STRUCTURE HYDRAULIC ANALYSIS

S.R. 18 over Bourne-Williams Ditch
Des. No. 1401835

KURT J. HEIDENREICH
REGISTERED
No.
300129
STATE OF
INDIANA
PROFESSIONAL ENGINEER

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September 12, 2016

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Introduction

The project involves replacing the small structure on SR 18 over Bourne-Williams Ditch, 3.49 miles east of SR 1 in Jay County. The existing structure has deteriorated and needs to be replaced to perpetuate vehicular crossing at the location. This study documents the hydrologic and hydraulic analysis used to determine the replacement structure waterway opening and establish hydraulic design parameters.

Project Overview

The existing structure is a 44 ft long reinforced concrete slab top culvert with wingwalls. The span is 16 ft and the rise is approximately 7.7 ft. The structure is not on a skew. An asphalt roadway is paved over the structure and the cover is approximately 5.5 ft. The proposed structure will be a 44 ft long reinforced concrete box with a 16 ft span and 10 ft rise with a 1 ft sump. The road profile will be the same as the existing condition and the low structure elevation will be increased by approximately 1.3 ft.

A topographical survey completed for the project was used to obtain site data and create the layout sheet. All elevations reference NAVD 88 datum.

Permit Requirements

An Indiana Department of Natural Resources (IDNR) "Construction in a Floodway" permit will not be required for this project since it is in a rural location with a drainage area of less than 50 square miles and meets the other requirements of the structure replacement exemption. Therefore, the proposed structure will only be subject to the INDOT backwater requirements.

A US Army Corps of Engineers 404 Permit and Indiana Department of Environmental Management 401 Water Quality Certification will be required for the work since it will take place below the ordinary high water mark.

Information from County Surveyor

According to the Jay County Surveyor, Brad Daniels, the drain is regulated. However, there are no permit requirements by the surveyor's office for replacing the structure. In addition, there are no plans for dredging and no known drainage problems caused by the structure.

Hydrologic Analysis

Based on the traffic data provided in the Engineer's Report, the design year AADT for the project is 1,510 vehicles per day. Indiana Design Manual (IDM) Figure 203-2C gives design frequencies for culverts and bridges. For culverts on two lane facilities with an AADT between 1,000 and 3,000 vehicles per day, the 1% Annual Event Probability (EP) is applicable for allowable backwater and the 4% EP is applicable for roadway serviceability and allowable velocity.

A Floodplain Analysis and Regulatory Assessment (FARA) was completed by the IDNR Division of Water for this project. The recommended Q_{100} discharge is 370 cfs and the drainage area is 1.29 square miles. The Q_{25} was estimated by taking 75% of the Q_{100} which results in a discharge of 280 cfs.

Hydraulic Analysis

The hydraulic analysis was completed using HY-8 version 7.30. The analysis included the existing structure, proposed R.C. box structure, and alternate 3-sided arch-top structure.

Flowline

The inlet and outlet flowline elevations were set at 841.0 and 840.8 based on the survey data obtained for the project.

Tailwater Depth

For all calculations, the tailwater was set using the normal depth method. This was based on a surveyed cross section located downstream of the existing structure. The location of the cross section is indicated on the Layout sheet included with this submission. The downstream channel slope of 0.0036 ft/ft was obtained from the USGS Map. Due to the presence of brush, a Manning's n of 0.08 was selected for the channel with 0.1 used for the overbanks.

Existing Structure

The existing structure was modeled as a 44 ft long concrete box with an 16 ft span and 8.7 ft rise (7.7 ft opening + 1 ft sump). The embedment depth was set at 12 in. The invert and roadway data was obtained from the topographical survey for the project. The Manning's n value for the top/sides was set at 0.012 and the bottom was set at 0.035. The inlet configuration was set as "Square Edge with Headwall", resulting in an entrance-loss coefficient of 0.5.

Proposed Box Structure

The proposed box structure was modeled using the same tailwater and roadway data as the existing structure. The culvert is 44 ft long with a 16 ft span and an 10 ft rise (9 ft opening + 1 ft sump). The embedment depth was set at 12 in. The Manning's n value for the top/sides was set at 0.012 and the bottom was set at 0.035. The inlet configuration was set as "Square Edge with Headwall", resulting in an entrance-loss coefficient of 0.5.

Proposed 3-Sided Structure Alternate

Section 714 of the INDOT Standard Specifications for reinforced concrete box structures states that the contractor will be allowed to substitute a three-sided structure of equivalent hydraulic capacity to the box structure. By inspection, a flat-top structure of the same span and rise will have the same capacity as the sumped box structure. Therefore, a 3-sided arch-top structure alternate was analyzed for the same site conditions. IDM Section 203-2.05(03)-1 states that an arch-top option may be included if its perpendicular span is no more than 4 feet greater than the span of the flat-top. An arch-top structure with a 16 ft span by 9 ft rise (opening) was analyzed using the same Manning's n values and inlet configuration as the box structure.

Allowable Headwater

Per section 203-2.02(02) of the IDM, the allowable headwater can be based on the least restrictive of the existing structure replacement policy or the in-kind replacement policy. Based on the analysis, it appears that both policies could be met. However, in order to the limit the headwall height, the structure rise has been increased.

Based on the analysis, the proposed RC box structure with a 16 ft span and 9 ft vertical opening meets the requirement of the IDM. With a 12 in sump, a structure rise of 10 ft will be required. An alternate flat-top structure with the same opening as the box or a 3-sided arch-top structure with a 16 ft span and 9 ft vertical opening also meets the backwater requirements. The following summary table gives the results of the HY-8 analysis.

Backwater = Control Depth - Tailwater Depth				
Structure Type Span x Opening x Length	Headwater Elev.	Control Depth	Tailwater Depth (ft)	Backwater (ft)
Existing Concrete Slab Top 16 ft x 7.7 ft x 44 ft	847.48	6.48	6.33	0.15
Proposed RC Box 16 ft x 9 ft x 44 ft	847.48	6.48	6.33	0.15
Alternate 3-Sided Arch-Top 16 ft x 9 ft x 44 ft	847.48	6.48	6.33	0.15

Roadway-Serviceability Freeboard

As mentioned above, the design year AADT for this project is 1,510 vehicles per day. For a two-lane facility with an AADT between 1,000 and 3,000 vehicles per day, IDM Figure 203-2C states that the required serviceability freeboard is 0 feet for a 4% EP event (Q_{25}). It defines roadway serviceability freeboard as the difference between the edge of pavement and the structure-headwater elevations throughout the floodplain or watershed. The Q_{25} headwater elevation for the proposed structure is over 8 ft below the edge of pavement. Therefore, the proposed structure meets the serviceability freeboard requirements.

Structure Freeboard

Per IDM 203-2.02(04), there is no freeboard requirement for a culvert. However, per 203-2.05(03), for a three-sided structure, there is a 1 ft minimum desirable freeboard. The proposed alternate 3-sided structure meets this requirement for the 1% EP.

Sumping

IDM 203-2.02(10) requires all culverts over one of the Waters of the United States to be sumped to satisfy IDEM Water Quality Section 401 permit requirements. This will allow the stream bed to fill in with silt over time, resulting in a natural bottom at the structure. For box structures, the required sump depth is shown in Figure 203-2E. Based on the soil type and structure span, a 12 in sump will be required for the proposed structure.

For constructability, the structure will be constructed level and the change in flowline elevation will be accounted for with a varying sump depth (i.e. the sump depth will be greater at the inlet than at the outlet).

Scour Protection

The Q_{25} outlet velocity for the proposed structure is 3.1 ft per second. Based on this value, Revetment Riprap can be placed at the ends of the culvert in accordance with IDM Figure 203-2D.

Hydraulic Data Summary

A 16 ft x 10 ft (9 ft opening) reinforced concrete box culvert is the recommended structure with the following hydraulic design parameters. A 16 ft x 11 ft (9 ft opening) 3-sided arch-top structure is recommended as an alternate structure.

Drainage Area	= 1.29 sq. mi.
Q_{100}	= 370 cfs
Elevation @ Q_{100} (Downstream Inv. + TW Depth)	= 847.13 NAVD 88
Proposed Backwater	= 0.15 ft.
Velocity @ Q_{25}	= 3.1 fps
Waterway Opening Over Road (Road Overflow)	= 0 sq. ft.
Gross Waterway Opening of Proposed Structure Below Q_{100}	= 101.3 sq. ft.
Gross Waterway Opening of Alt. 3-Sided Arch Below Q_{100}	= 101.2 sq. ft.
Minimum Low Structure Elevation	= 849.80 NAVD 88
Skew	= No Skew
Existing Velocity @ Q_{25}	= 3.1 fps
Existing Waterway Opening Over Road (Road Overflow)	= 0 sq. ft.
Existing Gross Waterway Opening of Structure	= 101.3 sq. ft.

Existing Backwater	= 0.15 ft.
Existing Low Structure	= 848.51 NAVD 88

Preparer Contact Information

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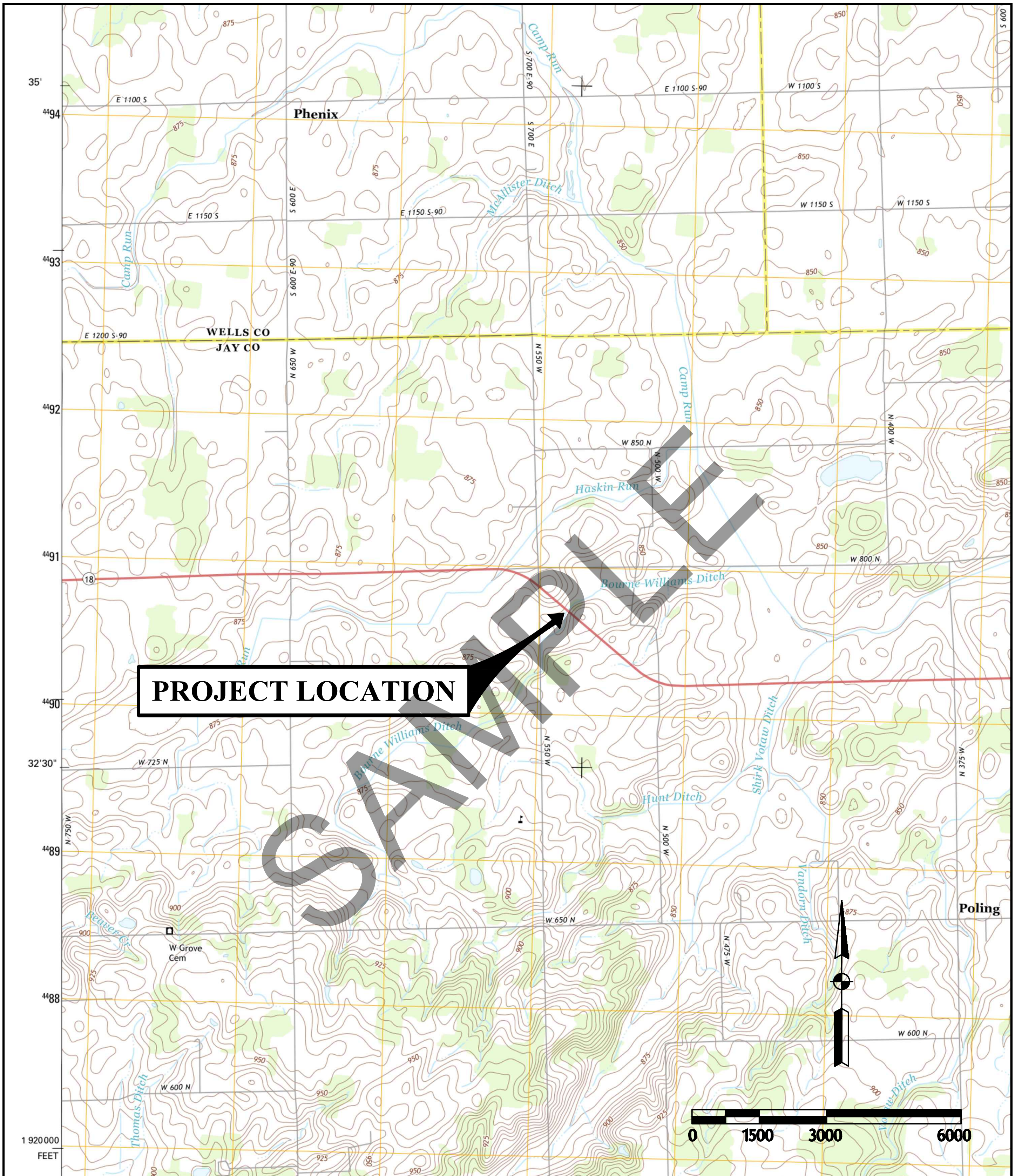
APPENDIX A
GENERAL PROJECT INFORMATION



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LOCATION MAP
SR 18 OVER BOURNE-WILLIAMS DITCH
JAY COUNTY
DES. NO. 1401835

Southwest (Upstream) Face of Structure - Looking East

Looking Downstream (Northeast) Through Structure

Looking Upstream (Southwest) from Structure

Looking Downstream (Northeast) from Structure

Southeast Approach to Structure - Looking Northwest

Northwest Approach to Structure - Looking Southeast

APPENDIX B
HYDROLOGIC ANALYSIS

THIS IS NOT A PERMIT

Indiana Department of Natural Resources / Division of Water
Floodplain Analysis and Regulatory Assessment

File Number: BQ-32634-0
Request Date: 02/04/2016
County: Jay
Waterbody: Bourne Williams Ditch

402 West Washington Street, Room W264
Indianapolis, IN 46204-2641
Telephone: (317) 232-4160 or (877) 928-3755
Fax: (317) 233-4579 Website: www.in.gov/dnr/water

Site Location: At the State Road 18 crossing, Jackson Township, Section 7, Township 24N, Range 13E

Discharge Recommendation: 370 cfs
Drainage Area: 1.29 square miles
Base Flood Elevation (BFE): Not Determined

Special Information

Division of Water Permitting

- Unless the bridge project meets the exemption criteria outlined below, approval of the DNR, Division of Water under the Flood Control Act (IC 14-28-1) is required for any construction in a floodway area including obstructing, filling, excavating, or building a structure. A provision which exempts certain bridge projects from permitting requirements under the Flood Control Act states: "A permit is not required for... a construction or reconstruction project on a state or county highway bridge in a rural area that crosses a stream having an upstream drainage area of ... 50 square miles or less ... "

  Therefore, in order for a bridge project to be exempt from the permit requirements, it must meet all of the following criteria:

  - be a state or county highway department project;
  - be a bridge (span structure, culverts, etc.);
  - be located in a rural area*; and
  - cross a stream having an upstream drainage area of less than 50 square miles

  * Rural area is defined as an area:
  1) where the lowest floor elevation, including a basement, of any residential, commercial, or industrial building impacted by the project is at least 2 feet above the base flood elevation with the project in place;
  2) located outside the corporate boundaries of a consolidated or an incorporated city or town; and
  3) located outside of the territorial authority for comprehensive planning (generally, a 2 mile planning buffer around a city or town)

  All construction associated with the rural bridge within the project right-of-way such as bank protection, spoil disposal, borrow pits, etc. are considered part of this exemption.

  This exemption has been grossly misunderstood and liberally applied in the past. As a result, the DNR, Division of Water is taking a firm stance on future violations. If challenged, it will be the responsibility of the person claiming the exemption to prove to the DNR, Division of Water that all 4 criteria have been satisfied. Failure to do so may result in the DNR, Division of Water initiating litigation with the potential for the imposition of fines.

  Note: This exemption only applies to the Flood Control Act (IC 14-28-1). If a bridge is to be constructed over a navigable waterway, or over or near a public freshwater lake, a permit may be required under the Navigable Waterways Act (IC 14-29-1), the Lowering of the Ten Acre Lake Act (IC 14-26-5) or the Lake Preservation Act (IC 14-26-2).

THIS IS NOT A PERMIT

This Floodplain Analysis and Regulatory Assessment is not a building permit, approval of any project, or a waiver of provisions of local or zoning ordinances. Additionally, projects must comply with all other applicable federal, state, and local permit requirements.

If you have any questions concerning this letter, please contact Scott H Dean at (317) 234-1077.

Larissa Muellner

Larissa Muellner, CFM 03/07/2016

Copies Sent To: Mr. John Hemmelgarn (Floodplain Administrator), Aaron Isch (Requestor)

Additional Permitting Agencies

- Local Ordinances / Permitting: For proposed construction on this tract, you may also be required to obtain permits from or coordinate with the local floodplain administrator, plan commission, zoning office, and county drainage board.

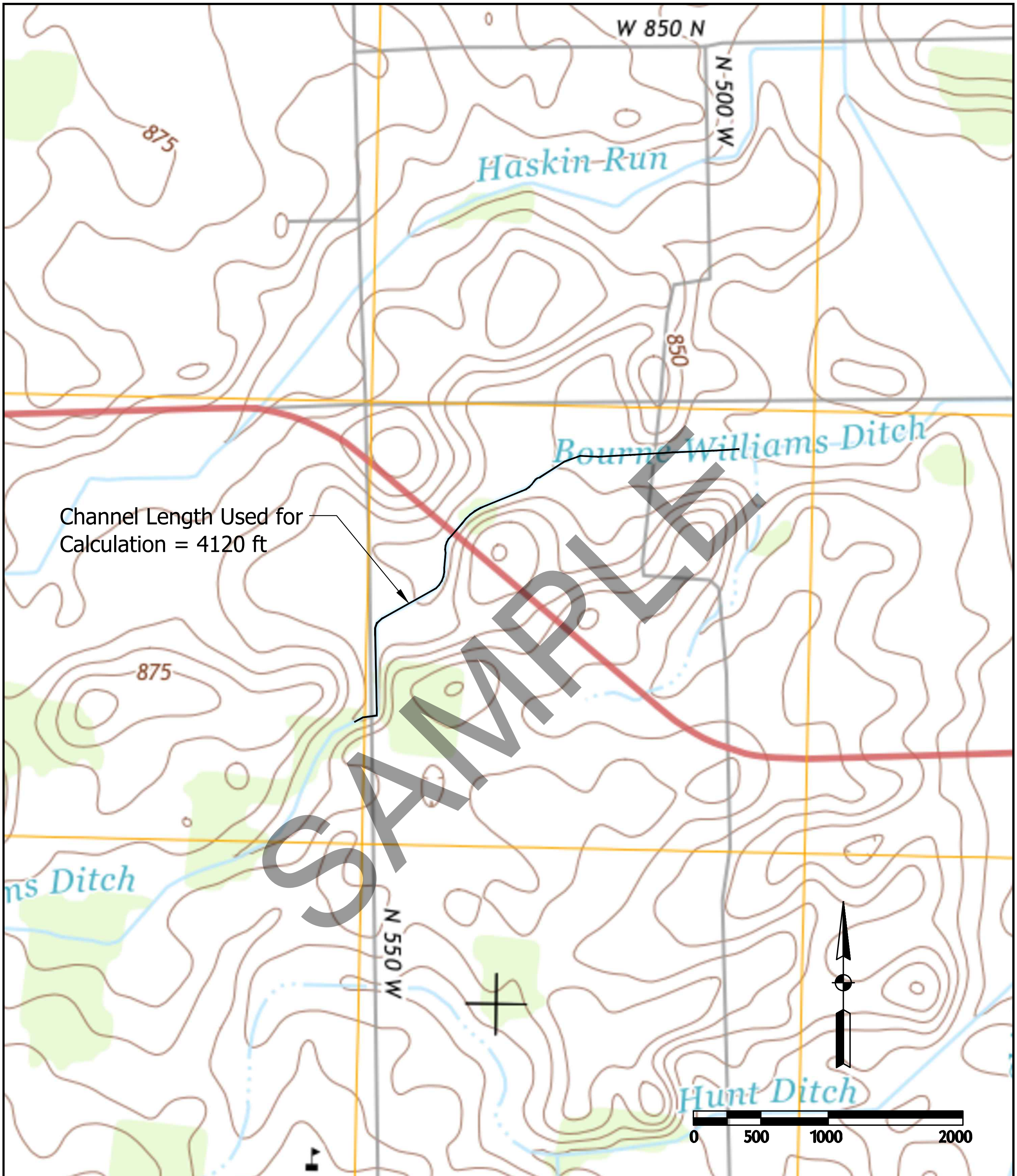
  Construction permitting by local government entities is independent of the State's permitting authority. Local floodplain ordinances may require that the lowest floor of a new building or an addition to an existing building proposed in the Special Flood Hazard Area (SFHA) be elevated at least 2 feet above the base flood elevation (BFE). If a basement is included, the basement floor should be considered to be the lowest floor.

  Indiana Department of Environmental Management: You may also be required to obtain construction permits from the Indiana Department of Environmental Management. Call (317) 233-8488 or (800) 451-6027 or visit their webpage at www.in.gov/idem.

  U.S. Army Corps' of Engineers: You may have to obtain a permit from the Corps of Engineers under Section 404 of the Clean Water Act or Section 10 of the Rivers and Harbors Act. Information relative to the Corps' of Engineers permits may be obtained by contacting:
  U.S. Army Corps of Engineers, Louisville District Office, Regulatory Branch
  P.O. Box 59, Louisville, Kentucky 40201-0059 Telephone: (502) 315-6686

  Contacting these agencies is your responsibility.

APPENDIX C
HYDRAULIC ANALYSIS



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SLOPE CALCULATION MAP
SR 18 OVER BOURNE-WILLIAMS DITCH
JAY COUNTY
DES. NO. 1401835

= USER INPUT

SLOPE CALCULATION

The stream slope used in the tailwater depth calculation is calculated below

Typically 20 ft of fall is considered to calculate the slope. This includes one contour line upstream and two downstream. In this situation, the USGS Map contains 5 ft contour intervals. Therefore, two contours were used upstream. Only two contours are available downstream before the stream joins with another one. Therefore, only two contours were used on the downstream side. The total fall is 15 ft.

Elevation Change =	15	ft	
Distance between Upstream Contour and Downstream Contour =	4120	ft	(See Map)
Slope for Normal Depth Calculation = Elevation Change / Distance =	0.0036	ft/ft	

HY-8 Culvert Analysis Report

Table 1 - Culvert Summary Table: Existing Culvert

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)
280.00	280.00	846.69	3.259	5.688	3-M1t	3.036	2.125	5.630	5.630	3.108	2.517
292.00	292.00	846.80	3.352	5.802	3-M1t	3.115	2.186	5.732	5.732	3.184	2.521
304.00	304.00	846.91	3.443	5.912	3-M1t	3.193	2.245	5.830	5.830	3.259	2.526
316.00	316.00	847.02	3.533	6.020	3-M1t	3.272	2.304	5.926	5.926	3.333	2.532
328.00	328.00	847.13	3.622	6.126	3-M1t	3.350	2.362	6.020	6.020	3.406	2.538
340.00	340.00	847.23	3.710	6.229	3-M1t	3.429	2.420	6.110	6.110	3.478	2.544
352.00	352.00	847.33	3.797	6.330	3-M1t	3.506	2.476	6.199	6.199	3.549	2.550
364.00	364.00	847.43	3.880	6.429	3-M1t	3.574	2.532	6.286	6.286	3.619	2.556
370.00	370.00	847.48	3.921	6.478	3-M1t	3.607	2.560	6.328	6.328	3.654	2.559
388.00	388.00	847.62	4.041	6.622	3-M1t	3.709	2.642	6.453	6.453	3.758	2.569
400.00	400.00	847.72	4.121	6.716	3-M1t	3.776	2.696	6.534	6.534	3.826	2.576

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Straight Culvert

Inlet Elevation (invert): 841.00 ft, Outlet Elevation (invert): 840.80 ft

Culvert Length: 44.00 ft, Culvert Slope: 0.0045

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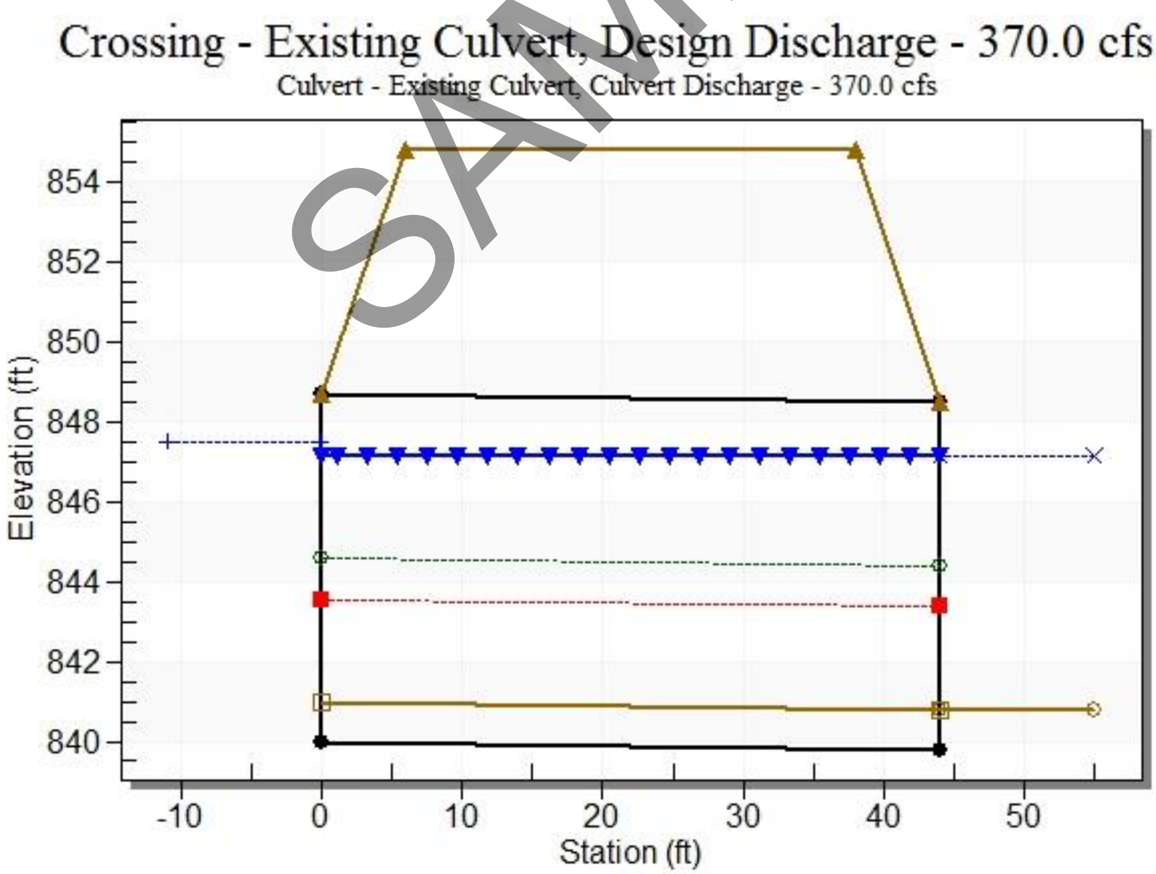
Water Surface Profile Plot for Culvert: Existing Culvert



Site Data - Existing Culvert

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 840.00 ft

Outlet Station: 44.00 ft

Outlet Elevation: 839.80 ft

Number of Barrels: 1

Culvert Data Summary - Existing Culvert

Barrel Shape: Concrete Box

Barrel Span: 16.00 ft

Barrel Rise: 8.70 ft

Barrel Material: Concrete

Embedment: 12.00 in

Barrel Manning's n: 0.0120 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: NONE

Table 2 - Downstream Channel Rating Curve (Crossing: Existing Culvert)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
280.00	846.43	5.63	2.52	1.26	0.28
292.00	846.53	5.73	2.52	1.29	0.28
304.00	846.63	5.83	2.53	1.31	0.28
316.00	846.73	5.93	2.53	1.33	0.27
328.00	846.82	6.02	2.54	1.35	0.27
340.00	846.91	6.11	2.54	1.37	0.27
352.00	847.00	6.20	2.55	1.39	0.27
364.00	847.09	6.29	2.56	1.41	0.27
370.00	847.13	6.33	2.56	1.42	0.27
388.00	847.25	6.45	2.57	1.45	0.27
400.00	847.33	6.53	2.58	1.47	0.27

Tailwater Channel Data - Existing Culvert

Tailwater Channel Option: Irregular Channel

Channel Slope: 0.0036

User Defined Channel Cross-Section:

Coord No.	Station (ft)	Elevation (ft)	Manning's n
1	-250.00	855.30	0.1000
2	-214.00	850.50	0.1000
3	-205.00	850.00	0.1000
4	-165.00	848.00	0.1000
5	-68.00	847.60	0.1000
6	-30.00	847.40	0.1000
7	-22.50	845.60	0.1000
8	-12.80	845.30	0.1000
9	-6.10	840.80	0.0800
10	5.50	840.80	0.1000
11	7.00	845.60	0.1000
12	13.70	845.60	0.1000
13	47.50	851.60	0.1000
14	72.00	854.10	0.1000
15	100.00	856.10	0.0000

HY-8 Culvert Analysis Report

Table 1 - Culvert Summary Table: Proposed Box

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)
280.00	280.00	846.69	3.259	5.689	3-M1t	3.035	2.128	5.630	5.630	3.108	2.517
292.00	292.00	846.80	3.352	5.802	3-M1t	3.118	2.184	5.732	5.732	3.184	2.521
304.00	304.00	846.91	3.443	5.913	3-M1t	3.202	2.244	5.830	5.830	3.259	2.526
316.00	316.00	847.02	3.533	6.021	3-M1t	3.284	2.303	5.926	5.926	3.333	2.532
328.00	328.00	847.13	3.622	6.126	3-M1t	3.356	2.361	6.020	6.020	3.406	2.538
340.00	340.00	847.23	3.710	6.230	3-M1t	3.428	2.419	6.110	6.110	3.478	2.544
352.00	352.00	847.33	3.797	6.331	3-M1t	3.500	2.476	6.199	6.199	3.549	2.550
364.00	364.00	847.43	3.882	6.430	3-M1t	3.572	2.532	6.286	6.286	3.619	2.556
370.00	370.00	847.48	3.925	6.479	3-M1t	3.608	2.560	6.328	6.328	3.654	2.559
388.00	388.00	847.62	4.051	6.622	3-M1t	3.716	2.642	6.453	6.453	3.758	2.569
400.00	400.00	847.72	4.134	6.716	3-M1t	3.788	2.696	6.534	6.534	3.826	2.576

****

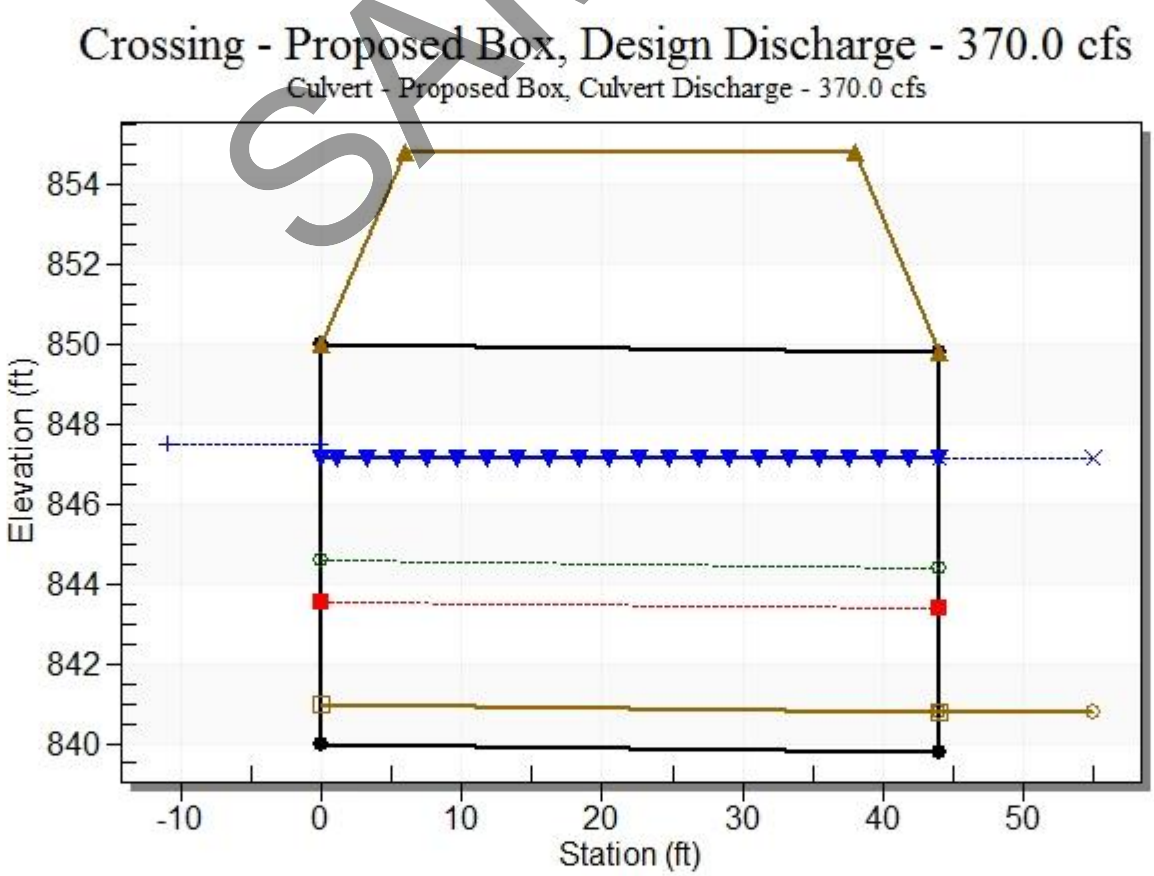
Straight Culvert

Inlet Elevation (invert): 841.00 ft,   Outlet Elevation (invert): 840.80 ft

Culvert Length: 44.00 ft,   Culvert Slope: 0.0045

****

Water Surface Profile Plot for Culvert: Proposed Box



Site Data - Proposed Box

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 840.00 ft

Outlet Station: 44.00 ft

Outlet Elevation: 839.80 ft

Number of Barrels: 1

Culvert Data Summary - Proposed Box

Barrel Shape: Concrete Box

Barrel Span: 16.00 ft

Barrel Rise: 10.00 ft

Barrel Material: Concrete

Embedment: 12.00 in

Barrel Manning's n: 0.0120 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: NONE

Table 2 - Downstream Channel Rating Curve (Crossing: Proposed Box)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
280.00	846.43	5.63	2.52	1.26	0.28
292.00	846.53	5.73	2.52	1.29	0.28
304.00	846.63	5.83	2.53	1.31	0.28
316.00	846.73	5.93	2.53	1.33	0.27
328.00	846.82	6.02	2.54	1.35	0.27
340.00	846.91	6.11	2.54	1.37	0.27
352.00	847.00	6.20	2.55	1.39	0.27
364.00	847.09	6.29	2.56	1.41	0.27
370.00	847.13	6.33	2.56	1.42	0.27
388.00	847.25	6.45	2.57	1.45	0.27
400.00	847.33	6.53	2.58	1.47	0.27

Tailwater Channel Data - Proposed Box

Tailwater Channel Option: Irregular Channel

Channel Slope: 0.0036

User Defined Channel Cross-Section:

Coord No.	Station (ft)	Elevation (ft)	Manning's n
1	-250.00	855.30	0.1000
2	-214.00	850.50	0.1000
3	-205.00	850.00	0.1000
4	-165.00	848.00	0.1000
5	-68.00	847.60	0.1000
6	-30.00	847.40	0.1000
7	-22.50	845.60	0.1000
8	-12.80	845.30	0.1000
9	-6.10	840.80	0.0800
10	5.50	840.80	0.1000
11	7.00	845.60	0.1000
12	13.70	845.60	0.1000
13	47.50	851.60	0.1000
14	72.00	854.10	0.1000
15	100.00	856.10	0.0000

HY-8 Culvert Analysis Report

Table 1 - Culvert Summary Table: Alternate Arch Top

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)
280.00	280.00	846.69	3.738	5.691	3-M1t	3.036	2.128	5.630	5.630	3.110	2.517
292.00	292.00	846.80	3.847	5.804	3-M1t	3.120	2.184	5.732	5.732	3.187	2.521
304.00	304.00	846.92	3.951	5.915	3-M1t	3.203	2.244	5.830	5.830	3.262	2.526
316.00	316.00	847.02	4.054	6.023	3-M1t	3.285	2.303	5.926	5.926	3.337	2.532
328.00	328.00	847.13	4.156	6.129	3-M1t	3.358	2.361	6.020	6.020	3.411	2.538
340.00	340.00	847.23	4.257	6.233	3-M1t	3.430	2.419	6.110	6.110	3.484	2.544
352.00	352.00	847.33	4.356	6.334	3-M1t	3.502	2.476	6.199	6.199	3.557	2.550
364.00	364.00	847.43	4.455	6.434	3-M1t	3.575	2.532	6.286	6.286	3.629	2.556
370.00	370.00	847.48	4.503	6.483	3-M1t	3.611	2.560	6.328	6.328	3.665	2.559
388.00	388.00	847.63	4.651	6.627	3-M1t	3.720	2.642	6.453	6.453	3.771	2.569
400.00	400.00	847.72	4.748	6.722	3-M1t	3.792	2.697	6.534	6.534	3.841	2.576

****

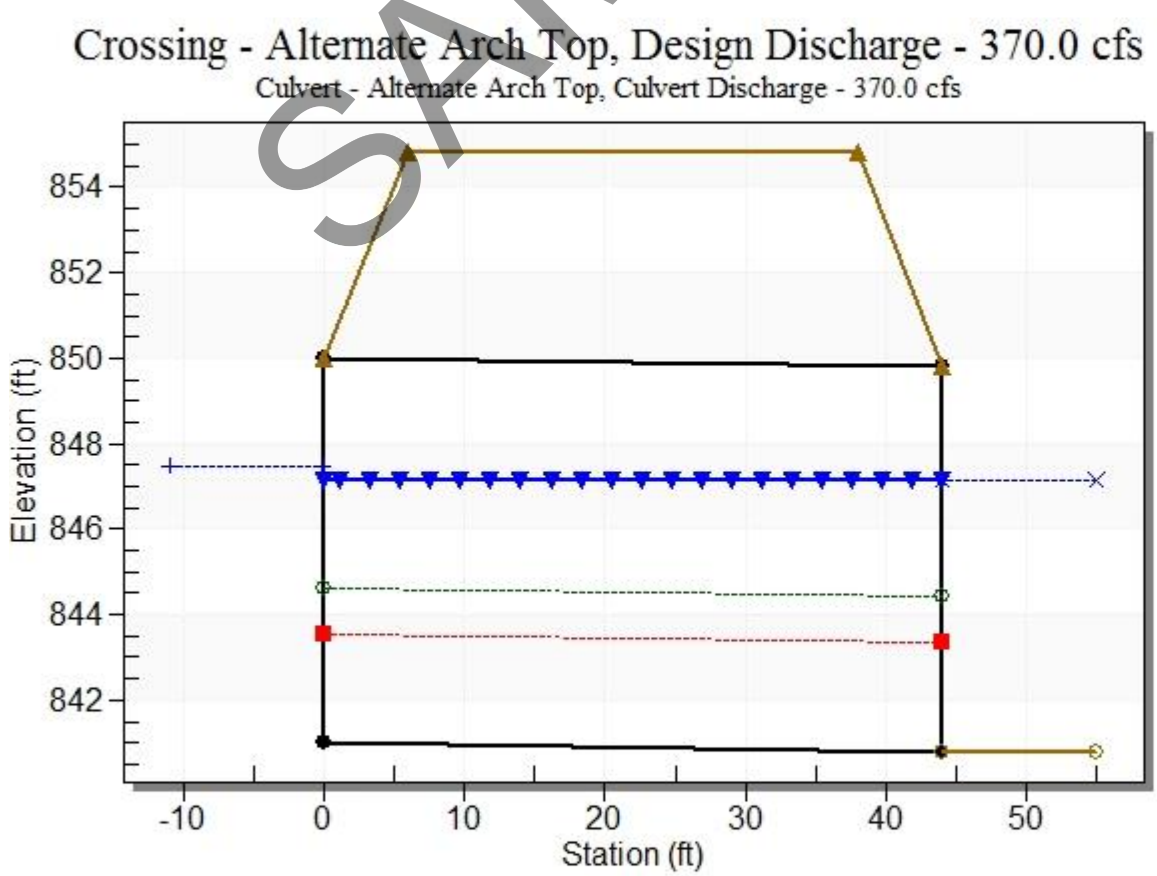
Straight Culvert

Inlet Elevation (invert): 841.00 ft, Outlet Elevation (invert): 840.80 ft

Culvert Length: 44.00 ft, Culvert Slope: 0.0045

****

Water Surface Profile Plot for Culvert: Alternate Arch Top



Site Data - Alternate Arch Top

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 841.00 ft

Outlet Station: 44.00 ft

Outlet Elevation: 840.80 ft

Number of Barrels: 1

Culvert Data Summary - Alternate Arch Top

Barrel Shape: Arch-Box, Concrete

Barrel Span: 16.00 ft

Barrel Rise: 9.00 ft

Notes about selected shape: The selected span to rise ratio is outside of the range tested.

Barrel Material: Concrete

Embedment: 0.00 in

Barrel Manning's n: 0.0120 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Square Edge with Headwall

Inlet Depression: NONE

Table 2 - Downstream Channel Rating Curve (Crossing: Alternate Arch Top)

Flow (cfs)	Water Surface Elev (ft)	Depth (ft)	Velocity (ft/s)	Shear (psf)	Froude Number
280.00	846.43	5.63	2.52	1.26	0.28
292.00	846.53	5.73	2.52	1.29	0.28
304.00	846.63	5.83	2.53	1.31	0.28
316.00	846.73	5.93	2.53	1.33	0.27
328.00	846.82	6.02	2.54	1.35	0.27
340.00	846.91	6.11	2.54	1.37	0.27
352.00	847.00	6.20	2.55	1.39	0.27
364.00	847.09	6.29	2.56	1.41	0.27
370.00	847.13	6.33	2.56	1.42	0.27
388.00	847.25	6.45	2.57	1.45	0.27
400.00	847.33	6.53	2.58	1.47	0.27

Tailwater Channel Data - Alternate Arch Top

Tailwater Channel Option: Irregular Channel

Channel Slope: 0.0036

User Defined Channel Cross-Section:

Coord No.	Station (ft)	Elevation (ft)	Manning's n
1	-250.00	855.30	0.1000
2	-214.00	850.50	0.1000
3	-205.00	850.00	0.1000
4	-165.00	848.00	0.1000
5	-68.00	847.60	0.1000
6	-30.00	847.40	0.1000
7	-22.50	845.60	0.1000
8	-12.80	845.30	0.1000
9	-6.10	840.80	0.0800
10	5.50	840.80	0.1000
11	7.00	845.60	0.1000
12	13.70	845.60	0.1000
13	47.50	851.60	0.1000
14	72.00	854.10	0.1000
15	100.00	856.10	0.0000

ENGINEERING
RESOURCES, INC.

JOB	3857 - SR 18 over Bourne-Williams Ditch, Des 1401835		
SHEET NO.		OF	
CALCULATED BY	AJI	DATE	9/7/2016
CHECKED BY	WCA	DATE	9/9/2016
SCALE			

= USER INPUT

GROSS WATERWAY OPENING CALCULATION

Existing Structure

Tailwater Depth = 6.33 ft

Structure Rise = 7.7 ft

Structure Span = 16 ft

Gross Waterway Opening Below Q_{100} Elevation = (Min. Value of Tailwater Depth, Structure Rise) * Structure Span =
101.3 sft

Proposed Box Structure

Tailwater Depth = 6.33 ft

Structure Rise = 9 ft

Structure Span = 16 ft

Gross Waterway Opening Below Q_{100} Elevation = (Min. Value of Tailwater Depth, Structure Rise) * Structure Span =
101.3 sft

Alternate 3-Sided Arch Structure

Tailwater Depth = 6.33 ft

Structure Rise = 9 ft

Structure Span = 16 ft

Gross Waterway Opening Below Q_{100} Elevation =
101.2 sft (Calculated in CAD due to water coming up on arched top)