Design Report

Summit HOA Project

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1.0 Project Introduction

1.1 Purpose

The purpose of the Summit Home Owner Association (HOA) project is to examine and redesign an unstable open channel. One of the homeowners is experiencing geotechnical issues as a portion of their backyard is slipping into the channel.

The slippage of the soil has created a slope instability, which resulted in property damage. On the other hand, the lateral pressure from the soil has also damaged the homeowner's fence. Therefore, the client requests the fence to be reasonably higher than the sidewalk. Other problem with the channel is that the sediments are building up near the storm outlets due to the watershed upstream. The sediment build up is not associated with the soil slippage so the group must consider a design to reduce the blockage.

1.2 Background

The Summit HOA channel is located in Flagstaff, Arizona on Pullium Road and is adjacent to three properties. Figure 1 shows channel and culverts location and flow direction.

Ponderosa Trails was established as community of different residential uses geared towards homeowners. Ponderosa Trails created Development Standards to make sure all homeowners follow the design and construction regulations. This will result in compatible neighborhoods and improved surrounding environment. A Section of The Ponderosa Trails residential Development Standards consists of site planning and landscape guidelines. These guidelines will be beneficial for designing the channel to avoid any violation.

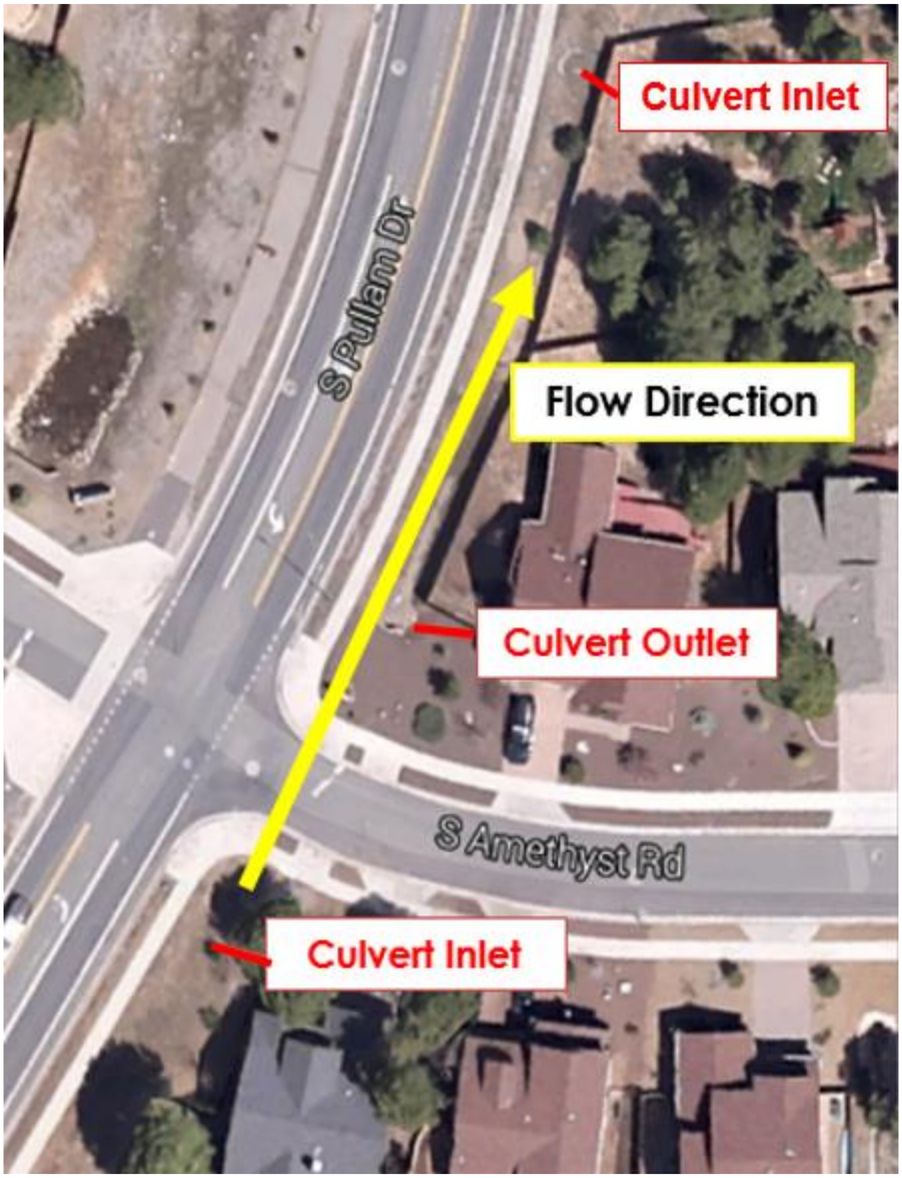

Figure 1: Culverts location and flow direction

2.0 Technical Analysis

In order to approach with the design, several analysis must be done. The team applied site analysis that includes surveying and geotechnical analysis to understand the channel condition and get the important parameters of the channel. Hydrological analysis is also applied to get the site precipitation data.

2.1 Surveying

2.1.1 Field Survey

The Summit team performed a field survey of the open channel and surrounding area. Using a total station and two local coordinate points that were provided by the technical advisor, as shown in the image below, the team created four additional control points on each corner of South Pulliam Drive and Amethyst Road. This procedure was done by setting up the total station on a local point and taking a back sight form the other local point. Five side shots on each new point and the average values for the northing, easting, and elevation were manually inserted into the data collector as a control point. A "x" was used to mark the sidewalk in order to locate the new control points for reference.

Figure 2 Control Points

2.1.2 Topography

The team took a total of 366 points of the site. The points include three trees, two culverts labeled A-E, the open channel, two storm drains, and sidewalks points along Pulliam Drive and Amethyst Road. A total of 256 shots were taken along the open channel as the team took 8 shots per 32 rows. 6 points were taken at each culvert including those that are across the street of Pullium Drive and Amethyst Road. Appendix A shows contour map developed for the channel using AutoCAD Civil 3D.

The purpose of surveying the site is to analyze the current conditions of the open channel as well as the area surrounding it. The channel dimensions and elevation change around the location will improve the team's design and meet the client's expectations. The Summit team have created six cross sections every 50 feet of the open channel as well as a profile view, which can be located in the appendix. The channel is roughly 260 feet long and has an average width of 18 feet. The average depth of the channel is 4 feet and the average elevation of the sidewalk next to the open channel is 6955 feet. These dimensions are important because the client would like for their fence to be approximately one foot higher than the sidewalk in order to improve their privacy.

2.2 Geotechnical Analysis

Applying geotechnical analysis is important to determine the soil type and characteristics in order to further understand the channel condition and problem.

2.2.1 Soil Testing

The team applied four different soil tests, which are: moisture content test, specific gravity test, Atterberg test, and sieve analysis test. Appendix B shows the data and calculation for the tests. Figure 3 shows where the samples were taken. 8 samples were obtained, however, only 4 of them were chosen for the tests because by looking at samples 3, 4, 5, 6, and 7, they looked exactly the same. On the other hand, sample 1, 2 and 8 were different since they are near culverts opening.

Figure 3: Soil sampling location

The soil samples were collected using containers provided by the soil lab at the Engineering Building. The team used two shovels full of soil for each sample.

Test 1: Moisture Content

The test was applied for all 4 samples. 2500 grams of each sample was obtained for the test because the soil samples contains particles that are greater than 19 mm in diameter. Table 1 shows the results for the experiment.

Table 1: Moisture Content Results (*w*%)

Sample #	S #1	S #2	S #4	S #8
w%	11.95	5.23	4.31	6.58

Sample 1 has the highest moisture content, which indicates that the soil has a higher void ratio. This test helps to understand the soil condition under drainage situation.

Test 2: Specific Gravity

Specific gravity is known as the ratio of the mass of unit volume of soil to the mass of the same volume of gas-free distilled water at a stated temperature. Specific Gravity test indicates the soil type and soil density.

Table 2: Specific Gravity Test Results

Sample #	S1	S2	S4	S8
Gs	2.50	2.59	2.66	2.64

Test 3: Atterberg Limits: Liquid Limit and Plastic Limit Tests.

The Atterberg limits are a basic measure of the critical water contents of a fine-grained. The soil obtained for each test must be passing number 40 sieve and weighs 50 grams. Both tests were performed for all samples and table 1 and 2 shows the results for the tests.

Table 3: Plastic Liquid Test Results.

Sample #	1	2	4	8
PL	17	17	15	16

Table 4: Liquid Limit Test Results.

Sample #	1	2	4	8
LL	22	23	21	22

The results for the Atterberg tests will be used in soil classification in the Sieve Analysis test.

Test 4: Sieve Analysis

The determination of the proportions of particles within certain size ranges in a granular material by separation on sieves of different size openings. Regarding this test, the team obtained 2000 grams of dry soil using 7 sieve openings, starting from 3/4', 3/8', 4, 16, 40, 100, and 200. All results for the tests can be shown in Appendix B.

Based on the results, the soil classification indicates that the channel has drainage property and the soil is good for compaction. In addition, the soil type is defined as gravel with sand and clay.

2.2.2 Slope Design/Fill

The results for the sample classification indicate that the soil will not be applicable for the drainage design. Pervious soil may not be suitable for the design because it will allow free passage of water. However, based on the results the soil has good compaction characteristics, so the soil can be compacted and used for the fill.

2.3 Drainage Design

2.3.1 Hydrology

Prior to designing a drainage system for the project, the team sought technical support from the City of Flagstaff by obtaining the previous engineering report to use as a reference. The reports include the watershed area of the site and additional drainage information that verify the group's calculated values. Appendix C shows the given watershed area for Pulliam Drive and Amethyst Road respectively.

The team applied a modified (weighted) Rational Method, as taken from standards of City of Flagstaff, to calculate the design discharge flow for the Summit channel. The equation converts surface water on the location into a design flow for the hydraulic design. The Rational Method was for the 10, 25, and 100-year storm as required by the City of Flagstaff Storm water Drainage Manual. Appendix D is the NOAA Atlas 14 precipitation table, which shows the rainfall intensity, used in the design calculations using the 60-minute storm. The Antecedent Coefficient and Roughness coefficient for all design discharge is 0.95.

2.3.2 Hydraulics

After computing the design discharge for the drainage system, the team used engineering software, Bentley Flow Master, to figure out the discharge velocity, normal depth, and if the channel can convey the flow effectively. Appendix E shows the values from Flow Master of the Summit channel. Further information of the hydraulic analysis will be explained in the design section of the report.

3.0 Design Restrictions

All design restrictions and standards were derived from City of Flagstaff storm water design manual [1] and Ponderosa Trails Document. [2].

3.1 Restrictions for Artificial Channels:

- All artificial open channels drainage systems shall be designed for the 25-year design storm and checked with the 100-year design storm
- Channel side slopes shall not be steeper than 3H:1V
- Channel depth shall not exceed 3 feet in residential areas.
- The minimum allowable channel slope is 0.5%
- Minimum freeboard is 1 foot

3.2 Restrictions for Storm Drain:

- The minimum Design Frequency for all public storm drain shall be the 10-year design storm, and should be checked for 100-year design storm
- The minimum acceptable diameter for any public storm drain is 18 in
- The minimum allowable storm drain slope for pipes is 0.5%
- Curved storm drain maybe permitted when long radius curves are necessary to conform street layout; the minimum radius shall not be less than 100 feet
- Clogging Factor Grate Inlet on Sag and Grade s 50%
- Minimum pipe cover is 2 feet and maximum is 10 feet

3.3 Restrictions for Retaining Wall

- Wall height cannot exceed 5 feet
- Frost line depth is 2.5 feet

4.0 Design Alternatives

The design alternatives for the project are Culvert Design, Engineered Channel, and Retaining Wall Design. In addition, there is a fourth option, which is leaving the existing channel without any changes. Our client recommended the design alternatives and further in this report section each design will be explained individually.

4.1 Existing Channel

The team analyzed the channel existing condition using surveying data. The channel length is 260 feet, channel height varies from 1.5 feet to 4 feet, channel top width in average is 16 feet, channel bottom width in average is 2.5 feet, side slopes of the channel from the fence side and sidewalk side is .35 ft/ft and .45 ft/ft respectively, and channel slope is 1.8%. Appendix F for channel AutoCAD drawings

Some of the parameters don't meet the standards; side slopes are steeper than required and height of the channel exceeds 3 feet. From there, the team must redesign the channel according the standards.

4.2 Culvert Design

4.2.1 Design Parameters

The team ran the engineering software, Flow Masters, to design the culvert using 10-year and 100-year design storm. The 100-year design storm is used to check with the minimum design frequency, as required by the City of Flagstaff Standards. However, the culvert was design with the 10-year design storm data. Appendix G shows the Flow Master Result Analysis. The team chose a grate inlet type F (see Appendix H for details). Which will be placed at the existing culvert at Amethyst Road. HDPE pipes will be used for the design, which will be two pipes with 1.5 feet in diameter and 160 feet long. The radius for the pipe is 486 feet. The pipes will end at the second culvert inlet at Pulluim Road. The pipes will have a concrete cast built around, and then a concrete sloped lining will be built at the pipes outlet to direct the water to the second culvert inlet (see Appendix I for AutoCAD drawings). The team used two pipes for the design because one pipe will not fit in the channel due to channel height limitation. Therefore, the team chose two pipes that will have lower diameter to fit in the channel. The two pipes will be covered throughout the channel at least with 0.5 feet of soil with side slopes of 1.8%. The fence side of the channel will be filled at least one foot above the sidewalk to meet the requirements of Ponderosa Trails Standards; Appendix E shows the cross sections of the design.

4.3 Engineered Channel

Second design alternative is to redesign the existing channel using the standards provided by City of Flagstaff. The channel could not be design according to the standards because there were not enough channel width to change side slopes as required. Side slopes of the channel is steeper than required, varies between 0.35 ft/ft to 0.45 ft/ft, and to change the slopes to the minimum required (0.33 ft/ft), not enough existing channel bottom width is available. Therefore, in order to make this design, the channel has to extend beyond homeowners properties, which is not an option. As a result, the team excluded this design alternative.

4.4 Retaining Wall Design

This design alternative is a concrete masonry unit (C.M.U.) retaining wall that will prevent further slippage of the homeowner's backyard into the open channel. The depth of the cast in place foundation will be at a frost line depth of 2.5 feet, raise the elevation 1 foot higher than the sidewalk, and will extend along the entire open channel. Each block will have a dimension of 8"x8"x16" and will be grouted solid with coarse mortar. The retaining wall will also have use No. 4 reinforcement bars with 24-inch on center vertically and 48-inch horizontal as well. The side slopes of the channel will not be altered for this design alternative. The profile of the C.M.U. retaining wall illustrates the change in elevation as shown in Appendix J. A fill soil will conceal the backside of the retaining wall and the homeowner's fence is placed above on the new elevation.

5.0 Summary of Project Cost

5.1 Engineering Hours Cost

Table 5: Staff Cost

Classification	Hours	Pay Rate $/hr	Cost $
S.ENG	90	90	8,100
ENG	200	60	12,000
LAB.T	70	35	2,450
A.A	15	30	450
		Total	23,000

5.2 Cost for Culvert Design

HDPE pipe 18" Diameter Cost	160 feet	$4,800
Pipe connections Cost		$80
Labor	46.7 hrs	$3,271
Filling Cost	190 cubic yards	$1,520
Concrete Cast Cost	20 square feet	$1,650
Total		$11,321

5.3 Cost for Retaining Wall Design

Block Retaining Wall Cost	908 square feet	$2,543
Block Retaining Wall Labor	46.7 hrs	$3,271
Block Retaining Wall Job Materials and Supplies	850 square feet	$274
Block Retaining Wall Equipment Allowance		$78
Block Retaining Wall Foundation		$250
Filling Cost	99 cubic yards	$792
Total	850 square feet	$7,208

6.0 Design Matrix

Design alternatives are ranked from 1 to 5 with 1 being the lowest and 5 is the highest. The total of the ranking will allow us to make the final decision for the final design.

Table 6: Design Matrix

	Culvert Design	Retaining Wall Design
Efficiency of Design	5	3
Aesthetic of Design	5	4
Cost of Design	3	4
Client's Preference	5	2
Total	18	13

7.0 Discussion

The Summit team have concluded that the culvert inlet is the ideal design for this project. The culvert inlet is the client's preferred design and is less expensive in comparison to the retaining wall. The culvert inlet will prevent property damages, is aesthetically pleasing, and redesigns the open channel to meet city standards side slope requirements. Although the retaining wall will resolve the slippage issue, it does not revise the poorly engineered channel section or reduce the sediment build up at the culvert outlet.

8.0 Conclusion

The purpose of the Summit HOA project is to reassess and redesign an unstable open channel in Flagstaff, Arizona. The homeowner's property lacks privacy as the fence is slipping into the channel and sediment is building up at the existing culvert outlet. After reviewing the analysis results of the current site conditions, the Summit team propose a culvert inlet for the channel that will route surface water through two HDPE pipe and fill the section to prevent additional slippage. The Summit project combines multiple civil engineering sub-disciplines to regulate the channel and meet the City of Flagstaff's code of standards.

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Appendix B: Geotechnical Data

Test 1: Moisture Content

Table 7: Moisture Content Raw Data and Results (*w*%)

	S 1	S 2	S 4	S 8
Weight of Empty Tray (Wc) (g)	438	343.6	363.8	368.6
Weight Of Tray + Moist Soil (W1) (g)	2938	2843.6	2863.8	2868.6
Weight of Tray + Dry Soil (W2) (g)	2671	2719.2	2760.4	2714.1
Weight of Moist (W1 - W2) (g)	267	124.4	103.4	154.5
Weight of Dried Sample (W2 - Wc) (g)	2233	2375.6	2396.6	2345.5
w% (W1-W2)/(W2-Wc) (g)	11.95	5.23	4.31	6.58

Test 2: Specific Gravity

Table 8: Specific Gravity Raw Data and Results

Sample #	S 1	S 2	S 4	S 8
Weight of Flask (g)	155.3	154.8	155.8	155.6
Weight of Dish (g)	453.3	482.1	463.5	500.4
Weight of Dish + soil (g)	553.3	582.1	563.5	600.4
Weight of Flask + 500mL Water (g)	653.7	653.4	654.3	654.2
Weight of Flask + soil + water (g)	710.5	713.3	715.5	714
Weight of Dish + moist Soil (g)	676.6	736.5	704.9	732.6
Weight of Dish + Dry Soil (g)	547.8	579.6	561.4	596.5
Mass of Dry Soil (g)	94.5	97.5	97.9	96.1
Mass of equal Volume of Water (g)	37.7	37.6	36.7	36.3
Gs	**2.50**	**2.59**	**2.66**	**2.64**

Test 3: Atterberg Limits:

Table 9: Liquid Limit and Plastic Limit Raw Data and Results

Sample #	S 1	S 2	S 4	S 8
Weight of Can (g)	21.8	12	20.4	11.5
Weight of Can + Moist Soil (g)	25.3	19.7	24.2	19.5
Weight of Can + Dry Soil (g)	24.8	18.6	23.7	18.4
PL	17	17	15	16

Table 10: Liquid Limit Raw Data and Results

Sample #	1	2	4	8
Weight of Can (g)	21.3	14.1	14.2	14.4
Weight of Can + Moist Soil (g)	68.5	21	30.9	34.9
Weight of Can + Dry Soil (g)	60.1	19.7	28	31
Number of Drops (g)	25	24	27	15
wN %	21.65	23.21	21.01	23.49
LL	22	23	21	22

Test 4: Sieve Analysis

Table 11: Sample 1 Grain Size Distribution Percent.

Sieve No.	Sieve Opening (mm)	Weight of Empty Tray (g)	Weight of Soil + Tray (g)	Weight of Soil (g)	Percent of Soil	Cumulative Percent	Percent Finer
3/4"	19	1403.7	1640.4	236.7	11.90	11.90	88.10
3/8"	9.51	1364.3	1687.4	323.1	16.24	28.14	71.86
4	4.76	1281.3	1497.6	216.3	10.87	39.02	60.98
16	1.19	738.8	1139.5	400.7	20.14	59.16	40.84
40	0.42	931.6	1151.2	219.6	11.04	70.20	29.80
100	0.149	548.8	752	203.2	10.22	80.41	19.59
200	0.074	525.5	754.4	228.9	11.51	91.92	8.08
Pan		890.5	1051.2	160.7	8.08	100.00	0.00

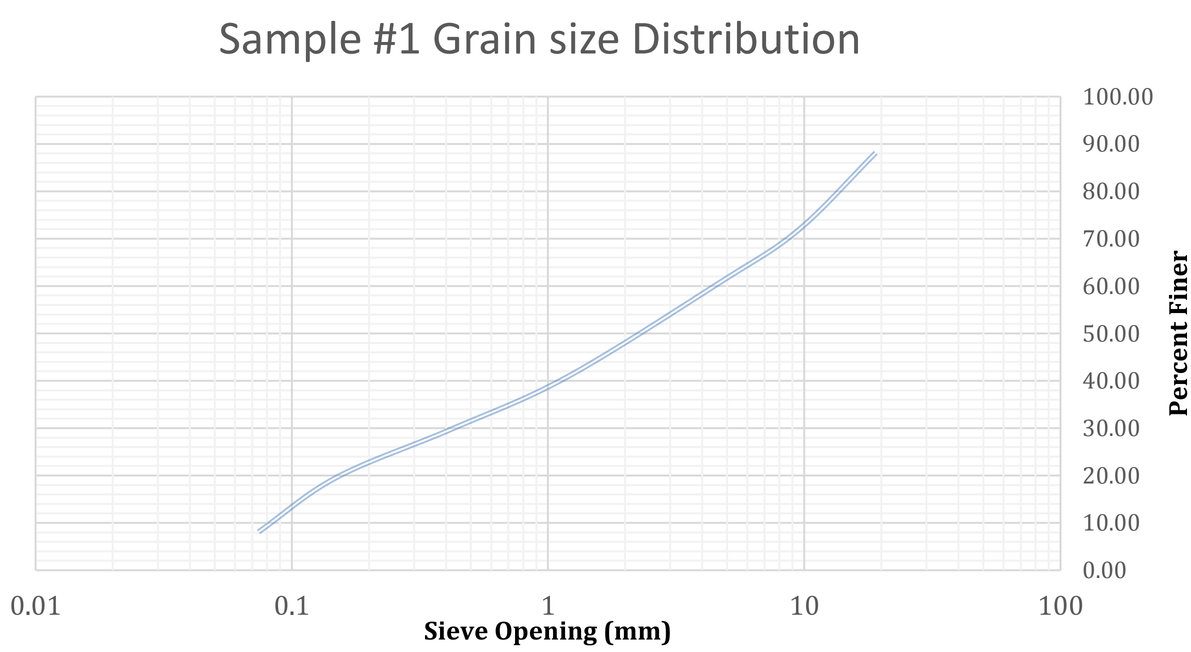

Table 12: Sample 2 Grain Size Distribution Percent.

Sieve No.	Sieve Opening (mm)	Weight of Empty Can (g)	Weight of Soil + Can (g)	Weight of Soil (g)	Percent of Soil	Cumulative Percent	Percent Finer
3/4"	19	1403.7	1934.4	530.7	24.90	24.90	75.10
3/8"	9.51	1364.3	1639.2	274.9	12.90	37.79	62.21
4	4.76	1281.3	1586	304.7	14.29	52.09	47.91
16	1.19	738.8	1236.8	498	23.36	75.45	24.55
40	0.42	931.6	1200.7	269.1	12.62	88.07	11.93
100	0.149	548.8	693.4	144.6	6.78	94.86	5.14
200	0.074	525.5	582.3	56.8	2.66	97.52	2.48
Pan		890.5	943.3	52.8	2.48	100.00	0.00

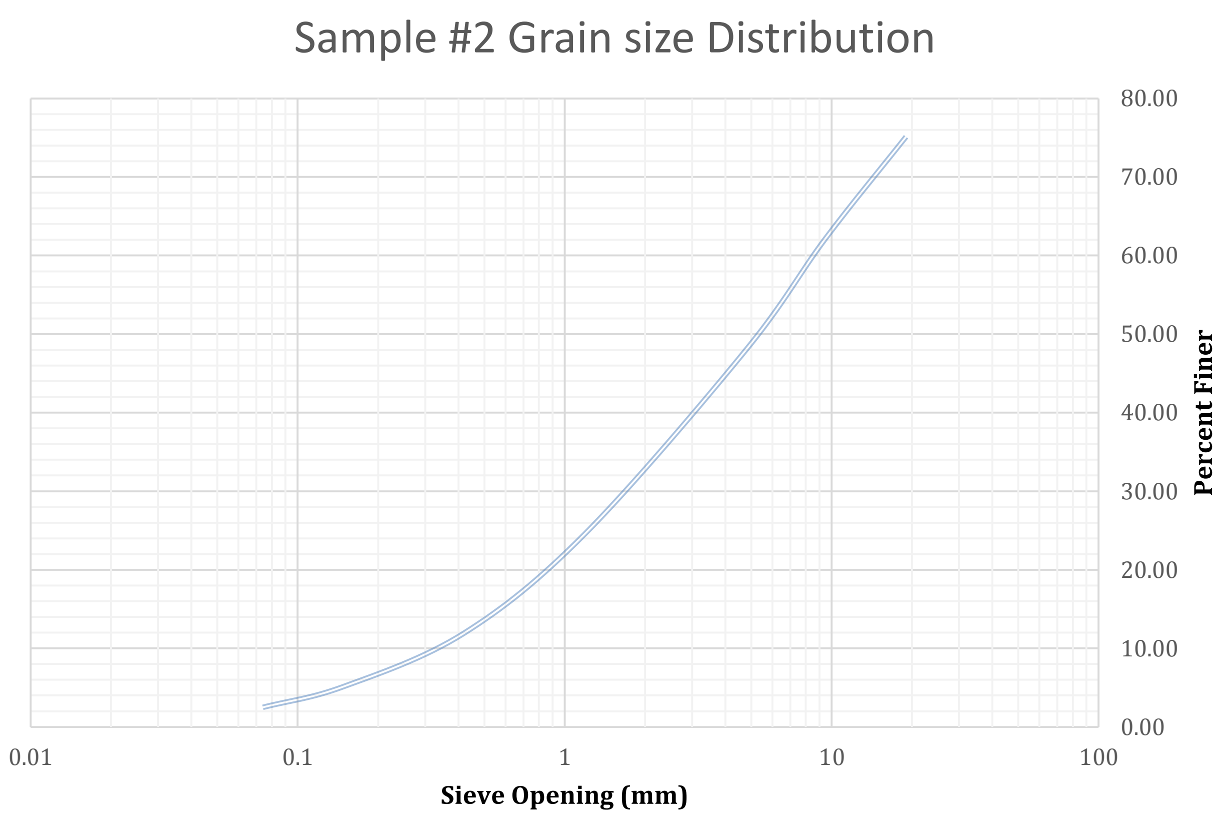

Table 13: Sample 4 Grain Size Distribution Percent.

Sieve No.	Sieve Opening (mm)	Weight of Empty Can (g)	Weight of Soil + Can (g)	Weight of Soil (g)	Percent of Soil	Cumulative Percent	Percent Finer
3/4"	19	1403.7	1422.1	18.4	0.85	0.85	99.15
3/8"	9.51	1364.3	1492.7	128.4	5.96	6.81	93.19
4	4.76	1281.3	1597.8	316.5	14.69	21.50	78.50
16	1.19	738.8	1485.6	746.8	34.66	56.16	43.84
40	0.42	931.6	1403.8	472.2	21.91	78.07	21.93
100	0.149	548.8	881.6	332.8	15.44	93.51	6.49
200	0.074	525.5	615	89.5	4.15	97.67	2.33
Pan		890.5	940.8	50.3	2.33	100.00	0.00

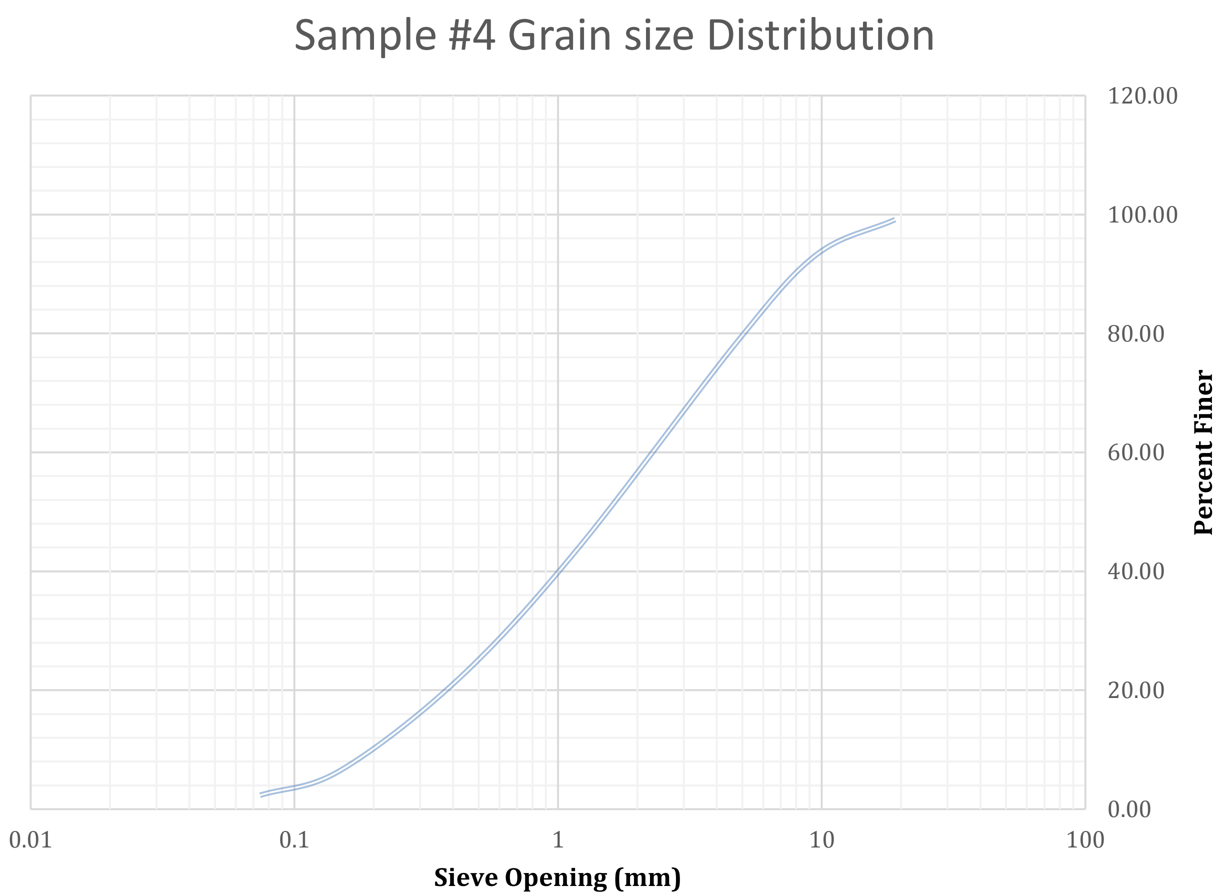

Table 14: Sample 8 Grain Size Distribution Percent.

Sieve No.	Sieve Opening (mm)	Weight of Empty Can (g)	Weight of Soil + Can (g)	Weight of Soil (g)	Percent of Soil	Cumulative Percent	Percent Finer
3/4"	19	1403.7	1497.1	93.4	4.45	4.45	95.55
3/8"	9.51	1364.3	1689.7	325.4	15.51	19.96	80.04
4	4.76	1281.3	1659.5	378.2	18.02	37.98	62.02
16	1.19	738.8	1201.2	462.4	22.03	60.01	39.99
40	0.42	931.6	1106.3	174.7	8.32	68.34	31.66
100	0.149	548.8	760.9	212.1	10.11	78.44	21.56
200	0.074	525.5	855.2	329.7	15.71	94.15	5.85
Pan		890.5	1013.2	122.7	5.85	100.00	0.00

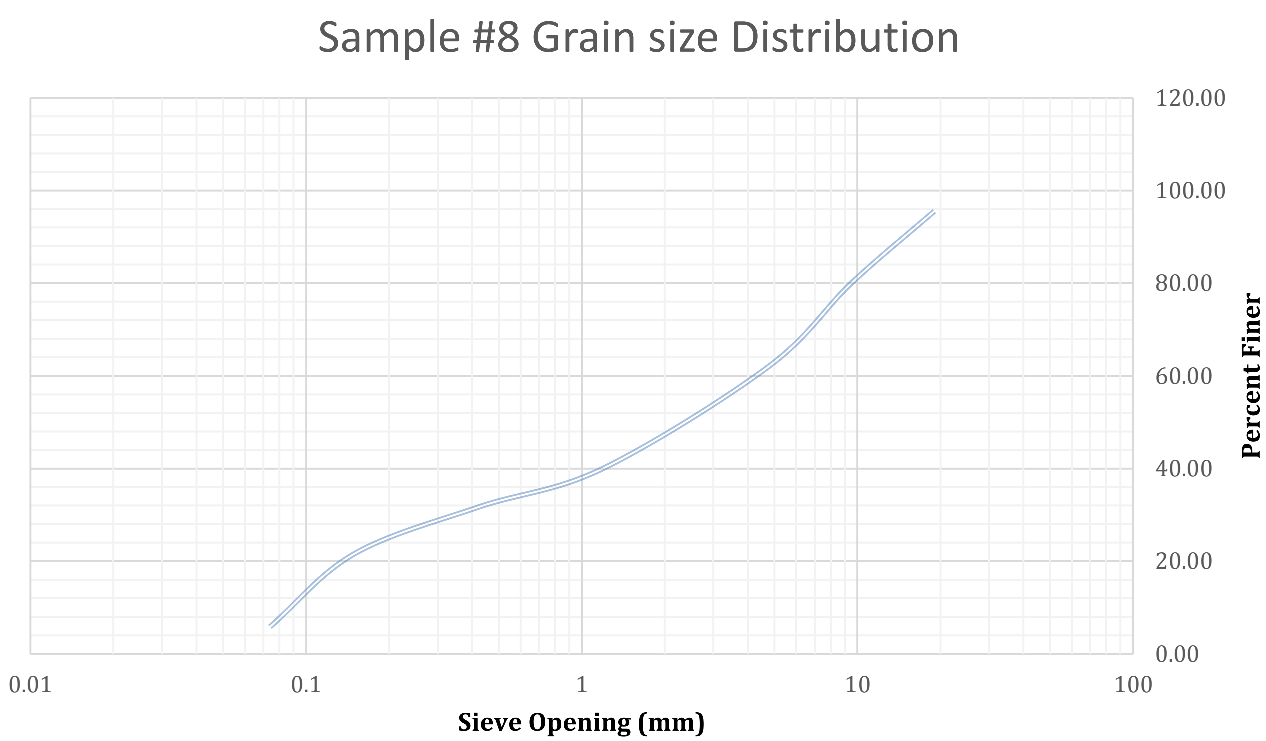

Table 15: Sample Classification Table

	AASHTO Classification	USCS Classification	Comments
Sample 1	A 2-4(0)	SP-SC Poorly-graded sand with clay and gravel	Excellent to good subgrade Good Drainage; pervious Good Compaction characteristics Reasonably stable for fill when dense
Sample 2	A 2-4(0)	GP Poorly-graded gravel with sand	Excellent to good subgrade Good Drainage; pervious Good Compaction characteristics Reasonably stable for fill
Sample 4	A 2-4(0)	GP Poorly-graded gravel with sand	Excellent to good subgrade Good Drainage; pervious Good Compaction characteristics Reasonably stable for fill
Sample 8	A 2-4(0)	GP-GC Poorly-graded gravel with sand and clay	Excellent to good subgrade Good Drainage; pervious Good Compaction characteristics Reasonably stable for fill

Appendix C: Watershed Areas

Table 16: Watershed Area

Hydrological Element	**Sub basins & Junctions**	**Area (Acres)**
Amethyst Road	Sub Basin P-12	0.64
	Sub Basin P-21	0
	Sub Basin P-22	1.92
	Junction J-21	5.16
	Junction J-23	7.04
	Junction J-24	5.12
	Total	19.8
Pulliam Road	Sub Basin P-20	1.92
	Junction J-48	9.86
	Total	10.78

Appendix D: Rational Method and Precipitation Data

Rational Method Equations:

$Q_{design} = C_f CIA\ (cfs)$

$C_f = Antecedent\ Coefficient\ (Unit\ less)$

$C = Roughness\ Coefficient\ (Unit\ less)$

$I = Rainfall\ Intensity\ (in/hr)$

$A = Watershed\ Area\ (Acres)$

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches/hour)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	2.38 (2.11-2.74)	3.10 (2.74-3.54)	4.18 (3.68-4.76)	5.08 (4.43-5.78)	6.36 (5.52-7.21)	7.43 (6.37-8.42)	8.60 (7.27-9.77)	9.86 (8.20-11.2)	11.7 (9.52-13.4)	13.2 (10.6-15.3)
10-min	1.81 (1.60-2.08)	2.36 (2.08-2.69)	3.17 (2.81-3.62)	3.86 (3.37-4.40)	4.84 (4.21-5.49)	5.66 (4.85-6.41)	6.55 (5.54-7.44)	7.50 (6.24-8.52)	8.89 (7.24-10.2)	10.1 (8.05-11.7)
15-min	1.50 (1.32-1.72)	1.95 (1.72-2.23)	2.62 (2.32-3.00)	3.19 (2.78-3.64)	4.00 (3.48-4.54)	4.68 (4.01-5.30)	5.41 (4.58-6.15)	6.20 (5.16-7.04)	7.35 (5.99-8.42)	8.33 (6.65-9.64)
30-min	1.01 (0.892-1.16)	1.31 (1.16-1.50)	1.77 (1.56-2.02)	2.15 (1.87-2.45)	2.70 (2.34-3.06)	3.15 (2.70-3.57)	3.64 (3.08-4.14)	4.18 (3.47-4.74)	4.95 (4.03-5.67)	5.61 (4.48-6.49)
60-min	0.624 (0.552-0.716)	0.812 (0.717-0.928)	1.09 (0.967-1.25)	1.33 (1.16-1.51)	1.67 (1.45-1.89)	1.95 (1.67-2.21)	2.25 (1.91-2.56)	2.58 (2.15-2.94)	3.06 (2.50-3.51)	3.47 (2.77-4.02)

Figure 4: NOAA Atlas 14 Rainfall Intensity near Flagstaff, Arizona

Appendix E: Flow Master Analysis for Existing Culvert

Worksheet for Existing Channel - 100 Year Check

Project Description

Friction Method	Manning Formula	
Solve For	Normal Depth	

Input Data

Roughness Coefficient	0.035	
Channel Slope	0.01800	ft/ft
Left Side Slope	0.45	ft/ft (H:V)
Right Side Slope	0.30	ft/ft (H:V)
Bottom Width	2.50	ft
Discharge	42.75	ft³/s

Results

Normal Depth	2.22	ft
Flow Area	7.40	ft²
Wetted Perimeter	7.25	ft
Hydraulic Radius	1.02	ft
Top Width	4.17	ft
Critical Depth	1.89	ft
Critical Slope	0.03059	ft/ft
Velocity	5.77	ft/s
Velocity Head	0.52	ft
Specific Energy	2.74	ft
Froude Number	0.76	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	2.22	ft
Critical Depth	1.89	ft
Channel Slope	0.01800	ft/ft

Worksheet for Existing Channel - 25 Year Check

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.035	
Channel Slope	0.01800	ft/ft
Left Side Slope	0.45	ft/ft (H:V)
Right Side Slope	0.30	ft/ft (H:V)
Bottom Width	2.50	ft
Discharge	25.73	ft³/s

Results

Normal Depth	1.62	ft
Flow Area	5.05	ft²
Wetted Perimeter	5.98	ft
Hydraulic Radius	0.85	ft
Top Width	3.72	ft
Critical Depth	1.38	ft
Critical Slope	0.03014	ft/ft
Velocity	5.09	ft/s
Velocity Head	0.40	ft
Specific Energy	2.03	ft
Froude Number	0.77	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	1.62	ft
Critical Depth	1.38	ft
Channel Slope	0.01800	ft/ft

Worksheet for Existing Channel - 10 Year Check

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.035	
Channel Slope	0.01800	ft/ft
Left Side Slope	0.45	ft/ft (H:V)
Right Side Slope	0.30	ft/ft (H:V)
Bottom Width	2.50	ft
Discharge	25.27	ft³/s

Results

Normal Depth	1.61	ft
Flow Area	4.99	ft²
Wetted Perimeter	5.94	ft
Hydraulic Radius	0.84	ft
Top Width	3.71	ft
Critical Depth	1.37	ft
Critical Slope	0.03012	ft/ft
Velocity	5.07	ft/s
Velocity Head	0.40	ft
Specific Energy	2.01	ft
Froude Number	0.77	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	1.61	ft
Critical Depth	1.37	ft
Channel Slope	0.01800	ft/ft

Appendix G: Flow Master Analysis for Culvert Design

Worksheet for Culvert Design - 100 Year Check

Project Description		
Friction Method	Manning Formula	
Solve For	Normal Depth	

Input Data		
Roughness Coefficient	0.030	
Channel Slope	0.01800	ft/ft
Left Side Slope	0.18	ft/ft (H:V)
Right Side Slope	0.18	ft/ft (H:V)
Discharge	42.75	ft³/s

Results		
Normal Depth	7.01	ft
Flow Area	8.84	ft²
Wetted Perimeter	14.24	ft
Hydraulic Radius	0.62	ft
Top Width	2.52	ft
Critical Depth	5.12	ft
Critical Slope	0.09638	ft/ft
Velocity	4.84	ft/s
Velocity Head	0.36	ft
Specific Energy	7.37	ft
Froude Number	0.46	
Flow Type	Subcritical	

GVF Input Data		
Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data		
Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	7.01	ft
Critical Depth	5.12	ft
Channel Slope	0.01800	ft/ft
Critical Slope	0.09638	ft/ft

Worksheet for Culvert Design - 25 Year Check

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.030	
Channel Slope	0.01800	ft/ft
Left Side Slope	0.18	ft/ft (H:V)
Right Side Slope	0.18	ft/ft (H:V)
Discharge	31.73	ft³/s

Results

Normal Depth	6.27	ft
Flow Area	7.07	ft²
Wetted Perimeter	12.74	ft
Hydraulic Radius	0.56	ft
Top Width	2.26	ft
Critical Depth	4.54	ft
Critical Slope	0.10029	ft/ft
Velocity	4.49	ft/s
Velocity Head	0.31	ft
Specific Energy	6.58	ft
Froude Number	0.45	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	6.27	ft
Critical Depth	4.54	ft
Channel Slope	0.01800	ft/ft
Critical Slope	0.10029	ft/ft

Worksheet for Culvert Design - 10 Year Check

Project Description

Friction Method	Manning Formula
Solve For	Normal Depth

Input Data

Roughness Coefficient	0.030	
Channel Slope	0.01800	ft/ft
Left Side Slope	0.18	ft/ft (H:V)
Right Side Slope	0.18	ft/ft (H:V)
Discharge	25.27	ft³/s

Results

Normal Depth	5.75	ft
Flow Area	5.96	ft²
Wetted Perimeter	11.69	ft
Hydraulic Radius	0.51	ft
Top Width	2.07	ft
Critical Depth	4.15	ft
Critical Slope	0.10338	ft/ft
Velocity	4.24	ft/s
Velocity Head	0.28	ft
Specific Energy	6.03	ft
Froude Number	0.44	
Flow Type	Subcritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Downstream Velocity	Infinity	ft/s
Upstream Velocity	Infinity	ft/s
Normal Depth	5.75	ft
Critical Depth	4.15	ft
Channel Slope	0.01800	ft/ft
Critical Slope	0.10338	ft/ft

Worksheet for Grate Inlet On Grade

Project Description

Solve For	Efficiency	

Input Data

Discharge	1.47	ft³/s
Slope	0.01867	ft/ft
Gutter Width	14.00	ft
Gutter Cross Slope	0.20	ft/ft
Road Cross Slope	0.20	ft/ft
Roughness Coefficient	0.030	
Grate Width	3.38	ft
Grate Length	2.45	ft
Grate Type	P-50 mm x 100 mm (P-1-7/8"-4")	
Clogging	50.00	%

Options

Grate Flow Option	Exclude None	

Results

Efficiency	100.00	%
Intercepted Flow	1.47	ft³/s
Bypass Flow	0.00	ft³/s
Spread	2.22	ft
Depth	0.44	ft
Flow Area	0.49	ft²
Gutter Depression	0.00	ft
Total Depression	0.00	ft
Velocity	2.97	ft/s
Splash Over Velocity	3.36	ft/s
Frontal Flow Factor	1.00	
Side Flow Factor	0.23	
Grate Flow Ratio	1.00	
Active Grate Length	1.23	ft

Messages

Messages	Grate Length should be within the defined range of HEC-22's Chart 5 (approx. 0.5-4.5 ft / 0.15-1.35 m).

Worksheet for Grate Inlet In Sag

Project Description

Solve For	Spread

Input Data

Discharge	13.74	ft³/s
Gutter Width	18.00	ft
Gutter Cross Slope	0.02	ft/ft
Road Cross Slope	0.02	ft/ft
Grate Width	10.00	ft
Grate Length	20.00	ft
Local Depression	0.00	in
Local Depression Width	0.00	ft
Grate Type	P-50 mm (P-1-7/8")	
Clogging	50.00	%

Results

Spread	22.52	ft
Depth	0.45	ft
Gutter Depression	0.00	ft
Total Depression	0.00	ft
Open Grate Area	90.00	ft²
Active Grate Weir Length	30.00	ft

Worksheet for Pipe Analysis

Project Description

Friction Method	Manning Formula
Solve For	Full Flow Diameter

Input Data

Roughness Coefficient	0.010	
Channel Slope	0.01870	ft/ft
Normal Depth	1.32	ft
Diameter	1.32	ft
Discharge	13.37	ft³/s

Results

Diameter	1.32	ft
Normal Depth	1.32	ft
Flow Area	1.38	ft²
Wetted Perimeter	4.16	ft
Hydraulic Radius	0.33	ft
Top Width	0.00	ft
Critical Depth	1.28	ft
Percent Full	100.0	%
Critical Slope	0.01647	ft/ft
Velocity	9.72	ft/s
Velocity Head	1.47	ft
Specific Energy	2.79	ft
Froude Number	0.00	
Maximum Discharge	14.38	ft³/s
Discharge Full	13.36	ft³/s
Slope Full	0.01872	ft/ft
Flow Type	SubCritical	

GVF Input Data

Downstream Depth	0.00	ft
Length	0.00	ft
Number Of Steps	0	

GVF Output Data

Upstream Depth	0.00	ft
Profile Description		
Profile Headloss	0.00	ft
Average End Depth Over Rise	0.00	%

Appendix I: Grate Inlet Type F