CORDOVA FISH PASSAGE IMPROVEMENTS COP 9 AND SHER 1

Draft Hydrologic and Hydraulic Report

Cordova, Alaska

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ACRONYMS

ADF&G ..... Alaska Department of Fish and Game
AWC ..... Anadromous Waters Catalog
cfs ..... cubic feet per second
CRWP ..... Copper River Watershed Project
FPID ..... Fish Passage Inventory Database
fps ..... feet per second
HW/D ..... headwater-to-depth ratio
mm ..... millimeters
NOAA ..... National Oceanic and Atmospheric Administration
OHW ..... ordinary high water
ROW ..... right-of-way
USDA ..... United States Department of Agriculture
USFWS ..... United States Fish and Wildlife Service
USFS ..... United States Forest Service
USGS ..... United States Geological Survey

1.0 INTRODUCTION

1.1 Objective

The objective of this project is to design two culvert replacements for two fish passage sites in the Copper River Delta near Cordova, Alaska. The replacement culverts will improve fish passage and ecologic function at the road crossings of Sheridan River Tributary by simulating the natural creek channel and provide conveyance of at least the 100-year flood flow. The culverts will also enhance maintenance conditions at each crossing and reduce the likelihood of future infrastructure damage caused by flooding along the road. The Sheridan River Tributary is an anadromous stream that flows south to Sheridan River. The Copper River Watershed and Delta is a system of relic channels, connected upstream and downstream, with base flows that are continuously changing over time. The project crossing drainage basin is shown in Figure 1.

The Sheridan River Tributary stream crossings have been identified as No. 20100475 (COP 9) and No. 20101903 (SHER 1) in the FPID. COP 9 has been given a Green rating and SHER 1 has been given a Red rating. These crossings have been identified by ADF&G, United States Fish and Wildlife Service (USFWS), Copper River Watershed Project (CRWP), United States Forest Service (USFS), and the National Oceanic and Atmospheric Administration (NOAA) as an impediment and barrier to upstream fish migration as well as causing disruption to the Delta's hydrology, reducing its ecological function.

To meet project objectives, a topographic survey of the project area was completed to facilitate hydraulic modeling. A geomorphic analysis was used to assess sediment transport and incorporate natural channel characteristics into the design. A geotechnical analysis, completed in April 2019 by others, was used to investigate subsurface soil conditions at the four crossings. Design alternatives were evaluated to determine the most economical means of replacing the existing structures to improve ecological function and flood conveyance.

1.2 Existing Conditions

SHER 1 is located on Goat Camp Road, upstream of COP 9. The existing culvert at SHER 1 is 1.5 feet in diameter and 54 feet long. The culvert has a gradient of 2% and a constriction ratio of 0.11. The existing culvert is backwatered and fully submerged. SHER 1 was given an overall fish passage rating of Red in 2011 by ADF&G. There is an old, damaged 8-foot pipe located north of the SHER 1 crossing on Goat Camp Road that is not in use.

COP 9 is located on the Copper River Highway, downstream of SHER 1. The existing culvert at COP 9 is 4 feet in diameter and 65 feet long. The culvert has a gradient of 1% and a constriction ratio 0.35. Corrosion has been observed on the existing culvert with a rust line of 1.9 feet. There is riprap placed within the culvert. The culvert was given an overall fish passage rating of Green in 2011 by ADF&G.

Figure 1: COP 9 and SHER 1 Drainage Basin

1.3 Design Criteria

The geomorphic analog method is the preferred design approaches for the SHER 1 and COP 9 crossings of the Sheridan River Tributary. The design of the proposed fish passage culverts is based on criteria and guidelines contained in the USFWS *Fish Passage Design Guidelines (Revision 6)* released June 2021, which follows the United States Forest Service (USFS) stream simulation approach with modifications. The USFS stream simulation approach is described in the 2008 *Stream Simulation: An Ecological Approach to Providing Passage for Aquatic Organisms at Road-Stream Crossings*. Key criteria from the sources include:

- The constructed channel within the crossing shall not differ from the reference reach condition under normal flow conditions regarding channel width, cross-sectional area, gradient, substrate, and ability to pass floating debris;
- The culvert width shall be at least 1.0 times bankfull width, with a minimum diameter of 5 feet;
- The embedment depth shall be the greater of 40 percent of the diameter or two feet for circular culverts;
- Embedment depth shall be the greater of 20 percent of the rise or two feet for all other culverts;
- Substrate material within the crossing shall be dynamically stable up to and including the 50-year flood;
- Stream banks inside the culvert shall be stable up to and including the 100-year flood;
- A continuous low flow channel that simulates the reference reach shall be incorporated in the substrate material;
- Culvert gradient shall be within 25% of the natural channel grade;
- Culverts shall be corrugated.
- Structures shall be designed to accommodate at least the 100-year flood flow, preferably with a headwater-to-depth (HW/D) ratio of 0.8.

1.4 Right-of-Way and Utilities

The Copper River Highway is owned by Alaska Department of Transportation and Public Facilities. The Copper River Highway is centered within a 200-foot-wide right-of-way (ROW).

A fiber optic vault is located south of the Copper River Highway near the intersection with Goat Camp Road and south of the SHER 1 crossing. A fiber optic line runs along the south side of the Copper River Highway under COP 9 and SHER 1 crossings. The line is at approximately 41.5’ El at COP 9 and 56.0’ at SHER 1. The fiber optic lines enter the utility vault at a 45-degree angle. Cordova Telephone Cooperative has been contacted regarding the crossings and potential reburial of the line for the SHER 1 crossing.

2.0 GEOTECHNICAL CONDITIONS

A geotechnical investigation consisting of two borings at each crossing was conducted at the two fish passage crossing locations by Northern Geotechnical Engineering, Inc. in April 2019. The geotechnical report for USFWS Fish Passage Improvements was completed by Northern

Geotechnical Engineering, Inc. The subsurface conditions, soil bearing capacity, and site-specific geotechnical construction recommendations are summarized below.

2.1 SHER 1

2.1.1 North

- 0 to 7 feet: Well graded sand with silt and gravel. Groundwater encountered at approximately 6.5 feet.
- 7 to 9.5 feet: Silty sand.
- 9.5 to 13 feet: Poorly graded sand with gravel.
- 13 to 15: Silty sand.
- 15 to 21.5 feet: Poorly graded sand.

2.1.2 Soil Bearing Capacity

The allowable soil bearing capacity of 3,900 pounds per square foot may be used for a box culvert foundation on undisturbed sand and gravel or compacted structural fill.

2.1.3 Construction Recommendations

Site bearing soils approximately 11 to 12 feet below the road surface consist of loose poorly graded sand with silt and gravel. Excavation is required a minimum of 2 feet below the bottom of the culvert. Then placement of geotextile, reinforcement, type 2 and Subbase, Grading F material is required, as described Section 2.4.

2.2 COP 9

2.2.1 Upstream

- 0 to 4.5 feet: Poorly graded gravel with sand.
- 4.5 to 9.5 feet: Poorly graded sand with silt and gravel. Groundwater encountered at approximately 7 feet.
- 9.5 to 12 feet: Well graded gravel with silt and sand.
- 12 to 14.5 feet: Poorly graded sand with gravel.
- 14.5 feet to 21.5: Sandy silt.

2.2.2 Downstream

- 0 to 12 feet: Well graded gravel with silt and sand. Groundwater encountered at approximately 9 feet.
- 12 feet to 21.5: Silty sand.

2.2.3 Soil Bearing Capacity

The allowable soil bearing capacity of 3,900 pounds per square foot may be used for a box culvert foundation on undisturbed sand and gravel or compacted structural fill.

2.2.4 Construction Recommendations

Site bearing soils approximately 13 to 15 feet below the road surface consist of loose to medium dense silty sand to sandy silt. Excavation is required a minimum of 2 feet below the bottom of the culvert. Then placement of geotextile, reinforcement, type 2 and Subbase, Grading F material is required, as described Section 2.4.

2.3 Summary

Additional recommendations provided in the geotechnical report include using culvert embedment material Subbase, Grading F, extended one foot below the bottom of the culvert, 18 inches to both sides of the culvert, and a minimum of one foot above the culvert. A layer of geotextile, reinforcement, type 2 should be placed between the Subbase, Grading F material and the native soil or Type A material. A layer of geotextile, reinforcement, type 2 should be placed between each one-foot layer of Subbase, Grading F material.

3.0 GEOMORPHIC ANALYSIS

A site investigation was conducted on July 20 through 23, 2021. During the site visit, DOWL engineers took channel measurements, conducted pebble counts, and observed bedform features. The reconnaissance-level map, field notes, and pebble count data from the site investigation are included in Appendix A. DOWL engineers and United States Fish and Wildlife revisited the site on August 2nd and 3rd to take discharge measurements and bankfull width dimensions.

3.1 Stream Morphology and Crossing Characteristics

3.1.1 SHER 1

The Sheridan River tributary flowing to the SHER 1 crossing originates in the marsh-wetlands southeast of the Sheridan River.

Upstream of the Goat Camp Road crossing, the Sheridan River tributary is a meandering stream. The predominant bedform features consist of slow, long pools with riffle sections, and areas of split flow and ponded water. Upstream is low gradient and heavily wooded with grassland. The stream substrate consists of fine to very course gravel with areas of organics. Riparian vegetation includes grasses, moss, fern, alder, and willow. The floodplain is wide and unconfined. A beaver pond (old gravel pit) is located approximately 525 feet upstream of the SHER 1 crossing.

Downstream of the SHER 1 Goat Camp Road crossing, the Sheridan River tributary currently follows the Copper River Highway and flows into COP 9. The stream flows through a marsh area and the predominant bedform features consist of riffles and pools. Bank instability is indicated by several vegetated bars within the channel. The stream substrate consists of very fine to very coarse gravel with sections of sand and organics. It is a stable, low energy system. Riparian vegetation includes grasses, moss, fern, alder, and willow.

The proposed SHER 1 crossing is located 30 feet east of Goat Camp Road along the Copper River Highway. Downstream of the proposed SHER 1 crossing the stream will flow southwest and empties into a pond (old gravel pit) approximately 1000 feet downstream of the crossing.

The downstream channels predominant bedform features consist of riffles and pools with ponded marsh areas. The downstream channel is low gradient and banks are present at varying locations, vegetated with ferns and alders.

A reference reach was defined approximately 300 feet upstream of the Goat Camp Road crossing. Observed bankfull width ranged from 10.5 to 11.5 feet, with the bankfull depth ranging from 6 to 13 inches. The average channel slope is approximately 0.5 percent. Riffles and pools provide grade controls along the longitudinal profile and predominantly consist of gravel/ cobbles and woody debris. Sediment transport is low upstream and downstream of the crossing. A second reach was also reviewed directly downstream of the proposed SHER 1 crossing. Bankfull widths downstream of the proposed crossing ranged from 7.5 to 9.7 feet.

The observed stream characteristics of Sheridan River Tributary at SHER 1 are summarized in Table 1.

Table 1: Stream Characteristics of Sheridan River Tributary at SHER 1

Stream Parameter	Existing Conditions
Slope	0.5 percent
Measured Bankfull Width	7.5 to 11.5 feet
Measured Bankfull Depth	6 to 13+/- inches
Bedform Features	Riffle-Pools

The Goat Camp Road roadway embankment at SHER 02 is partially vegetated and eroding at the inlets and outlets. No end sections or headwalls are present at the SHER 1 culvert and the culvert is fully submerged, crushed, and corroded. There is approximately 5 feet of roadway cover over the existing culvert.

3.1.2 COP 9

The Sheridan River Tributary flowing to the COP 9 crossing originates in the marsh-wetlands southeast of the Sheridan River and crosses Goat Camp Road at the SHER 1 crossing. The Sheridan River Tributary follows the Copper River Highway and flows into COP 9. Additional water flows into the Sheridan River Tributary approximately 260 feet upstream of the COP 9 crossing and approximately 290 feet downstream of the SHER 1 crossing. The additional flow comes from a large, ponded marsh-wetland northeast of the crossing.

Upstream of the COP 9 Copper River Highway crossing, Sheridan River Tributary flows through a marsh area and the predominant bedform features consist of riffles and pools. Bank instability is indicated by several vegetated bars within the channel. The stream substrate consists of very fine to very coarse gravel with sections of sand and organics. It is a stable, low energy system. Riparian vegetation includes grasses, moss, fern, alder, and willow.

Downstream of the COP 9 Copper River Highway crossing, Sheridan River Tributary flows southwest and empties into a pond (old gravel pit) approximately 600 feet downstream of the crossing. The predominant bedform features consist of riffles and pools with ponded marsh areas. Downstream is low gradient and banks are present at varying locations, vegetated with ferns and alders. The stream substrate consists of very fine to very coarse gravel with sections of organics. Riparian vegetation includes grasses, moss, fern, alder, and willow. The floodplain is wide.

A reference reach was defined approximately 300 feet downstream of the Copper River Highway crossing. Observed bankfull widths ranged from 9.5 to 17 feet, with the bankfull depth ranging from 10 to 15 inches. The average channel slope is approximately 0.5 percent. Riffles and pools provide grade control along the longitudinal profile and predominantly rock formed, consisting of gravel and woody debris. Sediment transport is low upstream and downstream of the crossing.

The observed stream characteristics of Sheridan River Tributary at COP 9 are summarized in Table 2.

Table 2: Stream Characteristics of Sheridan River Tributary at COP 9

Stream Parameter	Existing Conditions
Slope	0.5 percent
Measured Bankfull Width	9.5 to 17 feet
Measured Bankfull Depth	10 to 15+/- inches
Bedform Features	Riffle-Pools

The Copper River Highway roadway embankment at COP 9 is well vegetated. No end sections or headwalls are present at the Sheridan River Tributary COP 9 culvert. There is approximately 4 feet of roadway cover over the existing culvert.

3.2 Substrate Analysis

Pebble counts were completed on July 21 and 22, 2021. The D_{84} particle represents that size of which 84 percent of the streambed particles are expected to be smaller in size and is typically used as the basis for sizing rock that is only transported downstream during large flood events. Visual observations in the vicinity of the crossings agree with the pebble count results.

3.2.1 SHER 1

Three pebble counts were conducted at SHER 1. Pebble count 1 was performed 400 feet upstream of the crossing, pebble count 2 was performed 350 feet upstream of the crossing, and pebble count 3 was performed 35 feet downstream of the crossing. The average D_{84} particle size at SHER 1 was 46.7 mm. The armor layer at the SHER 1 crossing was found to range from very fine gravel to small cobble, with most of the stream substrate consisting of medium to very

coarse gravel. A summary of the pebble counts is shown in Figure 2 and Table 3.

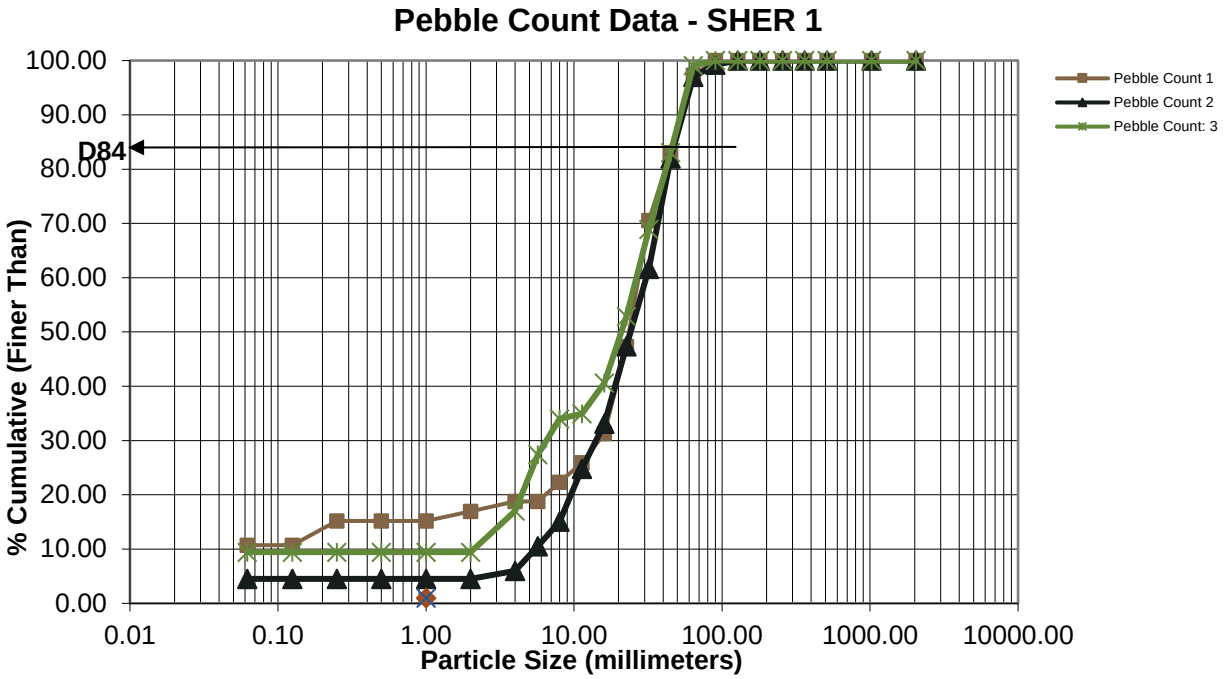


Figure 2: Summary of SHER 1 Pebble Counts

For stream substrate design, a stream bed mix will be specified based on the particle size distribution of the natural substrate observed onsite and to mitigate entrainment of bed material during Q_{100} flows. This will allow for natural sediment transport through the proposed culvert. The Fuller-Thompson equations will be used to size particles smaller than the D_{50} to provide adequate fines to fill voids and seal the simulation stream bed. Substrate design is included in Appendix B.

Table 3: SHER 1 Pebble Count Summary

Particle Size	Count 1	Count 2	Count 3
	400 feet Upstream	350 feet Upstream	35 feet Downstream
D_{100} (mm)	90	128	90
D_{84} (mm)	46.3	47.6	46.2
D_{50} (mm)	23.7	24.3	21.1

3.2.2 COP 9

Three pebble counts were conducted at COP 9. The pebble counts were performed at the three surveyed cross section locations. Pebble count 1 was performed 100 feet upstream of the crossing, pebble count 2 was performed 420 feet downstream of the crossing, and pebble count 3 was performed 365 feet downstream of the crossing. The average D_{84} particle size at COP 33 was 49.5 mm. The armor layer at the COP 33 crossing was found to range from very fine gravel

to small cobble, with most of the stream substrate consisting of medium to very coarse gravel. A summary of the pebble counts is shown in Figure 3 and Table 4.

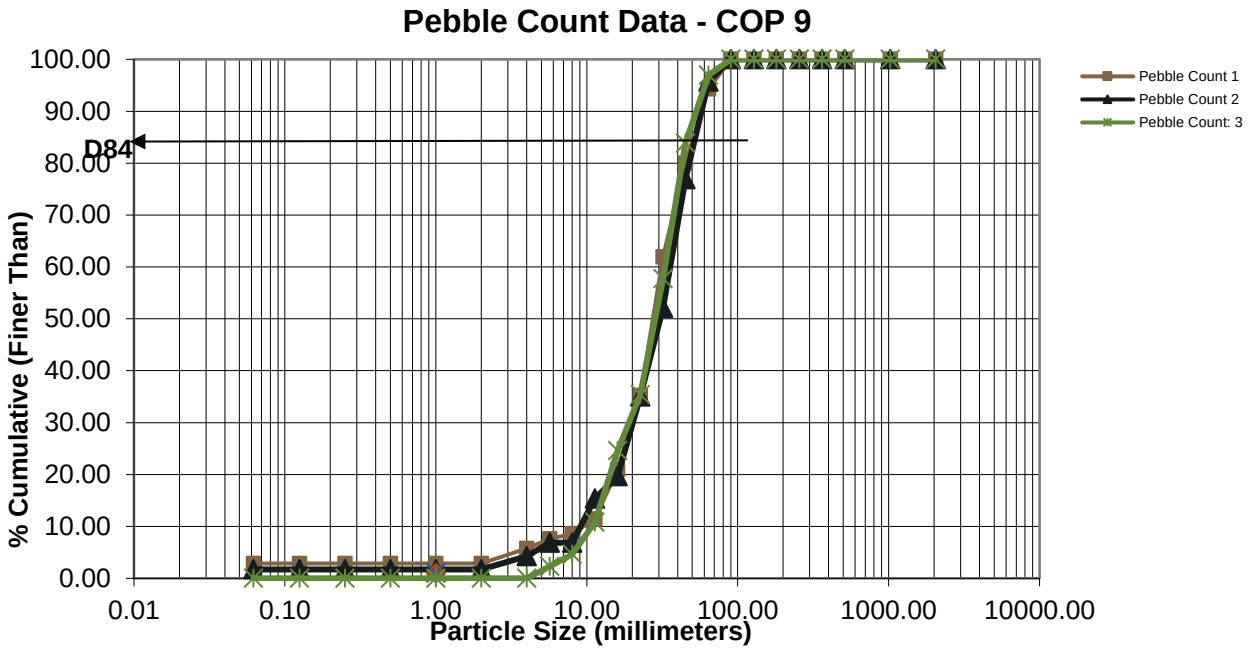


Figure 3: Summary of COP 9 Pebble Counts

For stream substrate design, a stream bed mix will be specified based on the particle size distribution of the natural substrate observed onsite and to mitigate entrainment of bed material during Q_{100} flows. This will allow for natural sediment transport through the proposed culvert. The Fuller-Thompson equations will be used to size particles smaller than the D_{50} to provide adequate fines to fill voids and seal the simulation stream bed. Substrate design is included in Appendix B.

Table 4: COP 9 Pebble Count Summary

Particle Size	Count 1	Count 2	Count 3
	100 feet Upstream	420 feet Downstream	365 feet Downstream
D_{100} (mm)	90	90	90
D_{84} (mm)	50.3	52.2	45.2
D_{50} (mm)	27.8	30.8	28.8

4.0 HYDROLOGIC ANALYSIS

4.1 Drainage Area Characteristics

The Sheridan River Tributary COP 9 and SHER 1 drainage basin flowing to Goat Camp Road and the Copper River Highway is approximately 438 acres (0.69 square miles) in size. The drainage basin is undeveloped and consists of wetlands, ponds (old gravel pits), and forested area within the glacial outwash area.

4.2 Methodology

Two methods of quantifying flow were compared to identify the most appropriate design discharge likely experienced by the crossings. Cordova's interconnected floodplain hydrology is difficult to accurately capture using the USGS regional regression equations. For these crossings, the flow estimates derived from the regression equations were supplemented by flow estimates derived from stage-discharge measurements at COP 9 completed by the USFWS.

The 2003 and the 2016 Regional Regression Equations were used to estimate peak discharges for the Sheridan River Tributary crossings. The 2016 Regional Regression Equations, published by the United States Geological Survey (USGS) in the Scientific Investigations Report 2016-5024, were used to estimate peak discharges for both crossings. The USGS PRISM data for the drainage areas was used to find a mean annual precipitation value of 106.28 inches for COP 9 and SHER 1. The drainage basin for COP 9 and SHER 1 is within the 0.4 square mile lower limit area and 1,000 square mile upper limit area and the annual precipitation is within the range of 8 to 280 inches on which the regression equations were developed. Therefore, the regression equations are expected to return reasonable flow estimates. Results of the 2016 Regional Regression Equations were compared to the results of the 2003 USGS Regional Regression Equations published by the USGS in Water-Resources Investigations Report 03-4188. For the 2003 USGS Regional Regression Equations, drainage basin areas, surface storage, and mean annual precipitation data were input into empirically derived equations to predict peak flow for varying recurrence intervals. A mean annual precipitation of 180 inches and a mean minimum January temperature of 16 degrees Fahrenheit was used for this analysis, as estimated from Plate 1 and 2 of the USGS publication Water-Resources Investigations Report 93-4179 Magnitude and Frequency of Floods in Alaska and Conterminous Basins of Canada (Jones & Fahl, 1994) in accordance with procedures listed in WRI 03-4188. The drainage area, temperature and storage percentage for both basins are within the acceptable range of variables for input. The 2003 USGS mean annual precipitation of 180 inches based on plate 2 is higher than 106.28 inches from the USGS PRISM data. Mean annual precipitation averages from three NOAA gages in Cordova range from 86.18 inches to 168.64 inches. The USGS Regional Regression Equation computations are included in Appendix C.

The stage was measured at COP 9 for two years. Flow measurements taken in the field by CRWP and USFS to generate stage-discharge relationships for the gauges and were correlated to the USGS Glacier Tributary gauge. A log-Pearson Type III analysis was conducted to estimate the flood frequency of the respective systems.

4.3 Results of Flood Flow Analysis

4.3.1 SHER 1 and COP 9

The peak runoff flows for each analysis method for SHER 1 and COP 9 are shown in Table 5.

Table 5: Estimated Peak Flows for SHER 1 and COP 9

Storm Event (year)	2016 Regional Regression (cfs)	2003 Regional Regression (cfs)	LPIII Flood Frequency Estimate (cfs)
2	81.4	110.0	18.3
5	131.0	145.0	24.0
10	169.0	170.0	27.4
25	221.0	201.0.	31.5
50	261.0	224.0	34.4
100	305.0	246.0	37.1

Notes: cfs = cubic feet per second

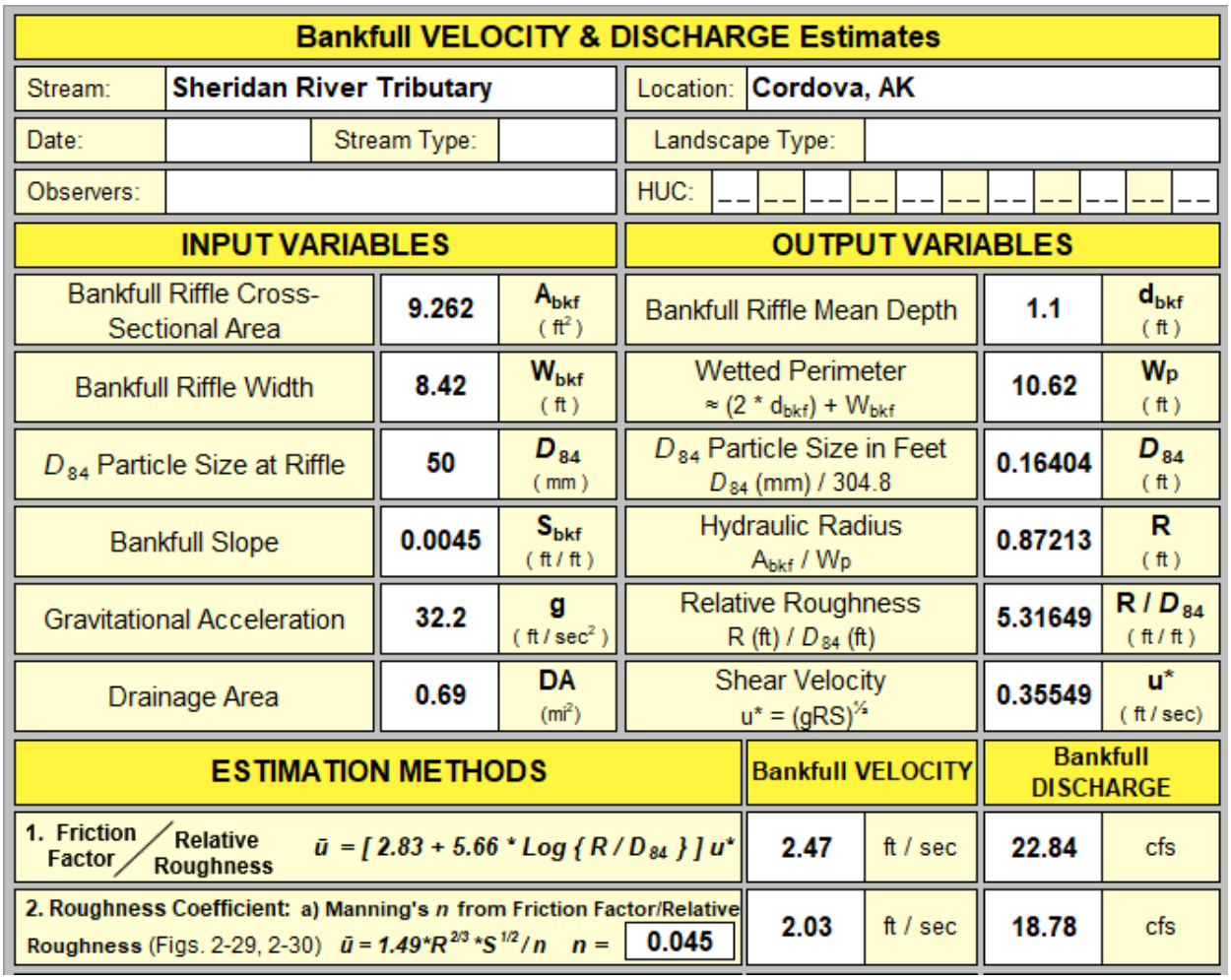
The flow estimates derived from measured stage at the site is significantly lower than the USGS regression equation estimates. The flow estimates based on measured stage appear to match observations made during the July 2021 site visits. Given the observations at site and size of the contributing basin, it appears that log-Pearson Type III estimates are appropriate to size the rehabilitated channel section.

Per the criteria identified in the project objectives, culverts for SHER 1 and COP 9 have been evaluated for hydraulic capacity based on the 100-year peak flow of 37.1 cubic feet per second (cfs). The Copper River Delta is a dynamic system and flow routing upstream across Goat Camp Road can shift over time supplying disproportionate flow to either COP 9 and/ or SHER 1. As such COP 9 and SHER 1 were evaluated under two scenarios. Scenario 1; Watershed is evenly split to each culvert. (50% Q100=18.3). Scenario 2; Entire watershed is directed to a single culvert (Q100=37.1). Results of the HY-8 analyses for the proposed culvert options are included in Section 7.0 Recommendations.

5.0 HYDRAULIC ANALYSIS

5.1 Bankfull Velocity and Discharge Estimates

The bankfull discharge and velocity were calculated for the measured cross section based on the cross section hydraulic dimensions, bankfull slope, and Manning's Equation using the River Stability Field Guide worksheets to check that average bankfull velocity is between 2.5 to 5 feet per second (fps) and that the bankfull discharge is close to the 2-year flood flow. Calculated bankfull velocity and discharge from the worksheet is shown below and based on guidance from the USFWS *Fish Passage Design Guidelines (Revision 6).* River Stability Field Guide worksheets are included in Appendix D.



Bankfull VELOCITY & DISCHARGE Estimates

Stream:	Sheridan River Tributary	Location:	Cordova, AK
Date:		Stream Type:	
Observers:		Landscape Type:	
		HUC:	__ __ __ __ __ __ __ __ __ __ __ __

INPUT VARIABLES			OUTPUT VARIABLES		
Bankfull Riffle Cross-Sectional Area	9.262	A_{bkf} (ft^2)	Bankfull Riffle Mean Depth	1.1	d_{bkf} (ft)
Bankfull Riffle Width	8.42	W_{bkf} (ft)	Wetted Perimeter ≈ (2 * d_{bkf}) + W_{bkf}	10.62	W_p (ft)
D_{84} Particle Size at Riffle	50	D_{84} (mm)	D_{84} Particle Size in Feet D_{84} (mm) / 304.8	0.16404	D_{84} (ft)
Bankfull Slope	0.0045	S_{bkf} (ft / ft)	Hydraulic Radius A_{bkf} / W_p	0.87213	R (ft)
Gravitational Acceleration	32.2	g (ft / sec^2)	Relative Roughness R (ft) / D_{84} (ft)	5.31649	R / D_{84} (ft / ft)
Drainage Area	0.69	DA (mi^2)	Shear Velocity $u^* = (gRS)^{½}$	0.35549	u^* (ft / sec)

ESTIMATION METHODS	Bankfull VELOCITY		Bankfull DISCHARGE	
1. Friction Factor / Relative Roughness $\bar{u} = [\,2.83 + 5.66 * Log\{ R / D_{84} \}\,] u^*$	2.47	ft / sec	22.84	cfs
2. Roughness Coefficient: a) Manning's n from Friction Factor/Relative Roughness (Figs. 2-29, 2-30) $\bar{u} = 1.49 R^{2/3} S^{1/2} / n$ $n =$ 0.045	2.03	ft / sec	18.78	cfs

Figure 4: SHER 1 Bankfull velocity and discharge estimates

At SHER 1 an 8.42-foot bankfull riffle width, 1.1-foot depth resulted in the calculated 18.78 cfs and 22.84 cfs bankfull discharge for the crossings which is between the 2 and 5-year storm event for the estimated peak flows (Figure 4). At COP 9 an 8.42-foot bankfull riffle width, 1.3-foot depth resulted in the calculated 24.20 cfs and 30.14 bankfull discharge for the crossings which is between the 5 and 25-year storm event for the estimated peak flows.

5.2 HY-8 Analysis

The Federal Highway Administration's HY-8 software was used for the hydraulic analysis of proposed culverts. The software was used to model the hydraulic capacity at the 2-year, 50-year and 100-year flow and calculate the overtopping flow. Results of the HY-8 analyses for the proposed culvert options are included in Section 7.0 Recommendations. Structures were selected for analysis based on span dictated by the measured bankfull widths, watershed split flows and HW/D ratios.

5.3 Low Flow Channel

5.3.1 COP 9 and SHER 1

The low-flow channels for the COP 9 and SHER 1 crossings were calculated based on guidance from the USFWS *Fish Passage Design Guidelines (Revision 6)*. A “V” shaped thalweg with a cross-sectional area of 15 to 30 percent of the bankfull cross-sectional area and a minimum depth of four inches for small streams and up to twelve inches for larger streams was used for design of the low-flow channels.

6.0 DESIGN ALTERNATIVES

Design guidelines recommend that culvert span for proposed replacement structures should be at least 1.0 times bankfull width. One of the main design parameters in the analysis of design options is the HW/D: a numerical representation of the depth of the water (headwater depth) at the culvert inlet to the height (depth) of the culvert relative to the stream bed. For stream simulation design, a HW/D of 0.8 or less is desirable when economically reasonable to reduce the likelihood for scour of bed material within the culvert during flood events and to provide freeboard for passing debris during flood events. A combination of measured bankfull information and HW/D ratios was used to determine acceptable structures for the crossings.

Several replacement alternatives have been evaluated including various aluminum pipe arch culvert sizes at COP 9 and SHER 1. Applicable culvert shapes for each crossing were determined with consideration given to groundwater elevations and available cover over the pipe.

Aluminum and steel structural pipe arch and round culvert options were considered, as well as aluminum and aluminized steel corrugated pipe arch and round culverts.

Culvert replacement options considered for COP 9 and SHER 1 include:

- 6-foot, round aluminum culvert embedded 2.0 feet. Approx. (Q100 HW/D=0.72)
- An 8-foot, 5-inch span by 6-foot, 3-inch rise aluminum box culvert embedded 2.0 feet Approx. (Q100 HW/D=0.68),
- A 9-foot, round aluminum culvert embedded 3.0 feet. Approx. (Q100 HW/D=0.58)
- A 10-foot, 11-inch span by 6-foot, 4-inch rise aluminum box culvert embedded 2.6 feet Approx. (Q100 HW/D=0.43),
- A 12-foot, 1-inch span by 6-foot, 7-inch rise aluminum box culvert embedded 2.6 feet Approx. (Q100 HW/D=0.37),
- A 13-foot, 3-inch span by 6-foot, 9-inch rise aluminum box culvert embedded 2.8 feet Approx. (Q100 HW/D=0.32), and
- A 15-foot, 4-inch span by 6-foot, 5-inch rise aluminum box culvert embedded 2.6 feet Approx. (Q100 HW/D=0.31).

7.0 RECOMMENDATIONS

7.1.1 SHER 1

Replacing the crushed culverts at the Goat Camp Road crossing with an 8-foot, 5-inch span by 6-foot, 3-inch rise aluminum pipe arch culvert is recommended to improve fish passage, increase watershed connectivity and flood conveyance. It is recommended that the culvert be relocated to span the Copper River Highway 30 feet to the east of Goat Camp Road.

This replacement option is anticipated to convey the Q_{100} of 37.1 cfs and the Q_{50} of 34.4 cfs from Scenario 2 with a HW/D ratio of approximately 0.68 and 0.58, respectively. The pipe arch culvert will be embedded 2.0 feet. Minimum allowable cover over the culvert is 2 feet and maximum allowable cover over the culvert is 16 feet. Roadway overtopping would occur at a flow of approximately 190 cfs.

Table 6: Estimated HW/D for SHER 1

Scenario	Storm Event	LPIII Flood Frequency Estimate (cfs)	Depth	HW/D
Scenario 1	2-Year	9.2	1.3	0.52
Scenario 1	50-Year	17.2	1.6	0.57
Scenario 1	100-year	18.6	1.7	0.58
Scenario 2	2-Year	18.3	1.7	0.58
Scenario 2	50-Year	34.4	2.2	0.67
Scenario 2	100-year	37.1	2.3	0.68

Notes: Scenario 1: Watershed is evenly split to each culvert.
Scenario 2: Watershed is directed to single culvert.

The recommended culvert meets the criteria to accommodate the theoretical 100-year flood flow with a HW/D ratio of less than 0.8. The capacity calculations for the culvert assume that all runoff upstream of the culvert is conveyed however, due to the ephemeral nature of the upstream floodplain, it is anticipated that the upstream banks will overtop and utilize floodplain storage before the HW/D reaches 0.68. No overtopping of the existing culvert has been noted during storm events, inferring that upstream storage and flow rerouting or storage of runoff upstream of COP 9 occurs. No reconstructed stream banks on each side of the channel will be placed in this pipe due to the shallow grade of the system. The culvert will be embedded with waterway bed material to mimic natural substrate. The simulated stream channel inside will be constructed as a roughened riffle. Reconstructed stream banks upstream and downstream from the culvert will consist of vegetated mats. The embankment slopes will be stabilized with Class I riprap to provide erosion protection.

An aluminum pipe was selected due to the higher corrosion resistance and longevity, ease of construction, low cost, and availability.

Table 7: Ratio of Culvert Width to Bankfull Width

Culvert Width	8-foot, 5-inch
Bankfull Width	7.5 feet
Ratio	1.1

7.1.2 COP 9

Replacing the 4-foot diameter round culvert at the COP 9 Copper River Highway crossing with an 8-foot, 5-inch span by 6-foot, 3-inch rise aluminum pipe arch culvert is the recommended option for improving fish passage and flood conveyance at the Copper River Highway crossing.

This replacement option is anticipated to convey the Q_{100} of 37.1 cfs and the Q_{50} of 34.4 cfs from Scenario 2 with a HW/D ratio of approximately 0.68 and 0.58, respectively. The pipe arch culvert will be embedded 2.0 feet. Minimum allowable cover over the culvert is approximately 2 feet and maximum allowable cover over the culvert is approximately 16 feet. Roadway overtopping would occur at a flow of approximately 210 cfs.

Table 8: Estimated HW/D for COP 9

Scenario	Storm Event	LPIII Flood Frequency Estimate (cfs)	Depth	HW/D
Scenario 1	2-Year	9.2	1.3	0.52
Scenario 1	50-Year	17.2	1.6	0.58
Scenario 1	100-year	18.6	1.7	0.59
Scenario 2	2-Year	18.3	1.7	0.59
Scenario 2	50-Year	34.4	2.2	0.67
Scenario 2	100-year	37.1	2.3	0.69

Notes: Scenario 1: Watershed is evenly split to each culvert.
Scenario 2: Watershed is directed to single culvert.

The recommended culvert meets the criteria to accommodate the theoretical 100-year flood flow with a HW/D ratio of less than 0.8. The capacity calculations for the culvert assume that all runoff upstream of the culvert is conveyed however, due to the ephemeral nature of the upstream floodplain, it is anticipated that the upstream banks will overtop and utilize floodplain storage before the HW/D reaches 0.68. No overtopping of the existing culvert has been noted during storm events, inferring that upstream storage and flow rerouting or storage of runoff

upstream of COP 9 occurs. No reconstructed stream banks on each side of the channel will be placed in this pipe due to the shallow grade of the system. The culvert will be embedded with waterway bed material to mimic natural substrate. The simulated stream channel inside will be constructed as a roughened riffle. Reconstructed stream banks upstream and downstream from the culvert will consist of vegetated mats. The embankment slopes will be stabilized with Class I riprap to provide erosion protection.

An aluminum pipe was selected due to the higher corrosion resistance and longevity, ease of construction, low cost, and availability.

Adjusting the SHER 1 culvert to provide more watershed connectivity across the Copper River Highway will improve the conveyance of the system and provide a more natural flow path. By redirecting flow from SHER 1 across the Copper River Highway, COP 9 will receive less flow than current conditions. COP 9 is designed assuming that the current hydrologic conditions will change. Bankfull indicators were not present in the wetland complexes upstream of the COP 9 culvert, therefore bankfull widths were taken downstream of the culvert, which include the SHER 1 flow. The culvert width to bankfull width ratio is less than the recommended minimum of 1.0 (Table 9). The reference reach bankfull width may not be representative of future conditions after construction (to exclude the SHER 1 flow). This criterion was reviewed but not used for the COP 9 design.

Table 9: Ratio of Culvert Width to Bankfull Width

Culvert Width	8-foot, 5-inch
Bankfull Width	9.5 feet
Ratio	0.9

7.2 Rejected Alternatives

7.2.1 SHER 1 and COP 9

An aluminum structure is recommended over steel due to the lower weight of material, higher corrosion resistance and the potential for faster installation reducing the traffic restrictions on the Copper River Highway. All steel structures were eliminated from the designs.

SHER 1 and COP 9 both considered the 10-foot, 11-inch span by 6-foot, 4-inch rise aluminum box culvert embedded 2.6 feet, the 13-foot, 1-inch span by 6-foot, 9-inch rise aluminum box culvert embedded 2.6 feet, and the 15-foot, 0-inch span by 6-foot, 7-inch rise aluminum pipe arch embedded 2.6 feet but were eliminated due to HW/D ratio.

Round structures were considered at COP 9 but due to the available cover over the pipe and water surface elevations at the project location, the structures were eliminated. The 6-foot round aluminum culvert embedded 2.0 feet was eliminated due to a bankfull width ratio of 0.63. The 9-foot round aluminum culvert embedded 3.0 feet was eliminated due to minimum cover requirements.

8.0 REFERENCES

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[Accessed 01 08 2020].

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APPENDIX A: GEOMORPHIC ANALYSIS

Stream Crossing Site Assessment
Reference Reach Data Sheet

DOWL
Revised RDP 08212015

Project: GO SHER1 | **Project Number:**

Date: 7/20/21 & 7/21/21 | **Assessed by:** EAM.

Crossing ID: SHER1

Weather Conditions: (1) 55°F. / DRY / ~~$~~ OVERCAST (2) 54°F cloudy/drizzling

CROSSING CHARACTERISTICS:

	US / DS
Existing Culvert/Crossing: 5.5' BARREL PROTRUDING FROM BANK ~~24~~ 18" CMP – 5.5' COVER FROM CROWN. 3/4 BARREL FILLED w/ WOODY DEBRIS GRADING TYPE E-1 SLUMPED AROUND BARREL	18 ~~24~~" CMP. / OUTLET: PARTIALLY BURIED
Geomorphology/Stream Type/Bedform Features: SMALL GRAVEL UNDER FOOT @ INLET / PONDED. LOTS OF WOODY DEBRIS FROM CLEARING 1st GC @ 47-52.5 FT – RIFFLE POOL	– Riffle Pool – Sand / Gravel / mix @ outlet Marsh
Substrate/Bed Mobility: LAYER OF ORGANICS. Small gravel in reaches, Small to medium cobbles in Riffles.	Sand / Gravel mix w/ ORGANICS. – Low ~~[illegible]~~ ENERGY / STABLE
Floodplain Characteristics/Entrenchment: Pool/Bank depth 1.5' @ 42ft HEAVILY WOODED / GRASSLAND ~~<0.25 ft~~.	– multiple deep pools / HEADCUTS 1st – 1' 2nd 2'
Flow/Velocity Estimates: <0.25 ft. / Almost stagnant.	<0.25 ft/s / ALMOST STAGNANT.
Tie-in Points:	

PEBBLE COUNT

Site:
Party:
Reach:
Date:

Inches	PARTICLE	Millimeters		PARTICLE COUNT US 1	US 2 2	DS 3	TOT #	ITEM %	% CUM
	Silt / Clay	< .062	S/C	[tally]	[tally]		[tally]		
	Very Fine	.062 - .125	SAND	[tally]					
	Fine	.125 - .25	SAND						
	Medium	.25 - .50	SAND						
	Coarse	.50 - 1.0	SAND						
.04 - .08	Very Coarse	1.0 - 2	SAND		[tally]	[tally]			
.08 - .16	Very Fine	2 - 4	GRAVEL		[tally]	[tally]			
.16 - .22	Fine	4 - 5.7	GRAVEL	[tally]	[tally]	[tally]			
.22 - .31	Fine	5.7 - 8	GRAVEL	[tally]	[tally]	[tally]			
.31 - .44	Medium	8 - 11.3	GRAVEL	[tally]	[tally]	[tally]			
.44 - .63	Medium	11.3 - 16	GRAVEL	[tally]	[tally]	[tally]			
.63 - .89	Coarse	16 - 22.6	GRAVEL	[tally]	[tally]	[tally]			
.89 - 1.26	Coarse	22.6 - 32	GRAVEL	[tally]	[tally]	[tally]			
1.26 - 1.77	Very Coarse	32 - 45	GRAVEL	[tally]	[tally]	[tally]			
1.77 - 2.5	Very Coarse	45 - 64	GRAVEL	[tally]	[tally]	[tally]			
2.5 - 3.5	Small	64 - 90	COBBLE	[tally]	[tally]	[tally]			
3.5 - 5.0	Small	90 - 128	COBBLE		[tally]				
5.0 - 7.1	Large	128 - 180	COBBLE						
7.1 - 10.1	Large	180 - 256	COBBLE						
10.1 - 14.3	Small	256 - 362	BOULDER						
14.3 - 20	Small	362 - 512	BOULDER						
20 - 40	Medium	512 - 1024	BOULDER						
40 - 80	Large-Vry Large	1024 - 2048	BOULDER						
	Bedrock		BDRK						
						TOTALS →			

PEBBLE COUNT			PEBBLE COUNT		
Reach:			Reach:		
Date:			Date:		
TOT #	ITEM %	% CUM	TOT #	ITEM %	% CUM

eam Crossing Site Assessment
eference Reach Data Sheet

Rev

Project: COP9 - CRWP/USFWS | Project Number:
Date: 7/21/21 | Assessed by: EAM9HJR
Crossing ID: COP9
Weather Conditions:
54°F, Cloudy

CROSSING CHARACTERISTICS:

	US	DS
Existing Culvert/Crossing:		48" CMP - PLACED ROCK / APPROX CLASS I
2 48" CMP PLACED ROCK @ INLET 12" ROCK IN BARREL.		
Geomorphology/Stream Type/Bedform Features: RIFFLE POOL / GRAVEL COBBLE MIX. CONFINED BY ORGANICS		RIFFLE POOL.
Substrate/Bed Mobility: STABLE / Organics & Cobbles in Pools. GRAVEL → Cobble.		STABLE / GRAVEL.
Floodplain Characteristics/Entrenchment: WIDE / Organics bound by Road / Berm Bank. DEEP POOL at Approx 230FT		GRAVEL.
Flow/Velocity Estimates: Low / Stagnant.		
Tie-in Points: - MATCH EMBANKMENT.		

PEBBLE COUNT

Site:
Party:
Reach:
Date:

PARTICLE COUNT

Inches	Particle	Millimeters		US1 1	DS1 2	DS2 3	TOT #	ITEM %	% CUM
	Silt / Clay	< .062	SAND	111	11				
	Very Fine	.062 - .125							
	Fine	.125 - .25							
	Medium	.25 - .50							
	Coarse	.50 - 1.0							
.04 - .08	Very Coarse	1.0 - 2							
.08 - .16	Very Fine	2 - 4	GRAVEL	11	111				
.16 - .22	Fine	4 - 5.7		11	111	11			
.22 - .31	Fine	5.7 - 8		1		1111			
.31 - .44	Medium	8 - 11.3		111	1111	1111 111			
.44 - .63	Medium	11.3 - 16		1111	1111	1111 1111 011			
.63 - .89	Coarse	16 - 22.6		1111 1111	1111 1111 111	1111 1111			
.89 - 1.26	Coarse	22.6 - 32		1111 1111 111	1111 1111 1111	1111 1111 1111 1111			
1.26 - 1.77	Very Coarse	32 - 45		1111 1111 111	1111 1111 1111 11	1111 1111 1111 1111 111			
1.77 - 2.5	Very Coarse	45 - 64		1111 1111	1111 1111 11	1111 1111 11			
2.5 - 3.5	Small	64 - 90	COBBLE	1111 1	1111	1111			
3.5 - 5.0	Small	90 - 128							
5.0 - 7.1	Large	128 - 180							
7.1 - 10.1	Large	180 - 256							
10.1 - 14.3	Small	256 - 362	BOULDER						
14.3 - 20	Small	362 - 512							
20 - 40	Medium	512 - 1024							
40 - 80	Large-Vry Large	1024 - 2048							
	Bedrock		BEDROCK						
				TOTALS →					

PEBBLE COUNT — Reach: / Date:

TOT #	ITEM %	% CUM

PEBBLE COUNT — Reach: / Date:

TOT #	ITEM %	% CUM

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THE RESERVE RESERVE FIELD BOOK

, Crossing Site Assessment
ence Reach Data Sheet

DOIL
Revised RDP 082215

e: | Project Number:

STREAM REFERENCE REACH: COP 9

hannel Cross Section Shape: RECTANGULAR. | Channel Slope: < 1%

Δ from Xing	Bankfull Width	Bankfull Depth	Bed Width	Floodplain Width	Riffles	
					Δ Xing	Length
					102-134 210-219	32FT.

Channel Stability Notes:
5. - Stable organics OVER CLAY SUBSTRATE

Stability: 1 = lowest (very temporary)
5 = highest (permanent)

Pools			Steps				Ribs		Notes:
Δ Xing	Length	Depth	Δ Xing	Height	Type	Stability	Δ Xing	Stability	
134-160 219-238		2FT.							

Vegetation: GRASSES / REEDS.

Bedrock Observed: NONE

DOWNSTREAM REFERENCE REACH:

Channel Cross Section Shape: | Channel Slope:

Δ from Xing	Bankfull Width	Bankfull Depth	Bed Width	Floodplain Width	Riffles	
					Δ Xing	Length
					12-18 35-41 55-60 66-109. 206-232 250-	6FT.

Channel Stability Notes:
5 - Stable. /

Stability: 1 = lowest (very temporary)
5 = highest (permanent)

Pools			Steps				Ribs		Notes:
Δ Xing	Length	Depth	Δ Xing	Height	Type	Stability	Δ Xing	Stability	
18-35 60-66 175-204 232-250		2FT							

Vegetation:

Bedrock Observed:

CAB1, CAB2, COP9, Sher1 — July 2021, Cordova

1. existing culvert/crossing
2. geomorphology/stream type/Bedform Features
3. Substrate/Bed Mobility
4. Floodplain characteristics/entrenchment
5. Flow/velocity estimates
6. Reference Reach description
   → dist. US/DS
   → BFW/BFD
   → cross section shape
7. vegetation
8. Stability

Tues: 7/20	Wed:	Thurs:	Fri:
4:30 Sher 1 US	7:00am start	7am start	
	8:40 to Sher 1 DS	to CAB 1/2	
~7:00pm end	~2 hrs COP 20-25	10am back to cabin	
		DS Petersen	
		3pm Sher 1 US	

Sher 1 US – 5.5' cover → Remove existing large culvert / cost
- gravel/fill in pond US
- 5.5' of 18" culvert ponding submerged
- sheen on water
- gravel bottom

Reference Reach start ~300' first riffle

① upper Riffle flagged BFW=10.7' BFD ~ 6"
② pool DS Riffle BFW = 4' 10" BFD ~ 1'
③ 2nd Riffle BFW = 11' 10" BFD ~ 8"
④ pool DS 2nd Riffle BFW = 11' 6" BFD ~ 14"

2) Riffle/pool
3) organics/low mobility
4) wooded/grass wide
6) → 300' to 400'
   → trapezoidal
7) Ferns

* survey Beaver Pond elev. ...

Pebble Count #1
Flagged upper Riffle ~400'

Pebble count #2
Flagged 2nd Riffle down ~350'

Flagged @ 400' & 300'

Old crushed culvert
top to channel Bed = 5'
width ~ 8' 10"

→ check Sher 02 drainage area
map flow & drainage Area

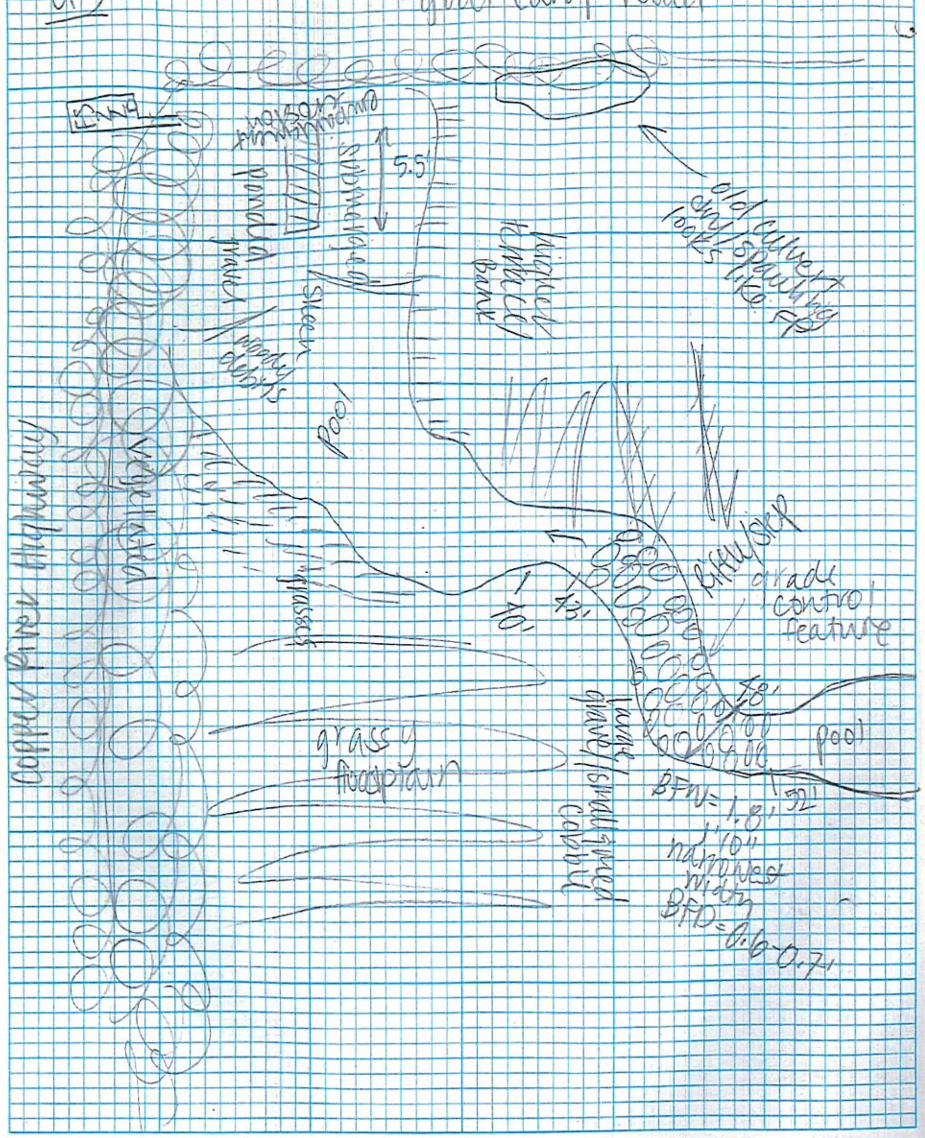
- lake US

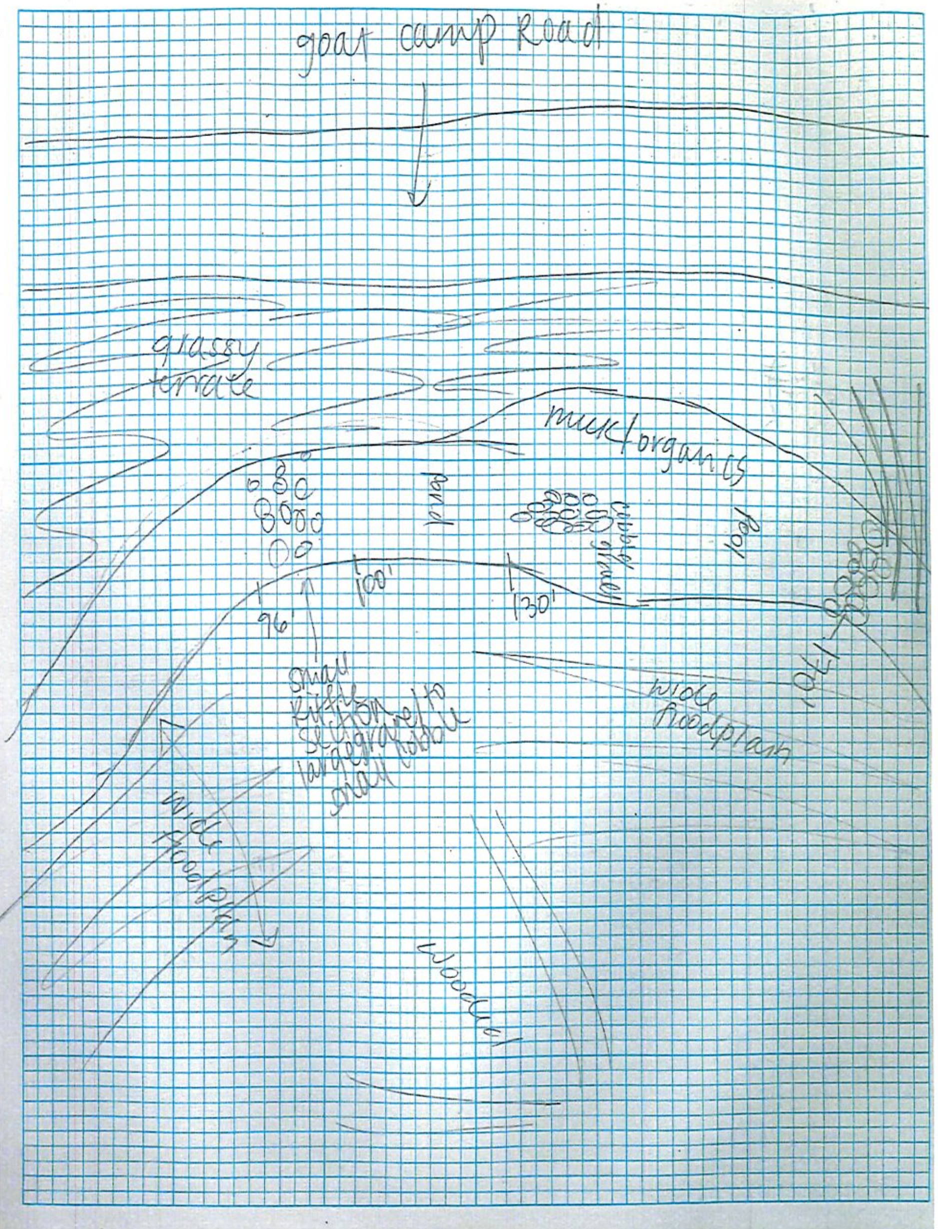
→ survey thalweg up from Ref Reach to beaver Dam

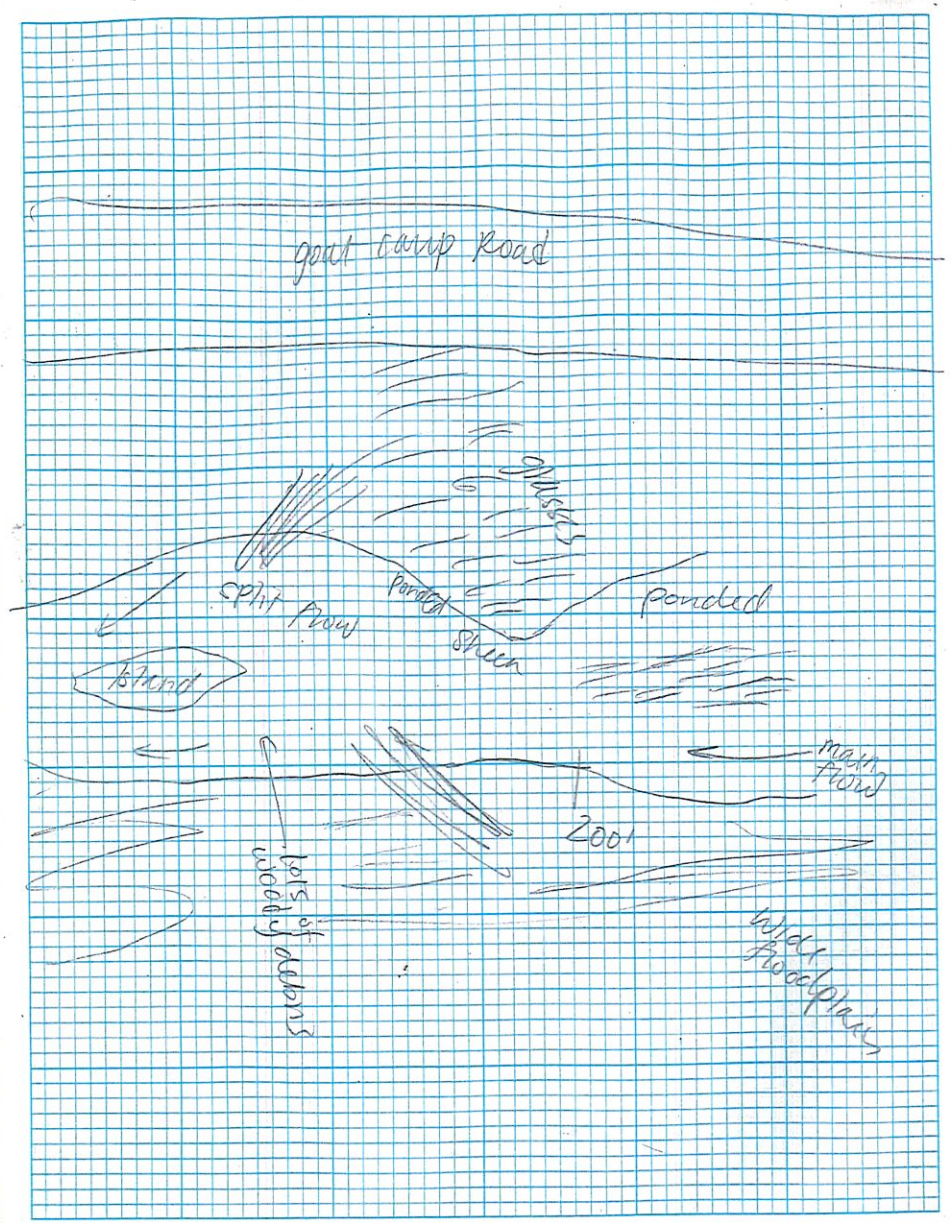
7/20/21 SHER01

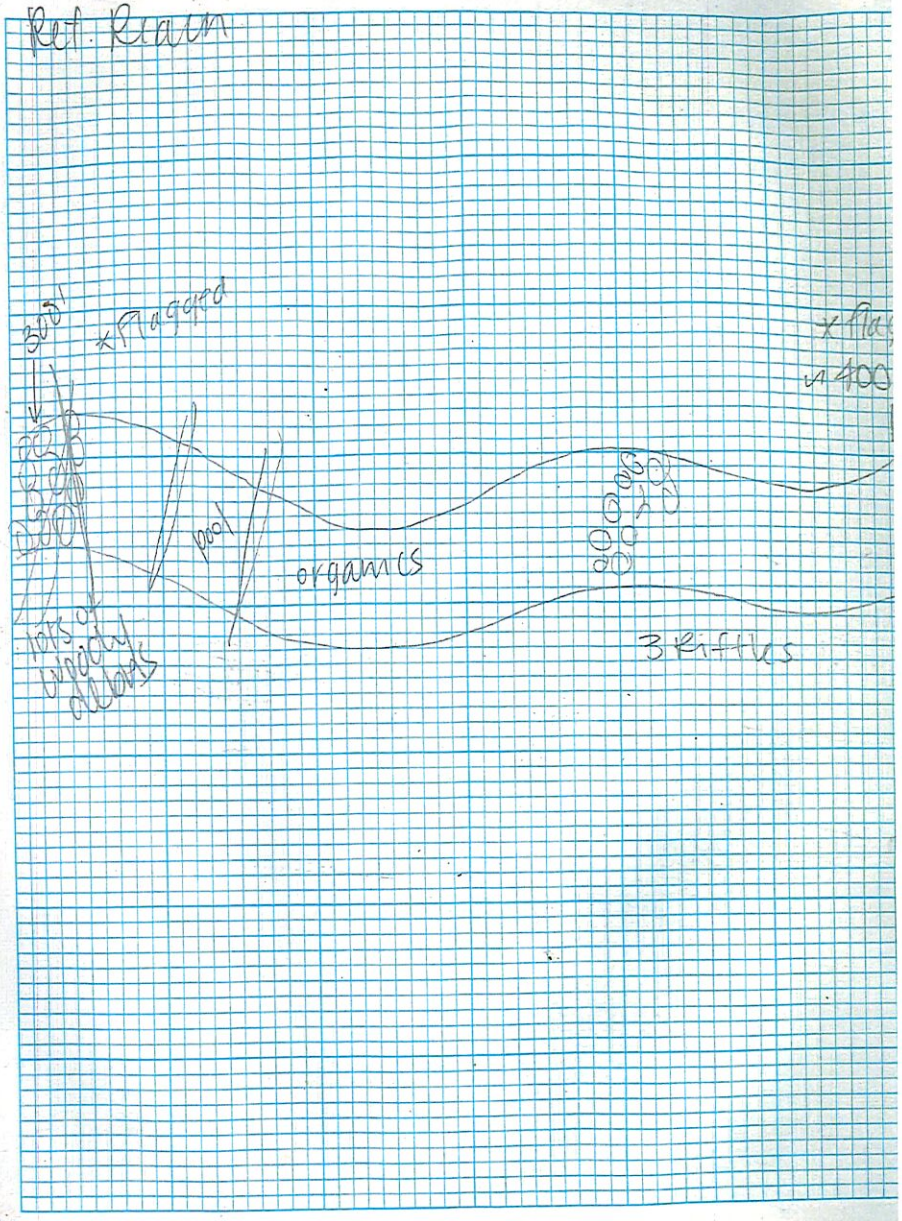
US

~5.5' cover at inlet






goat camp Road
grasses
split flow
ponded
shrubs
ponded
main flow
2001
lots of woody debris
back floodplain


Ref. Reach
300'
Placard
lots of
organics
pool
organics
3 riffles

Sher 1 DS 7/21/21

- lots of fry observed
- willow/alder/grasses/ferns
- ~6' cover @ outlet
- pipe submerged
- gravel bar @ outlet
- 2 headcuts
- pond merges @ ~260'
- Pebble count @ riffle 35' DS
- can increase goat camp Road elev, Raise Road

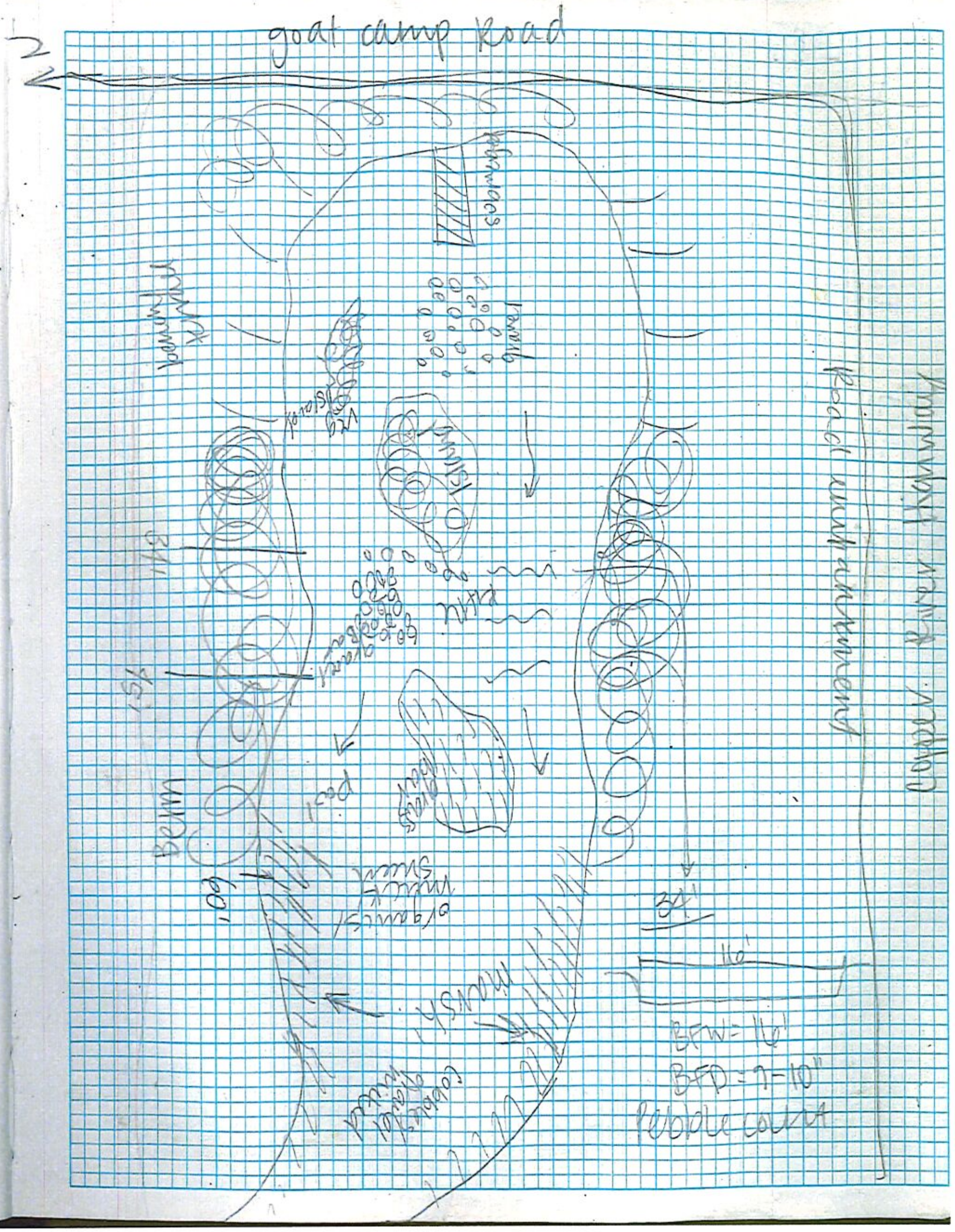
survey: goat camp Road from crown of copper River highway to 200'-300' (old large culvert)

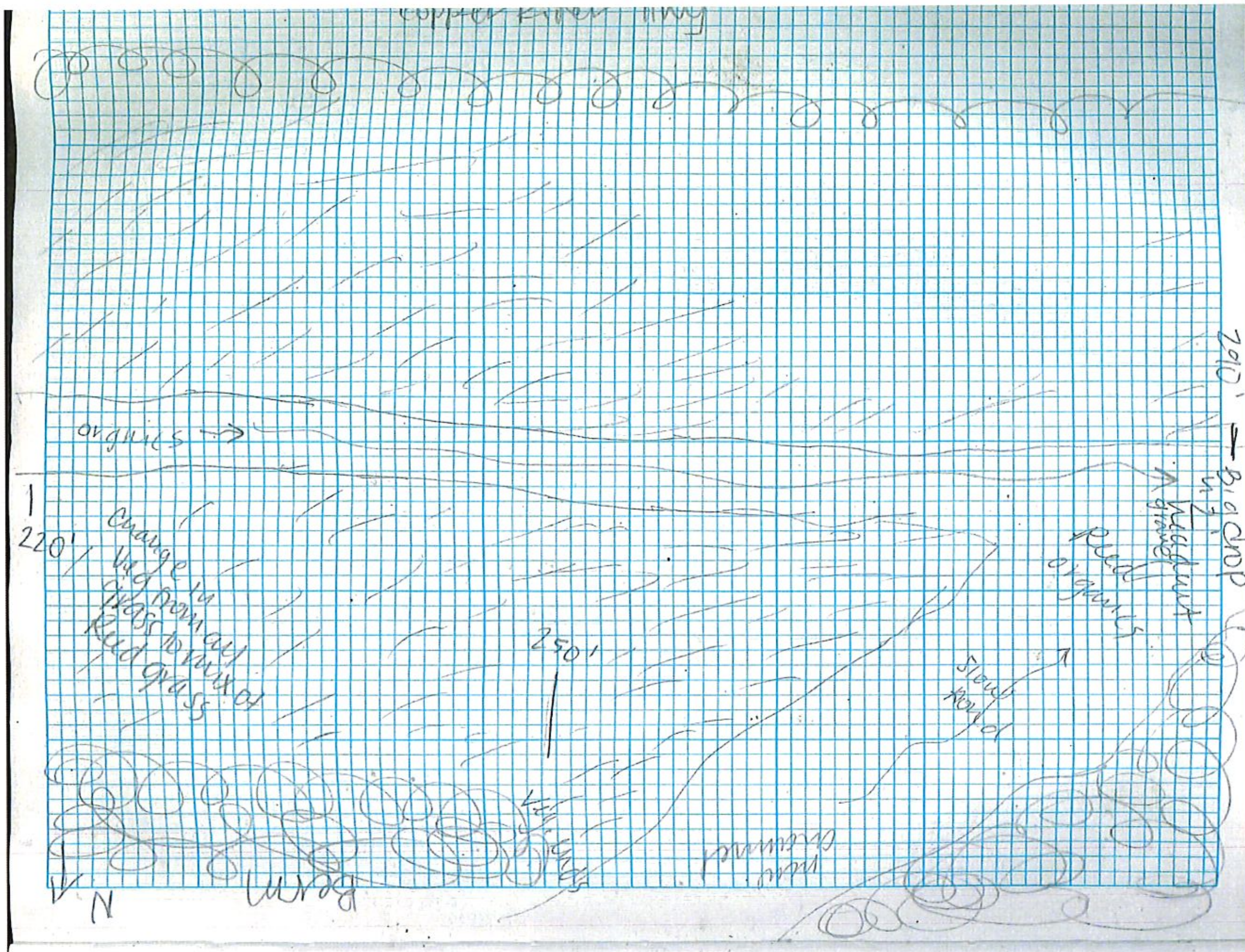
DS: ~300' to where streams connect
Big drop @ ~290'

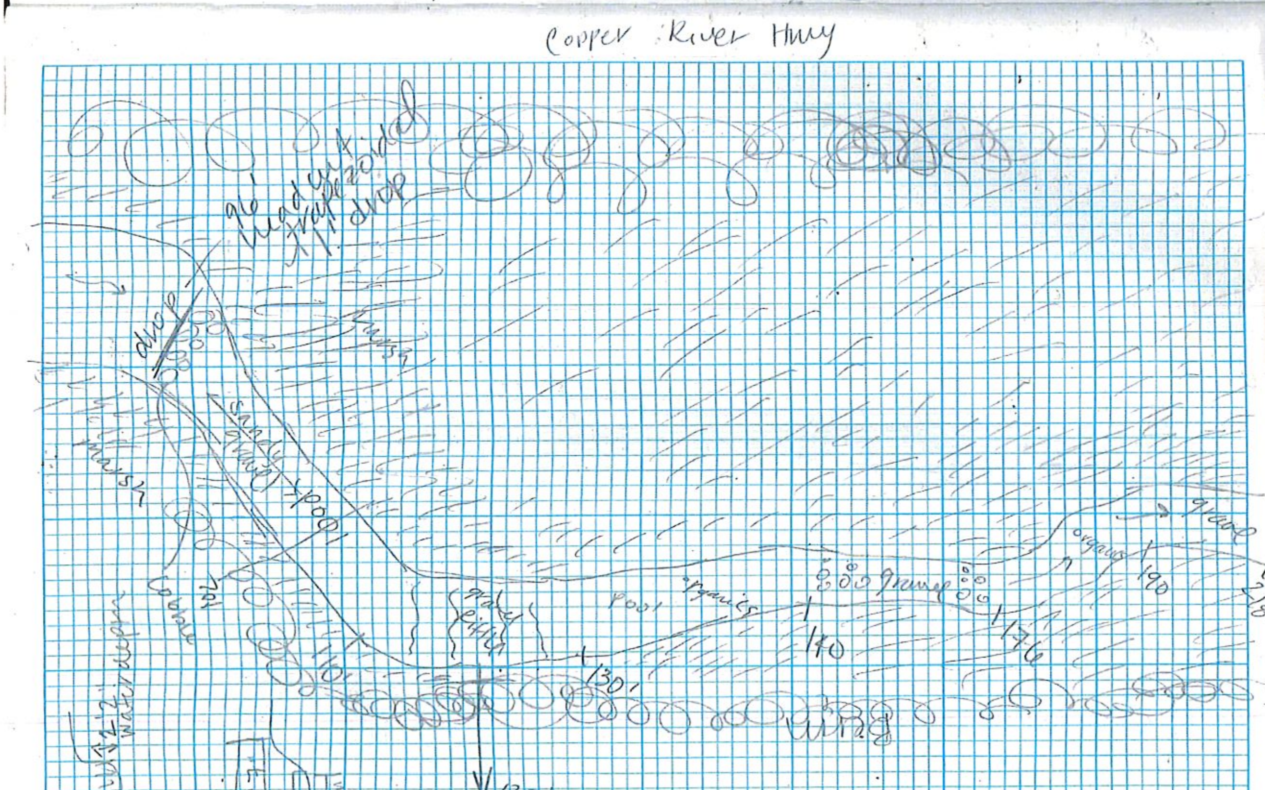
2: Riffle/pool & marsh

4: confined by Road and bench N

6: no Ref. Reach

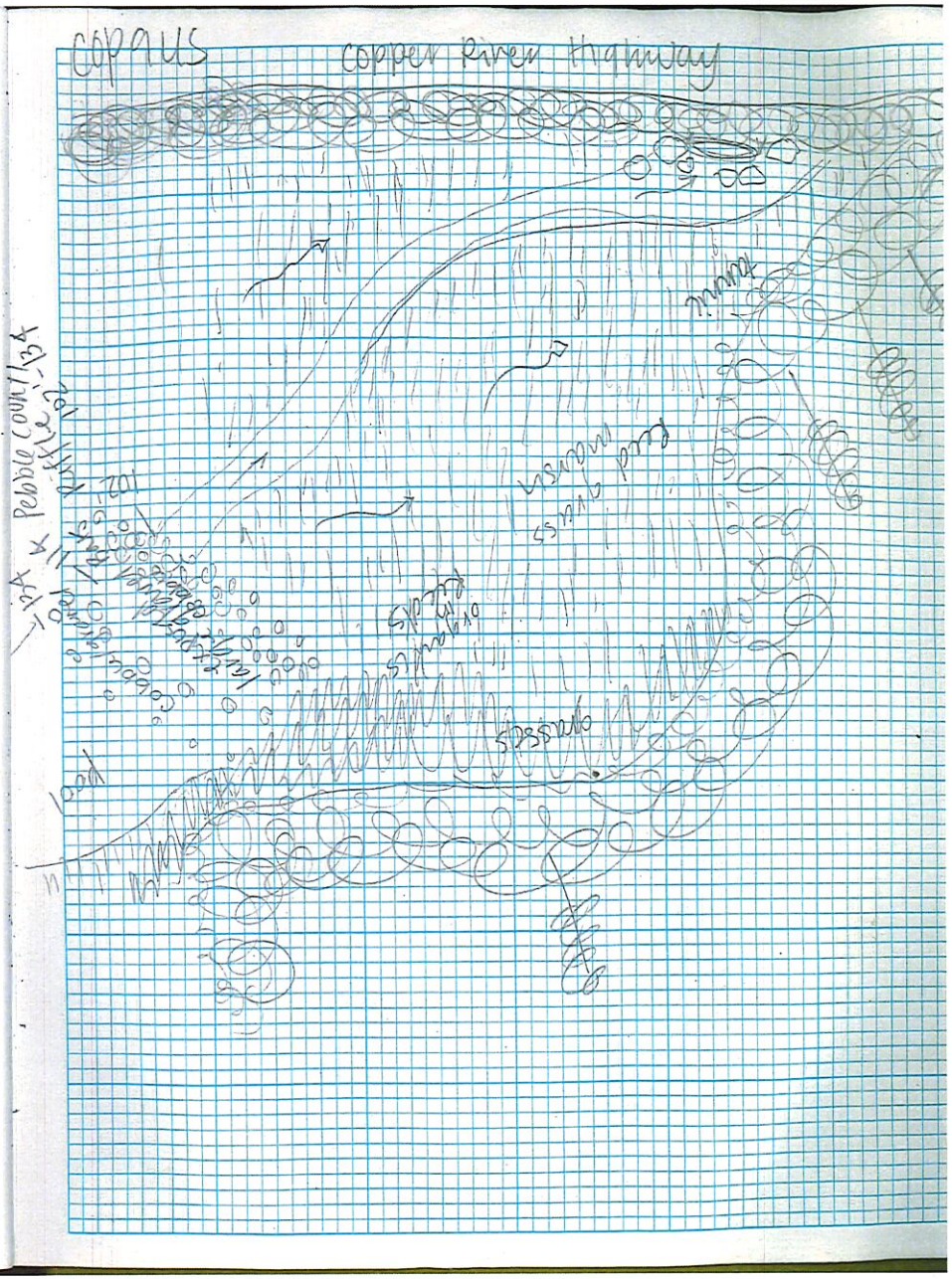


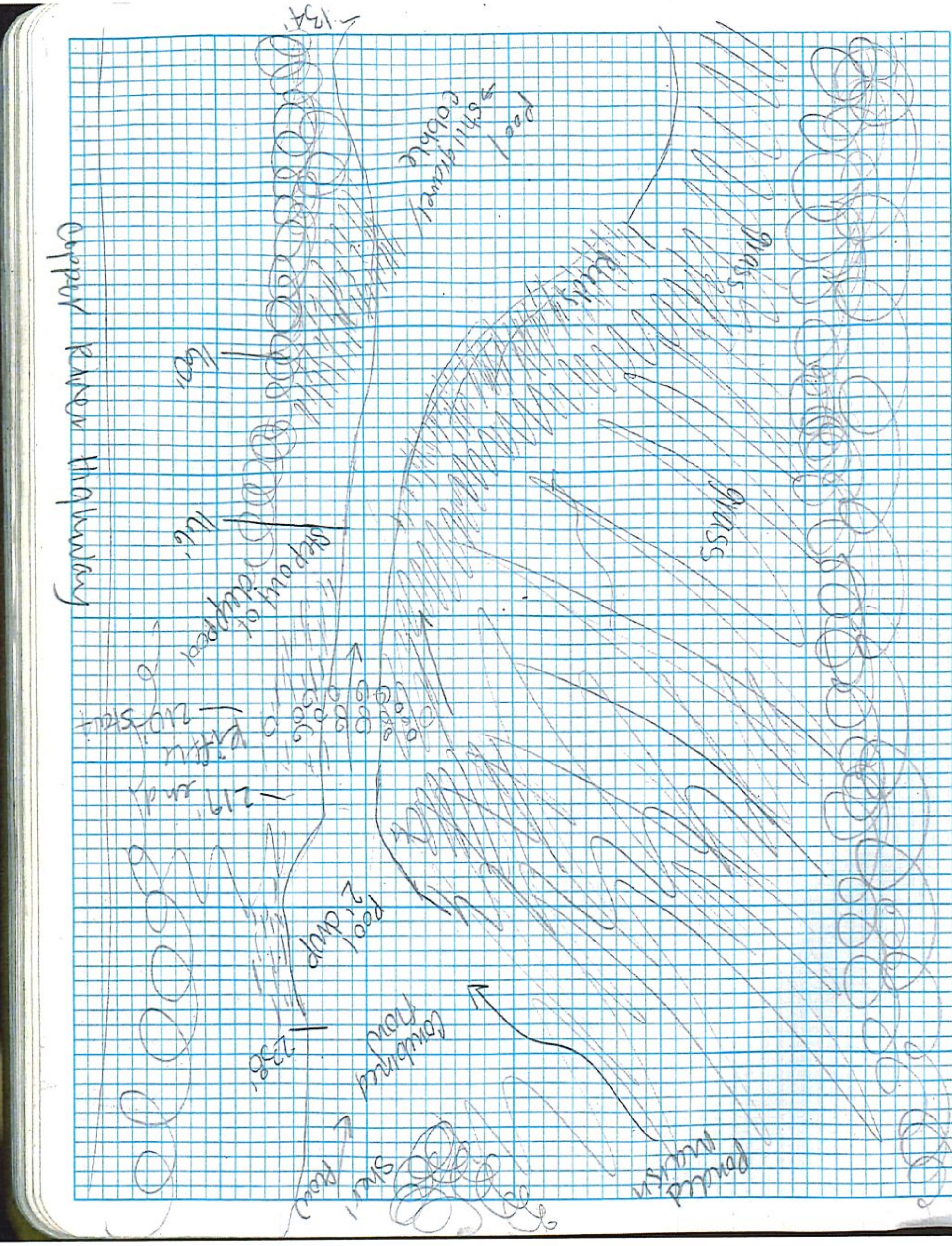

organics
220'
change in veg from all grass to mix of reed grass
250'
210'
Big drop w/ headcut
Reed organics
slow pool
WRG
N


Copper River Hwy
90' headcut trapezoidal 1' drop
drop
marsh
sandy gravel
pool
cobble
graded riffle
pool
organics
gravel
110'
130'
140
170
190
218'
WRG
125'
water depth
3.6'
21.8'
5.4'
moss bar
BFW=21.8'
BFD=1'
10'
12.5'

Cop 9 7/21/21 US

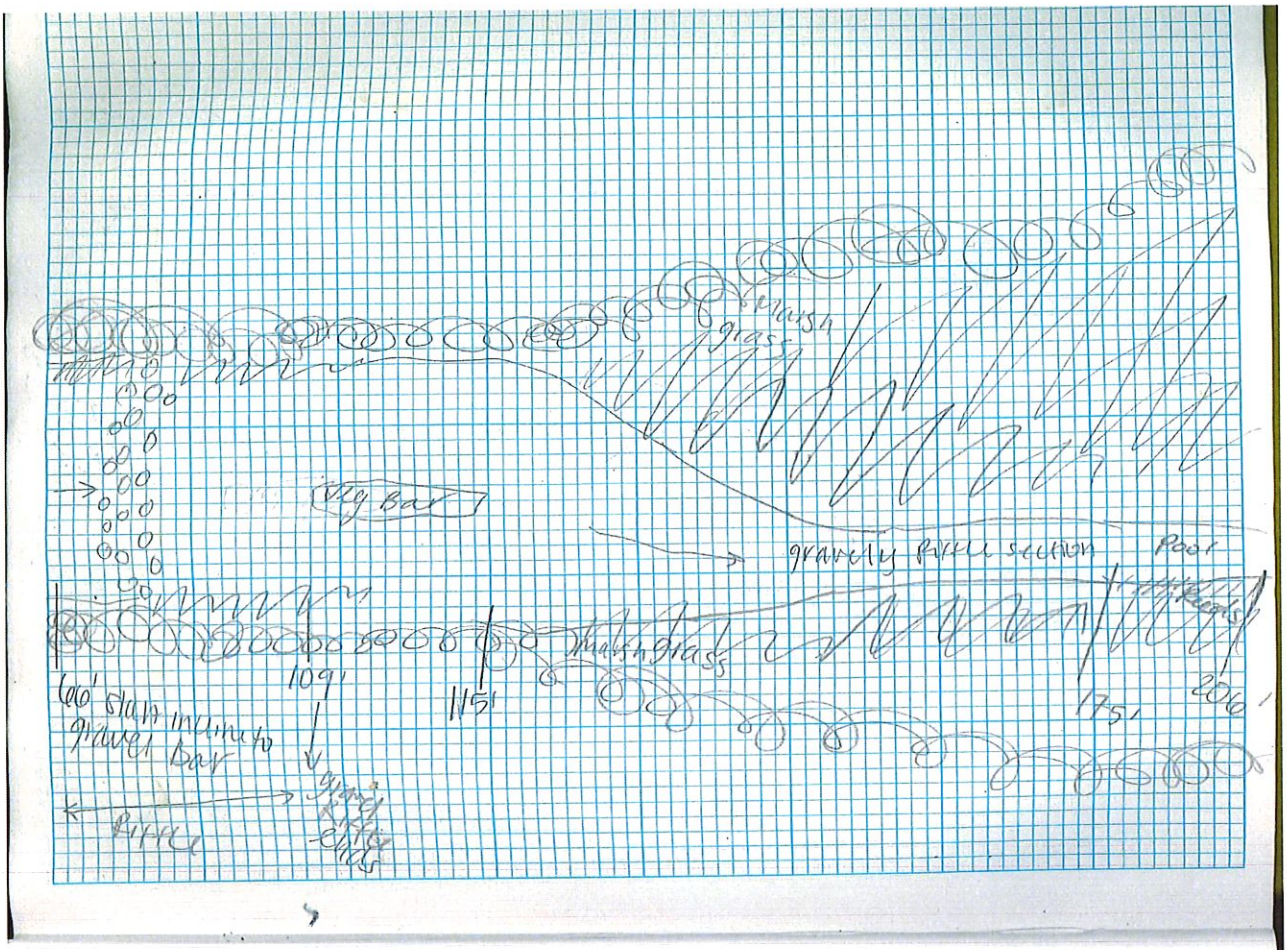
- 4' existing culvert
- Rust mark @ half Barrel
- WSE ~ 1/4 Barrel
- large boulder in middle
- 4-5' cover @ inlet
- Pebble count @ 102' Riffle
- Survey: US ~ 300' to short tie in
  - go upriver channel for remaining
- 2: Riffle/pools & marsh
- 3: gravel-cobble & organics/tannic
- 4: wide FP
- 6: no Ref Reach use short Ref. Reach & do sym. width or C/A method
  - all marsh us. no culvert on goat camp Road US
- 7: grasses, reeds, willow/alder

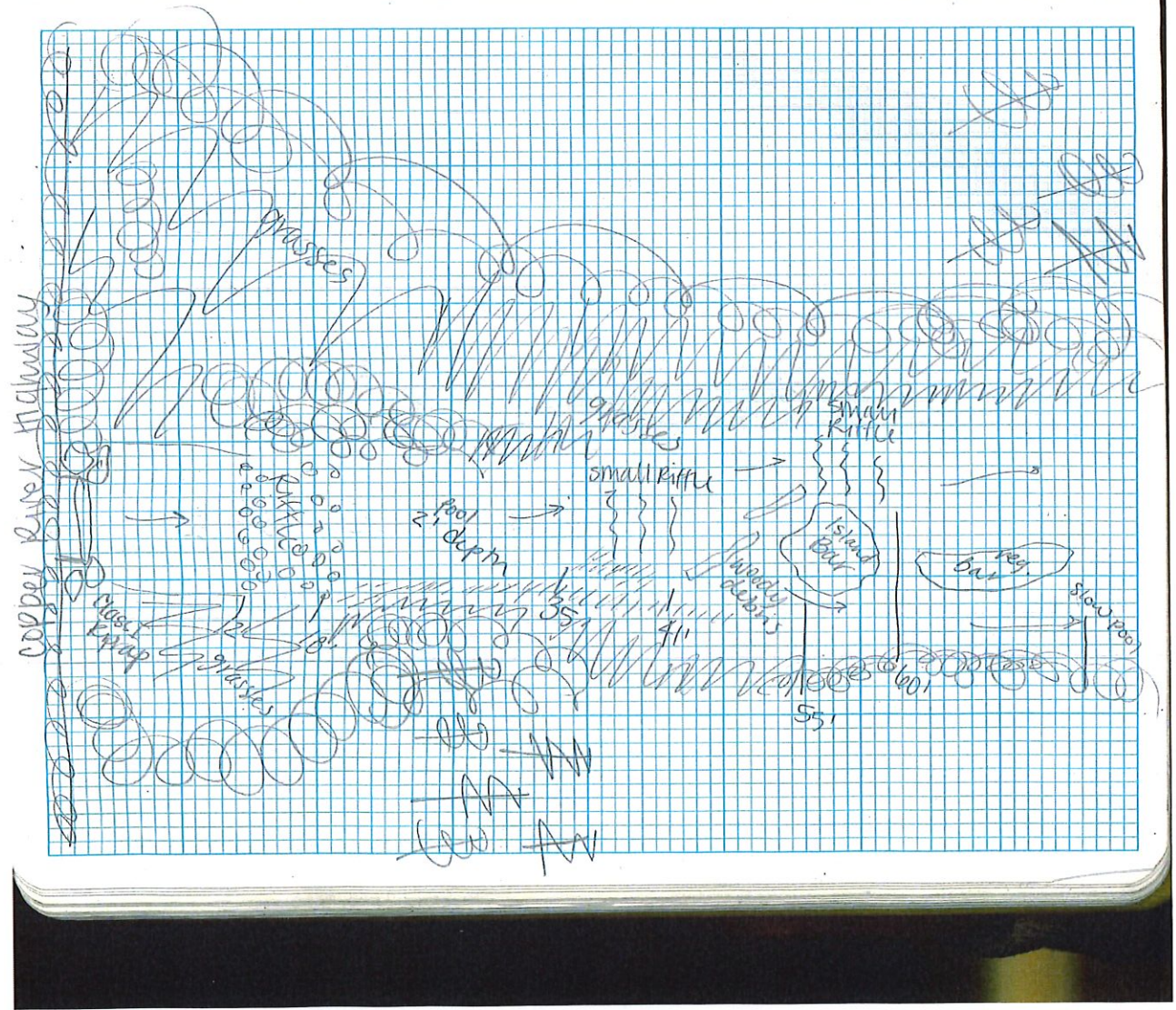


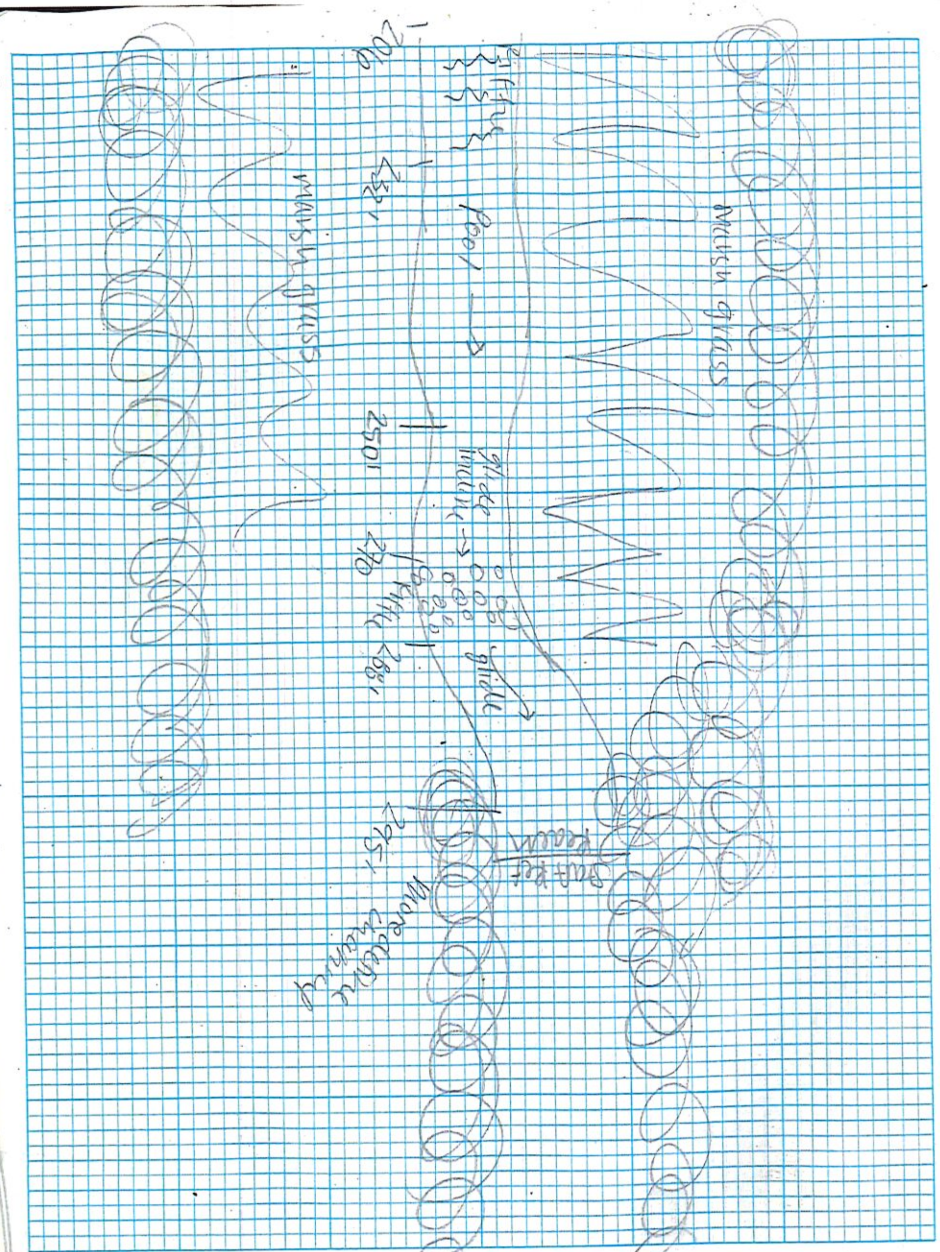


COP9DS 7/21/21
- placed rock @ outlet ~ RIPRAP CLASS [illegible]
- ~4' cover @ outlet
- Reference Reach DS ~300' to 400'
approx. 100' ~3 riffle section
flagged @ top/bottom

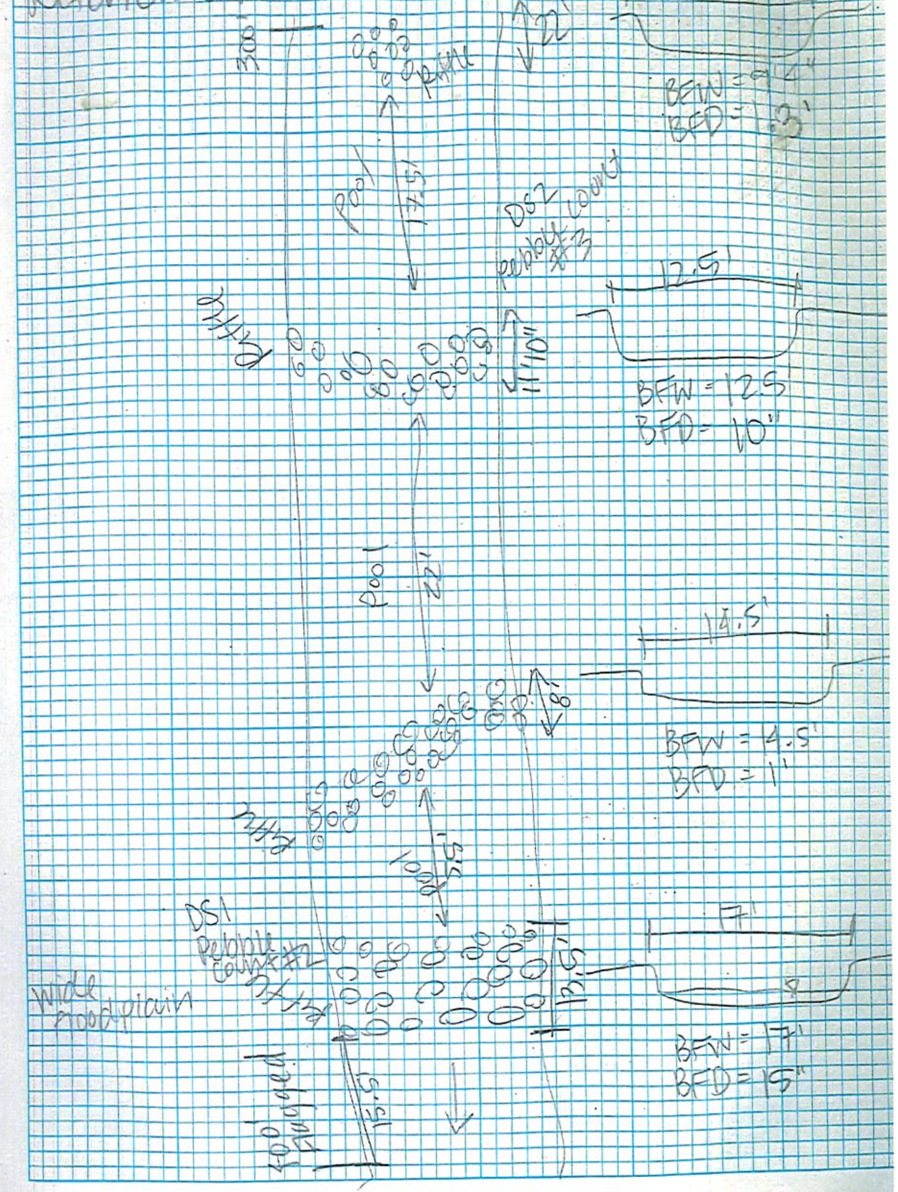
pebble count #2 @ DS riffle


grass
gravelly riffle section
Pool
Shallow grass
109'
115'
175'
200'
Riffle


Cooper River Walkway
grasses
small Riffle
Pool 2' depth
Island Bar
reg. bar
Slow pool
55'
60'



Reference Reach



7/21/21

Call from Mike - Gustavus, wants update cost est. for grandpa's farm Road

↳ wants est. to update estimate, potentially need to update plans

Forester COP 20-25 advice:

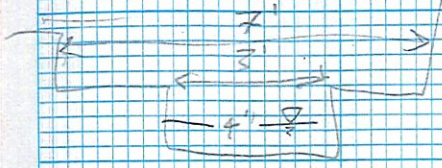
→ add removal of structures and obstruction

7/22/21

CAB 1/2 US

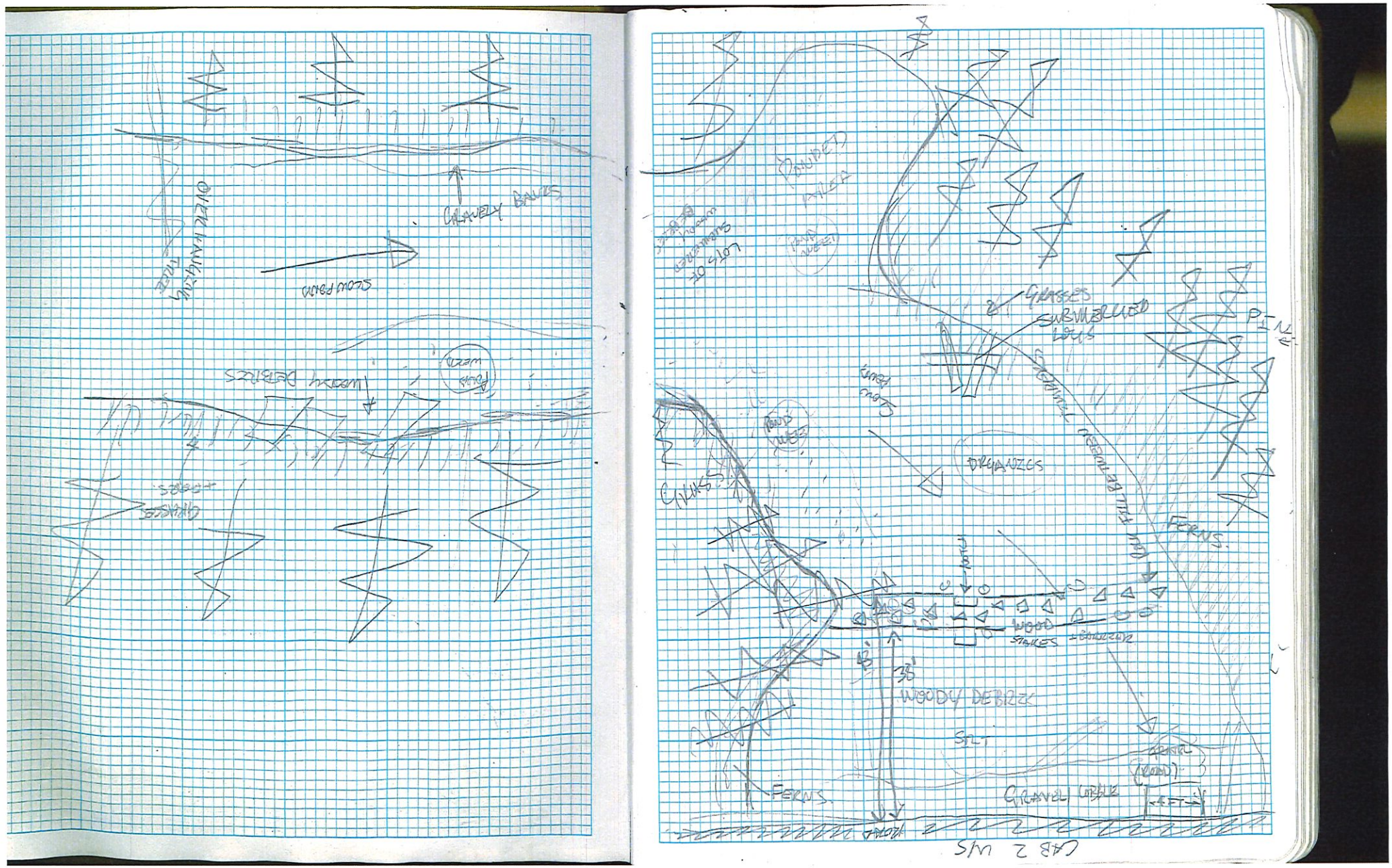
- APPROX 1FT COVER ON PIPE
- GPS SURVEY TRIMBLE USER
- CONSTRUCTION ACCESS FOR CAB 1 VIA ROAD/GRAVEL PATH
- CULTURAL RESOURCE - ROB TRIMBLE USER
- POTENTIAL UPWELLING
  ↳ WATER NOT WARM

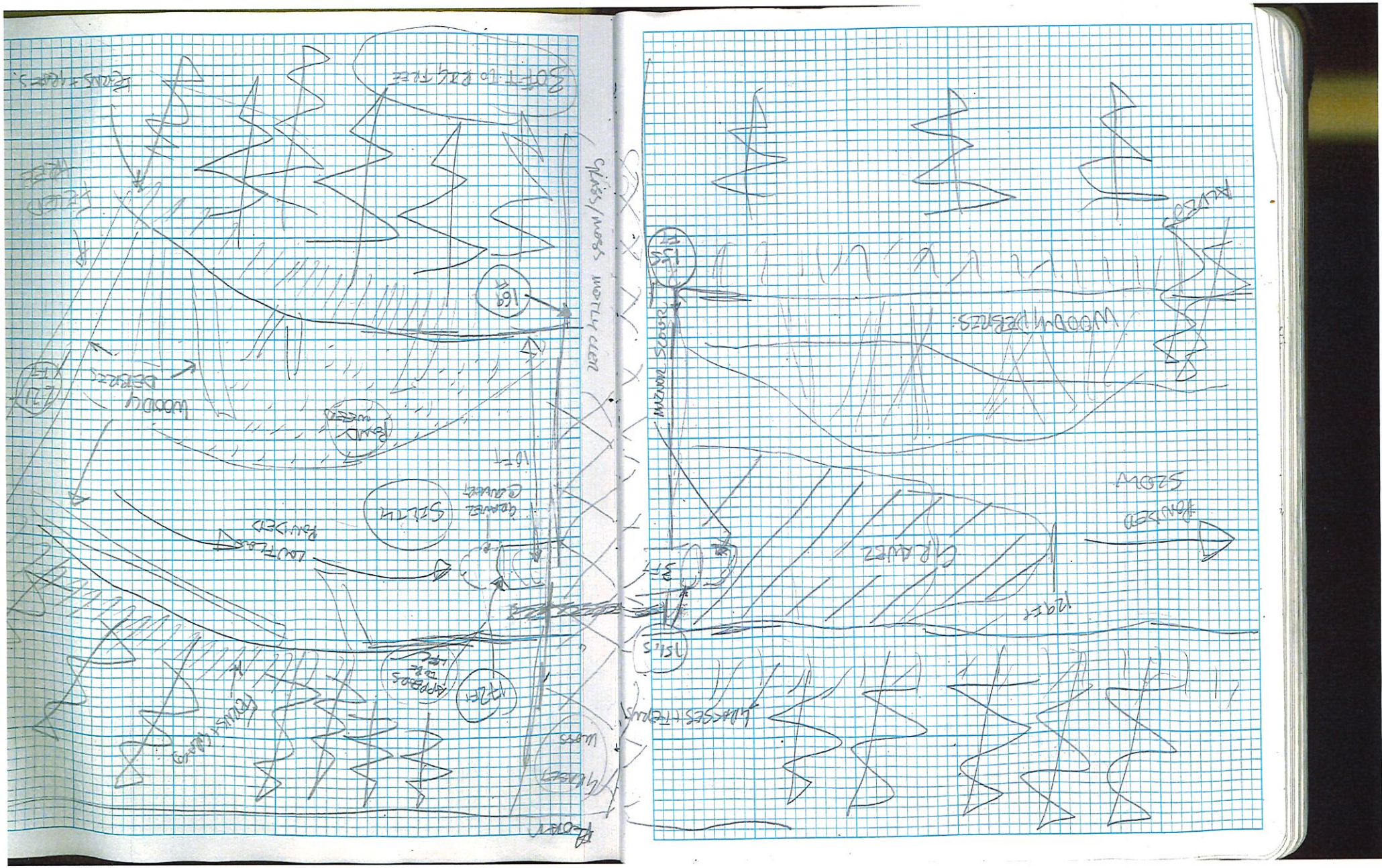
- CAB 1 APPEARS TO OVERFLOW
  ↳ FLOW PATH EVIDENT

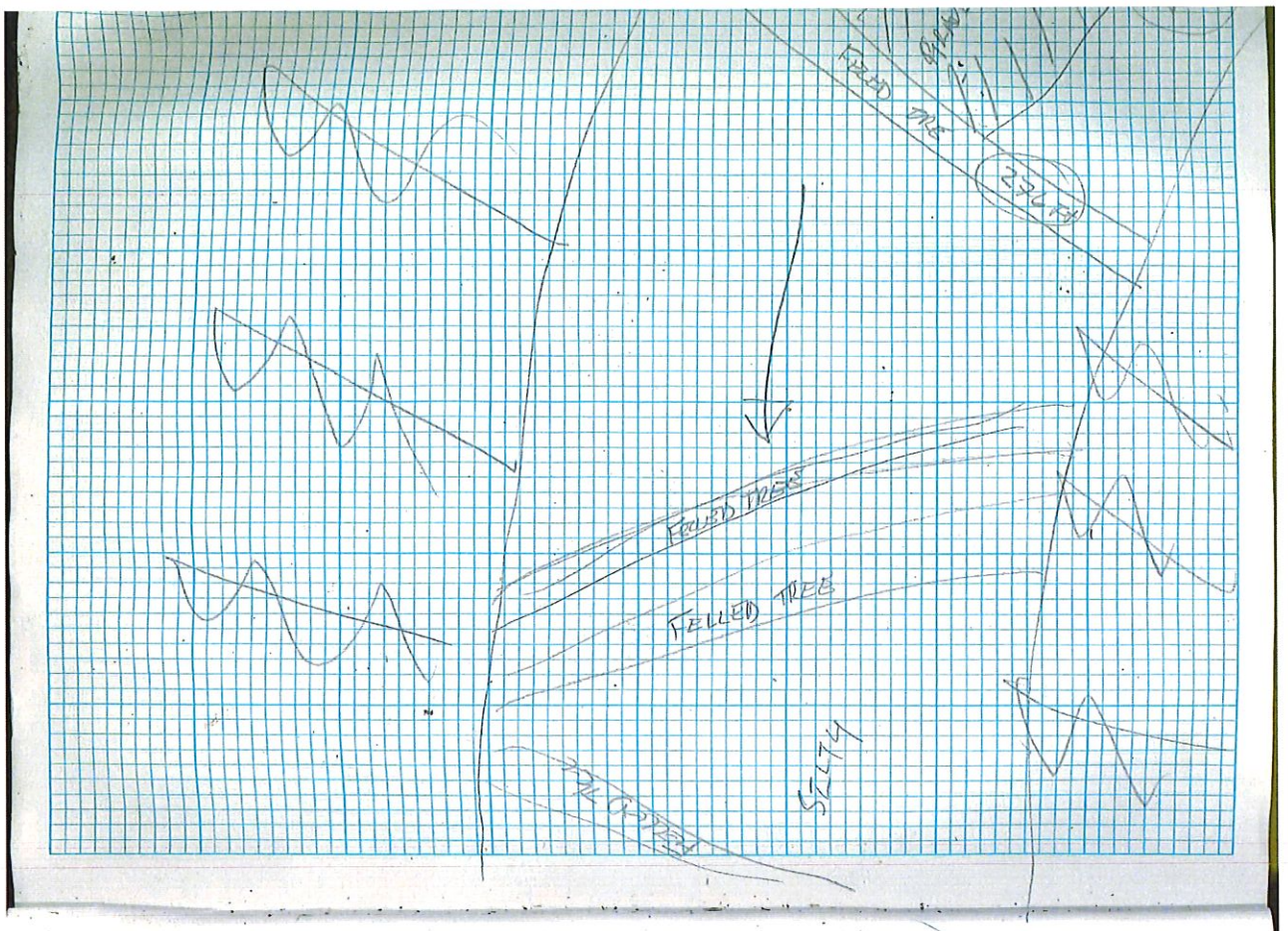


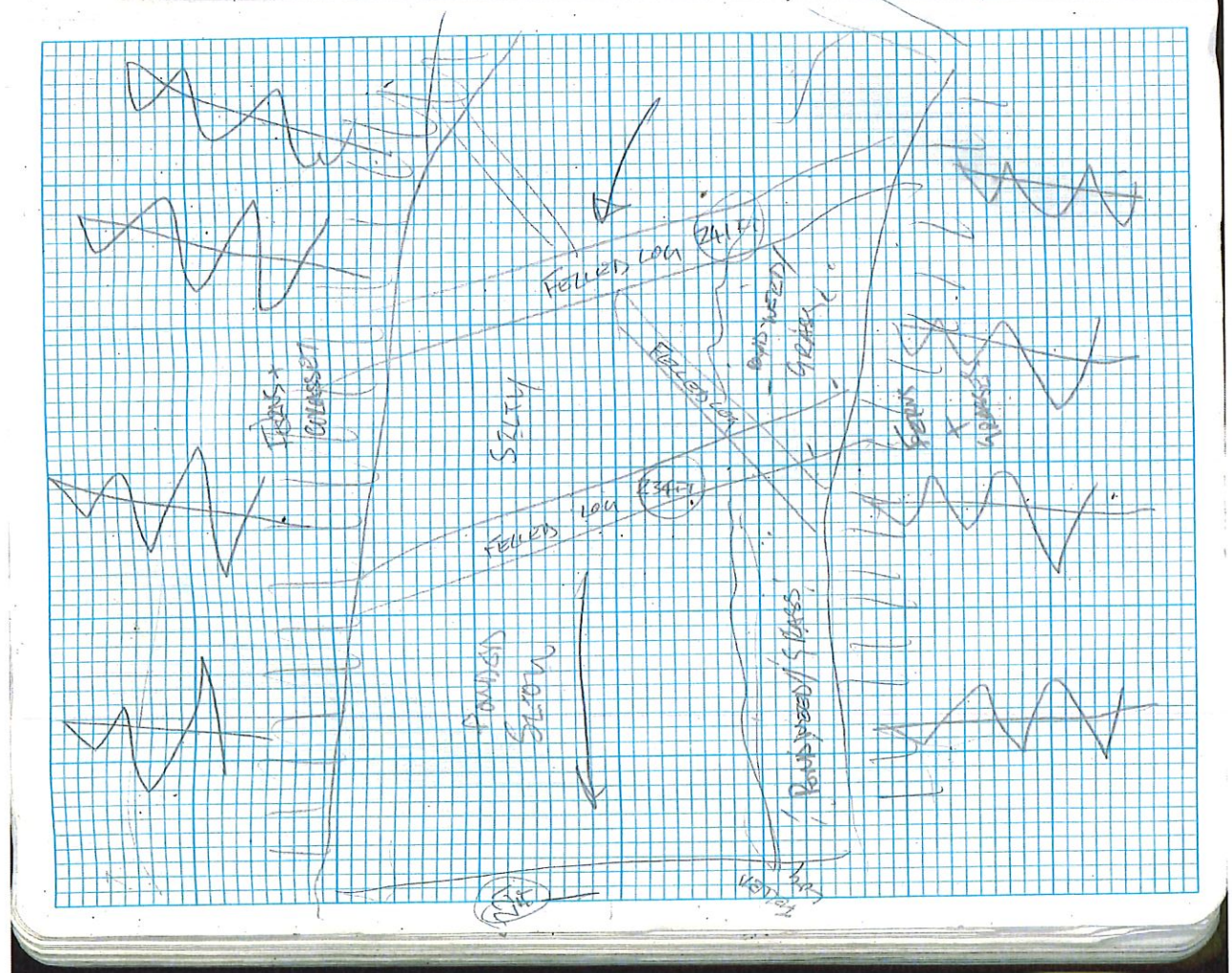
SURVEY
- GET WSE
- GET UP OF PIPE INVERT
- 300' UPSTREAM/DS not flagged

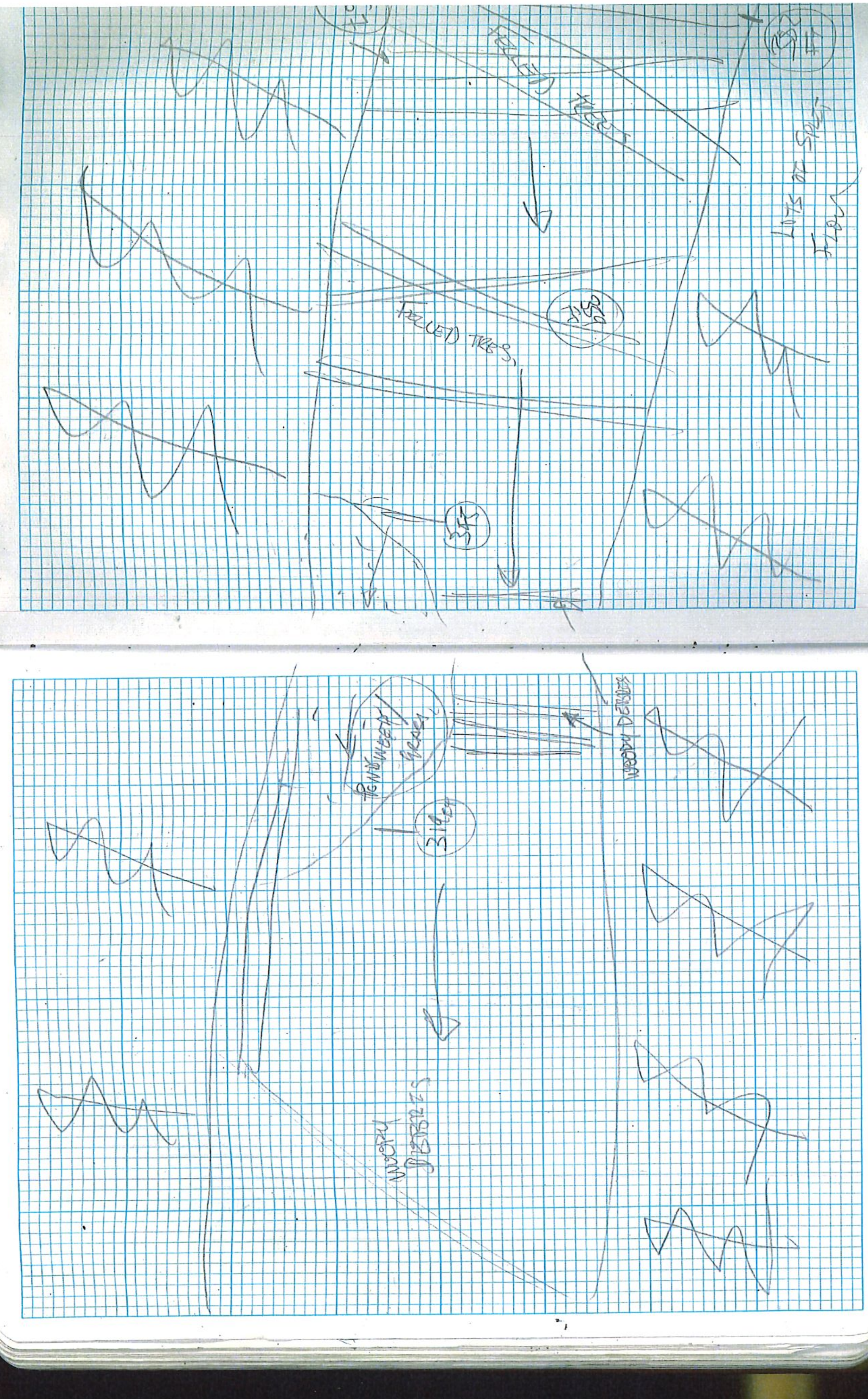
- ASK FRANKLIN FOR PRESSURE TRANSDUCER?
  DO TS.

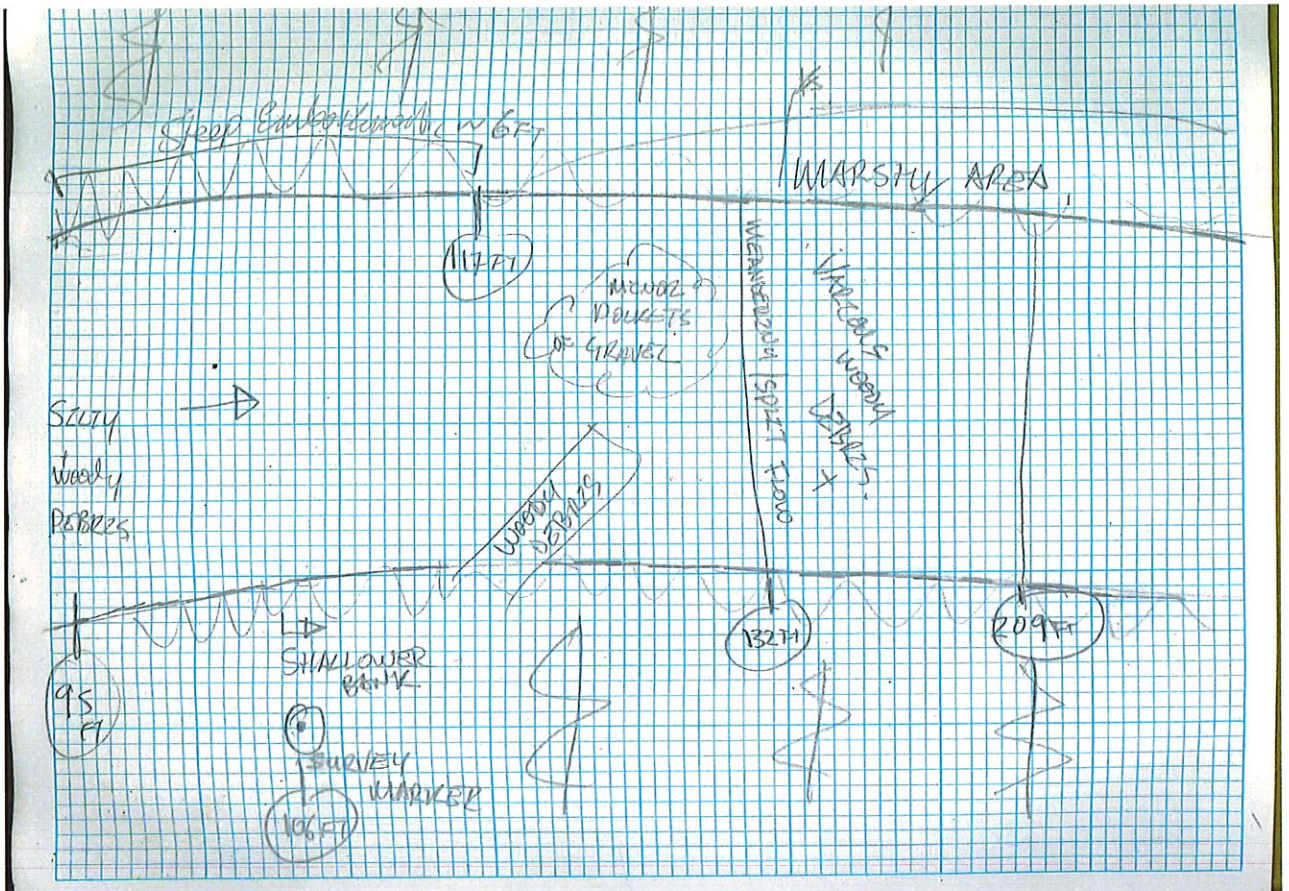

GRAVEL BARS
SCOUR POOL
WOODY DEBRIS
GRASSES
FERNS
DRY ALDERS
WOOD STAKES
35'
WOODY DEBRIS
SALT
GRAVEL BARS
FERNS
CAB 2 WS

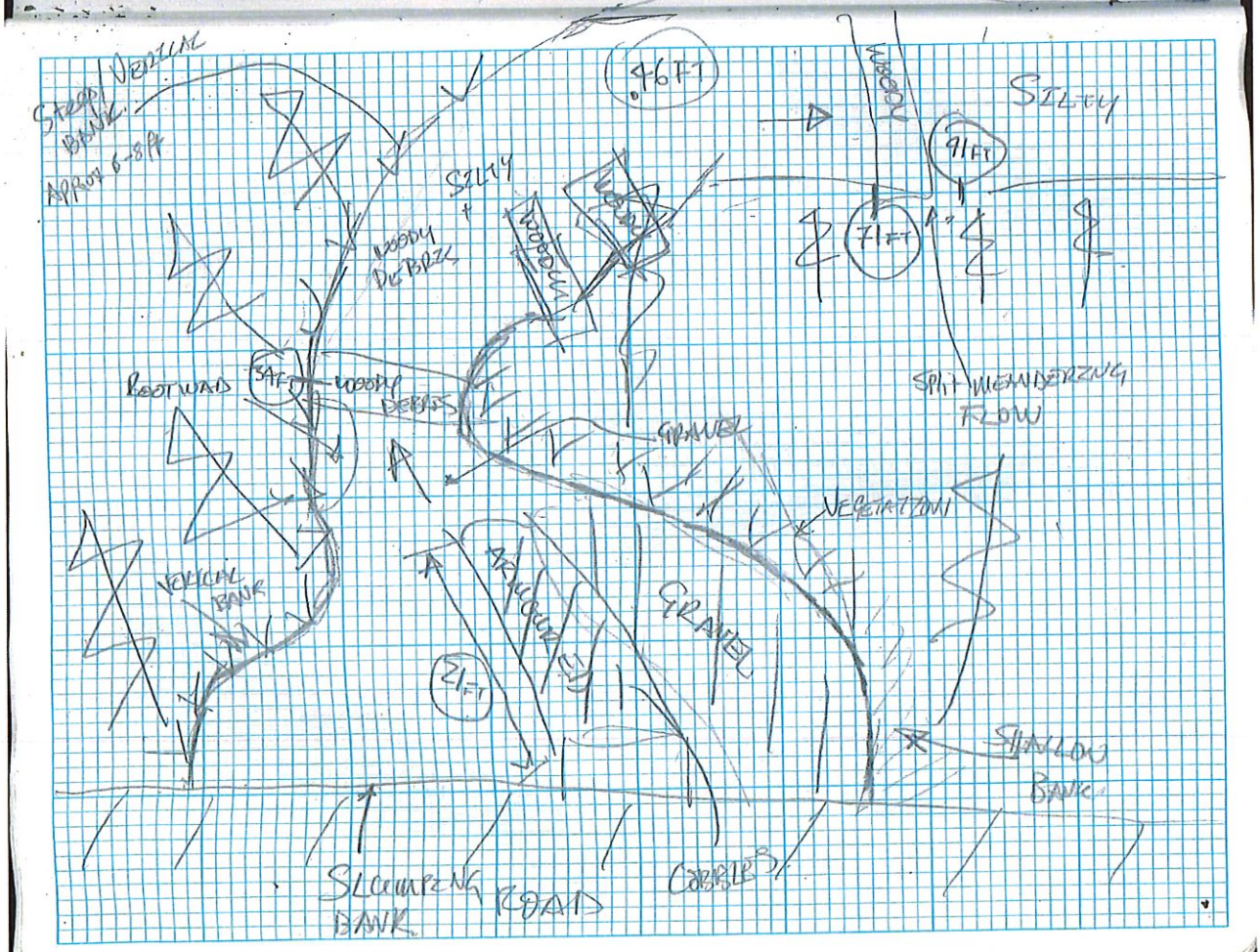


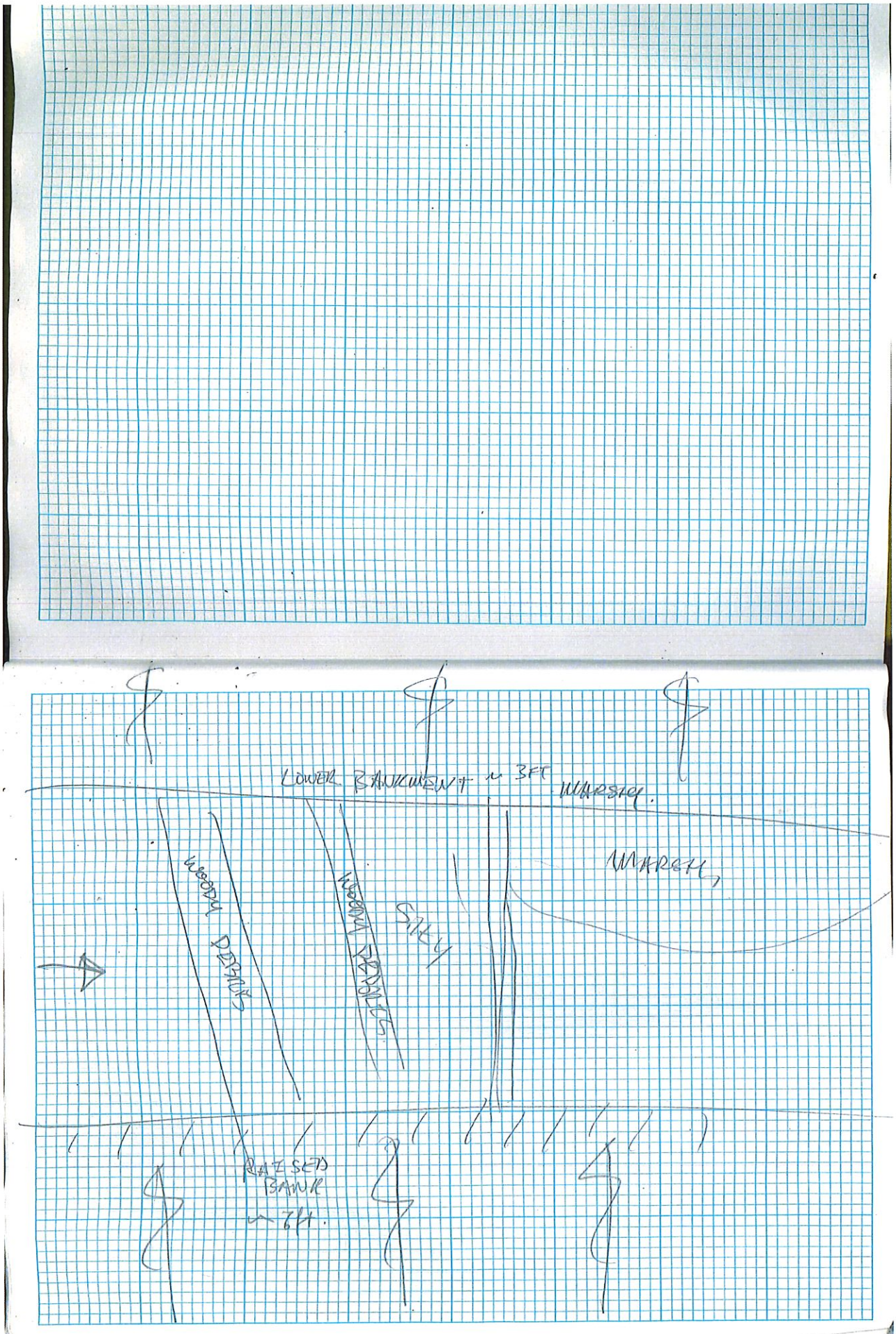

FELLED TREES
FELLED TREE
STATS


FELLED LOG (HALF)
FELLED LOG
STATS


FELLED TREES
LOTS OF SPLIT FLOW
WOODY DEBRIS
WOODY DEBRIS


Steep embankment ~ 6FT
MARSHY AREA
117FT
MINOR DEPOSITS OF GRAVEL
MEANDERING SPLIT FLOW
WOODY DEBRIS
SILTY
WOODY
PEBBLES
WOODY DEBRIS
SHALLOWER BANK
95 FT
SURVEY MARKER
106FT
132FT
209FT


STEEP VEGETATED BANK
APPROX 6-8FT
76FT
SILTY
WOODY DEBRIS
WOODY
91FT
71FT
ROOTWADS
SAND
WOODY DEBRIS
SPLIT MEANDERING FLOW
GRAVEL
VEGETATION
VERTICAL BANK
21FT
GRAVEL
SHALLOW BANK
SLUMPING BANK
ROAD
COBBLES


LOWER BASEMENT
MARKET
MARKET
RAISED BANK

APPENDIX B: SUBSTRATE DESIGN

New Stream Channel Design (Culvert, Rock Ramp)

Using Corps of Engineers Equations - FHWA Circular on Development in the River System - Page 6.25.
FHWA NHI 01-004; River Engineering for Highway Encroachments, 2001
http://www.fhwa.dot.gov/engineering/hydraulics/library_arc.cfm?pub_number=8&id=20

YELLOW ARE INPUTS			
Safety Factor	1.5		
Stability Coefficient for Incipient Failure	0.36	(0.36 round rock, 0.3 angular rock)	
Vertical Velocity Distribution Coeff	1.00	(1.0 for straight channels)	
Blanket Thickness Coeff	1	(1xD100 or 1.5 or D50 max, whichever is greater)	
Local depth of flow	2.3	ft for 100 year event	
Unit Weight of water	62.4	lb/ft^3	assumed
Unit weight of rock	165	lb/ft^3	assumed
Local depth-average velocity	5.23	ft/s from 100-year event avg. velocity in pipe	Approximate depth-ave for outlet velocities
Side Slope correction factor	1		
Gravitational Acceleration	32.2	ft/s^2	
D85/D15	3	(1.7-5.2)	
D50/D30	2		

Note: This method is based on the minimum D30 size

Riprap Design Method - Selecting Proper Gradation, Page 131.
Design Hydrology and Sedimentology for Small Catchments, Haan, Barfield and Hayes, 1981.

D15	0.1	ft	2.0	inches
D30	0.2	ft	3.0	inches
D50	0.3	ft	4.0	inches
D85	0.5	ft	6.0	inches
D100	0.6	ft	7.0	inches

Using D50 size, used FHWA circular for Rip Rap design to spec out D100, D85 and D15.
D100 = 2.0D50

Fuller-Thompson Estimating for Maximum Density: D100 (inch 12.0

Method Adapted from US Forest Service Stream Simulation Guideli D30 6.0 Stability (D30 OK

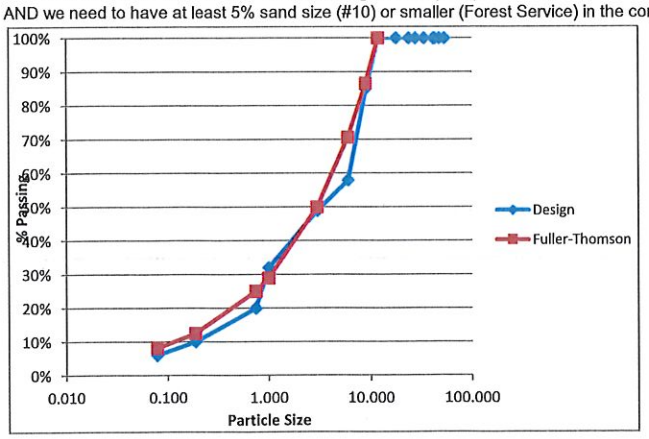
D30 Req'd 3.0

YELLOW ARE INPUTS

		COARSE	FINES				
		Custom	Fine Aggre	Combined ' F-T EQN		Check Coarse Material	
	RELATIVE % =	0.60	0.40	1.0000		Riprap	D30 Ripra
Size (inches)	Sieve Size	% Passing	% Passing	% Passing	% Passing	% Passing	D30 Size
54	54 in	1.00	1.00	100%	212%	100%	No
48	48 in	1.00	1.00	100%	200%	100%	No
44	44 in	1.00	1.00	100%	191%	100%	No
42	42 in	1.00	1.00	100%	187%	100%	No
34	34 in	1.00	1.00	100%	168%	100%	No
28	28 in	1.00	1.00	100%	153%	100%	No
24	24 in	1.00	1.00	100%	141%	100%	No
18	18 in	1.00	1.00	100%	122%	100%	No
12	12 in	1.00	1.00	100%	100%	100%	No
9	9 in	0.75	1.00	85%	87%	75%	No
6	6 in	0.30	1.00	58%	71%	30%	6.00
3	3 in	0.15	1.00	49%	50%	15%	3.00
1	1 in	0.10	0.65	32%	29%	10%	1.00
0.75	0.75 in	0.00	0.50	20%	25%	0%	0.75
0.187	#4	0.00	0.25	10%	12%	0%	0.19
0.0787	#10 Sand	0.00	0.15	6%	8%	0%	0.08

FA: Porous Backfill

Gradation values should be within +/-5% of this gradation (Rice)
AND we need to have at least 5% sand size (#10) or smaller (Forest Service) in the combined gradation



DATA for Graph & Fuller-Thomson

Size (in)	Combined %	F-T equati
54.000	100%	212%
48.000	100%	200%
44.000	100%	191%
42.000	100%	187%
34.000	100%	168%
28.000	100%	153%
24.000	100%	141%
18.000	100%	122%
12.000	100%	100%
9.000	85%	87%
6.000	58%	71%
3.000	49%	50%
1.000	32%	29%
0.750	20%	25%
0.187	10%	12%
0.079	6%	8%

APPENDIX C: HYDROLOGIC ANALYSIS

Cordova Hydrology - COP 9 and SHER 1						
Percent chance exceedance	Recurrence interval	2016 Regression (cfs)	2003 Regression (cfs)	COP9 Gage Record	COP9 Measured Discharge Coorelated to USGS Gage 15min (cfs)	COP9 Gage Daily to USGS Gage Daily (cfs)
	Q2D2	32.56	43.81	5.67	**7.30**	4.75
50	2	81.4	109.5	14.2	**18.3**	11.9
20	5	131.0	145.3	25.8	**24.0**	15.5
10	10	169.0	169.9	35.1	**27.4**	17.7
4	25	221.0	200.8	48.5	**31.5**	20.3
2	50	261.0	224.1	59.6	**34.4**	22.2
1	100	305.0	246.4	71.7	**37.1**	23.9
0.5	200	350.0	270.5	84.8	**39.8**	25.6
0.2	500	413.0	301.3			

APPENDIX D: HYDRAULIC ANALYSIS

HY-8 Culvert Analysis Report

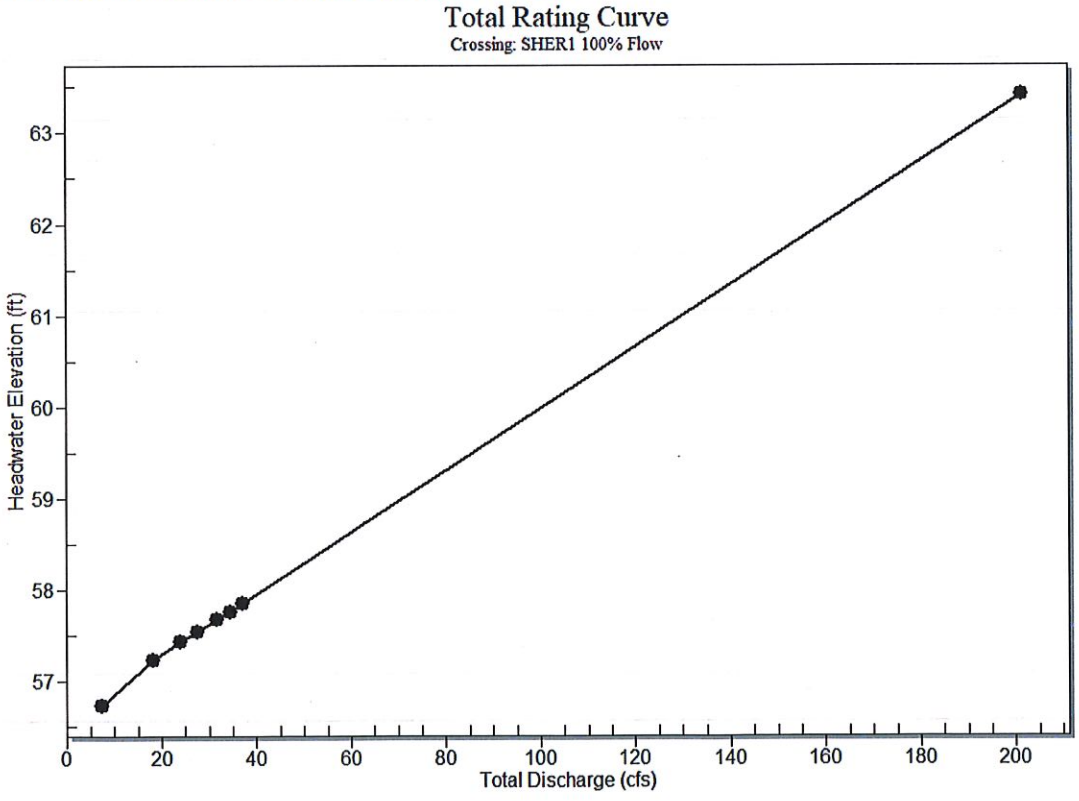
Crossing Discharge Data

Discharge Selection Method: User Defined

Table 1 - Summary of Culvert Flows at Crossing: SHER1 100% Flow

Headwater Elevation (ft)	Discharge Names	Total Discharge (cfs)	SHER1 65% 8-5 BY 6-3 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
56.74	Q2D2	7.32	7.32	0.00	1
57.23	Q2	18.30	18.30	0.00	1
57.43	Q5	24.00	24.00	0.00	1
57.54	Q10	27.40	27.40	0.00	1
57.68	Q25	31.50	31.50	0.00	1
57.77	Q50	34.40	34.40	0.00	1
57.85	Q100	37.10	37.10	0.00	1
63.35	Overtopping	193.84	193.84	0.00	Overtopping

Rating Curve Plot for Crossing: SHER1 100% Flow



Culvert Data: SHER1 65% 8-5 BY 6-3

Table 1 - Culvert Summary Table: SHER1 65% 8-5 BY 6-3

Discharge Names	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Q2D2	7.32 cfs	56.74	0.94	1.159	1.06	0.75	0.75	0.44	3.63	1.65
Q2	18.30 cfs	57.23	1.35	1.648	1.49	1.11	1.11	0.79	4.22	2.32
Q5	24.00 cfs	57.43	1.50	1.850	1.66	1.23	1.23	0.94	4.48	2.56
Q10	27.40 cfs	57.54	1.58	1.963	1.77	1.29	1.29	1.02	4.70	2.69
Q25	31.50 cfs	57.68	1.68	2.097	1.89	1.36	1.36	1.12	4.93	2.82
Q50	34.40 cfs	57.77	1.75	2.186	1.97	1.40	1.40	1.18	5.09	2.91
Q100	37.10 cfs	57.85	1.80	2.270	2.05	1.44	1.44	1.24	5.23	2.99

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

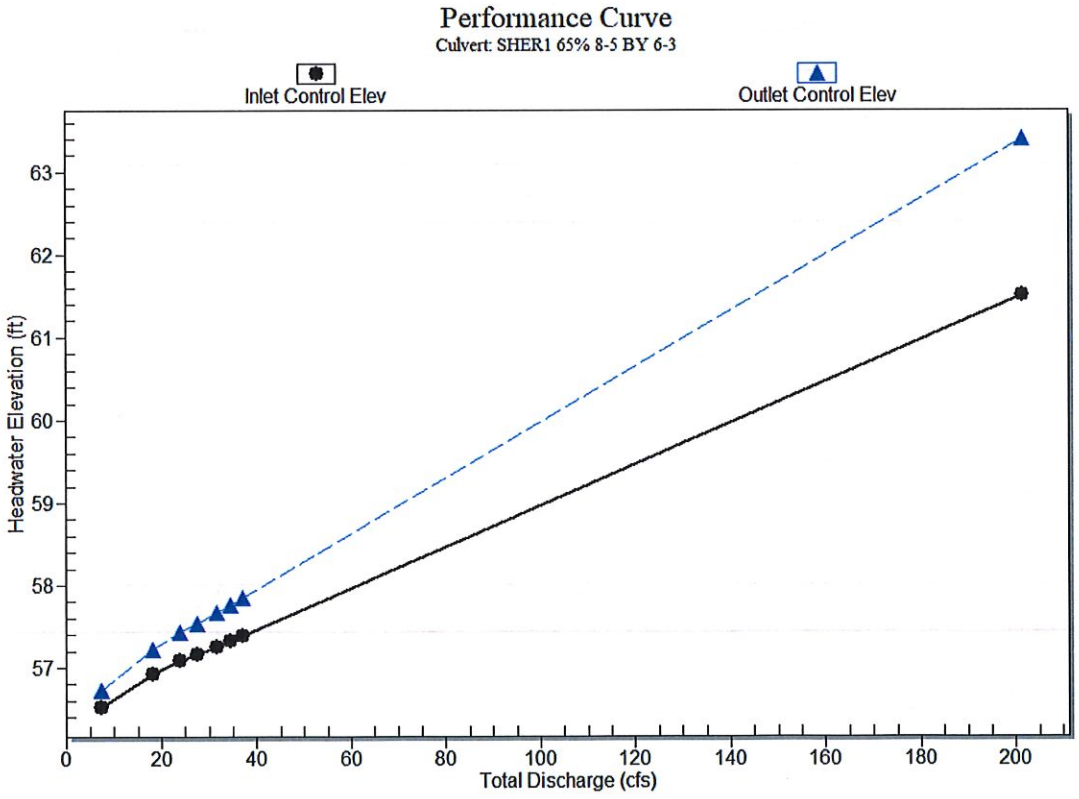
Inlet Elevation (invert): 55.58 ft,

Outlet Elevation (invert): 55.21 ft

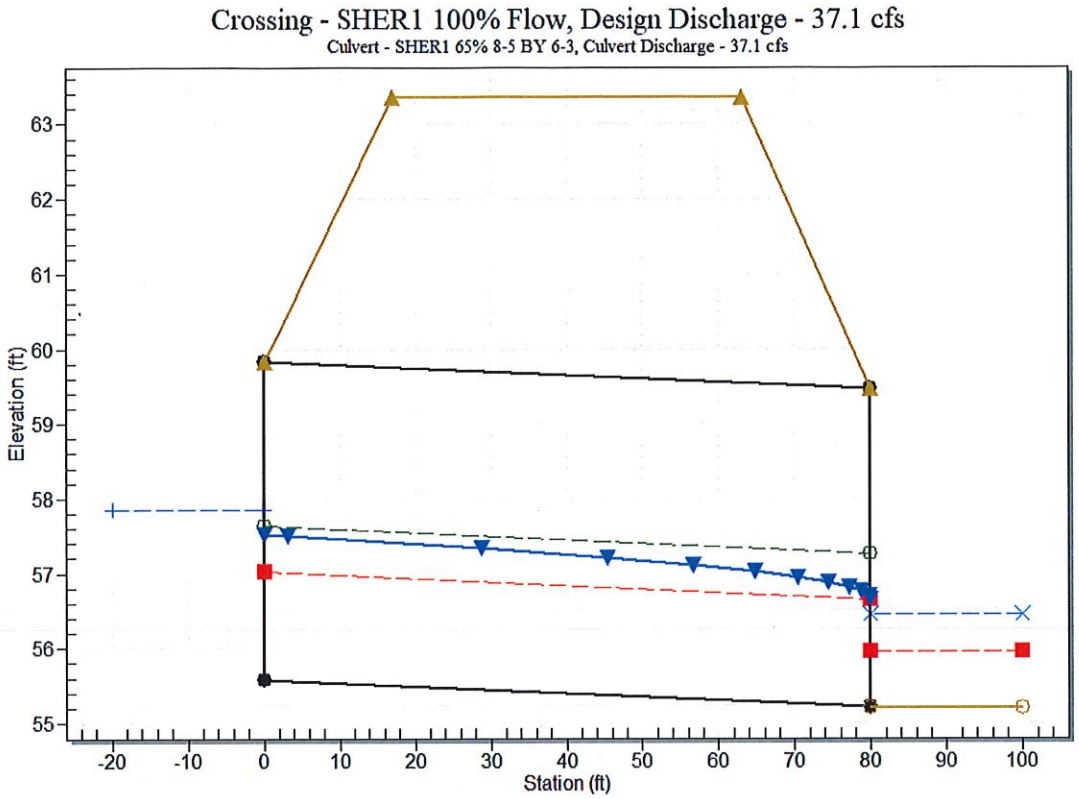
Culvert Length: 80.00 ft,

Culvert Slope: 0.0046

Culvert Performance Curve Plot: SHER1 65% 8-5 BY 6-3



Water Surface Profile Plot for Culvert: SHER1 65% 8-5 BY 6-3



Site Data - SHER1 65% 8-5 BY 6-3

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 55.58 ft

Outlet Station: 80.00 ft

Outlet Elevation: 55.21 ft

Number of Barrels: 1

Culvert Data Summary - SHER1 65% 8-5 BY 6-3

Barrel Shape: User Defined

Barrel Span: 8.59 ft

Barrel Rise: 4.25 ft

Barrel Material: Corrugated Metal Riveted or Welded

Embedment: 0.00 in

Barrel Manning's n: 0.0350 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

Tailwater Data for Crossing: SHER1 100% Flow

Table 2 - Downstream Channel Rating Curve (Crossing: SHER1 100% Flow)

Flow (cfs)	Water Surface Elev (ft)	Velocity (ft/s)	Depth (ft)	Shear (psf)	Froude Number
7.32	55.64	0.44	1.65	0.14	0.44
18.30	55.99	0.79	2.32	0.25	0.46
24.00	56.14	0.94	2.56	0.29	0.47
27.40	56.22	1.02	2.69	0.32	0.47
31.50	56.32	1.12	2.82	0.35	0.47
34.40	56.38	1.18	2.91	0.37	0.47
37.10	56.44	1.24	2.99	0.39	0.47

Tailwater Channel Data - SHER1 100% Flow

Tailwater Channel Option: Rectangular Channel

Bottom Width: 10.00 ft

Channel Slope: 0.0050

Channel Manning's n: 0.0350

Channel Invert Elevation: 55.20 ft

Roadway Data for Crossing: SHER1 100% Flow

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 63.35 ft

Roadway Surface: Paved

Roadway Top Width: 46.00 ft

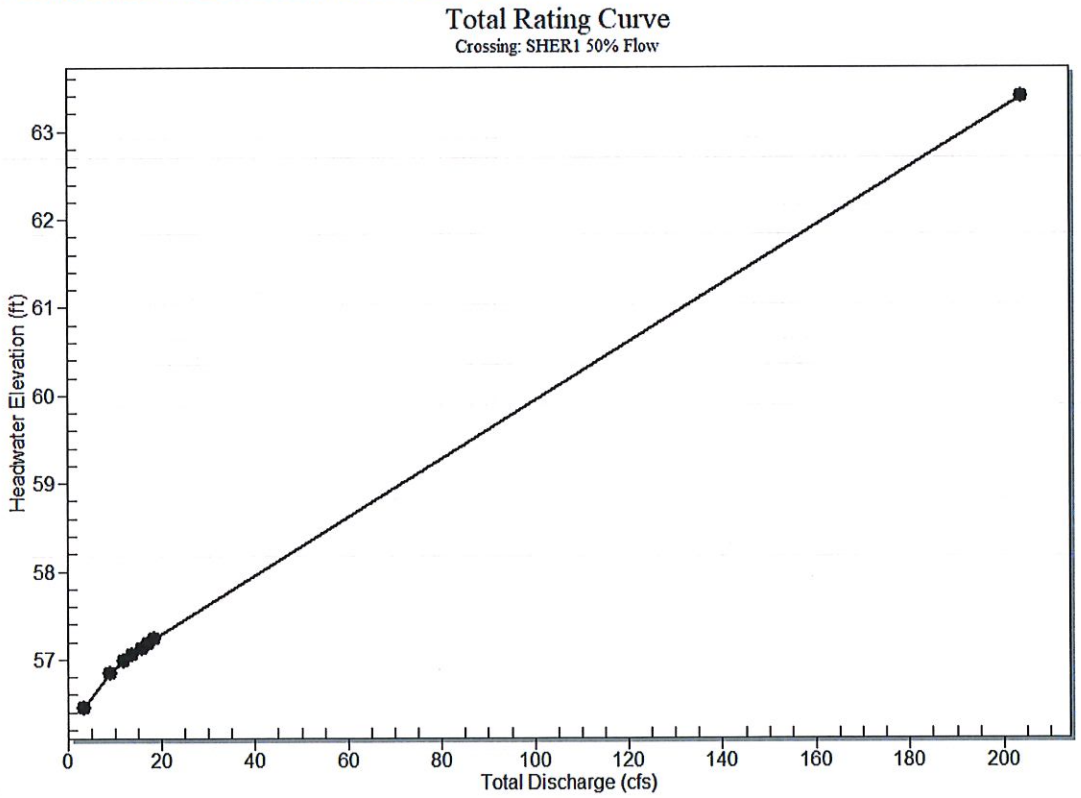
Crossing Discharge Data

Discharge Selection Method: User Defined

Table 3 - Summary of Culvert Flows at Crossing: SHER1 50% Flow

Headwater Elevation (ft)	Discharge Names	Total Discharge (cfs)	SHER1 65% 8-5 BY 6-3 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
56.45	Q2D2	3.66	3.66	0.00	1
56.84	Q2	9.15	9.15	0.00	1
56.98	Q5	12.00	12.00	0.00	1
57.05	Q10	13.70	13.70	0.00	1
57.13	Q25	15.75	15.75	0.00	1
57.19	Q50	17.20	17.20	0.00	1
57.24	Q100	18.55	18.55	0.00	1
63.35	Overtopping	199.67	199.67	0.00	Overtopping

Rating Curve Plot for Crossing: SHER1 50% Flow



Culvert Data: SHER1 65% 8-5 BY 6-3

Table 2 - Culvert Summary Table: SHER1 65% 8-5 BY 6-3

Discharge Names	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Q2D2	3.66 cfs	56.45	0.74	0.875	0.80	0.53	0.53	0.22	3.24	1.09
Q2	9.15 cfs	56.84	1.02	1.262	1.16	0.83	0.83	0.39	3.75	1.55

Q5	12.00 cfs	56.98	1.14	1.399	1.27	0.93	0.93	0.46	3.92	1.73
Q10	13.70 cfs	57.05	1.20	1.469	1.33	0.99	0.99	0.50	4.01	1.82
Q25	15.75 cfs	57.13	1.27	1.550	1.40	1.05	1.05	0.55	4.11	1.92
Q50	17.20 cfs	57.19	1.32	1.606	1.45	1.08	1.08	0.58	4.17	1.98
Q100	18.55 cfs	57.24	1.36	1.657	1.49	1.12	1.12	0.61	4.23	2.04

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

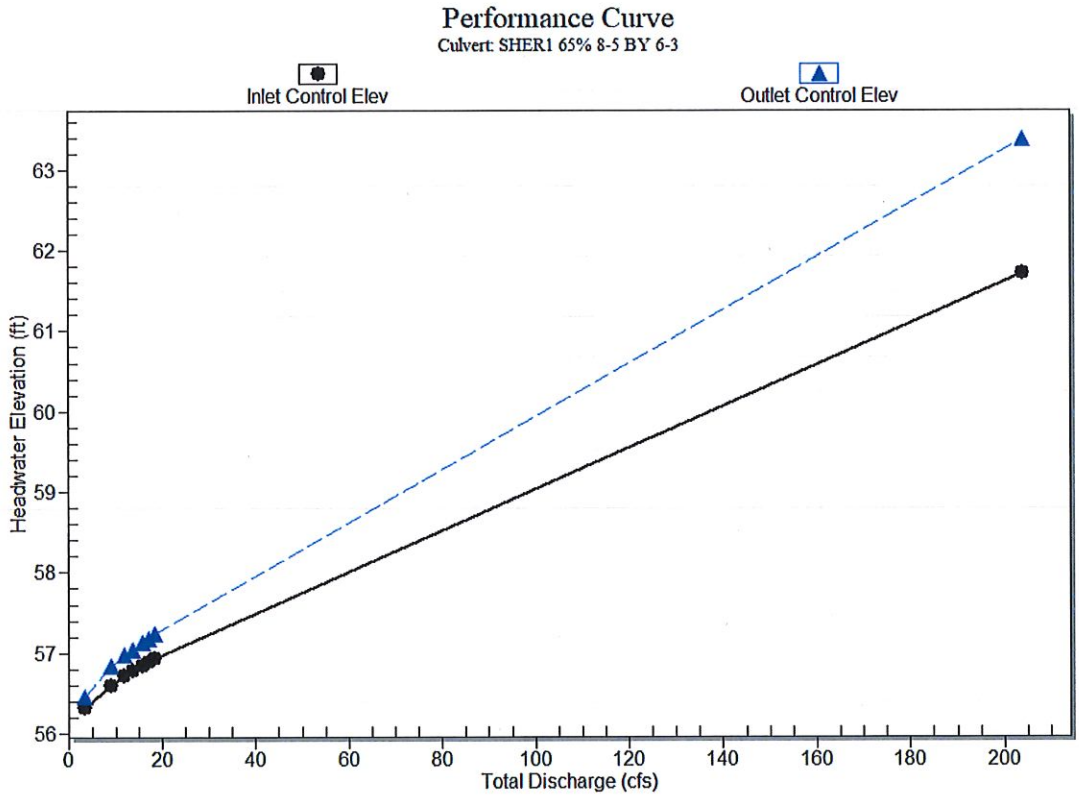
Inlet Elevation (invert): 55.58 ft,

Outlet Elevation (invert): 55.21 ft

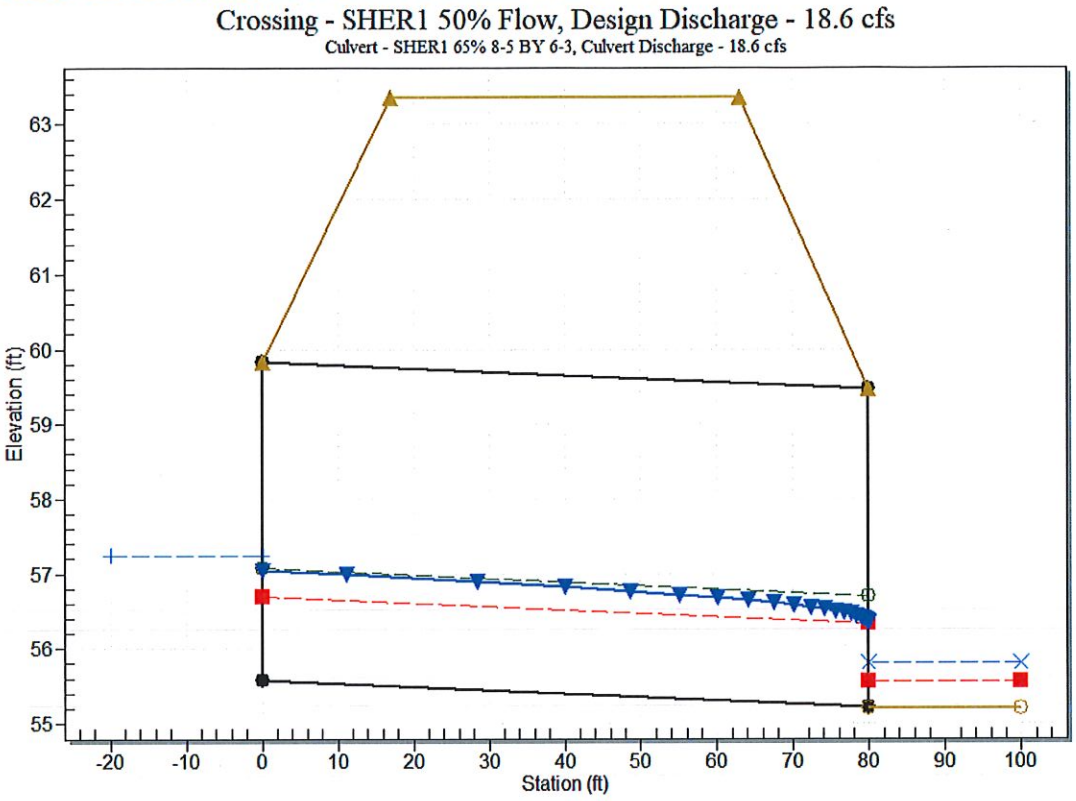
Culvert Length: 80.00 ft,

Culvert Slope: 0.0046

Culvert Performance Curve Plot: SHER1 65% 8-5 BY 6-3



Water Surface Profile Plot for Culvert: SHER1 65% 8-5 BY 6-3



Site Data - SHER1 65% 8-5 BY 6-3

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 55.58 ft

Outlet Station: 80.00 ft

Outlet Elevation: 55.21 ft

Number of Barrels: 1

Culvert Data Summary - SHER1 65% 8-5 BY 6-3

Barrel Shape: User Defined

Barrel Span: 8.59 ft

Barrel Rise: 4.25 ft

Barrel Material: Corrugated Metal Riveted or Welded

Embedment: 0.00 in

Barrel Manning's n: 0.0350 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

Tailwater Data for Crossing: SHER1 50% Flow

Table 4 - Downstream Channel Rating Curve (Crossing: SHER1 50% Flow)

Flow (cfs)	Water Surface Elev (ft)	Velocity (ft/s)	Depth (ft)	Shear (psf)	Froude Number
3.66	55.42	0.22	1.09	0.07	0.40
9.15	55.59	0.39	1.55	0.12	0.44
12.00	55.66	0.46	1.73	0.14	0.45
13.70	55.70	0.50	1.82	0.16	0.45
15.75	55.75	0.55	1.92	0.17	0.46
17.20	55.78	0.58	1.98	0.18	0.46
18.55	55.81	0.61	2.04	0.19	0.46

Tailwater Channel Data - SHER1 50% Flow

Tailwater Channel Option: Rectangular Channel

Bottom Width: 15.00 ft

Channel Slope: 0.0050

Channel Manning's n: 0.0350

Channel Invert Elevation: 55.20 ft

Roadway Data for Crossing: SHER1 50% Flow

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 63.35 ft

Roadway Surface: Paved

Roadway Top Width: 46.00 ft

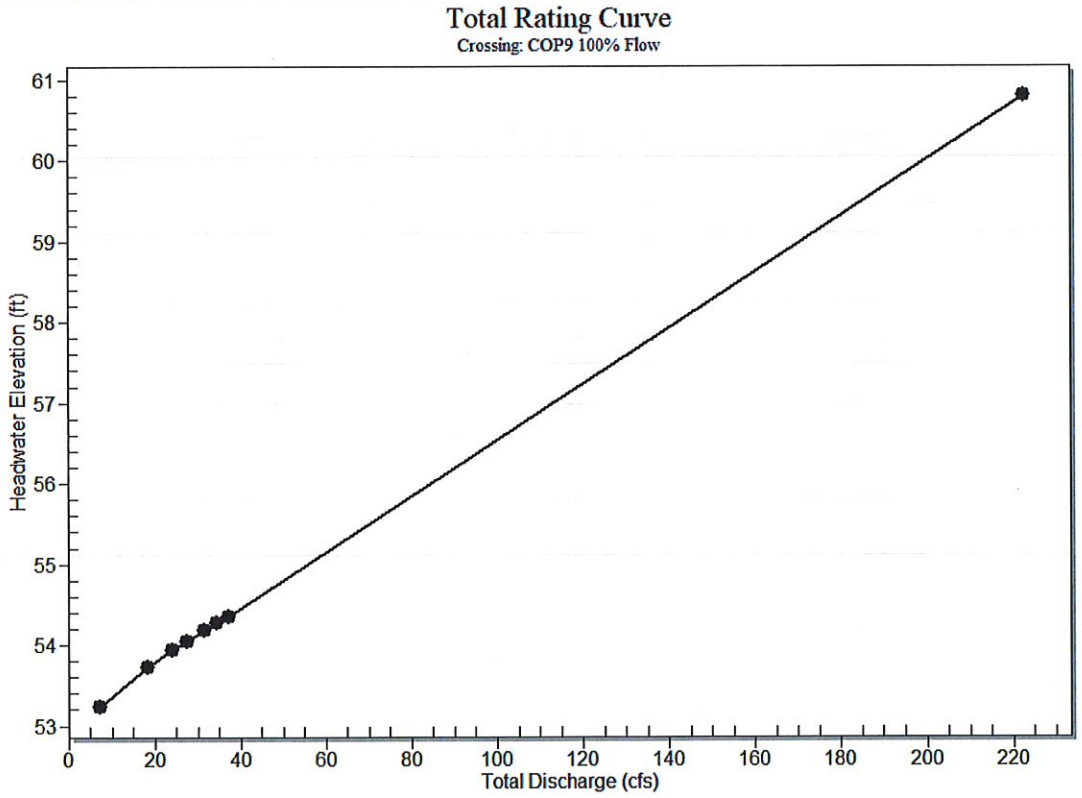
Crossing Discharge Data

Discharge Selection Method: User Defined

Table 5 - Summary of Culvert Flows at Crossing: COP9 100% Flow

Headwater Elevation (ft)	Discharge Names	Total Discharge (cfs)	COP9 65% 8-5 BY 6-3 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
53.24	Q2D2	7.32	7.32	0.00	1
53.73	Q2	18.30	18.30	0.00	1
53.94	Q5	24.00	24.00	0.00	1
54.05	Q10	27.40	27.40	0.00	1
54.18	Q25	31.50	31.50	0.00	1
54.28	Q50	34.40	34.40	0.00	1
54.36	Q100	37.10	37.10	0.00	1
60.74	Overtopping	214.18	214.18	0.00	Overtopping

Rating Curve Plot for Crossing: COP9 100% Flow



Culvert Data: COP9 65% 8-5 BY 6-3

Table 3 - Culvert Summary Table: COP9 65% 8-5 BY 6-3

Discharge Names	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Q2D2	7.32 cfs	53.24	0.94	1.171	1.09	0.75	0.75	0.34	3.63	1.43
Q2	18.30 cfs	53.73	1.35	1.662	1.52	1.11	1.11	0.60	4.22	2.03

Q5	24.00 cfs	53.94	1.50	1.866	1.71	1.23	1.23	0.71	4.48	2.25
Q10	27.40 cfs	54.05	1.59	1.983	1.82	1.29	1.29	0.77	4.70	2.37
Q25	31.50 cfs	54.18	1.68	2.114	1.94	1.36	1.36	0.84	4.93	2.49
Q50	34.40 cfs	54.28	1.75	2.205	2.03	1.40	1.40	0.89	5.09	2.58
Q100	37.10 cfs	54.36	1.81	2.288	2.12	1.44	1.44	0.93	5.23	2.65

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

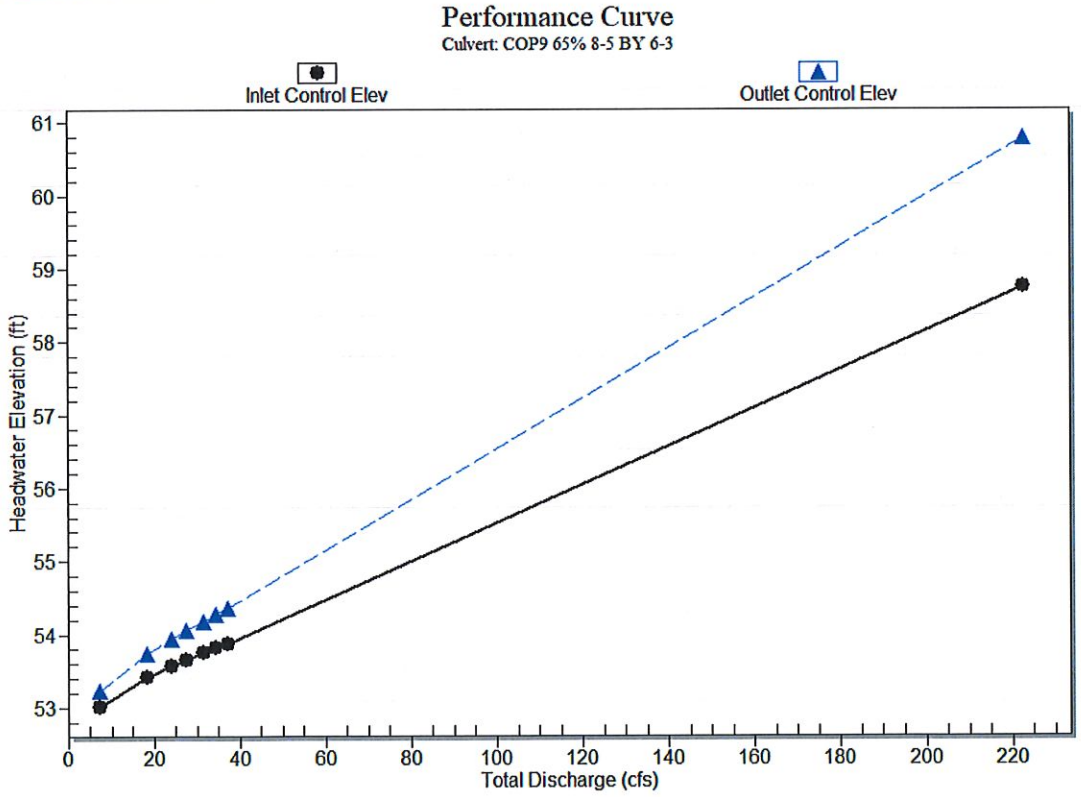
Inlet Elevation (invert): 52.07 ft,

Outlet Elevation (invert): 51.73 ft

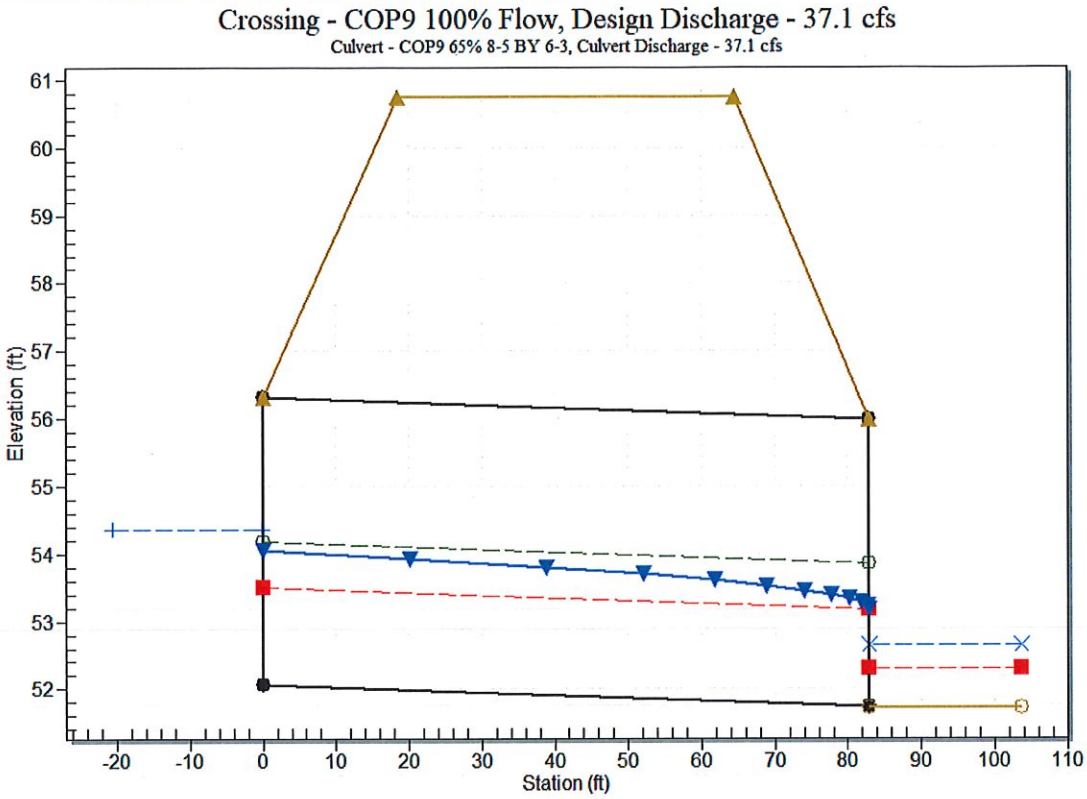
Culvert Length: 83.00 ft,

Culvert Slope: 0.0041

Culvert Performance Curve Plot: COP9 65% 8-5 BY 6-3



Water Surface Profile Plot for Culvert: COP9 65% 8-5 BY 6-3



Site Data - COP9 65% 8-5 BY 6-3

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 52.07 ft

Outlet Station: 83.00 ft

Outlet Elevation: 51.73 ft

Number of Barrels: 1

Culvert Data Summary - COP9 65% 8-5 BY 6-3

Barrel Shape: User Defined

Barrel Span: 8.59 ft

Barrel Rise: 4.25 ft

Barrel Material: Corrugated Metal Riveted or Welded

Embedment: 0.00 in

Barrel Manning's n: 0.0350 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting (Ke=0.9)

Inlet Depression: None

Tailwater Data for Crossing: COP9 100% Flow

Table 6 - Downstream Channel Rating Curve (Crossing: COP9 100% Flow)

Flow (cfs)	Water Surface Elev (ft)	Velocity (ft/s)	Depth (ft)	Shear (psf)	Froude Number
7.32	52.06	0.34	1.43	0.11	0.43
18.30	52.32	0.60	2.03	0.19	0.46
24.00	52.43	0.71	2.25	0.22	0.47
27.40	52.49	0.77	2.37	0.24	0.47
31.50	52.56	0.84	2.49	0.26	0.48
34.40	52.61	0.89	2.58	0.28	0.48
37.10	52.65	0.93	2.65	0.29	0.48

Tailwater Channel Data - COP9 100% Flow

Tailwater Channel Option: Rectangular Channel

Bottom Width: 15.00 ft

Channel Slope: 0.0050

Channel Manning's n: 0.0350

Channel Invert Elevation: 51.72 ft

Roadway Data for Crossing: COP9 100% Flow

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 60.74 ft

Roadway Surface: Paved

Roadway Top Width: 46.00 ft

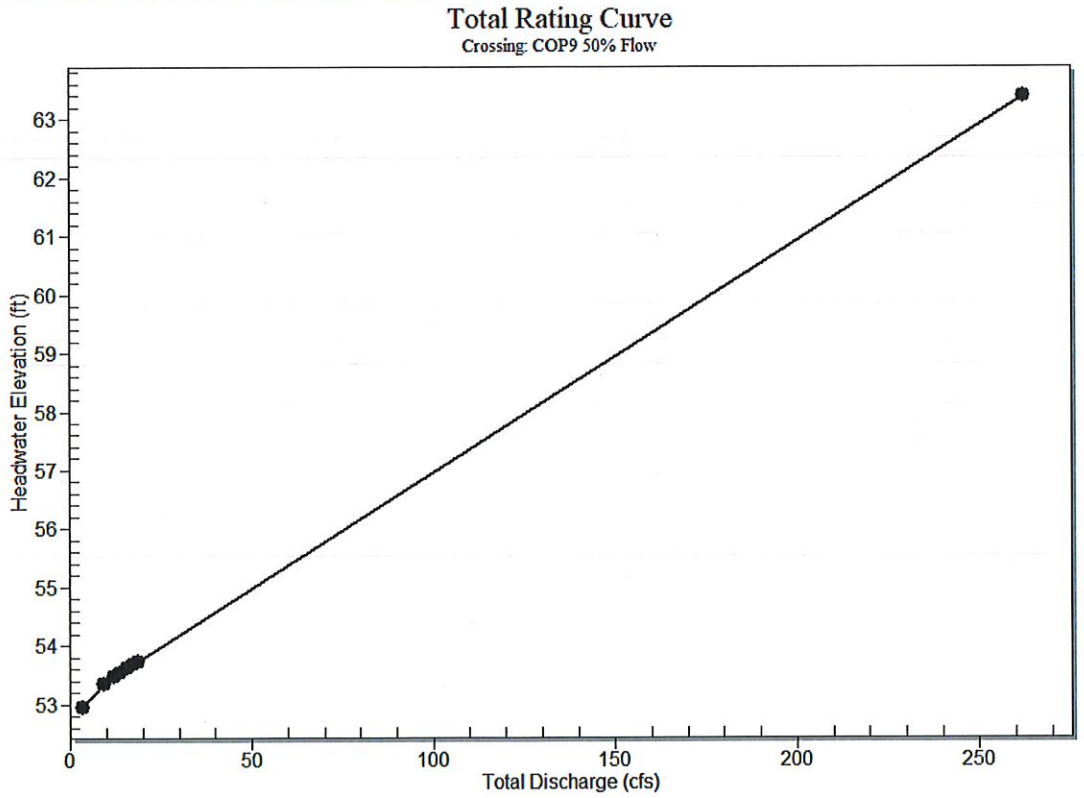
Crossing Discharge Data

Discharge Selection Method: User Defined

Table 7 - Summary of Culvert Flows at Crossing: COP9 50% Flow

Headwater Elevation (ft)	Discharge Names	Total Discharge (cfs)	COP9 65% 8-5 BY 6-3 Discharge (cfs)	Roadway Discharge (cfs)	Iterations
52.96	Q2D2	3.66	3.66	0.00	1
53.34	Q2	9.15	9.15	0.00	1
53.48	Q5	12.00	12.00	0.00	1
53.55	Q10	13.70	13.70	0.00	1
53.63	Q25	15.75	15.75	0.00	1
53.69	Q50	17.20	17.20	0.00	1
53.74	Q100	18.55	18.55	0.00	1
63.35	Overtopping	258.74	258.74	0.00	Overtopping

Rating Curve Plot for Crossing: COP9 50% Flow



Culvert Data: COP9 65% 8-5 BY 6-3

Table 4 - Culvert Summary Table: COP9 65% 8-5 BY 6-3

Discharge Names	Culvert Discharge (cfs)	Headwater Elevation (ft)	Inlet Control Depth (ft)	Outlet Control Depth (ft)	Normal Depth (ft)	Critical Depth (ft)	Outlet Depth (ft)	Tailwater Depth (ft)	Outlet Velocity (ft/s)	Tailwater Velocity (ft/s)
Q2D2	3.66 cfs	52.96	0.74	0.887	0.82	0.53	0.53	0.22	3.24	1.09
Q2	9.15 cfs	53.34	1.02	1.275	1.18	0.83	0.83	0.39	3.75	1.55

Q5	12.00 cfs	53.48	1.14	1.410	1.30	0.93	0.93	0.46	3.92	1.73
Q10	13.70 cfs	53.55	1.20	1.482	1.36	0.99	0.99	0.50	4.01	1.82
Q25	15.75 cfs	53.63	1.27	1.565	1.43	1.05	1.05	0.55	4.11	1.92
Q50	17.20 cfs	53.69	1.32	1.621	1.48	1.08	1.08	0.58	4.17	1.98
Q100	18.55 cfs	53.74	1.36	1.672	1.53	1.12	1.12	0.61	4.23	2.04

Culvert Barrel Data

Culvert Barrel Type Straight Culvert

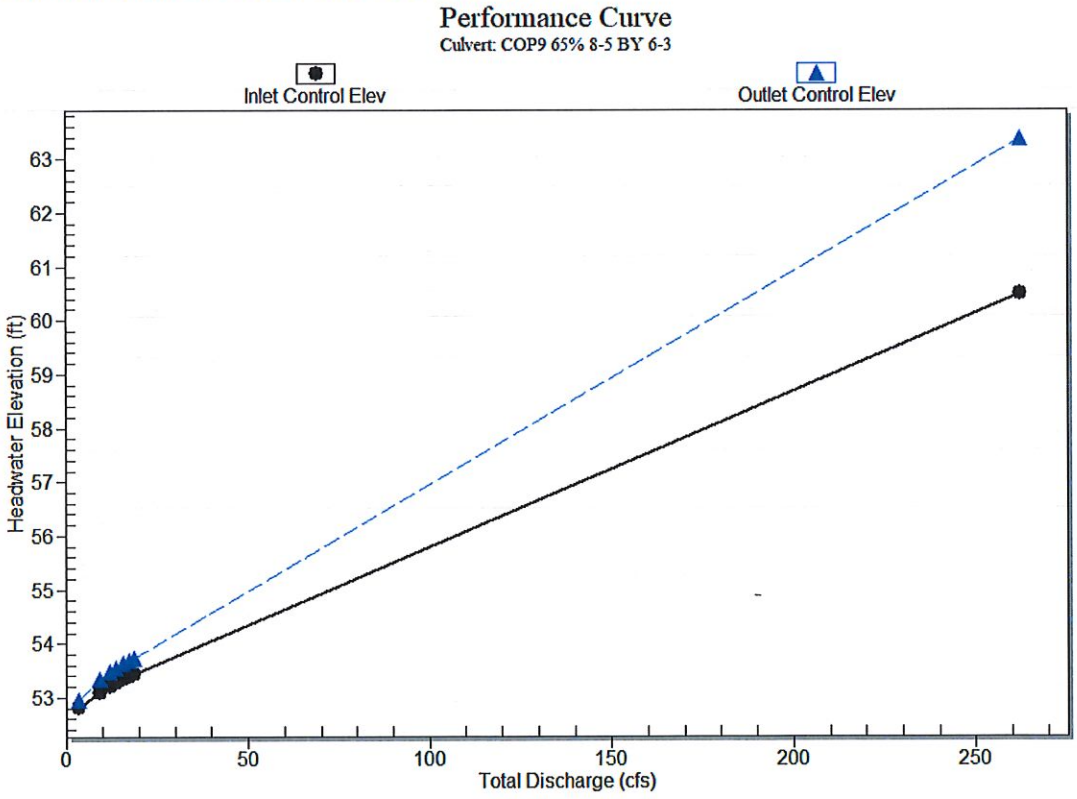
Inlet Elevation (invert): 52.07 ft,

Outlet Elevation (invert): 51.73 ft

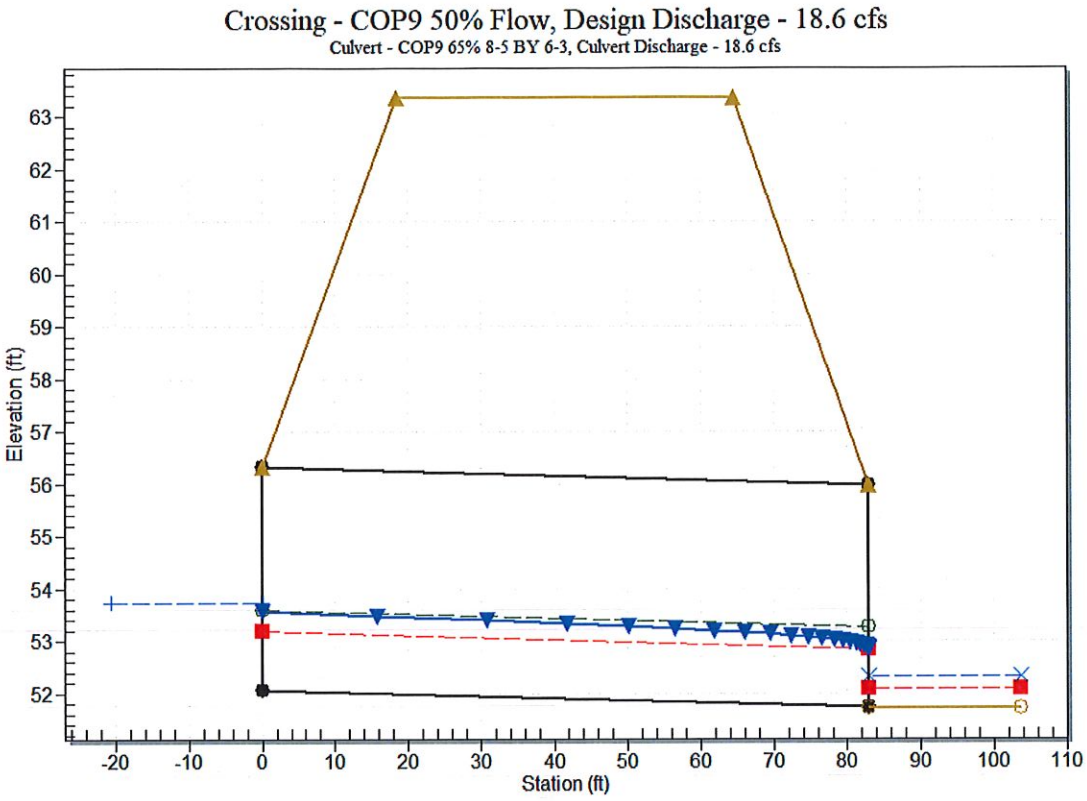
Culvert Length: 83.00 ft,

Culvert Slope: 0.0041

Culvert Performance Curve Plot: COP9 65% 8-5 BY 6-3



Water Surface Profile Plot for Culvert: COP9 65% 8-5 BY 6-3



Site Data - COP9 65% 8-5 BY 6-3

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 52.07 ft

Outlet Station: 83.00 ft

Outlet Elevation: 51.73 ft

Number of Barrels: 1

Culvert Data Summary - COP9 65% 8-5 BY 6-3

Barrel Shape: User Defined

Barrel Span: 8.59 ft

Barrel Rise: 4.25 ft

Barrel Material: Corrugated Metal Riveted or Welded

Embedment: 0.00 in

Barrel Manning's n: 0.0350 (top and sides)

Manning's n: 0.0350 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

Tailwater Data for Crossing: COP9 50% Flow

Table 8 - Downstream Channel Rating Curve (Crossing: COP9 50% Flow)

Flow (cfs)	Water Surface Elev (ft)	Velocity (ft/s)	Depth (ft)	Shear (psf)	Froude Number
3.66	51.94	0.22	1.09	0.07	0.40
9.15	52.11	0.39	1.55	0.12	0.44
12.00	52.18	0.46	1.73	0.14	0.45
13.70	52.22	0.50	1.82	0.16	0.45
15.75	52.27	0.55	1.92	0.17	0.46
17.20	52.30	0.58	1.98	0.18	0.46
18.55	52.33	0.61	2.04	0.19	0.46

Tailwater Channel Data - COP9 50% Flow

Tailwater Channel Option: Rectangular Channel

Bottom Width: 15.00 ft

Channel Slope: 0.0050

Channel Manning's n: 0.0350

Channel Invert Elevation: 51.72 ft

Roadway Data for Crossing: COP9 50% Flow

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 63.35 ft

Roadway Surface: Paved

Roadway Top Width: 46.00 ft