

Reviewing Coefficients in Embedded Circular Culverts from NCHRP Report 734

The Problem

NCHRP Report 734 was published the results of a study on embedded culverts that was used to determine coefficients for inlet control computations. However, the data from the study contained a mathematical error. The research resulted in a table of $Q/(AD^{0.5})$ vs HW/D that was not included in the NCHRP report. The variables $AD^{0.5}$ was computed incorrectly and led to incorrect computations.

Additionally, the results of the 50% embedded beveled inlet edge culvert scenario had false data. The results when compared to the other results of the study were inconsistent and too limited to generate a stable curve.

The data with a beveled inlet edge is plotted below. Note that the 50% embedded case results in a lower headwater at the same flows than a 40% embedded culvert. It even shows a lower headwater than a 20% embedded culvert for part of the curve. Also note that the 50% embedded case does not have the same origin location. Finally, note that there are only a few data points along the arc.

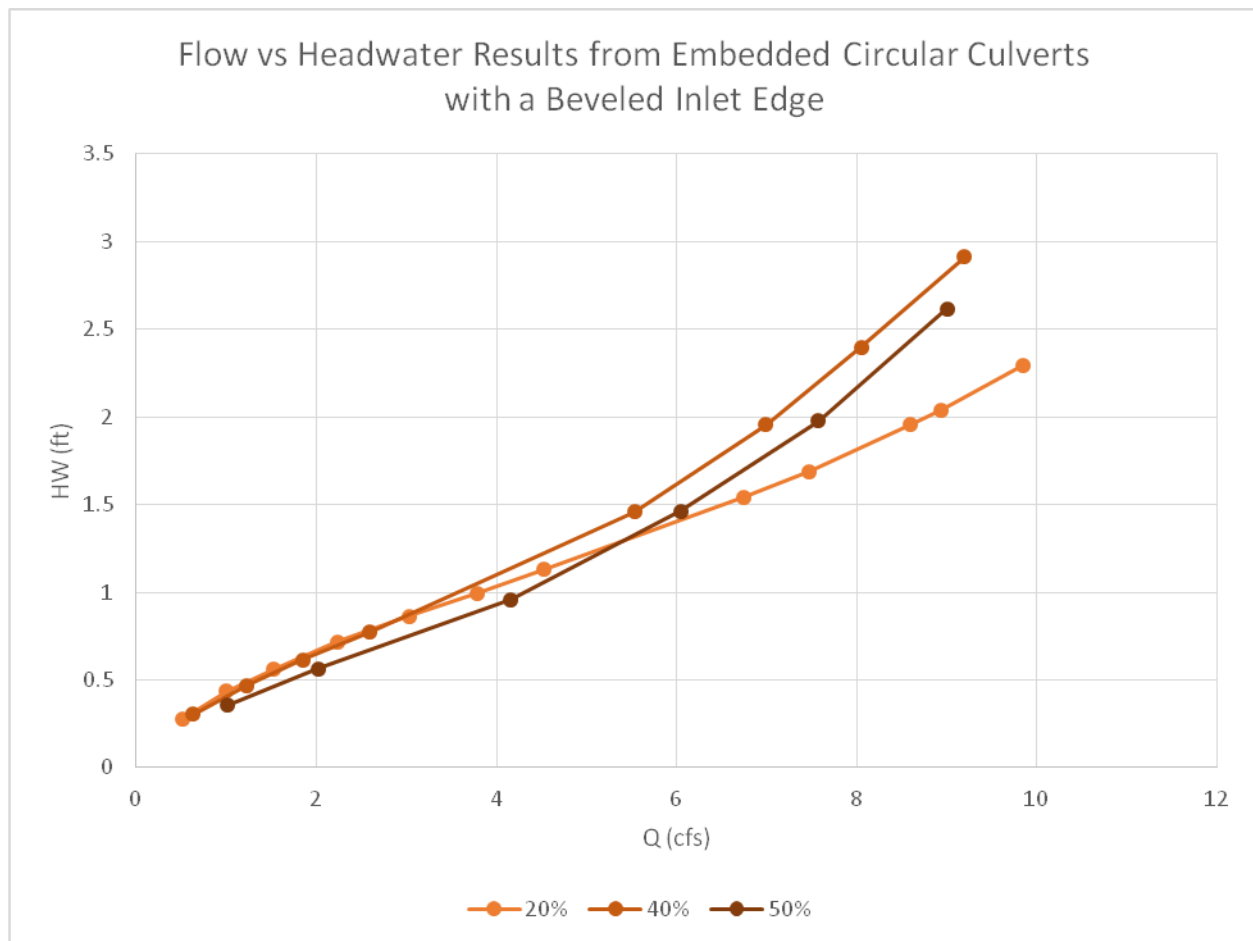


Figure 1: Flow vs Headwater results from embedded circular culverts with a beveled inlet edge with flawed data

Correcting the Mathematical Error

The 50% embedded beveled inlet edge table with false data was replaced with original data. The original data was reviewed and the original 50% embedded case data was recovered with a suitable number of data points to provide stability. This data was consistent with the other results of the study. The source of the erroneous data was never determined. This data still had the mathematical issue that would be corrected as described below.

In Figure 2: Flow vs Headwater results from Embedded circular culverts with a beveled inlet edge with recovered data, the 50% embedded culvert with a beveled inlet edge is plotted along with the 20% embedded and 40% embedded culverts with beveled inlet edges. Note that the 50% embedded case begins at a similar location as the other 2 cases. It is also consistent in shape and trend while generally providing a higher headwater than the other 2 cases. Finally, note that there are more data points along the arc than the arc based on flawed data.

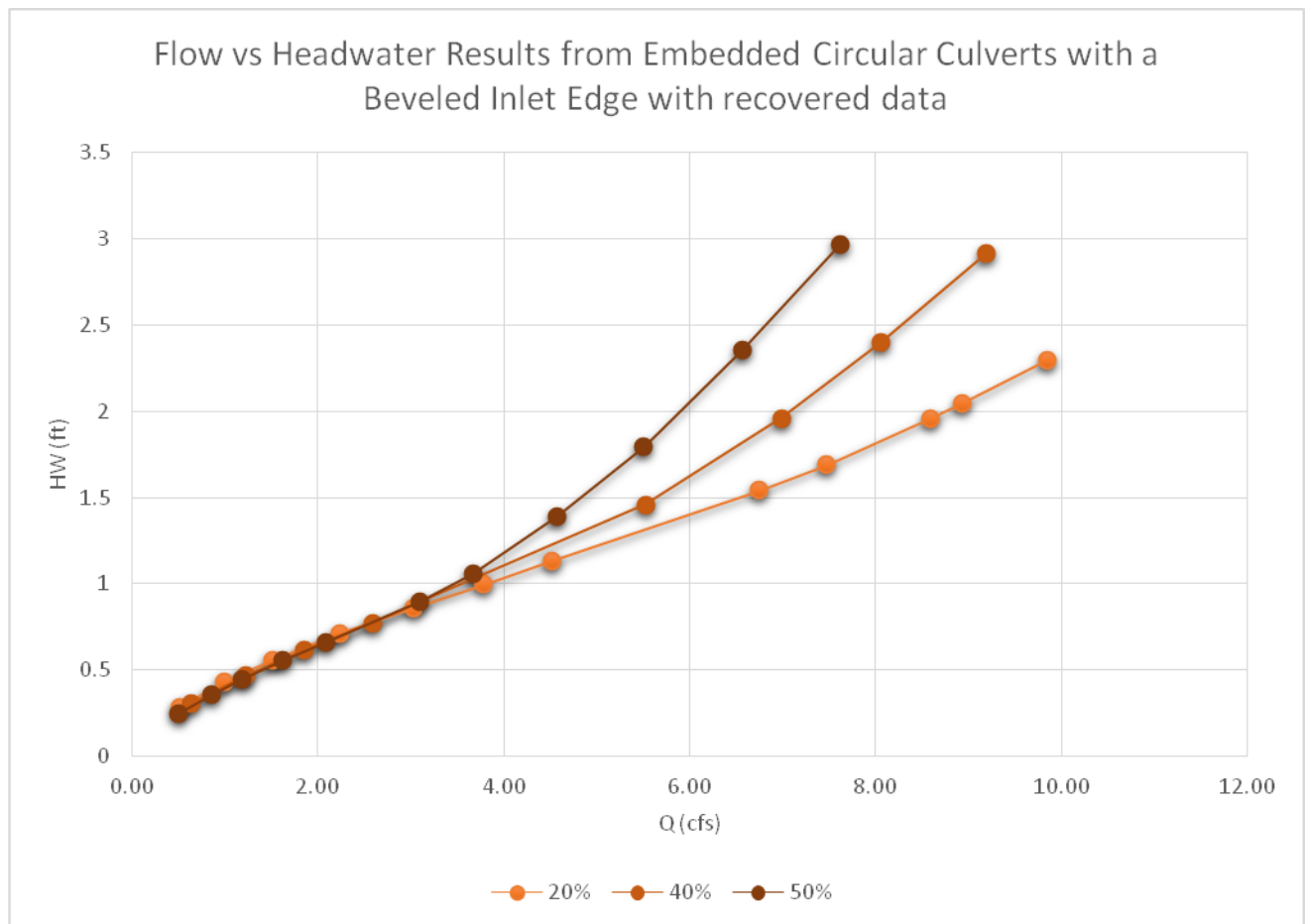


Figure 2: Flow vs Headwater results from Embedded circular culverts with a beveled inlet edge with recovered data

Now that we have consistent data, we needed to correct the data for the flawed mathematics. The flawed tables also included the flow rates. The variable $AD^{0.5}$ is a constant value; it is the full flow area times the square root of the culvert rise. Thus, it is an easy procedure to generate a new table with the correct values.

The table corresponding to a culvert with 20% embedment and a projecting inlet with original and corrected values are given below. For the remaining tables, see Appendix A.

The first row shows the source of the data in the column. It may be from the NCHRP research data, computed, or from HY-8.

Table 1: Table 2B-1 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 1.15 and the corrected $AD^{0.5}$ is 1.699

From NCHRP	From NCHRP	From NCHRP Original	Computed Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.49	0.25	0.42	0.29
0.69	0.31	0.60	0.41
0.89	0.36	0.78	0.52
1.16	0.43	1.01	0.68
1.54	0.51	1.34	0.91
1.95	0.6	1.70	1.15
2.39	0.68	2.07	1.41
2.85	0.77	2.48	1.68
3.31	0.85	2.88	1.95
3.62	0.91	3.15	2.13
4	0.97	3.48	2.35
4.36	1.04	3.79	2.57
4.74	1.12	4.12	2.79
5.11	1.2	4.44	3.01
5.52	1.29	4.80	3.25
6.02	1.4	5.23	3.54
6.54	1.55	5.68	3.85
7	1.69	6.09	4.12
7.04	1.7	6.12	4.14
7.49	1.85	6.51	4.41
8.04	2.04	6.99	4.73
8.23	2.12	7.16	4.84
9.07	2.46	7.89	5.34
10.15	2.93	8.83	5.97

Determining Polynomial Coefficients

The purpose of the coefficients is to be able to predict a headwater for a given flow through a specific inlet controlled culvert configuration. First, the flow is converted to $Q/(AD^{0.5})$. The coefficients and a polynomial equation is then used to convert that value to a HW/D value. This is then converted to a headwater depth by multiplying by the culvert's rise.

The form of the polynomial equation is

$$\frac{Hw}{D} = a + bx + cx^2 + dx^3 + ex^4 + fx^5$$

Where x is $\frac{Q}{A\sqrt{D}}$

The coefficients were determined through using the zun zun website, available at <http://www.zunzun.com/>. “Polynomial” is selected from the 2D Functions. Then “5th Order (Quintic) 2D” is clicked. Select “Text Data Editor” from the Pulldown Menu. A window will appear with an XY data series. Copy or type the $Q/(AD^{0.5})$ and HW/D data in columns in the data window. Then click the submit button. The Zun Zun Site will generate a report into a single PDF file that will have the coefficients that will fit a 5th degree polynomial curve to the data from the experimental data results.

Stabilizing the Resulting Curve

Once the coefficients were determined, the resulting curves were generated and checked. It was observed that the curves became unstable when used outside of the range of the experimental data. The results from the 20% embedded culvert with a projecting inlet edge type is shown below. The unembedded projecting case is included for comparison.

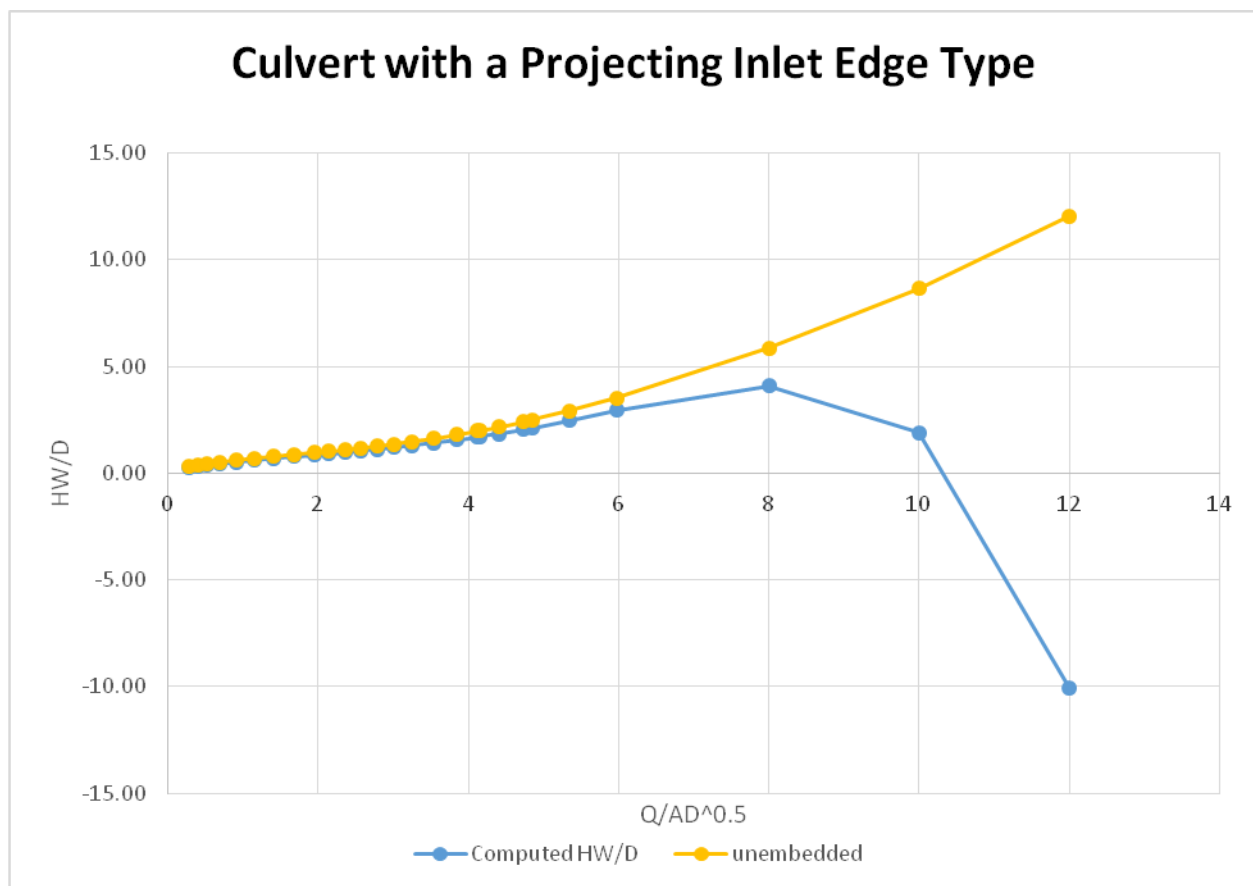


Figure 3: 20% embedded culvert with a projecting inlet edge type with instability above the research range.

It was decided to extend the range of data used to determine the coefficients. First, the $Q/(AD^{0.5})$ data was extended by adding even numbers until the $Q/(AD^{0.5})$ reached at least 10 and the curve stabilized. The HW/D value was determined by following the trend of the unembedded culvert. The percentage of the embedded result to the unembedded result was used to determine the values corresponding to the values added to the $Q/(AD^{0.5})$ column. A table showing the results of the 20% embedded culvert with a projecting inlet edge is given below.

Table 2: Development of 'updated and Adjusted' Hw/D data to generate stable coefficients.

<u>Computed</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From HY-8</u>	<u>Computed</u>	
Corrected $Q/(A(D)^{0.5})$	Hw/D	Computed Hw/D	unembedded	Updated and Adjusted	Updated / unembedded
0.288405	0.25	0.25	0.325	0.250	
0.406121	0.31	0.31	0.382	0.307	
0.523838	0.36	0.36	0.436	0.361	
0.682755	0.43	0.43	0.504	0.428	
0.906416	0.51	0.51	0.592	0.515	
1.147734	0.6	0.60	0.681	0.600	
1.40671	0.68	0.68	0.770	0.684	
1.677457	0.77	0.77	0.862	0.767	
1.948205	0.85	0.85	0.954	0.849	
2.130665	0.91	0.91	1.017	0.904	
2.354326	0.97	0.98	1.098	0.973	
2.566215	1.04	1.04	1.180	1.041	
2.789876	1.12	1.12	1.271	1.117	
3.007652	1.2	1.19	1.366	1.196	
3.24897	1.29	1.29	1.480	1.289	
3.543261	1.4	1.41	1.631	1.412	
3.849323	1.55	1.55	1.805	1.553	
4.120071	1.69	1.69	1.974	1.690	
4.143614	1.7	1.70	1.989	1.702	
4.408476	1.85	1.85	2.168	1.848	
4.732195	2.04	2.05	2.406	2.041	
4.844026	2.12	2.12	2.493	2.112	
5.338434	2.46	2.46	2.907	2.450	
5.974102	2.93	2.93	3.505	2.942	84%
8	4.886	4.08	5.844	4.883	84%
10	7.229	1.90	8.648	7.230	84%
12	10.072	-10.09	12.047	10.072	84%

The resulting extended data is then entered into the Zun Zun site and new coefficients were determined. The new coefficients are used to determine the HW/D values in the 'Updated and Adjusted' column. The results in this table are plotted below.

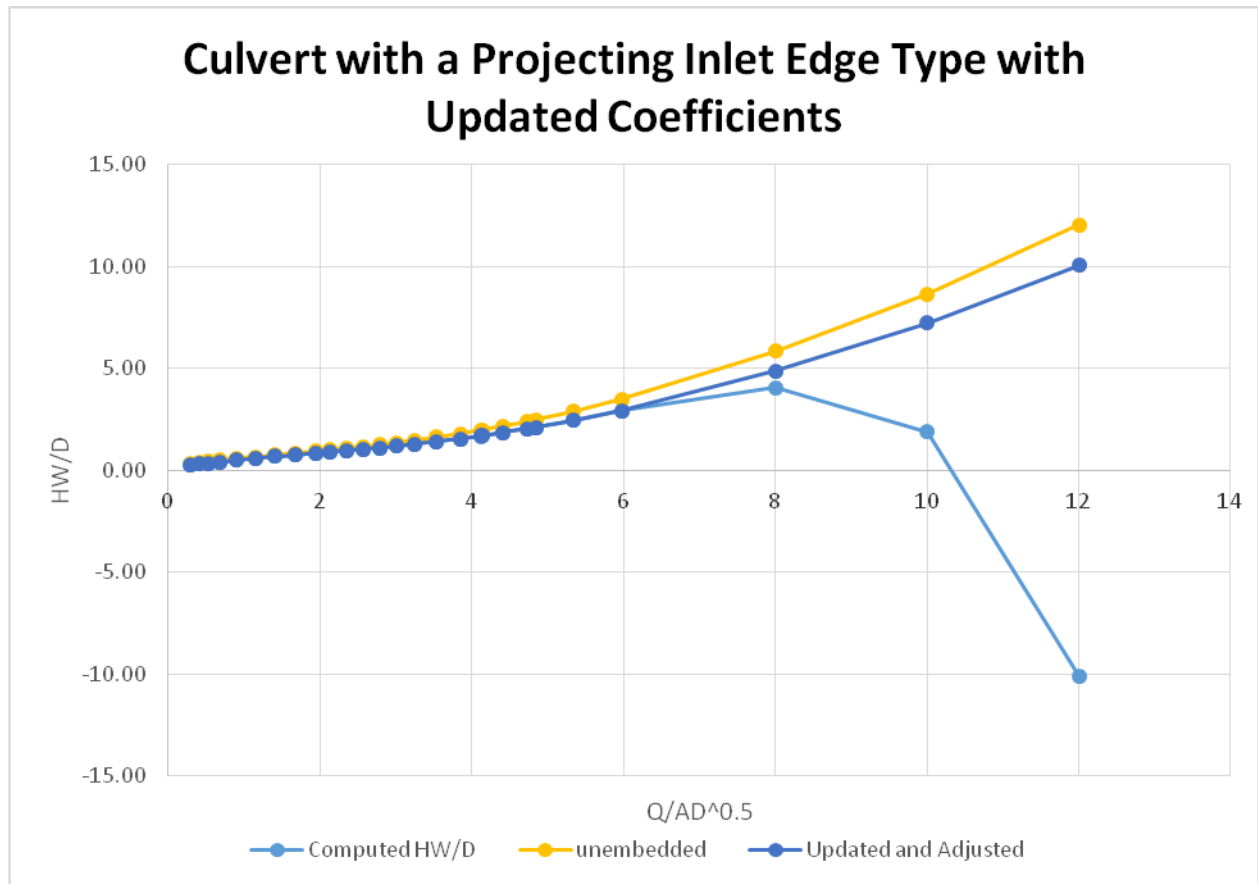


Figure 4: unembedded culvert with a projecting inlet edge, 20% embedded culvert with a projecting inlet edge type with instability above the research range, and 20% embedded culvert with a projecting inlet edge type that follows the unembedded trend.

The polynomial coefficients that were determined are included below.

Table 3: Polynomial Coefficients for a 20% embedded culvert.

	20% embedment			
	projecting	mitered	square edge	beveled
a	9.2257E-02	7.2793E-02	8.5637E-02	3.6159E-02
b	5.9588E-01	6.1675E-01	5.5992E-01	6.6382E-01
c	-1.8034E-01	-2.3390E-01	-1.7619E-01	-2.4095E-01
d	4.4397E-02	6.5436E-02	4.4942E-02	5.6614E-02
e	-3.5559E-03	-7.1261E-03	-4.7677E-03	-5.6398E-03
f	1.0374E-04	2.9918E-04	2.0762E-04	2.2724E-04

Table 4: Polynomial Coefficients for a 40% embedded culvert.

40% embedment				
	projecting	mitered	square edge	beveled
a	4.8088E-03	7.5511E-02	7.1862E-02	1.6866E-01
b	7.9062E-01	5.4738E-01	5.4571E-01	3.0516E-01
c	-3.3201E-01	-2.0195E-01	-1.7331E-01	-1.5593E-02
d	9.2931E-02	5.9755E-02	4.7346E-02	4.9917E-03
e	-1.0003E-02	-6.6918E-03	-5.2299E-03	-8.8365E-04
f	3.9655E-04	2.8662E-04	2.2919E-04	7.3112E-05

Table 5: Polynomial Coefficients for a 50% embedded culvert.

50% embedment				
	projecting	mitered	square edge	beveled
a	2.6228E-02	-4.8002E-02	8.6634E-02	-6.1560E-02
b	6.5668E-01	7.6639E-01	4.3472E-01	5.7902E-01
c	-2.2467E-01	-3.4300E-01	-8.3362E-02	-1.6663E-01
d	5.6954E-02	9.2637E-02	1.5987E-02	3.0292E-02
e	-5.2307E-03	-9.8467E-03	-8.3244E-04	-2.3849E-03
f	1.8244E-04	3.8649E-04	1.1144E-05	7.2070E-05

Verification of the Polynomial Coefficients

The purpose of this project has been to update the coefficients within HY-8. To verify the results of the process, HY-8 computer models of the research flume configurations were setup in HY-8. Then the same flows were computed through HY-8 and compared to the research results.

It is expected that HY-8 will vary from the research results. First, because the curve will not provide a perfect fit to the data. Second, the equation that HY-8 utilizes has a correction for slopes as is given below. Third, in high flow situations, HY-8 will correct the inlet control depths. A discussion of this logic is not included and the values included in this report will not include this effect. It is merely mentioned for those who seek to duplicate the results of this report.

$$\frac{HW}{D} = a + bx + cx^2 + dx^3 + ex^4 + fx^5 + SR * S$$

Where SR is a slope correction coefficient.

The following table shows the comparison of the research study along with the computed headwater elevations from HY8 for an embedded culvert with a projecting inlet edge. The remaining tables are given in Appendix B.

Table 6: Table 2B-1 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u> <u>Corrected</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	
Q (cfs)	$Q/(A(D)^{0.5})$	Hw/D	Hw (ft)	HW (ft)	Difference (ft)
0.49	0.29	0.25	0.30	0.32	0.02
0.69	0.41	0.31	0.38	0.39	0.01
0.89	0.52	0.36	0.44	0.46	0.02
1.16	0.68	0.43	0.52	0.55	0.03
1.54	0.91	0.51	0.62	0.65	0.03
1.95	1.15	0.6	0.73	0.76	0.03
2.39	1.41	0.68	0.83	0.87	0.04
2.85	1.68	0.77	0.93	0.97	0.04
3.31	1.95	0.85	1.03	1.07	0.04
3.62	2.13	0.91	1.10	1.14	0.04
4	2.35	0.97	1.18	1.22	0.04
4.36	2.57	1.04	1.26	1.29	0.03
4.74	2.79	1.12	1.36	1.37	0.01
5.11	3.01	1.2	1.46	1.44	-0.02
5.52	3.25	1.29	1.57	1.54	-0.03
6.02	3.54	1.4	1.70	1.69	-0.01
6.54	3.85	1.55	1.88	1.86	-0.02
7	4.12	1.69	2.05	2.03	-0.02
7.04	4.14	1.7	2.06	2.04	-0.02
7.49	4.41	1.85	2.25	2.22	-0.03
8.04	4.73	2.04	2.48	2.46	-0.02
8.23	4.84	2.12	2.57	2.54	-0.03
9.07	5.34	2.46	2.99	2.95	-0.04
10.15	5.97	2.93	3.56	3.55	-0.01

Finally an HY-8 model was made that compared the same configuration from unembedded, with 20%, 40% and 50% embedment levels. The results of this model test were consistent with expectations. The unembedded culverts predicted the lowest headwater results, and increasing the embedment increased the headwater. These models did not keep a constant cross-sectional flow area and would decrease the flow area available. The results of an unembedded concrete, unembedded steel, an unembedded HDPE, 20% embedded, 40% embedded, and 50% embedded culverts all with projecting inlet edge types are plotted below. The remainder of the plots will be included in Appendix C.

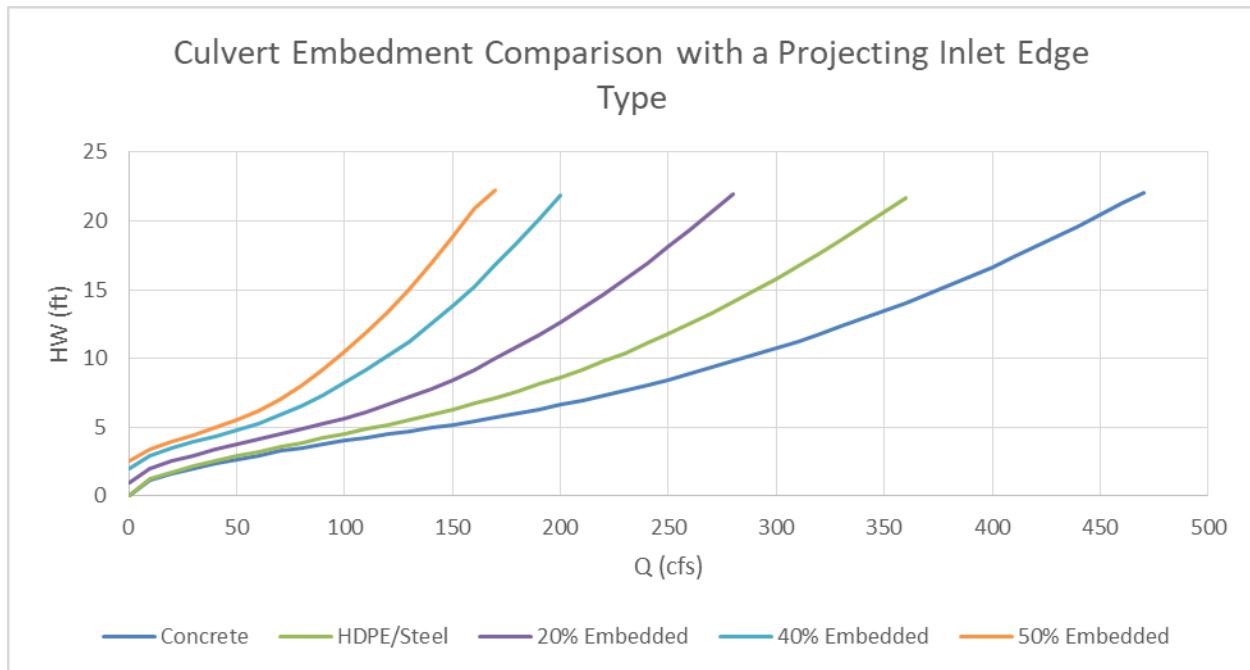


Figure 5: Culvert Embedment Comparison plot (steel & HDPE overlap—combine into 1 curve)

Determining NBS Coefficients

These coefficients are used with equations determined by the National Bureau of Standards (NBS). There are two forms of the equations for the unsubmerged condition and an equation for the submerged condition.

Unsubmerged NBS Equation Form 1

$$\frac{HW}{D} = \frac{H_c}{D} + K \left[\frac{K_u Q}{AD^{0.5}} \right]^M + K_s S$$

Unsubmerged NBS Equation Form 2

$$\frac{HW}{D} = K \left[\frac{K_u Q}{AD^{0.5}} \right]^M$$

Submerged NBS Equation

$$\frac{HW}{D} = c \left[\frac{K_u Q}{AD^{0.5}} \right]^2 + Y + K_s S$$

Where:

- HW Headwater depth, ft (m)
- D Culvert Rise, ft (m)
- H_c Specific head at critical depth ($d_c + V_c^2/2g$), ft (m)

Q	Flow, cfs (cms)
A	Full flow cross sectional area of culvert barrel, ft ² (m ²)
S	Culvert barrel slope, ft/ft (m/m)
K, M, c, Y	Constants from Tables based on configuration
K _u	Unit Conversion 1.0 (1.811 SI)
K _s	Slope correction, -0.5 (mitered inlet + 0.7)

A spreadsheet was created in excel with the tables of data from the research. These tables included columns for $Q/(AD^{0.5})$, H_w/D , and $H_w/D - H_c/D + 0.5S$.

Next, a column was created that would compute H_w/D according to the unsubmerged NBS Form 1 Equation until H_w/D was less than 1.0, and compute H_w/D according to the submerged NBS equation when H_w/D was greater than 1.0. This column would reference a set of coefficients that were assigned a value.

Another column was added to compare the results of the computed H_w/D to the H_w/D reported as a result from the research. This column was then averaged to a single value.

In Microsoft Excel 2010 and later, there is a tool called 'Solver' that can be activated by going to File | Options, click Add-Ins, and then in the Manage box, select Excel Add-ins. Click Go. In the Add-Ins available, select the Solver Add-in and click OK. See this website if these steps did not work for you: <https://support.office.com/en-us/article/load-the-solver-add-in-in-excel-612926fc-d53b-46b4-872c-e24772f078ca>

The solver tool allows the user to select a cell and set it as an objective, and then select a series of other cells that can be modified. To determine the best fit for coefficients for the NBS equations, the coefficients were selected to be modified by the solver and the average difference between the H_w/D values set as the objective to minimize. The 'Solver' tool would determine the coefficients that would have smallest average difference from the H_w/D research results.

The table used for computing the form 1 NBS coefficients for a 20% embedded culvert with a projecting inlet edge type is given below.

Table 7: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a projecting inlet edge type.

Corrected $Q/(AD^{0.5})$	Hw/D	HW/D- Hc/D+0.5S	HW/D	Difference
0.30	0.25	0.06	0.24	0.02
0.42	0.31	0.07	0.30	0.01
0.55	0.36	0.07	0.35	0.01
0.72	0.43	0.08	0.42	0.01
0.95	0.51	0.09	0.50	0.01
1.20	0.60	0.11	0.59	0.01
1.47	0.68	0.12	0.67	0.01
1.75	0.77	0.14	0.75	0.02
2.04	0.85	0.16	0.83	0.02
2.23	0.91	0.18	0.88	0.03
2.46	0.97	0.19	0.94	0.03
2.68	1.04	0.21	1.04	0.00
2.91	1.12	0.25	1.11	0.01
3.14	1.20	0.28	1.20	0.01
3.40	1.29	0.32	1.29	0.00
3.70	1.40	0.37	1.42	0.02
4.02	1.55	0.46	1.57	0.02
4.31	1.69	0.54	1.71	0.02
4.33	1.70	0.54	1.72	0.02
4.61	1.85	0.64	1.86	0.01
4.95	2.04	0.76	2.05	0.02
5.07	2.12	0.82	2.12	0.00
5.58	2.46	1.05	2.45	0.01
6.25	2.93	1.39	2.91	0.02
Average Difference				
K	0.103776			0.014
M	0.651501			
c	0.058729			
Y	0.615687			

This process was repeated for each configuration type (20%, 40%, and 50% embedment levels and projecting, mitered, square edge, and beveled inlet types) and repeated for the unsubmerged Form 2 equations; however, only K and M coefficients were altered in determining Form 2 coefficients.

The table below provides all of the coefficients determined by this process.

Table 8: Coefficients for the NBS equations

Embedded	Top Edge	Inlet Configuration	Unsubmerged				Submerged	
			K Form 1	M Form 1	K Form 2	M Form 2	c	y
0.2D	thin	Projecting End, Ponded	0.1178	0.65	0.5337	0.66	0.0596	0.59
0.2D	thin	Projecting End, Channelized	0.0878	0.52	0.5180	0.63	0.0501	0.62
0.2D		Mitered End 1.5H:1V	0.0784	0.00	0.4976	0.63	0.0495	0.62
0.2D	90°	Square Headwall	0.0800	0.51	0.0404	0.66	0.0404	0.66
0.2D	45°	Beveled End	0.0635	0.43	0.4811	0.63	0.0321	0.72
0.4D	thin	Projecting End, Ponded	0.1214	0.67	0.5051	0.69	0.0577	0.60
0.4D	thin	Projecting End, Channelized	0.1349	0.53	0.5144	0.66	0.0542	0.53
0.4D		Mitered End 1.5H:1V	0.0681	0.60	0.4504	0.69	0.0488	0.57
0.4D	90°	Square Headwall	0.0849	0.60	0.4659	0.69	0.0422	0.63
0.4D	45°	Beveled End	0.0736	0.47	0.4709	0.67	0.0350	0.69
0.5D	thin	Projecting End, Ponded	0.1041	0.73	0.4963	0.71	0.0612	0.52
0.5D	thin	Projecting End, Channelized	0.1074	0.58	0.4974	0.68	0.0580	0.43
0.5D		Mitered End 1.5H:1V	0.0503	0.49	0.4384	0.69	0.4739	0.47
0.5D	90°	Square Headwall	0.0603	0.63	0.4525	0.71	0.0408	0.62
0.5D	45°	Beveled End	0.0451	0.40	0.4430	0.68	0.0330	0.64

These curves were visually verified by plotting the NCHRP data with the Hw/D results of the NBS computations.

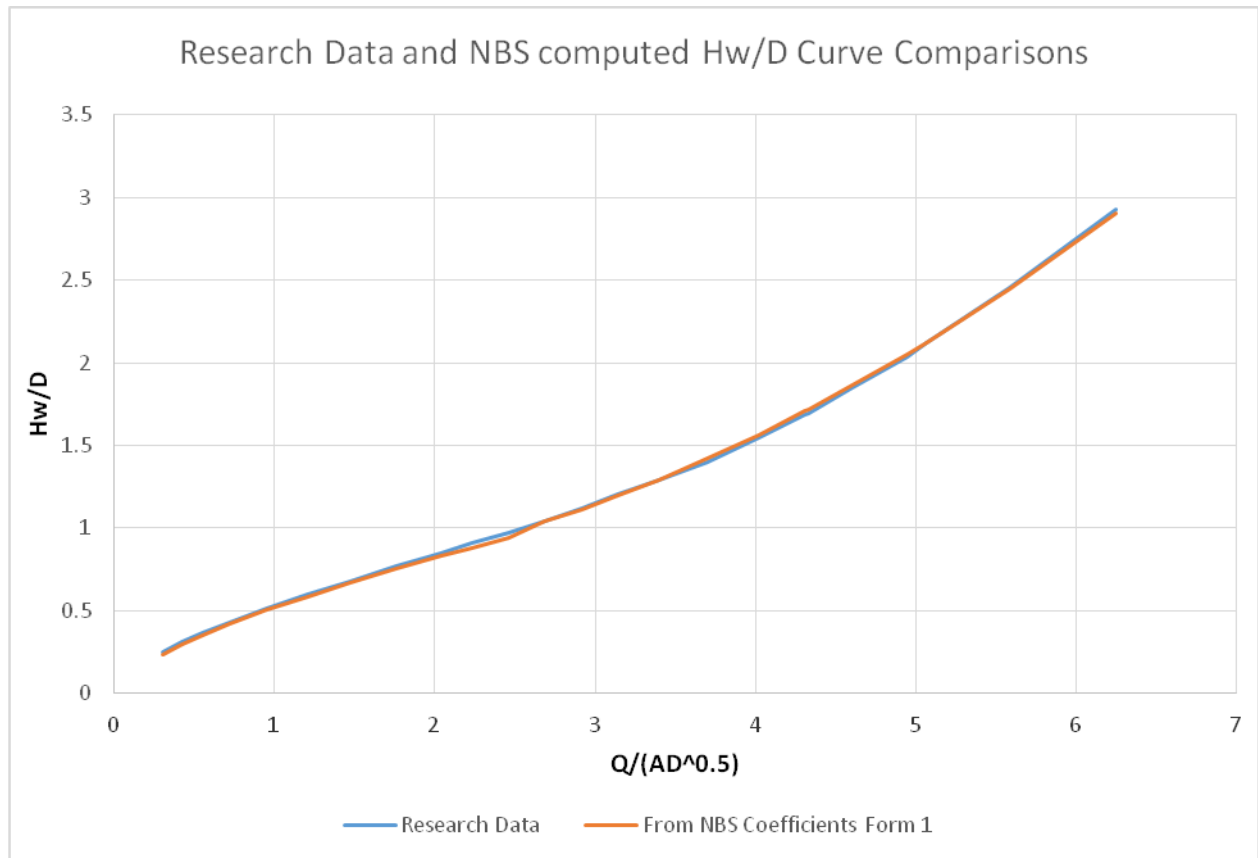


Figure 6: The research results and the NBS computed Hw/D results plotted together.

Conclusion

The flaws in the research data of the NCHRP report 734 has been corrected and coefficients developed that match the data. The polynomial coefficients were verified within the HY-8 program to approximate the research results. The NBS equation coefficients were verified through visually comparison.

Below are the final coefficients determined by this project.

Table 9: Polynomial Coefficients for a 20% embedded culvert.

20% embedment				
	projecting	mitered	square edge	beveled
a	9.2257E-02	7.2793E-02	8.5637E-02	3.6159E-02
b	5.9588E-01	6.1675E-01	5.5992E-01	6.6382E-01
c	-1.8034E-01	-2.3390E-01	-1.7619E-01	-2.4095E-01
d	4.4397E-02	6.5436E-02	4.4942E-02	5.6614E-02
e	-3.5559E-03	-7.1261E-03	-4.7677E-03	-5.6398E-03
f	1.0374E-04	2.9918E-04	2.0762E-04	2.2724E-04

Table 10: Polynomial Coefficients for a 40% embedded culvert.

40% embedment				
	projecting	mitered	square edge	beveled
a	4.8088E-03	7.5511E-02	7.1862E-02	1.6866E-01
b	7.9062E-01	5.4738E-01	5.4571E-01	3.0516E-01
c	-3.3201E-01	-2.0195E-01	-1.7331E-01	-1.5593E-02
d	9.2931E-02	5.9755E-02	4.7346E-02	4.9917E-03
e	-1.0003E-02	-6.6918E-03	-5.2299E-03	-8.8365E-04
f	3.9655E-04	2.8662E-04	2.2919E-04	7.3112E-05

Table 11: Polynomial Coefficients for a 50% embedded culvert.

50% embedment				
	projecting	mitered	square edge	beveled
a	2.6228E-02	-4.8002E-02	8.6634E-02	-6.1560E-02
b	6.5668E-01	7.6639E-01	4.3472E-01	5.7902E-01
c	-2.2467E-01	-3.4300E-01	-8.3362E-02	-1.6663E-01
d	5.6954E-02	9.2637E-02	1.5987E-02	3.0292E-02
e	-5.2307E-03	-9.8467E-03	-8.3244E-04	-2.3849E-03
f	1.8244E-04	3.8649E-04	1.1144E-05	7.2070E-05

Table 12: Coefficients for the NBS equations

Embedded	Top Edge	Inlet Configuration	Unsubmerged				Submerged	
			K Form 1	M Form 1	K Form 2	M Form 2	c	y
0.2D	thin	Projecting End, Ponded	0.1178	0.65	0.5337	0.66	0.0596	0.59
0.2D	thin	Projecting End, Channelized	0.0878	0.52	0.5180	0.63	0.0501	0.62
0.2D		Mitered End 1.5H:1V	0.0784	0.00	0.4976	0.63	0.0495	0.62
0.2D	90°	Square Headwall	0.0800	0.51	0.0404	0.66	0.0404	0.66
0.2D	45°	Beveled End	0.0635	0.43	0.4811	0.63	0.0321	0.72
0.4D	thin	Projecting End, Ponded	0.1214	0.67	0.5051	0.69	0.0577	0.60
0.4D	thin	Projecting End, Channelized	0.1349	0.53	0.5144	0.66	0.0542	0.53
0.4D		Mitered End 1.5H:1V	0.0681	0.60	0.4504	0.69	0.0488	0.57
0.4D	90°	Square Headwall	0.0849	0.60	0.4659	0.69	0.0422	0.63
0.4D	45°	Beveled End	0.0736	0.47	0.4709	0.67	0.0350	0.69
0.5D	thin	Projecting End, Ponded	0.1041	0.73	0.4963	0.71	0.0612	0.52
0.5D	thin	Projecting End, Channelized	0.1074	0.58	0.4974	0.68	0.0580	0.43
0.5D		Mitered End 1.5H:1V	0.0503	0.49	0.4384	0.69	0.4739	0.47
0.5D	90°	Square Headwall	0.0603	0.63	0.4525	0.71	0.0408	0.62
0.5D	45°	Beveled End	0.0451	0.40	0.4430	0.68	0.0330	0.64

Appendix A: Correcting NCHRP Table-2B

The first row shows the source of the data in the column. It may be from the NCHRP research data, computed, or from HY-8.

Table 13: Table 2B-1 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 1.15 and the corrected $AD^{0.5}$ is 1.699

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From NCHRP</u> <u>Original</u>	<u>Computed</u> <u>Corrected</u>
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.49	0.25	0.42	0.29
0.69	0.31	0.60	0.41
0.89	0.36	0.78	0.52
1.16	0.43	1.01	0.68
1.54	0.51	1.34	0.91
1.95	0.6	1.70	1.15
2.39	0.68	2.07	1.41
2.85	0.77	2.48	1.68
3.31	0.85	2.88	1.95
3.62	0.91	3.15	2.13
4	0.97	3.48	2.35
4.36	1.04	3.79	2.57
4.74	1.12	4.12	2.79
5.11	1.2	4.44	3.01
5.52	1.29	4.80	3.25
6.02	1.4	5.23	3.54
6.54	1.55	5.68	3.85
7	1.69	6.09	4.12
7.04	1.7	6.12	4.14
7.49	1.85	6.51	4.41
8.04	2.04	6.99	4.73
8.23	2.12	7.16	4.84
9.07	2.46	7.89	5.34
10.15	2.93	8.83	5.97

Table 14: Table 2B-2 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 1.15 and corrected $AD^{0.5}$ is 1.699

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.72	0.3	0.63	0.42
1.23	0.42	1.07	0.72
1.93	0.55	1.67	1.14
2.64	0.67	2.29	1.55
3.37	0.79	2.93	1.98
4.07	0.9	3.54	2.40
5.95	1.24	5.17	3.50
6.8	1.49	5.91	4.00
7.49	1.67	6.51	4.41
8.49	1.97	7.38	5.00
9.46	2.28	8.22	5.57

Table 15: Table 2B-3 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 1.15 and corrected $AD^{0.5}$ is 1.699

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.51	0.24	0.45	0.30
1.01	0.37	0.88	0.59
1.53	0.47	1.33	0.90
2.16	0.59	1.88	1.27
2.82	0.7	2.45	1.66
3.47	0.8	3.02	2.04
4.23	0.93	3.68	2.49
4.97	1.04	4.32	2.93
5.99	1.21	5.21	3.53
6.99	1.41	6.07	4.11
7.99	1.64	6.95	4.70
9.06	1.92	7.88	5.33
10.01	2.19	8.70	5.89

Table 16: Table 2B-4 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 1.15 and corrected $AD^{0.5}$ is 1.699

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.52	0.23	0.45	0.31
1	0.36	0.87	0.59
1.52	0.46	1.32	0.89
2.23	0.59	1.94	1.31
3.03	0.71	2.63	1.78
3.79	0.82	3.29	2.23
4.52	0.93	3.93	2.66
6.75	1.27	5.87	3.97
7.47	1.39	6.49	4.40
8.59	1.61	7.47	5.06
8.94	1.68	7.77	5.26
9.85	1.89	8.56	5.80

Table 17: Table 2B-5 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.92 and corrected $AD^{0.5}$ is 1.092

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.58	0.34	0.63	0.53
1.01	0.5	1.09	0.92
1.48	0.65	1.61	1.36
1.9	0.77	2.07	1.74
2.32	0.89	2.51	2.12
2.74	1.01	2.98	2.51
4.37	1.64	4.75	4.00
5.3	2.16	5.76	4.85
6.18	2.75	6.7	5.66
6.96	3.36	7.55	6.37
7.64	3.79	8.3	7.00
8.23	4.31	8.94	7.54
8.74	4.68	9.48	8.00

Table 18: Table 2B-6 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.92 and corrected $AD^{0.5}$ is 1.092

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.81	0.39	0.9	0.7
1.18	0.5	1.3	1.1
1.79	0.65	2.0	1.6
2.35	0.79	2.6	2.2
2.71	0.88	2.9	2.5
3.06	0.96	3.3	2.8
4.64	1.56	5.0	4.2
5.07	1.75	5.5	4.6
5.39	1.91	5.9	4.9
5.73	2.09	6.2	5.2
6.16	2.33	6.7	5.6
6.46	2.5	7.0	5.9
7.06	2.86	7.7	6.5

Table 19: Table 2B-7 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.92 and corrected $AD^{0.5}$ is 1.092

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.64	0.34	0.7	0.59
0.88	0.42	0.95	0.81
1.14	0.5	1.23	1.04
1.83	0.69	1.98	1.68
2.56	0.87	2.77	2.34
4.99	1.62	5.42	4.57
6.76	2.46	7.34	6.19
8.01	3.2	8.69	7.34
8.87	3.73	9.63	8.12

Table 20: Table 2B-8 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.92 and corrected $AD^{0.5}$ is 1.092

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.63	0.33	0.69	0.576923
1.23	0.51	1.33	1.13
1.85	0.67	2.01	1.69
2.59	0.84	2.82	2.37
5.53	1.59	6	5.06
6.99	2.13	7.59	6.40
8.05	2.61	8.74	7.37
9.19	3.17	9.98	8.42

Table 21: Table 2B-9 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.75 and corrected $AD^{0.5}$ is 0.776

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.400	0.32	0.53	0.52
0.64	0.44	0.85	0.82
0.89	0.55	1.18	1.15
1.21	0.69	1.61	1.56
1.50	0.8	1.98	1.93
1.76	0.91	2.33	2.27
2.58	1.26	3.41	3.32
3.18	1.59	4.20	4.10
3.55	1.84	4.70	4.57
4.42	2.61	5.85	5.70
4.52	2.69	5.97	5.82
5.12	3.3	6.77	6.60
5.71	3.98	7.55	7.36
6.39	4.86	8.45	8.23

Table 22: Table 2B-10 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.75 and corrected $AD^{0.5}$ is 0.776

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.45	0.31	0.59	0.58
0.63	0.39	0.83	0.81
0.87	0.48	1.15	1.12
1.12	0.57	1.48	1.44
1.52	0.71	2.01	1.96
1.86	0.82	2.46	2.40
2.18	0.92	2.88	2.81
2.49	1.01	3.29	3.21
3.02	1.27	3.99	3.89
3.68	1.69	4.87	4.74
4.03	1.98	5.33	5.19
4.49	2.31	5.93	5.79
5.03	2.77	6.65	6.48
5.54	3.26	7.33	7.14
6.00	3.66	7.94	7.73
6.58	4.31	8.7	8.48

Table 23: Table 2B-11 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.75 and corrected $AD^{0.5}$ is 0.776

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.42	0.3	0.55	0.54
0.77	0.45	1.01	0.99
1.11	0.58	1.47	1.43
1.57	0.75	2.08	2.02
2.00	0.89	2.64	2.58
2.62	1.11	3.46	3.38
3.11	1.31	4.12	4.01
3.66	1.59	4.84	4.72
4.57	2.09	6.04	5.89
5.46	2.74	7.23	7.04
6.34	3.49	8.39	8.17
7.47	4.58	9.88	9.63

Table 24: Table 2B-12 with corrected $Q/(AD^{0.5})$ values. The original $AD^{0.5}$ value was originally 0.75 and corrected $AD^{0.5}$ is 0.776

<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u>	<u>From</u> <u>NCHRP</u> Original	<u>Computed</u> Corrected
Q (cfs)	Hw/D	$Q/(AD^{0.5})$	$Q/(AD^{0.5})$
0.50	0.33	0.66	0.64
0.86	0.48	1.14	1.11
1.18	0.59	1.56	1.53
1.63	0.73	2.15	2.10
2.09	0.87	2.75	2.69
3.09	1.19	4.08	3.99
3.67	1.40	4.84	4.73
4.57	1.84	6.02	5.89
5.51	2.38	7.26	7.10
6.56	3.12	8.65	8.46
7.61	3.94	10.04	9.81

Appendix B: Tables Comparing Table 2B to HY-8 Computation Results

Table 25: Table 2B-1 with corrected values compared to HY-8 results

<u>From</u> NCHRP	<u>Computed</u> Corrected	<u>From</u> NCHRP	<u>Computed</u>	<u>From</u> HY-8	Difference
Q (cfs)	$Q/(A(D)^{0.5})$	Hw/D	Hw (ft)	HW (ft)	(ft)
0.49	0.29	0.25	0.30	0.32	0.02
0.69	0.41	0.31	0.38	0.39	0.01
0.89	0.52	0.36	0.44	0.46	0.02
1.16	0.68	0.43	0.52	0.55	0.03
1.54	0.91	0.51	0.62	0.65	0.03
1.95	1.15	0.6	0.73	0.76	0.03
2.39	1.41	0.68	0.83	0.87	0.04
2.85	1.68	0.77	0.93	0.97	0.04
3.31	1.95	0.85	1.03	1.07	0.04
3.62	2.13	0.91	1.10	1.14	0.04
4	2.35	0.97	1.18	1.22	0.04
4.36	2.57	1.04	1.26	1.29	0.03
4.74	2.79	1.12	1.36	1.37	0.01
5.11	3.01	1.2	1.46	1.44	-0.02
5.52	3.25	1.29	1.57	1.54	-0.03
6.02	3.54	1.4	1.70	1.69	-0.01
6.54	3.85	1.55	1.88	1.86	-0.02
7	4.12	1.69	2.05	2.03	-0.02
7.04	4.14	1.7	2.06	2.04	-0.02
7.49	4.41	1.85	2.25	2.22	-0.03
8.04	4.73	2.04	2.48	2.46	-0.02
8.23	4.84	2.12	2.57	2.54	-0.03
9.07	5.34	2.46	2.99	2.95	-0.04
10.15	5.97	2.93	3.56	3.55	-0.01

Table 26: Table 2B-2 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u> <u>Corrected</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u> Difference
Q (cfs)	$Q/(A(D)^{0.5})$	Hw/D	Hw (ft)	HW (ft)	(ft)
0.72	0.42	0.30	0.36	0.35	-0.01
1.23	0.72	0.42	0.51	0.49	-0.02
1.93	1.14	0.55	0.67	0.66	-0.01
2.64	1.55	0.67	0.81	0.80	-0.01
3.37	1.98	0.79	0.96	0.93	-0.03
4.07	2.40	0.90	1.09	1.07	-0.02
5.95	3.50	1.24	1.51	1.51	0.00
6.8	4.00	1.49	1.81	1.76	-0.05
7.49	4.41	1.67	2.03	1.99	-0.04
8.49	5.00	1.97	2.39	2.37	-0.02
9.46	5.57	2.28	2.77	2.77	0.00

Table 27: Table 2B-3 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u> <u>Corrected</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u> Difference
Q (cfs)	$Q/(AD^{0.5})$	Hw/D	Hw (ft)	HW (ft)	(ft)
0.51	0.30	0.24	0.29	0.28	-0.01
1.01	0.59	0.37	0.45	0.43	-0.02
1.53	0.90	0.47	0.57	0.56	-0.01
2.16	1.27	0.59	0.72	0.70	-0.02
2.82	1.66	0.7	0.85	0.83	-0.02
3.47	2.04	0.8	0.97	0.95	-0.02
4.23	2.49	0.93	1.13	1.10	-0.03
4.97	2.93	1.04	1.26	1.24	-0.02
5.99	3.53	1.21	1.47	1.46	-0.01
6.99	4.11	1.41	1.71	1.70	-0.01
7.99	4.70	1.64	1.99	1.97	-0.02
9.06	5.33	1.92	2.33	2.30	-0.03
10.01	5.89	2.19	2.66	2.63	-0.03

Table 28: Table 2B-4 with corrected values compared to HY-8 results

<u>From</u> NCHRP	<u>Computed</u> Corrected	<u>From</u> NCHRP	<u>Computed</u>	<u>From</u> HY-8	<u>From</u> NCHRP Difference
Q (cfs)	Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	(ft)
0.52	0.31	0.23	0.28	0.28	0.00
1.00	0.59	0.36	0.44	0.43	-0.01
1.52	0.89	0.46	0.56	0.56	0.00
2.23	1.31	0.59	0.72	0.72	0.00
3.03	1.78	0.71	0.86	0.86	0.00
3.79	2.23	0.82	1.00	0.98	-0.02
4.52	2.66	0.93	1.13	1.12	-0.01
6.75	3.97	1.27	1.54	1.49	-0.05
7.47	4.40	1.39	1.69	1.65	-0.04
8.59	5.06	1.61	1.95	1.94	-0.01
8.94	5.26	1.68	2.04	2.04	0.00
9.85	5.80	1.89	2.29	2.33	0.04

Table 29: Table 2B-5 with corrected values compared to HY-8 results

<u>From</u> NCHRP	<u>Computed</u> Corrected	<u>From</u> NCHRP	<u>Computed</u>	<u>From</u> HY-8	<u>From</u> NCHRP Difference
Q (cfs)	Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	(ft)
0.58	0.531136	0.34	0.312233	0.31	-0.00223
1.01	0.924908	0.5	0.459167	0.45	-0.00917
1.48	1.355311	0.65	0.596917	0.58	-0.01692
1.9	1.739927	0.77	0.707117	0.69	-0.01712
2.32	2.124542	0.89	0.817317	0.79	-0.02732
2.74	2.509158	1.01	0.927517	0.91	-0.01752
4.37	4.001832	1.64	1.506067	1.52	0.013933
5.3	4.85348	2.16	1.9836	2	0.0164
6.18	5.659341	2.75	2.525417	2.53	0.004583
6.96	6.373626	3.36	3.0856	3.0547	-0.0309
7.64	6.996337	3.79	3.480483	3.5326	0.052117
8.23	7.53663	4.31	3.958017	3.9796	0.021583
8.74	8.003663	4.68	4.2978	4.4036	0.1058

Table 30: Table 2B-6 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u>
Q (cfs)	Corrected Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	Difference (ft)
0.81	0.741758	0.39	0.35815	0.34	-0.01815
1.18	1.080586	0.5	0.459167	0.44	-0.01917
1.79	1.639194	0.65	0.596917	0.58	-0.01692
2.35	2.152015	0.79	0.725483	0.71	-0.01548
2.71	2.481685	0.88	0.808133	0.79	-0.01813
3.06	2.802198	0.96	0.8816	0.89	0.0084
4.64	4.249084	1.56	1.4326	1.43	-0.0026
5.07	4.642857	1.75	1.607083	1.61	0.002917
5.39	4.935897	1.91	1.754017	1.76	0.005983
5.73	5.247253	2.09	1.919317	1.93	0.010683
6.16	5.641026	2.33	2.139717	2.15	0.010283
6.46	5.915751	2.5	2.295833	2.31	0.014167
7.06	6.465201	2.86	2.626433	2.66	0.033567

Table 31: Table 2B-7 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u>
Q (cfs)	Corrected Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	Difference (ft)
0.64	0.586081	0.34	0.312233	0.3	-0.01223
0.88	0.805861	0.42	0.3857	0.38	-0.0057
1.14	1.043956	0.5	0.459167	0.45	-0.00917
1.83	1.675824	0.69	0.63365	0.62	-0.01365
2.56	2.344322	0.87	0.79895	0.78	-0.01895
4.99	4.569597	1.62	1.4877	1.51	0.0223
6.76	6.190476	2.46	2.2591	2.26	0.0009
8.01	7.335165	3.2	2.938667	2.93358	-0.00509
8.87	8.122711	3.73	3.425383	3.52	0.094617

Table 32: Table 2B-8 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u> <u>Corrected</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u> Difference
Q (cfs)	Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	(ft)
0.63	0.576923	0.33	0.30305	0.28	-0.02305
1.23	1.126374	0.51	0.46835	0.44	-0.02835
1.85	1.694139	0.67	0.615283	0.59	-0.02528
2.59	2.371795	0.84	0.7714	0.77	-0.0014
5.53	5.064103	1.59	1.46015	1.49	0.02985
6.99	6.401099	2.13	1.95605	1.93	-0.02605
8.05	7.371795	2.61	2.39685	2.36	-0.03685
9.19	8.415751	3.17	2.911117	3.0487	0.137583

Table 33: Table 2B-9 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u> <u>Corrected</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u> Difference
Q (cfs)	Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	(ft)
0.4	0.515464	0.32	0.241333	0.24	-0.00133
0.64	0.824742	0.44	0.331833	0.33	-0.00183
0.89	1.146907	0.55	0.414792	0.42	0.005208
1.21	1.559278	0.69	0.520375	0.51	-0.01038
1.5	1.93299	0.8	0.603333	0.6	-0.00333
1.76	2.268041	0.91	0.686292	0.67	-0.01629
2.58	3.324742	1.26	0.95025	0.95	-0.00025
3.18	4.097938	1.59	1.199125	1.22	0.020875
3.55	4.574742	1.84	1.387667	1.43	0.042333
4.42	5.695876	2.61	1.968375	2	0.031625
4.52	5.824742	2.69	2.028708	2.08	0.051292
5.12	6.597938	3.3	2.48875	2.5649	0.07615
5.71	7.358247	3.98	3.001583	3.098	0.096417
6.39	8.234536	4.86	3.66525	3.783	0.11775

Table 34: Table 2B-10 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u>
Q (cfs)	Corrected Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	Difference (ft)
0.45	0.579897	0.31	0.23	0.23	0.00
0.63	0.811856	0.39	0.29	0.29	0.00
0.87	1.121134	0.48	0.36	0.37	0.01
1.12	1.443299	0.57	0.43	0.43	0.00
1.52	1.958763	0.71	0.54	0.52	-0.02
1.86	2.396907	0.82	0.62	0.60	-0.02
2.18	2.809278	0.92	0.69	0.68	-0.01
2.49	3.208763	1.01	0.76	0.78	0.02
3.02	3.891753	1.27	0.96	0.98	0.02
3.68	4.742268	1.69	1.27	1.31	0.04
4.03	5.193299	1.98	1.49	1.50	0.01
4.49	5.786082	2.31	1.74	1.79	0.05
5.03	6.481959	2.77	2.09	2.14	0.05
5.54	7.139175	3.26	2.46	2.51	0.05
6	7.731959	3.66	2.76	2.86	0.10
6.58	8.479381	4.31	3.25	3.35	0.10

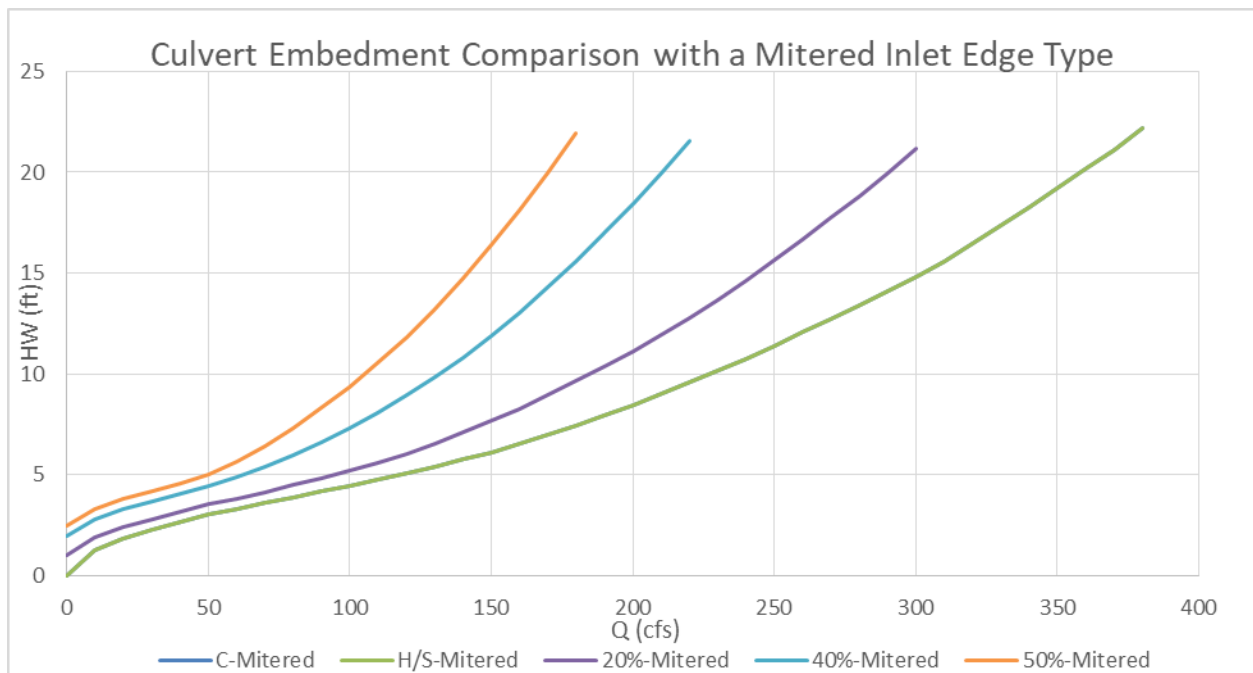
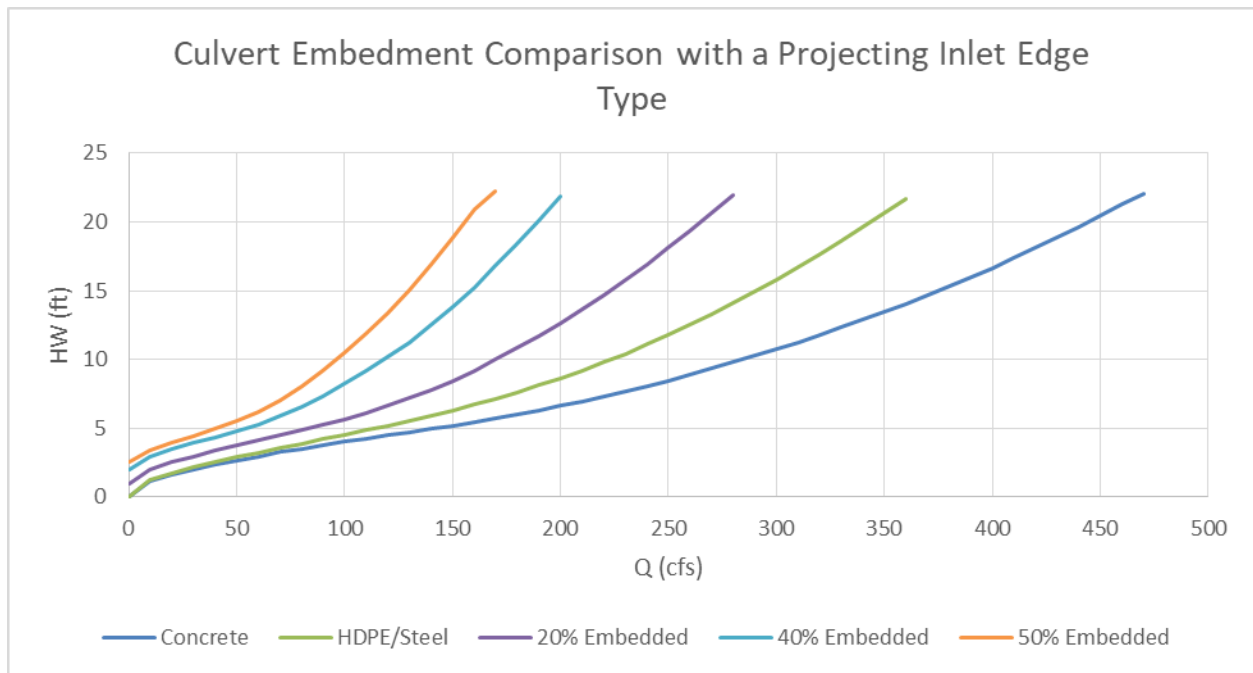
Table 35: Table 2B-11 with corrected values compared to HY-8 results

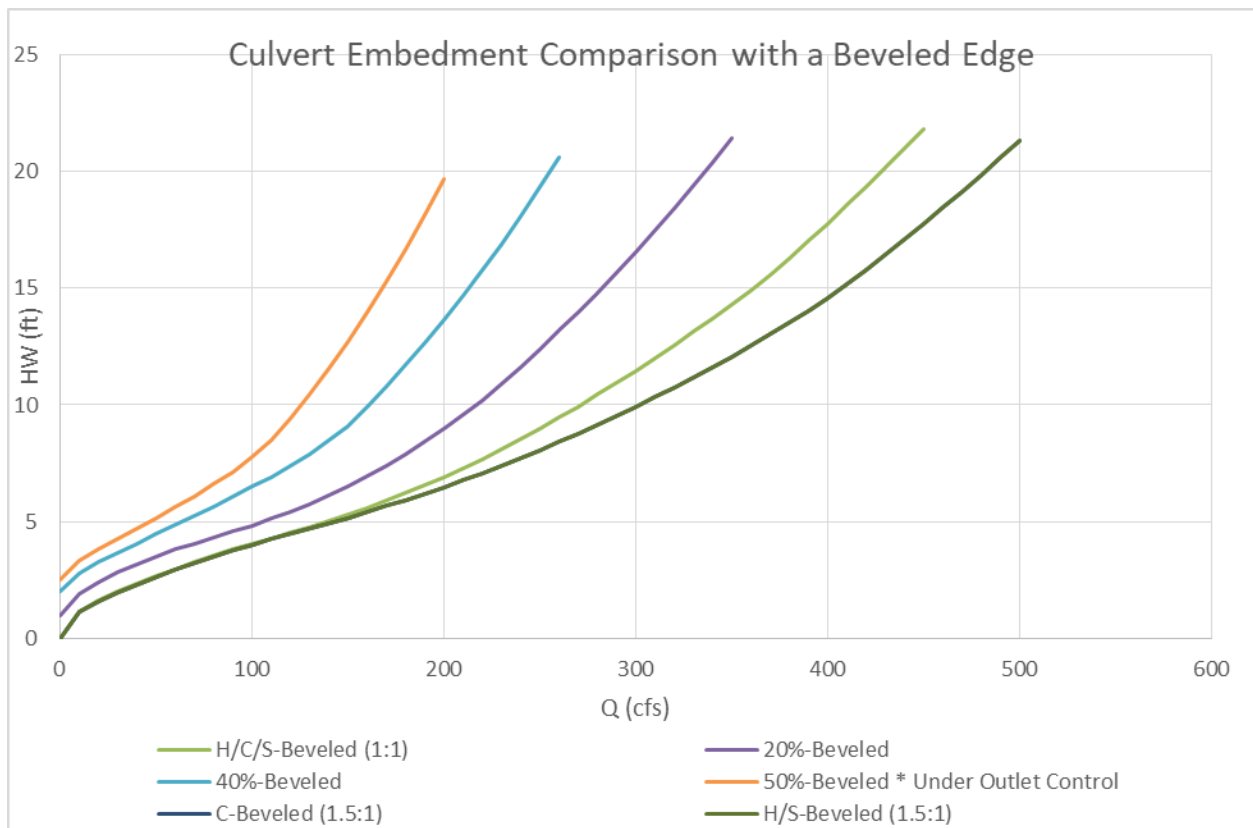
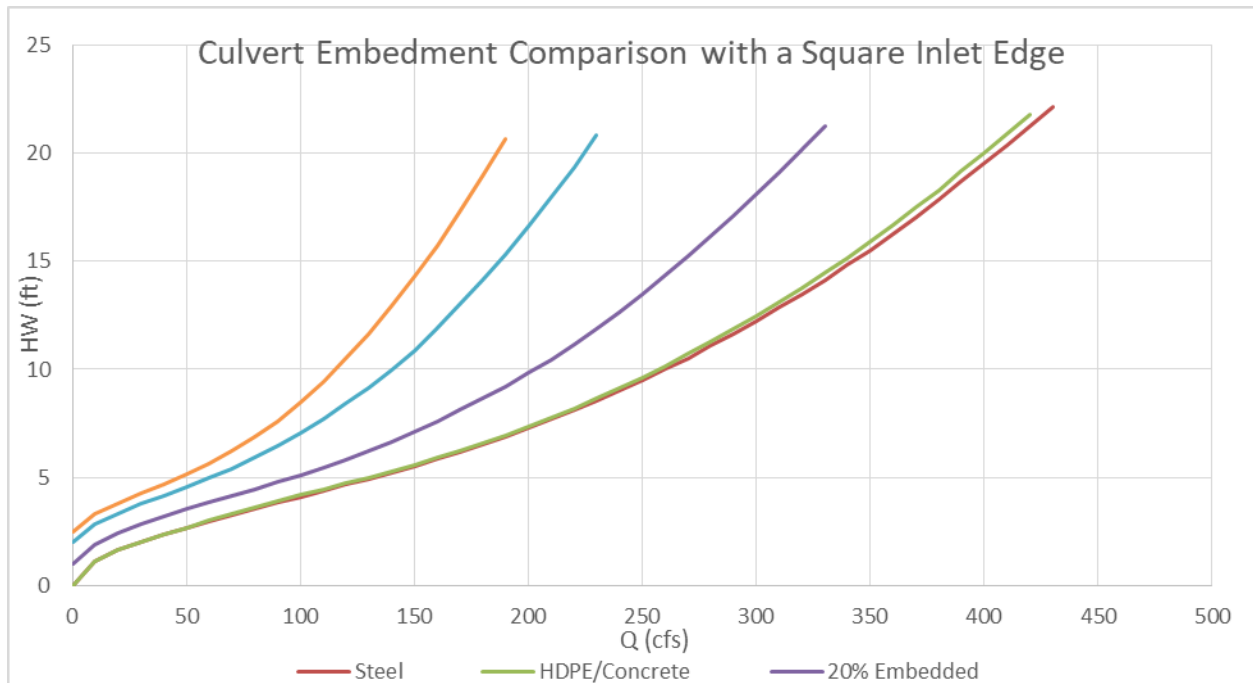
<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u>
Q (cfs)	Corrected Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	Difference (ft)
0.42	0.541237	0.3	0.2277	0.24	0.01
0.77	0.992268	0.45	0.34155	0.36	0.02
1.11	1.430412	0.58	0.44022	0.43	-0.01
1.57	2.023196	0.75	0.56925	0.55	-0.02
2	2.57732	0.89	0.67551	0.7	0.02
2.62	3.376289	1.11	0.84249	0.85	0.01
3.11	4.007732	1.31	0.99429	0.98	-0.01
3.66	4.716495	1.59	1.20681	1.17	-0.04
4.57	5.889175	2.09	1.58631	1.56	-0.03
5.46	7.036082	2.74	2.07966	2.04	-0.04
6.34	8.170103	3.49	2.64891	2.59391	-0.06
7.47	9.626289	4.58	3.47622	3.40896	-0.07

Table 36: Table 2B-12 with corrected values compared to HY-8 results

<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>NCHRP</u>	<u>Computed</u>	<u>From</u> <u>HY-8</u>	<u>From</u> <u>NCHRP</u>
Q (cfs)	Corrected Q/(AD ^{0.5})	Hw/D	Hw (ft)	HW (ft)	Difference (ft)
0.50	0.641459	0.327442	0.25	0.24	-0.01
0.86	1.110555	0.475739	0.36	0.35	-0.01
1.18	1.525332	0.589471	0.44	0.43	-0.01
1.63	2.097422	0.733307	0.55	0.54	-0.01
2.09	2.688829	0.873799	0.66	0.64	-0.02
3.09	3.987725	1.189348	0.90	0.88	-0.02
3.67	4.728265	1.397855	1.05	1.05	0.00
4.57	5.885509	1.841631	1.39	1.36	-0.03
5.51	7.096236	2.380182	1.80	1.77	-0.03
6.56	8.45975	3.122782	2.36	2.32	-0.04
7.61	9.812638	3.935627	2.97	2.93	-0.04

Appendix C: Plots Comparing Embedment Levels





Appendix D NBS Computation Tables and Plots

Table 37: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a projecting inlet edge type with an upstream pond.

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3006	0.2516	0.0600	0.2418	0.0098
0.4245	0.3105	0.0700	0.3043	0.0062
0.5504	0.3638	0.0700	0.3602	0.0036
0.7159	0.4289	0.0800	0.4289	0.0000
0.9464	0.5116	0.0900	0.5162	0.0046
1.2027	0.5965	0.1100	0.6025	0.0060
1.4674	0.6792	0.1200	0.6875	0.0083
1.7532	0.7689	0.1400	0.7719	0.0030
2.0392	0.8516	0.1600	0.8516	0.0000
2.2298	0.9084	0.1800	0.9036	0.0048
2.4599	0.9735	0.1900	0.9653	0.0082
2.6831	1.0394	0.2100	1.0222	0.0172
2.9130	1.1214	0.2500	1.0989	0.0225
3.1427	1.2020	0.2800	1.1818	0.0202
3.3980	1.2938	0.3200	1.2813	0.0125
3.7017	1.4011	0.3700	1.4099	0.0088
4.0214	1.5490	0.4600	1.5571	0.0081
4.3094	1.6898	0.5400	1.7001	0.0103
4.3336	1.6976	0.5400	1.7126	0.0150
4.6059	1.8489	0.6400	1.8577	0.0088
4.9481	2.0382	0.7600	2.0526	0.0144
5.0661	2.1230	0.8200	2.1230	0.0000
5.5822	2.4573	1.0500	2.4506	0.0067
6.2466	2.9297	1.3900	2.9191	0.0106
K	0.1178		Average Difference	0.0087
M	0.56			
c	0.0596			
Y	0.59			

NBS and Data Curve Comparisons

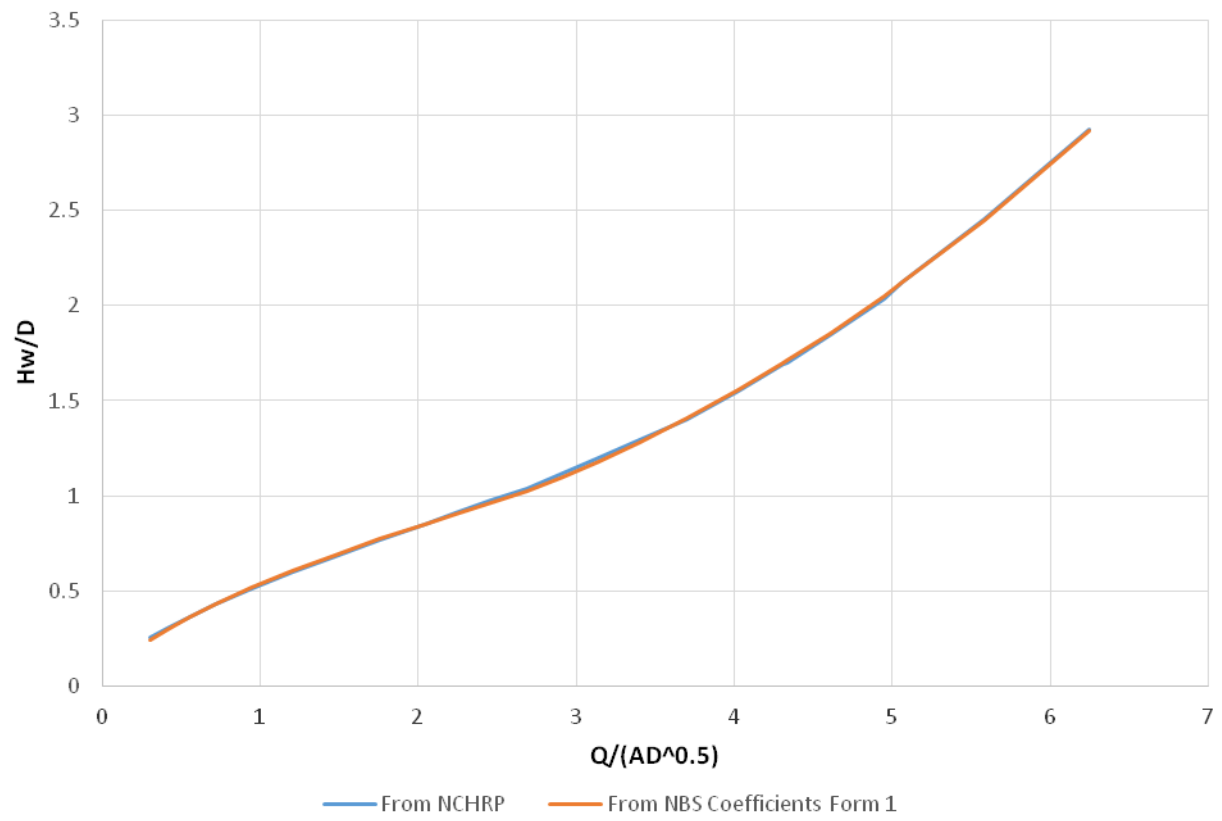


Table 38: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a projecting inlet edge type and an upstream channel

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3149	0.2551	0.0557	0.2407	0.0144
0.6271	0.3855	0.0689	0.3763	0.0092
0.9377	0.4948	0.0824	0.4839	0.0109
1.3415	0.6224	0.1010	0.6074	0.0150
1.6217	0.7016	0.1113	0.6861	0.0155
1.8820	0.7731	0.1220	0.7536	0.0195
2.3077	0.8838	0.1385	0.8583	0.0255
2.7786	1.0072	0.1626	1.0072	0.0000
2.9130	1.0450	0.1728	1.0455	0.0005
3.2354	1.1460	0.2084	1.1449	0.0011
3.4739	1.2125	0.2273	1.2251	0.0126
3.6970	1.3114	0.2818	1.3053	0.0061
3.8445	1.3709	0.3121	1.3611	0.0098
4.1407	1.4880	0.3706	1.4797	0.0083
4.3094	1.5511	0.4004	1.5511	0.0000
4.6547	1.6863	0.4672	1.7063	0.0200
5.0901	1.8826	0.5761	1.9190	0.0364
5.5447	2.1461	0.7467	2.1613	0.0152
6.1710	2.5470	1.0152	2.5291	0.0179
K	0.0878		Average Difference	0.0125
M	0.52			
c	0.0501			
Y	0.62			

NBS and Data Curve Comparisons

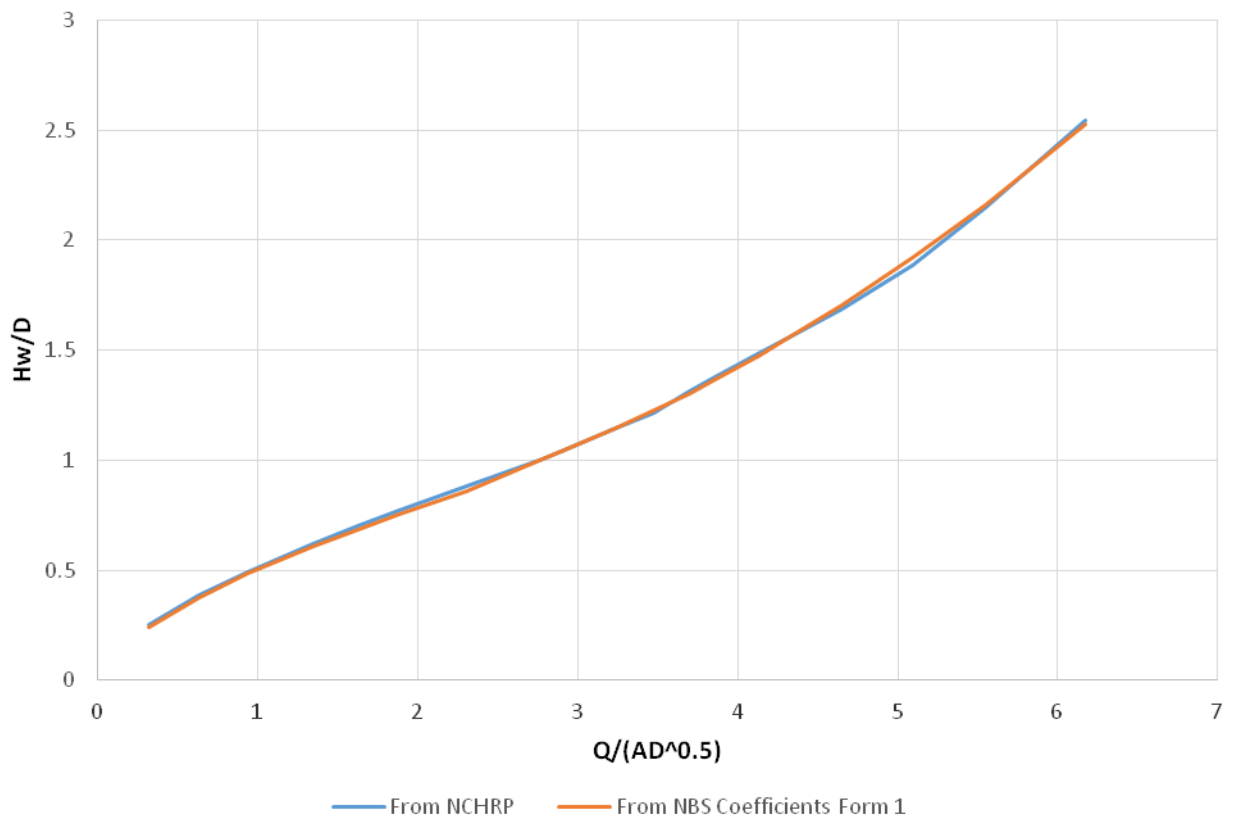


Table 39: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a square inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3154	0.2382	0.0382	0.2369	0.0013
0.6210	0.3684	0.0535	0.3678	0.0006
0.9412	0.4749	0.0610	0.4787	0.0038
1.3280	0.5912	0.0729	0.5949	0.0037
1.7351	0.7005	0.0829	0.7038	0.0033
2.1337	0.8034	0.0956	0.8034	0.0000
2.6018	0.9260	0.1178	0.9136	0.0124
3.0558	1.0402	0.1385	1.0402	0.0000
3.6842	1.2132	0.1857	1.2112	0.0020
4.2934	1.4065	0.2586	1.4075	0.0010
4.9119	1.6405	0.3695	1.6374	0.0031
5.5709	1.9164	0.5113	1.9164	0.0000
6.1541	2.1875	0.6589	2.1926	0.0051
K	0.0800		Average Difference	0.0028
M	0.51			
c	0.0404			
Y	0.66			

NBS and Data Curve Comparisons

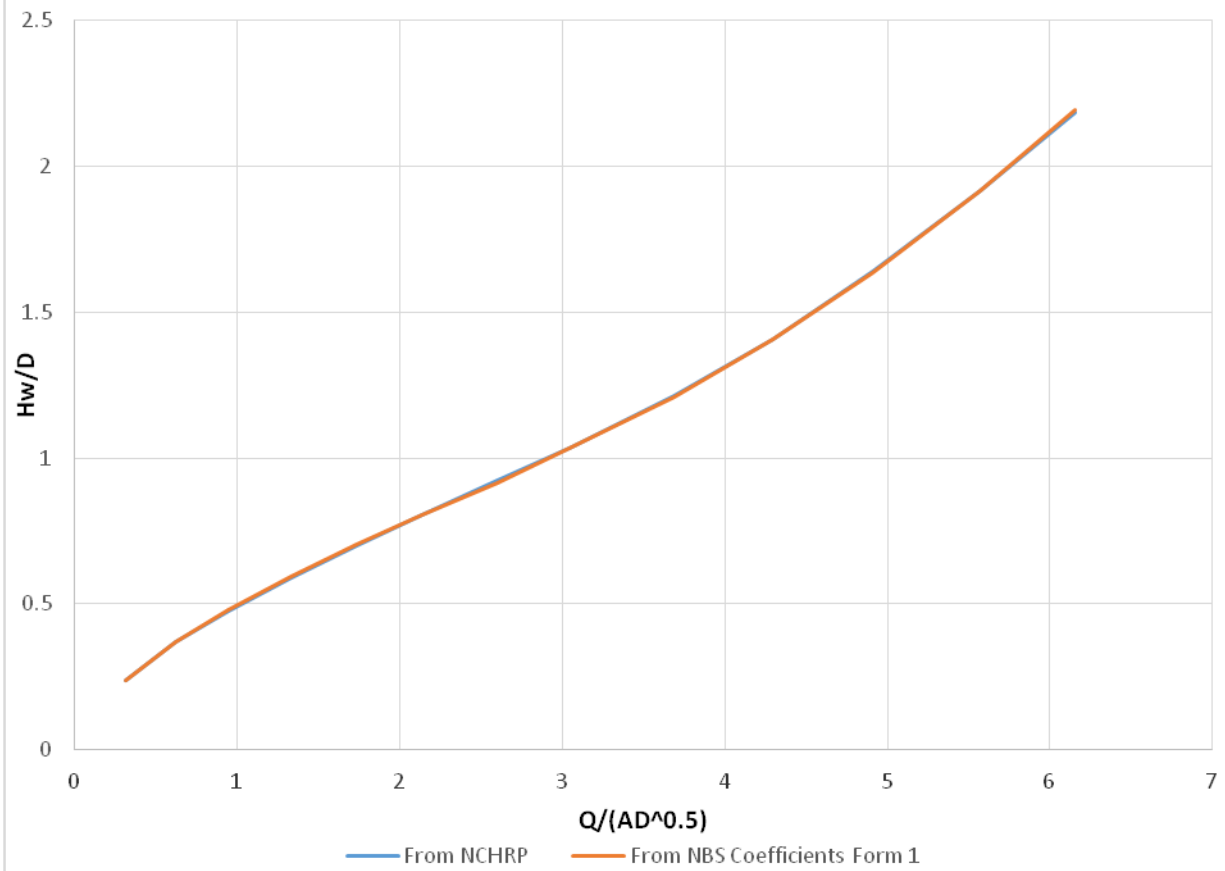


Table 40: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a 45° beveled inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3170	0.2331	0.0324	0.2336	0.0005
0.6139	0.3564	0.0439	0.3543	0.0021
0.9325	0.4608	0.0494	0.4606	0.0002
1.3736	0.5861	0.0563	0.5861	0.0000
1.8606	0.7087	0.0621	0.7100	0.0013
2.3268	0.8194	0.0695	0.8194	0.0000
2.7761	0.9308	0.0863	0.9180	0.0128
4.1495	1.2698	0.1503	1.2698	0.0000
4.5904	1.3910	0.1842	1.3934	0.0024
5.2797	1.6130	0.2677	1.6115	0.0015
5.4924	1.6844	0.2955	1.6850	0.0006
6.0546	1.8932	0.3860	1.8932	0.0000
K	0.0635		Average Difference	0.0016
M	0.43			
c	0.0321			
Y	0.72			

NBS and Data Curve Comparisons

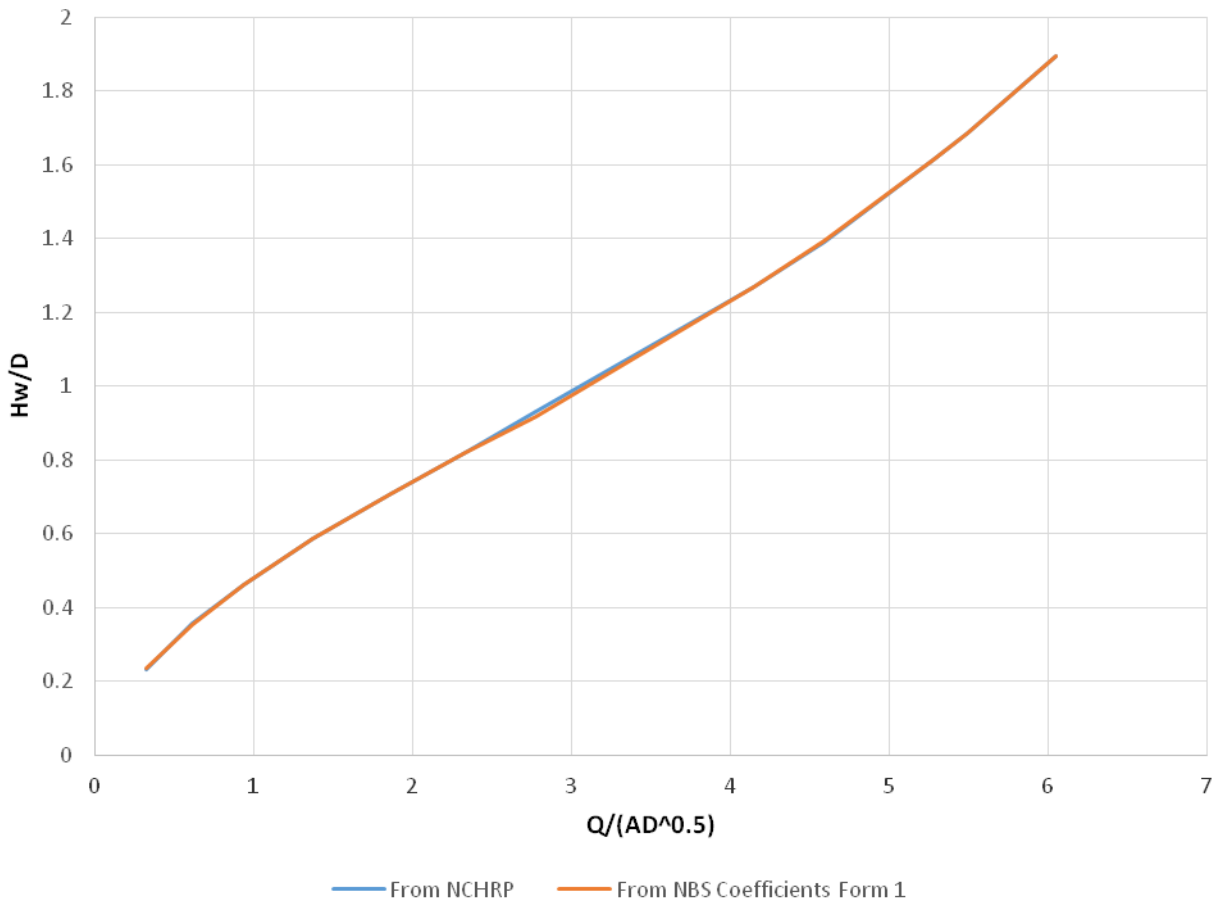


Table 41: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with an 1.5H:1V mitered inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.4450	0.3026	0.0175	0.3064	0.0038
0.7543	0.4168	0.0260	0.4145	0.0023
1.1844	0.5506	0.0368	0.5449	0.0057
1.6202	0.6710	0.0479	0.6684	0.0026
2.0693	0.7859	0.0596	0.7951	0.0092
2.4997	0.9008	0.0813	0.9189	0.0181
3.6558	1.2426	0.1880	1.2836	0.0410
4.1787	1.4864	0.3284	1.4864	0.0000
4.6017	1.6713	0.4295	1.6702	0.0011
5.2202	1.9711	0.6051	1.9710	0.0001
5.8118	2.2814	0.7931	2.2940	0.0126
K	0.0784		Average Difference	0.0074
M	0.00			
c	0.0495			
Y	0.62			

NBS and Data Curve Comparisons

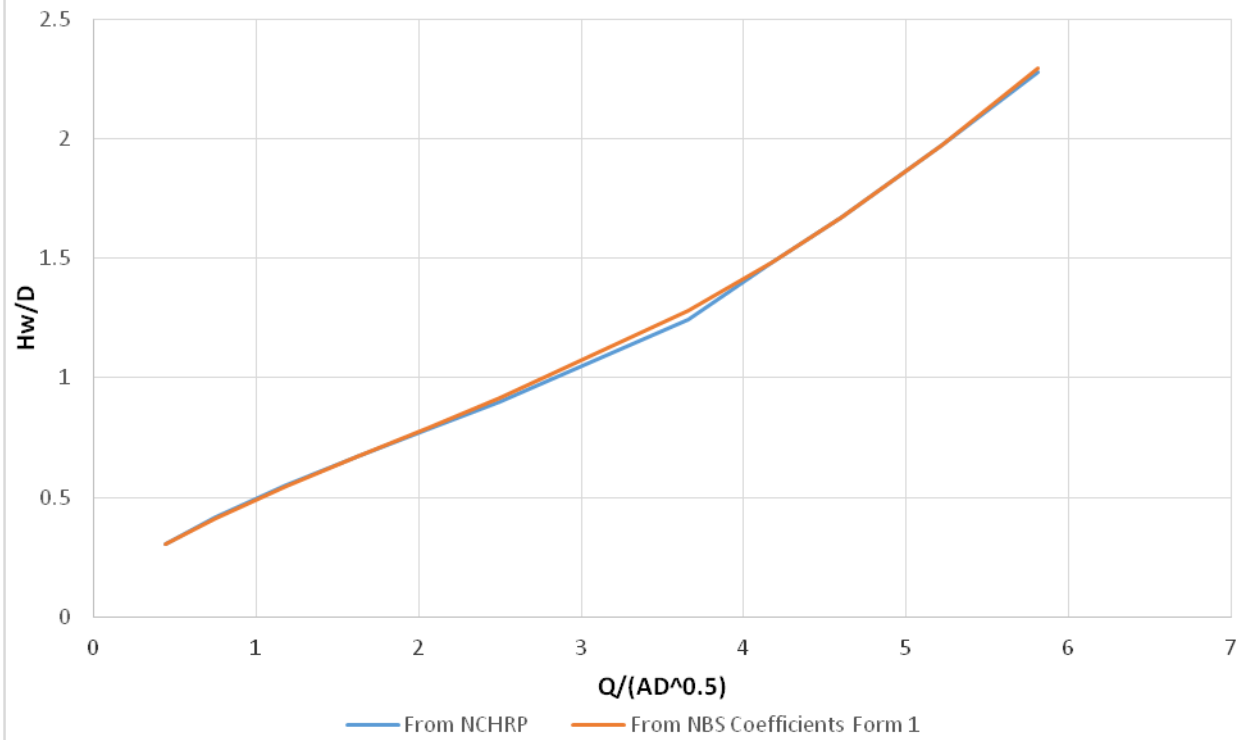


Table 42: Table used for Form 2 NBS Coefficients for a 20% embedded culvert with a projecting inlet edge type with an upstream pond.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3006	0.2516	0.2426	0.0090
0.4245	0.3105	0.3043	0.0062
0.5504	0.3638	0.3608	0.0030
0.7159	0.4289	0.4287	0.0002
0.9464	0.5116	0.5148	0.0032
1.2027	0.5965	0.6024	0.0059
1.4674	0.6792	0.6863	0.0071
1.7532	0.7689	0.7713	0.0024
2.0392	0.8516	0.8516	0.0000
2.2298	0.9084	0.9030	0.0054
2.4599	0.9735	0.9631	0.0104
2.6831	1.0394	1.0222	0.0172
2.9130	1.1214	1.0989	0.0225
3.1427	1.2020	1.1818	0.0202
3.3980	1.2938	1.2813	0.0125
3.7017	1.4011	1.4099	0.0088
4.0214	1.5490	1.5571	0.0081
4.3094	1.6898	1.7001	0.0103
4.3336	1.6976	1.7126	0.0150
4.6059	1.8489	1.8577	0.0088
4.9481	2.0382	2.0526	0.0144
5.0661	2.1230	2.1230	0.0000
5.5822	2.4573	2.4506	0.0067
6.2466	2.9297	2.9191	0.0106
K		Average	
	0.5337	Difference	0.0087
M	0.66		
c	0.0596		
Y	0.59		

NBS and Data Curve Comparisons

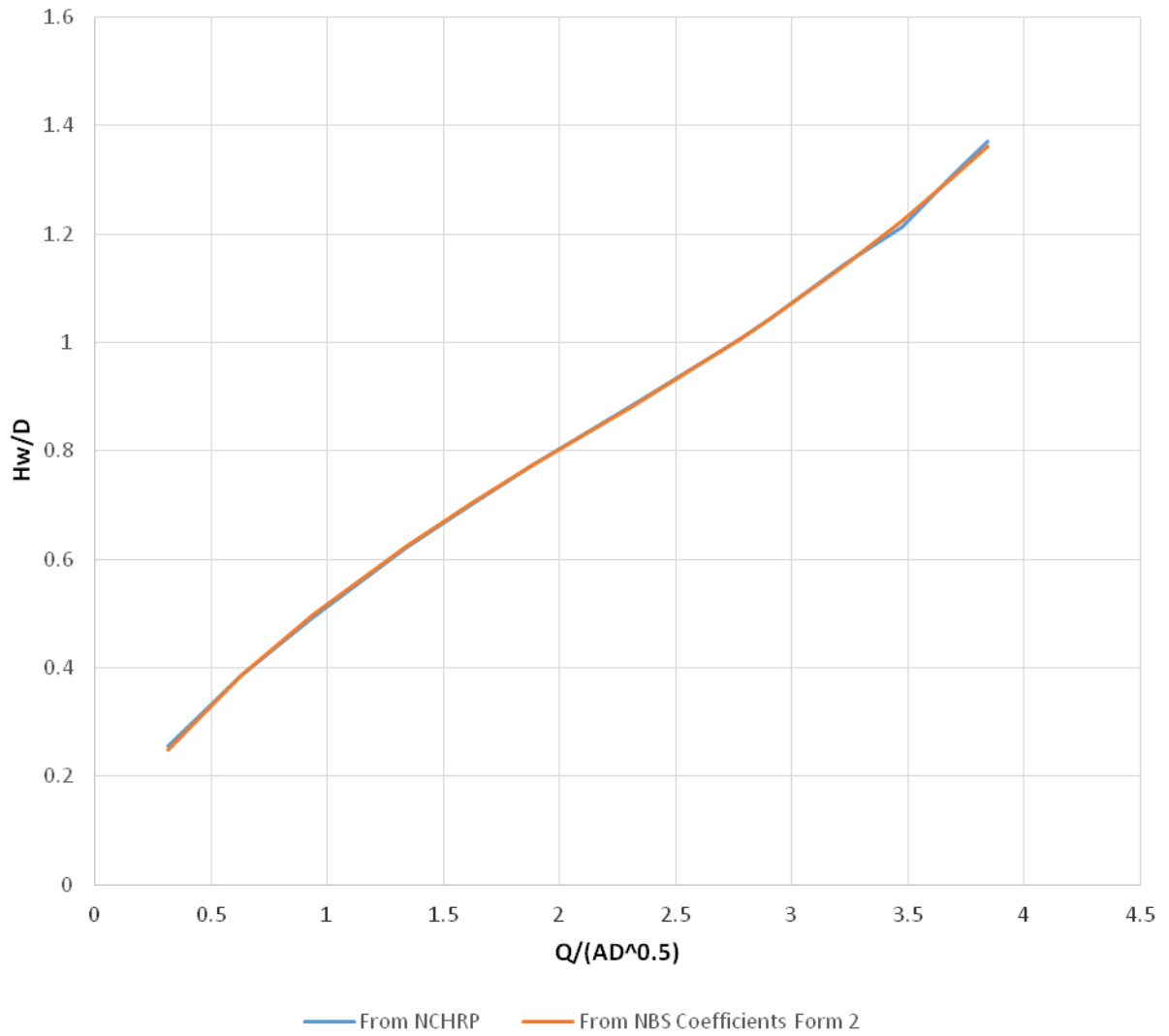


Table 43: Table used for Form 2 NBS Coefficients for a 20% embedded culvert with a projecting inlet edge type and an upstream channel.

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3149	0.2551	0.2492	0.0059
0.6271	0.3855	0.3855	0.0000
0.9377	0.4948	0.4973	0.0025
1.3415	0.6224	0.6239	0.0015
1.6217	0.7016	0.7035	0.0019
1.8820	0.7731	0.7731	0.0000
2.3077	0.8838	0.8797	0.0041
2.7786	1.0072	1.0072	0.0000
2.9130	1.0450	1.0455	0.0005
3.2354	1.1460	1.1449	0.0011
3.4739	1.2125	1.2251	0.0126
3.6970	1.3114	1.3053	0.0061
3.8445	1.3709	1.3611	0.0098
K	0.5180	Average Difference	0.0036
M	0.63		
c	0.0501		
Y	0.62		

NBS and Data Curve Comparisons

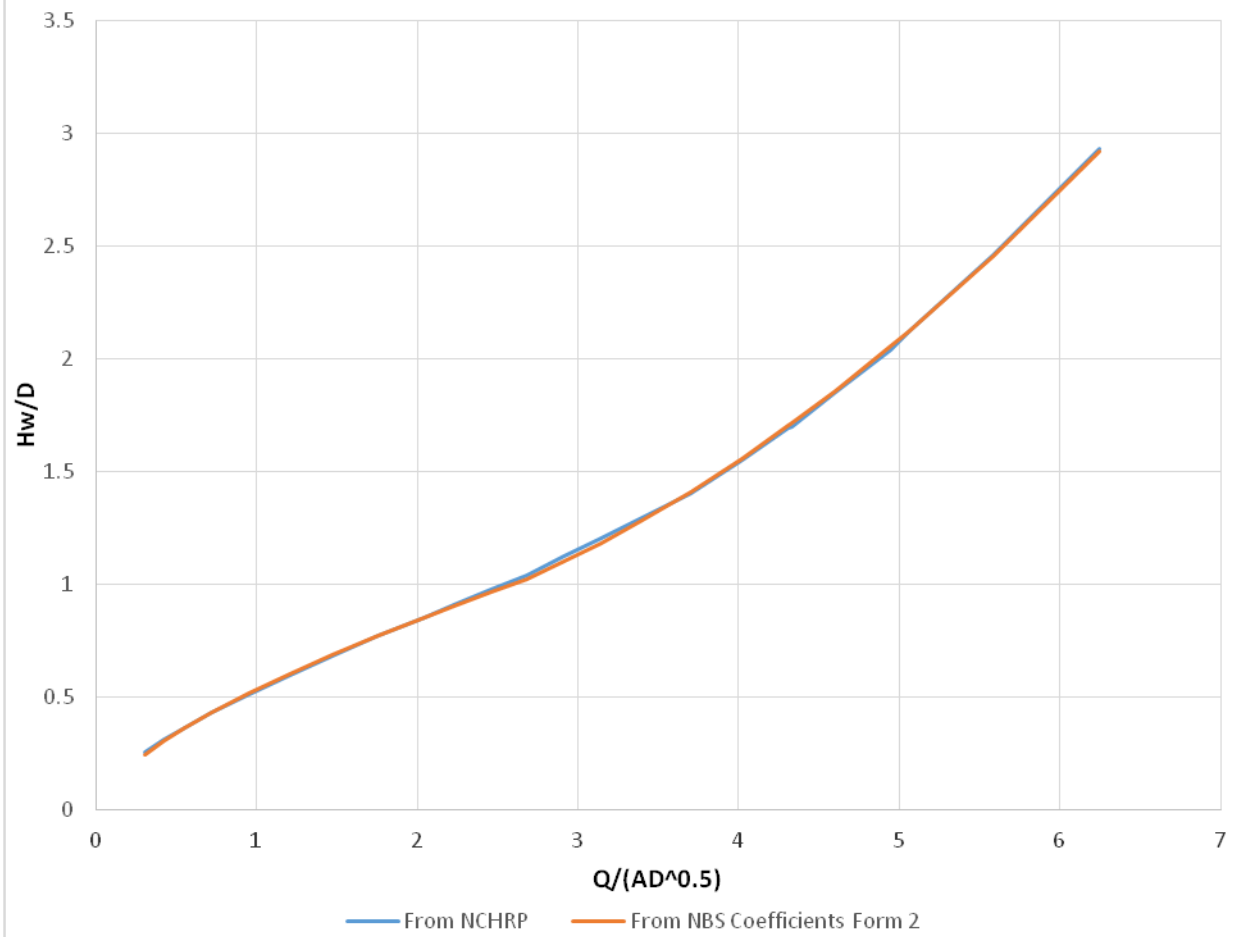


Table 44: Table used for Form 2 NBS Coefficients for a 20% embedded culvert with a square inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3154	0.2382	0.2353	0.0029
0.6210	0.3684	0.3636	0.0048
0.9412	0.4749	0.4749	0.0000
1.3280	0.5912	0.5925	0.0013
1.7351	0.7005	0.7035	0.0030
2.1337	0.8034	0.8034	0.0000
2.6018	0.9260	0.9126	0.0134
3.0558	1.0402	1.0402	0.0000
3.6842	1.2132	1.2112	0.0020
4.2934	1.4065	1.4075	0.0010
4.9119	1.6405	1.6374	0.0031
5.5709	1.9164	1.9164	0.0000
6.1541	2.1875	2.1926	0.0051
K	0.4938	Average Difference	0.0028
M	0.64		
c	0.0404		
Y	0.66		

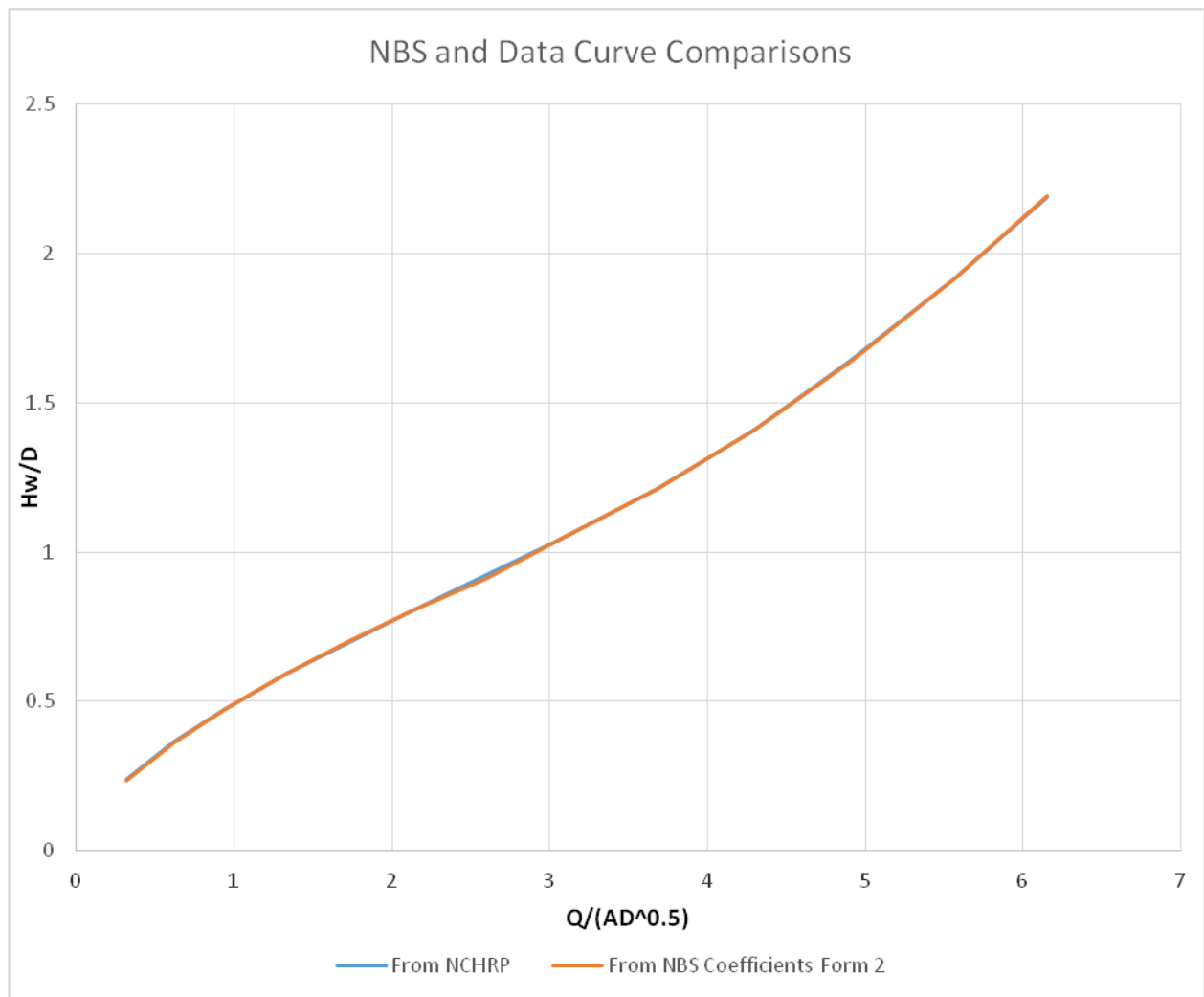


Table 45: Table used for Form 2 NBS Coefficients for a 20% embedded culvert with a 45° beveled inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.3170	0.2331	0.2331	0.0000
0.6139	0.3564	0.3536	0.0028
0.9325	0.4608	0.4603	0.0005
1.3736	0.5861	0.5877	0.0016
1.8606	0.7087	0.7116	0.0029
2.3268	0.8194	0.8194	0.0000
2.7761	0.9308	0.9159	0.0149
4.1495	1.2698	1.2698	0.0000
4.5904	1.3910	1.3934	0.0024
5.2797	1.6130	1.6115	0.0015
5.4924	1.6844	1.6850	0.0006
6.0546	1.8932	1.8932	0.0000
K		Average	
	0.4811	Difference	0.0023
M	0.63		
c	0.0321		
Y	0.72		

NBS and Data Curve Comparisons

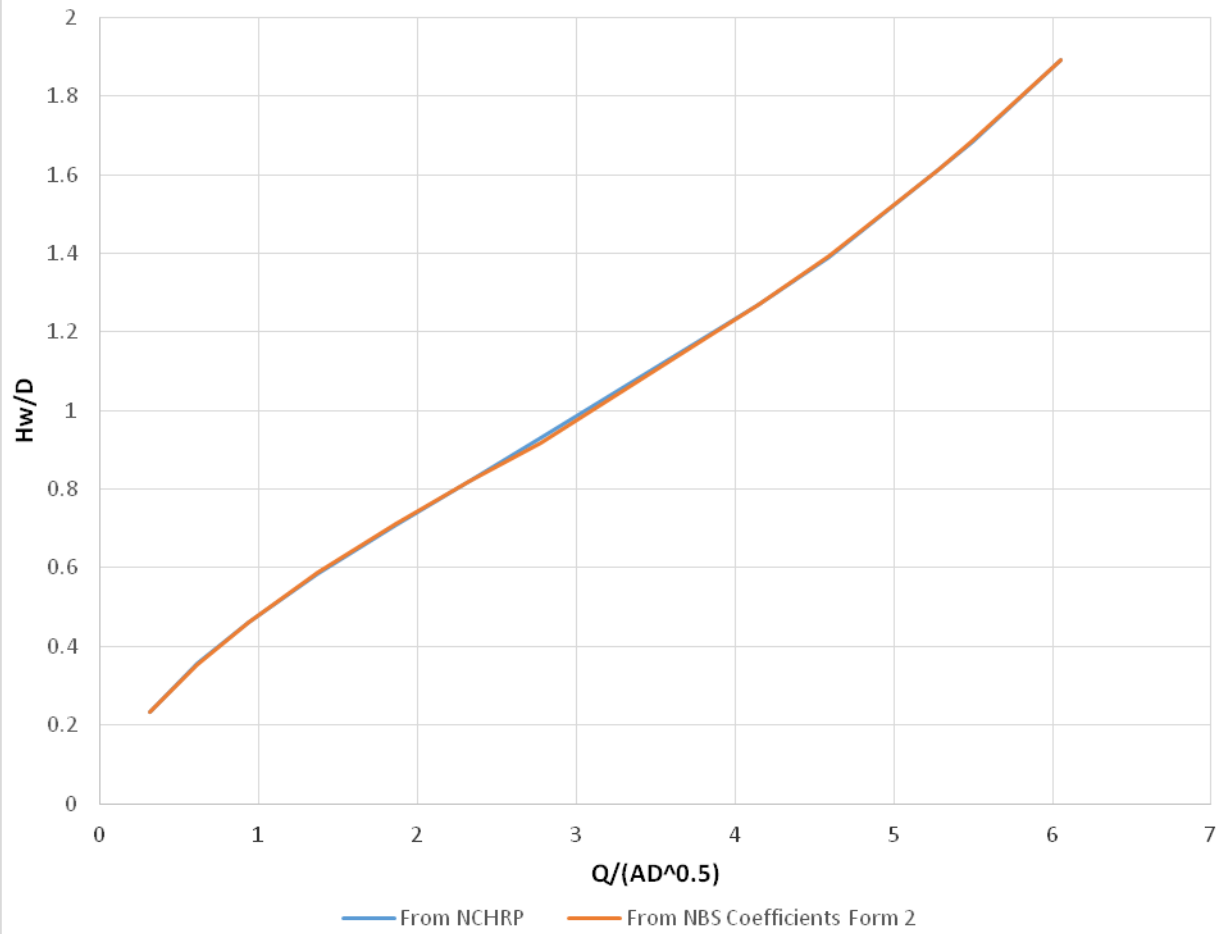


Table 46: Table used for Form 2 NBS Coefficients for a 20% embedded culvert with an 1.5H:1V mitered inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.4450	0.3026	0.2992	0.0034
0.7543	0.4168	0.4168	0.0000
1.1844	0.5506	0.5534	0.0028
1.6202	0.6710	0.6739	0.0029
2.0693	0.7859	0.7859	0.0000
2.4997	0.9008	0.8850	0.0158
3.6558	1.2426	1.2836	0.0410
4.1787	1.4864	1.4864	0.0000
4.6017	1.6713	1.6702	0.0011
5.2202	1.9711	1.9710	0.0001
5.8118	2.2814	2.2940	0.0126
K	0.4976	Average Difference	0.0073
M	0.63		
c	0.0495		
Y	0.62		

NBS and Data Curve Comparisons

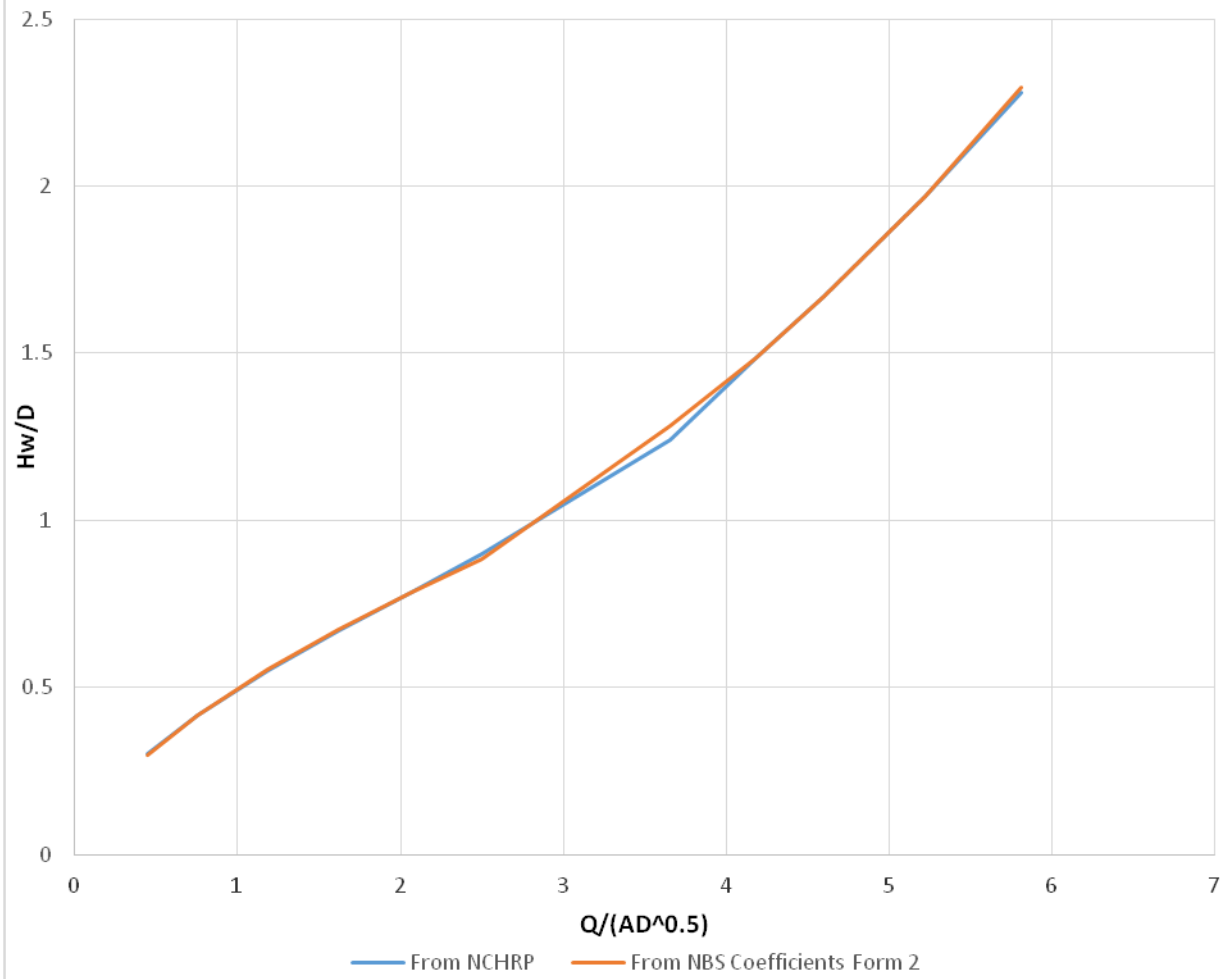


Table 47: Table used for Form 1 NBS Coefficients for a 40% embedded culvert with a projecting inlet edge type with an upstream pond.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5632	0.3440	0.0735	0.3396	0.0044
0.9793	0.4979	0.1009	0.4986	0.0007
1.4417	0.6490	0.1307	0.6490	0.0000
1.8539	0.7688	0.1520	0.7713	0.0024
2.2546	0.8877	0.1806	0.8851	0.0026
2.6685	1.0102	0.2138	1.0103	0.0000
4.2562	1.6369	0.5147	1.6445	0.0077
5.1624	2.1566	0.8492	2.1369	0.0196
6.0119	2.7500	1.2626	2.6846	0.0654
6.7747	3.3572	1.6991	3.2473	0.1100
7.4424	3.7950	1.9779	3.7949	0.0000
8.0171	4.3073	2.3452	4.3074	0.0001
8.5072	4.6805	2.5881	4.7747	0.0942
K	0.1214		Average Difference	0.0236
M	0.67			
c	0.0577			
Y	0.60			

NBS and Data Curve Comparisons

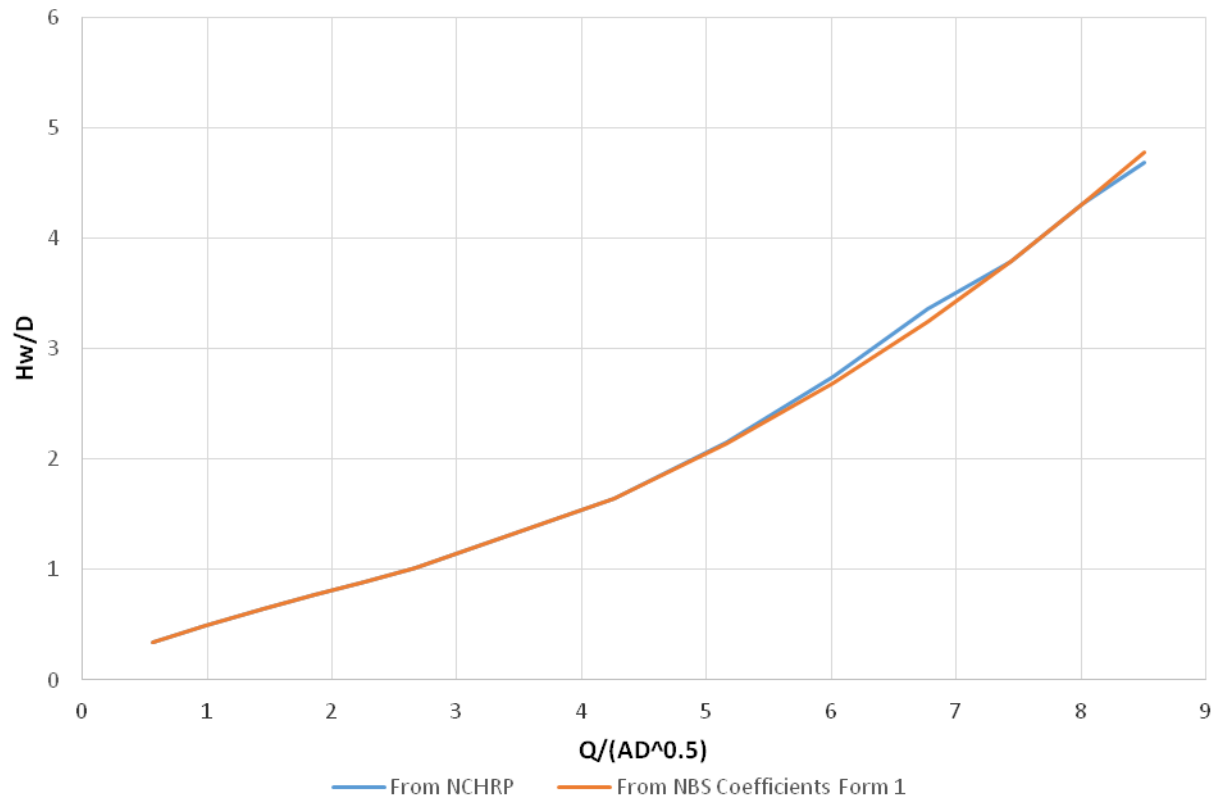


Table 48: Table used for Form 1 NBS Coefficients for a 40% embedded culvert with a projecting inlet edge type and an upstream channel

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5141	0.3385	0.0846	0.3367	0.0018
0.7801	0.4408	0.1015	0.4408	0.0000
1.1855	0.5753	0.1225	0.5793	0.0040
1.6544	0.7163	0.1463	0.7195	0.0032
1.8705	0.7743	0.1537	0.7791	0.0048
2.2409	0.8785	0.1744	0.8785	0.0000
2.6685	0.9937	0.1972	0.9862	0.0075
4.1421	1.4737	0.3747	1.4574	0.0164
4.7494	1.7502	0.5278	1.7502	0.0000
5.4256	2.1133	0.7510	2.1233	0.0100
6.2044	2.5906	1.0610	2.6144	0.0238
7.5297	3.6014	1.7629	3.6014	0.0000
8.1196	4.1460	2.1572	4.1020	0.0440
			Average Difference	0.0089
K	0.1349			
M	0.53			
c	0.0542			
Y	0.53			

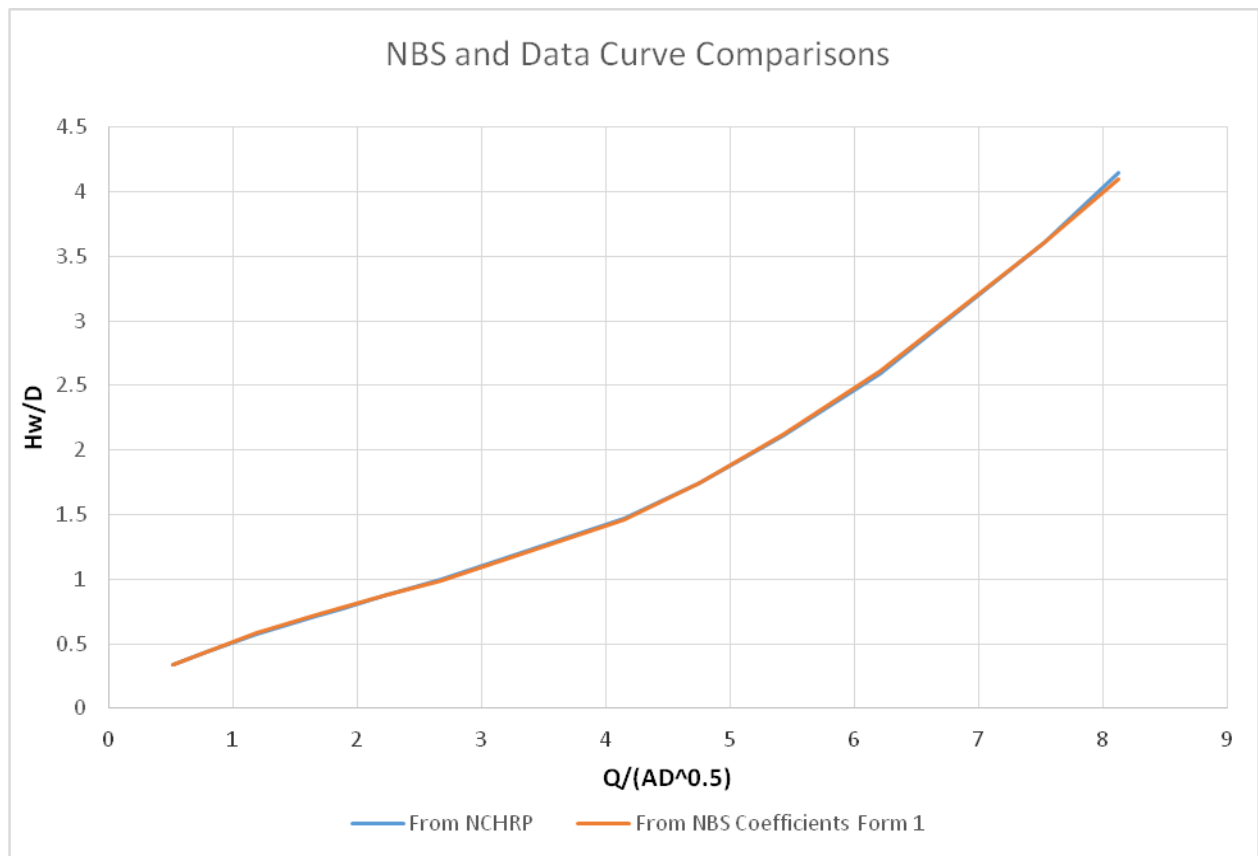


Table 49: Table used for Form 1 NBS Coefficients for a 40% embedded culvert with a square inlet edge type.

From NCHRP Corrected Q/(AD ^{0.5})	From NCHRP Hw/D	From NCHRP HW/D- Hc/D+0.5S	Computed HW/D	Computed Difference
0.6253	0.3431	0.0521	0.3394	0.0037
0.8535	0.4214	0.0673	0.4214	0.0000
1.1052	0.4988	0.0604	0.5019	0.0031
1.7803	0.6877	0.0880	0.6917	0.0040
2.4889	0.8702	0.1121	0.8702	0.0000
4.8582	1.6203	1.6070	1.6255	0.0052
6.5824	2.4579	1.2895	2.4579	0.0000
7.7968	3.1951	0.8437	3.1947	0.0003
8.6342	3.7341	0.3756	3.7754	0.0413
K	0.0849	Average Difference		0.0064
M	0.60			
c	0.0422			
Y	0.63			

NBS and Data Curve Comparisons

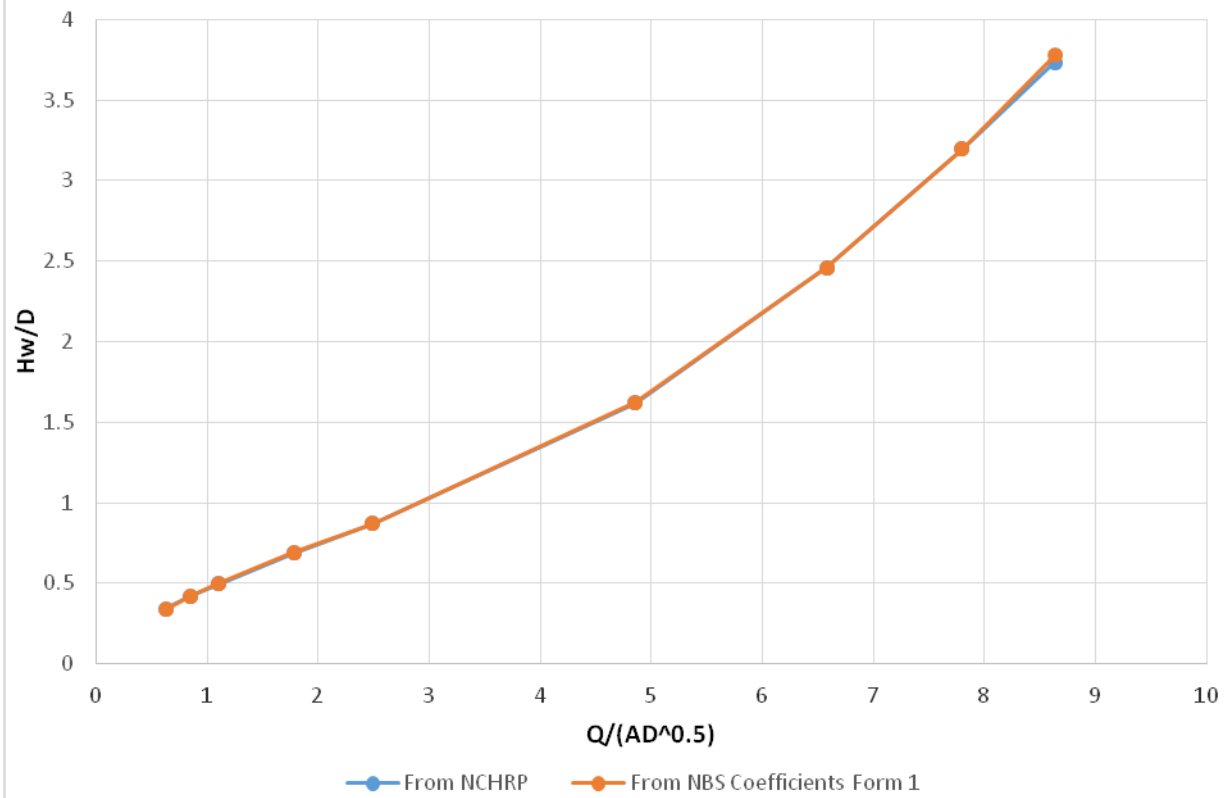


Table 50: Table used for Form 1 NBS Coefficients for a 40% embedded culvert with a 45° beveled inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5769	0.3300	0.0418	0.3299	0.0001
1.1264	0.5100	0.0517	0.5124	0.0024
1.6941	0.6700	0.0624	0.6700	0.0000
2.3718	0.8400	0.0738	0.8400	0.0000
5.0641	1.5900	0.2351	1.5901	0.0001
6.4011	2.1300	0.4670	2.1261	0.0039
7.3718	2.6100	0.6931	2.5937	0.0163
8.4158	3.1700	0.9561	3.1700	0.0000
K	0.0736		Average Difference	0.0025
M	0.47			
c	0.0350			
Y	0.69			

NBS and Data Curve Comparisons

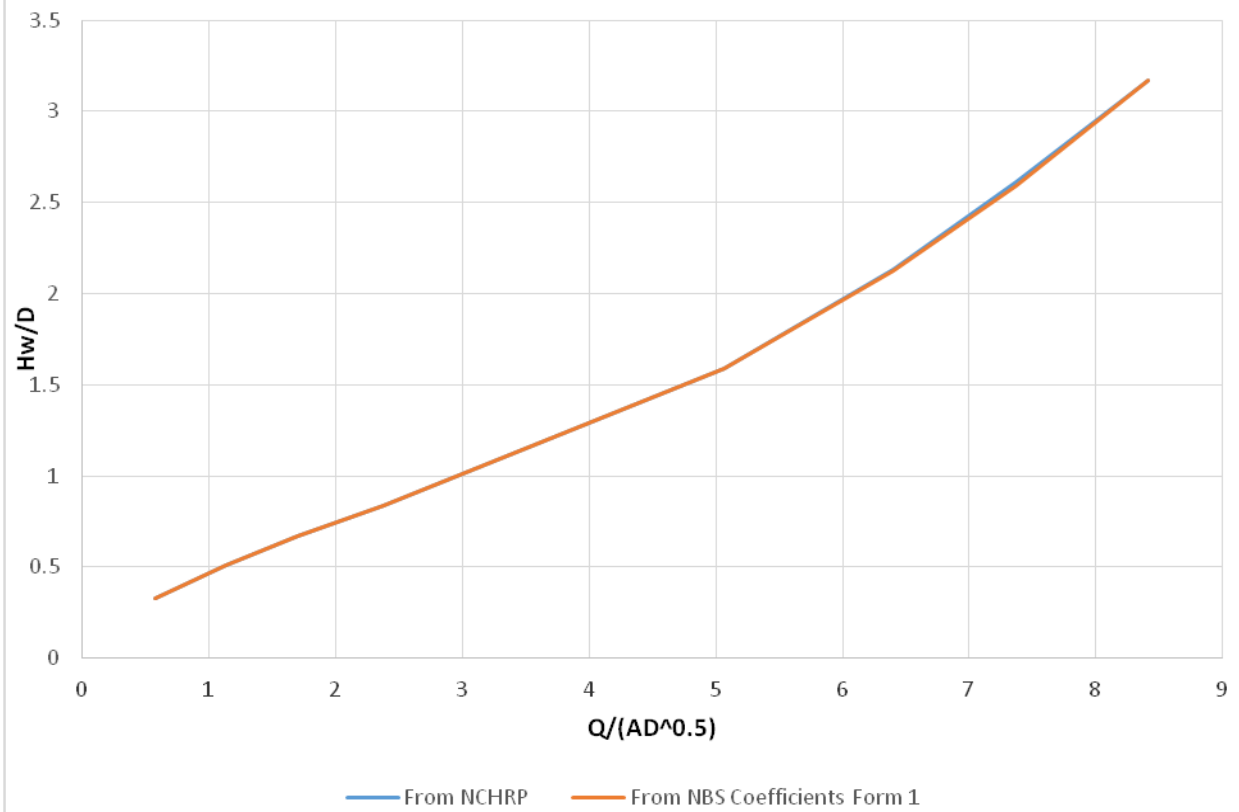


Table 51: Table used for Form 1 NBS Coefficients for a 40% embedded culvert with an 1.5H:1V mitered inlet edge type.

<u>From</u> NCHRP Corrected Q/(AD ^{0.5})	<u>From</u> NCHRP Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.7856	0.3870	0.3834	0.0036
1.1502	0.4958	0.4958	0.0000
1.7452	0.6533	0.6586	0.0053
2.2863	0.7888	0.7929	0.0041
2.6335	0.8754	0.8754	0.0000
2.9817	0.9583	0.9538	0.0046
4.5143	1.5601	1.5601	0.0000
4.9382	1.7517	1.7556	0.0039
5.2460	1.9056	1.9087	0.0030
5.5760	2.0890	2.0830	0.0060
5.9974	2.3286	2.3210	0.0075
6.2880	2.4954	2.4953	0.0000
6.8736	2.8630	2.8716	0.0085
K	0.0681	Average Difference	0.0035
M	0.60		
c	0.0488		
Y	0.57		

NBS and Data Curve Comparisons

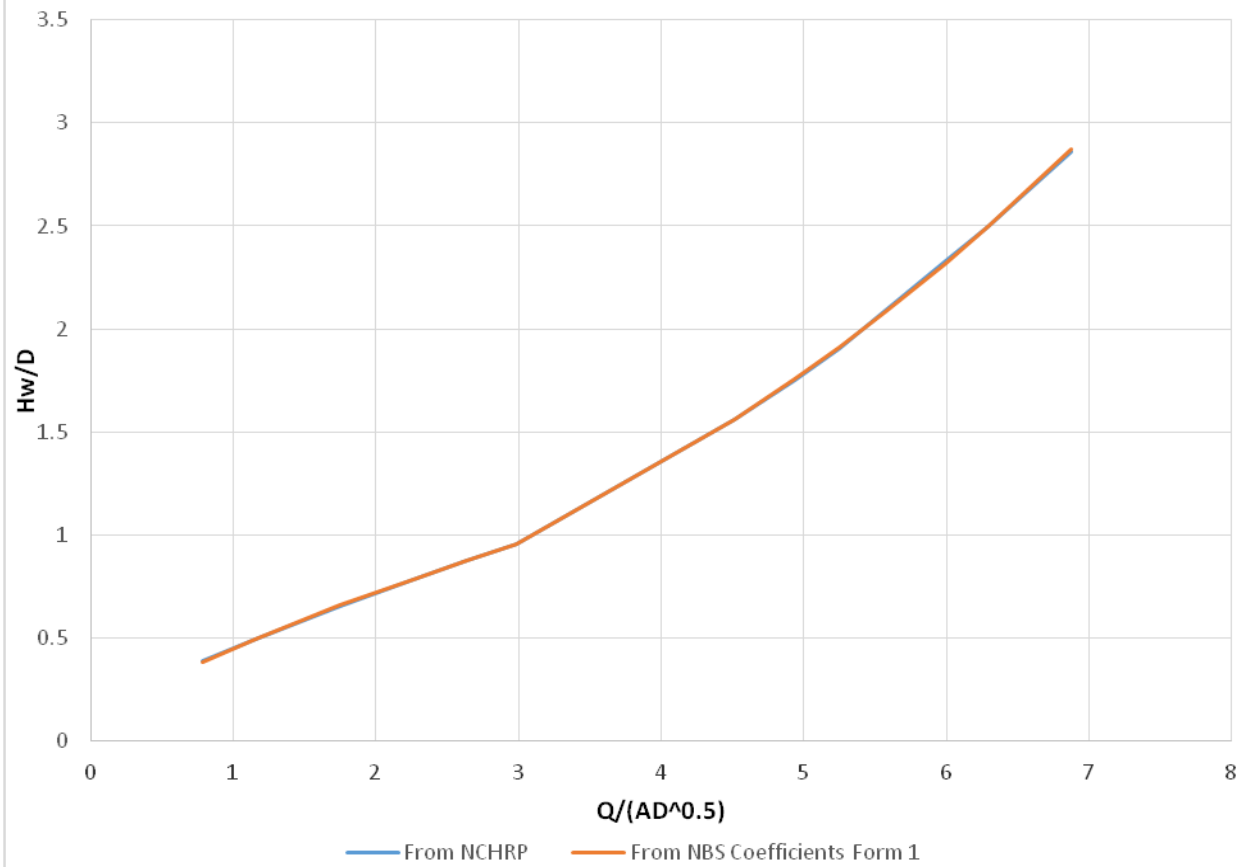


Table 52: Table used for Form 2 NBS Coefficients for a 40% embedded culvert with a projecting inlet edge type with an upstream pond.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5632	0.3440	0.3409	0.0032
0.9793	0.4979	0.4979	0.0000
1.4417	0.6490	0.6490	0.0000
1.8539	0.7688	0.7710	0.0022
2.2546	0.8877	0.8817	0.0060
2.6685	1.0102	1.0103	0.0000
4.2562	1.6369	1.6445	0.0077
5.1624	2.1566	2.1369	0.0196
6.0119	2.7500	2.6846	0.0654
6.7747	3.3572	3.2473	0.1100
7.4424	3.7950	3.7949	0.0000
8.0171	4.3073	4.3074	0.0001
8.5072	4.6805	4.7747	0.0942
K	0.5051	Average Difference	0.0195
M	0.69		
c	0.0577		
Y	0.60		

NBS and Data Curve Comparisons

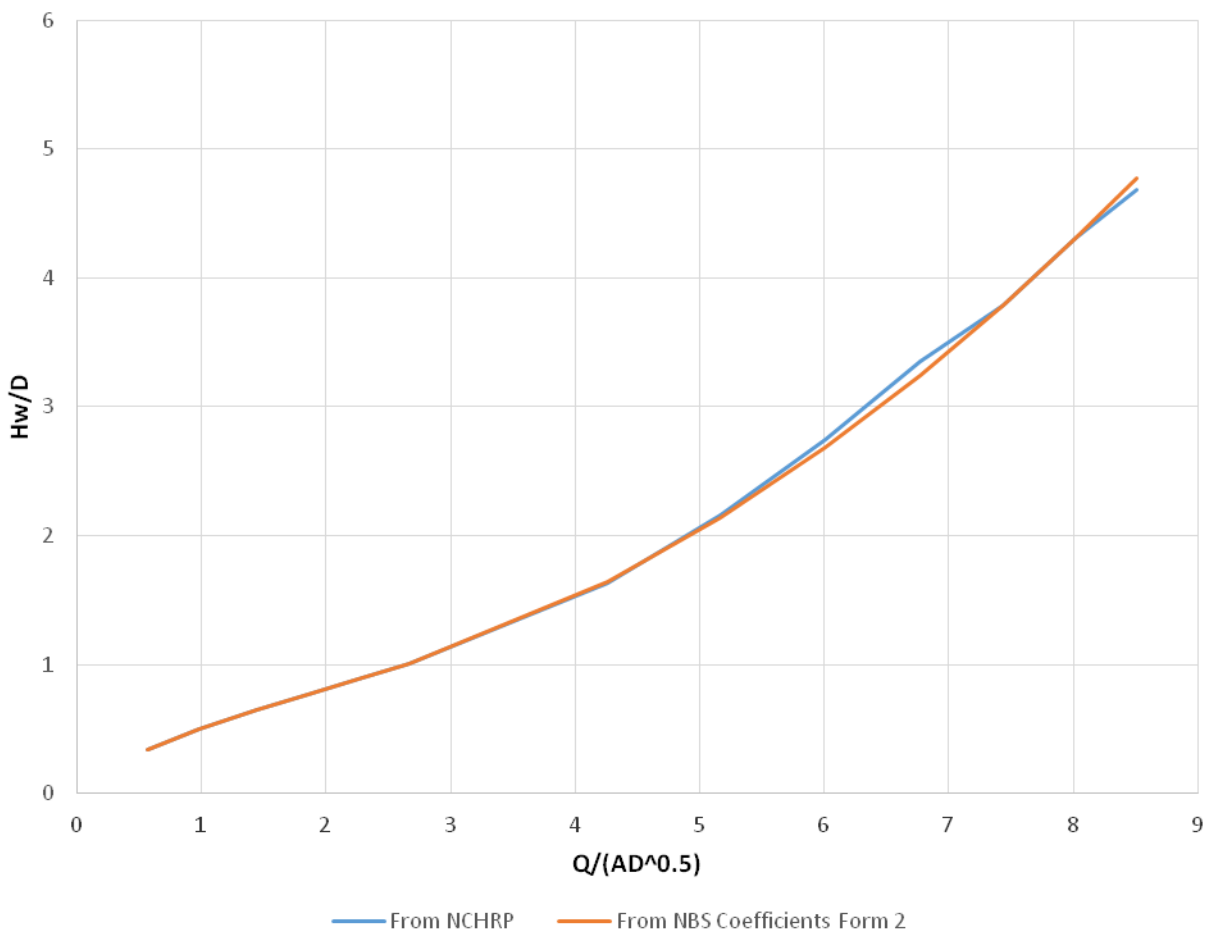


Table 53: Table used for Form 2 NBS Coefficients for a 40% embedded culvert with a projecting inlet edge type and an upstream channel.

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5141	0.3385	0.3320	0.0065
0.7801	0.4408	0.4368	0.0040
1.1855	0.5753	0.5753	0.0000
1.6544	0.7163	0.7164	0.0001
1.8705	0.7743	0.7767	0.0024
2.2409	0.8785	0.8748	0.0037
2.6685	0.9937	0.9814	0.0123
4.1421	1.4737	1.4574	0.0164
4.7494	1.7502	1.7502	0.0000
5.4256	2.1133	2.1233	0.0100
6.2044	2.5906	2.6144	0.0238
7.5297	3.6014	3.6014	0.0000
8.1196	4.1460	4.1020	0.0440
K	0.5144	Average Difference	0.0095
M	0.66		
c	0.0542		
Y	0.53		

NBS and Data Curve Comparisons

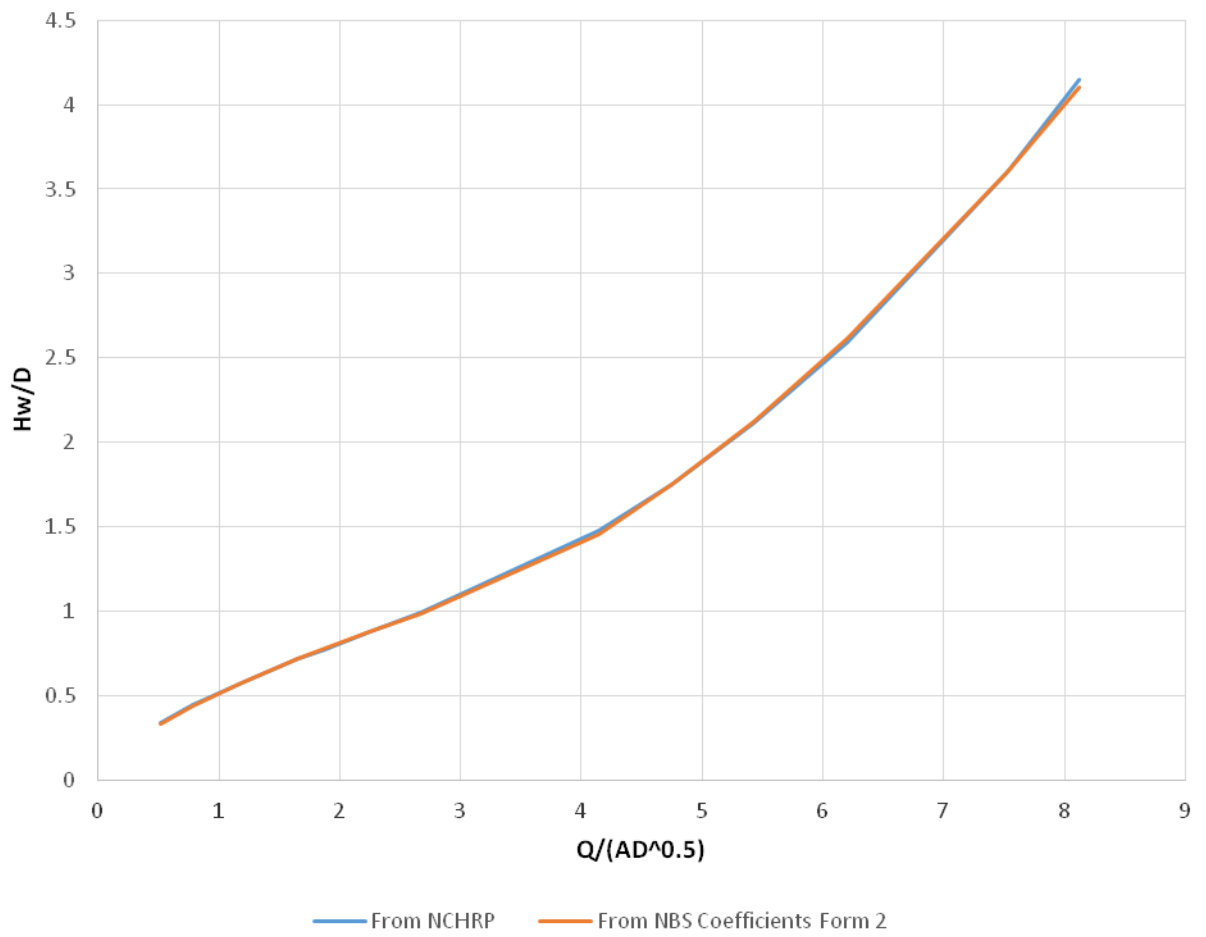


Table 54: Table used for Form 2 NBS Coefficients for a 40% embedded culvert with a square inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.6253	0.3431	0.3377	0.0054
0.8535	0.4214	0.4180	0.0034
1.1052	0.4988	0.4989	0.0001
1.7803	0.6877	0.6917	0.0039
2.4889	0.8702	0.8702	0.0000
4.8582	1.6203	1.6255	0.0052
6.5824	2.4579	2.4579	0.0000
7.7968	3.1951	3.1947	0.0003
8.6342	3.7341	3.7754	0.0413
K	0.4659	Average Difference	0.0046
M	0.69		
c	0.0422		
Y	0.63		

NBS and Data Curve Comparisons

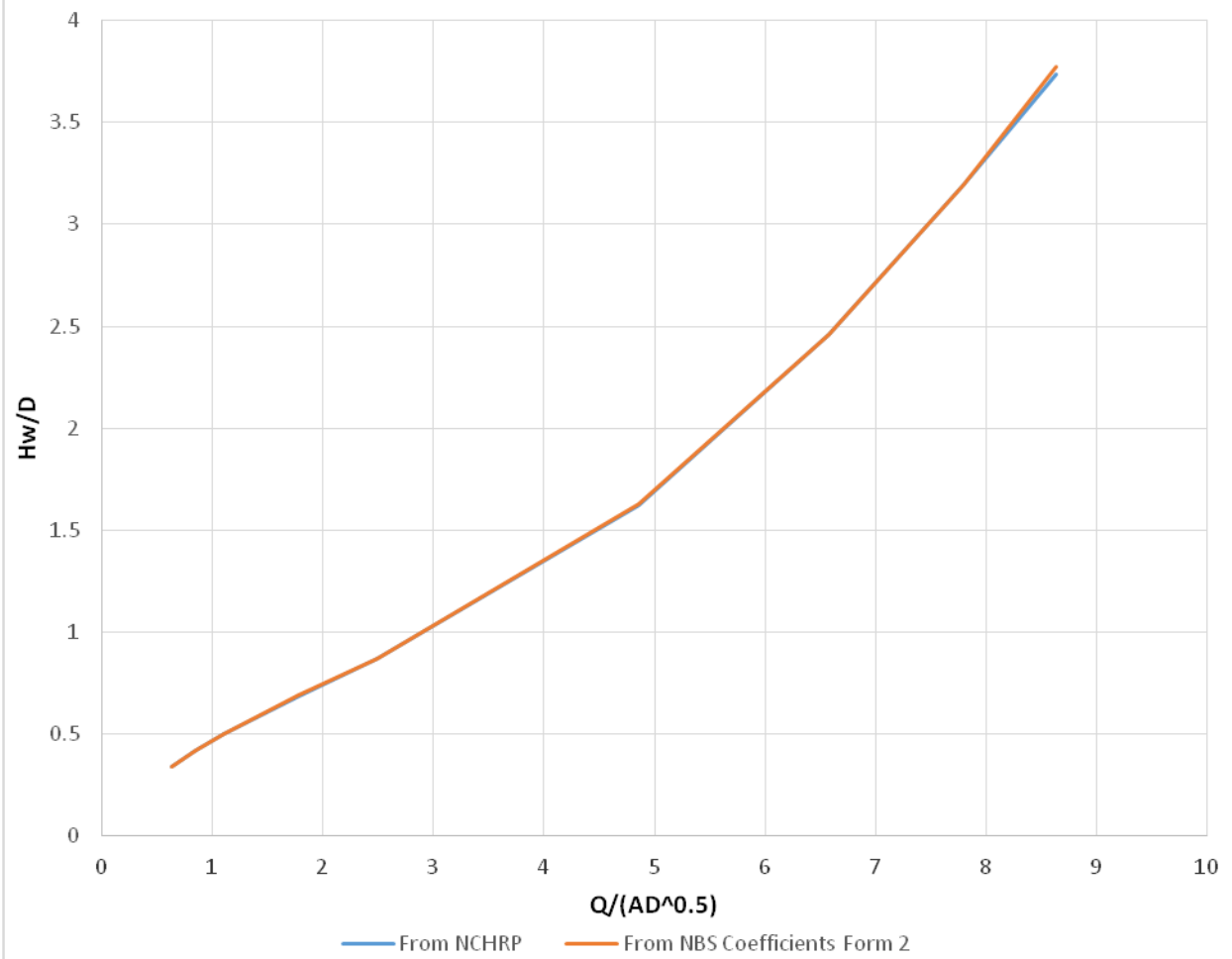


Table 55: Table used for Form 2 NBS Coefficients for a 40% embedded culvert with a 45° beveled inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5769	0.3300	0.3257	0.0043
1.1264	0.5100	0.5100	0.0000
1.6941	0.6700	0.6704	0.0004
2.3718	0.8400	0.8400	0.0000
5.0641	1.5900	1.5901	0.0001
6.4011	2.1300	2.1261	0.0039
7.3718	2.6100	2.5937	0.0163
8.4158	3.1700	3.1700	0.0000
K	0.4709	Average Difference	0.0031
M	0.67		
c	0.0350		
Y	0.69		

NBS and Data Curve Comparisons

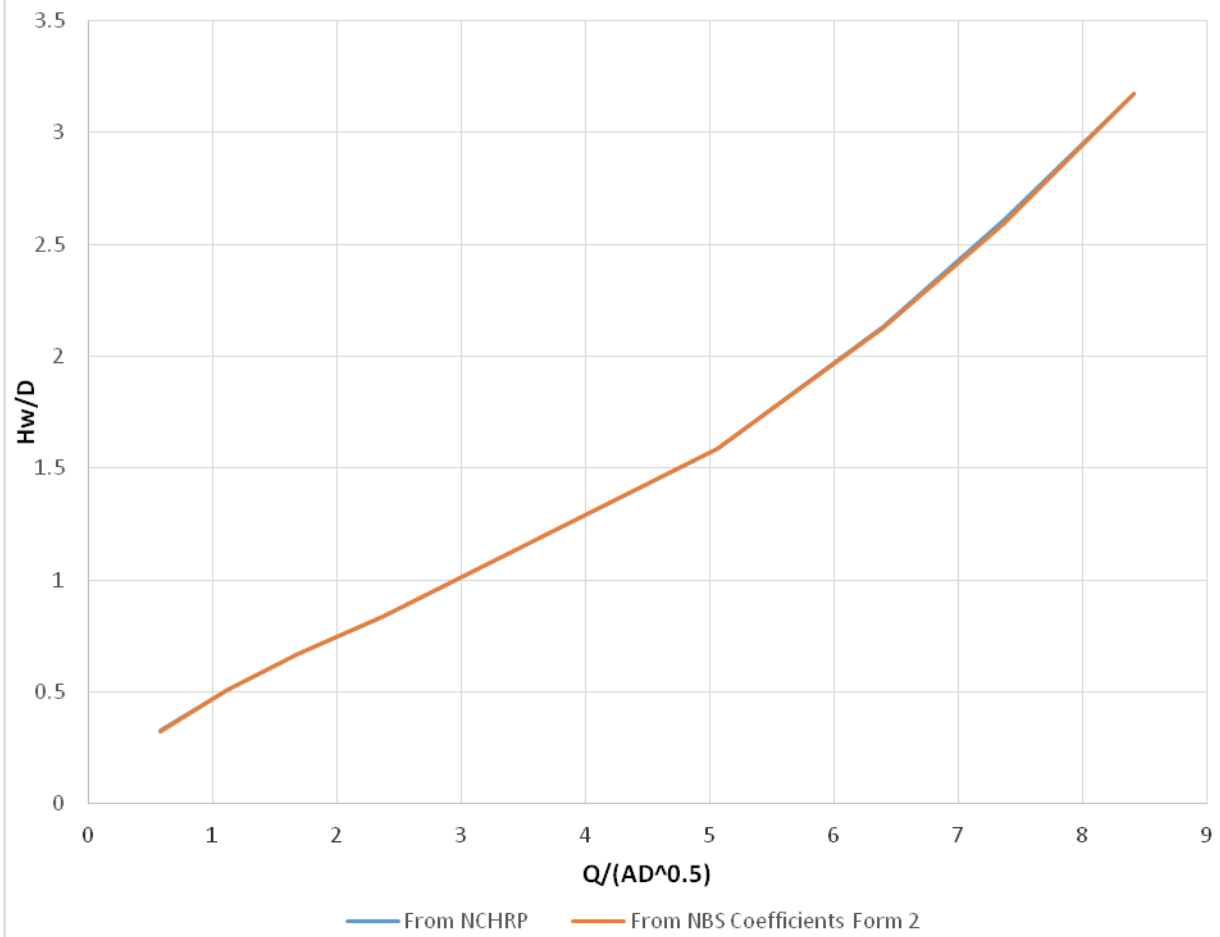


Table 56: Table used for Form 2 NBS Coefficients for a 40% embedded culvert with an 1.5H:1V mitered inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.7856	0.3870	0.3816	0.0054
1.1502	0.4958	0.4958	0.0000
1.7452	0.6533	0.6600	0.0067
2.2863	0.7888	0.7944	0.0057
2.6335	0.8754	0.8754	0.0000
2.9817	0.9583	0.9533	0.0050
4.5143	1.5601	1.5601	0.0000
4.9382	1.7517	1.7556	0.0039
5.2460	1.9056	1.9087	0.0030
5.5760	2.0890	2.0830	0.0060
5.9974	2.3286	2.3210	0.0075
6.2880	2.4954	2.4953	0.0000
6.8736	2.8630	2.8716	0.0085
K	0.4504	Average Difference	0.0040
M	0.69		
c	0.0488		
Y	0.57		

NBS and Data Curve Comparisons

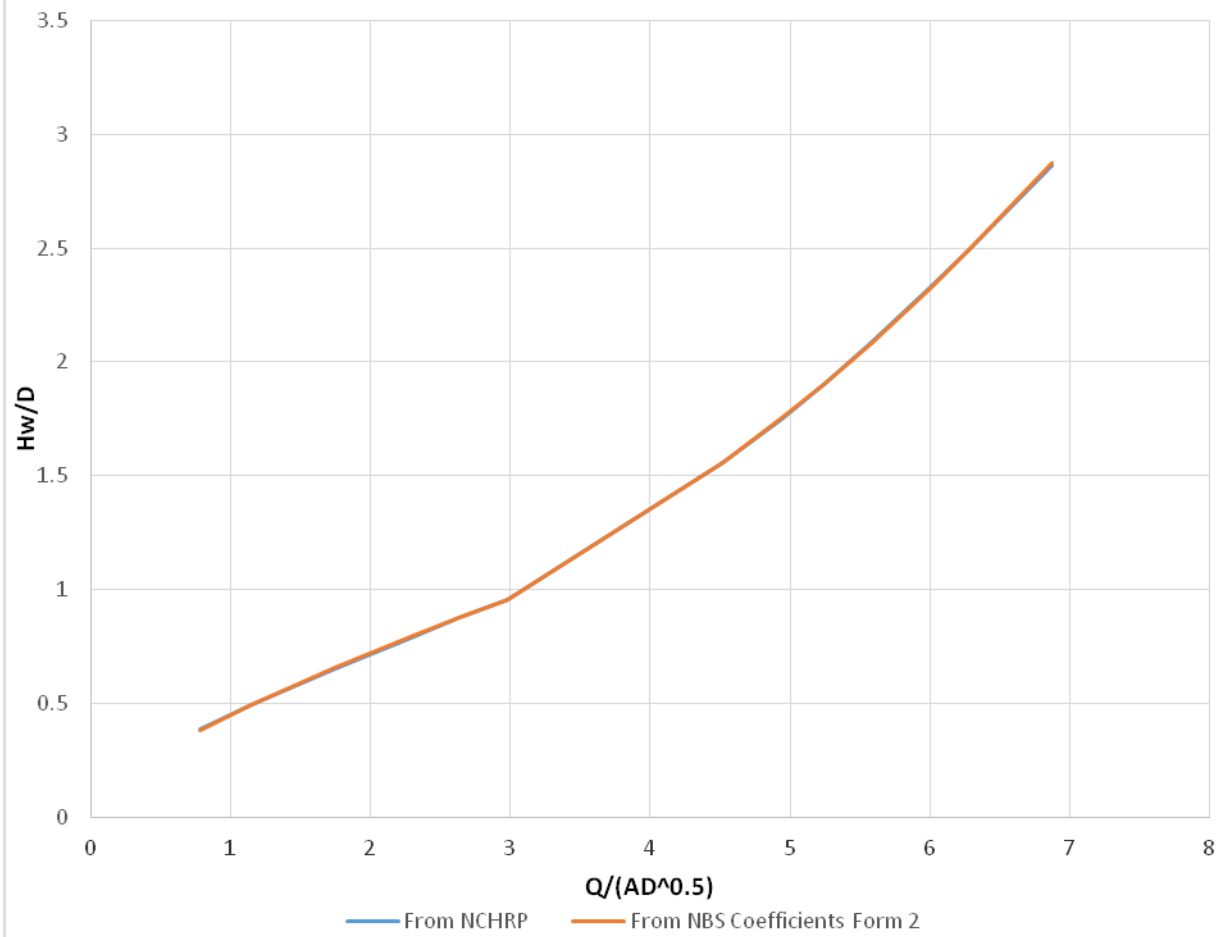


Table 57: Table used for Form 1 NBS Coefficients for a 50% embedded culvert with a projecting inlet edge type with an upstream pond.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5245	0.3163	0.0703	0.3134	0.0029
0.8441	0.4401	0.0952	0.4393	0.0008
1.1785	0.5549	0.1184	0.5550	0.0001
1.6004	0.6865	0.1446	0.6907	0.0042
1.9716	0.8047	0.1761	0.8047	0.0000
2.3231	0.9072	0.2001	0.9041	0.0032
3.4039	1.2585	0.3225	1.2282	0.0303
4.1914	1.5941	0.4965	1.5946	0.0005
4.6867	1.8416	0.6423	1.8639	0.0222
5.8325	2.6088	1.1676	2.6021	0.0066
5.9545	2.6902	1.2224	2.6902	0.0000
6.7467	3.3012	1.6551	3.3064	0.0052
7.5298	3.9769	2.1427	3.9911	0.0143
8.4209	4.8633	2.7978	4.8617	0.0016
K	0.1041		Average Difference	0.0066
M	0.73			
c	0.0612			
Y	0.52			

NBS and Data Curve Comparisons

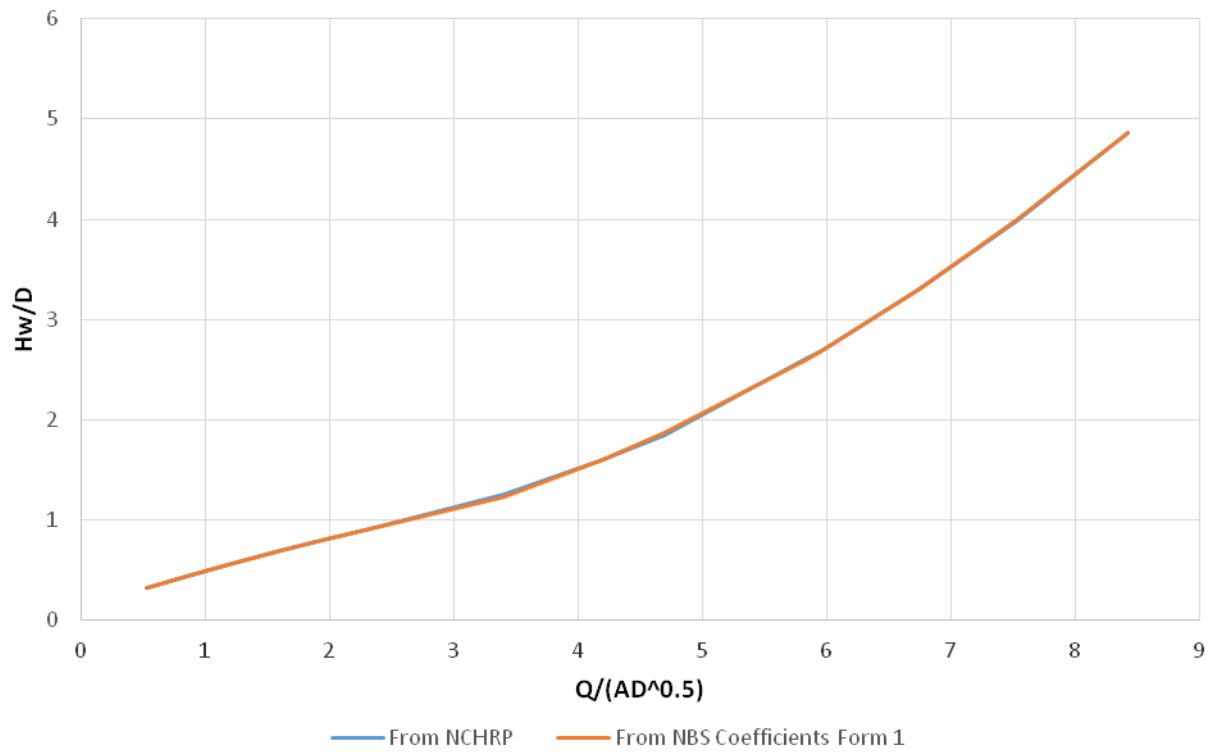


Table 58: Table used for Form 1 NBS Coefficients for a 50% embedded culvert with a projecting inlet edge type and an upstream channel

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5456	0.3308	0.2976	0.3279	0.0029
0.8072	0.4300	0.6516	0.4300	0.0000
1.0755	0.5226	1.1567	0.5250	0.0024
1.4054	0.6263	1.9751	0.6289	0.0026
1.7805	0.7378	3.1702	0.7375	0.0003
2.1103	0.8292	4.4533	0.8303	0.0011
2.4186	0.9184	5.8497	0.9117	0.0067
3.4588	1.2183	11.9636	1.1228	0.0956
4.6218	1.6565	21.3609	1.6680	0.0114
5.6305	2.2453	31.7025	2.2680	0.0227
6.7289	3.0559	45.2779	3.0556	0.0003
7.6246	3.8264	58.1346	3.8015	0.0249
8.6177	4.7373	74.2653	4.7373	0.0000
			Average Difference	0.0131
K	0.1074			
M	0.58			
c	0.0580			
Y	0.43			

NBS and Data Curve Comparisons

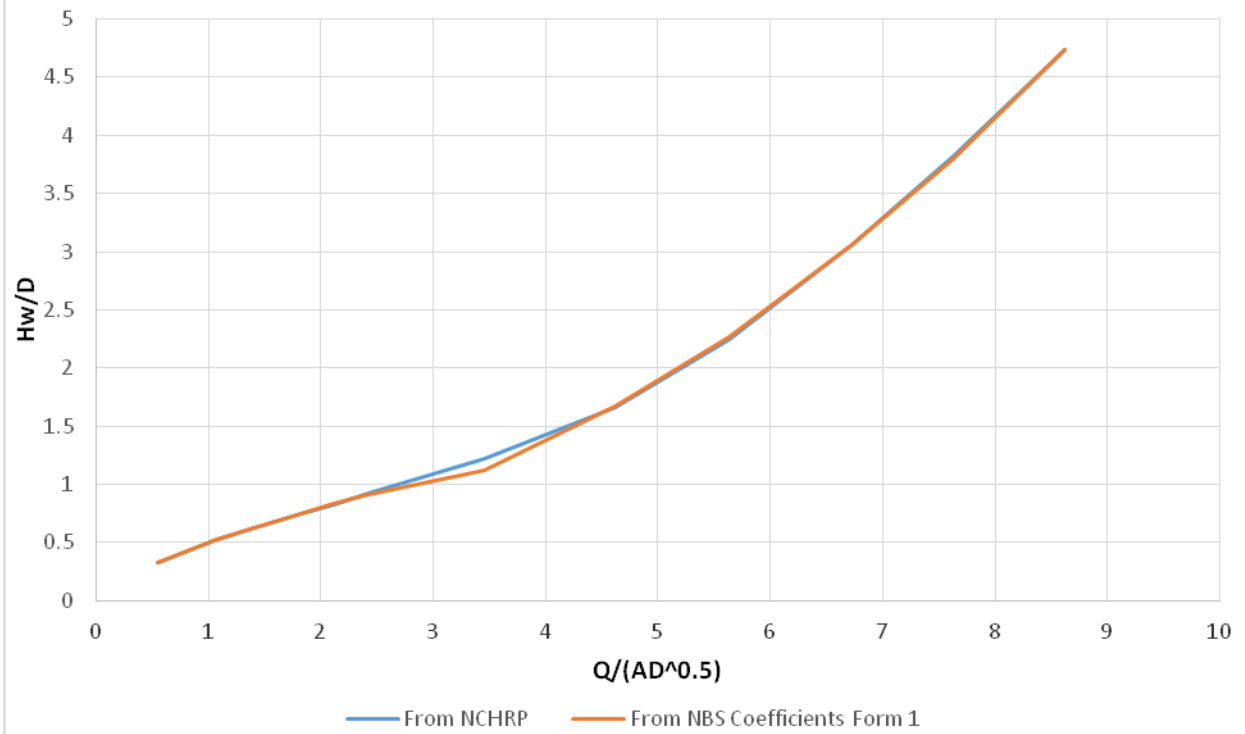


Table 59: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a square inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5476	0.2973	0.3563	0.2974	0.0001
1.0095	0.4534	0.2348	0.4526	0.0008
1.4674	0.5839	0.1618	0.5842	0.0003
2.0742	0.7467	0.1136	0.7466	0.0001
2.6352	0.8883	0.0949	0.8866	0.0017
3.4479	1.1068	0.0743	1.1081	0.0013
4.1027	1.3142	0.0621	1.3098	0.0044
4.8294	1.5852	0.0437	1.5746	0.0106
6.0212	2.0947	2.0985	2.1021	0.0074
7.2046	2.7403	1.4440	2.7406	0.0003
8.3638	3.4941	0.9858	3.4768	0.0173
9.8460	4.5779	0.6124	4.5779	0.0000
K	0.0603		Average Difference	0.0037
M	0.63			
c	0.0408			
Y	0.62			

NBS and Data Curve Comparisons

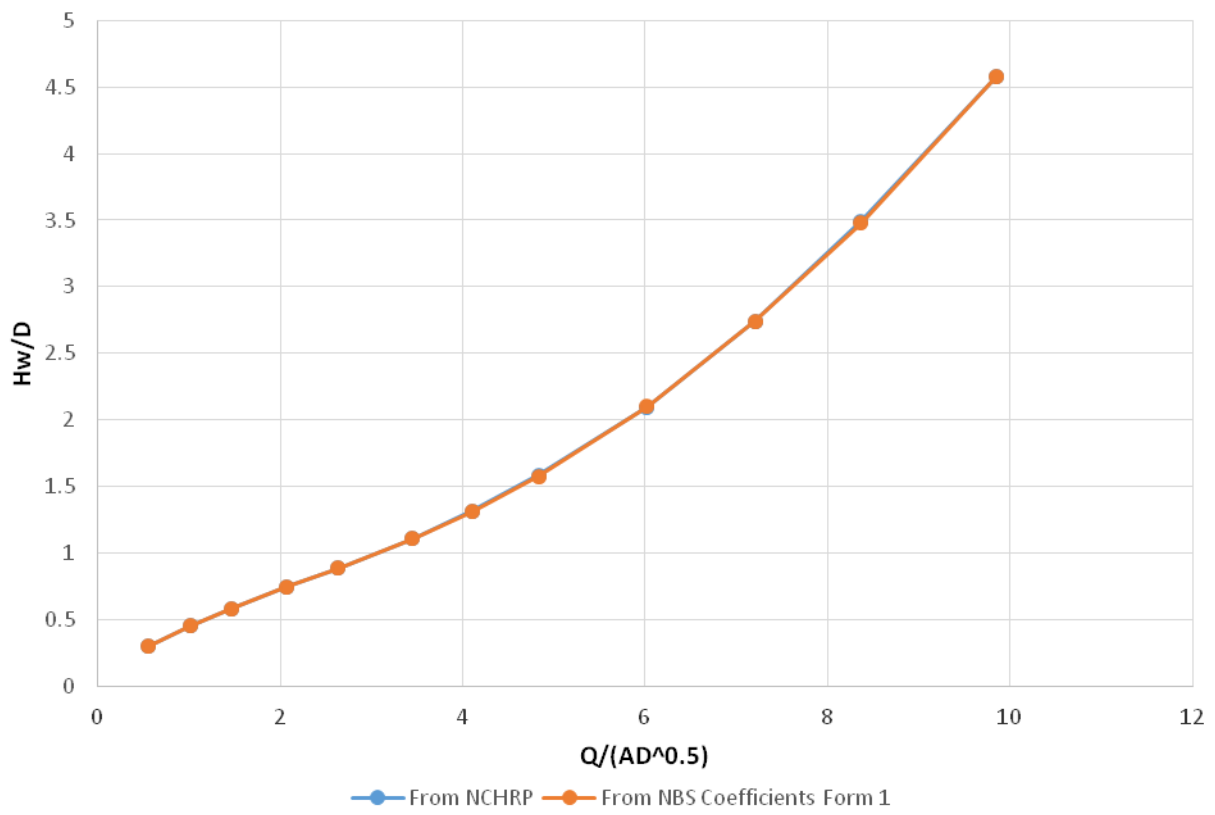


Table 60: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with a 45° beveled inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.6562	0.3274	0.1673	0.3290	0.0015
1.1361	0.4757	0.1147	0.4745	0.0012
1.5605	0.5895	0.0744	0.5878	0.0017
2.1458	0.7333	0.0654	0.7341	0.0007
2.7508	0.8738	0.0572	0.8738	0.0000
4.0796	1.1893	0.0504	1.1895	0.0001
4.8372	1.3979	0.0389	1.4125	0.0147
6.0212	1.8416	1.3959	1.8370	0.0046
7.2598	2.3802	0.9932	2.3802	0.0000
8.6547	3.1228	0.6123	3.1132	0.0096
10.0388	3.9356	0.3593	3.9675	0.0319
K	0.0451		Average Difference	0.0060
M	0.40			
c	0.0330			
Y	0.64			

NBS and Data Curve Comparisons

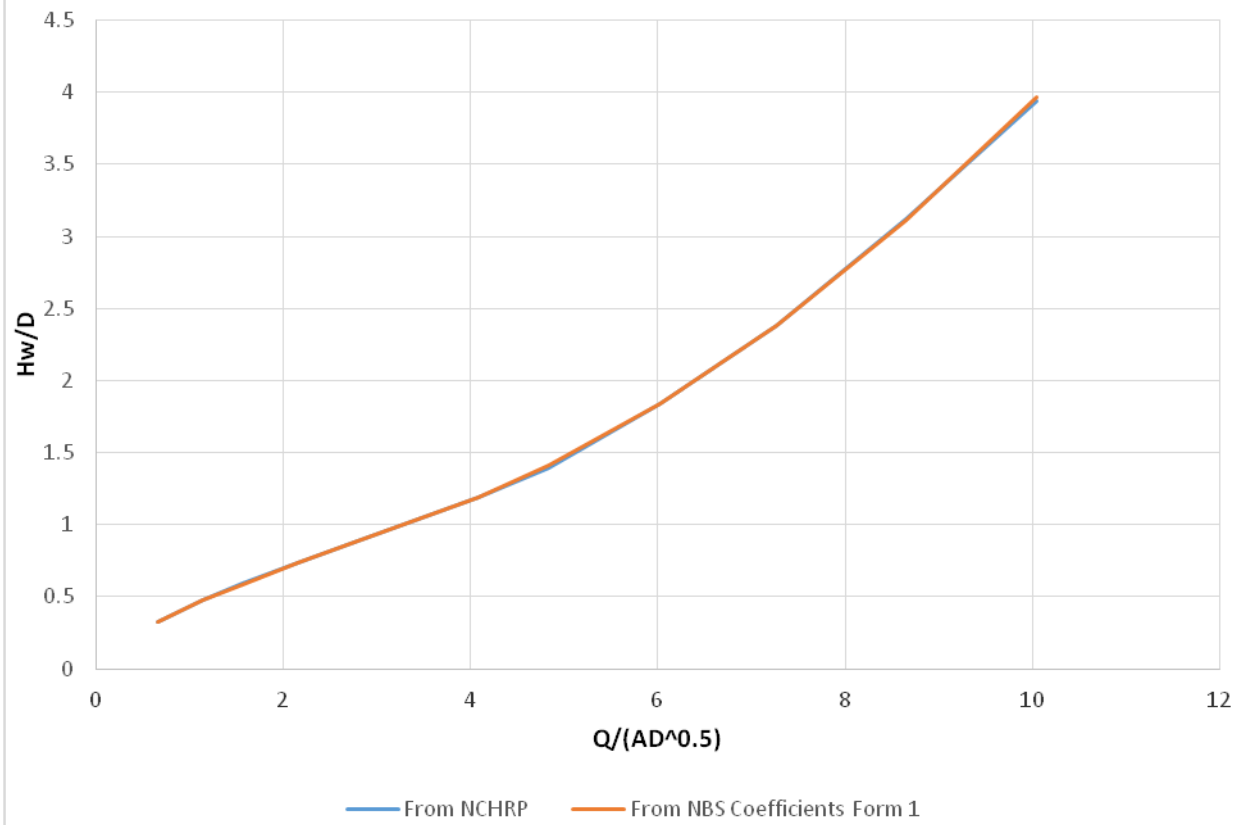


Table 61: Table used for Form 1 NBS Coefficients for a 20% embedded culvert with an 1.5H:1V mitered inlet edge type.

<u>From</u> NCHRP Corrected Q/(AD ^{0.5})	<u>From</u> NCHRP Hw/D	<u>From</u> NCHRP HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5912	0.3122	0.0000	0.3094	0.0028
0.8266	0.3891	0.0031	0.3891	0.0000
1.1495	0.4828	0.0077	0.4848	0.0020
1.4720	0.5731	0.0162	0.5753	0.0021
2.0001	0.7058	0.0245	0.7106	0.0048
2.4573	0.8173	0.0347	0.8173	0.0000
2.8749	0.9188	0.0469	0.9158	0.0030
3.2796	1.0147	0.0582	1.0276	0.0129
3.9766	1.2745	0.1747	1.2879	0.0135
4.8567	1.6881	0.4074	1.6881	0.0000
5.3168	1.9791	0.6021	1.9291	0.0500
5.9141	2.3081	0.8030	2.2744	0.0337
6.6272	2.7697	1.1050	2.7348	0.0349
7.3036	3.2614	1.4367	3.2198	0.0416
7.9124	3.6639	1.6866	3.6967	0.0327
8.6685	4.3051	2.1254	4.3420	0.0370
K	0.0503		Average Difference	0.0169
M	0.49			
c	0.0515			
Y	0.47			

NBS and Data Curve Comparisons

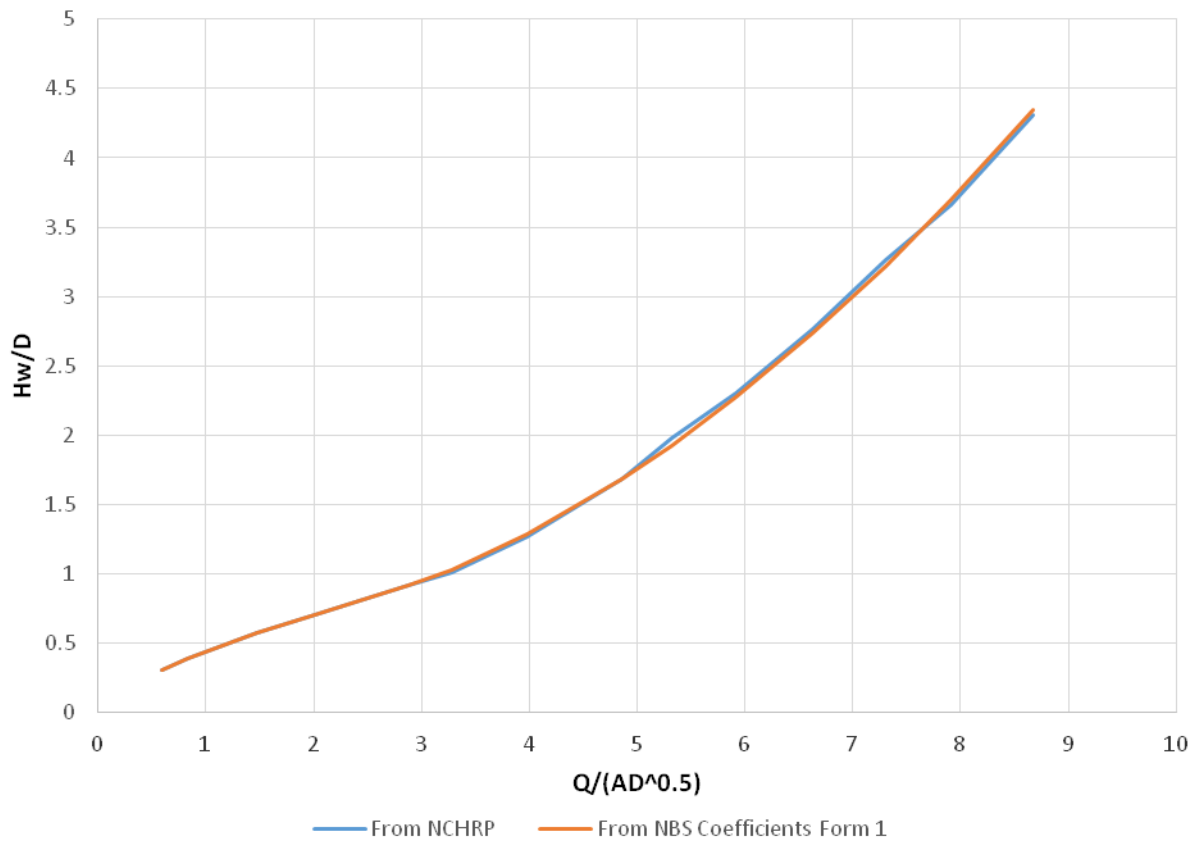


Table 62: Table used for Form 2 NBS Coefficients for a 50% embedded culvert with a projecting inlet edge type with an upstream pond.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5245	0.3163	0.3135	0.0028
0.8441	0.4401	0.4399	0.0002
1.1785	0.5549	0.5579	0.0029
1.6004	0.6865	0.6936	0.0072
1.9716	0.8047	0.8047	0.0000
2.3231	0.9072	0.9044	0.0029
3.4039	1.2585	1.2282	0.0303
4.1914	1.5941	1.5946	0.0005
4.6867	1.8416	1.8639	0.0222
5.8325	2.6088	2.6021	0.0066
5.9545	2.6902	2.6902	0.0000
6.7467	3.3012	3.3064	0.0052
7.5298	3.9769	3.9911	0.0143
K	0.4963	Average Difference	0.0073
M	0.71		
c	0.0612		
Y	0.52		

NBS and Data Curve Comparisons

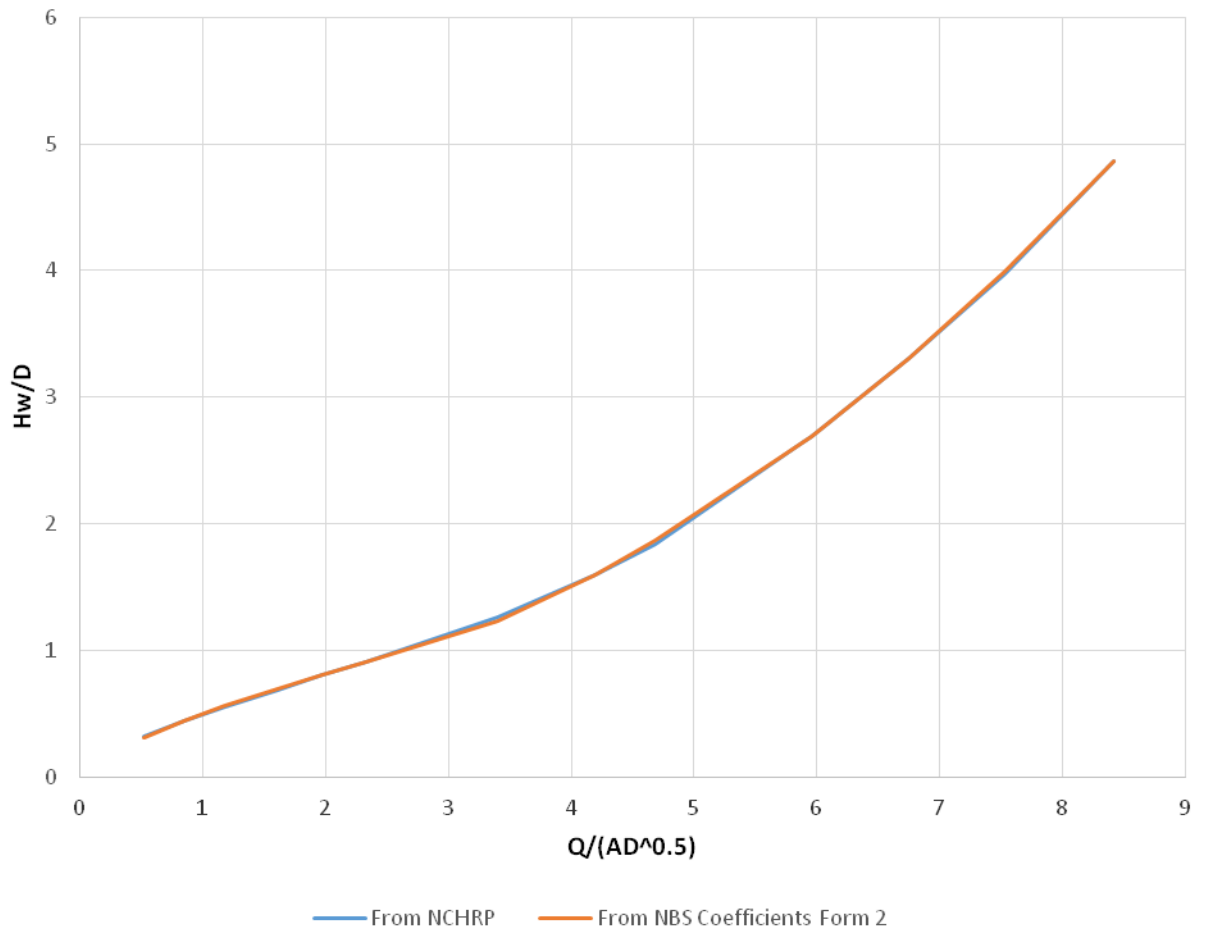


Table 63: Table used for Form 2 NBS Coefficients for a 50% embedded culvert with a projecting inlet edge type and an upstream channel

<u>From</u> <u>NCHRP</u> Corrected $Q/(AD^{0.5})$	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5456	0.3308	0.3286	0.0022
0.8072	0.4300	0.4296	0.0004
1.0755	0.5226	0.5228	0.0002
1.4054	0.6263	0.6278	0.0016
1.7805	0.7378	0.7382	0.0004
2.1103	0.8292	0.8292	0.0000
2.4186	0.9184	0.9103	0.0081
3.4588	1.2183	1.1228	0.0956
4.6218	1.6565	1.6680	0.0114
5.6305	2.2453	2.2680	0.0227
6.7289	3.0559	3.0556	0.0003
7.6246	3.8264	3.8015	0.0249
8.6177	4.7373	4.7373	0.0000
K	0.4974	Average Difference	0.0129
M	0.68		
c	0.0580		
Y	0.43		

NBS and Data Curve Comparisons

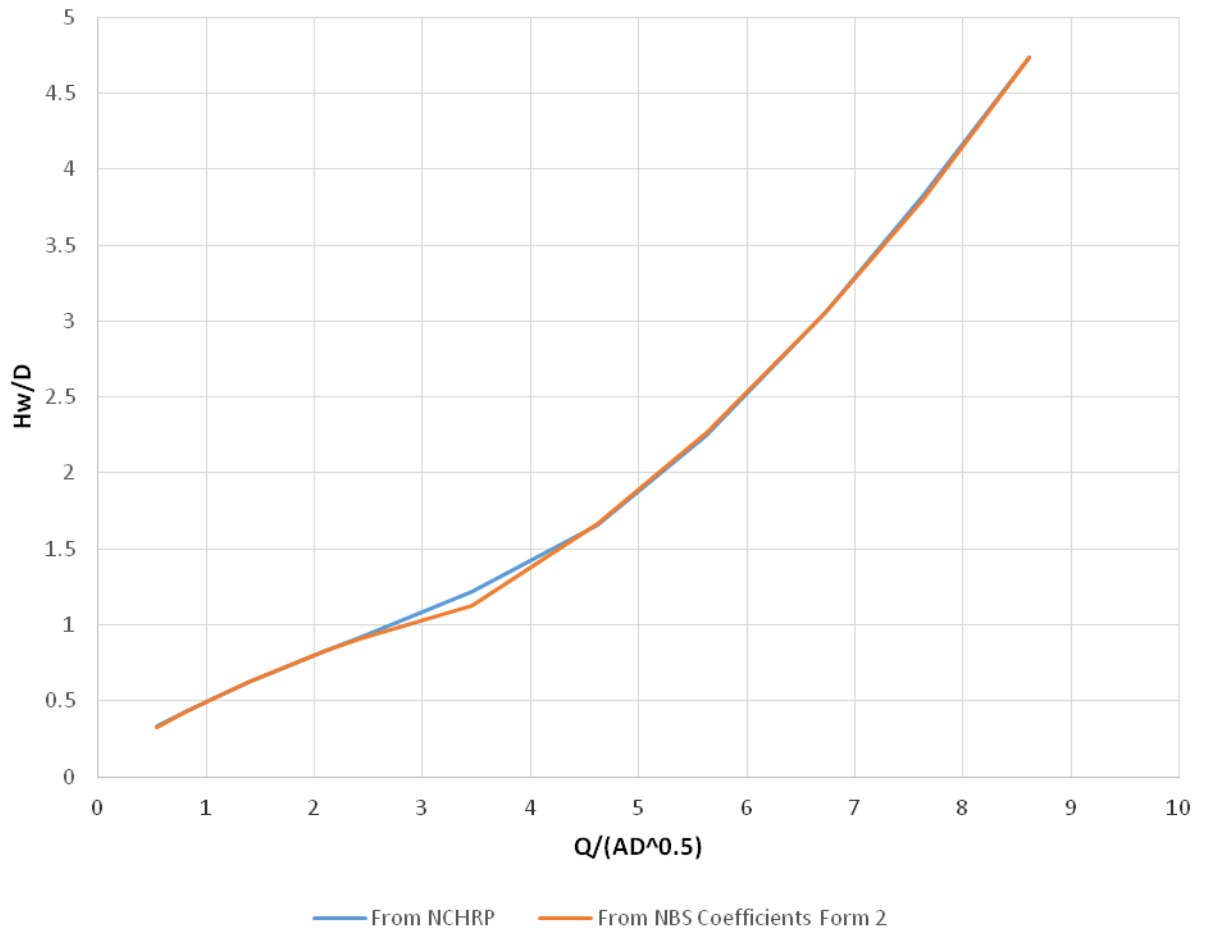


Table 64: Table used for Form 2 NBS Coefficients for a 50% embedded culvert with a square inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>From</u> <u>NCHRP</u> HW/D- Hc/D+0.5S	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5476	0.2973	0.0000	0.2943	0.0030
1.0095	0.4534	0.0031	0.4556	0.0021
1.4674	0.5839	0.0077	0.5951	0.0112
2.0742	0.7467	0.0162	0.7619	0.0152
2.6352	0.8883	0.0245	0.9040	0.0157
3.4479	1.1068	0.0347	1.1081	0.0013
4.1027	1.3142	0.0469	1.3098	0.0044
4.8294	1.5852	0.0582	1.5746	0.0106
6.0212	2.0947	0.1747	2.1021	0.0074
7.2046	2.7403	0.4074	2.7406	0.0003
8.3638	3.4941	0.6021	3.4768	0.0173
9.8460	4.5779	0.8030	4.5779	0.0000
K			Average	
	0.4525		Difference	0.0074
M	0.71			
c	0.0408			
Y	0.62			

NBS and Data Curve Comparisons

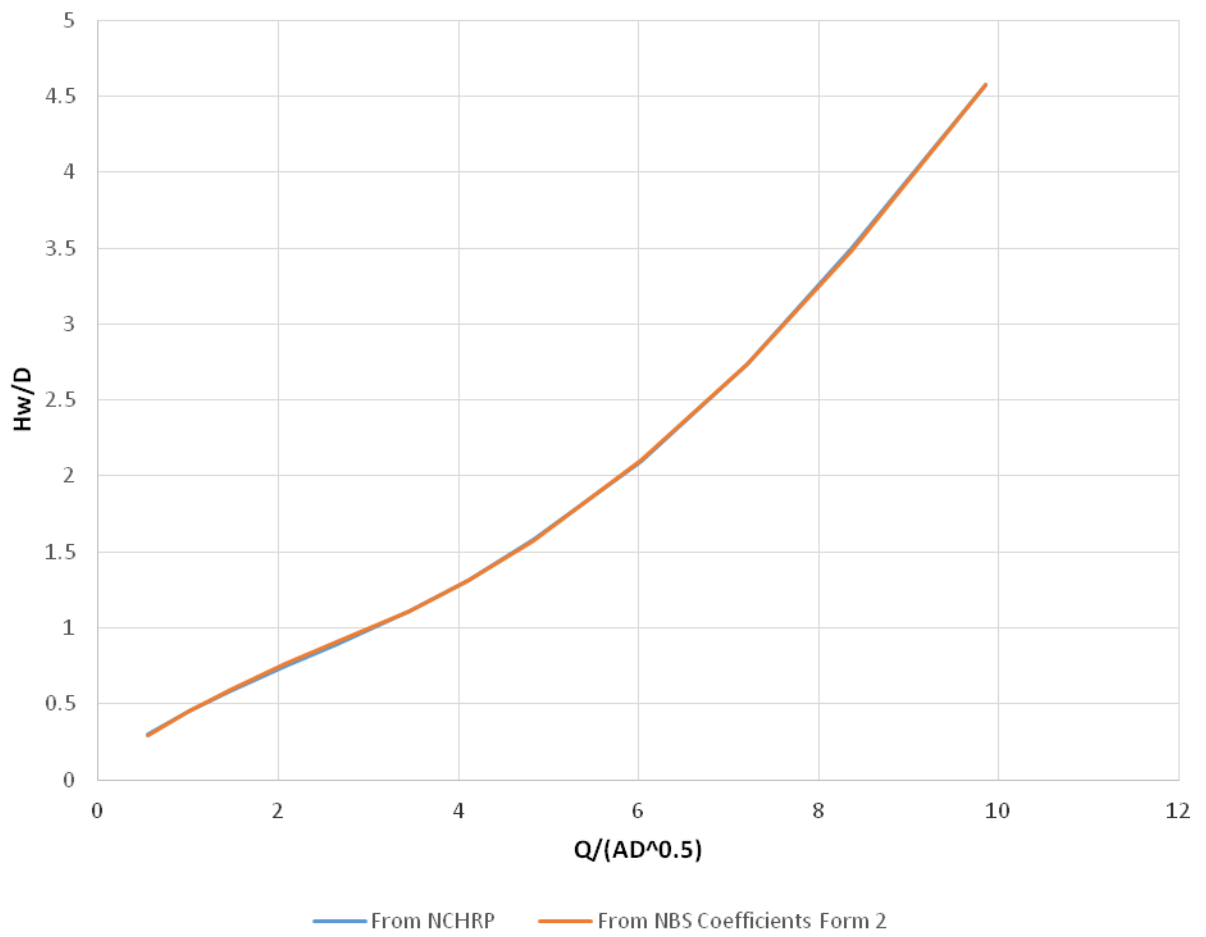


Table 65: Table used for Form 2 NBS Coefficients for a 50% embedded culvert with a 45° beveled inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.6415	0.3274	0.3274	0.0000
1.1106	0.4757	0.4757	0.0000
1.5253	0.5895	0.5904	0.0010
2.0974	0.7333	0.7333	0.0000
2.6888	0.8738	0.8684	0.0054
3.9877	1.1893	1.1893	0.0000
4.7283	1.3979	1.4112	0.0134
5.8855	1.8416	1.8334	0.0082
7.0962	2.3802	2.3737	0.0065
8.4598	3.1228	3.1028	0.0200
9.8126	3.9356	3.9525	0.0169
K	0.4430	Average Difference	0.0065
M	0.68		
c	0.0344		
Y	0.64		

NBS and Data Curve Comparisons

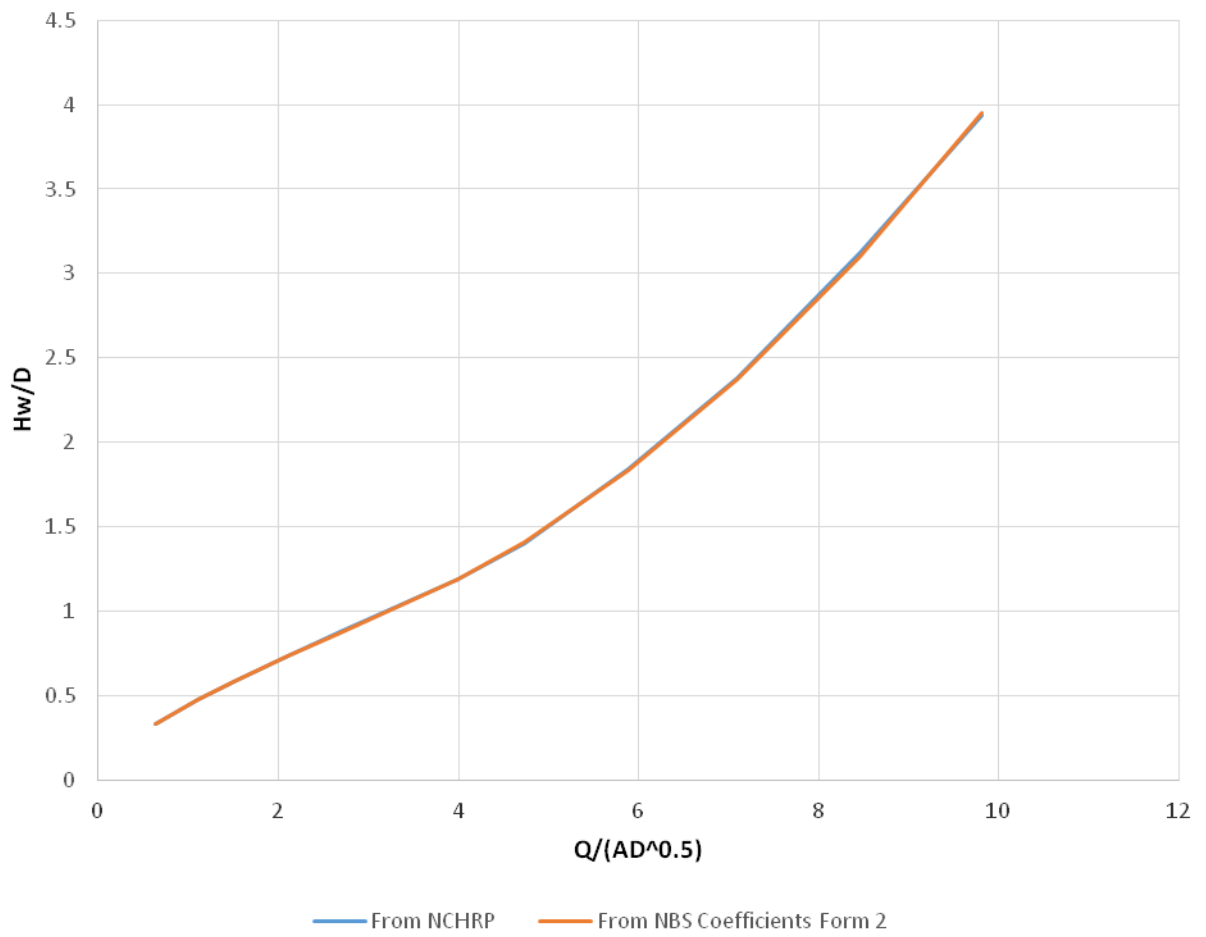


Table 66: Table used for Form 2 NBS Coefficients for a 50% embedded culvert with an 1.5H:1V mitered inlet edge type.

<u>From</u> <u>NCHRP</u> Corrected Q/(AD ^{0.5})	<u>From</u> <u>NCHRP</u> Hw/D	<u>Computed</u> HW/D	<u>Computed</u> Difference
0.5912	0.3122	0.3045	0.0077
0.8266	0.3891	0.3841	0.0050
1.1495	0.4828	0.4828	0.0000
1.4720	0.5731	0.5731	0.0000
2.0001	0.7058	0.7088	0.0030
2.4573	0.8173	0.8176	0.0003
2.8749	0.9188	0.9115	0.0072
3.2796	1.0147	1.0276	0.0129
3.9766	1.2745	1.2879	0.0135
4.8567	1.6881	1.6881	0.0000
5.3168	1.9791	1.9291	0.0500
K	0.4384	Average Difference	0.0091
M	0.69		
c	0.0515		
Y	0.47		

NBS and Data Curve Comparisons

