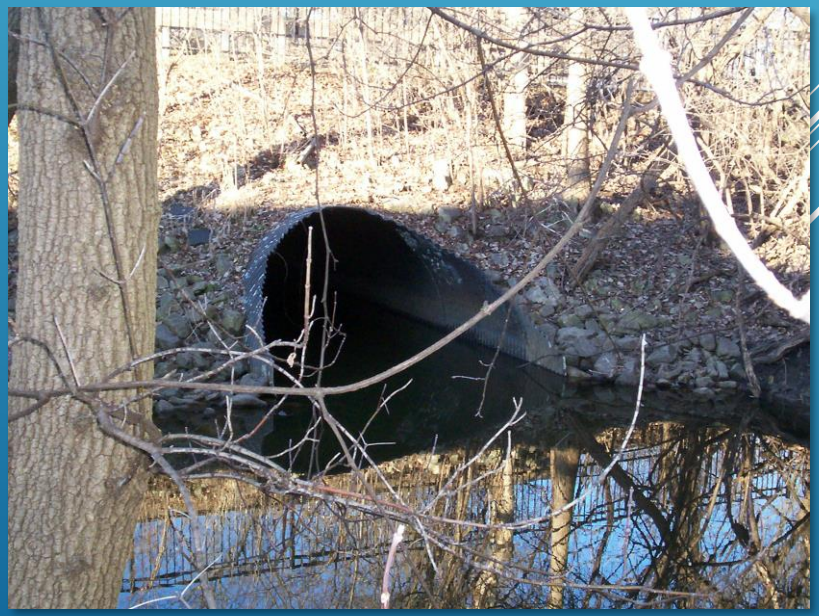
Tripe Reinforced Concrete Box Culverts (RCBCs)

Triple Concrete Circular

PLASTIC & METAL

Corrugated Metal Arch

High-Density Polyethylene (HDPE)



Corrugated Metal Circular

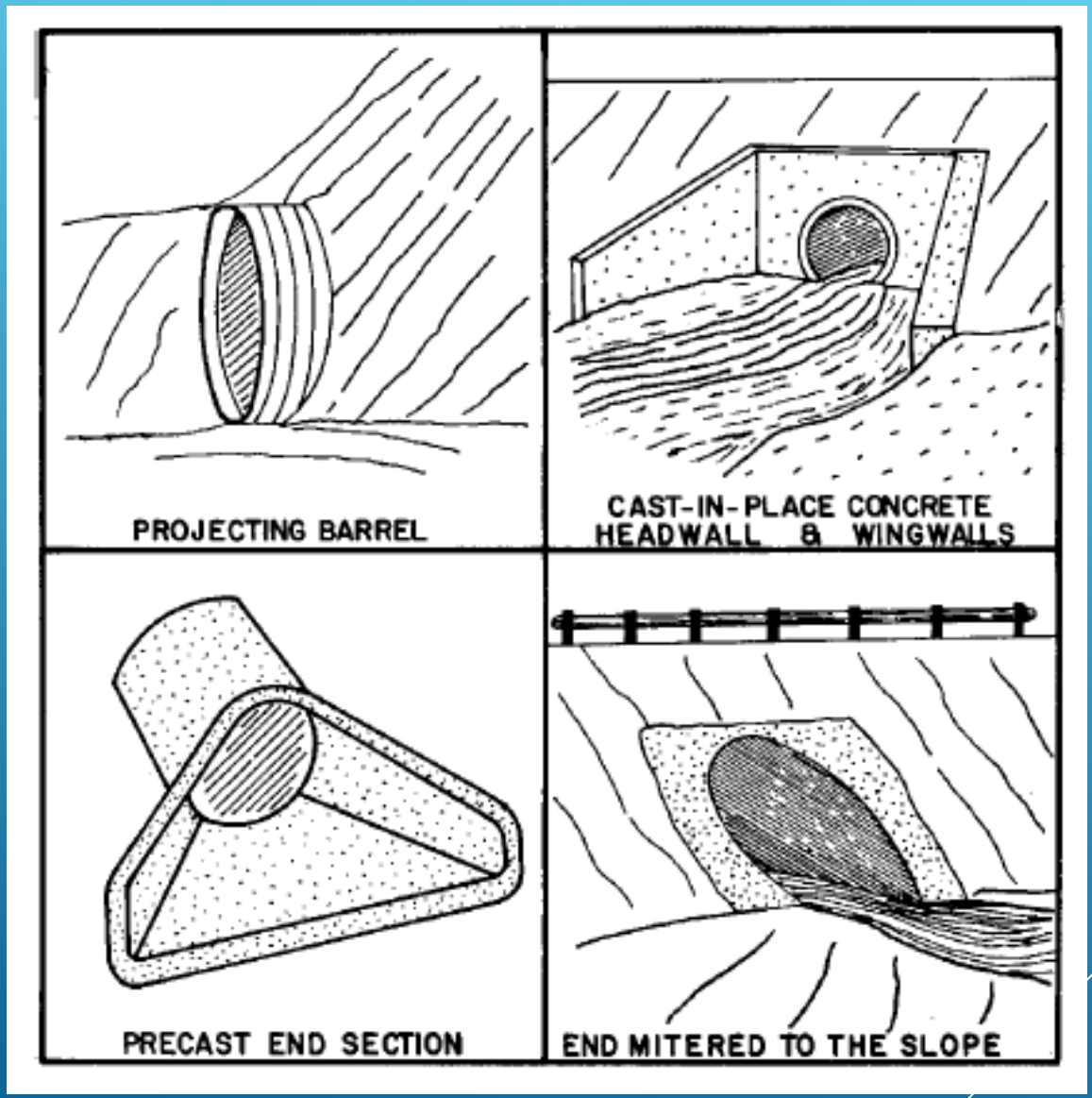
ROUGHNESS COEFFICIENTS

n = Manning's roughness coefficient

Type of Conduit	Wall Description	Manning's n
Concrete Pipe	Smooth Interior	0.012
Concrete Box	Smooth Walls	0.012- 0.015
Corrugated Metal Pipe or Arch, Annular or Helical Pipe	2.75 in. x 0.5 in Corrugations 6 in. x 1 in. corrugations 5 in. x 1 in. corrugations 3 in. x 1 in. corrugations 6 in. x 2 in. structural plate 9.25 in. x 2.5 in. structural plate	0.024 0.022-0.025 0.025-0.026 0.027-0.028 0.033-0.035 0.033-0.037
Spiral Rib Metal Pipe	Semi-Smooth Interior	0.015
Thermoplastic/HDPE Pipe	Smooth Interior	0.012
Cured in Place Liner (CIPP)	Smooth Interior	0.012

Source: InDOT Design Manual

END SECTIONS



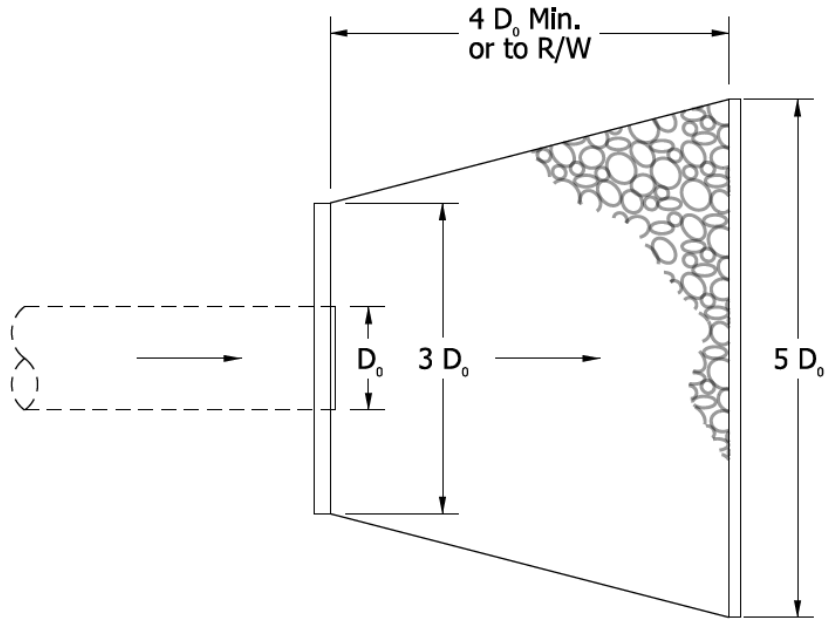
ENTRANCE LOSS COEFFICIENTS

End-Treatment Type	Entrance Type	K_E
Grated Box End Section, Type 1	Concrete Pipe, headwall with square edge	0.5
Grated Box End Section, Type 2	Concrete Pipe, headwall with square edge	0.5
Multiple-Pipes Concrete Anchor	Concrete Pipe, projecting from fill, square cut end	0.5
Multiple-Pipes Concrete Anchor	Corrugated Metal Pipe, Projecting from fill	0.9
Metal Pipe End Section	Corrugated Metal Pipe, end section conforming to fill slope	0.5
Precast-Concrete End Section	Concrete Pipe, end section conforming to fill slope	0.5
Safety Metal End Section	Corrugated Metal Pipe, mitered to conform to fill slope	0.7
Safety Metal End Section	Corrugated Metal Pipe, end section conforming to fill slope	0.5
Safety Metal End Section	Corrugated Metal Pipe, mitered to conform to fill slope	0.7
Safety Metal End Section	Corrugated Metal Pipe, end section conforming to fill slope	0.5
Single-Pipe Concrete Anchor	Corrugated Metal Pipe, projecting from fill	0.9
Single-Pipe Concrete Anchor	Concrete Pipe, projecting from fill, square cut end	0.5
Single-Pipe Concrete Anchor	Corrugated Metal Pipe-Arch, projecting from fill	0.9
Multiple-Pipe Concrete Anchor	Concrete Pipe-Arch, projecting from fill, square cut end	0.5
Multiple-Pipe Concrete Anchor	Corrugated Metal Pipe-Arch, projecting from fill	0.9

ENTRANCE-LOSS COEFFICIENT, K_E, FOR STANDARD INDOT CULVERT

Source: InDOT Design Manual

RIPRAP



D$_0$ = Outside Diameter of structure

Source: InDOT Design Manual

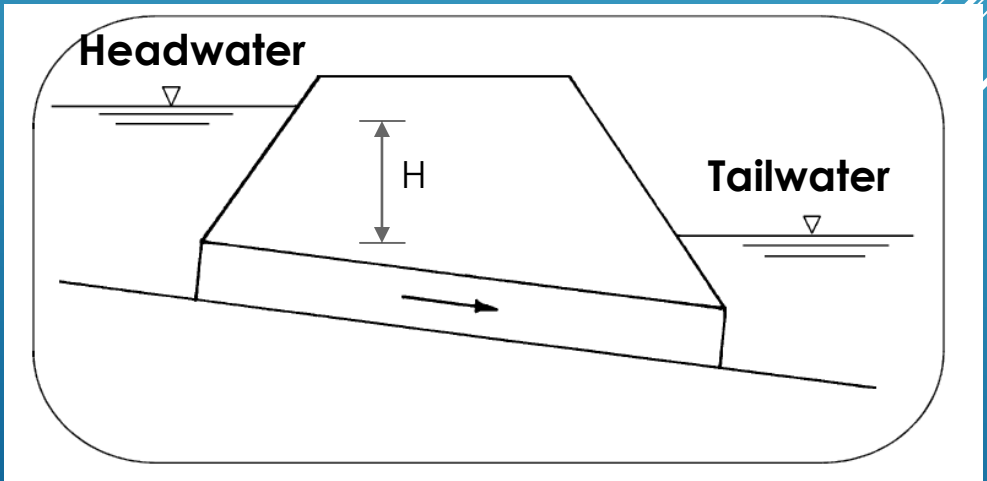
Erosion-Protection Method	Velocity, v (ft/s)
Revetment Riprap	≤ 6.5
Class 1 Riprap	$6.5 < v < 10$
Class 2 Riprap	$10 \leq v \leq 13$
Energy Dissipator	> 13

CULVERT HYDRAULICS

- Flow conditions vary from culvert to culvert
- Flow conditions vary over time
- May flow full or partially full
- Flow control types
  - Inlet
  - Outlet

HEADWATER AND TAILWATER

- Headwater (HW) - Depth of upstream water surface measured from invert of culvert entrance
  - Should not exceed edge of roadway shoulder elevation to allow for freeboard
  - Should not be so high as to cause flooding upstream
- Tailwater (TW) - Depth of downstream water surface measured from invert of culvert outlet
  - For stream crossings, usually determined by backwater calculations through hydraulic modeling
- H = Difference in elevation of upstream pool level and the water surface at the culvert outlet

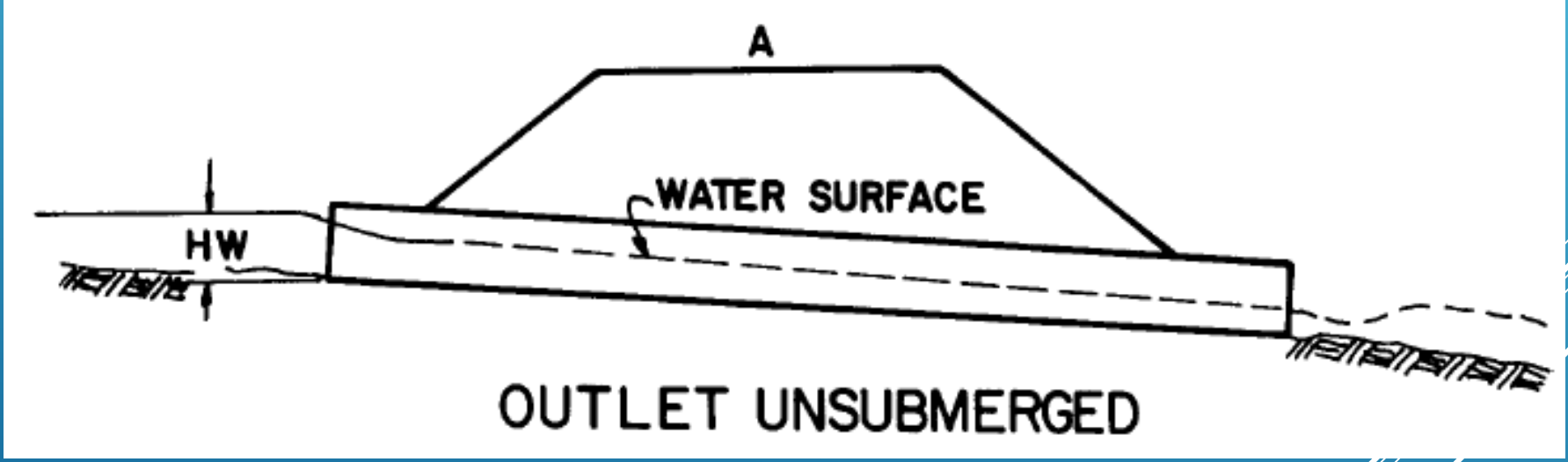


INLET CONTROL

- Culvert inlet controls (or limits) the flow
- More difficult for flow to get through the entrance of the culvert than it is to flow through the remainder of the culvert

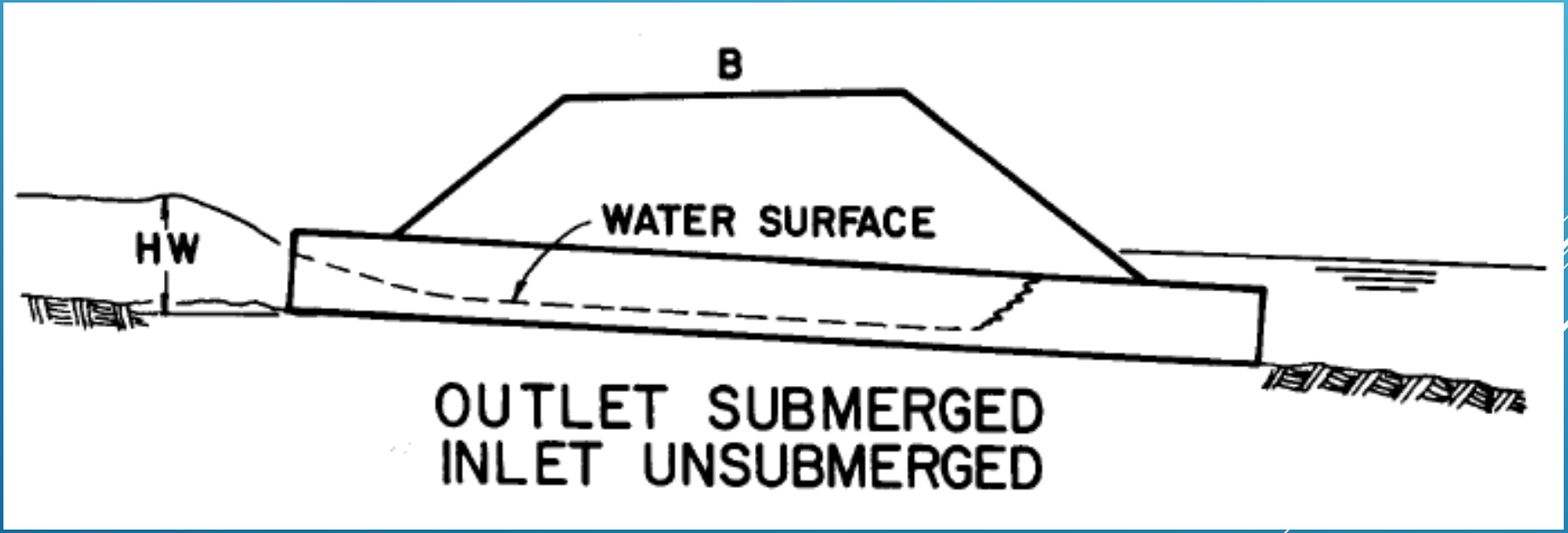
INLET CONTROL - A

- Pipe flow is partially full
- Outlet not submerged



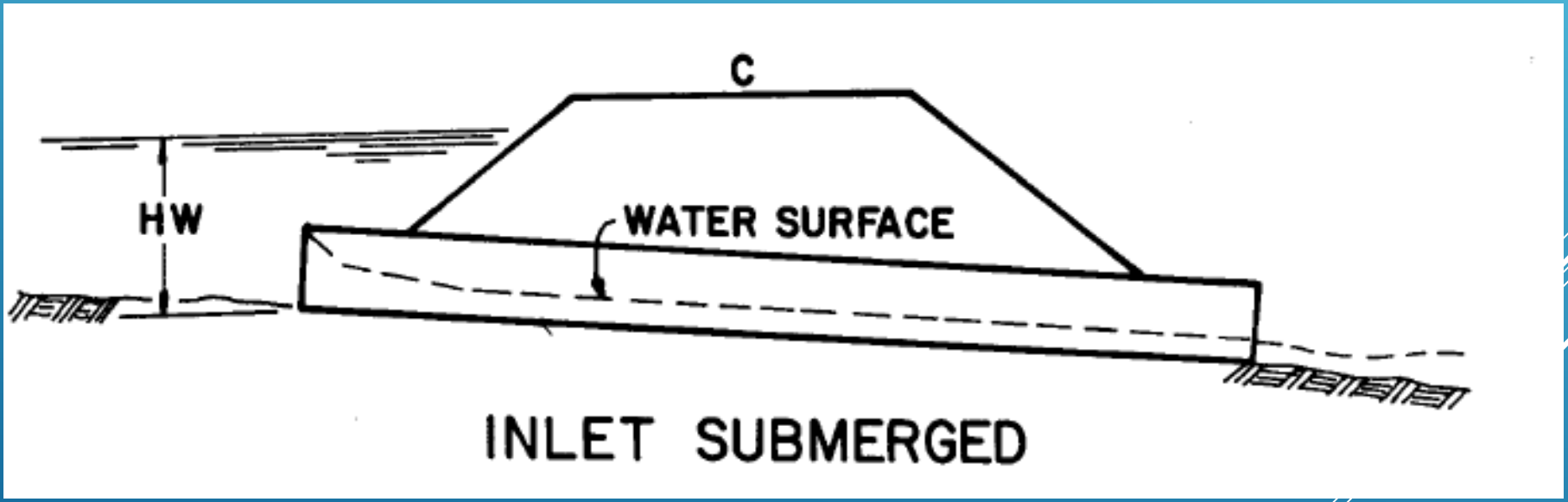
INLET CONTROL - B

- Inlet not submerged
- Outlet submerged



INLET CONTROL - C

- Pipe is flowing partially full
- Inlet submerged

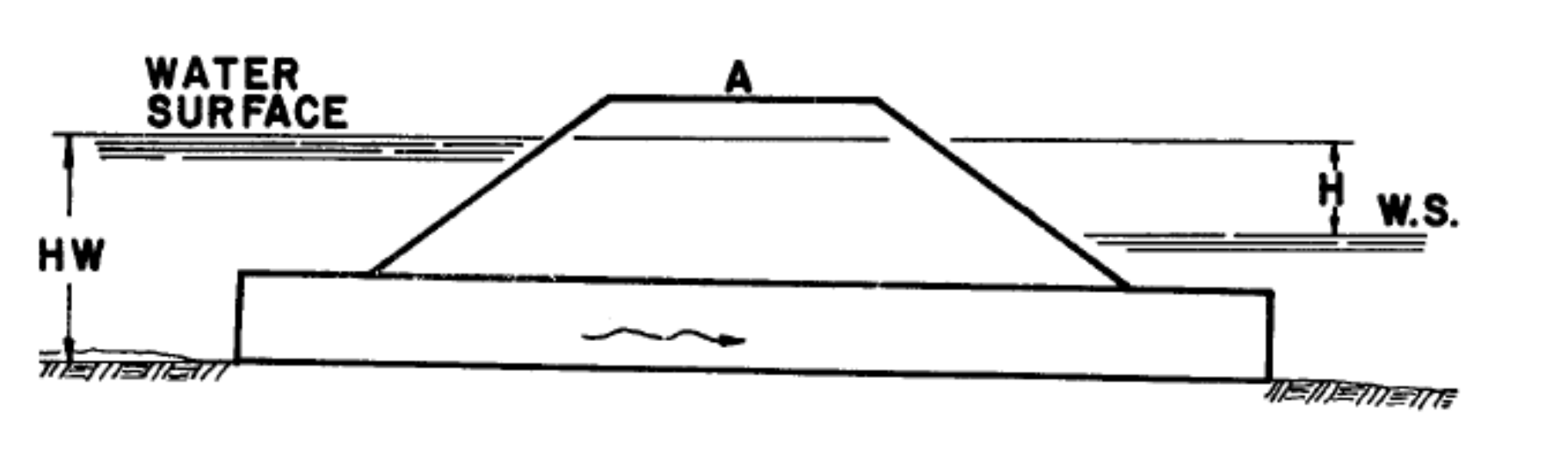


OUTLET CONTROL

- Culvert barrel capacity or outlet controls (or limits) the flow
- More difficult for flow to negotiate length of culvert than it is to get through the inlet (entrance)

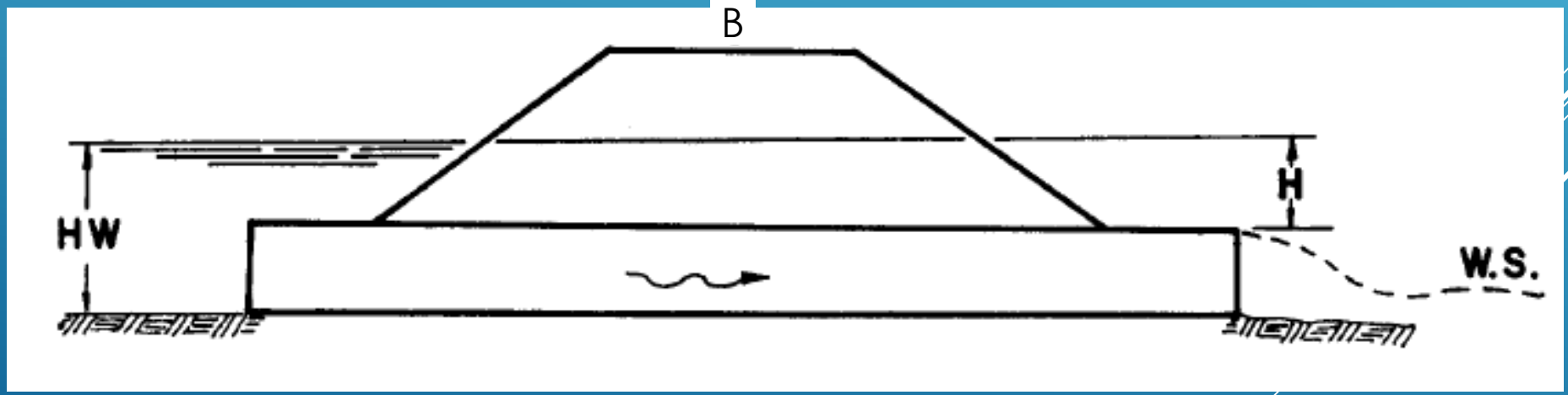
OUTLET CONTROL - A

- Pressure flow
- Full Flow
- Inlet and outlet submerged



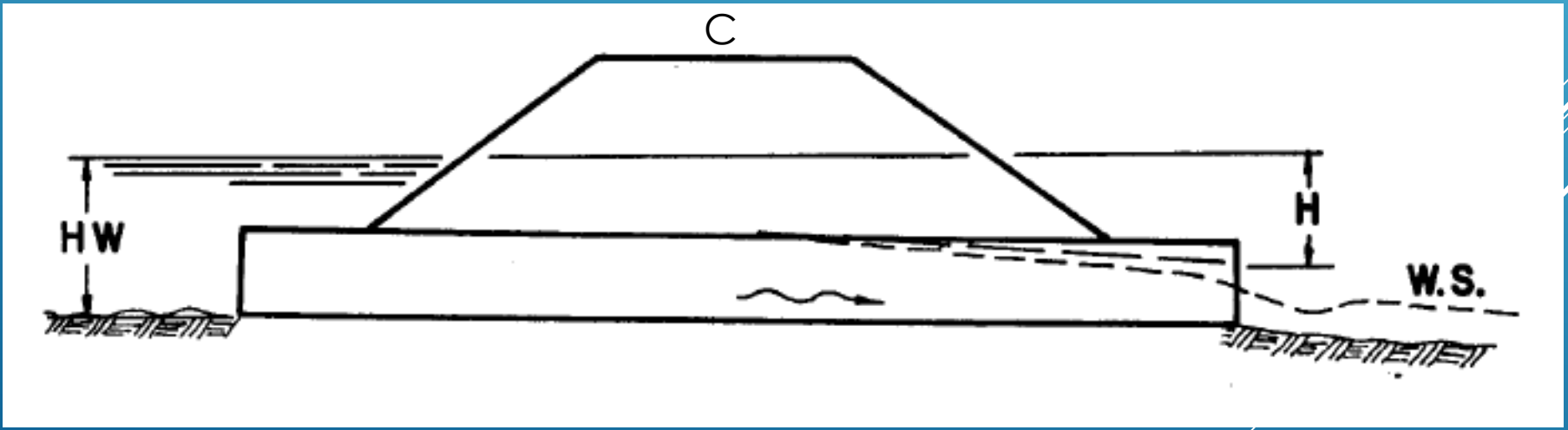
OUTLET CONTROL - B

- Submerged inlet
- Outlet not submerged
- Outlet velocities usually high



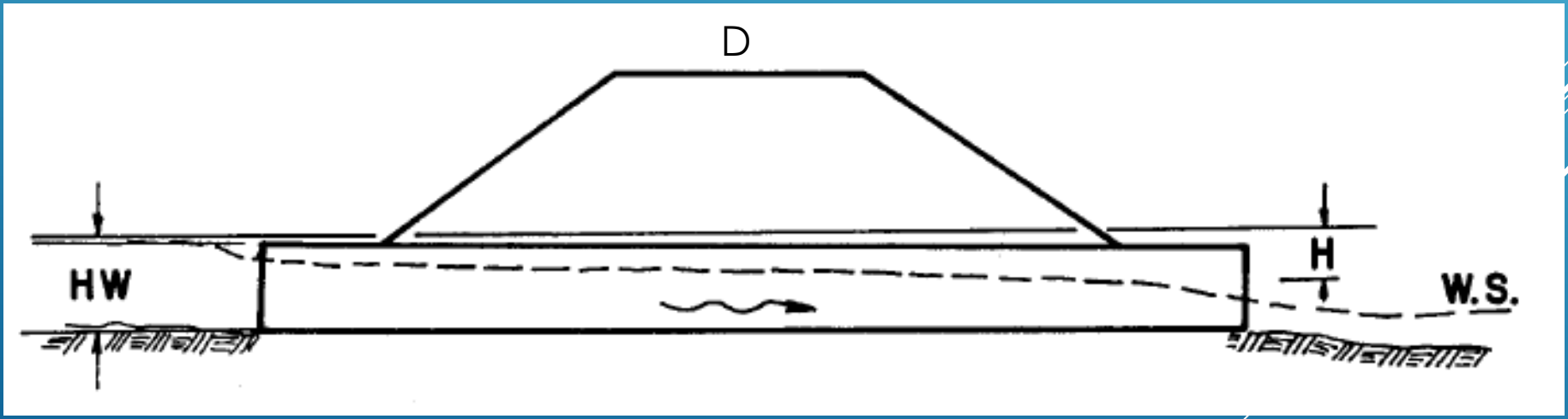
OUTLET CONTROL - C

- Submerged inlet
- Outlet not submerged
- Low TW



OUTLET CONTROL - D

- Inlet not submerged
- Outlet not submerged



CULVERT PERFORMANCE FACTORS

Factor	Inlet Control	Outlet Control
Headwater Elevation	X	X
Inlet Area	X	X
Inlet Edge Configuration	X	X
Inlet Shape	X	X
Pipe Roughness		X
Pipe Area		X
Pipe Shape		X
Pipe Length		X
Pipe Slope		X
Tailwater Elevation		X

CULVERT DESIGN STEPS

1. Summarize known data: Flowrate (Q) in cfs, target upstream water surface elevation
2. Choose the culvert dimensions (diameter, length)
3. Assume inlet control
4. Use chart to calculate the upstream total head (HW) for the design flowrate using design table
5. Repeat step 3 until the upstream head (HW) satisfies design specifications
6. Use design chart to calculate the head loss (H) from inlet to outlet for the design flowrate
7. Calculate the upstream total head (HW = H + TW)
8. Compare the inlet and outlet control results
    - The higher headwater governs and indicates the flow control (inlet or outlet control)

EXAMPLE CALCULATION

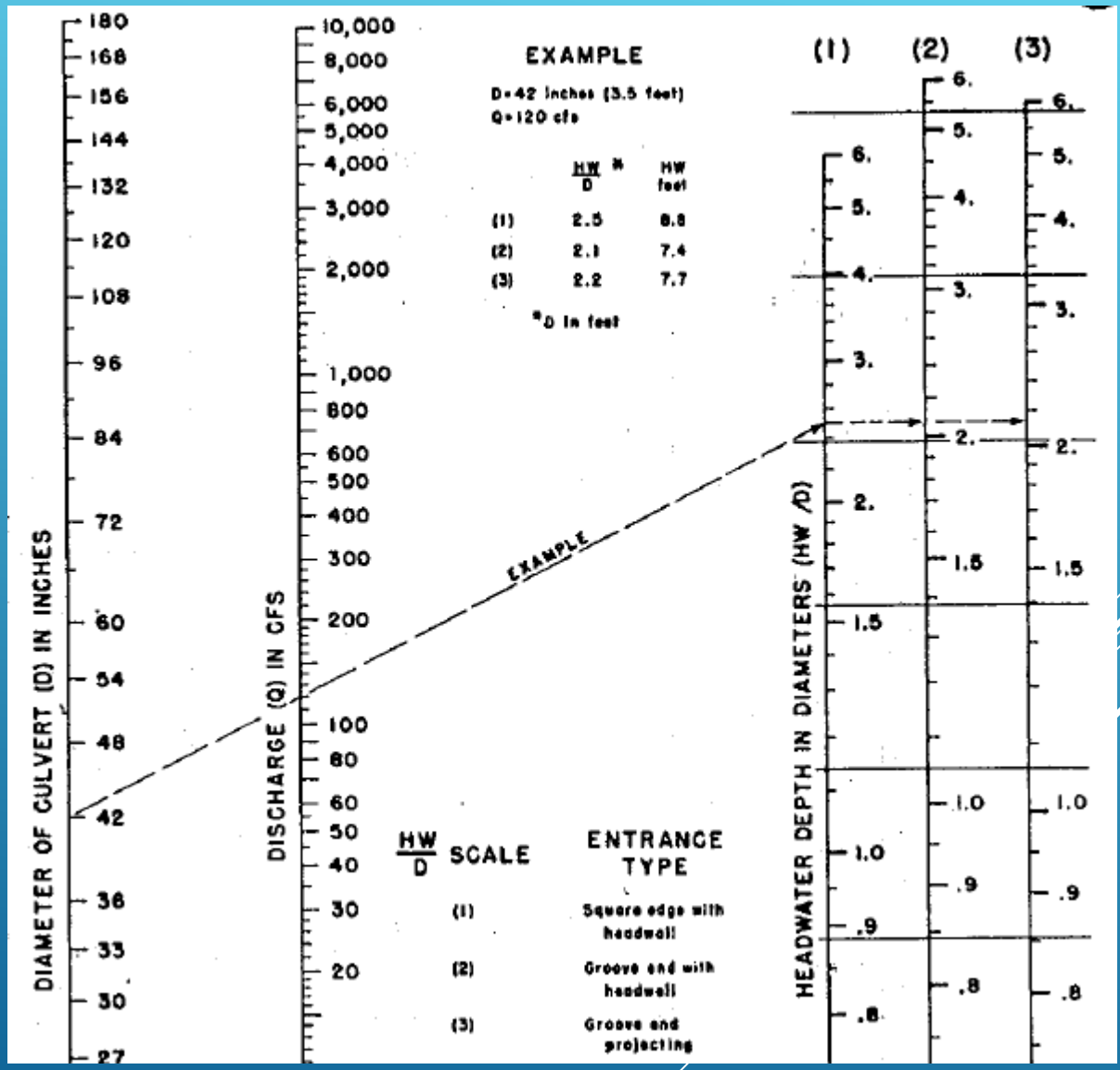
Inlet Control Sheet

Diameter = 42” (3.5 ft)

Q=120 cfs

L=50 ft

Inlet submerged



INLET CONTROL RESULTS

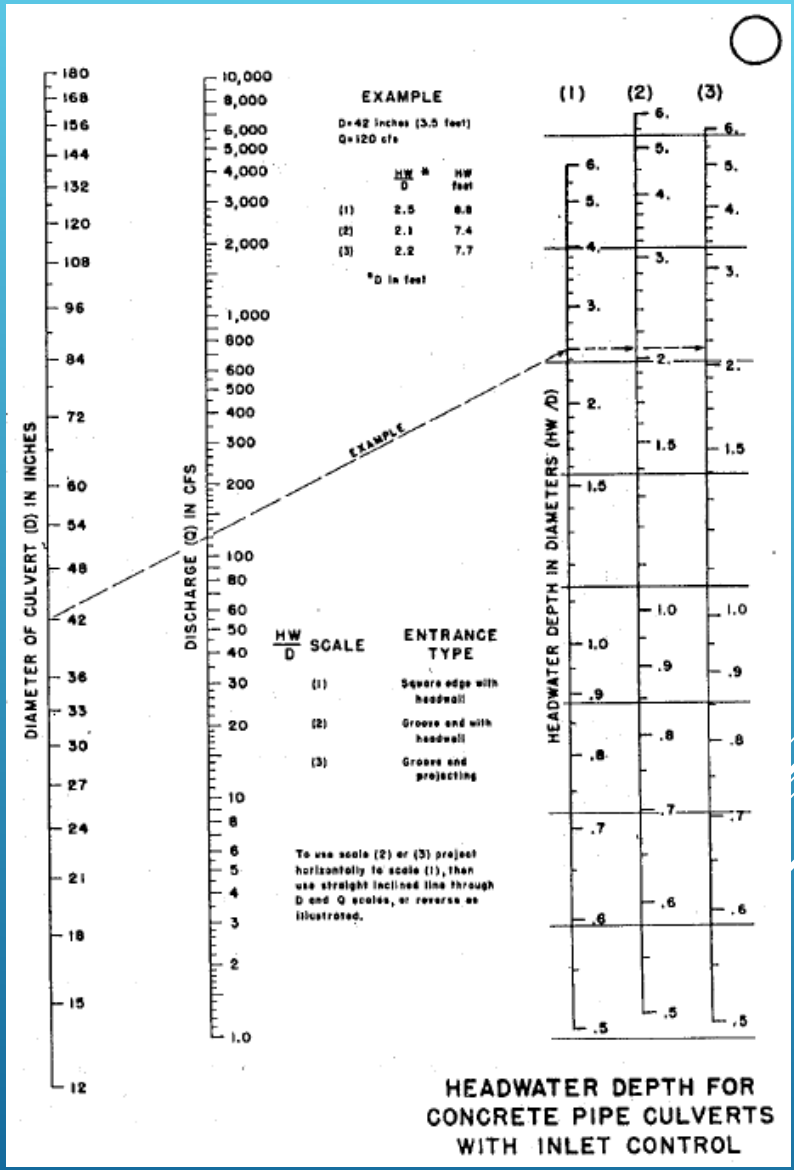
Culvert Diameter , D = 42” (3.5 feet)

Q=120 cfs

HW = (HW/D) x D (ft)

1. Square edge with headwall
   - HW/D = 2.5

     = 2.5 x 3.5 ft
   - HW = 8.8 ft



EXAMPLE CALCULATION

Outlet Control Sheet

Diameter = 42” (3.5 ft)

Q=120 cfs

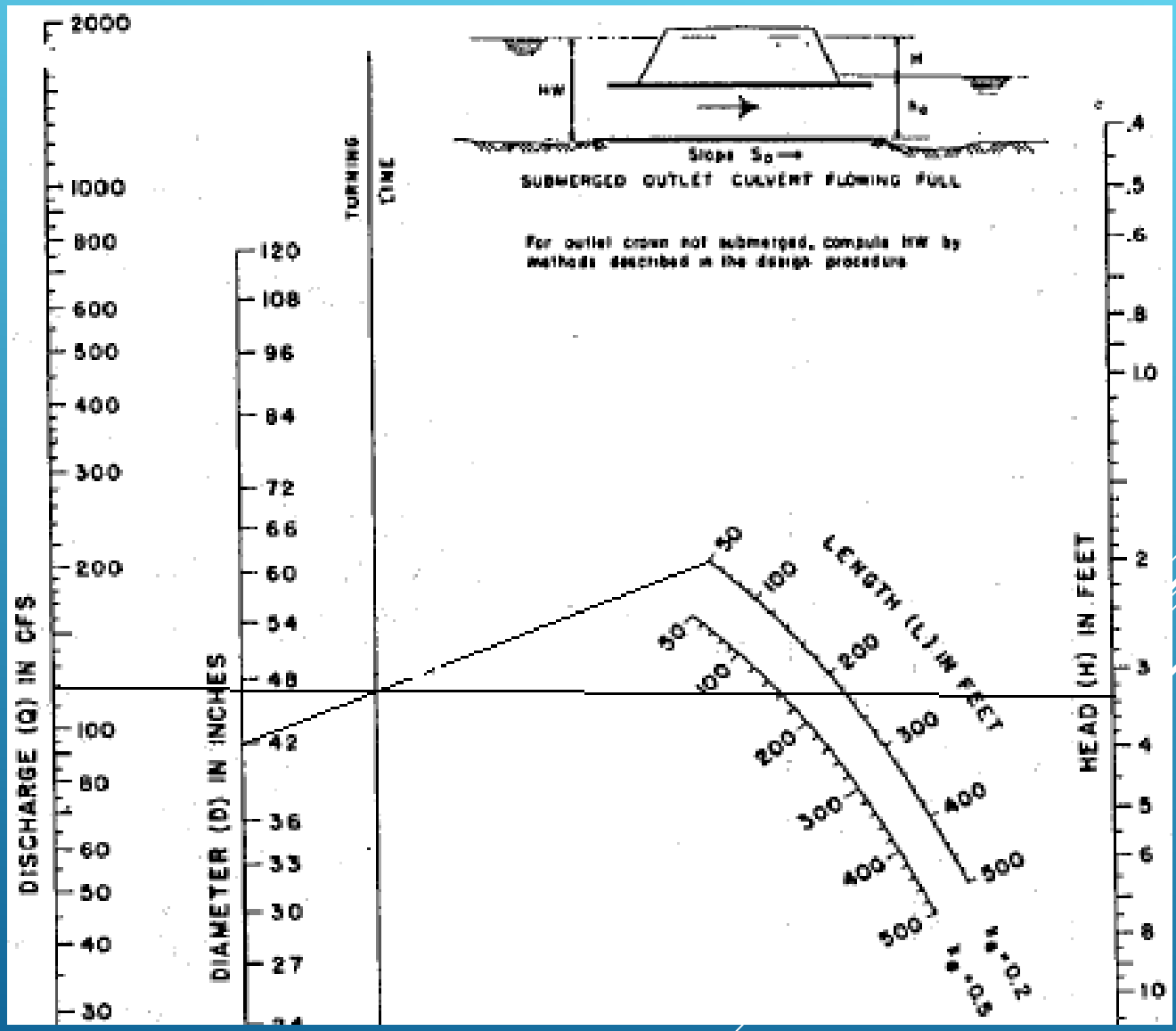
L = 50 ft

TW = 4.3 ft

From chart, H = 3.3’

HW = TW + 3.3’

HW = 4.3’ + 3.3’ = 7.6’



INLET CONTROL VS. OUTLET CONTROL RESULTS

Culvert Diameter , D = 42” (3.5 feet)

Q=120 cfs

L = 50 feet

TW = 4.3 feet

INLET CONTROL

HW = (HW/D) x D (ft)

1. Square edge with headwall
    - HW = 8.8’ ft

OUTLET CONTROL

HW = 7.6 ft

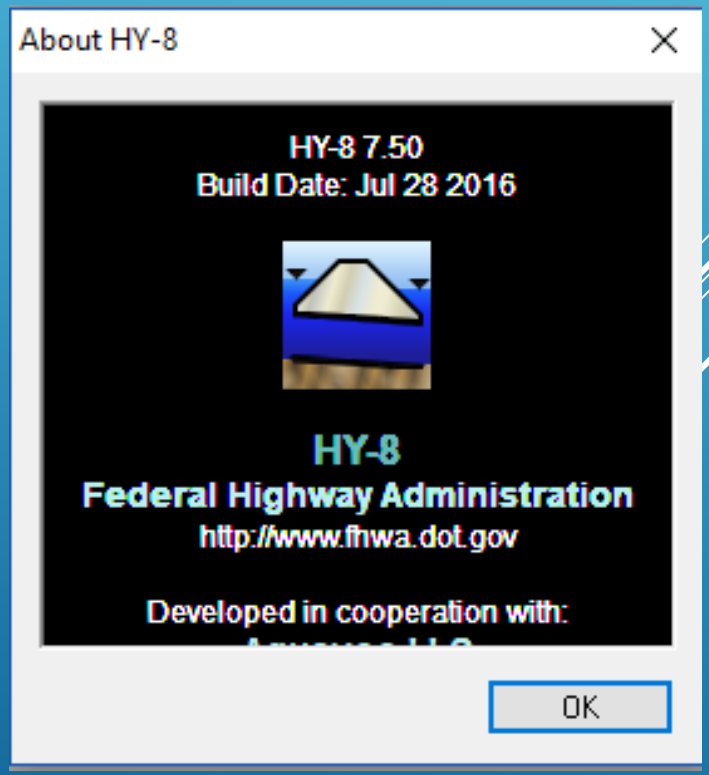
CONCLUSION: 8.8 ft > 7.6 ft

inlet controlled, use

inlet control answer

HY-8

- Federal Highway Administration culvert analysis program
- Yields headwater rating curve (elevation, Q relationship)
- Parameters:
  - Enter design Q
  - Culvert length
  - Culvert shape and roughness
  - Entrance type
  - Overtop elevation (road profile)
  - Additional inputs:
    - Tailwater rating curve



HY-8 EXAMPLE PROBLEM #1

Use HY-8 to determine the size of a culvert required for a proposed road crossing. The local ordinance specifies that culverts be sized to pass the 100-year peak flowrate and also provide two feet of freeboard.

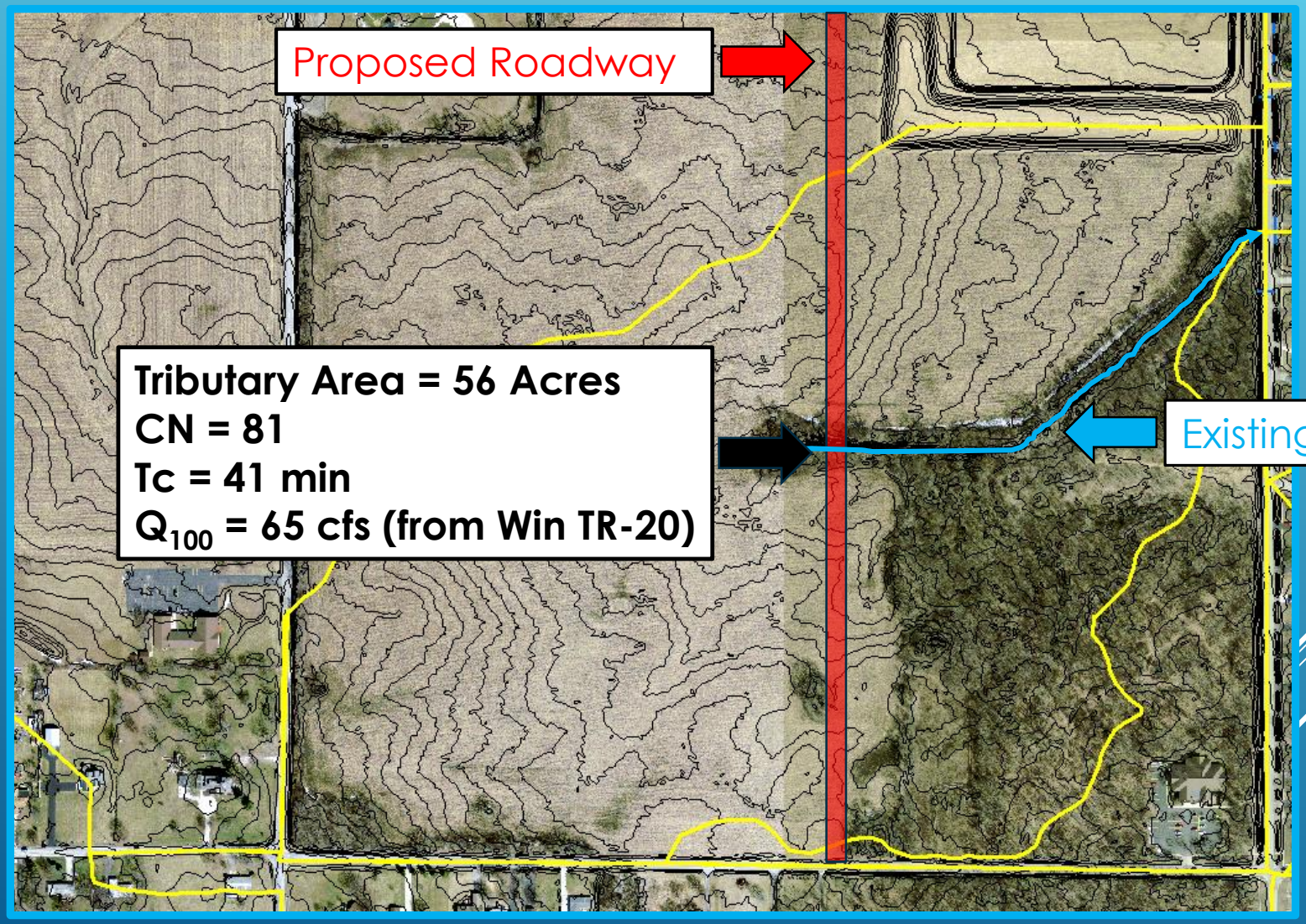
The design information for this site is summarized by the following:

- HYDROLOGY
  - 100-Year Peak Flowrate is 65 cfs (Based on WinTR-20 Hydrologic Model of Tributary Area)
- SITE DATA
  - Upstream invert elevation = 661.15 ft.
  - Downstream invert elevation = 659.00 ft.
  - Culvert length = 120 ft.
  - Culvert will project from headwall
  - No depression at conventional-type inlet

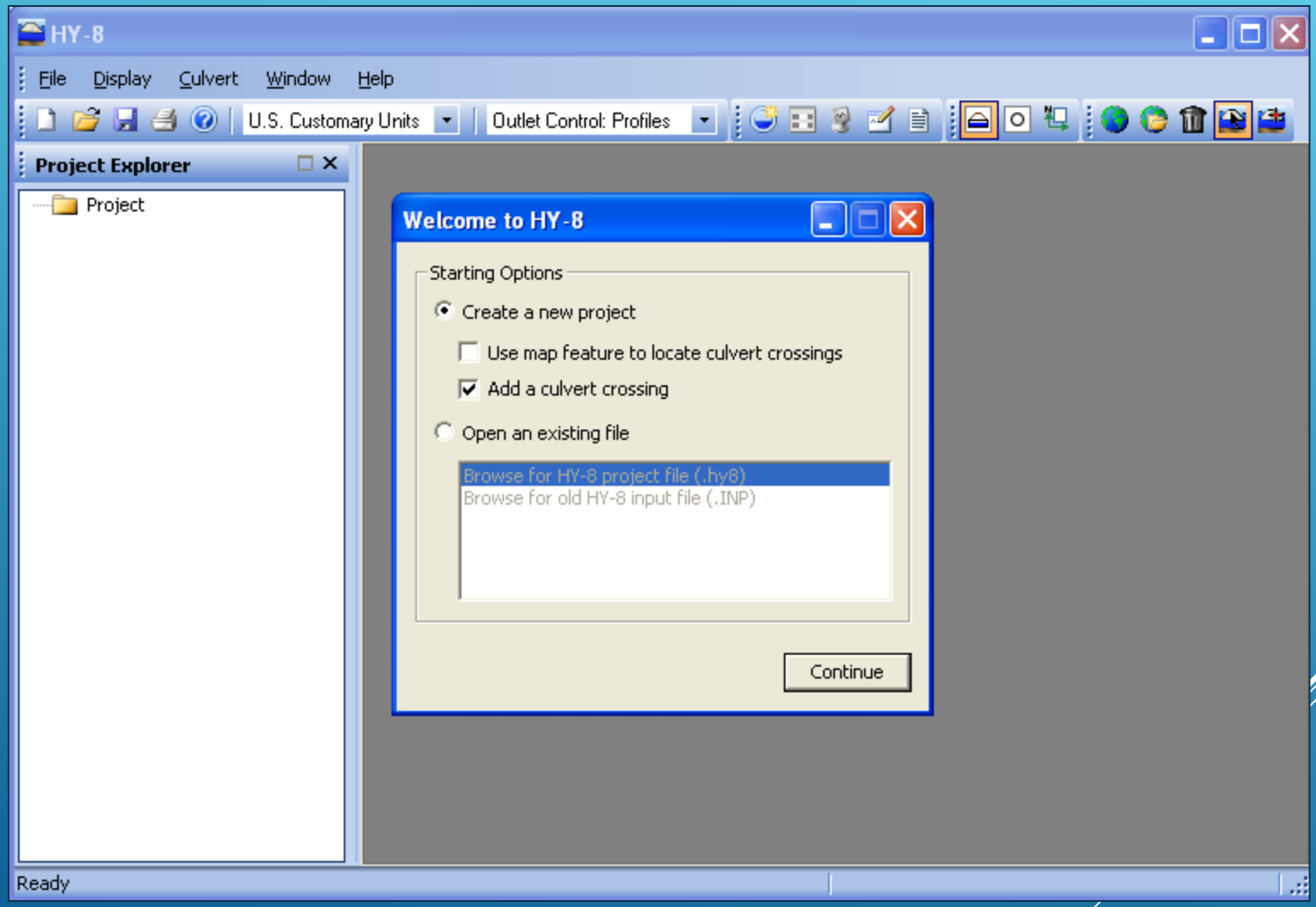
HY-8 EXAMPLE PROBLEM #1 (CONTINUED)

- WATERWAY DATA
  - Input existing channel information to model tailwater conditions acting on the culvert.
- ROADWAY DATA
  - Roadway overtopping elevation is 667.0 (Determined from proposed roadway profile).
  - Proposed roadway is 80 feet wide.

HY-8 EXAMPLE PROBLEM #1
(CONTINUED)

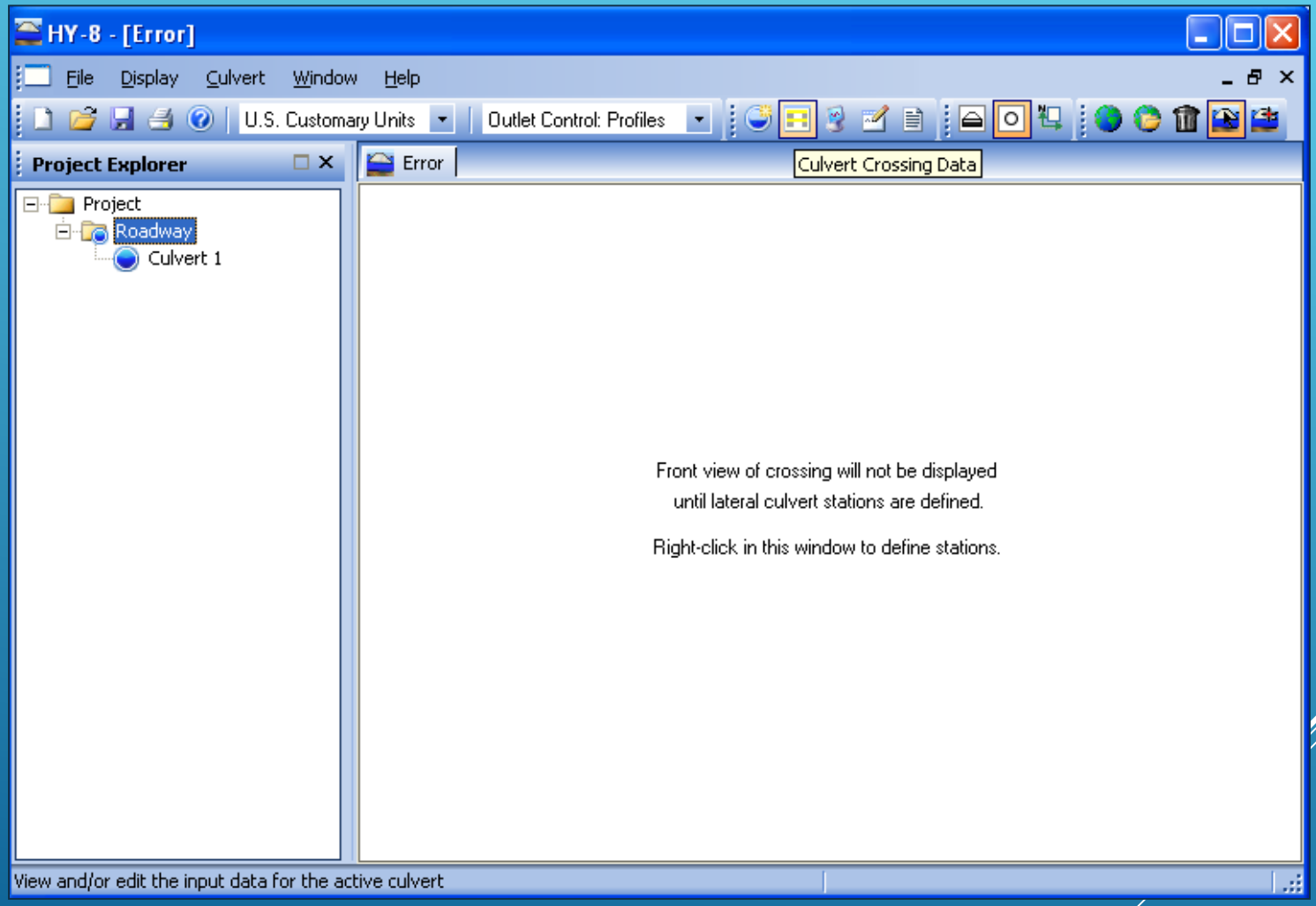


HY-8: CREATING A NEW PROJECT



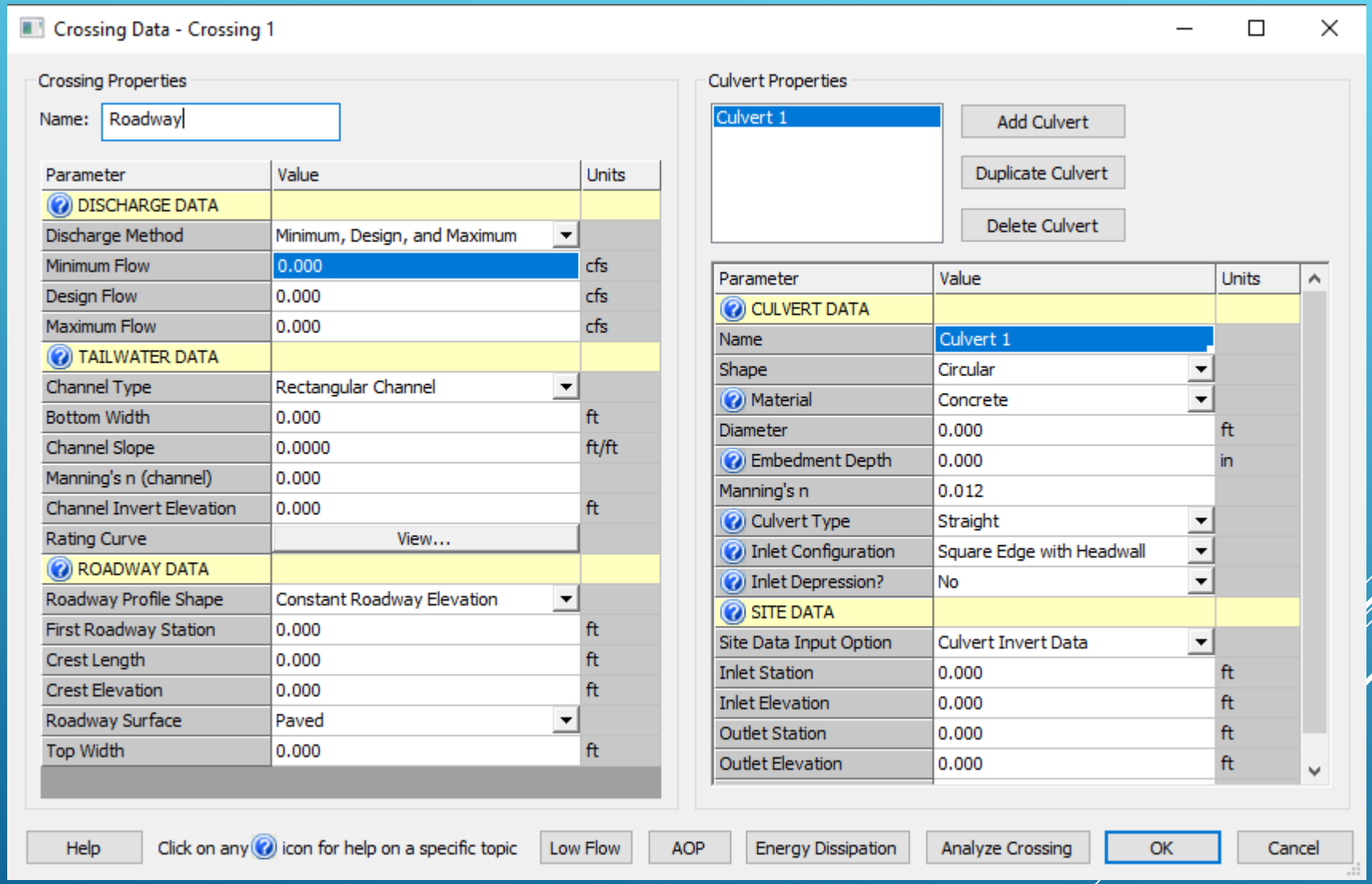
HY-8 Introduction Screen

HY-8: INPUT OF ROADWAY/CULVERT DATA



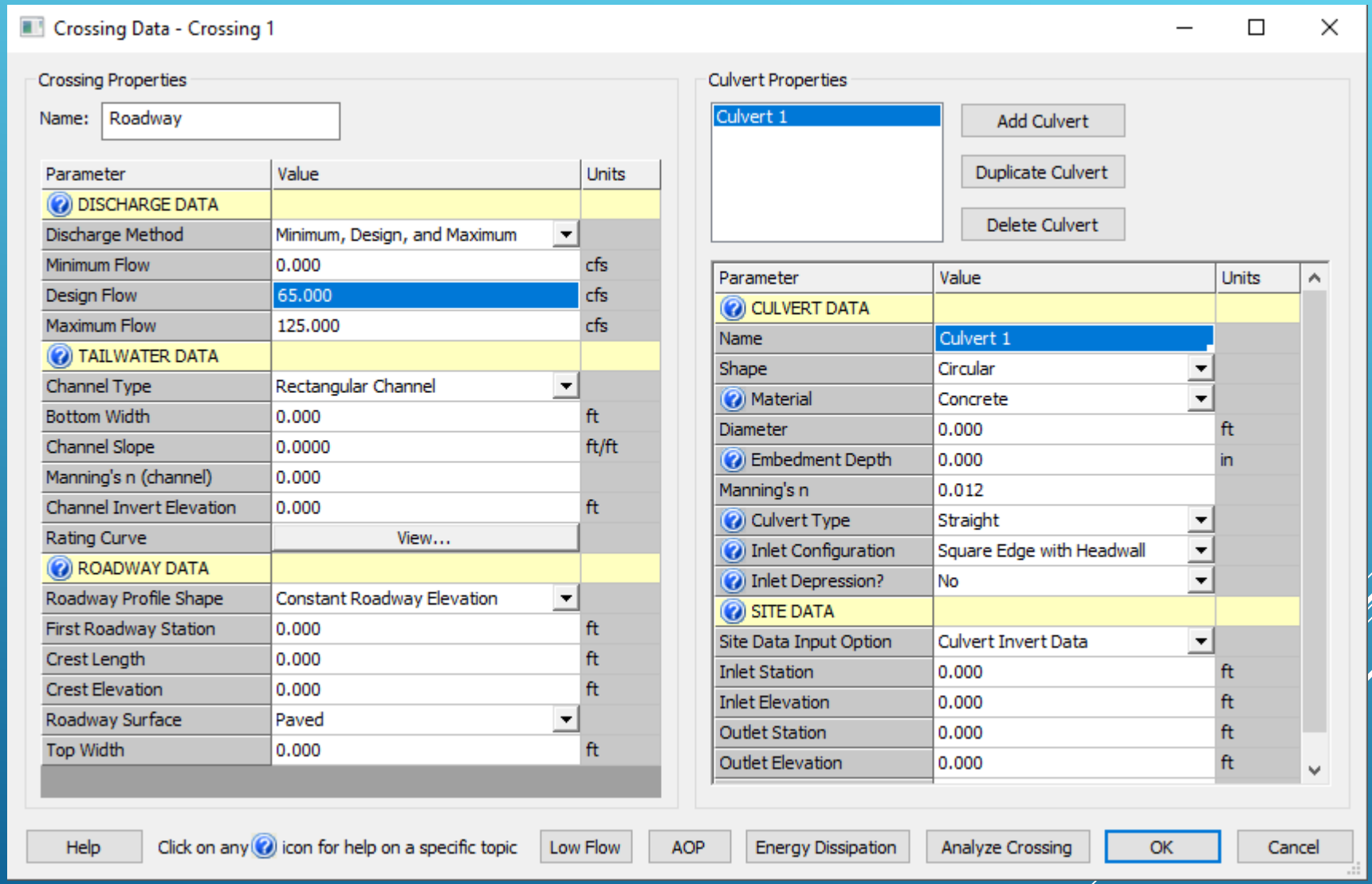
Use the “Culvert Crossing Data” icon to enter the roadway/culvert information.

HY-8: INPUT OF CULVERT DATA



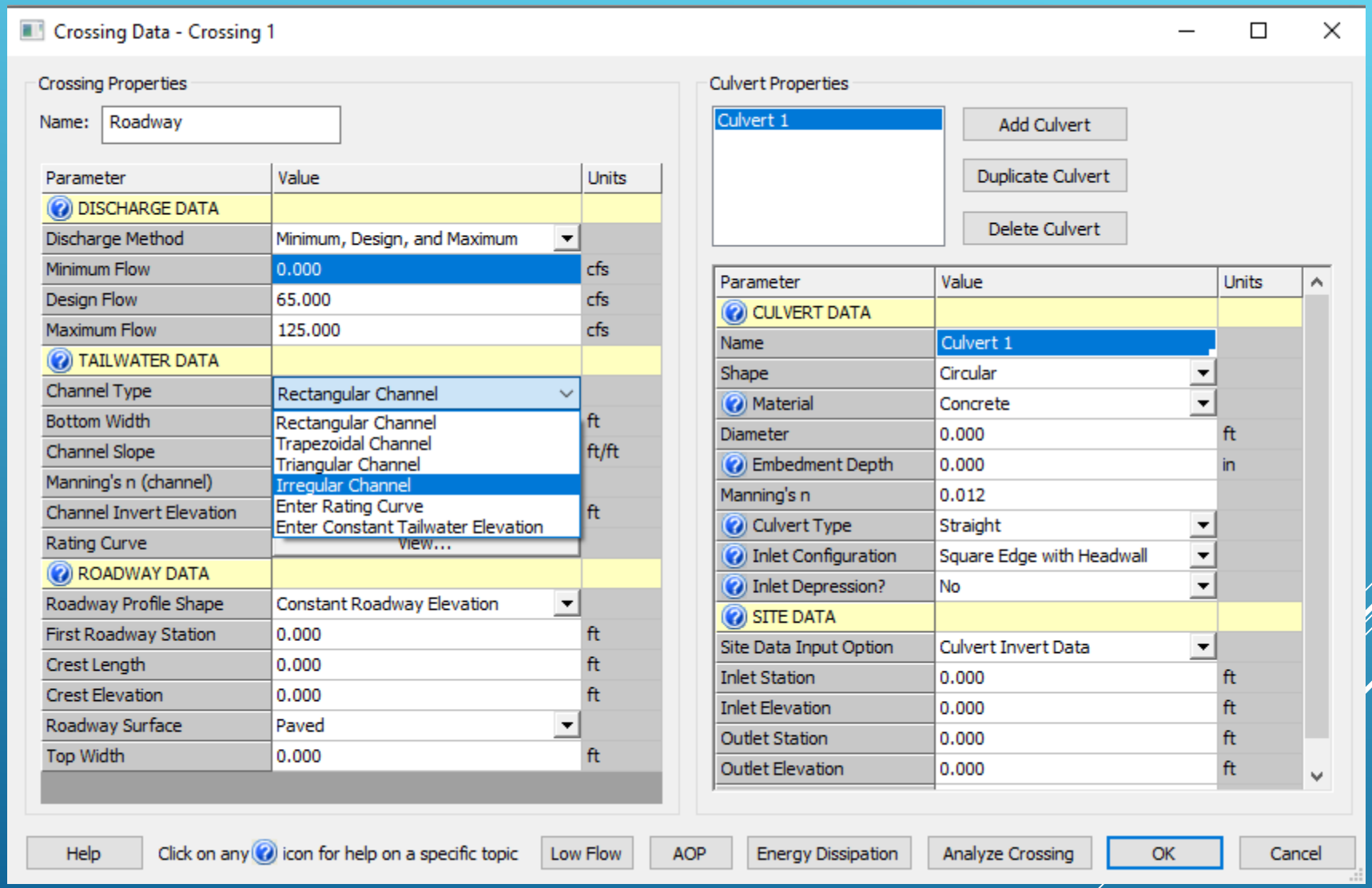
HY-8 Crossing Data Screen

HY-8: INPUT OF DISCHARGE DATA



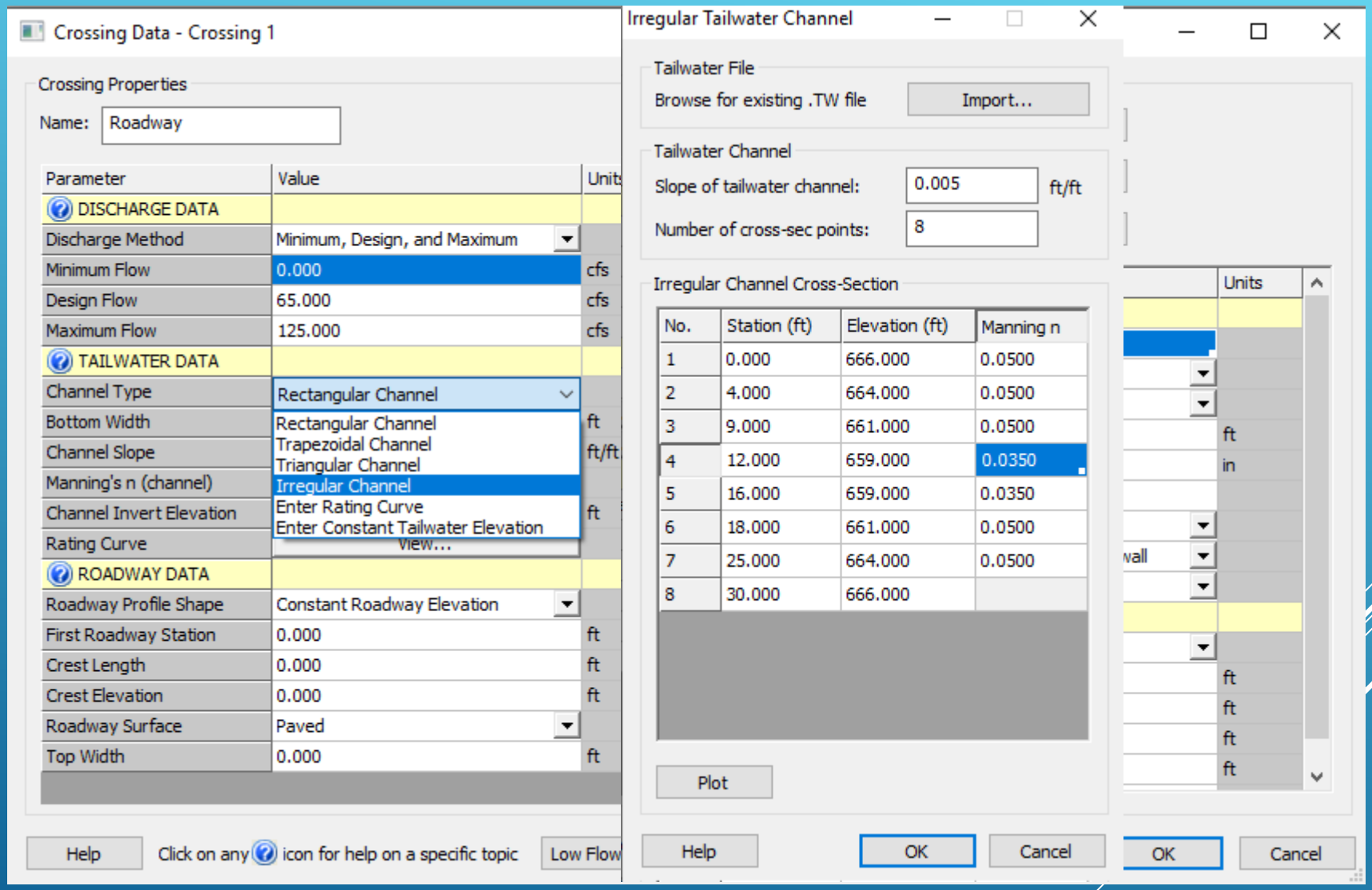
Input of Discharge Data – Enter the design and maximum flow.

HY-8: INPUT OF TAILWATER DATA



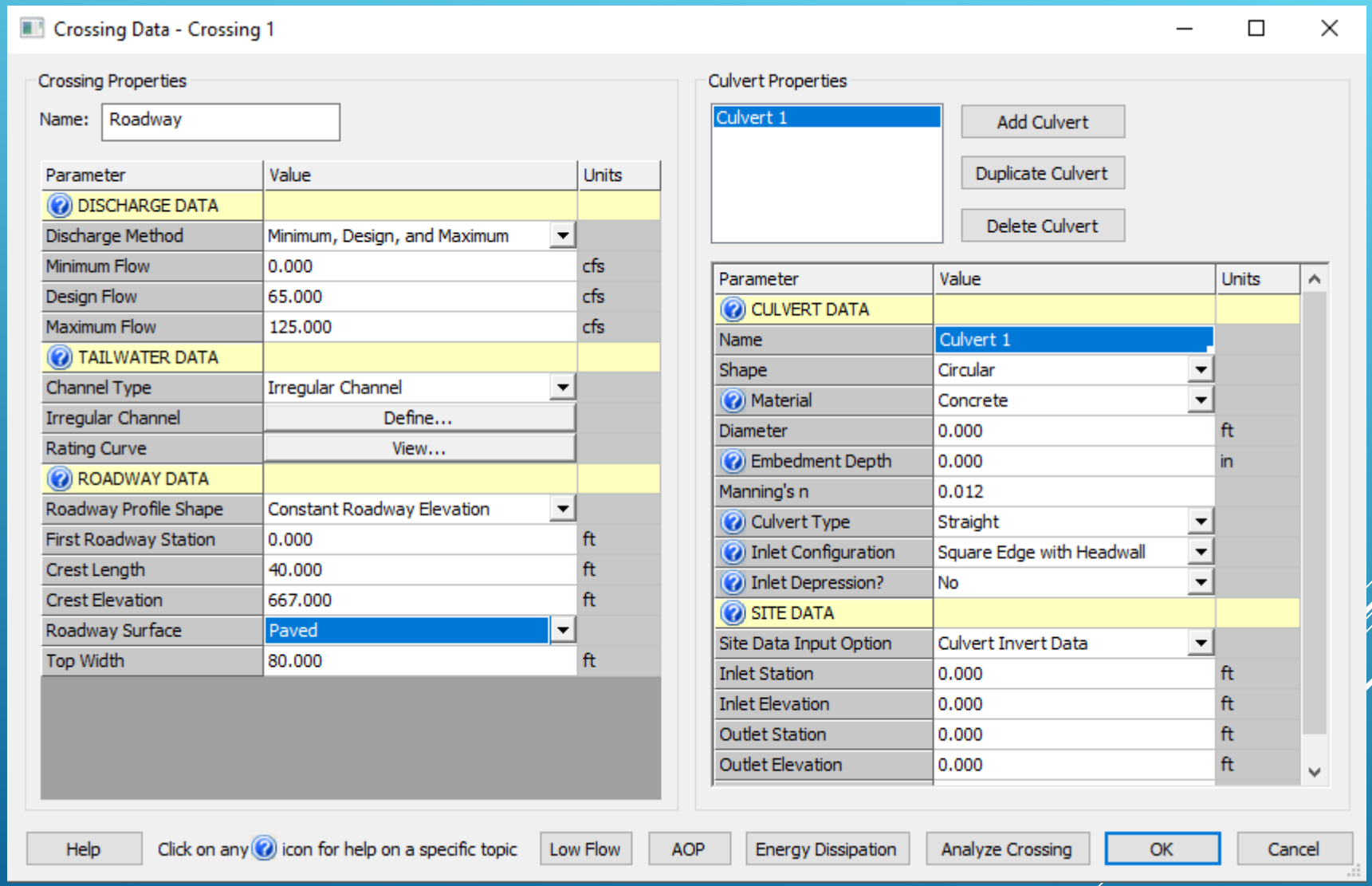
Input of Tailwater Data – Note that we will input site-specific channel Information to model tailwater conditions for this example.

HY-8: INPUT OF TAILWATER DATA



Input of Tailwater Data – Channel Geometry Based on Topography

HY-8: INPUT OF ROADWAY DATA



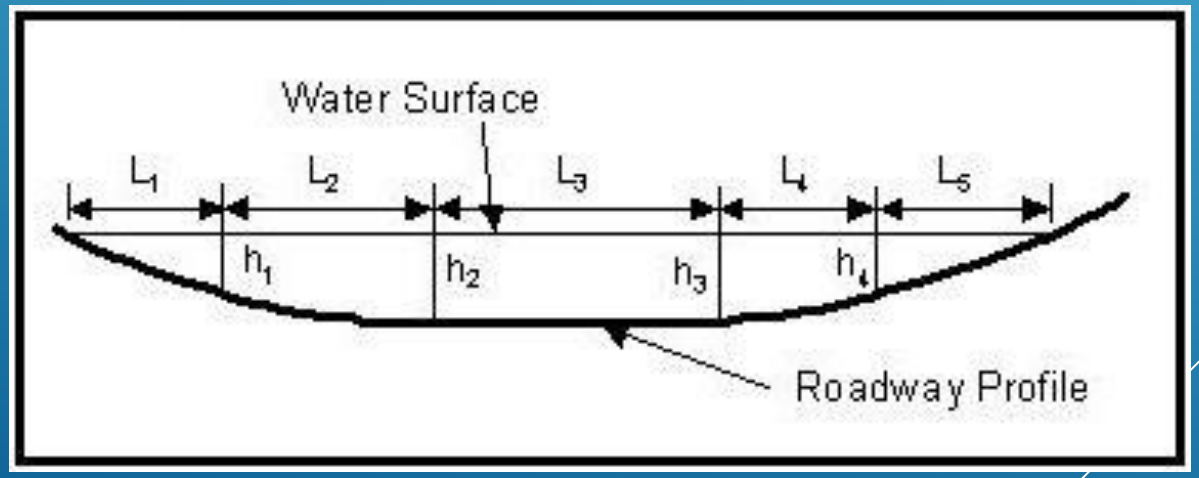
Input of Roadway Data – Overtopping elevation, crest length, width of roadway, and type of surface.

HY-8: INPUT OF ROADWAY DATA

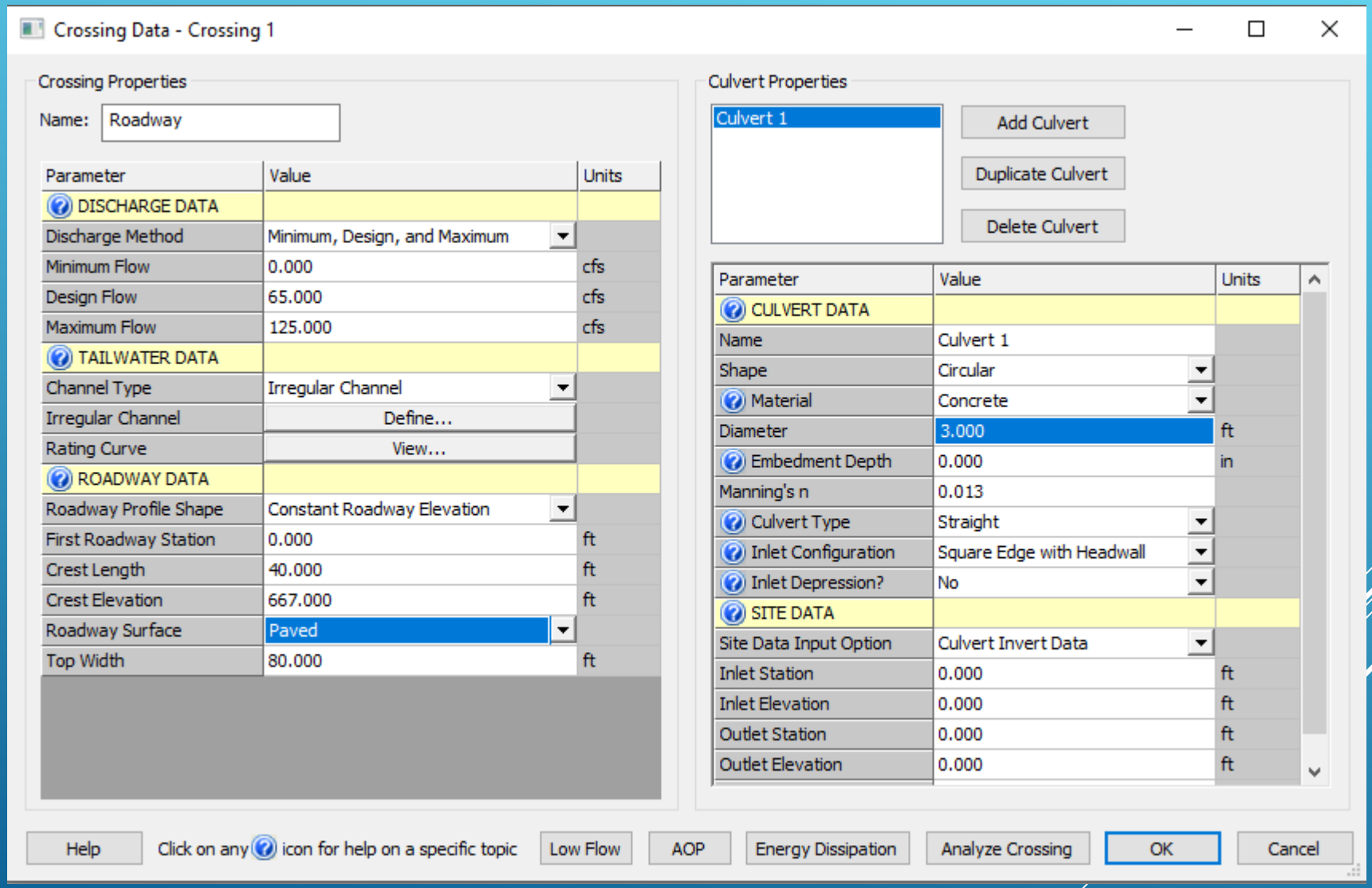
HY-8 uses the weir equation to calculate flow over a roadway.

When the user specifies a constant roadway elevation with a specified crest length (L), HY-8 will calculate the flow using the rectangular weir equation ($Q = C_d*L*H^{3/2}$). If input discharge coefficient is selected, the user will enter a discharge coefficient between 2.5 and 3.095.

For a user-defined (irregular) roadway, HY-8 calculates a weighted average of the *L* and *H* terms in the weir equation:

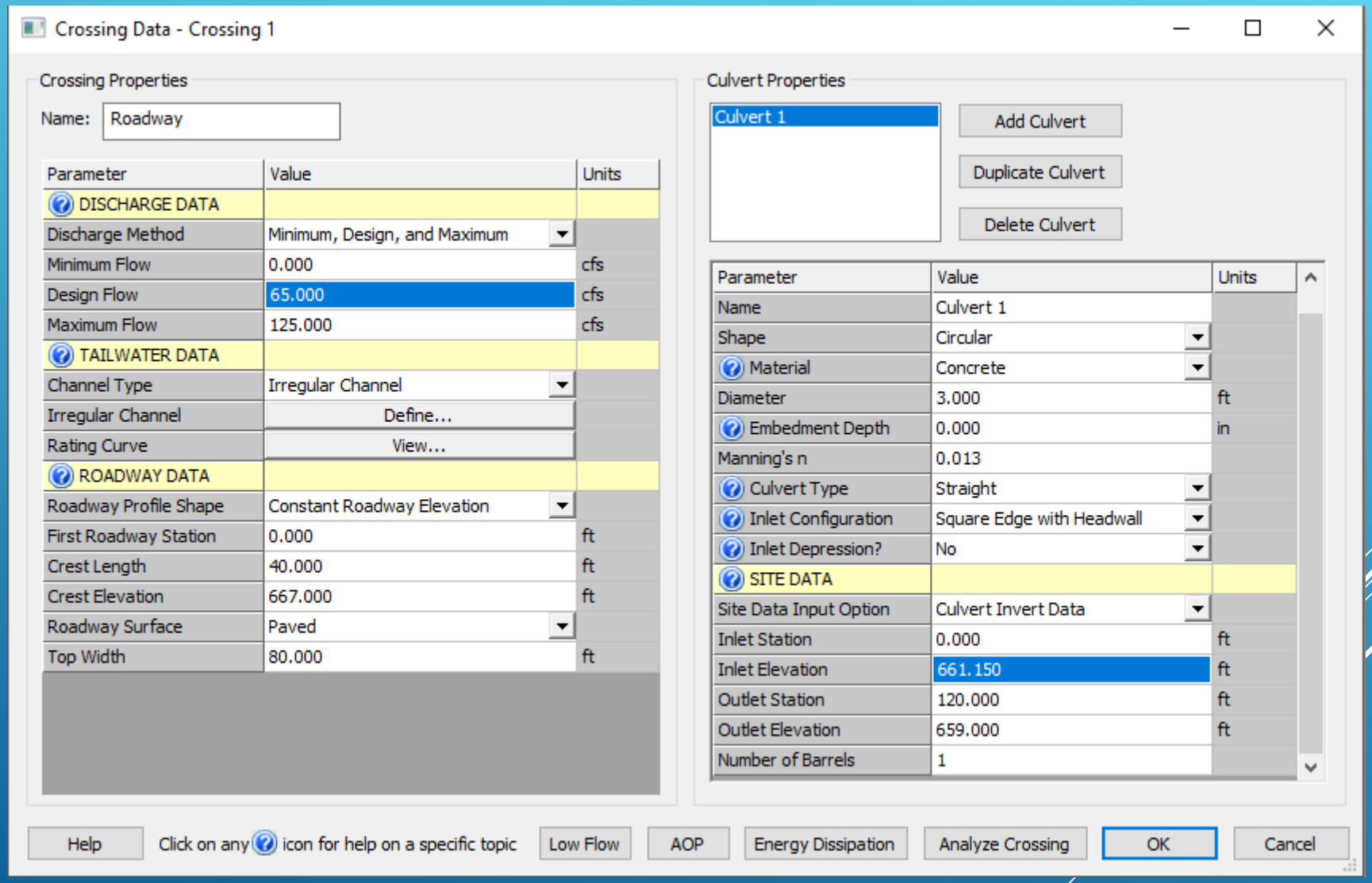


HY-8: INPUT OF CULVERT DATA



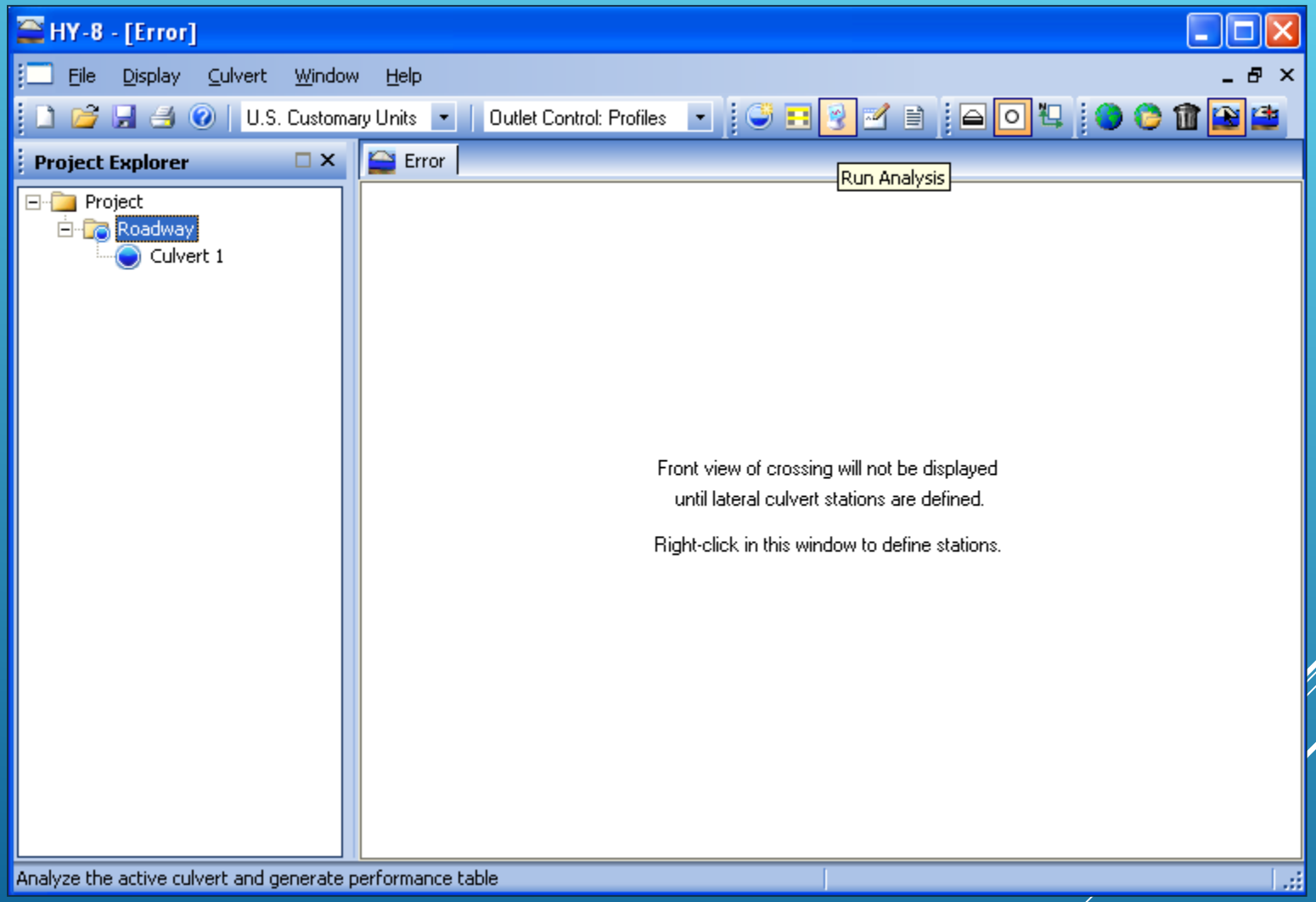
Input of Culvert Data – Note that a 36-inch (3-foot) diameter culvert was used.

HY-8: INPUT OF SITE DATA



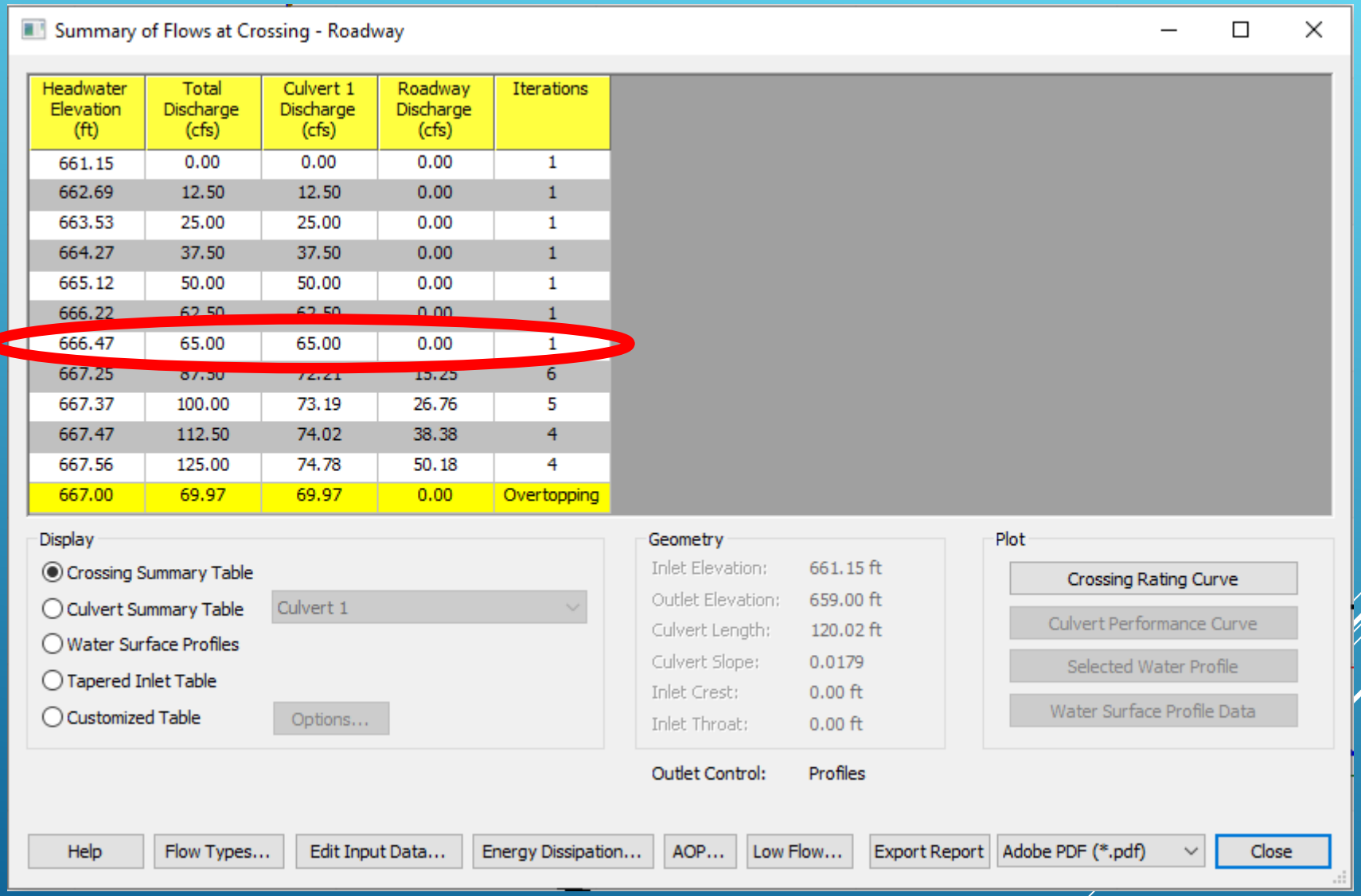
Input of Site Data – Culvert length, inverts, and number of barrels.

HY-8: RUNNING THE CULVERT ANALYSIS



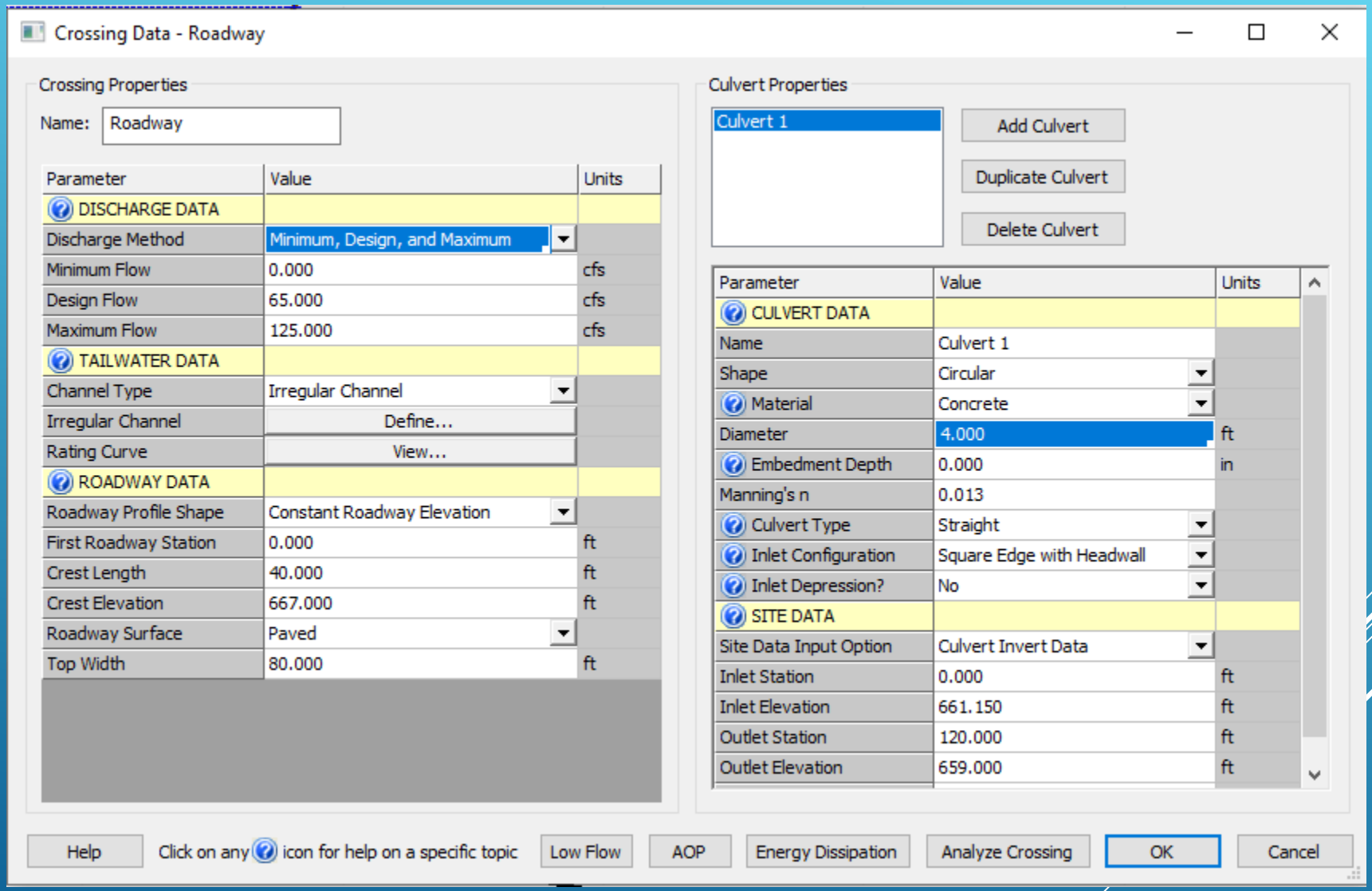
The “Run Analysis” icon on the toolbar performs the culvert analysis.

HY-8: VIEWING THE OUTPUT



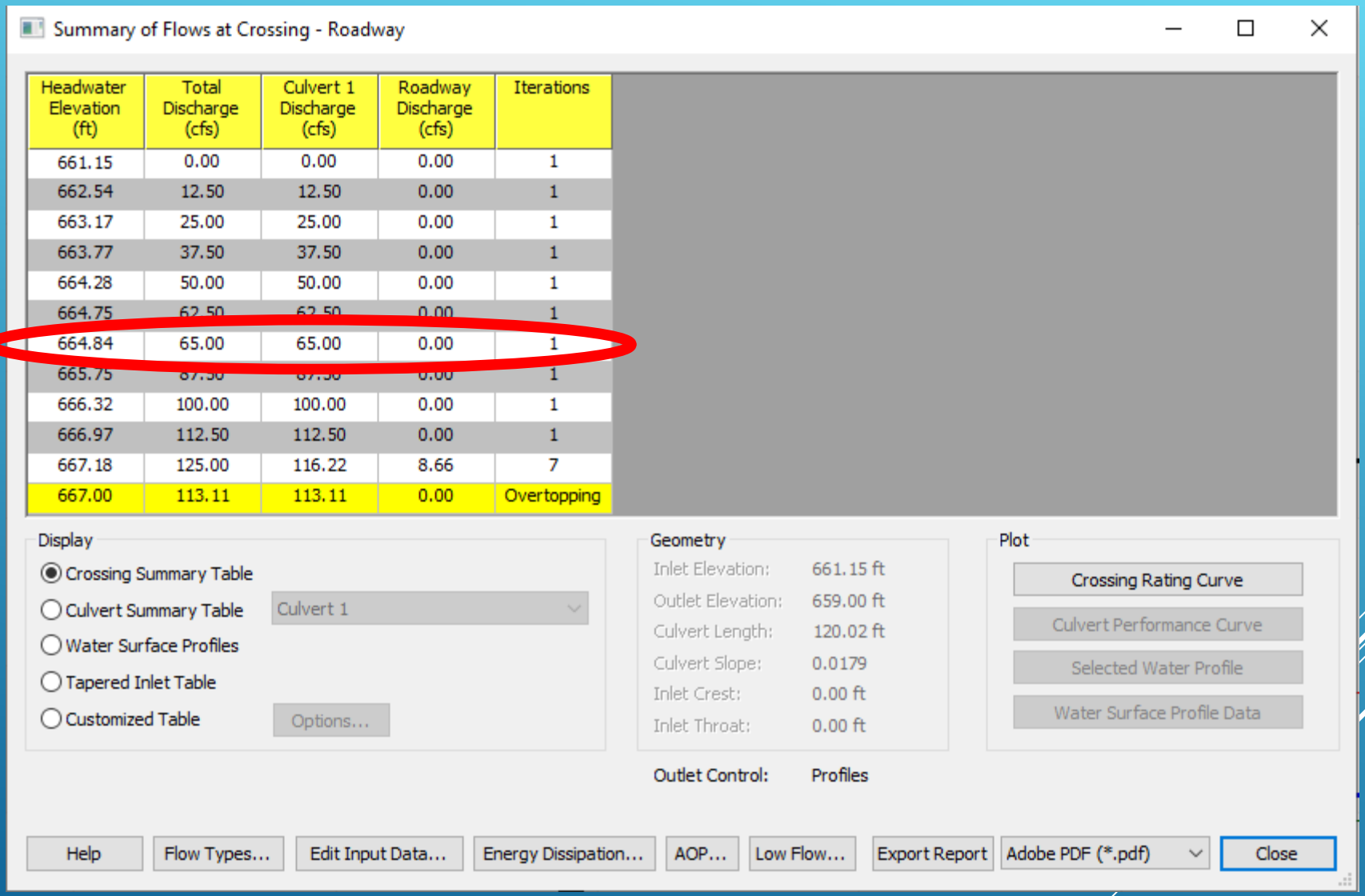
Output for Example #1 – Does the proposed culvert meet the design requirements?

HY-8: VIEWING THE OUTPUT



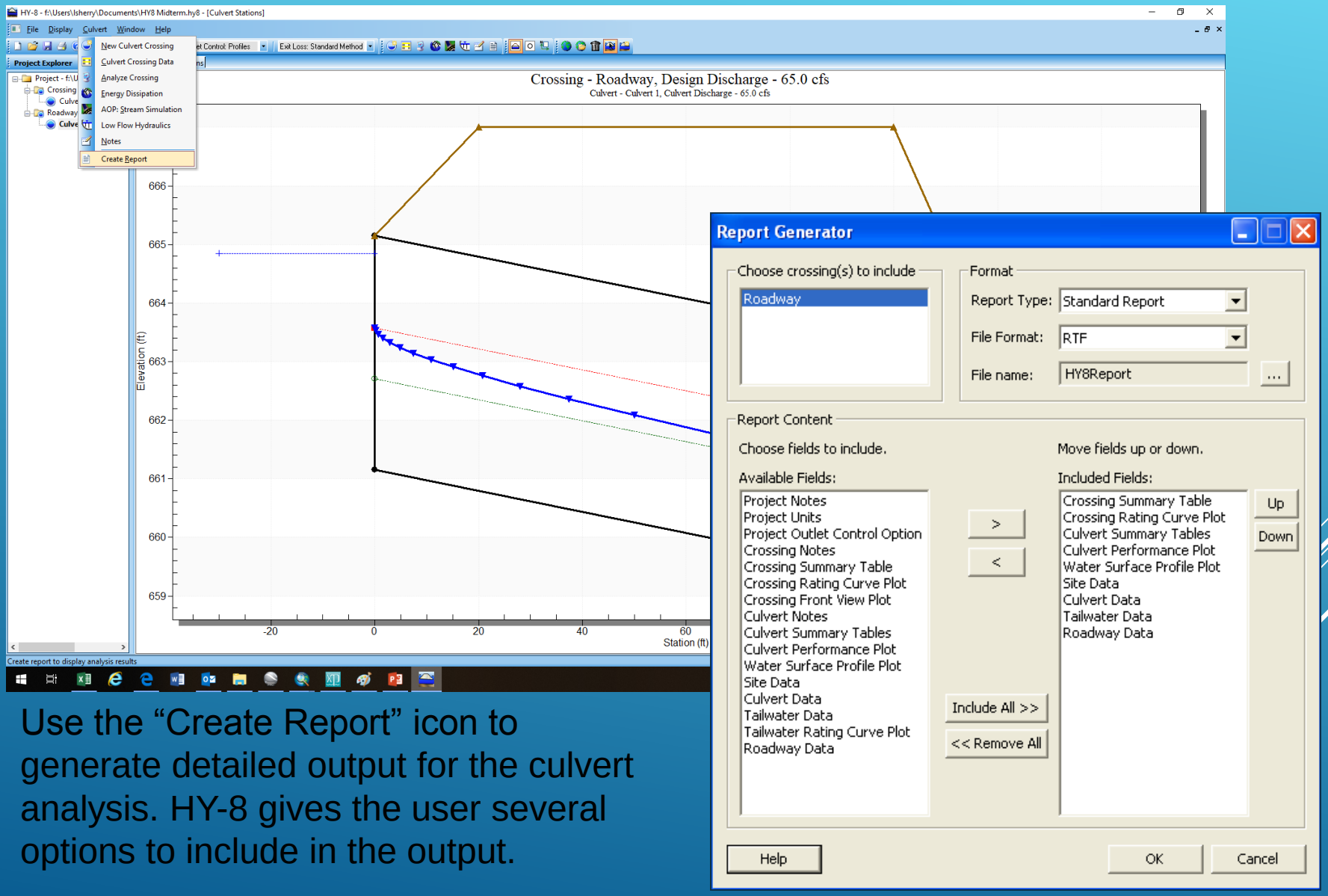
Upsizing the culvert is an option to meet requirements.

HY-8: VIEWING THE OUTPUT



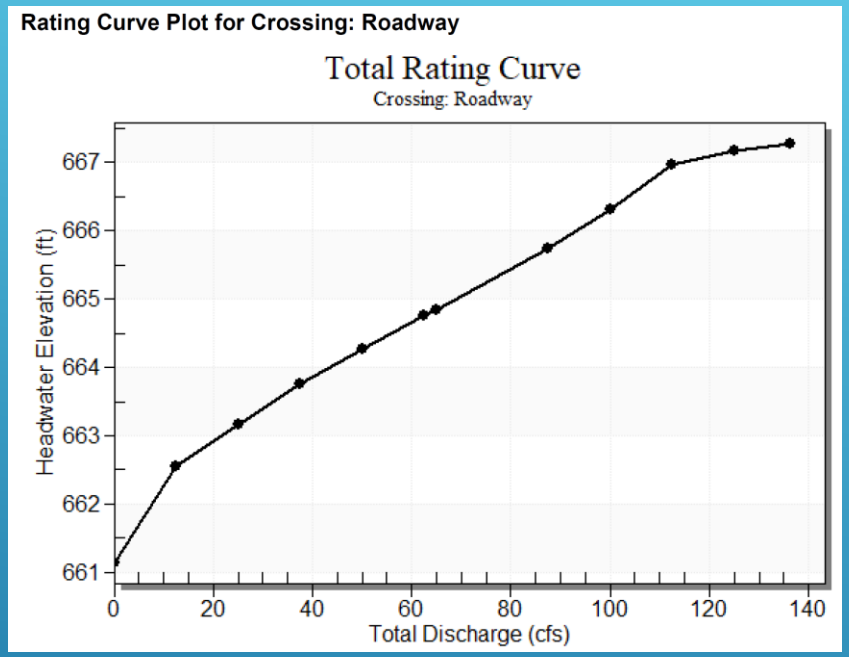
Output for Example #1 – Note that the headwater elevation at the design flowrate (664.84 ft) is 2.16 feet below the roadway overtopping (667.0 ft).

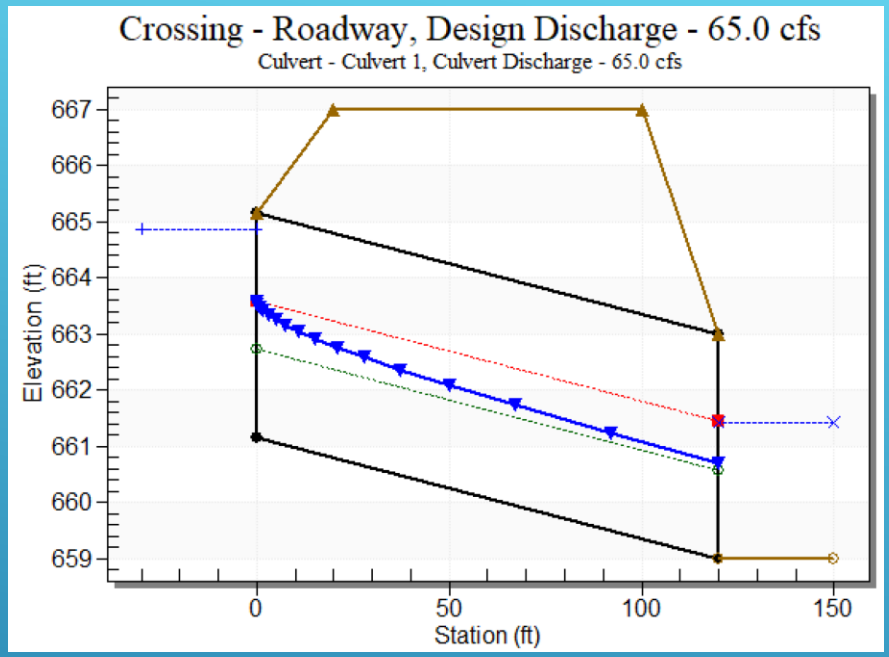
HY-8: CREATING A REPORT



Use the “Create Report” icon to generate detailed output for the culvert analysis. HY-8 gives the user several options to include in the output.

HY-8: VIEWING THE REPORT





Headwater Elevation (ft)	Total Discharge (cfs)	Culvert 1 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
661.15	0.00	0.00	0.00	1
662.54	12.50	12.50	0.00	1
663.17	25.00	25.00	0.00	1
663.77	37.50	37.50	0.00	1
664.28	50.00	50.00	0.00	1
664.75	62.50	62.50	0.00	1
664.84	65.00	65.00	0.00	1
665.75	87.50	87.50	0.00	1
666.32	100.00	100.00	0.00	1
666.97	112.50	112.50	0.00	1
667.18	125.00	116.22	8.66	7
667.00	113.11	113.11	0.00	Overtopping

CULVERT DESIGN

- Criteria to keep in mind:
  - Return Period
    - Interstate –100-year
    - Primary – 25-year
    - Secondary – 10-year
    - While design criteria may be a 10-year return period, keep in mind potential impacts to adjacent or upstream structures that may warrant an increase to the system capacity
  - Minimum cleaning velocity: 3 ft/sec
  - Minimum freeboard requirements

Functional Classification	Allowable Backwater	Roadway Serviceability	Allowable Velocity
Freeway	Q_{100}	Q_{100}	Q_{50}
Non-Freeway ≥ 4 Lanes	Q_{100}	Q_{100}	Q_{50}
Two-Lane Facility			
AADT ≥ 3000	Q_{100}	Q_{100}	Q_{50}
3000 > AADT ≥ 1000	Q_{100}	Q_{25}	Q_{25}
AADT < 1000	Q_{100}	Q_{10}	Q_{10}
Drive	Q_{100}	Q_{10}	Q_{10}

Note: The design-storm frequency for a culvert-extension structure is identical to that for a new culvert structure. Traffic volume is for a 20-year projection.

DESIGN-STORM FREQUENCY, CULVERT

Source: InDOT Design Manual

CULVERT SHAPE SELECTION

- Criteria to keep in mind:
  - Minimum pipe size
  - Site / location restrictions – what fits? What about installation?
  - County / community ordinance guidelines
  - Cost

Structure Application	Minimum Circular-Pipe Size	Minimum Deformed-Pipe Area
Drive	15 in.	1.1 ft^2
Mainline or Public-Road Approach (2 lanes)	15 in.	1.1 ft^2
Mainline or Public-Road Approach (≥ 3 Lanes)	36 in.	6.7 ft^2

MINIMUM PIPE-CULVERT SIZE

Source: InDOT Design Manual

CULVERT MATERIAL SELECTION

- General criteria:
  - Loading / cover over the pipe
    - Minimum cover is typically 2 feet; however, check applicable regulations
    - Boone County, IN requires 3 feet for culverts within ROW
  - Purpose
    - Drain tile versus highway crossing
  - County / community ordinance guidelines
    - Are plastic pipes allowed?
    - Is concrete required?
  - Cost

INSTALLATION

- Plan and specifications signed by a Licensed PE
- Permits
- Best Management Practices (BMPs)
- Inlet and outlet protection
- Bedding materials
- Backfill
- Inspection

REFERENCES

- LTAP Stormwater Drainage Manual
- InDOT Design Manual
- HY-8 Users Manual (FHWA)

QUESTIONS