Appendix C: Culvert Hydraulics Analysis:

Culvert Hydraulics Calculations:
Equations, Tables, and Diagrams taken from Useful Culvert Design Information Packet

I. Equations

A. Submerged Outlet (Pipe Flow I):

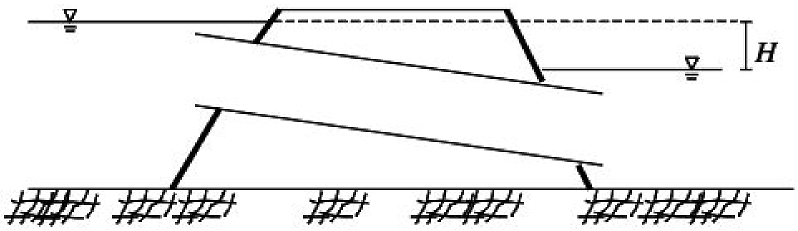

Figure A.1: Schematic of the submerged outlet culvert design condition.

a. Submerged Outlet Pipe Flow Equation:

$$q = \frac{a\sqrt{2gH}}{\sqrt{1+K_e+K_cL}}$$

Where:
q = flow rate (m^3/s)
g = gravitational constant = 9.81 m/s^2
H = energy head (m) as seen in Figure A.1
K_e = entrance loss coefficients (dimensionless), see Table A.2
n = manning's coefficient ($s/m^{1/3}$), see Table A.1
A = culvert cross-sectional area (m^2)
WP = culver cross-sectional wetted perimeter (m)
R = hydraulic radius (m) = A/WP
K_c = pipe frictional loss (m^{-1}) = $\frac{2gn^2}{R^{4/3}}$

B. Free Outlet (Pipe Flow II):

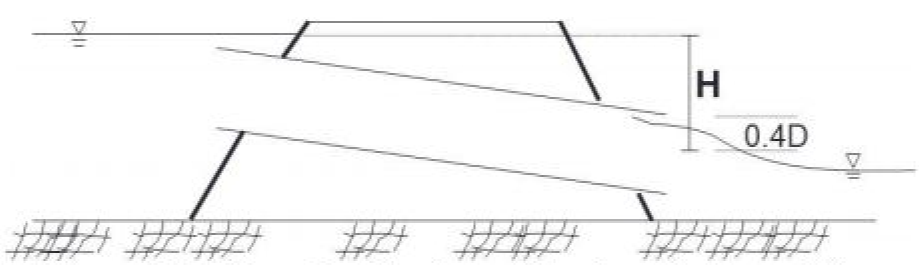

Figure B.1: Schematic of the free outlet culvert design condition

a. Type II analysis utilizes free outlet flow conditions. Free outlet flow conditions simply mean that the pressure head created by the water flowing through the culvert is measured at the outlet of the culvert, as illustrated in Figure 2, where H is the term used to describe the pressure head and D is the diameter of the culvert. Utilizing free outlet control conditions, the culvert pipe is flowing full.

b. Free Outlet Pipe Flow Equation:

$$q = \frac{a\sqrt{2gH}}{\sqrt{1+K_e+K_cL}}$$

Where:
q = flow rate (m^3/s)
g = gravitational constant = 9.81 m/s^2
H = energy head (m) as seen in the Figure B.1
K_e = entrance loss coefficients (dimensionless), see Table A.2
n = Manning's coefficient ($s/m^{1/3}$), see Table A.1
A = culvert cross-sectional area (m^2)
WP = culver cross-sectional wetted perimeter (m)
R = hydraulic radius (m) = A/WP
K_c = pipe frictional loss (m^{-1}) = $\frac{2gn^2}{R^{4/3}}$

C. <u>Orifice Outlet Control (Inlet Control III)</u>

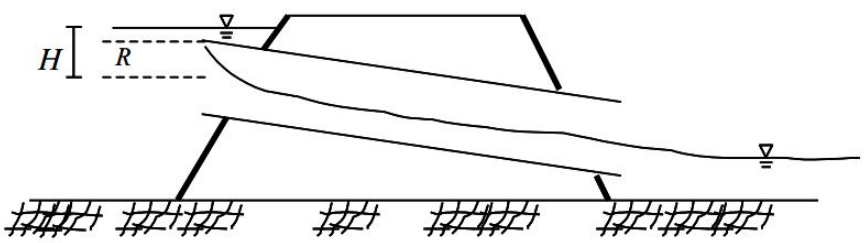

Figure C.1: Schematic of the orifice outlet control culvert design condition

a. Type III analysis utilizes orifice conditions, also known as inlet control conditions. As illustrated in Figure 3, orifice conditions represent the pressure head (H) created by the water flowing through the inlet of the culvert. Essentially, inlet control conditions represent a hydraulic scenario in which the culvert pipe is not necessarily flowing full.

b. Orifice Outlet Control Equation:

$$= \sqrt{2gH}$$

Where:
q = flow rate (m^3/s)
g = gravitational constant = 9.81 m/s^2
H = energy head (m) as seen in the Figure C.1

C = head loss coefficient (dimensionless)
= 0.611

D. <u>Federal Highway Administration approach for Inlet Control (Inlet Control III)</u>

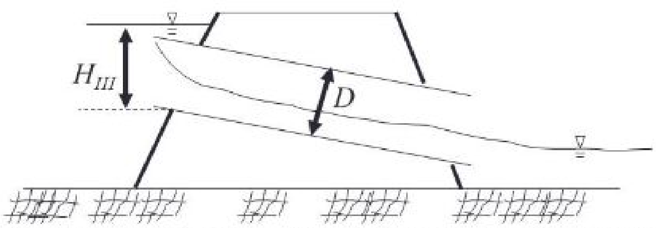

Figure D.1: Schematic of the orifice flow culvert design condition

a. The Federal Highway Administration (FHA) analysis also utilizes inlet control conditions. Like the Type III analysis, the FHA analysis utilizes the pressure head (H_{III}) created by the water flowing through the inlet of the culvert, as illustrated in Figure 4. Again, inlet control conditions represent a hydraulic scenario in which the culvert pipe is not necessarily flowing full.
b. FHA Approach for Inlet Control Equation:

$$q = A_c\sqrt{D}\sqrt{\frac{\frac{H_{III}}{D}-Y-k_s s_a}{c}}$$

Where:

q	culvert peak flow capacity (m^3 s^{-1})
A_c	culvert cross-sectional area (m^2)
D	culvert diameter (m)
H_{III}	headwater depth, from culvert invert to top of road (m)
Y,c	tabulated constants (Table D.1)
k_s	slope adjustment constant; -0.5 (mitered inlets +0.7)
s_a	culvert barrel slope (percent)

II. Tables

Table A.1. Some common Manning coefficients used to calculate friction coefficient K_c. Adapted from Schall et al. (2012).

Bottom material		Manning's n
Culvert	Concrete	0.012
	Metal	0.024
	Plastic	0.012
Stream Bed		0.024

Table A.2. Entrance loss coefficients adapted from Schall et al. (2012).

Culvert Shape	Culvert Material	Inlet Type	k_e
Arch	Concrete	Headwall	0.5
		Mitered	0.7
		Wingwall	0.5
	Metal	Headwall	0.5
		Mitered	0.7
		Projecting	0.9
Box	Concrete	Headwall	0.5
		Wingwall	0.5
	Plastic	Headwall	0.5
Circular/Oval	Concrete	Headwall	0.5
		Projecting	0.5
		Wingwall	0.2
	Metal	Headwall	0.5
		Projecting	0.9
		Mitered	0.7
		Wingwall	0.5
	Plastic	Headwall	0.5
		Mitered	0.7
		Projecting	0.9
		Wingwall	0.5

Table D.1. Constants for inlet control equation, A.5. Adapted from Schall et al. (2012)

Culvert Shape	Culvert material	Inlet type	C	Y
arch	concrete, stone	headwall	0.041	0.570
		mitered	0.040	0.480
		wingwall	0.040	0.620
		wingwall and headwall	0.040	0.620
	metal, plastic	headwall	0.043	0.610
		mitered	0.054	0.500
		projecting	0.065	0.120
		wingwall and headwall	0.043	0.610
box	concrete, stone	headwall	0.038	0.870
		wingwall	0.038	0.870
		wingwall and headwall	0.038	0.870
	metal, plastic	headwall	0.038	0.690
	wood	wingwall	0.038	0.870
ellipse	concrete, stone	headwall	0.048	0.800
		wingwall and headwall	0.048	0.800
	metal, plastic	headwall	0.048	0.800
		mitered	0.048	0.800
		projecting	0.060	0.750
		wingwall	0.048	0.800
		wingwall and headwall	0.048	0.800
embedded ellipse	concrete, stone	headwall	0.043	0.610
		mitered	0.054	0.500
	metal, plastic	headwall	0.043	0.610
		mitered	0.054	0.500
		other	0.065	0.120
		projecting	0.065	0.120
		wingwall	0.043	0.610
		wingwall and headwall	0.043	0.610

Table D.2 (cont.)

Culvert Shape	Culvert material	Inlet type	C	Y
embedded round	concrete, stone	headwall	0.040	0.650
		other	0.057	0.480
		projecting	0.057	0.480
		wingwall	0.040	0.650
		wingwall and headwall	0.040	0.650
	metal, plastic	headwall	0.040	0.650
		other	0.057	0.480
		projecting	0.057	0.480
		wingwall	0.040	0.650
		wingwall and headwall	0.040	0.650
round	concrete, stone	headwall	0.029	0.740
		mitered	0.029	0.740
		other	0.032	0.690
		projecting	0.032	0.690
		wingwall	0.029	0.740
		wingwall and headwall	0.029	0.740
	metal, plastic	headwall	0.038	0.690
		mitered	0.046	0.750
		other	0.055	0.540
		projecting	0.055	0.540
		wingwall	0.038	0.690
		wingwall and headwall	0.038	0.690

Culvert Data for Each Stream Crossing Used in Calculations:

Location	Culvert Type	Culvert Width in meters (w)	Culvert Height in meters (h)	Depth from road surface to top of culvert in meters (HW)	Slope of Culvert (S)	Length of Culvert in meters (L)	Ke Value for Culvert	Manning's Number for Culvert (n)	c (tabulated constant for FHA)	Y (tabulated constant for FHA)
Bostwick Road	Box	4	4	1.9	0	33	0.5	0.012	0.038	0.87
Enfield Main Road	Box	12.2	3.9	1.4	0.2577	38.8	0.5	0.012	0.038	0.87
Connecticut Hill Road	Elliptical	10.2	5.3	1.1	0.2421	41.3	0.5	0.024	0.048	0.8
Leonard Road	Box	20.1	6.2	0	0.3922	25.5	0.5	0.012	0.038	0.87
Butternut Creek Road	Round	4	3.9	0.9	0.495	20.2	0.9	0.024	0.06	0.75
Stonehaven Circle Road	Box	19	7.5	0	0.8299	24.1	0.5	0.012	0.038	0.87
Station Road	Round	2.5	2.5	2.1	0.2151	46.5	0.5	0.024	0.038	0.69
Valley View Road	Elliptical	9.4	4.4	2.8	0.8451	35.5	0.5	0.024	0.048	0.8
West Danby Road (34)	Box	8.1	6.3	7.4	0.13	76.9	0.5	0.012	0.038	0.87
Smiley Hill Road	Round	3.5	3	1.6	0.9804	51	0.9	0.024	0.055	0.54
Ekroos Road (1)	Round	7.9	8.2	2.7	0.7481	40.1	0.5	0.024	0.038	0.69
Ekroos Road (2)	Round	8.3	7.7	2.7	0.4926	40.6	0.5	0.024	0.038	0.69
Vanostrand Road (1)	Round	2	2	5.2	0	37	0.5	0.024	0.038	0.69
Vanostrand Road (2)	Round	1.5	1.6	1.6	0.2688	37.2	0.9	0.024	0.055	0.54
Douglas Road	Round	3	2.8	2.2	0.3373	59.3	0.5	0.024	0.038	0.69
Fishkill Road	Round	8.3	5.1	1.8	1.25	32	0.5	0.024	0.038	0.69
Thomas Road	Box	4.9	1.9	1.5	3.6	28.1	0.5	0.012	0.038	0.87
Curry Road (1)	Elliptical	16.8	10.5	1	4.8	40	0.7	0.024	0.048	0.8
Curry Road (2)	Elliptical	16.9	10.2	1	3.7	40.5	0.7	0.024	0.048	0.8
Genung Road	Round	3	3	2.2	1	51	0.9	0.012	0.055	0.54
38 North	Box	4	3	2.2	4	53	0.5	0.012	0.038	0.87