The University of Maine

Watershed Study of Church Avenue in Frenchville, Maine

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Executive Summary

The town of Frenchville, Maine, has requested an analysis of the existing culverts along Church Avenue and Fort Kent Street, with recommendations on improving the capacity of this existing infrastructure. Our proposed infrastructure upgrades are designed to withstand a 100-year runoff event, and involve erosion control measures to reduce future washout risk. Our client also asked for us to provide standard sizing, using corrugated aluminized steel pipe culverts.

We are ASIDE Engineering, a senior capstone group within the Civil Engineering Department at the University of Maine. Our group is composed of students passionate about the fields of water resources, environmental engineering, and transportation engineering. We are pleased to present our recommendations, which meet all of our clients' expectations.

To meet the Town of Frenchville's requests, we conducted an inventory of the existing infrastructure along Church Avenue and Fort Kent Street. We determined that all of the stormwater infrastructure in this area was culverts, either underneath the main roadway or adjacent driveways. For each culvert, we collected data on the geometry of the culvert, and the flow entering the culvert. Resources used for watershed delineation and analysis include Google Earth Pro, TR-55, ArcGIS, and HEC-RAS.

To meet the Town of Frenchville's goal of minimizing ancillary changes to the roadway, an analysis of each resized culvert's impact on the roadway was conducted. Roadway modifications were designed as necessary. These modifications were conducted in accordance with AASHTO and MaineDOT standards.

As with any project, there are risks associated with the decisions that we made. To help improve the Town of Frenchville's understanding of these risks, we conducted a comprehensive risk analysis. We created a risk matrix weighing the flow analysis, use case, and existing conditions of each culvert.

In consideration of the Town of Frenchville's budget, we conducted a construction cost estimate for installing the new culverts. Our total opinion of the probable cost for replacing the nine culverts we analyzed is $1,359,485.00. This total cost includes adjustments to the roadway for cross culvert 17, overhead and profit, and a remoteness factor of 1.15. We formed our opinion of probable cost based on information from RSMeans, and similar MaineDOT projects from 2023. Costs were based on these 2023 estimates, with an increase of five percent to account for inflation and decreased scope of work.

Acknowledgements

ASIDE Engineering would like to thank the following individuals and organizations for their assistance in preparing this report. Without their assistance, this experience would not have been possible.

First and foremost, we would like to thank our client, David Cyr, and the Town of Frenchville. He provided us with this challenging and rewarding experience, which helped us grow as students and professionals.

Next, we would like to thank the faculty at the University of Maine, including the following individuals:

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Additional thanks goes to the following consulting engineers and companies:

- Contech Engineered Solutions
- Maine Department of Transportation

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1.0 Introduction

ASIDE engineering proudly presents the analysis of the stormwater infrastructure along Church Avenue and Fort Kent Street in Frenchville, Maine. The analysis looked at a total of forty culverts spanning the desired roadways, where we highlighted necessary actions that should be taken for culverts to help improve functionality. The purpose of this report is to provide Frenchville a better understanding of their stormwater drainage system and steps they should take to enhance this.

2.0 Project Overview

The town of Frenchville has requested a comprehensive map and list of the inadequate culvert infrastructure with the necessary upgrades to dimensions. It was informed to us that all infrastructure must be able to support a 100-year runoff event. With our understanding that Frenchville, Maine doesn't necessarily have a large allocated budget to right-size every piece of infrastructure in the town, an assessment was conducted to determine which culverts are most critical. Alongside this, erosion control measures were determined to mitigate washout risks for the culverts. Roadway alignments were adjusted based on the new recommended infrastructure.

Elements that require further consideration for future designs include:

1. Conduct a geotechnical investigation for the culvert locations and for determining infiltration given a 100-year runoff event.
2. Creating a construction schedule.
3. Conduct a hydraulic analysis using a software like HydroCAD for more accurate modeling purposes.

3.0 Permits

3.1 Maine State Permitting

Permits for replacement of existing culverts are not required based on Maine state legislature 480-Q Activities for which a permit is not required, section 2A. Existing Road Culverts. This includes culverts that will not see significant changes in size (length, or diameter), and culverts for crossings that fit the requirements in legislature 480-Q.

The town of Frenchville ME is responsible for maintenance on Church Ave. therefore Maine DOT (MDOT) permits will not be required. Road superelevation changes will not require a permit.

3.2 Maine Department of Environmental Protection (MEDEP): Natural Resources Protection Act (NRPA) Permit-By-Rule (PBR)

A permit for section 2: Activities Adjacent to Protected Natural Resources 06-096-305 ME Code will be necessary for cross road culvert seven, thirteen, and fifteen (CC7, CC13, and CC15). The wetlands bordering these three culvert locations exceed 20,000 square feet of aquatic vegetation. A permit for section 10: Stream Crossings 06-096-305 ME Code, will not be necessary for CC7 and CC13 because each watershed is less than 25 square miles.

3.3 US Army Corps of Engineers (USACE) Permitting

Although the flow chart signifies category 2, permitting under ME-GP, category 2 is not necessary as the project does not include navigable waters.

Permitting under ME-GP, number 22 is necessary because the project occurs by wetland.

4.0 Permits Supplementary Documents

4.1 PBR Section 2

- ➢ Submit photographs of the affected area
- ➢ Submit photographs of the completed project within 20 days of the projects completion.The photographs must be sent with a copy of the notification form.
- ➢ Submit a brief narrative explaining why there is no practicable alternative to location of the activity within the 75 foot setback, and how this impacts the remaining buffer.

- A scaled drawing including the entire property on which the activity will take place, including property lines, the 75 foot setback, and the boundaries or location of protected natural resources such as streams and wetlands. As well as proposed and existing development on the parcel including buildings, parking areas, roads, fill areas, landscaped areas, etc., and any site constraints limiting development beyond the 75 foot setback, such as steep slopes.
- The PBR Notification Form requires a $307 fee and location map.

4.2 ME-GP, #22

- To acquire this permit an approved PBR Notification Form must be submitted.
- Requires Category 2 permit due to presence of Atlantic salmon at CC7.
- ENG Form 4345 must be filled out.
- Permit submissions should be done in accordance with the Department of the Army General Permit for Maine criteria[1].
- This permit requires a $10 fee for non-commercial work.

5.0 Existing Culvert Data

5.1 General Culvert Information

Information gathered from our site visit on October, 2023 can be summarized in Table 1, which includes measured properties (length and diameter) and observed properties (material, condition, and culvert slope). Culverts in Table 1 are listed in order beginning at the Dickey Brook crossing on Church Avenue and continuing down Route 1 ending at the border of Frenchville and Fort Kent. All cross culverts are labeled CC and numbered 1 through 17, all driveway culverts are labeled DC and numbered 1 through 23.

5.2 Recorded Culvert Properties

The length and diameters of the culverts are in feet and inches respectively. Diameter sizes are not standardized to industry culvert sizing (12in, 15in, 18in, 24in, 36in, 48in, 60in) and are based on the culvert gauge at the openings[2]; we assume the culvert barrel is the same diameter across the entire length. Material of the culvert included PVC, corrugated and non-corrugated steel and galvanized steel. Conditions of the culverts were determined by observation and noted, most culverts were in good condition however outlet and inlet conditions were included if they were likely to impact the culverts effectiveness. Other conditions include fully rusted bottoms and very poor general culvert conditions.

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[1] *https://www.nae.usace.army.mil/Portals/74/docs/regulatory/StateGeneralPermits/MEGP.pdf*

[2] Damaged and obstructed openings were measured at the point where a complete diameter could be obtained; all culverts had at least one point with a complete diameter.

The culvert's slope was not collected on the site visit, but rather from using topographic map elevations and spacing along the roadway where the culvert lies. Site images were also used to help distinguish these slopes.

Table 1: *Existing Culvert Information*

	Culvert Properties					Additional Notes
Culvert	**Length (ft)**	**Diameter (in)**	**Material Type**	**Condition of Culvert**	**Culvert Slope**	**Landscape**
1 CC	60.5	26	PVC	Ovaled/Crushed	1.6%	Overgrown Area, Sediment buildup
1 DC	69.0	24	Corrugated Galvanized Steel	Shredded at end, Entrance is Good	4.0%	Rip rap uphill (spaced @ 16', 56', 43', 77', 19.5')
2 DC	20.5	22	PVC	Good Condition	2.4%	Rip rap uphill (spaced @ 30', 62.5', 64', 48', 57', 54')
3 DC	29.0	12	PVC	Good Condition	1.0%	Culvert placed too high, Rocks Clogged
4 DC	34.0	15	PVC	Good Condition	2.9%	Sludge/Sediment (5 inches), Overgrown
5 DC	33.5	12 in 15 out	PVC	Good Condition	1.5%	Heavily Overgrown
2 CC	40.5	16	Corrugated Galvanized Steel	Crushed Entrance	2.4%	Several rocks blocking entrance, overgrown exit
3 CC	48.0	15	Steel	Crushed	2.1%	Overgrown Area, Blocking entrance/exit
4 CC	49.0	18	Corrugated Steel	Slightly Deformed	2.0%	Overgrown Area, Sediment Buildup
5 CC	60.0	24	PVC	Good Condition, briefly ovaled	2.5%	Running water into it, greenery at entrance
6 CC	54.5	18	PVC	Good Condition	1.8%	Rock in front of entrance (L>R)
7 CC	75.0	60, 30	PVC (2)	Good Condition	2.6%	New Culverts, 2 culverts, smaller used for overflow

	Culvert Properties					Additional Notes
Culvert	**Length (ft)**	**Diameter (in)**	**Material Type**	**Condition of Culvert**	**Culvert Slope**	**Landscape**
6 DC	41.0	15	Corrugated Steel	Good Condition	2.4%	Overgrown at entrance and exit
8 CC	60.0	24	Corrugated Steel	Crumpled	4.1%	Water flowing(R>L), overgrown
7 DC	30.0	18	Corrugated Steel	Good Condition	3.3%	Overgrown, heavy sediment in pipe
8 DC	167.0	18	PVC	Good Condition	2.4%	Overgrown, Catch Basin, 81ft>catch basin>86ft
9 DC	32.0	15	Corrugated Steel	Bottom Rusted, Bad Condition,	6.3%	Sediment, Blind Spot on driveway
10 DC	30.0	15	PVC	Good Condition	0.8 %	Overgrown, rock in front of entrance
9 CC	60.0	36	PVC	Good Condition, New	1.6%	Well Maintained
11 DC	52.0	18	Corrugated Steel	Good Condition	1.9%	No Signs of Washout, Overgrown
10 CC	60.0	18 in 21 out	PVC	Good Condition, New	3.3%	Signs of Washout Above Rd, outlet overgrown
11 CC	50.0	36	PVC	Good Condition	2.0%	Overgrown, No sign of washout (R>L)
12 CC	60.0	24	PVC	Good Condition	3.3%	Overgrown, Flows to Pond
12 DC	40.0	15	PVC	Good condition	1.3%	Heavily Overgrown
13 DC	40.0	18	PVC	Looks New, Pipe Crushed(Rocks)	1.3%	Briefly Overgrown
14 DC	41.0	18	PVC	Good Quality	1.0%	Overgrown, Heavy sediment on out flow
13 CC	40.0	30	PVC	Good Condition	2.5%	Flows out of Pond (Entrance has a cover)
15 DC	30.0	18	Corrugated Steel	Pipe in bad condition	1.3%	Overgrown, sediment

	Culvert Properties					Additional Notes
Culvert	**Length (ft)**	**Diameter (in)**	**Material Type**	**Condition of Culvert**	**Culvert Slope**	**Landscape**
16 DC	36.0	18	Steel	Rusted, Good condition	0.6%	Overgrown Ditch , sediment
17 DC	25.0	18	Corrugated Steel	Bad Condition, Rusted	0.4%	Overgrown
18 DC	40.0	18	Corrugated Steel	Bad Condition, Rusted	0.3%	Overgrown, not a lot of sediment
14 CC	50.0	40	PVC	Good Condition	4.0%	Well maintained, water can't keep up
19 DC	25.0	18	Corrugated Steel	Broken on bottom, rusted	1.2%	Overgrown
20 DC	30.0	15	Corrugated Steel	Rusted, broken on bottom	1.3%	Overgrown, Full of Sediment, water flow
15 CC	38.0	18	PVC	Crushed but functional	2.6%	Overgrown, Directs water towards house
16 CC	50.0	18	PVC	Egg shaped but functional	4.5%	Overgrown, catch runoff from farm fields
21 DC	40.0	18	Corrugated Steel	Bad condition	0.3%	Rip rap above it, overgrown
22 DC	28.0	18	Corrugated Steel	Bad Condition, Rusted	1.4%	Sediment in it, Erosion
17 CC	50.0	20	PVC	Good Condition	2.0%	Overgrown, not adequate
23 DC	27.0	20	Corrugated Steel	Rusted on bottom	1.1%	Overgrown, washout

6.0 Comprehensive Watershed Map

6.1 Subcatchments and Maps

Our project scope includes several small streams, having the culverts exist within multiple watersheds. Subcatchments for culverts that feed into each other are combined to create cumulative flow for the furthest culvert. This consideration is especially important for driveway culverts (DC) in series and when channelized ditches cross under the roadway through cross-road culverts (CC).

All culvert data is presented in Table 2. The time required for runoff to travel from the hydraulically most distant point in the watershed to the outlet is defined as time of concentration (TC). These time of concentration lines are defined for each of the culverts shown in Table 2. CC 7 is of particular note in our project as it is our largest sub catchment and requires a permanent stream crossing under the roadway which is considered for a StreamSmart crossing. Another notable catchment area is CC 13, which has an area of 222.5 acres. This culvert has water flowing out of a pond.

Of the driveway culvert data outlined in Table 2, the catchment area for DC 23 has the largest area of 58.7 acres. This culvert has significant signs of washout and is directly next to farmland.

The final watershed map is attached in the appendix labeled Watershed Map.

Table 2: *Watershed Properties*

	Watershed Properties			
Culvert	**Watershed Area (acres)**	**TC Line Distance (mi)**	**TC Elevation Change (ft)**	**TC Slope (%)**
CC 1	2.9	.21	33	3.0
DC 1	1.2	.08	16	3.6
DC 2	0.7	.13	25	3.7
DC 3	0.6	.04	5	2.6
DC 4	16.7	.38	72	3.6
DC 5	10.4	.38	72	3.6
CC 2	11.1	.39	76	3.7
CC 3	5.0	.30	75	4.7
CC 4	11.0	.33	76	4.4
CC 5	135.9	.93	135	2.7

	Watershed Properties			
Culvert	**Watershed Area (acres)**	**TC Line Distance (mi)**	**TC Elevation Change (ft)**	**TC Slope (%)**
CC 6	24.8	.44	82	2.2
CC 7	1096.0	1.64	104	1.2
DC 6	3.9	.15	80	9.9
CC 8	50.0	.70	126	3.4
DC 7	1.8	.12	14	2.2
DC 8	5.5	.19	32	3.1
DC 9	2.6	.12	12	1.9
DC 10	1.8	.06	8	2.5
CC 9	53.7	.23	61	4.9
DC 11	6.0	.27	65	4.6
CC 10	23.6	.35	75	4.1
CC 11	50.0	.30	32	2.0
CC 12	48.0	.52	24	.90
DC 12	0.6	.06	4	1.2
DC 13	1.7	.12	12	1.9
DC 14	3.5	.14	16	2.2

	Watershed Properties			
Culvert	Watershed Area (acres)	TC Line Distance (mi)	TC Elevation Change (ft)	TC Slope (%)
CC 13	222.5	.88	38	.80
DC 15	2.2	.19	37	3.7
DC 16	4.4	.18	32	3.4
DC 17	6.7	.21	70	6.2
DC 18	1.0	.12	10	1.6
CC 14	152.5	.64	34	1.0
DC 19	0.6	.06	6	1.8
DC 20	0.6	.07	6	1.6
CC 15	17.6	.23	13	1.1
CC 16	22.0	.30	17	1.1
DC 21	1.5	.13	11	1.5
DC 22	4.4	.22	24	2.0
CC 17	22.5	.24	25	2.0
DC 23	58.7	.46	22	.90

6.2 Soil Types

From the delineated watershed, the sub catchments of each culvert were analyzed to determine the soil types that were present. Each culvert then received a soil classification based on its pertaining soil types, which were used for the flow analysis. Table 3 demonstrates each culvert and the soil types that took up more than 15% of the catchment area. Where table 4 expresses the soil type specifications.

Table 3: *Soil types for each culvert in order of occurrence on roadway, including only those greater than 15%*

Culvert	Soil Type	Percentage
CC 1	PgC	99.2
DC 1	PgC	84.9
DC 2	PgC	90.8
DC 3	PgC	100
DC 4	PgB PgC PgD	21.7 57.4 20.9
DC 5	PgB PgC PgD	23.1 55.8 21.1
CC 2	PgC PgD	57.5 27.4
CC 3	PgC PgD PgE	43.6 27.7 18.7

Culvert	Soil Type	Percentage
CC 10	ThC ThD ThB	51.7 21.2 16.1
CC 11	PgB PgC ThC ThD	24.9 19.1 22.2 17.6
CC 12	PgB PgC	37.7 31.7
DC 12	HoB	99.5
DC 13	HoB PgC	72.6 27.4
DC 14	HoB PgC	46.2 52.1

CC 4	PgC PgD PgE	48.1 21.4 21.0
CC 5	ThC ThD	31.3 37.6
CC 6	PgD PgE ThD	18.3 14.5 53.9
CC 7	ThC MoB PgC	29.8 12.4 13.2
DC 6	HoC PgC	37.3 53
CC 8	PgB ThC ThD	26.4 36.4 16.1
DC 7	PgC	85.2
DC 8	PgC	99.0
DC 9	MoA PgB PgC	18.6 53.9 27.6
DC 10	PgB PgC	70 30
CC 9	PgC ThC ThD	35.4 16.1 16.6
DC 11	PgB ThC ThD	20.9 20.9 50.8

CC 13	HoB PgB	25 29.2
DC 15	PgB PgC PgD	26.5 55.3 18.2
DC 16	PgB PgC	27.5 72.5
DC 17	PgB PgC	20.3 79.7
DC 18	HoB PgB PgC	16.3 55.3 28.4
CC 14	HoB MoB PgB	15.1 19.4 59.2
DC 19	HoB PgC	59.8 38.5
DC 20	PgB PgC HoB	38.9 38.5 22.6
CC 15	PgC PgB HoB	42.1 27.7 17.2
CC 16	PgB HoB PgC	55.1 23.7 21.2
DC 21	PgC PgB	77.7 22.3
DC 22	PgC PgB	82.1 17.9
CC 17	PgC PgB	82.3
DC 23	PgB PgC	49.2 21.7

Table 4: *Soil type specifications*

Soil Abbreviation	Soil Description	Percent Slope	Hydrologic Soil Group
PgA	Plaisted gravelly loam	0 to 3	C
PgB	Plaisted gravelly loam	3 to 8	C
PgC	Plaisted gravelly loam	8 to 15	C
PgD	Plaisted gravelly loam	15 to 30	C
PgE	Plaisted gravelly loam	30 to 45	C
ThB	Thorndike channery silt loam, rocky	0 to 8	D
ThC	Thorndike channery silt loam, rocky	8 to 15	D
ThD	Thorndike channery silt loam, very rocky	15 to 25	D
ThE	Thorndike channery silt loam, very rocky	25 to 45	D
TkC	Thorndike silt loam, very rocky	8 to 15	D
TkD	Thorndike silt loam, very rocky	15 to 30	D
TkE	Thorndike silt loam, very rocky	25 to 45	D
HoB	Howland Gravelly loam	3 to 8	C
HoC	Howland Gravelly loam	8 to 15	C
MoA	Monarda-Burnham complex	0 to 3	D
MoB	Monarda-Burnham complex	3 to 8	D

7.0 Data Analysis
7.1 TR-55 Analysis

We used TR-55 to model the hydrology of each watershed, TR-55 is a software application to model urban hydrology for small watersheds. The peak flow entering each specific culvert was found by adding the peak flows exiting each watershed that flows into the specific culvert, this is a very conservative method. Table 5 shows the peak CC and DC flows that each of the respective culverts experiences.

Table 5: *Culvert Network*

Culvert	CC Flows	DC Flows
CC1	-	1,2,3,4,5
DC1	-	2,3,4,5
DC2	-	3,4,5
DC3	-	4,5
DC4	-	5
CC7	8, 9,10	7,8,9,10,11
CC8	9,10	9,11
DC7	-	8,10
CC9	10	-
DC8	-	10
DC13	-	12
DC14	-	12,13
CC13	11,12	15,16,
CC16	-	21
CC12	-	12
DC15	-	16
CC14	15	17
DC18	-	19,20
CC16	-	21
DC19	-	20

CC17	-	22

In order to analyze the flow from a watershed, land use details must be defined by determining the curve number (CN), a greater CN yields greater runoff and vice versa. Then the time of concentration details must be defined, this determines the length and slope of sheet flow, shallow concentrated flow, and channel flow lengths. The channel length was distinguished from any defined channel shown on the topographic map. The area and wetted perimeter of the channel was estimated from the data collected from the site visit. A surface roughness was assumed for each of the type of flow segments based on the Civil 3D map and pictures taken on the site visit. The model was by using a rainfall distribution of a 100 year return period, 24 hour storm, commonly referred to as a 100-year runoff event.

We did not account for the impact of snow melt in our analysis. To properly size the culverts, a detailed analysis of snow accumulation and runoff rates will need to be conducted. Figure 1 shows historical snow data for the town of Fort Kent, which borders the town of Frenchville and the project site. The data shows a peak in water equivalent occurring between March 9th and April 8th. At the historical median, this research site experiences nearly 8 inches of water equivalent. This much runoff will have an outsized impact on the performance of the culverts. We utilized USGS data from the Fish River in Fort Kent to determine the regional runoff characterics of snowmelt in the month of May. We compared the monthly mean data of May and August, and found that in May, the mean was 4920 cfs, and 732 cfs in August. This shows that May has 572% greater flow than August. We anticipate that Frenchville experiences similar conditions due to its proximity. The snowmelt characteristics of the project site will need to be analyzed to properly size the culverts.

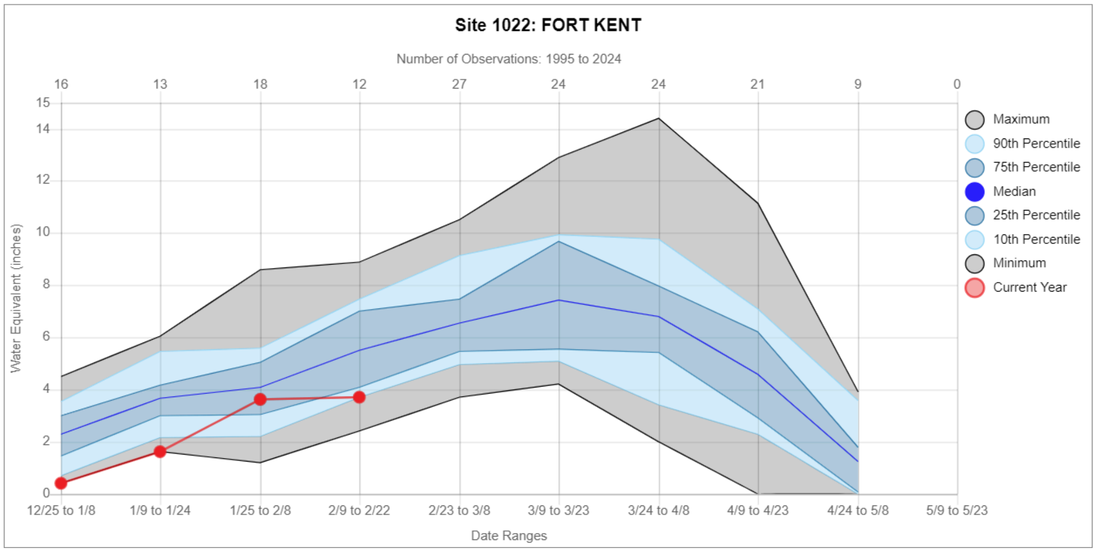

Figure 1: *Maine Cooperative snow survey historical and current year data for Fort Kent.*

7.2 Culvert Hydraulic Capacity

The method of generalized orifice-flow analysis is based on the headwater created by a set flow at a culvert opening. The method of analyzing hydraulic culvert capacity for the Federal Highway Administration (FHWA) is done by either assuming inlet or outlet control. This method is used to create nomographs which are easy tools to quickly determine if a culvert is effective, however, the equation is more effective for analyzing and resizing 40 separate culverts. The culverts were designed using inlet control because with a 100-year runoff event condition, the flow from the culverts do not pond greater than the ponding on the inlet side.

The summary of information determined for all of the culverts is shown in Table 6. As shown, adjusted diameter is the updated diameter for the 100-year runoff event situation for both orifice flow equation and nomograph method. The equations were set up to run until the headwater calculated was less than or equal to headwater actual, then were adjusted for industry pipe sizing.

Table 6: *Summary of Hydraulic Calculations*

Current Conditions				FHWA Nomograph Method			Orifice Flow Equation		
Culvert	Flow Rate (cfs)	Headwater Actual (ft)	Diameter (in)	Adjusted Diameter (in)	Headwater Calculated (ft)	Change in Diameter (%)	Adjusted Diameter (in)	Headwater Calculated (ft)	Change in Diameter (%)
CC 1	88.8	5.0	26.0	34.0	4.0	30.8	36.0	4.5	38
DC 1	75.5	4.0	24.0	34.0	3.0	41.7	36.0	3.7	50
DC 2	69.9	3.7	22.0	36.0	2.1	63.6	34.0	3.8	55
DC 3	66.8	5.2	12.0	36.0	2.0	200.0	34.0	3.6	183
DC 4	64.3	4.4	15.0	32.0	3.0	113.3	32.0	3.9	113
DC 5	24.7	3.3	12.0	26.0	1.6	116.7	24.0	2.2	100
CC 2	23.1	2.8	16.0	28.0	1.1	75.0	24.0	2.0	50
CC 3	12.0	3.3	15.0	20.0	1.4	33.3	16.0	2.1	7
CC 4	29.5	2.7	18.0	32.0	1.0	77.8	26.0	2.3	44
CC 5	194.5	7.0	24.0	42.0	6.3	75.0	58.0	9.4	142
CC 6	51.0	3.7	18.0	34.0	1.7	88.9	32.0	2.9	78
CC 7	1085.6	20.0	60.0, 30.0	68.0	16.7	13.3	126	15	0
DC 6	11.5	5.0	15.0	15.0	4.0	0.0	15.0	2.3	0
CC 8	321.0	4.7	24.0	60.0	3.2	150.0	66.0	6.2	175

Current Conditions				FHWA Nomograph Method			Orifice Flow Equation		
Culvert	Flow Rate (cfs)	Headwater Actual (ft)	Diameter (in)	Adjusted Diameter (in)	Headwater Calculated (ft)	Change in Diameter (%)	Adjusted Diameter (in)	Headwater Calculated (ft)	Change in Diameter (%)
DC 7	29.1	4.7	18.0	24.0	2.6	33.3	21.0	3.7	17
DC 8	22.5	3.7	18.0	24.0	1.8	33.3	20.0	2.9	11
DC 9	11.2	3.8	15.0	18.0	1.8	20.0	15.0	2.2	0
DC 10	5.3	3.0	15.0	15.0	1.3	0.0	15.0	1.0	0
CC 9	196.8	4.0	36.0	50.0	3.0	38.9	53.0	5.4	47
DC 11	19.8	3.5	18.0	22.0	2.0	22.2	19.0	2.7	6
CC 10	60.9	6.5	18.0	30.0	3.6	66.7	27.0	5.6	50
CC 11	189.2	4.0	36.0	50.0	2.8	38.9	52.0	5.3	44
CC 12	163.5	4.5	24.0	48.0	2.6	100.0	49.0	5.0	104
DC 12	3.3	4.5	15.0	15.0	0.8	0.0	15.0	0.8	0
DC 13	12.5	3.0	18.0	18.0	2.2	0.0	18.0	1.7	0
DC 14	29.4	4.2	18.0	26.0	2.0	44.4	22.0	3.3	22
CC 13	722.5	5.2	30.0	80.0	3.7	166.7	92.0	8.5	207
DC 15	29.5	4.7	18.0	24.0	2.7	33.3	21.0	3.8	17
DC 16	22.8	3.8	18.0	24.0	1.8	33.3	20.0	2.9	11
DC 17	31.2	5.0	18.0	24.0	3.0	33.3	21.0	4.1	17

Current Conditions				FHWA Nomograph Method			Orifice Flow Equation		
Culvert	Flow Rate (cfs)	Headwater Actual (ft)	Diameter (in)	Adjusted Diameter (in)	Headwater Calculated (ft)	Change in Diameter (%)	Adjusted Diameter (in)	Headwater Calculated (ft)	Change in Diameter (%)
DC 18	9.8	7.0	18.0	18.0	1.6	0.0	18.0	1.3	0
CC 14	447.3	3.2	40.0	80.0	1.7	100.0	81.0	6.4	103
DC 19	5.1	2.5	18.0	18.0	0.8	0.0	18.0	0.9	0
DC 20	2.4	3.5	15.0	15.0	0.7	0.0	15.0	0.7	0
CC 15	65.6	4.7	18.0	34.0	2.4	88.9	32.0	4.0	78
CC 16	73.1	6.0	18.0	32.0	3.7	77.8	30.0	5.5	67
DC 21	5.9	4.0	18.0	18.0	0.9	0.0	18.0	1.0	0
DC 22	15.9	4.0	18.0	18.0	3.2	0.0	18.0	2.3	0
CC 17	119.8	4.8	20.0	42.0	2.7	110.0	42.0	4.7	110
DC 23	201.0	5.5	20.0	48.0	3.7	140.0	50.0	6.2	150

7.3 Risk Matrix Criteria and Ranking System

A risk matrix was conducted to help indicate which culverts are in need of replacement or attention. The risk matrix uses a set of six criteria and weights to determine the criticality of each culvert to be replaced. The six criteria are the following:

1. Flow Value at culvert inlet
2. Orifice-Flow Analysis
3. FHWA Nomograph Analysis
4. Channel Condition
5. Culvert Condition
6. Use/Impact
7. Culvert Network

Each culvert is ranked on a scale 1-10 based on the criteria. Lower scores indicate that the culvert is in good condition and changes should not be made. Whereas higher scores imply that the culvert should be considered for change.

Flow value score depends on the total peak flow each culvert inlet experiences, this value includes additive flow from upchannel culverts and watershed runoff. A score of 1 indicates a culvert handling less than 25 cubic feet per second (cfs) at peak flow, and a score of 10 indicates a culvert handling over 750 cfs at peak flow.

1. Less than 25 cfs
2. 25 to 50 cfs
3. 50 to 75 cfs
4. 75 to 100 cfs
5. 100 to 150 cfs
6. 150 to 200 cfs
7. 200 to 300 cfs
8. 300 to 500 cfs
9. 500 to 750 cfs
10. Greater than 750 cfs

Orifice-flow and FHWA Nomograph analysis scores are based on the change in diameter size recommended by the headwater overflow condition as a percent change. A score of 1 indicates no change necessary, and a score of 10 indicates a change in diameter over 200%.[3]

1. 0%
2. 0-25%
3. 25-50%
4. 50-75%
5. 75-100%
6. 100-125%
7. 125-150%
8. 150-175%
9. 175-200%
10. 200% +

Channel condition is based on whether the channel will be able to maintain high flow conditions without reaching excessive velocity, washing over the roadway, or eroding under the roadway. The scoring range is as follows: 1 is a channel with grass to limit erosion and velocity, good depth to not wash over the roadway, and a good shoulder offset so the roadway subgrade will not erode; 4 is a channel missing one of these criteria; 7 is a channel missing two of these criteria; 10 is a channel missing all criteria. Intermediary scores are based on inspection, channels that are overgrown will receive 1 extra point.

The culvert condition is scored on a range where a 1 indicates that the culvert is in good physical condition and should be able to pass flow rated for that size culvert. A rating of a 10 is a culvert that is almost completely obstructed or destroyed either by deteriorated material, sediment buildup at inlet, exit, or through the culvert, or an obstructed inlet or exit by rocks or other material. Scores in between these extremes indicate how well the particular culvert should pass flow in their current state.[4]

Use of the culvert is a score to summarize how critical the culvert is to infrastructure if it were to fail. This criteria takes into account the type of surface the culvert is under and what it is used for. All cross road culverts are rated 10 as they cross underneath either Church Avenue or Route 1, washout would impact these major roadways so they are the highest risk. Scores for this criteria are internally weighted and assigned as follows:

[3] CC7 is not sizable through generalized orifice-flow analysis due to its size.
[4] Flushing of culverts in the network could potentially change these values by clearing sediment or other debris.

1. The culvert is under an unused surface.
3. The culvert is under a surface used for basic access (ATV, foot traffic).
5. The culvert is under an unpaved driveway.
6. The culver is under an access point to farmland.
7. The culvert is under a paved driveway.
9. The culvert is under an unpaved road.
10. The culvert is under a paved road.

The culvert network criteria identifies culverts that are used to move flow from various other culverts in the system. A score of 1 indicates that this culvert is standalone and only deals with runoff, a score of 10 indicates a culvert that handles flow from 9 or more other culverts.

The following weighted risk matrices are shown in the tables below. The Culverts are listed in order beginning at the Dickey Brook crossing on Church Avenue and continuing down Route 1 ending at the border of Frenchville and Fort Kent. As you can see in the tables below, if there's a score below 3 it receives a green marker, between a 3 and 6 it receives a yellow marker, and if it's above a 6 it receives a red marker.

7.4 Weighted Risk Matrix

Table 7: *Weighted Risk Matrix CC1 to CC5*

Criteria	Weight	CC 1	DC 1	DC 2	DC 3	DC 4	DC 5	CC 2	CC 3	CC 4	CC 5
Flow Value	0.15	4	4	3	3	3	6	1	1	2	6
Orifice - Flow	0.20	3	4	4	9	6	6	4	2	3	7
FHWA - Nomograph	0.25	3	3	4	9	6	6	4	3	5	4
Channel Conditions	0.10	4	4	3	8	2	4	7	6	2	5
Culvert Conditions	0.10	7	6	2	3	6	2	10	10	5	2
Use	0.15	10	10	3	7	5	5	10	10	10	10
Network	0.15	6	5	4	3	2	1	1	1	1	1
Total	**1**	**4.85**	**4.9**	**3.4**	**6.8**	**4.8**	**5**	**5.2**	**4.45**	**4.4**	**5.55**

Table 8: *Weighted Risk Matrix CC6 to DC11*

Criteria	Weight	CC 6	CC 7	DC 6	CC 8	DC 7	DC 8	DC 9	DC 10	CC 9	DC 11
Flow Value	0.15	3	10	1	8	2	1	1	1	6	1
Orifice - Flow	0.20	5	6	1	8	2	2	1	1	3	2
FHWA - Nomograph	0.25	5	2	1	7	3	3	2	1	3	2
Channel Conditions	0.10	2	1	2	4	3	2	3	4	1	7
Culvert Conditions	0.10	1	1	4	4	5	7	8	6	1	4
Use	0.15	10	10	5	10	7	10	5	3	10	9
Network	0.15	1	9	1	5	3	2	1	1	1	1
Total	**1**	**4.55**	**5.35**	**2**	**7.1**	**3.45**	**3.8**	**2.75**	**2.1**	**4**	**3.55**

Table 9: *Weighted Risk Matrix CC10 to DC17*

Criteria	Weight	CC 10	CC 11	CC 12	DC 12	DC 13	DC 14	CC 13	DC 15	DC 16	DC 17
Flow Value	0.15	3	6	6	1	1	2	9	2	1	2
Orifice - Flow	0.20	4	3	6	1	1	2	10	2	2	2
FHWA - Nomograph	0.25	4	1	5	1	1	3	8	3	3	3
Channel Conditions	0.10	6	3	2	1	4	7	1	4	2	2
Culvert Conditions	0.10	1	2	3	2	2	9	2	7	6	6
Use	0.15	10	10	10	1	5	9	10	1	1	6
Network	0.15	1	1	2	1	2	3	5	2	1	1
Total	**1**	**4.5**	**3.8**	**5.45**	**1.1**	**2.05**	**4.55**	**7.4**	**2.8**	**2.3**	**3.2**

Table 10: *Weighted Risk Matrix DC18 to DC23*

Criteria	Weight	DC 18	CC 14	DC 19	DC 20	CC 15	CC 16	DC 21	DC 22	CC 17	DC 23
Flow Value	0.15	1	8	1	1	3	3	1	1	5	7
Orifice - Flow	0.20	1	6	1	1	5	4	1	1	6	7
FHWA - Nomograph	0.25	1	5	1	1	5	5	1	1	6	6
Channel Conditions	0.10	2	1	5	2	1	4	3	6	8	4
Culvert Conditions	0.10	3	1	8	2	4	2	7	5	4	6
Use	0.15	1	10	3	3	10	10	6	6	10	3
Network	0.15	3	3	2	1	1	2	1	1	2	1
Total	**1**	**1.4**	**5.5**	**2.45**	**1.5**	**4.75**	**4.7**	**2.55**	**2.65**	**6.25**	**5.45**

7.5 Corrective Action

After conducting the risk matrix and investigating these culverts on the site visit, corrective action for every culvert was determined to help enhance the culverts functionality. Table 11 demonstrates the culverts that are in good shape and do not require any action for improvement. Table 12 are culverts that can be improved from rehabilitating the culvert and improving channel conditions. Lastly, table 13 displays culverts that need to be resized.

Table 11: *No Action Required Culverts*

Cuverts— No Action Required	
DC2	DC13
CC7	DC16
DC6	DC17
CC9	DC18
CC11	DC20

Cuverts— No Action Required	
DC12	

Table 12: *Recommended Rehabilitation for Culverts*

Culvert	Recommended Action - Rehab
CC1	Improve channel conditions and flush pipe
CC4	Flush pipe
CC5	Improve channel conditions consider larger diameter pipe
CC6	Consider larger diameter pipe
DC7	Clear debris from pipe inlet and outlet and flush pipe
DC8	Clear debris from pipe inlet and outlet and flush pipe
DC10	Clear debris from pipe inlet and outlet and flush pipe
DC11	Improve channel conditions
CC10	Improve channel conditions
CC15	Consider larger diameter pipe
CC16	Consider larger diameter pipe
DC22	Improve channel conditions Consider new pipe

Table 13: *Recommended Replacement for Culverts*

Culvert	Recommended Action – Replacement
DC1	Replace with 36 in. pipe
DC3	Replace with 36 in. pipe Improve channel conditions
DC4	Replace with 36 in. pipe
DC5	Replace with 30 in. pipe
CC2	Replace with 30 in. pipe Improve channel conditions
CC3	Replace with 24 in. pipe Improve channel conditions
CC8	Replace with 60 in. pipe
DC9	Replace with 18 in. pipe

Culvert	Recommended Action – Replacement
CC12	Replace with 48 in. pipe
DC14	Replace with 30 in. pipe Improve channel conditions
CC13	Replace with 80 in. pipe
DC15	Replace with 24 in. pipe
CC14	Replace with 84 in. pipe
DC19	Replace with new 18 in. pipe
DC21	Replace with new 18 in. pipe
CC17	Replace with 42 in. pipe Improve channel conditions
DC23	Replace with 54 in. pipe

7.6 Summary of Culverts in Need of Replacement

The culverts which don't have the necessary minimum headwater depth to handle the incoming flow are deemed "in need of replacement". This calculation was done by performing a Goal-Seek function on Excel, where we changed the existing diameter to result in a solution to the headwater depth equation that was in line with the existing headwater depth. These data were inputted in the risk matrix as described above and was factored in with other criteria of consideration to determine a list of critical pipes in the network.

Table 14 ranks the culverts based on their criticality score determined in the risk matrix. The ranking for the criticality: 1 represents the most critical culvert and 40 represents the least critical culvert. The flow score ranking is a gauge on which culverts will overtop the respective roadway section first and the total score ranking is a gauge on which culverts should be replaced based on the criteria and weights shown in the risk matrix section.

CC7 is an outlier, the orifice flow equation isn't as accurate with higher flow and size of pipe. The scoring criteria for the orifice-flow equation was assumed to be the same as the nomograph method which states that it doesn't need to be resized. Using the maximum orifice-flow equation, the risk matrix yields a value of 6.35.

Table 14: *Culverts Ranked based on Criticality*

Ranking	Culvert based on Total Score
1	CC13
2	CC8
3	DC3
4	CC17
5	CC5
6	CC14
7	DC23
8	CC12
9	CC7
10	CC2
11	DC5
12	DC1
13	CC1
14	DC4
15	CC15
16	CC16
17	CC6
18	DC14
19	CC10
20	CC3
21	CC4
22	CC9
23	DC8

Ranking	Culvert based on Total Score
24	CC11
25	DC11
26	DC7
27	DC2
28	DC17
29	DC15
30	DC9
31	DC22
32	DC21
33	DC19
34	DC16
35	DC10
36	DC13
37	DC6
38	DC20
39	DC18
40	DC12

8.0 Resizing Driveway Culverts

8.1 Culvert Selection and Sizing

Based on the risk assessment scores of all 40 culverts in the watershed, we selected the 5 driveway culverts with the highest average scores and have included drawings of their resized culverts in the appendix, labeled Driveway Culvert Drawings. Selected culverts were: DC 3 with a score of 6.8, DC 4 with a score of 4.8, DC 5 with a score of 5.0, DC 14 with a score of 4.55, and DC 23 with a score of 5.45.

Size changes for all culverts are based on the FHWA nomograph calculations, and rounded up to the nearest industry sizing standard. Table 15 includes the recommended sizing for all driveway culverts.

Table 15: *Recommended Driveway Culvert Sizes*

Culvert	Size (in)	Culvert	Size (in)	Culvert	Size (in)	Culvert	Size (in)
DC 1	36	**DC 7**	24	**DC 13**	18*	**DC 19**	18
DC 2	36	**DC 8**	24	**DC 14**	30	**DC 20**	15
DC 3	36	**DC 9**	18	**DC 15**	24	**DC 21***	18
DC 4	36	**DC 10**	15*	**DC 16**	24	**DC 22***	18
DC 5	30	**DC 11**	24	**DC 17**	24	**DC 23**	54
DC 6	15*	**DC 12**	15*	**DC 18**	18*		

*same as current size

8.2 Drawing Parameters

The drawings are based on certain parameters in industry for culvert installation. The fill around the culvert is recommended to be either gravel or the existing material as the cover up until the road surface, and clean gravel or crushed rock as the bedding for the culvert. The drawings only take into consideration the new positioning and size of the culverts and do not account for changes that must be made to the drainage channels that feed into the culverts. These changes in drainage are due to the changing depth of the culvert. The major dimensions included in section drawings are the diameter, headwater[5], and invert[6] of the culvert. Major dimensions for the profile drawings are diameter, slope, and length.

9.0 Resizing Cross Road Culverts

9.1 Culvert Selection and Sizing

Based on the risk assessment scores of all 40 culverts in the watershed, culverts with the highest average scores from the risk matrix have drawings with resized dimensions included in the appendix, labeled CrossRoad Culvert Drawings. Selected culverts are: CC 8 with a score of 7.1, CC 13 with a score of 7.4, CC 14 with a score of 5.5, and CC 17 with a score of 6.25.

[5] Headwater is the depth of overflow expected in a 100 year storm measured from the center of the culvert up.
[6] Invert is the depth of the culvert under the road surface at its inlet measured from the bottom of the culvert to the road surface.

Size changes for all culverts are based on the FHWA nomograph calculations. Standard culvert sizes for corrugated aluminized steel pipe generally range from 12 in. to 72 in. in diameter. Culverts larger than this will need to be considered for use of different materials like high density polyethylene (HDPE). Table 16 includes the recommended sizing for all cross road culverts.

Table 16: *Recommended Cross Road Culvert Sizes*

Culvert	Size (in)	Culvert	Size (in)	Culvert	Size (in)	Culvert	Size (in)
CC 1	36	**CC 6**	36	**CC 10**	30	**CC 14**	84
CC 2	30	**CC 7**	72	**CC 11**	60	**CC 15**	36
CC 3	24	**CC 8**	60	**CC 12**	48	**CC 16**	36
CC 4	36	**CC 9**	60	**CC 13**	84	**CC 17**	42
CC 5	42						

9.2 Drawing Parameters

The drawings are based on certain parameters in industry for culvert installation. The fill around the culvert is recommended to be either gravel or the existing material as the cover up until the road surface, and clean gravel or crushed rock as the bedding for the culvert. The drawings only take into consideration the new positioning and size of the culverts and do not account for changes that must be made to the drainage channels that feed into the culverts. These changes in drainage are due to the changing depth of the culvert. The major dimensions included in section drawings are the diameter, headwater, and invert of the culvert. Major dimensions for the profile drawings are diameter, slope, and length.

Unlike the driveway culverts, changes to the cross road culverts may impact the vertical curves of the road. The design drawings and values for the invert and headwater are based on the current road position with assumptions that the culverts can be moved deeper underneath the road surface. There is no road redesign included in the culvert drawings.

10.0 Erosion Control Measures

We recommend that any drainage channels for culverts that are lowered under the road also are excavated to accommodate that new depth. Certain channels have been recently updated and others will need attention regardless of changes to local culverts. Drainage channels are indicated by their downstream culvert designation and changes are based on water velocity, slope of channel, current erosion conditions, and possibility of overflow onto adjacent land or roadway.

Erosion control measures are recommended for any changed drainage channels. We recommend methods in line with what is currently being used in some channels in the area including erosion control matting, stone rip-rap, and hay layers. Erosion control is recommended depending on channel slopes, flow velocity, and current conditions.

10.1 Changed Culvert Depths

Any culverts recommended to move down over 1 ft. and are of mid to high risk are recommended to have drainage channels updated. If changes are made to the roadway above the culvert, the drainage channels must be updated. Table 17 summarizes which channels will require updates under these parameters.

Table 17: *Depth change of channels into culverts*

Channel	Depth Change (ft)	Channel	Depth Change (ft)
DC1	-1.0	**DC11***	-2.0
DC2*	-1.2	**CC10**	-1.0
DC3	-2.0	**CC11**	-2.0
DC4	-1.8	**CC12***	-2.0
DC5	-1.5	**CC13**	-4.5
CC2	-1.2	**CC14**	-3.7
CC4	-1.5	**CC15**	-1.5
CC6	-1.5	**CC16**	-1.5
CC8	-3.0	**CC17**	-1.8
CC9	-3.0	**DC23**	-2.8

*Low risk

10.2 Channels - Recently Updated or Need Attention

The conditions of the culvert channels have been recorded. Table 18 demonstrates the culvert channels that have been recently updated and the culvert channels that still seek attention for culvert functionality.

Table 18: *Condition of Specified Channels*

Recently Updated		Need Attention	
Channel	Condition	Channel	Condition
CC1	Has fresh riprap and erosion mat.	**DC 3**	Sediment buildup over time has solidified, low depth channels.
DC1	Has fresh riprap and erosion mat.	**CC3**	Culvert inlet is obstructed.
DC2	Has fresh riprap and erosion mat.	**DC14**	Shallow channel, sediment buildup.
CC6	Riprap around culvert inlet.	**CC14**	Across residents property rather than roadside drainage.
DC9	New riprap and erosion matting along the channel.	**CC16**	Overgrown.
DC13	New crushed rock around culvert inlet.	**CC17**	Shallow, lots of ponding with limited culvert use. Will overflow the road.
CC14	Across residents property, deep channel.		

10.3 Erosion Control Parameters

We recommend certain methods of erosion control for all drainage channels under certain parameters. These parameters revolve around a minimum flow velocity and channel conditions. Channels experiencing flow in excess of 4 ft/s where the channel has a fair amount of grass to resist erosion, will need riprap to reduce the flow velocity. In situations where the channel is susceptible to erosion, the maximum flow is 3.2 ft/s before riprap and erosion control are needed. In situations where the channel slope is above 5%, flow with a fair amount of natural erosion resistance cannot exceed 3.4 ft/s, and flow in erosion susceptible channels cannot exceed 2.7 ft/s before riprap and erosion control are needed.[7]

Table 19 includes channels with high flow velocities (in excess of 2.7 ft/s) and high slopes (in excess of 5%). Some of these channels already have riprap for erosion control measures in place.

Table 19: *Channels likely to need erosion control or riprap*

Channel	Velocity (ft/s)	Slope (%)	Max Velocity (ft/s)
CC1	3.38	3.0	4.0
DC1*	3.82	3.6	4.0
DC6	2.53	9.9	3.4
DC9*	3.09	6.3	2.7
CC9	2.78	4.9	3.4
DC17	3.43	6.2	3.4
CC14	3.19	1.0	4.0

*Currently have riprap and/or erosion control measures

Drawings of the typical details are in the appendix labeled Erosion Control.

11.0 Redesigned Affected Roadways

11.1 Detail Sheet

To determine what sections of the road will be affected by larger diameter culverts, the current depth of cover was estimated and compared to the proposed culvert diameter, as well as manufacturer specifications. The depth of cover of a culvert is the difference in elevation

[7] Based on https://www.agric.wa.gov.au/water-management/suggested-maximum-velocities-surface-water-flow

between the top of the culvert pipe and the bottom of the road surface. The depth of cover of the cross road culverts was estimated using site photographs. The minimum cover requirement of 12" was supplied by Contech solutions, based on H20 and H25 live loads. This cover was the specification for all existing and proposed culvert diameters.

The depth of cover for the driveway culverts was determined using the same method as the cross road culverts. Most of the driveway culverts exist beneath an unpaved driveway. When a driveway is unpaved, we assume there will be no impact on the driveway sight lines and vertical curvature. We found only one DC that will impact the roadway, this is DC 2. This was determined to have an impact on the driveway because the existing depth of cover will not be adequate for the new pipe diameter. The only other paved DC's are DC 1, DC 3, DC 7, and DC 8. These were determined to be adequate because there is enough existing cover to accommodate the increase in pipe diameter and minimum cover requirement.

11.2 Road Redesign

Based on criticality ranking, we redesigned the roadway for the CC 17. Based on the new invert depth, diameter, and existing road cover CC 12 will be 18 inches above the existing road surface. CC 17 will be 11.6 inches below the existing road surface.

The roadway above CC 17 is at an elevation of 977' with a grade of 0.3%, based on a Google Earth elevation profile of the project. The new CC 17 will have a depth below the road surface of 11.6 inches. Based on manufacturer and MaineDOT specifications, the road surface will need to be raised by 21.6 inches.

To accommodate the anticipated road elevation change for CC 17, we propose a -0.08% grade starting 238' before the culvert, and and a -0.11% grade after the culvert. With these grades and distances, the roadway will become approximately level at the location of the culvert (which does not receive much runoff volume from the road itself). Further details can be found in the appendix labeled Affected Roadway Design.

12.0 Streamsmart Alternative

12.1 Introduction

An open bottom pipe arch was designed to replace the existing CC7 at Dickey Brook. This pipe arch will accommodate water flows for the given watershed, while allowing sediment, debris, and fish to travel through. This crossing was designed utilizing a StreamSmart design.

12.2 Hydraulic Analysis

The primary goals of StreamSmart are to ensure the stream crossing spans the stream, the entrance elevation is adequate, slope and skew match the stream, and ensure adequate substrate in the crossing. These ensure that the culvert is being adequately designed for wildlife passage as well as the flow of a 100-year runoff event without overtopping the roadway. The width of the culvert was found based on the bankfull width as well as including space for substrate to be built up on the side of the arch for wildlife passage. The elevations were adjusted to ensure a consistent flow for passage of aquatic species. Salmon passage is necessary through this culvert based on a report by the Maine Habitat Viewer, as shown by Figure 2. In order to assess the salmon passage through the culvert, a low flow situation for this culvert needs to be modeled, this is 100 ft^3/s. When this is modeled, a velocity of 4.5 ft/s is determined and this is acceptable for salmon passage for a length of 70 feet based on figure 3. Salmon won't need to pass this channel within a 100-year runoff event, it was designed for the purpose to pass at normal flow conditions. The dimensions for the arch culvert were determined based on bankfull width and necessary flow velocity by working iteratively with HEC-RAS.

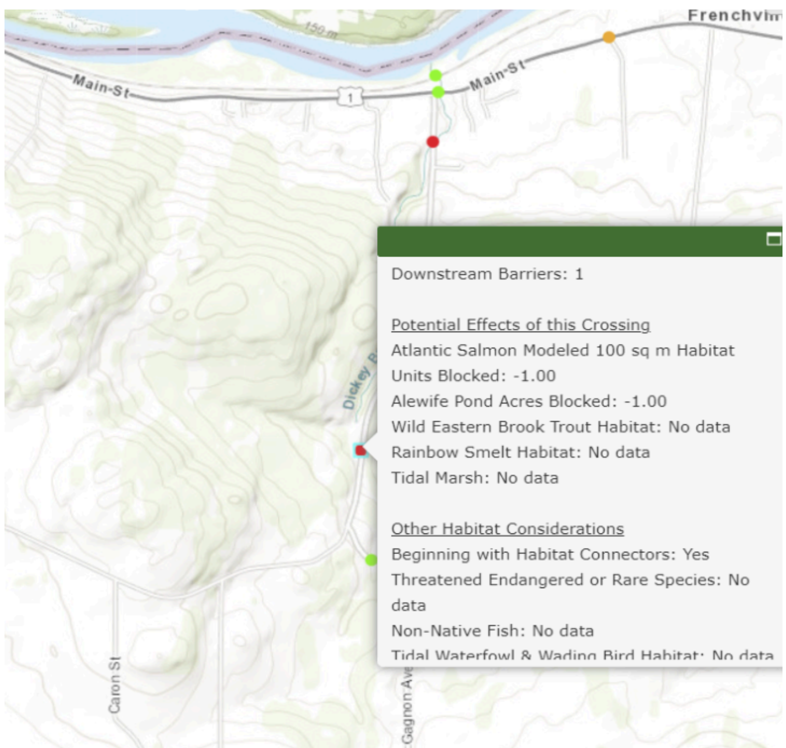

Figure 2: *Maine Stream Habitat Viewer*

Culvert Length (ft)	Velocity (fps) - Adult Salmonids
<60	6
60-100	5
100-200	4
200-300	3
>300	2

Figure 3: *Maximum flow experienced for Salmon passage through a culvert*

12.3 Soil Analysis

The majority of the soil in each culvert's respective watershed is a gravelly loam type, which is less susceptible to erosion than finer grained soils, such as sand and clay.

A riprap apron was designed to ensure adequate erosion protection at the outlet of the culvert. A riprap apron is a bed of crushed rock in the flow path of an outlet. This apron will protect against erosion by reducing flow velocity and trapping sediment, preventing it from moving further downstream. The apron was developed based on the flow modeled in HEC-RAS. The tailwater, or water level at the outlet, flow velocity, and diameter of the outlet were used to determine the size of the riprap stones, and the necessary length of the apron.

12.4 Structural Analysis

We recommend replacing the existing culvert at CC7 with an Armtec pipe, MP-A-19 or a similar culvert to replace the existing one. This pipe spans 14 feet wide with a 6 foot rise. The material of the pipe is corrugated steel, with corrugations of 152mm x 51mm, and a wall thickness of 2.8mm. The foundation was designed to have a width of 2.5 feet, and a depth of 1 feet. It is important to note that the foundation was not designed with reinforced concrete. The drawing for this design is found in the appendix labeled StreamSmart Redesign.

12.5 Impact Assessment

In order to safely allow for the passage of wildlife through the culvert, the entrance needs to be revised for an acceptable velocity entering the pipe and acceptable exit elevation. Currently there are two separate pipes, one is 60” which accommodates regular flow conditions and the other is 30” for higher flow conditions, they are both inadequate for passage upstream. These culverts limit the passage of marine species and cannot handle the 100 year storm event flows. This is shown by figure 4 and 5.

The new culvert design will accommodate the wildlife and fish passage by being at the same elevation as the stream if there was no roadway built above it. The bedding for within the open bottom culvert will contain adequate substrate for the wildlife and fish to pass and not to be scoured away by a 100 year storm event. The foundations for the arch culvert are designed to avoid scouring for a 100 year storm event.

This option needs to be considered by the engineers designing the culverts but in terms of cost and impact, a resized corrugated metal pipe (CMP) would be adequate. The location should be professionally surveyed to ensure it’s installed with respect to the slope and location of the stream then it would accomplish some of the problems associated with the existing pipes. From resizing all of the culverts, it was determined that a 10’ diameter CMP is necessary to handle the 100 year storm event.

Figure 4: *Downstream end of existing 60” culvert pipe*

Figure 5: *Downstream end of existing culvert pipes*

14.0 Opinion of Probable Cost

14.1 Cost Estimate

The estimate of cost was performed using several references such as MaineDOT, manufacturers, RSMeans, and previous employers. The quantity of materials were estimated from takeoffs from the redesigned culverts and the labor was estimated from the other references. Estimation of the cost of equipment was built into the estimation of cost based on the specific task being performed. The permits did not require payment. For projects done in 2023: Increase the cost of each item in the DOT Bid Archive by 5% to account for inflation as well as decreased scope of work. For future use, corrugated aluminized steel pipe (CASP). Table 20 shows the cost that we assumed for the sections of pipe, and below is a description of the cost estimation assumptions and another summary of assumed costs using RSMeans along with comparing to previous MaineDOT projects. Table 21 shows the summary of costs of each specific culvert and the designated cost for each step in the construction sequence. Table 22 shows the total cost for the driveway, cross road, and StreamSmart culverts.

Table 20: *Estimating Cost for Pipe*

	Unit	Average Contractor Price	References	Assumed Cost
12 Gauge 30" CASP	LF	31.65	sccmo.org (2019)	41
10 Gauge 36" CASP	LF	47.33	sccmo.org (2019)	61
10 Gauge 42" CASP	LF	55.38	sccmo.org (2019)	71
10 Gauge 48" CASP	LF	63.11	sccmo.org (2019)	81
10 Gauge 60" CASP	LF	79.29	sccmo.org (2019)	101
10 Gauge Open Bottom Culvert	LF	800	Armtec Multiplate	1000

Table 21: *Summary of Costs per Section*

Culvert	Site Setup	Demolition	Trench Prep + Pipe Placement	Backfill + Final Work	Total Cost	O+P + Remoteness Factor (*1.15)
DC3	$3,640.00	$25,189.99	$3,310.47	$8,589.52	$40,729.98	$46,839.48
DC4	$3,640.00	$23,846.90	$3,931.18	$5,446.76	$36,864.84	$42,394.57
DC5	$3,140.00	$23,086.00	$3,171.18	$3,870.61	$33,267.79	$38,257.96
DC14	$3,140.00	$23,396.80	$3,671.90	$4,443.29	$34,651.99	$39,849.79
DC23	$3,640.00	$25,935.00	$5,730.99	$9,724.70	$45,030.69	$51,785.30
CC8	$9,020.00	$64,492.78	$10,052.00	$20,367.83	$103,932.61	$119,522.50
CC12	$8,520.00	$62,069.17	$8,871.80	$15,609.13	$95,070.10	$109,330.62
CC13	$8,520.00	$62,607.78	$9,692.40	$15,198.40	$96,018.58	$110,421.36
CC17	$8,020.00	$60,673.00	$7,064.40	$13,409.40	$89,166.80	$102,541.82
StreamSmart	$19,940.00	$127,272.59	$75,182.00	$37,207.00	$259,601.59	$298,541.83
Roadway Redesign					$400,000	$460,000

Table 22: *Summary of Costs*

Project Component	Total Cost
Driveway Culverts	$219,127.09
Cross Road Culverts	$441,816.30
Streamsmart	$298,541.83
Roadway	$400,000.00
Total Scope	$1,359,485.23

15.0 Disclaimer

The materials contained in this document and any supporting documentation were developed by us as students as part of our education in the College of Engineering in order to gain supervised engineering problem-solving experience. Therefore, information and recommendations, while useful for understanding a particular project's scope and possibilities for implementing solutions, should not be relied upon solely for the purposes of advancing a project beyond conceptual levels. Furthermore, such material should not substitute for or replace the services of a design professional practicing in the areas of engineering or architecture, particularly for projects whose direct or indirect impact may affect the safety, health, or welfare of the public. We students who prepared this information look forward to the opportunity to serve with fidelity the public, our future employers, and clients. In providing you with this information, our intention is to uphold and enhance the honor, integrity, and dignity of the engineering profession. We thank you for the opportunity to develop our skills through our work on this project.

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17.0 Appendix

Key

Subcatchment Boundary

Tc Line

CC = Cross Culvert

DC = Driveway Culvert

Notes

* Culverts Not to Scale
* Reference to NAVD83–10' Contours

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			Drawn By:	ETHAN SHELL	1/23/2023
Sheet C101 of C108	Frenchville Maine	WATERSHED MAP	Checked By:	DOMINIC PERKINS	1/29/2023
			Approved By:	DOMINIC PERKINS	1/29/2023

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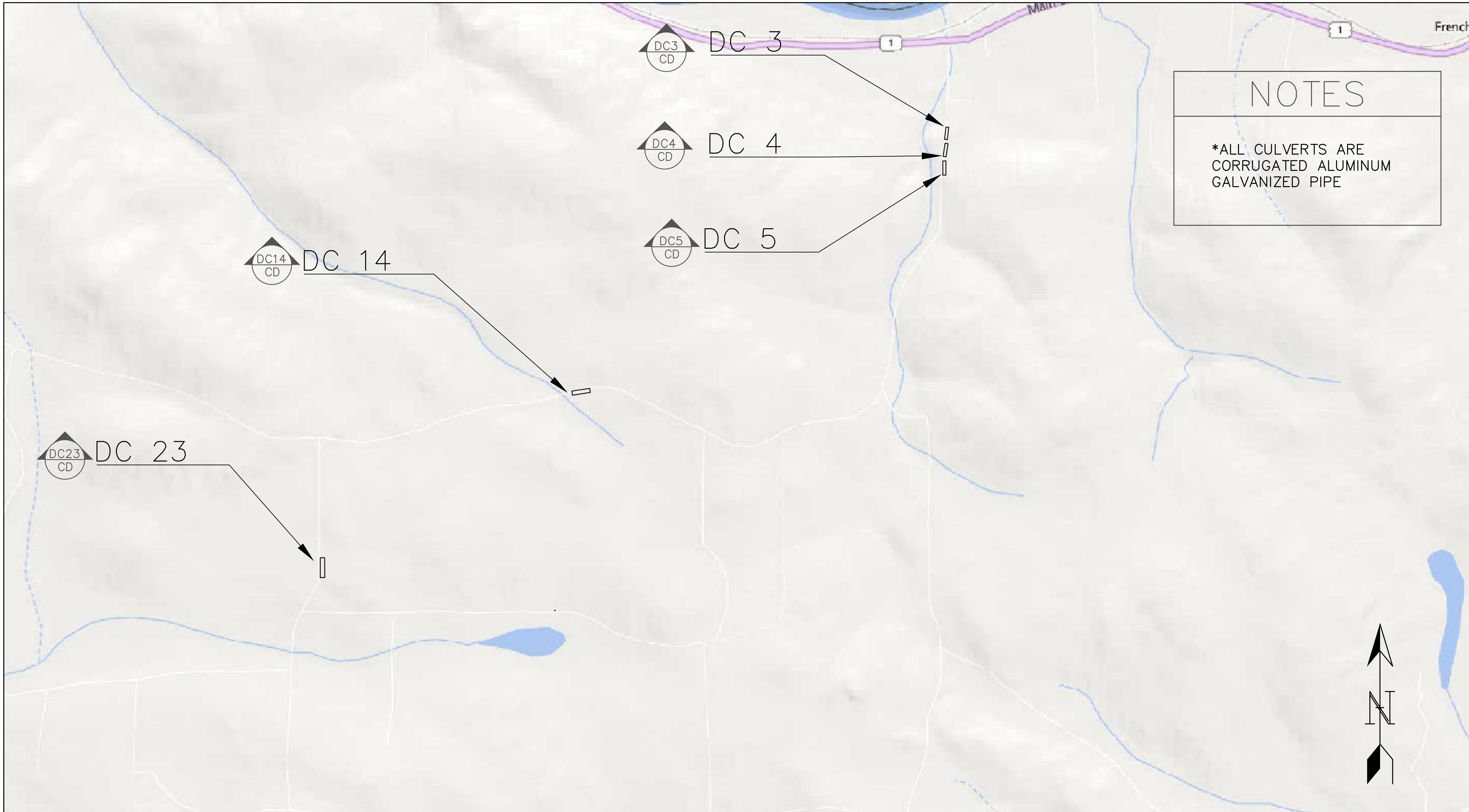

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Sheet 1 of 6	Frenchville Maine	Driveway Culvert	Checked By:	SAM LAROCHELLE	4/25/2024
			Approved By:	DOMINIC PERKINS	4/25/2024

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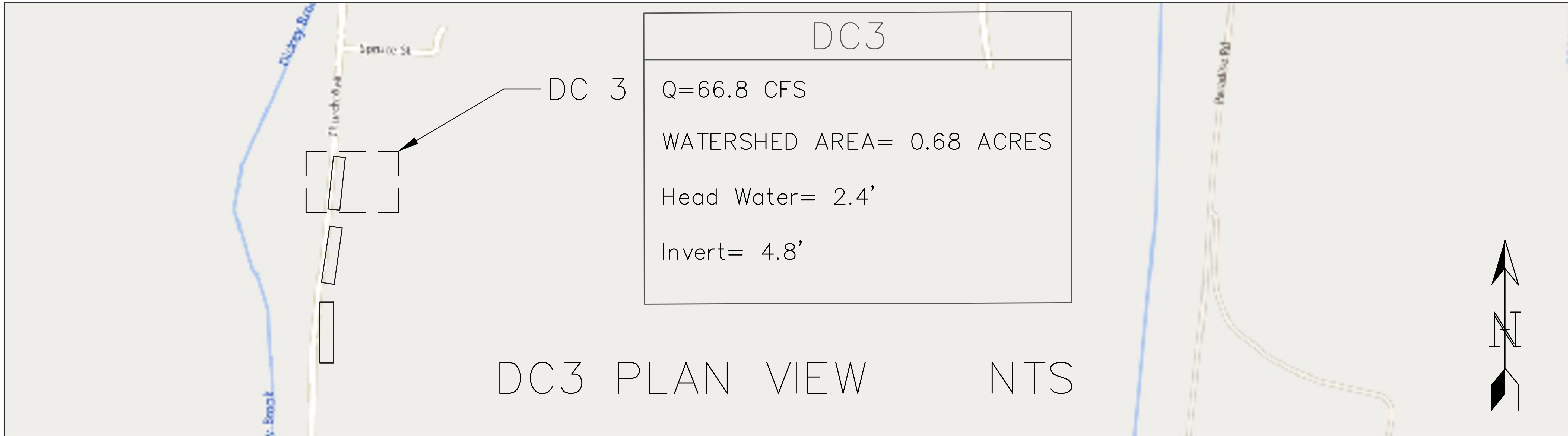

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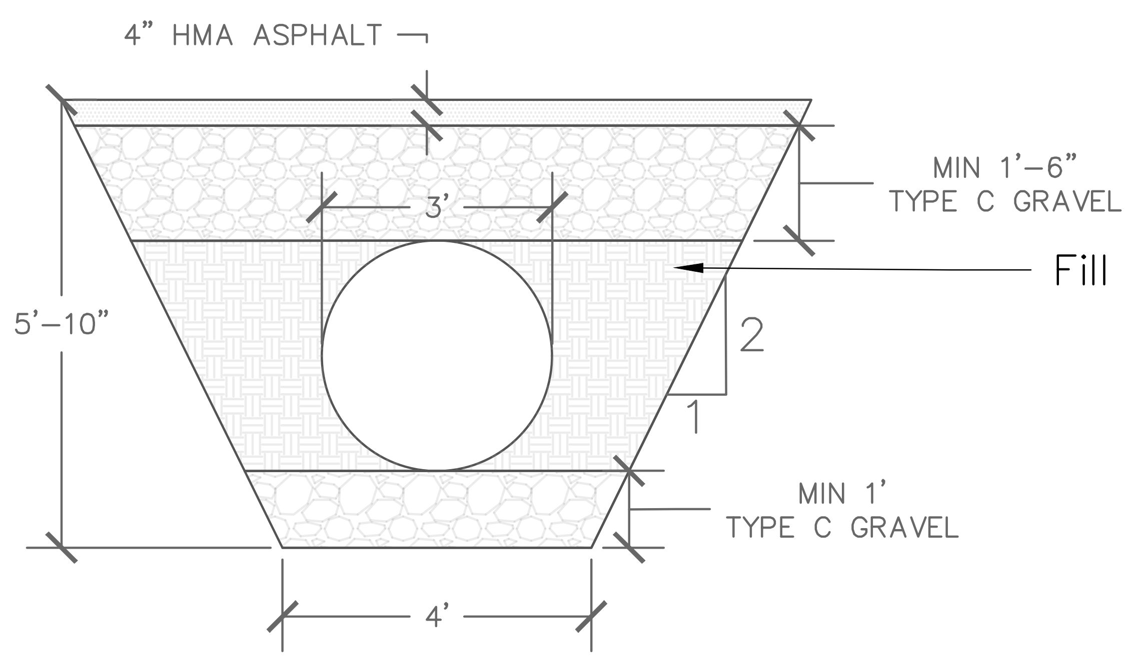

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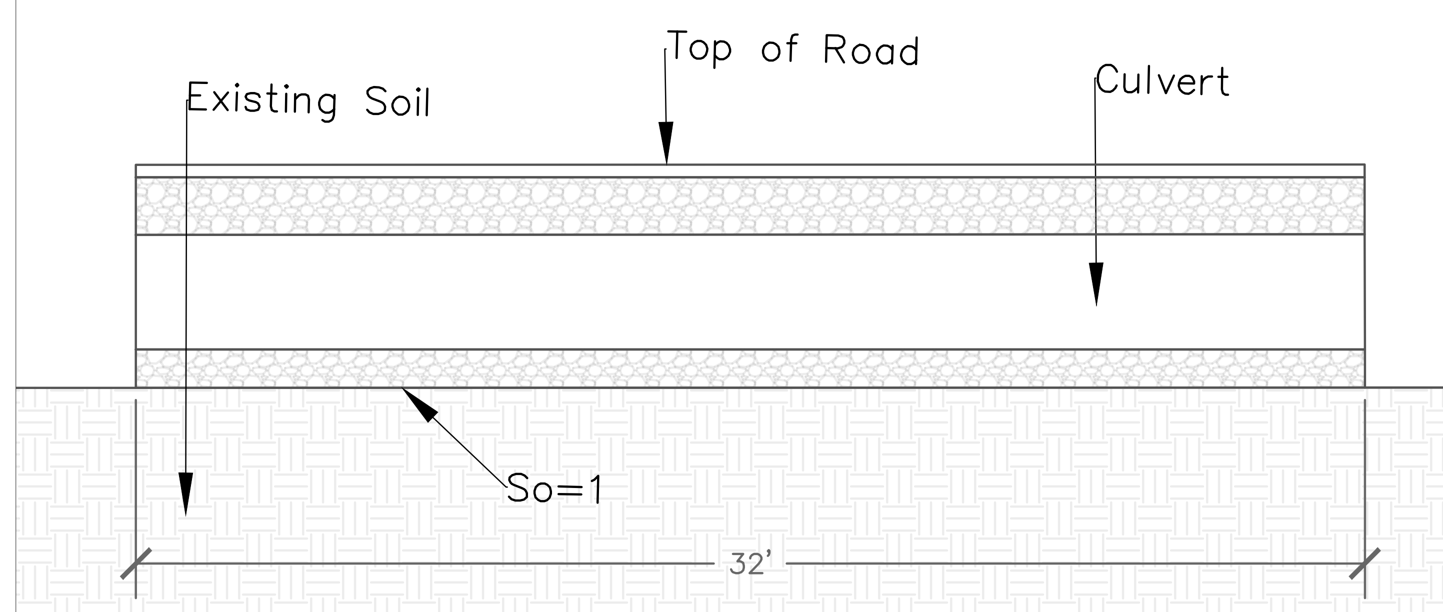

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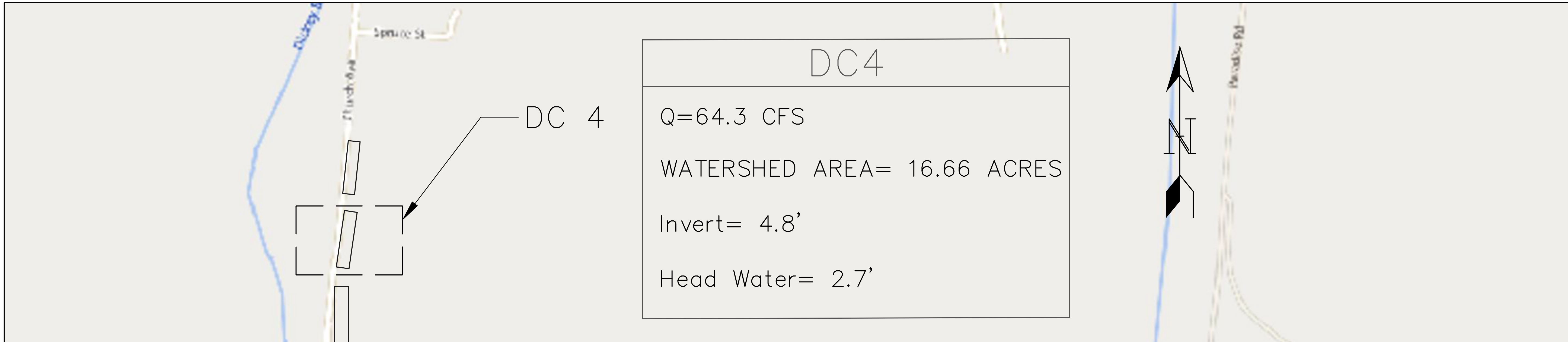

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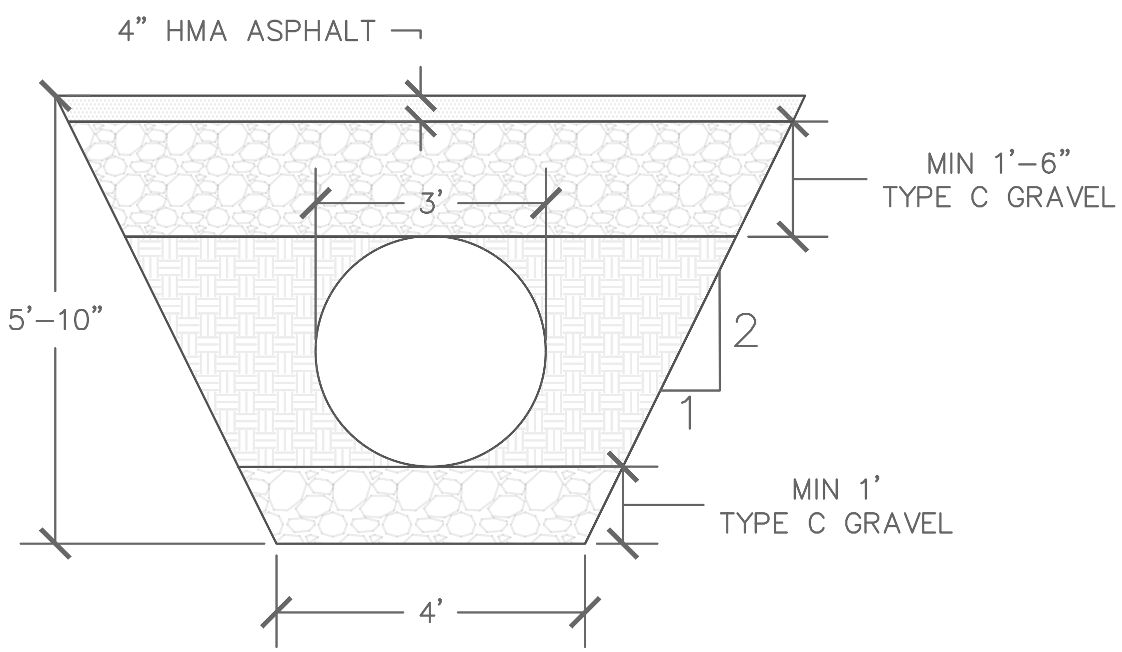

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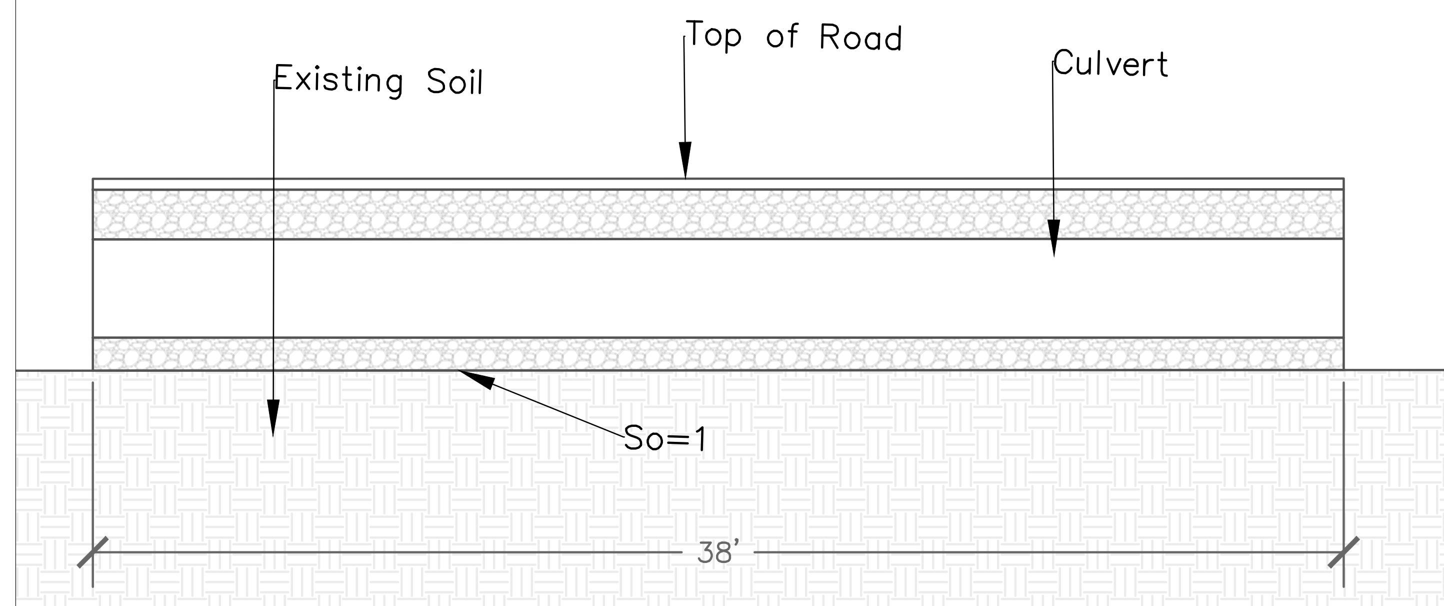

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	Drawn By:	ALEX BEAULIEU	4/25/2024
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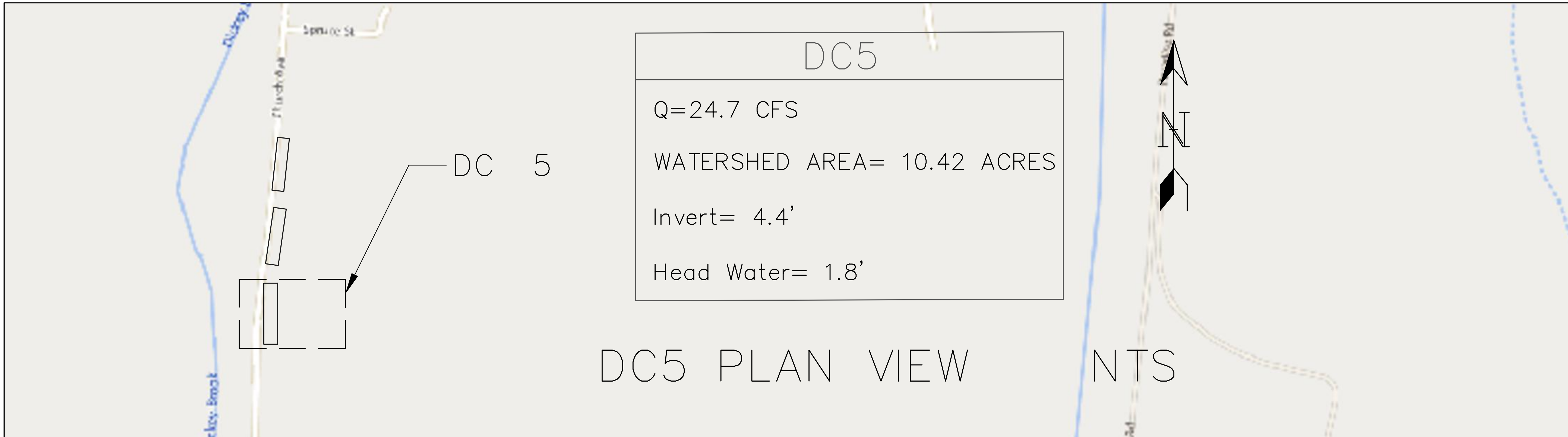

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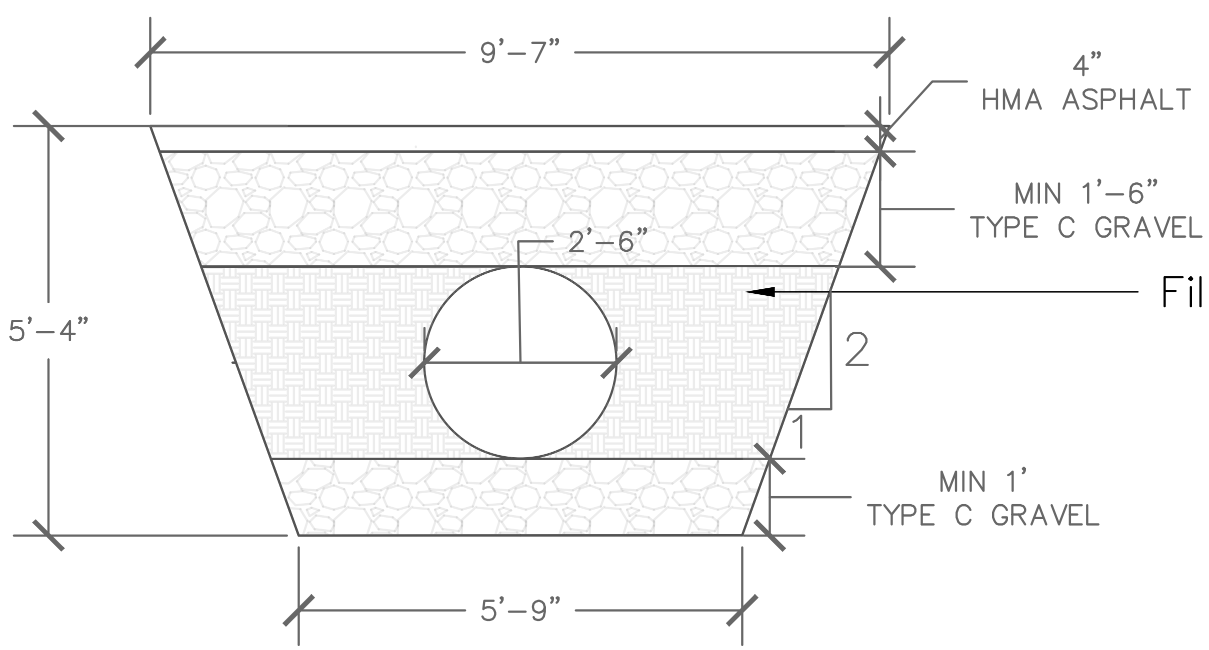

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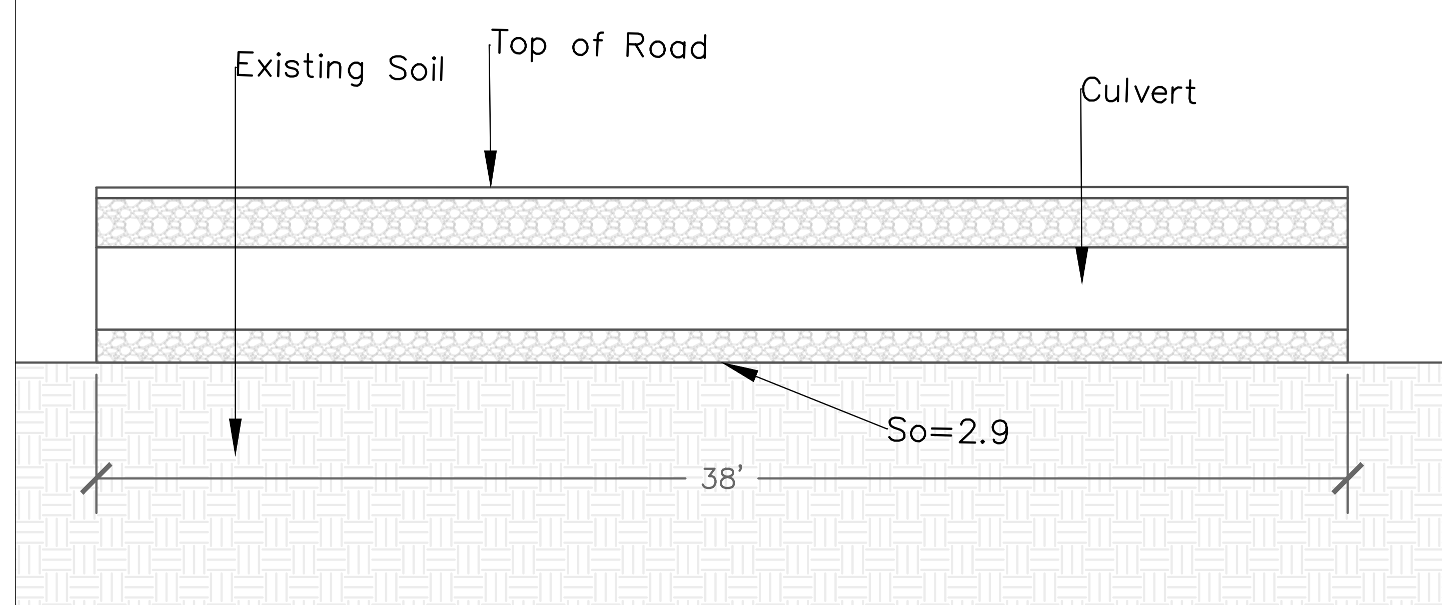

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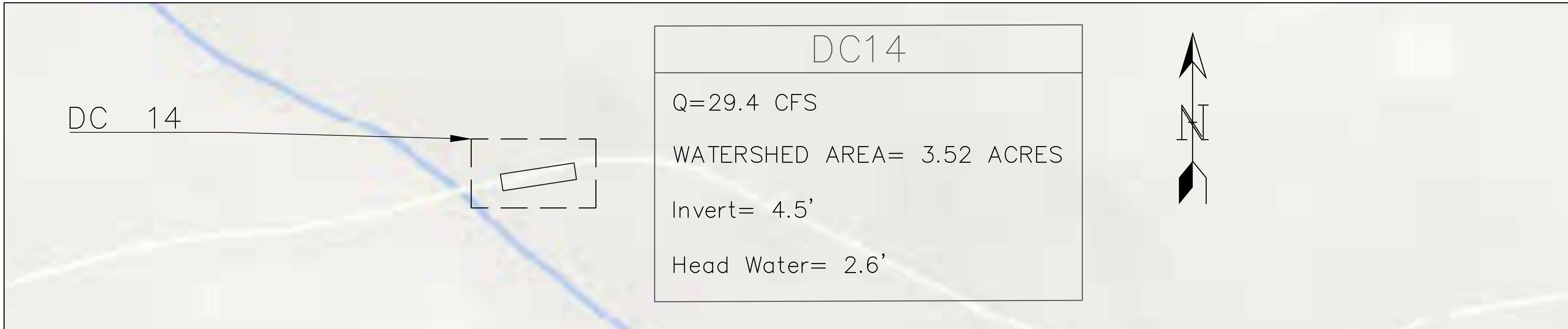

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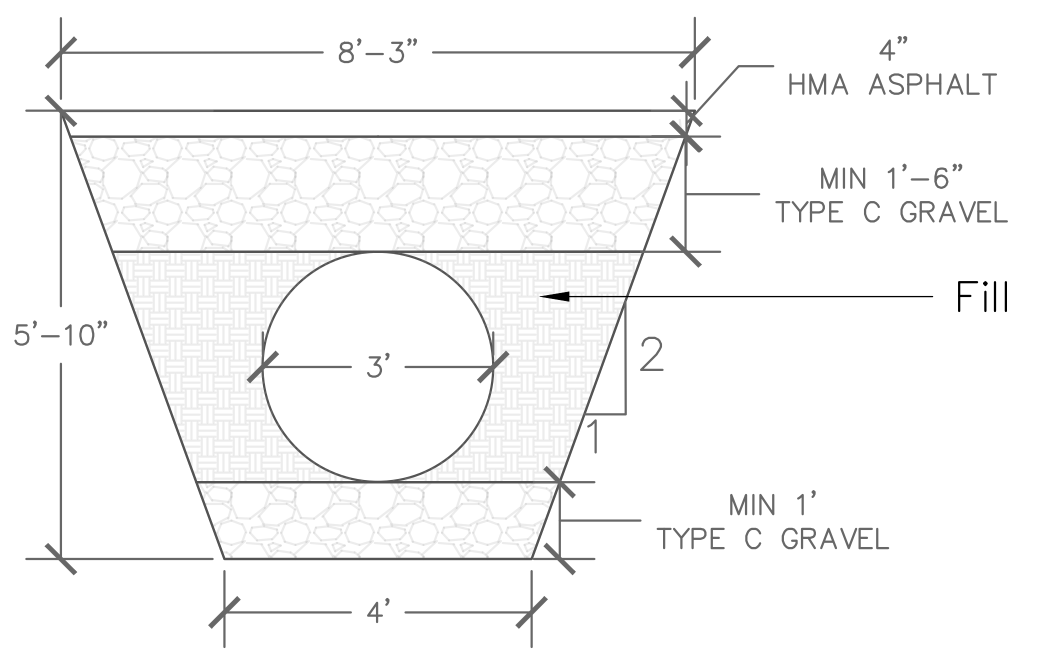

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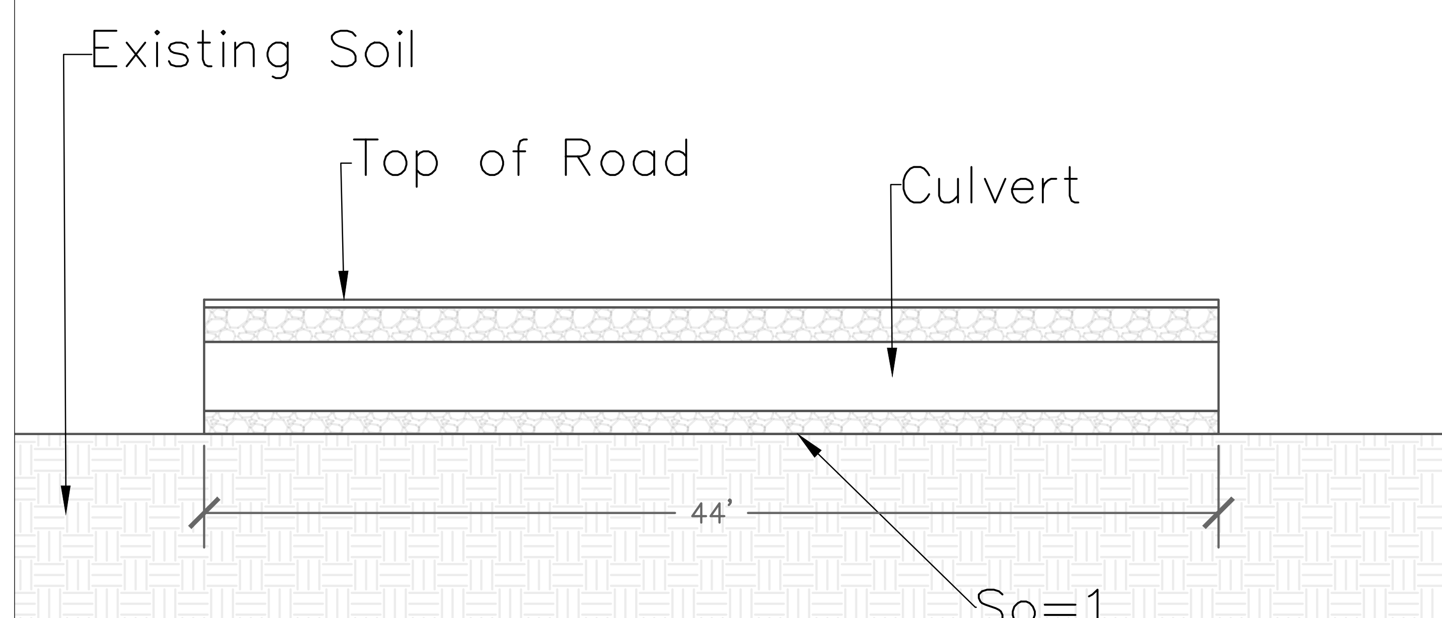

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			Drawn By: ALEX BEAULIEU	4/25/2024
	Frenchville Maine	Driveway Culverts	Checked By: SAM LAROCHELLE	4/25/2024
Sheet 5 of 6			Approved By: DOMINIC PERKINS	4/25/2024

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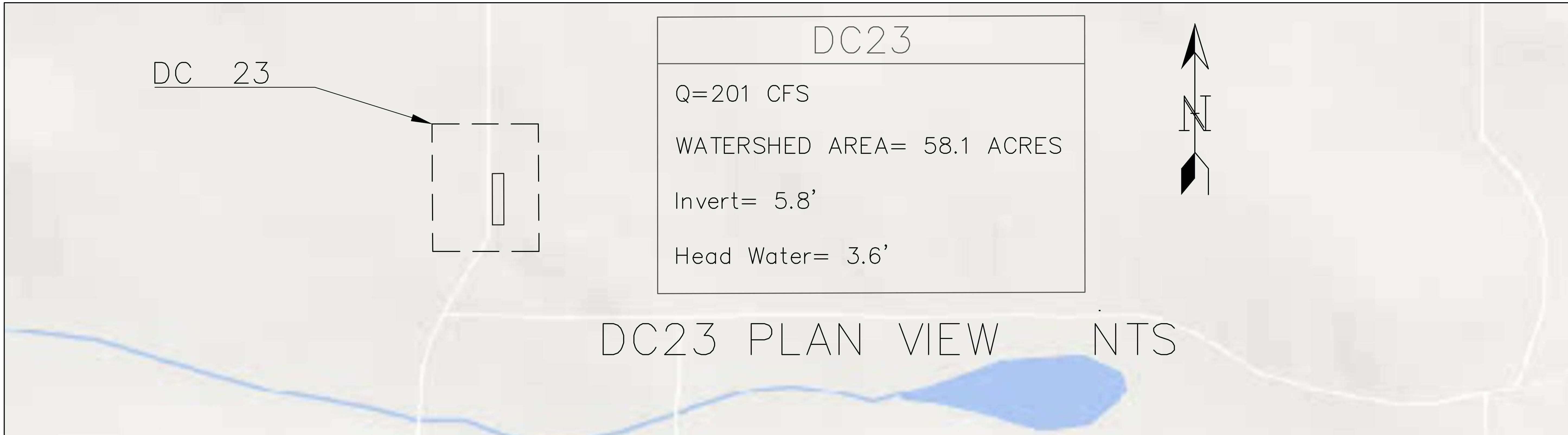

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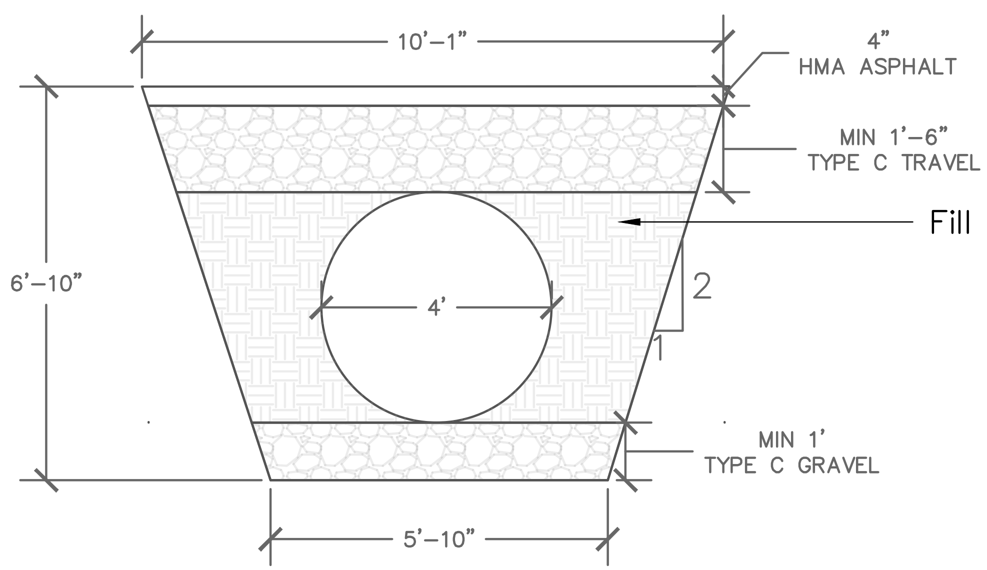

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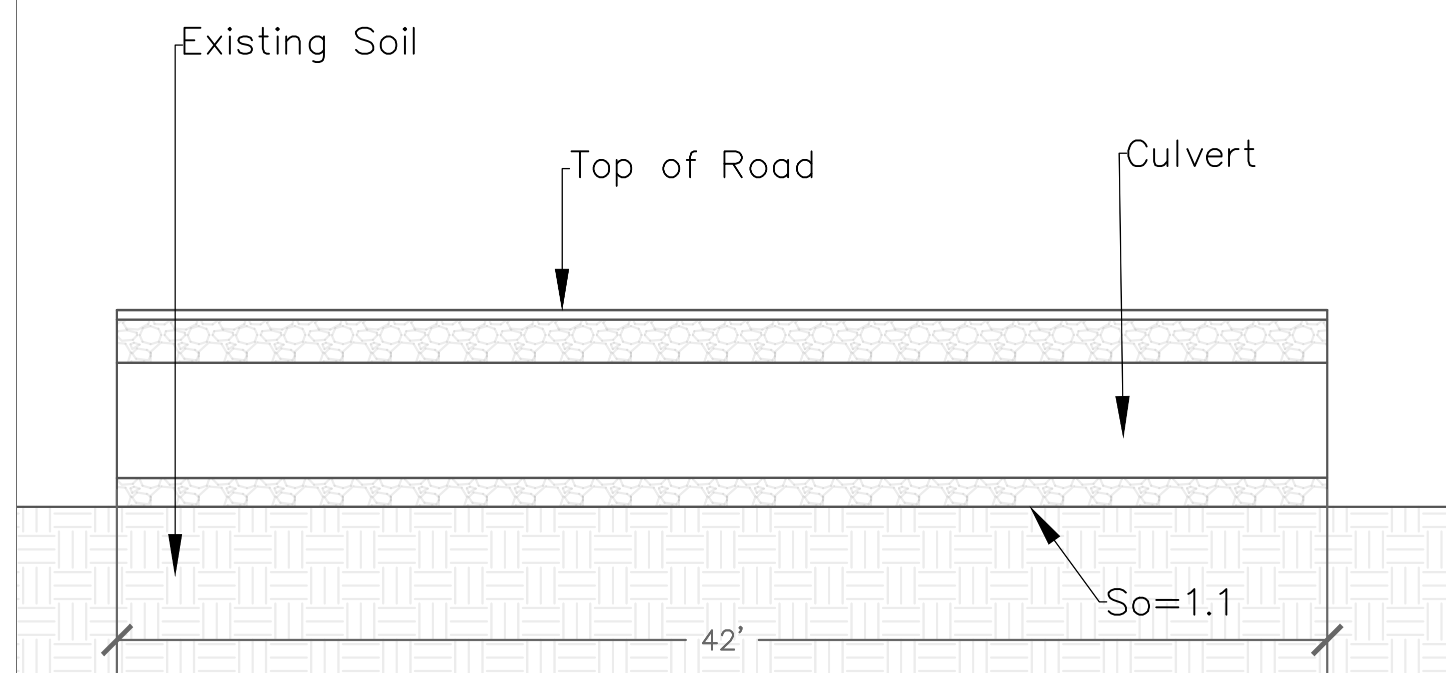

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Work Package: Driveway Culvert Drawings

Scale: 1" = Noted In Viewports

Sheet 6 of 6

Location: Frenchville Maine

Deliverable: Driveway Culverts

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Drawn By:	ETHAN SHELL	4/25/2024
Checked By:	DOMINIC PERKINS	4/25/2024
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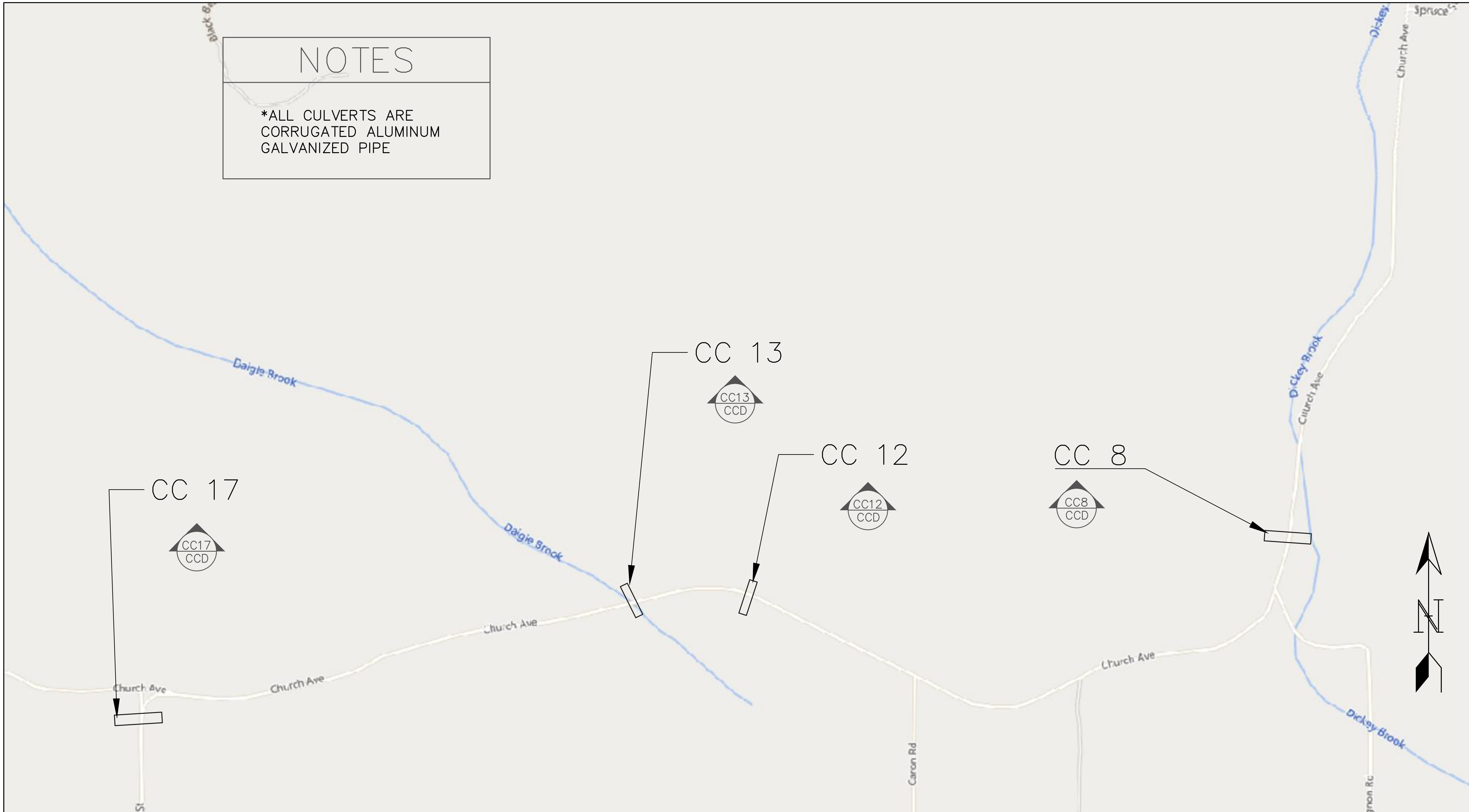

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Sheet 1 of 5	Frenchville Maine	Cross Culverts	Checked By:	DOMINIC PERKINS	4/25/2024
			Approved By:	SAM LAROCHELLE	4/25/2024

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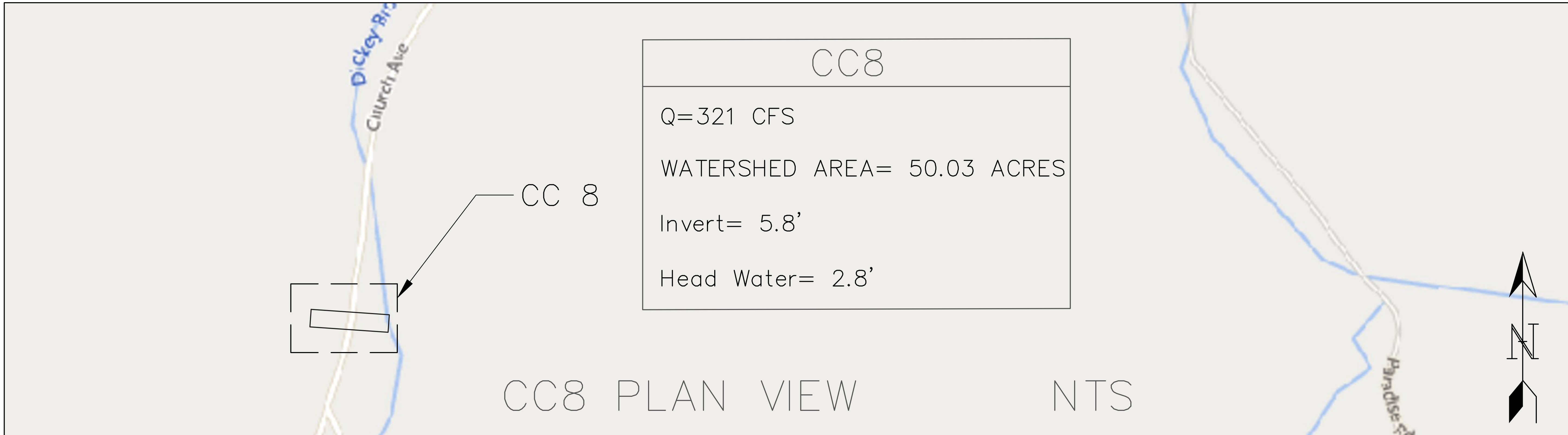

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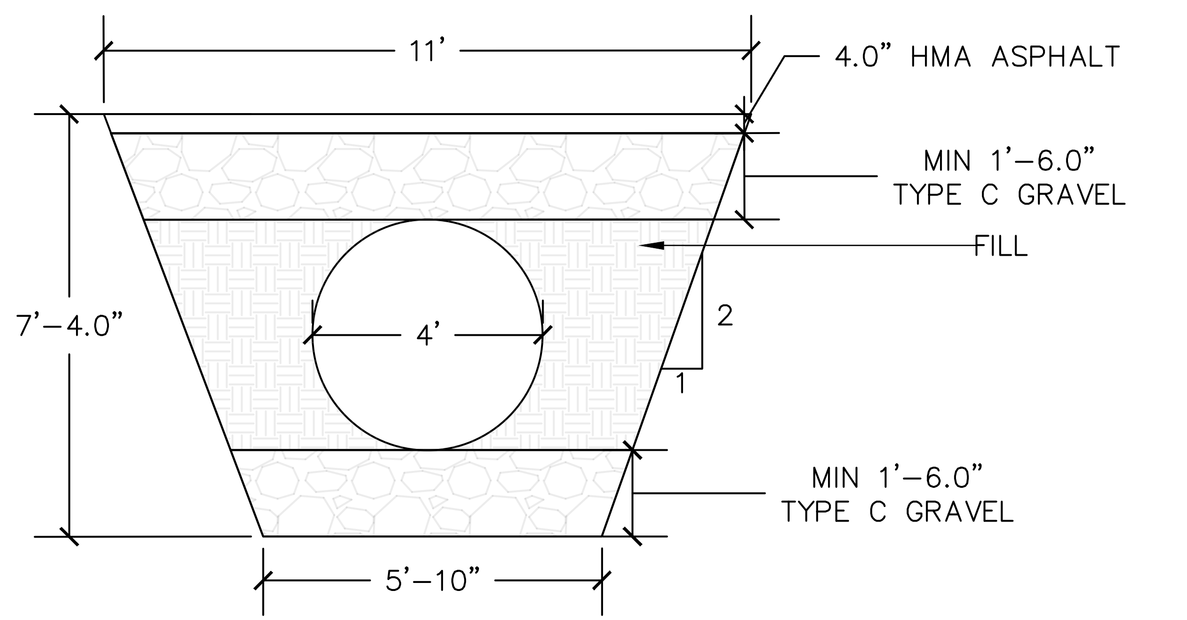

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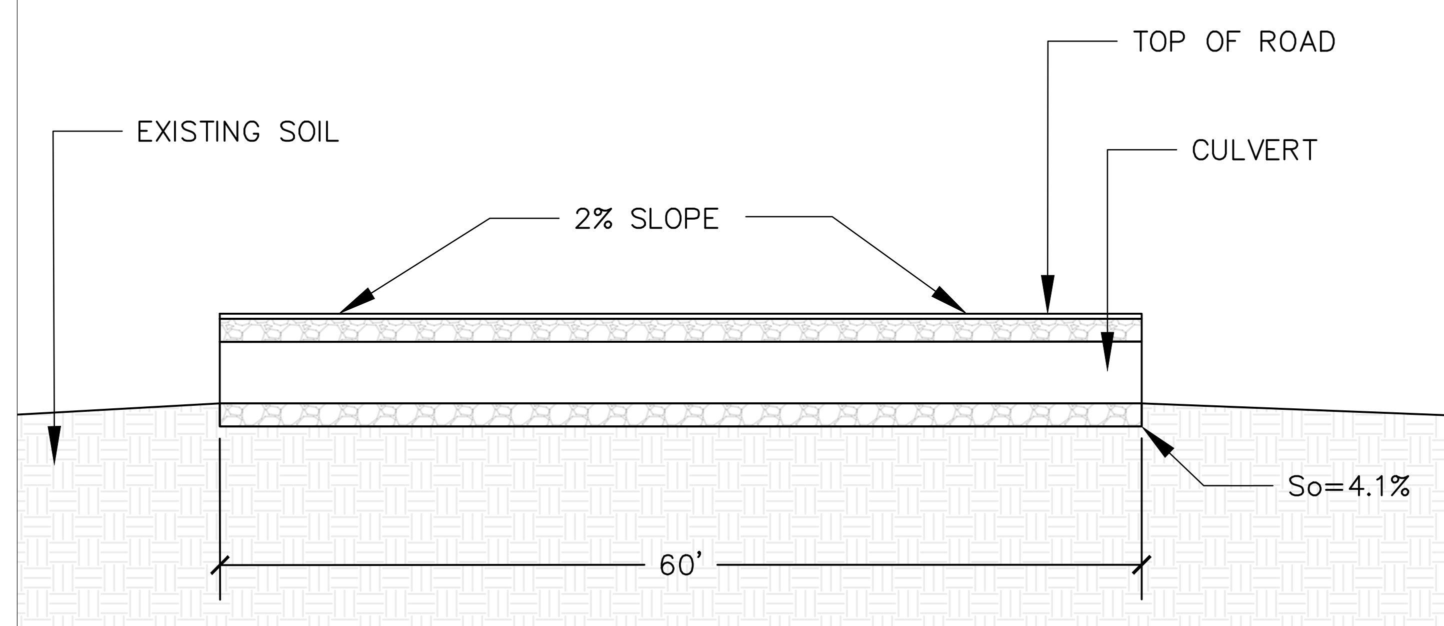

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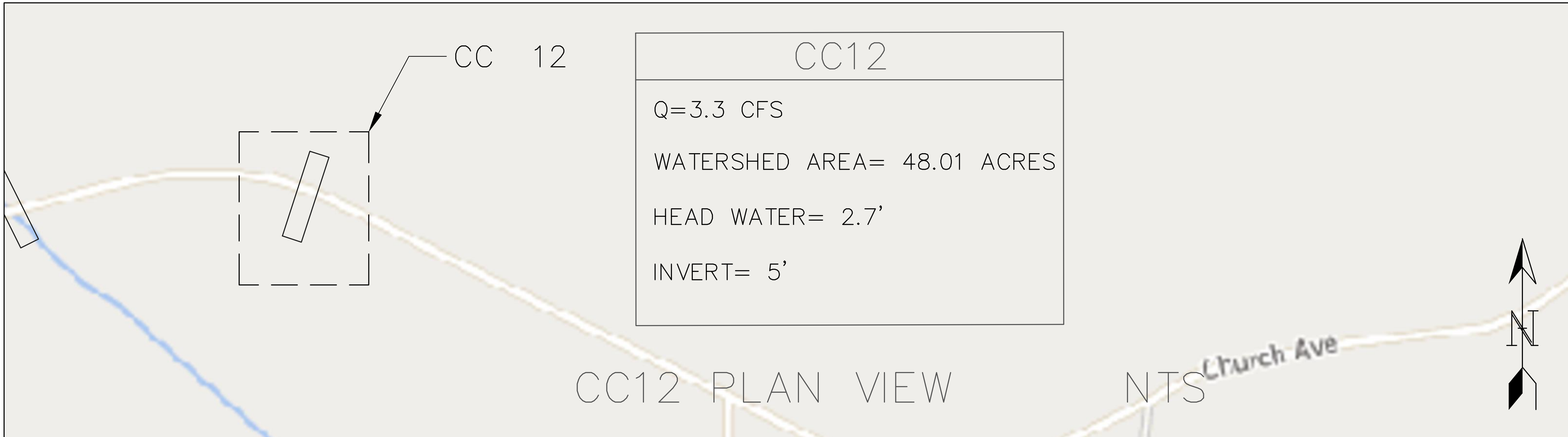

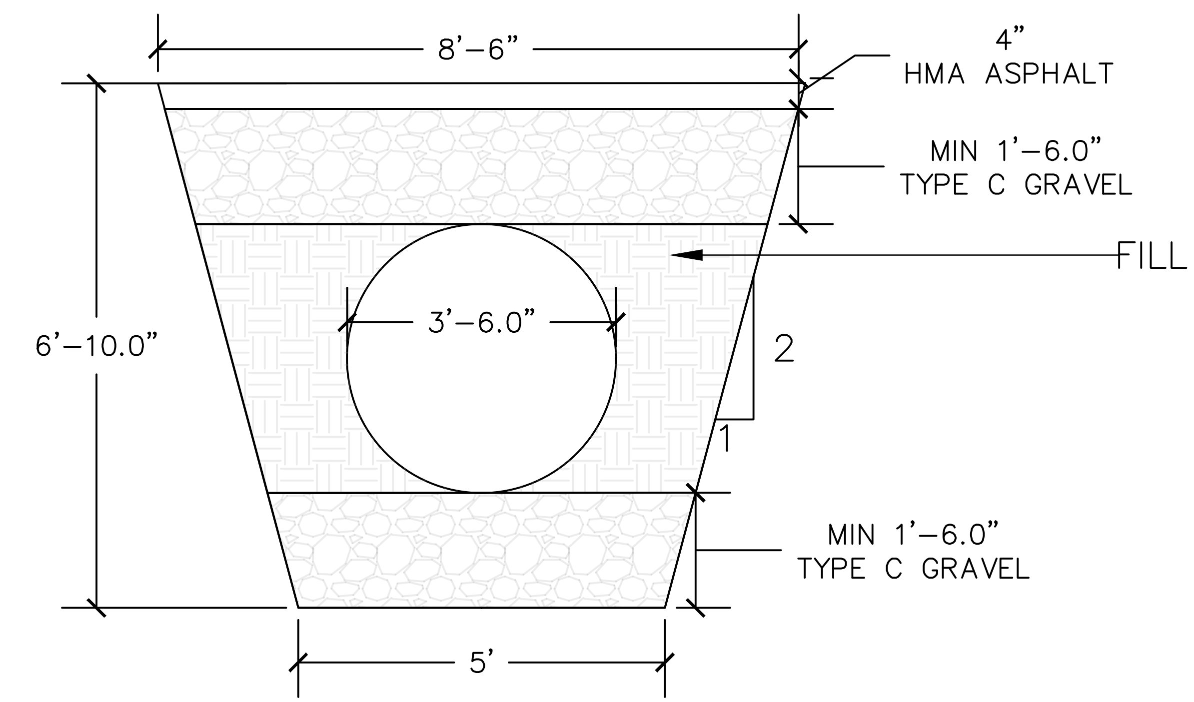

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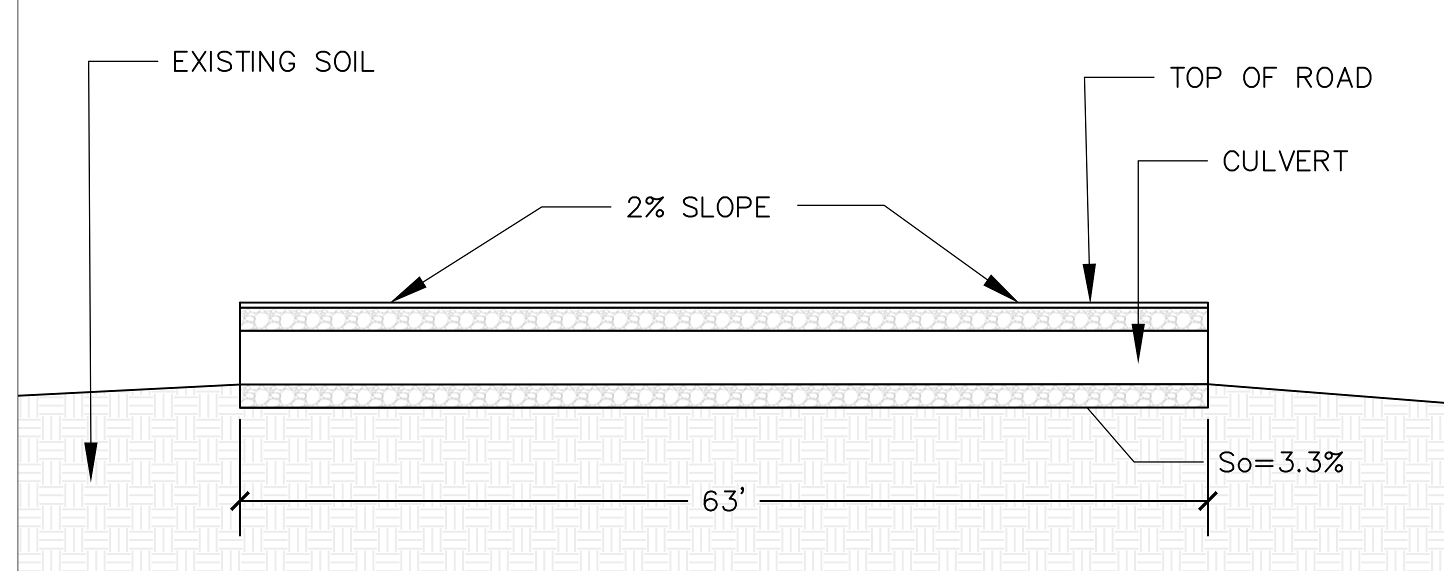

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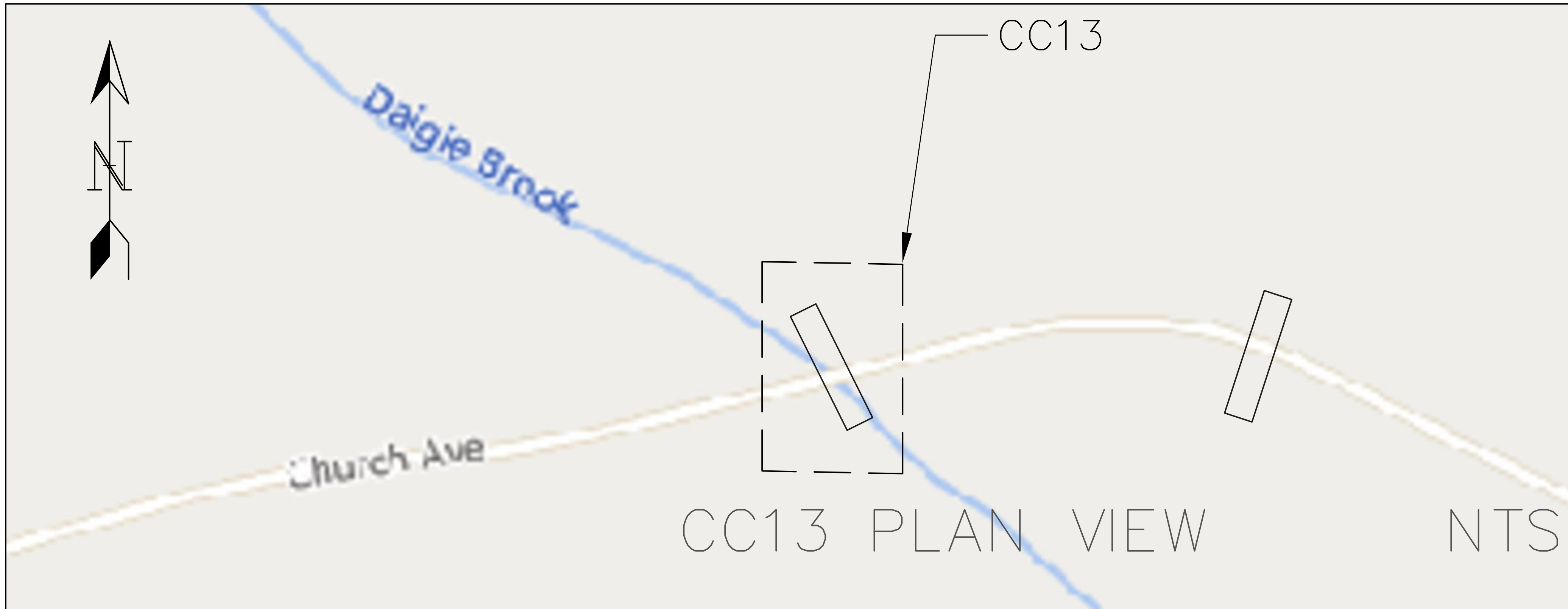


CC13 PLAN VIEW NTS

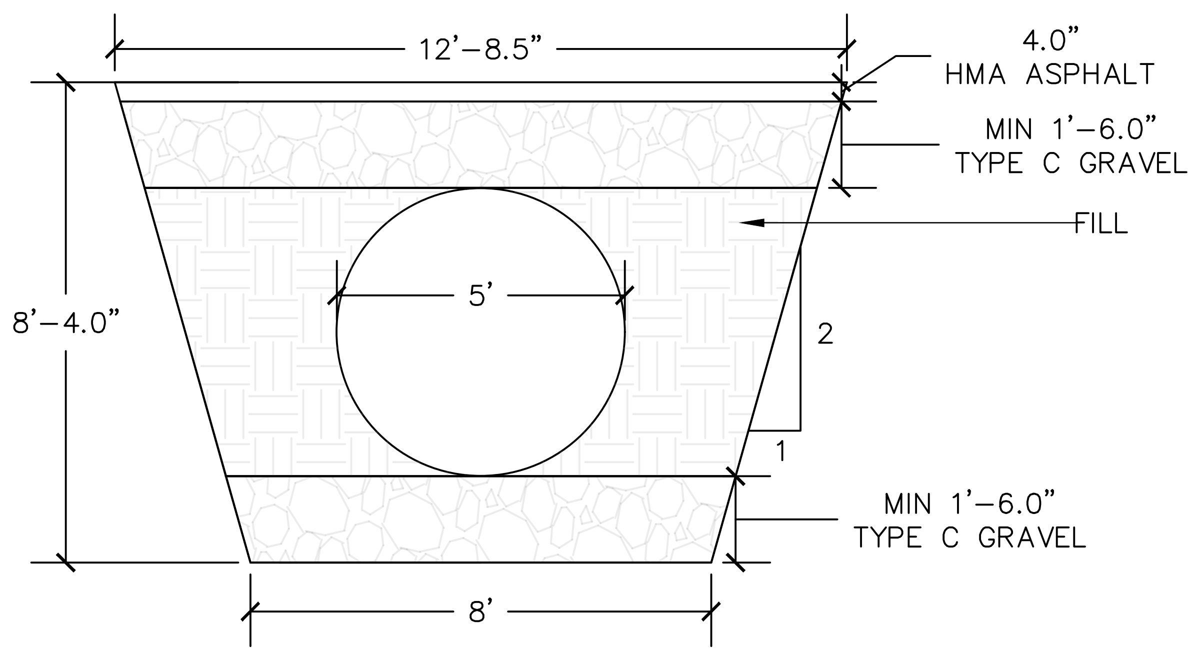
CC13

Q=722.5 CFS

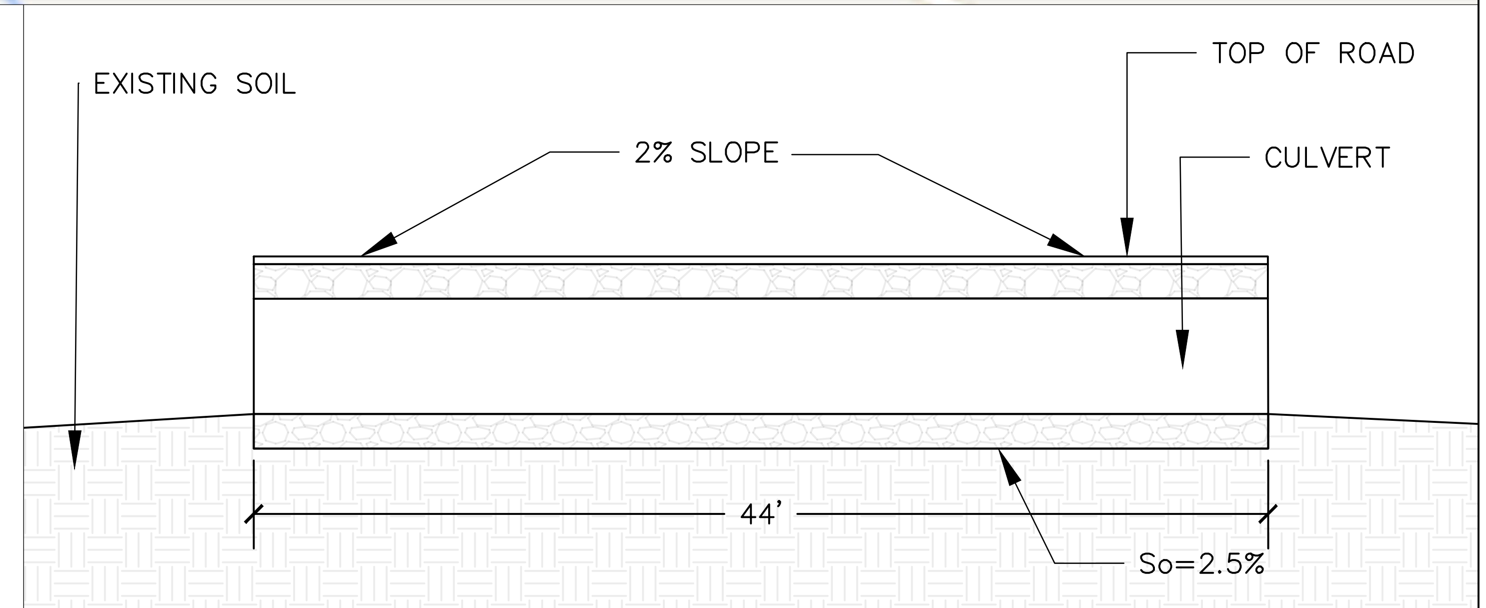
WATERSHED AREA= 22.52 ACRES

INVERT=6.8'

HEAD WATER= 2.9'



CC13 SECTION VIEW 1"=40'



CC13 PROFILE VIEW 1"=100'

Project Title: Frenchville Watershed Study	Work Package: Cross Culvert Drawings		Name:	Date:
Scale: 1" = Noted In Viewports	Location:	Deliverable:		
			Designed By: ALEX BEAULIEU	4/25/2024
			Drawn By: ALEX BEAULIEU	4/25/2024
	Frenchville Maine	Culvert Drawings	Checked By: SAM LAROCHELLE	4/25/2024
Sheet 4 of 5			Approved By: DOMINIC PERKINS	4/25/2024

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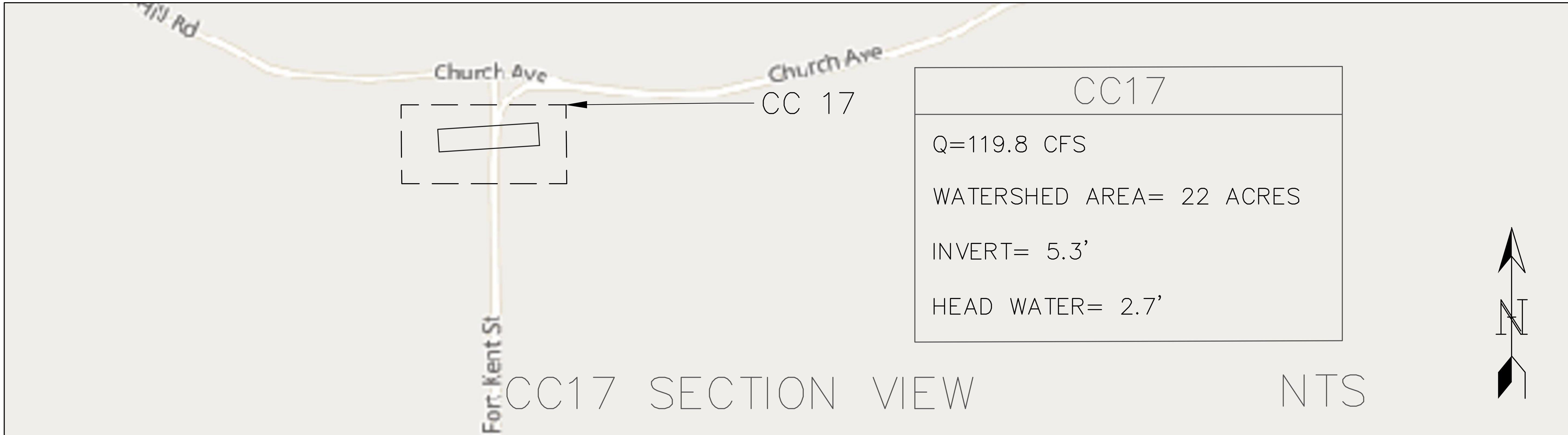
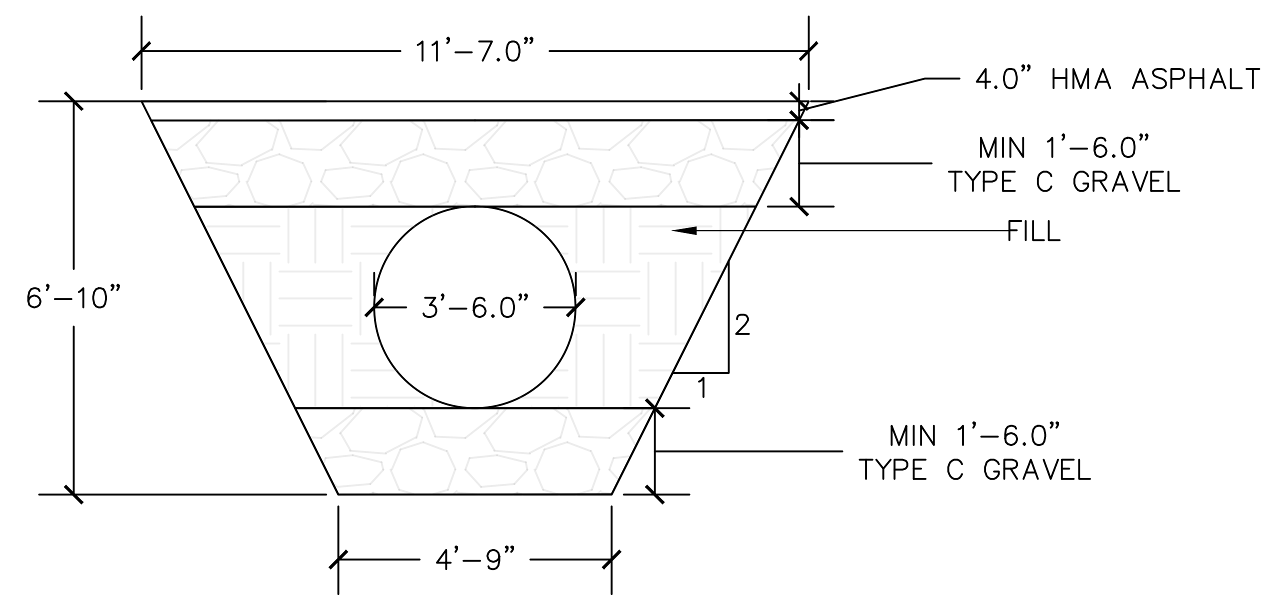
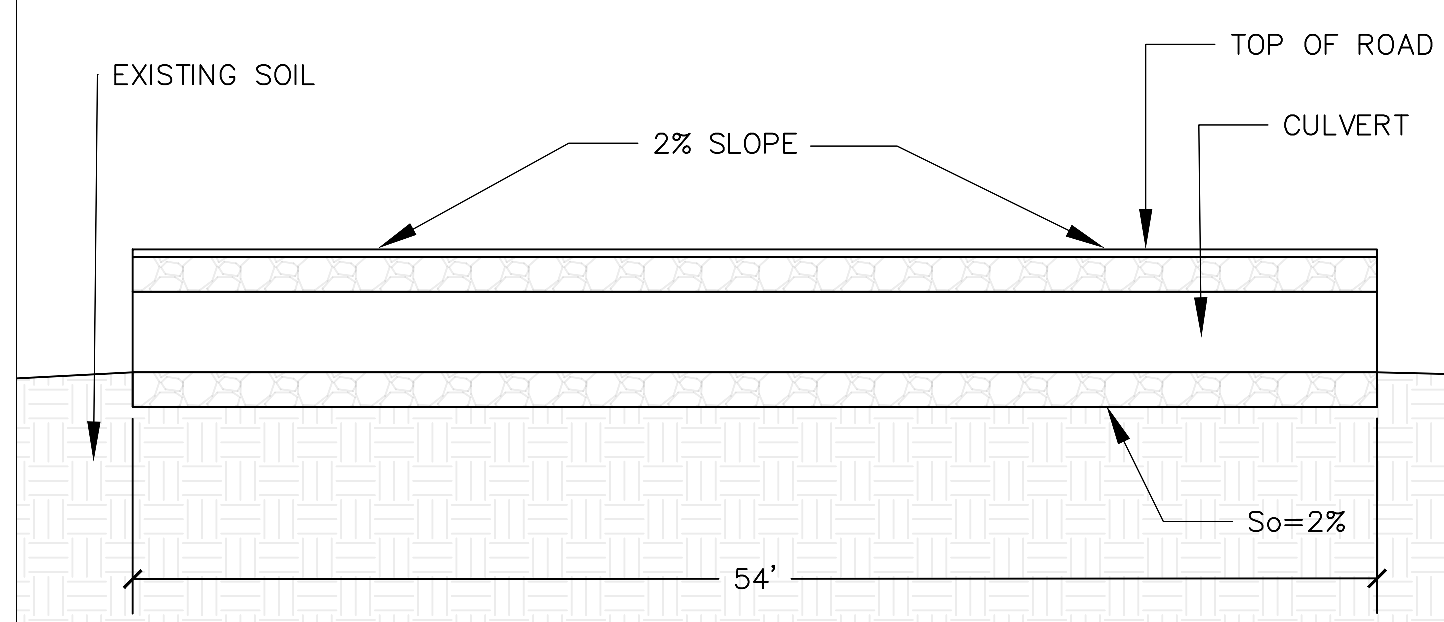
ASIDE
ENGINEERING



CC17 SECTION VIEW NTS



CC17 SECTION VIEW 1"=40'



CC17 SECTION VIEW 1"=100'

Project Title: Frenchville Watershed Study	Work Package: Cross Culvert Drawings			Name:	Date:
Scale: 1" = Noted In Viewports	Location:	Deliverable:	Designed By:	ALEX BEAULIEU	4/25/2024
			Drawn By:	ALEX BEAULIEU	4/25/2024
	Frenchville Maine	Culvert Drawings	Checked By:	SAM LAROCHELLE	4/25/2024
Sheet 5 of 5			Approved By:	DOMINIC PERKINS	4/25/2024

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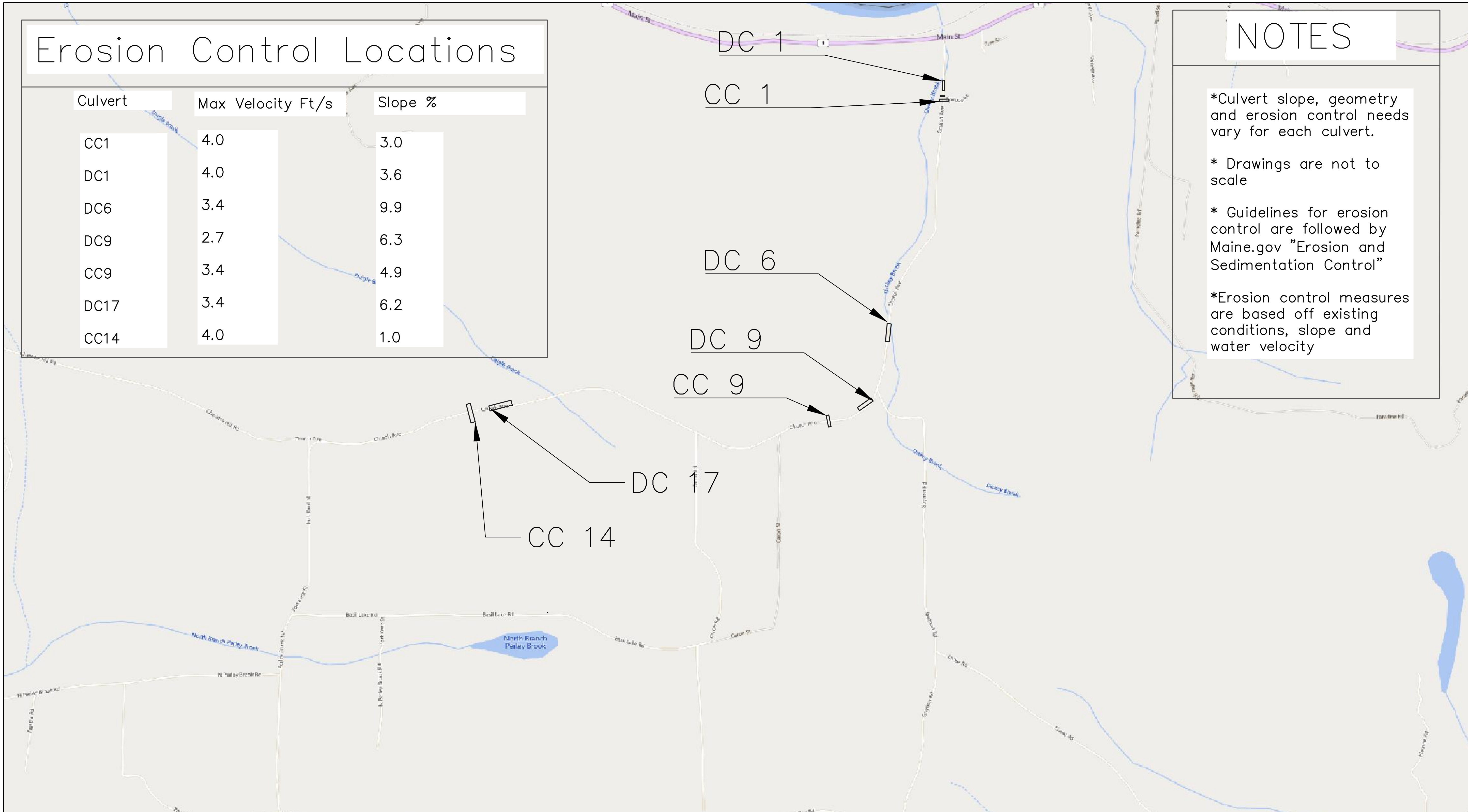
Erosion Control Locations

Culvert	Max Velocity Ft/s	Slope %
CC1	4.0	3.0
DC1	4.0	3.6
DC6	3.4	9.9
DC9	2.7	6.3
CC9	3.4	4.9
DC17	3.4	6.2
CC14	4.0	1.0



NOTES

*Culvert slope, geometry and erosion control needs vary for each culvert.

* Drawings are not to scale

* Guidelines for erosion control are followed by Maine.gov "Erosion and Sedimentation Control"

*Erosion control measures are based off existing conditions, slope and water velocity

Project Title: Frenchville Watershed Study	Work Package: 9		Name:	Date:
Scale: 1" = NTS	Location: Frenchville Maine	Designed By:	ISAK CARNEY	3/25/2024
	Deliverable: EROSION CONTROL	Drawn By:	ALEX BEAULIEU	3/25/2024
		Checked By:	SAM LAROCHELLE	3/25/2024
Sheet 1 of 2		Approved By:	DOMINIC PERKINS	3/25/2024

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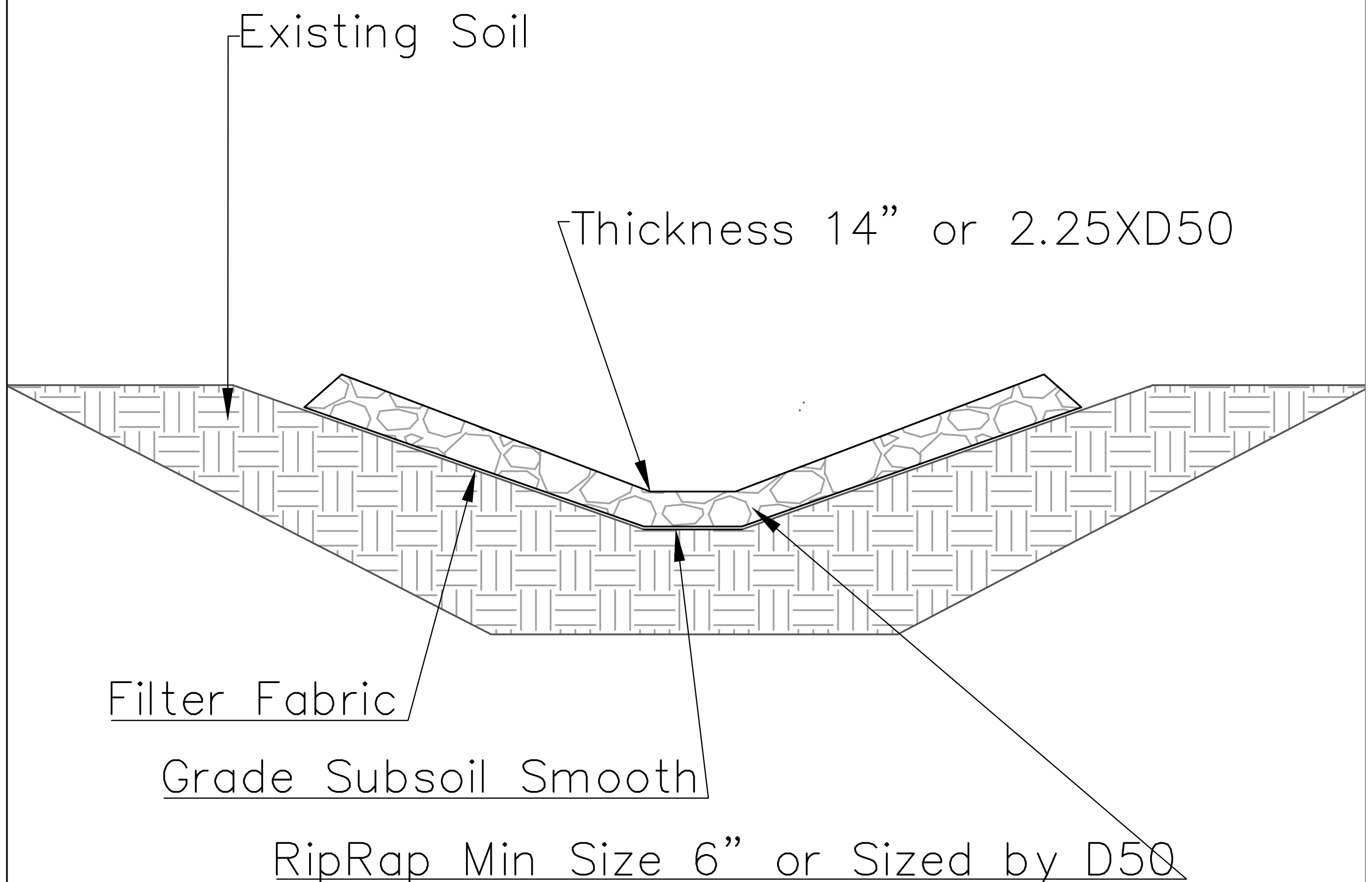
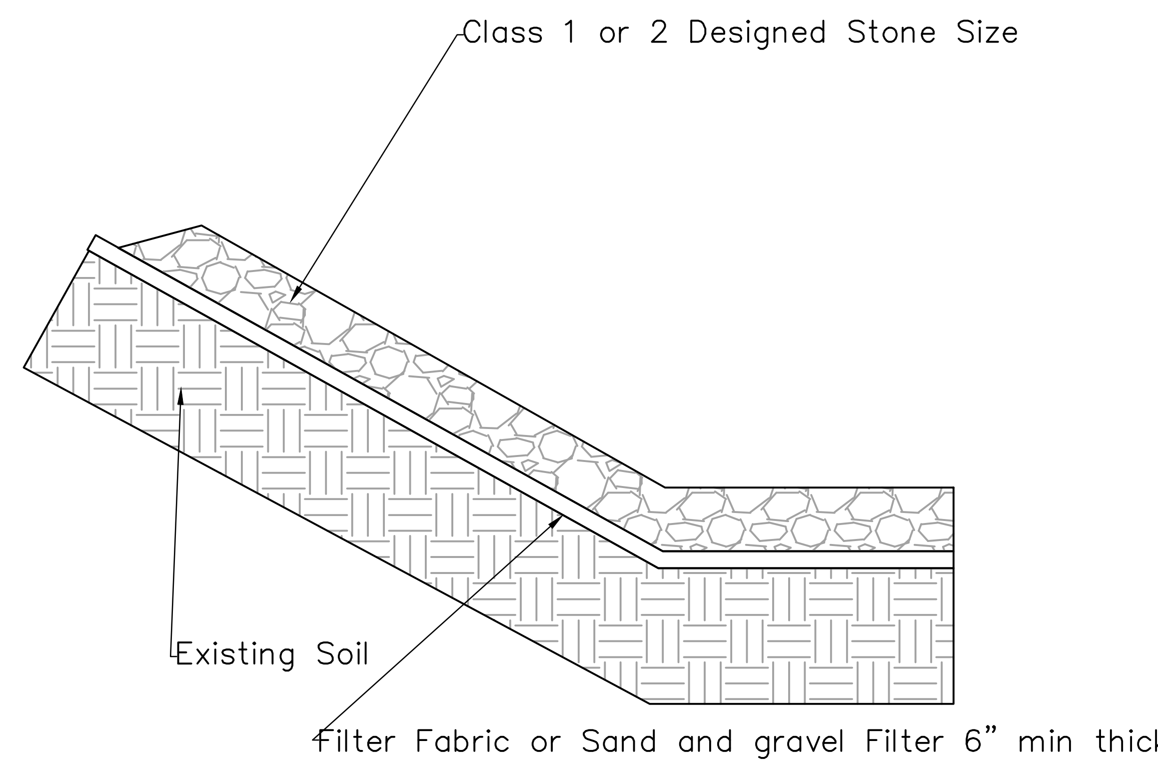


Typical Erosion Control Cross Section



Typical Erosion Control Profile

Project Title: Frenchville Watershed Study	Work Package: 9			Name:	Date:
Scale: 1" = NTS	Location:	Deliverable:	Designed By:	ISAK CARNEY	3/25/2024
			Drawn By:	ALEX BEAULIEU	3/25/2024
	Frenchville Maine	EROSION CONTROL	Checked By:	SAM LAROCHELLE	3/25/2024
Sheet 2 of 2			Approved By:	DOMINIC PERKINS	3/25/2024

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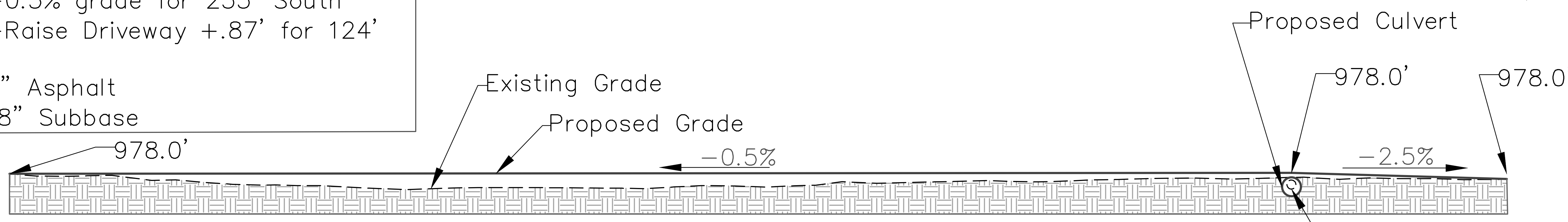
CC17

Elevation Change: +0.87'

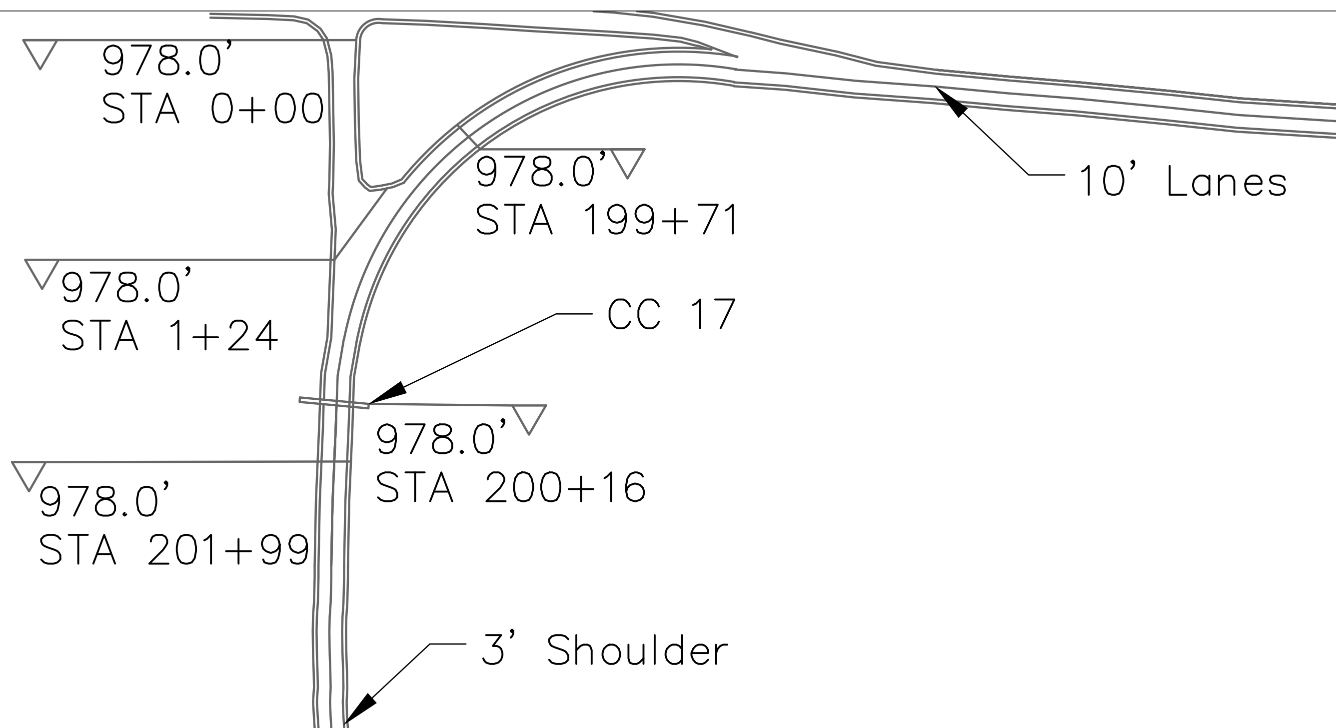
-2.5% grade for 45' Northeast
-0.5% grade for 233' South
-Raise Driveway +.87' for 124'

4" Asphalt
18" Subbase

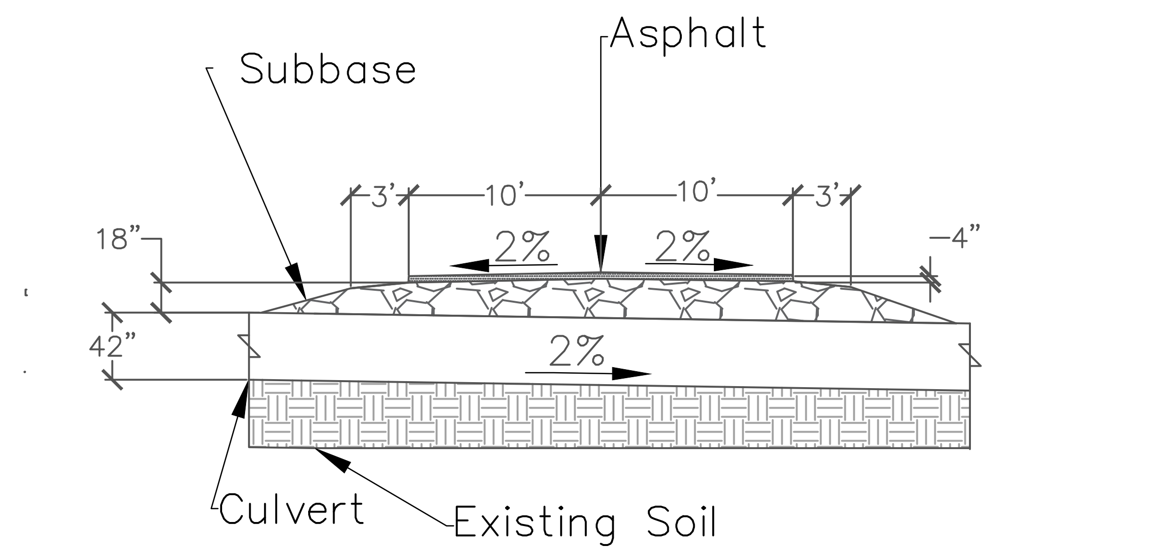
N



CC17 ROADWAY PLAN VIEW 1"=20'



CC17 PROFILE VIEW 1" = 150'



CC17 ROADWAY CROSS SECTION 1"= 10'

Project Title: Frenchville Watershed Study	Work Package: AFFECTED ROADWAY DESIGN		Name:	Date:
Scale: 1" = Noted In Drawings	Location:	Deliverable:		
		Designed By:	ETHAN SHELL	4/1/2024
		Drawn By:	SAM LAROCHELLE	4/1/2024
	Frenchville Maine	Roadway Design	Checked By: ETHAN SHELL	4/1/2024
Sheet CC17 of CRC		Approved By:	DOMINIC PERKINS	4/1/2024

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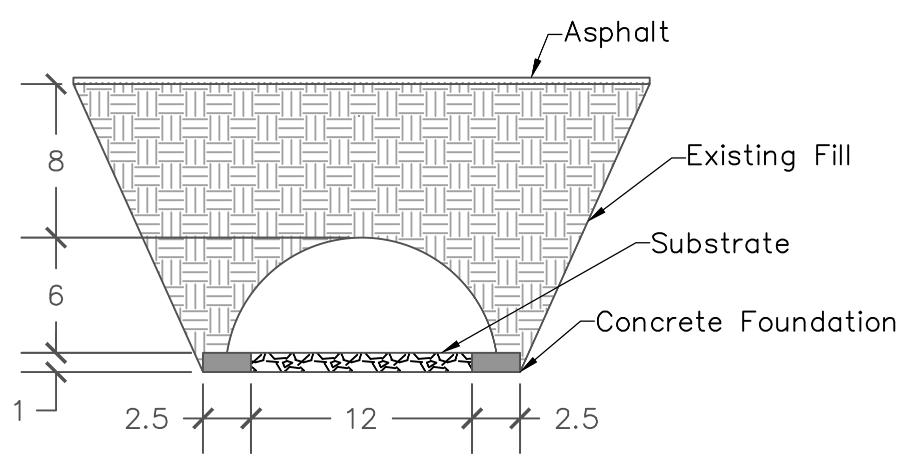
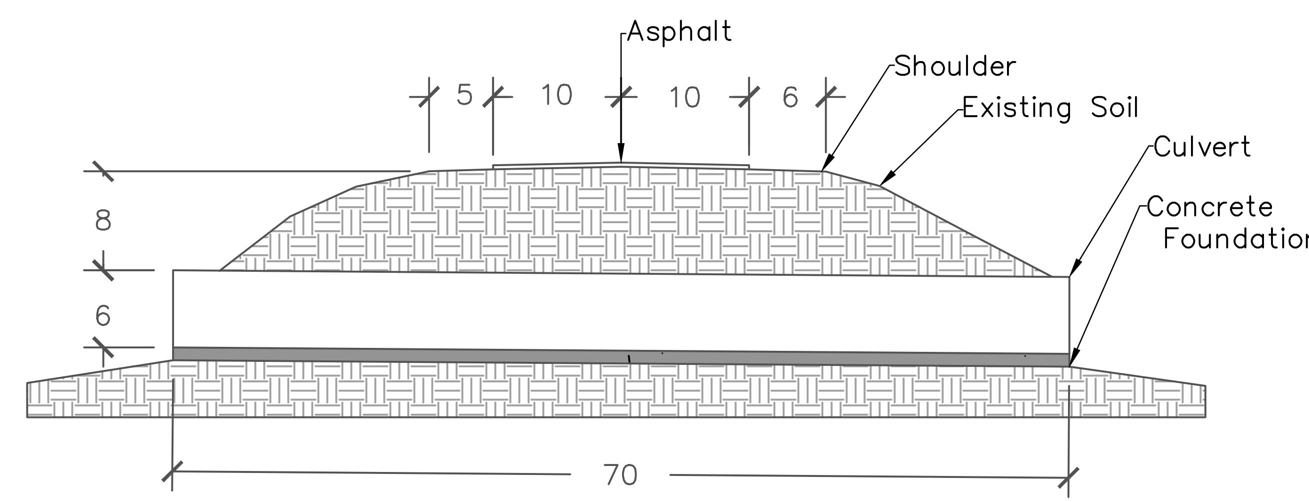
Open Bottom Culvert

MP–A–19 Armtec Multiplate
Corrugation: 152mm X 51mm
Wall Thickness: 2.8mm
Foundation designed without
Steel Reinforcement
Soil Headwall

Streamsmart Plan View



Streamsmart Cross Section 1”=10’



Streamsmart Profile View 1”=15’

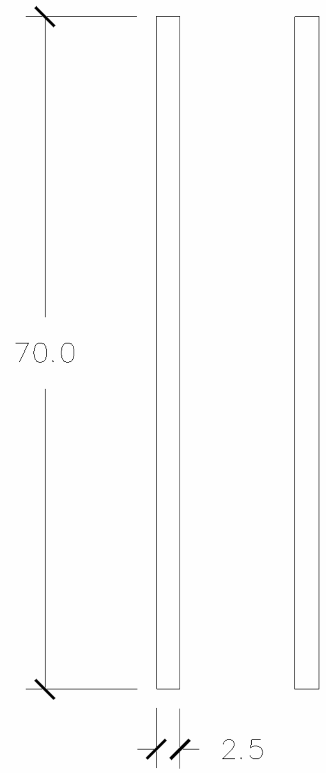
Project Title: Frenchville Watershed Study	Work Package: Streamsmart Design		Name:	Date:
Scale: 1” = Noted In Drawings	Location:	Deliverable:		
			Designed By: ETHAN SHELL	4/1/2024
			Drawn By: SAM LAROCHELLE	4/1/2024
	Frenchville Maine	StreamSmart	Checked By: ETHAN SHELL	4/1/2024
Sheet 1 of 2			Approved By: DOMINIC PERKINS	4/1/2024

EST. 2023
ASIDE
ENGINEERING

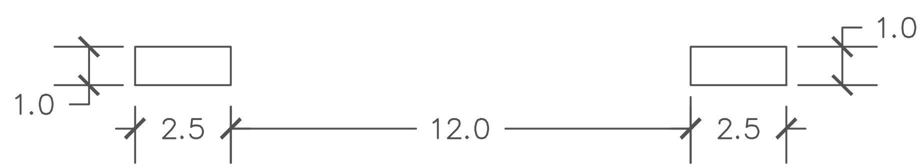
Open Bottom Culvert

MP–A–19 Armtec Multiplate
Corrugation: 152mm X 51mm
Wall Thickness: 2.8mm

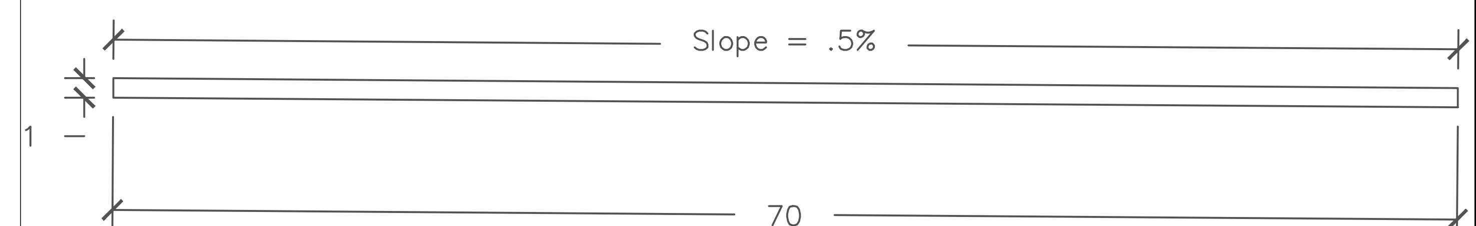
Foundation designed without
Steel Reinforcement



Foundation Plan View 1”=20’



Foundation Cross Section 1”=5’



Foundation Profile View 1”=10’

Project Title: Frenchville Watershed Study	Work Package: Streamsmart Design		Name:	Date:
Scale: 1” = Noted In Drawings	Location:	Deliverable:		
			Designed By: ETHAN SHELL	4/1/2024
	Frenchville Maine	Streamsmart	Drawn By: SAM LAROCHELLE	4/1/2024
			Checked By: ETHAN SHELL	4/1/2024
Sheet 2 of 2			Approved By: DOMINIC PERKINS	4/1/2024

EST. 2023
ASIDE
ENGINEERING