# CORDOVA FISH PASSAGE IMPROVEMENTS – CAB 1 AND CAB 2

## 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 remove two existing culverts in the Copper River Delta near Cordova, Alaska, replacing one of them with a new culvert that will improve fish passage and providing channel and stream bank restoration where the second culvert is removed. The replacement culvert and stream bank restoration will enhance flood and fish passage and ecologic function at the road crossings of Elsner River Tributary by simulating the natural creek channel and provide conveyance of at least the 100-year flood flow. The culvert will also enhance maintenance conditions at the remaining crossing and reduce the likelihood of future infrastructure damage caused by flooding along the road. The Elsner River Tributary is an anadromous stream originating northeast of Cabin Lake Road and flowing southwest to Elsner River and the Little Glacier Slough. The Elsner Creek Tributary is fed by subsurface flows and does not respond significantly to precipitation. The project crossing drainage basin is shown in Figure 1.

The Elsner River Tributary is identified in the Alaska Department of Fish and Game's (ADF&G) Anadromous Waters Catalog (AWC) as number 212-10-10030-2150-3016. The stream crossings have been identified as No. 20101904 (CAB 1) and No. 20101905 (CAB 2) in the ADF&G's Fish Passage Inventory Database (FPID). CAB 2 has been given a Red rating and CAB 1 has been given a Green rating. The Elsner River Tributary provides rearing habitat for Coho salmon.

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 to 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

CAB 2 is located on Cabin Lake Road, downstream of CAB 1. The existing culvert at CAB 2 is 3 feet in diameter and 35 feet long. The culvert has a gradient of 1.1% and a constriction ratio of 0.34. Corrosion has been observed on the existing culvert with a rust line height of 2.8 feet. Additionally, the culvert is backwatered and the culvert inlet is squashed with the bottom of culvert bent up preventing low flows to enter the pipe. There is minimal cover over the pipe. CAB 2 was given an overall fish passage rating of Red in 2011 by ADF&G. Remnants of an old timber weir are located just upstream of CAB 2.

CAB 1 in located on an old, abandoned spur road of Cabin Lake Road, upstream of CAB 2 and the old weir. The existing culvert at CAB 1 is 3 feet in diameter and 21 feet long. The culvert has a gradient of 2% and a constriction ratio of 0.22. Corrosion has been observed on the existing culvert with a rust line height of 1.65 feet. The crossing was observed to have inadequate road fill volume above the culvert. Despite these negative characteristics, CAB 1 was given an overall fish passage rating of Green in 2011 by ADF&G due to the backwater characteristics.


**Figure 1: CAB 1 and CAB 2 Drainage Basin**

## 1.3 Design Criteria

The geomorphic analog method is the preferred design approach for the CAB 1 and CAB 2 crossings of Elsner 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; and
- 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 or less.

## 1.4 Right-of-Way and Utilities

Cabin Lake Road is owned by the USFS.

No known utilities are located along Cabin Lake Road at the CAB 1 and CAB 2 crossings.

# 2.0 GEOTECHNICAL CONDITIONS

A geotechnical investigation consisting of two borings at each crossing was conducted at the two fish passage crossing locations in April 2019 by Northern Geotechnical Engineering, Inc. The subsurface conditions encountered, soil bearing capacity, and site-specific geotechnical construction recommendations are summarized below.

## 2.1 CAB 1 and CAB 2

### *2.1.1 North*

- 0 to 7 feet: Well graded gravel with silt and sand. Groundwater encountered at approximately 4.5 feet.
- 7 to 15 feet: Well graded sand with silt and gravel.
- 15 to 18 feet: Sandy silt.
- 18 to 21.5 feet: Silty sand

### *2.1.2 South*

- 0 to 3 feet: Poorly graded gravel with silt and sand.
- 3 to 4.5 feet: Silt with sand. Groundwater encountered at approximately 4.5 feet.
- 4.5 to 6 feet: Silty sand with gravel.
- 6 to 7 feet: Wood.
- 7 to 15 feet: Well graded gravel with sand.
- 15 to 18 feet: Sandy silt.
- 18 to 21.5 feet: Silty sand.

### *2.1.3 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.

### *2.1.4 Construction Recommendations*

Site bearing soils approximately 10 to 11 feet below the road surface consist of loose well graded sand and gravel. Excavation is required a minimum of 2 feet below the bottom of the culvert. Organic material observed must be completely removed and inspected to ensure all organic materials have been removed. The very loose/soft soils should be removed during excavation of the unsuitable organic material. Then placement of geotextile, reinforcement, type 2 and Subbase, Grading F material is required, as described in the next section.

## 2.2 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.

## 3.1 Stream Morphology and Crossing Characteristics

### *3.1.1 CAB 1 and CAB 2*

Elsner River Tributary is a spring fed tributary that originates northeast of Cabin Lake Road and flows southwest into Elsner River.

CAB 1 is located upstream of CAB 2. Upstream of the CAB 1 Old Timber Road crossing, the Elsner River Tributary is heavily vegetated, with significant woody debris. The stream is meandering with several channels of split flow and ponded areas. Gravel is present inside the pipe and near the outlet of the pipe. The Old Timber Road embankment over the pipe is split open, indicating overtopping. The predominant bedform features consist of slow pools with occasional riffles, woody debris steps, and ponded areas. Upstream is low gradient and the banks are low and vegetation and woody debris provide bank stabilization. The stream substrate consists of a various range of gravel sizes and organics. Riparian vegetation includes grasses, moss, fern, alder, willow, hemlock, and spruce trees. The floodplain is wide.

There is a gravel bar just downstream of the CAB 1 culvert. A ponded area with woody debris is located downstream of CAB 1 and upstream of CAB 2 with remnants of an old timber weir approximately 30 feet upstream of CAB 2. Downstream of the CAB 2 Cabin Lake Road crossing, the Elsner River Tributary is meandering with slow pools and woody debris steps. Downstream is low gradient and the banks are low and vegetation and woody debris provide bank stabilization. It appears that the relic channel is beginning to narrow and become more confined. Stream substrate consists of a various range of gravel sizes with some small cobbles, sand and organics. Riparian vegetation includes grasses, moss, fern, alder, willow, hemlock, and spruce trees. The floodplain is wide.

A reference reach was not defined at this crossing, but two cross sections were measured upstream and downstream of the crossings, outside of the surveyed area. Observed bankfull width at the crossing upstream was 4 feet with a bankfull depth of 16 inches. The observed bankfull width at the crossing downstream was 3 feet with a bankfull depth of 11 inches. The channel slope is approximately 0.6 percent.

The observed stream characteristics of Elsner River Tributary at the measured cross sections at CAB 1 and CAB 2 are summarized in Table 1.

**Table 1: Observed Stream Characteristics of Elsner River Tributary at CAB 1 and CAB 2**

| Stream Parameter | Existing Conditions |
|---|---|
| Surveyed WSE Slope | 0.6 percent |

| | |
|---|---|
| Measured Bankfull Width | 3 to 4 feet |
| Measured Bankfull Depth | 1.1+/- feet |
| Bedform Features | Step-Pools, Riffles, Fines |

The Cabin Lake Road roadway embankment at CAB 2 is well vegetated with recent grading of the gravel road. There is between 0.5 and 1.3 feet of roadway cover over the existing culvert. No end sections or headwalls are present at the CAB 1 and CAB 2 culverts.

## 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 CAB 1 and CAB 2 Upstream*

One pebble count was conducted approximately 140 feet upstream of CAB 2 and just downstream of CAB 1. The $D_{84}$ particle size was 55.0 millimeters (mm). The armor layer upstream of CAB 2 and downstream of CAB 1 was found to range from fine gravel to small cobble, with most of the stream substrate consisting of course and very coarse gravel. A summary of the pebble counts is shown in Figure 2 and Table 2.

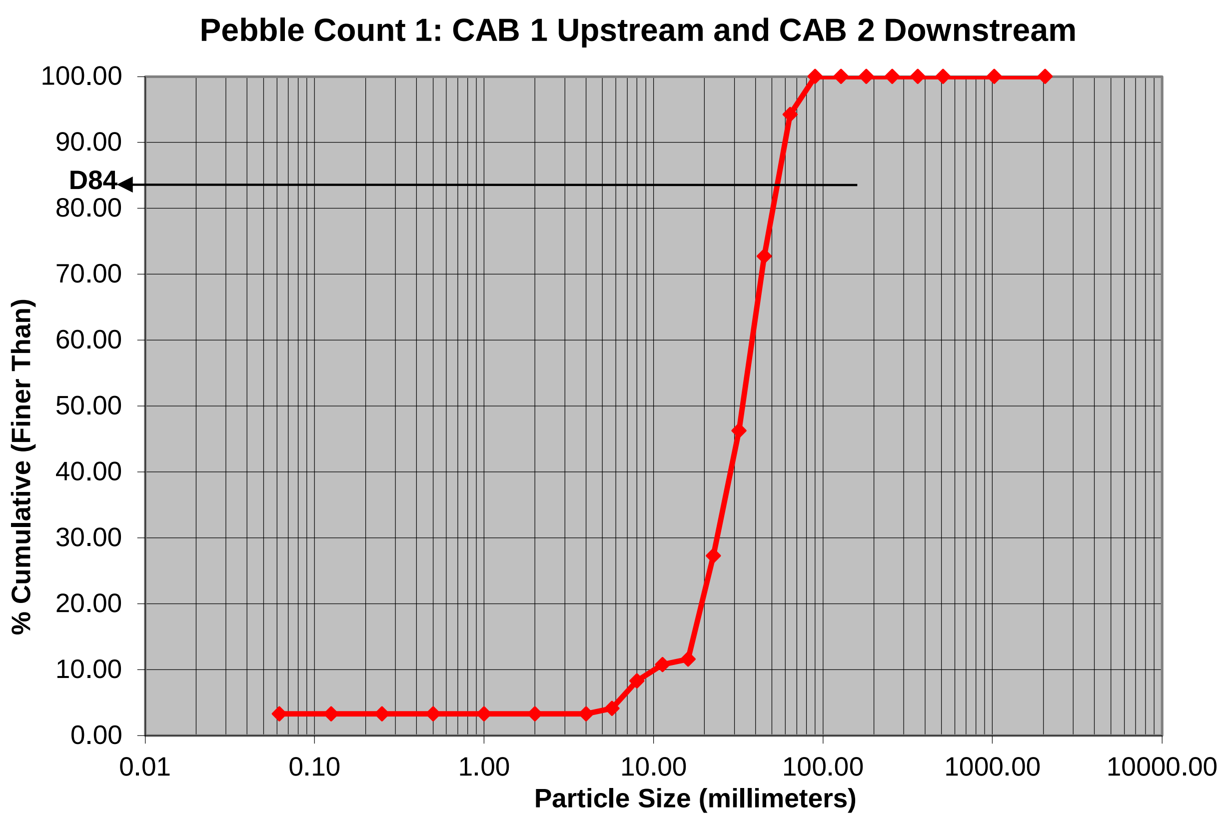


**Figure 2: Summary of CAB 1 and CAB 2 Upstream Pebble Count**

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 stream section. 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 2: CAB 1 and CAB 2 Upstream Pebble Count Summary**

| **Particle Size** | **Count 1** |
|---|---|
| | **140 feet Upstream CAB 2** |
| *$D_{100}$ (mm)* | 90 |
| *$D_{84}$ (mm)* | 55.0 |
| *$D_{50}$ (mm)* | 33.8 |

### *3.2.2 CAB 1 and CAB 2 Downstream*

Two pebble counts were conducted downstream of CAB 1 and CAB 2; pebble count 1 was taken in a riffle and pebble count 2 was taken at the outlet of CAB 2. The average $D_{84}$ particle size downstream of CAB 1 and CAB 2 was 80 millimeters (mm). The armor layer downstream of CAB 1 and CAB 2 was found to range from medium gravel to small cobble, with most of the stream substrate consisting of medium to very coarse cobble. A summary of the pebble counts is shown in Figure 3 and Table 3.

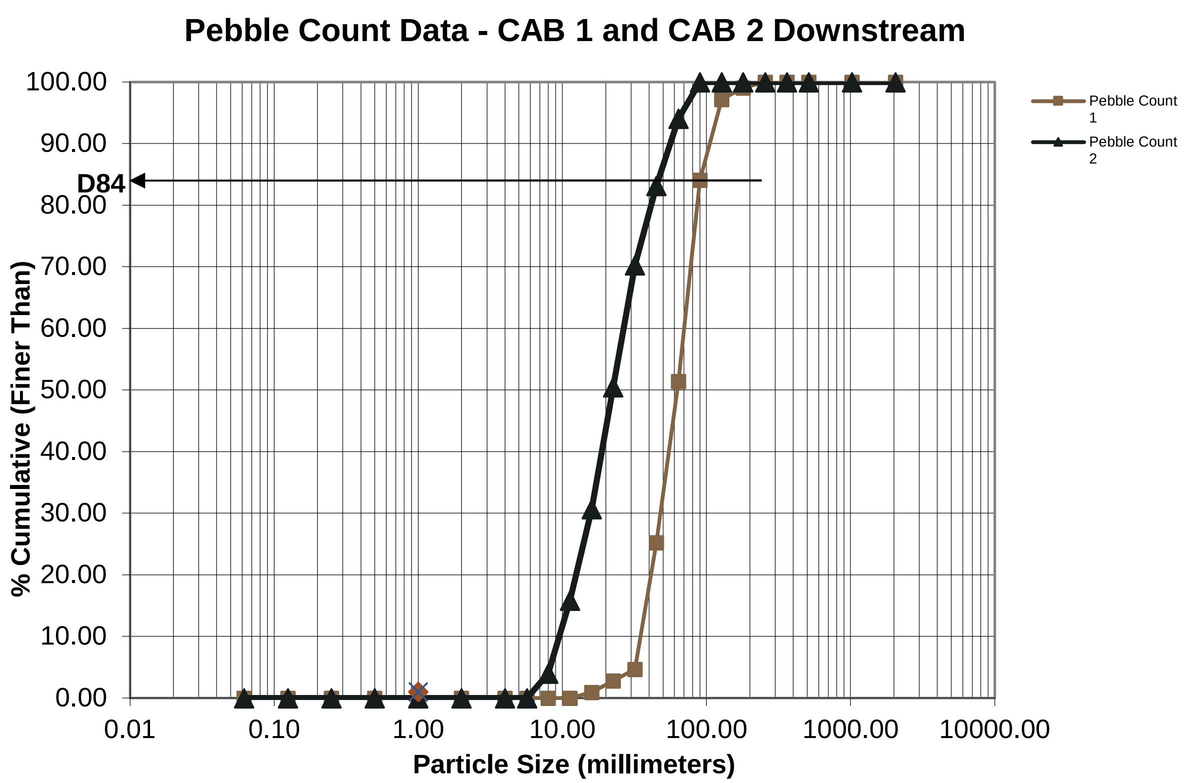


**Figure 3: Summary of CAB 1 and CAB 2 Downstream Pebble Counts**

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: CAB 1 and CAB 2 Downstream Pebble Count Summary**

| Particle Size | Count 1 | Count 2 |
|---|---|---|
| | Downstream | Downstream |
| $D_{100}$ *(mm)* | 256 | 90 |
| $D_{84}$ *(mm)* | 90 | 46.5 |
| $D_{50}$ *(mm)* | 63 | 22.4 |

# 4.0 HYDROLOGIC ANALYSIS

## 4.1 Drainage Area Characteristics

The Elsner River Tributary CAB 1 and CAB 2 drainage basin flowing to Cabin Lake Road is approximately 48 acres (0.08 square miles) in size. The drainage basin is an undeveloped, forested area.

## 4.2 Methodology

Four methods of quantifying flow were compared to identify the most appropriate design discharge likely experienced by the crossings. Cordova's interconnected floodplain hydrology is not thought to be accurately captured by the USGS regional regression equations. The flow estimates derived from the regression equations were supplemented by flow estimates derived from stage-discharge measurements at CAB 2 completed by the USFWS.

The 2003 and the 2016 Regional Regression Equations were used to estimate peak discharges for the Elsner 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 104.46 inches for CAB 1 and CAB 2. The drainage basin for CAB 1 and CAB 2 is smaller than the 0.4 square mile lower limit area so WinTR-55 was used in addition to the Regional Regression Equations.

The stage was measured at CAB 2 for two and three years, respectively. Flow measurements were taken in the field by CRWP and USFWS 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.

## 4.3 Results of Flood Flow Analysis

### *4.3.1 CAB 1 and CAB 2*

The peak runoff flows for each analysis method for CAB 1 and CAB 2 are shown in Table 4.

**Table 4: Estimated Peak Flows for CAB 1 and CAB 2**

| Storm Event (year) | 2016 Regional Regression (cfs) | 2003 Regional Regression (cfs) | WinTR-55 (cfs) | LPIII Flood Frequency Estimate (cfs) |
|---|---|---|---|---|
| 2 | 12.6 | 23.4 | 16.3 | **6.3** |
| 5 | 22.3 | 31.6 | 23.8 | **8.0** |
| 10 | 30.0 | 37.1 | 30.0 | **9.0** |
| 25 | 41.0 | 44.0 | 38.9 | **10.1** |
| 50 | 49.8 | 49.1 | 46.2 | **10.9** |
| 100 | 59.7 | 54.1 | 53.9 | **11.7** |

Notes: cfs = cubic feet per second

The flow estimates derived from measured stage at the site are significantly lower than the USGS regression equations and Win TR-55 flow estimates. The flow estimates based on measured stage appear to match observations made during the July 2021 site visits and the groundwater fed nature of this system. Given the period of record, 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 CAB 2 and stream widths for CAB 1 have been evaluated for hydraulic capacity based on the 100-year peak flow of 11.7 cubic feet per second (cfs).

# 5.0 HYDRAULIC ANALYSIS

## 5.1 Bankfull Velocity and Discharge Estimates

The bankfull discharge and velocity was 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.

| ESTIMATION METHODS | Bankfull VELOCITY | | Bankfull DISCHARGE | |
|---|---|---|---|---|
| 1. Friction Factor / Relative Roughness $\bar{u} = [\,2.83 + 5.66 * Log\,\{\,R / D_{84}\,\}\,]\,u^*$ | 1.89 | ft / sec | 6.25 | 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 | 1.73 | ft / sec | 5.71 | cfs |

A 3-foot bankfull riffle width resulted in the calculated 6.25 cfs and 5.71 cfs bankfull discharge for the crossings which is less than the 2-year storm event for the estimated peak flows.

| ESTIMATION METHODS | Bankfull VELOCITY | | Bankfull DISCHARGE | |
|---|---|---|---|---|
| 1. Friction Factor / Relative Roughness $\bar{u} = [\,2.83 + 5.66 * Log\,\{\,R / D_{84}\,\}\,]\,u^*$ | 2.09 | ft / sec | 9.22 | 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 | 1.86 | ft / sec | 8.20 | cfs |

A 4-foot bankfull riffle width resulted in the calculated 9.22 cfs and 8.20 cfs bankfull discharge for the crossings which is between the 5- and 10-year storm event for the estimated peak flows.

The 4-foot bankfull width was used for the design to be conservative, due to the limited duration of stage measurements and the higher peak flows calculated using the Regression and WinTR-55 peak runoff flow methods.

## 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 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. Supporting calculations are included in Appendix D. Structures were selected for analysis based on span dictated by the measured bankfull widths and HW/D ratios.

## 5.3 Low Flow Channel

### *5.3.1 CAB 2*

The low-flow channel for the CAB 2 crossing was 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.

### *5.3.2 CAB 1*

The USDA Forest Service *Low Water Crossings: Geomorphic, Biological, and Engineering Design Considerations* (2008) was used as guidance to determine site hydraulic factors needed for design of the low-water crossing at CAB 1. Manning's equation was used to determine flow depth and velocity through the respective components of the channel section. Supporting calculations are included in Appendix D. The geometry of the crossing was selected for analysis based existing measured bankfull widths and the ability to pass a 60mm design fish during $Q_2D_2$ flows.

# 6.0 DESIGN ALTERNATIVES

Design guidelines recommend that culvert span for proposed replacement structures should be at least 1.0 times bankfull width and up to 1.4 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 box culvert, pipe arch culvert and round culvert sizes at CAB 2. Applicable culvert shapes for each crossing were determined with consideration given to groundwater elevations and available cover over the pipe.

Aluminum and steel structural plate 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 CAB 2 include:

- 73-inch span by 55-inch rise aluminized corrugated steel pipe arch embedded 2 feet ($Q_{100}$ HW/D=0.41),
- 81-inch span by 59-inch rise aluminized corrugated steel pipe arch embedded 2 feet ($Q_{100}$ HW/D=0.35),
- 6-foot aluminized corrugated steel round pipe embedded 2.9 feet ($Q_{100}$ HW/D=0.34),
- 7-foot aluminized corrugated steel round pipe embedded 3.9 feet ($Q_{100}$ HW/D=0.33),
- A 9-foot, 7-inch span by 4-foot, 1-inch rise aluminum box culvert embedded 2 feet ($Q_{100}$ HW/D=0.62),
- A 10-foot, 0-inch span by 4-foot, 10-inch rise aluminum box culvert embedded 2 feet ($Q_{100}$ HW/D=0.45),
- A 10-foot, 7-inch span by 3-foot,5-inch rise aluminum box culvert embedded 2 feet ($Q_{100}$ HW/D=0.95),
- A 11-foot, 11-inch span by 3-foot, 7-inch rise aluminum box culvert embedded 2 feet ($Q_{100}$ HW/D=0.78),
- A 13-foot, 7-inch span by 4-foot, 7-inch rise aluminum box culvert embedded 2 feet ($Q_{100}$ HW/D=0.47), and

Channel and streambank replacement options considered for CAB 1 include:

- A 4-foot wide, 1V:1.5H slope trapezoidal channel section, with $Q_2D_2$ flows depth to meet 60 mm (2.36 inches) design fish minimum depth. ($Q_2D_2$ flow depth=4.15 inches),
- A 7.5-foot wide, 1V:5H slope trapezoidal channel section, with $Q_2D_2$ flows depth to meet 60 mm (2.36 inches) design fish minimum depth. ($Q_2D_2$ flow depth=2.90 inches),
- A 10-foot wide, 1V:5H slope trapezoidal channel section, with $Q_2D_2$ flows depth to meet 60 mm (2.36 inches) design fish minimum depth. ($Q_2D_2$ flow depth=2.45 inches), and

# 7.0 RECOMMENDATIONS

### *7.1.1 CAB 2*

Replacing the 3-foot diameter round culvert at the CAB 2 crossing with a 6-foot round aluminized steel culvert is the recommended option for improving fish passage and flood conveyance at the Elsner River Tributary crossing.

This replacement option is anticipated to convey the $Q_{100}$ of 11.7 cfs and the $Q_{50}$ of 10.9 cfs with a HW/D ratio of approximately 0.34 and 0.32, respectively. The round culvert will be embedded 2.9 feet. Minimum allowable cover over the culvert is approximately 2 feet. Roadway overtopping would occur at a flow of approximately 67.51 cfs.

The recommended culvert meets the criteria to accommodate the 100-year flood flow with a HW/D ratio less than 0.8. No overtopping of the existing culvert has been noted during storm events, inferring that flow rerouting or storage of runoff upstream of CAB 2 occurs. The round culvert will provide an adequate span to facilitate construction of an approximately 4-foot-wide channel. The culvert will be embedded with waterway bed material to mimic natural substrate. The waterway bed fill material, which is a mix of selected material, type A and class I riprap will be shaped to retain a 4-foot bankfull width inside the culvert. Reconstructed stream banks upstream and downstream from the culvert will consist of vegetated mats and woody debris where necessary. The embankment slopes will be stabilized with Class I riprap to provide erosion protection.

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

**Table 5: Ratio of Culvert Width to Bankfull Width**

| | |
|---|---|
| Culvert Width | 6 feet |
| Bankfull Width | 4 feet |
| Ratio | 1.5 |

### *7.1.2 CAB 1*

Replacing the 3-foot diameter round culvert at the CAB 1 crossing with a 4-foot wide channel section with 4-foot woody debris banks topped with vegetative mat is the recommended option for improving fish passage and flood conveyance at the Elsner River Tributary crossing.

This replacement option is anticipated to convey the $Q_{100}$ of 11.7 cfs and the $Q_{50}$ of 10.9 cfs with a flow depth of approximately 0.83 feet and 0.80 feet, respectively.

## 7.2 Rejected Alternatives

### *7.2.1 CAB 2*

The 73-inch span by 55-inch rise pipe arch and the 81-inch span by 59-inch rise pipe arch were considered for the crossing but eliminated due to rise, constructability for placing embedment material and availability. The 7-foot round pipe embedded 3.9 feet was considered but eliminated due to the additional depth of excavation and embedment for minimal additional hydraulic capacity. The 9-foot, 7-inch span by 4-foot, 1-inch rise aluminum box culvert, the 10-foot, 7-inch span by 3-foot, 5-inch rise aluminum box culvert, the 11-foot,11-inch span by 3-foot, 7-inch rise aluminum box culvert, and the 13-foot, 7-inch span by 4-foot, 7-inch rise aluminum box culvert were considered for the crossing but eliminated due to over widening of the crossing.

Aluminum and steel structural plate pipe arch and round culvert options were considered but rejected due to higher cost and installation time. Aluminum corrugated pipe arch and round culverts were eliminated due to limited available cover over the pipe.

### *7.2.2 CAB 1*

The 7.5-foot width channel section was considered for the crossing but eliminated due to bankfull width. The 15-foot-wide channel section was considered for the crossing but eliminated due to bankfull width and the $Q_2D_2$ flow depth being too shallow for the design fish.

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# APPENDIX A: GEOMORPHIC ANALYSIS

**Stream Crossing Site Assessment**
**Reference Reach Data Sheet**

**DOWL**
**Revised RDP 08212015**

| | |
|---|---|
| **Project:** | **Project Number:** |
| **Date:** 7/22/21 | **Assessed by:** EAM/HCR/BMM |
| **Crossing ID:** CAB 1 & 2 Downstream | |
| **Weather Conditions:**<br>55°F Cloudy | |
| **CROSSING CHARACTERISTICS:** | |
| **Existing Culvert/Crossing:**<br>4' Round Rusted (not smushed), 1' cover over pipe, Rust line ½ half Barrel<br>CAB2DS | |
| **Geomorphology/Stream Type/Bedform Features:**<br>sorted cobble/gravel @ outlet → Relic channel filling in, narrowing<br>woody, step/pool - evidence beaver activity | |
| **Substrate/Bed Mobility:**<br>→ downstream turns sandy/organics<br>woody debris | |
| **Floodplain Characteristics/Entrenchment:**<br>wide | |
| **Flow/Velocity Estimates:** | |
| **Tie-in Points:** DS1 → Flow path: large Rock for velocity<br>DS2 → Pipe outlet pebble count | |

**PEBBLE COUNT**

Site:
Party:
Reach:
Date:

| Inches | PARTICLE | Millimeters | | PARTICLE COUNT 1 (DS1) | 2 (DS2) | 3 | TOT # | ITEM % | % CUM | TOT # | ITEM % | % CUM | TOT # | ITEM % | % CUM |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | Silt / Clay | < .062 | S/C | | | | | | | | | | | | |
| | Very Fine | .062 - .125 | SAND | | | | | | | | | | | | |
| | Fine | .125 - .25 | SAND | | | | | | | | | | | | |
| | Medium | .25 - .50 | SAND | | | | | | | | | | | | |
| | Coarse | .50 - 1.0 | SAND | | | | | | | | | | | | |
| .04 - .08 | Very Coarse | 1.0 - 2 | SAND | | | | | | | | | | | | |
| .08 - .16 | Very Fine | 2 - 4 | GRAVEL | | | | | | | | | | | | |
| .16 - .22 | Fine | 4 - 5.7 | GRAVEL | | | | | | | | | | | | |
| .22 - .31 | Fine | 5.7 - 8 | GRAVEL | | \|\|\|\| | | | | | | | | | | |
| .31 - .44 | Medium | 8 - 11.3 | GRAVEL | | 卌 卌 \| | | | | | | | | | | |
| .44 - .63 | Medium | 11.3 - 16 | GRAVEL | \| | 卌 卌 卌 | | | | | | | | | | |
| .63 - .89 | Coarse | 16 - 22.6 | GRAVEL | \|\| | 卌 卌 卌 卌 | | | | | | | | | | |
| .89 - 1.26 | Coarse | 22.6 - 32 | GRAVEL | \|\| | 卌 卌 卌 卌 | | | | | | | | | | |
| 1.26 - 1.77 | Very Coarse | 32 - 45 | GRAVEL | 卌 卌 卌 卌 \|\| | 卌 卌 \|\|\| | | | | | | | | | | |
| 1.77 - 2.5 | Very Coarse | 45 - 64 | GRAVEL | 卌 卌 卌 卌 卌 \|\|\| | 卌 \| | | | | | | | | | | |
| 2.5 - 3.5 | Small | 64 - 90 | COBBLE | 卌 卌 卌 卌 卌 卌 | 卌 \| | | | | | | | | | | |
| 3.5 - 5.0 | Small | 90 - 128 | COBBLE | 卌 卌 \|\|\|\| | | | | | | | | | | | |
| 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 → | | | | | | | | | | |

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THE REFERENCE REACH FIELD BOOK

Stream Crossing Site Assessment
Reference Reach Data Sheet

DOWL
Revised RDP 08212015

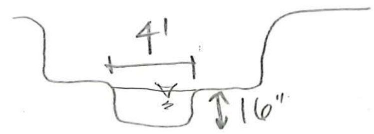
| Date: | Project Number: |
|---|---|

**UPSTREAM REFERENCE REACH:**

| Channel Cross Section Shape: | Channel Slope: |
|---|---|

| Δ from Xing | Bankfull Width | Bankfull Depth | Bed Width | Floodplain Width | Riffles | |
|---|---|---|---|---|---|---|
| | | | | | Δ Xing | Length |
| | | | | | | |

**Channel Stability Notes:**




BFW=4' BFD=16"

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

| Pools | | | Steps | | | | Ribs | | Notes: |
|---|---|---|---|---|---|---|---|---|---|
| Δ Xing | Length | Depth | Δ Xing | Height | Type | Stability | Δ Xing | Stability | |
| | | | | | | | | | |

**Vegetation:**
hemlock, spruce, devels club, moss, alder, willow

**Bedrock Observed:**

**DOWNSTREAM REFERENCE REACH:**

| Channel Cross Section Shape: | Channel Slope: |
|---|---|

| Δ from Xing | Bankfull Width | Bankfull Depth | Bed Width | Floodplain Width | Riffles | |
|---|---|---|---|---|---|---|
| | | | | | Δ Xing | Length |
| | | | | | | |

**Channel Stability Notes:**

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

| Pools | | | Steps | | | | Ribs | | Notes: |
|---|---|---|---|---|---|---|---|---|---|
| Δ Xing | Length | Depth | Δ Xing | Height | Type | Stability | Δ Xing | Stability | |
| | | | | | | | | | |

**Vegetation:**

**Bedrock Observed:**

US wingwall
ds

**Stream Crossing Site Assessment**
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**DOWL**
**Revised RDP 08212015**

**Project:**
**Project Number:**
**Date:** 7/22/21
**Assessed by:** EAM/HCK/BMM
**Crossing ID:** CAB 1 & 2 Upstream
**Weather Conditions:** 55°F Cloudy

**CROSSING CHARACTERISTICS:**

**Existing Culvert/Crossing:** old trail/Road cultural Res?
CAB2 @ cabin lake Rd. → Rusted, 48" Round, crushed, oval now (inlet)
CAB 1 @ old Rd. 3' Round Rusted, good shape ~new 60" Round Aluminum

**Geomorphology/Stream Type/Bedform Features:** low flow channel: 6-8" deep 1.5' wide!
ponded @ inlet, ponding,
step/pool (woody debris steps)

**Substrate/Bed Mobility:**
silt/clay US, organics, Reeds/Pondweed, woody debris (a lot @ bottom) gravel near Banks CAB2
CAB1: gravel/cobble @ outlet, no fine sediments, low mobility/no sed transport
sand US, woody debris

**Floodplain Characteristics/Entrenchment:**
~40-50' US wide!
→ further US steep high bank more entrenched

**Flow/Velocity Estimates:**
slow pond US, clear → GW fed

**Tie-in Points:**
gravel bar @ outlet CAB1 → 129-151.5'
CAB2 US1 → pebble count just DS of CAB 1

**PEBBLE COUNT**

Site:
Party:
Reach:
Date:

| Inches | PARTICLE | Millimeters | | PARTICLE COUNT 1 (US1 / DS1) | 2 | 3 | TOT # | ITEM % | % CUM |
|---|---|---|---|---|---|---|---|---|---|
| | Silt / Clay | < .062 | S/C | \|\|\|\| | | | | | |
| | Very Fine | .062 - .125 | SAND | | | | | | |
| | Fine | .125 - .25 | | | | | | | |
| | Medium | .25 - .50 | | | | | | | |
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| .31 - .44 | Medium | 8 - 11.3 | | \|\|\| | | | | | |
| .44 - .63 | Medium | 11.3 - 16 | | \| | | | | | |
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| .89 - 1.26 | Coarse | 22.6 - 32 | | 卌 卌 卌 卌 \|\|\| | | | | | |
| 1.26 - 1.77 | Very Coarse | 32 - 45 | | 卌 卌 卌 卌 卌 卌 \|\| | | | | | |
| 1.77 - 2.5 | Very Coarse | 45 - 64 | | 卌 卌 卌 卌 卌 \| | | | | | |
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| 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 | | BDRK | | | | | | |
| | | | | TOTALS → | | | | | |

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

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WSE will drop u/s → show Before/after WSE (gw?) upwelling?
CAB 1 has overflow path
how far to tie new str
culvert
mini survey of old Road for removal → low flow channel @ outlet, Build floodplain? Rd ACC

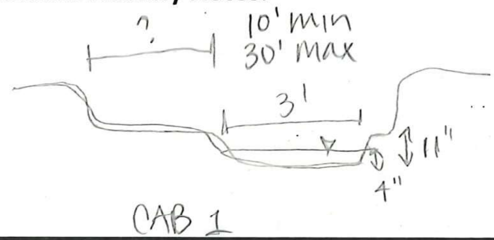
| **Date:** | **Project Number:** |
|---|---|

**UPSTREAM REFERENCE REACH:**

| **Channel Cross Section Shape:** | **Channel Slope:** |
|---|---|

| **Δ from Xing** | **Bankfull Width** | **Bankfull Depth** | **Bed Width** | **Floodplain Width** | **Riffles** | |
|---|---|---|---|---|---|---|
| | | | | | Δ Xing | Length |
| | | | | | | |

**Channel Stability Notes:**




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

| **Pools** | | | **Steps** | | | | **Ribs** | | **Notes:** |
|---|---|---|---|---|---|---|---|---|---|
| Δ Xing | Length | Depth | Δ Xing | Height | Type | Stability | Δ Xing | Stability | |
| | | | | | | | | | |

**Vegetation:** fern, devils club, moss, spruce, willow, alder, hemlock, salmonberries, blueberries

**Bedrock Observed:**

**DOWNSTREAM REFERENCE REACH:**

| **Channel Cross Section Shape:** | **Channel Slope:** |
|---|---|

| **Δ from Xing** | **Bankfull Width** | **Bankfull Depth** | **Bed Width** | **Floodplain Width** | **Riffles** | |
|---|---|---|---|---|---|---|
| | | | | | Δ Xing | Length |
| | | | | | | |

**Channel Stability Notes:**

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

| **Pools** | | | **Steps** | | | | **Ribs** | | **Notes:** |
|---|---|---|---|---|---|---|---|---|---|
| Δ Xing | Length | Depth | Δ Xing | Height | Type | Stability | Δ Xing | Stability | |
| | | | | | | | | | |

**Vegetation:**

**Bedrock Observed:**

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Reference Reach Data Sheet

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| Date: | Project Number: |
|---|---|

**UPSTREAM REFERENCE REACH:**

| Channel Cross Section Shape: | Channel Slope: |
|---|---|

| Δ from Xing | Bankfull Width | Bankfull Depth | Bed Width | Floodplain Width | Riffles | | Channel Stability Notes: |
|---|---|---|---|---|---|---|---|
| | | | | | Δ Xing | Length | |
| | | | | | | | |
| | | | | | | | Stability: 1 = lowest (very temporary)<br>5 = highest (permanent) |

| Pools | | | Steps | | | | Ribs | | Notes: |
|---|---|---|---|---|---|---|---|---|---|
| Δ Xing | Length | Depth | Δ Xing | Height | Type | Stability | Δ Xing | Stability | |
| | | | | | | | | | |

Vegetation:

Bedrock Observed:

**DOWNSTREAM REFERENCE REACH:**

| Channel Cross Section Shape: | Channel Slope: |
|---|---|

| Δ from Xing | Bankfull Width | Bankfull Depth | Bed Width | Floodplain Width | Riffles | | Channel Stability Notes: |
|---|---|---|---|---|---|---|---|
| | | | | | Δ Xing | Length | |
| | | | | | | | |
| | | | | | | | Stability: 1 = lowest (very temporary)<br>5 = highest (permanent) |

| Pools | | | Steps | | | | Ribs | | Notes: |
|---|---|---|---|---|---|---|---|---|---|
| Δ Xing | Length | Depth | Δ Xing | Height | Type | Stability | Δ Xing | Stability | |
| | | | | | | | | | |

Vegetation:

Bedrock Observed:

CAB 1, CAB 2, COP 9, Sher 1

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<br>~7:00pm end | 7:00am start<br>8:40 to Sher 1 D/S<br>~2 hrs COP 20-25 | 7am start<br>to CAB 1/2<br>10am back to cabin<br>0.5 petition<br>3pm Sher 1 US | |

Sher 1 US – 5.5' cover
- gravel/e-1 in pond US
- 5.5' of 18" culvert ponding submerged
- sheen on water
- gravel bottom

→ Remove existing large culvert cost

Reference Reach start ~300' dist 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 ~ 10"

* survey Beaver Pond elev. US

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

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"

- lake US

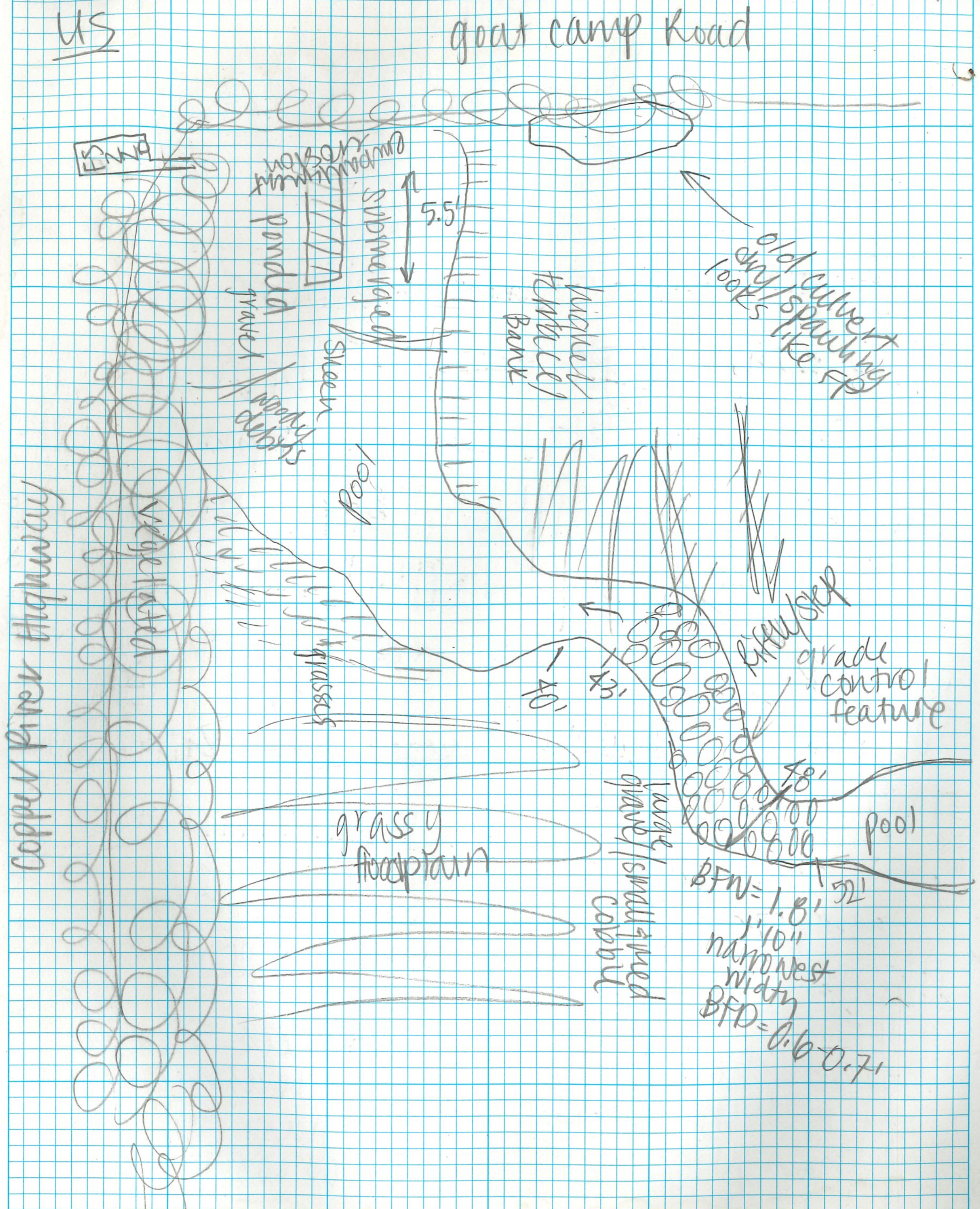
→ check Sher 02 drainage area
map flow & drainage Area

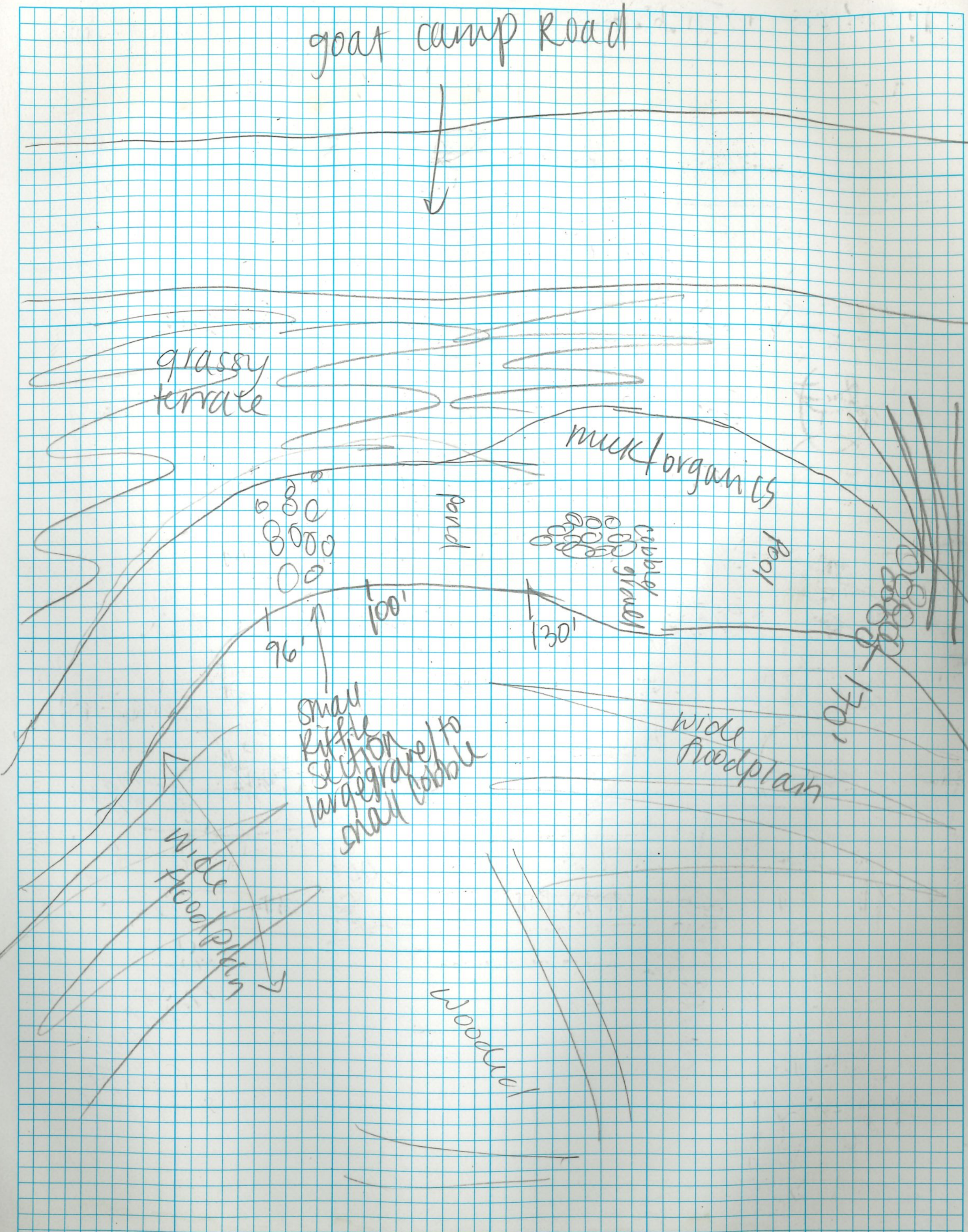
→ survey thalweg up from Ref Reach to Beaver Dam

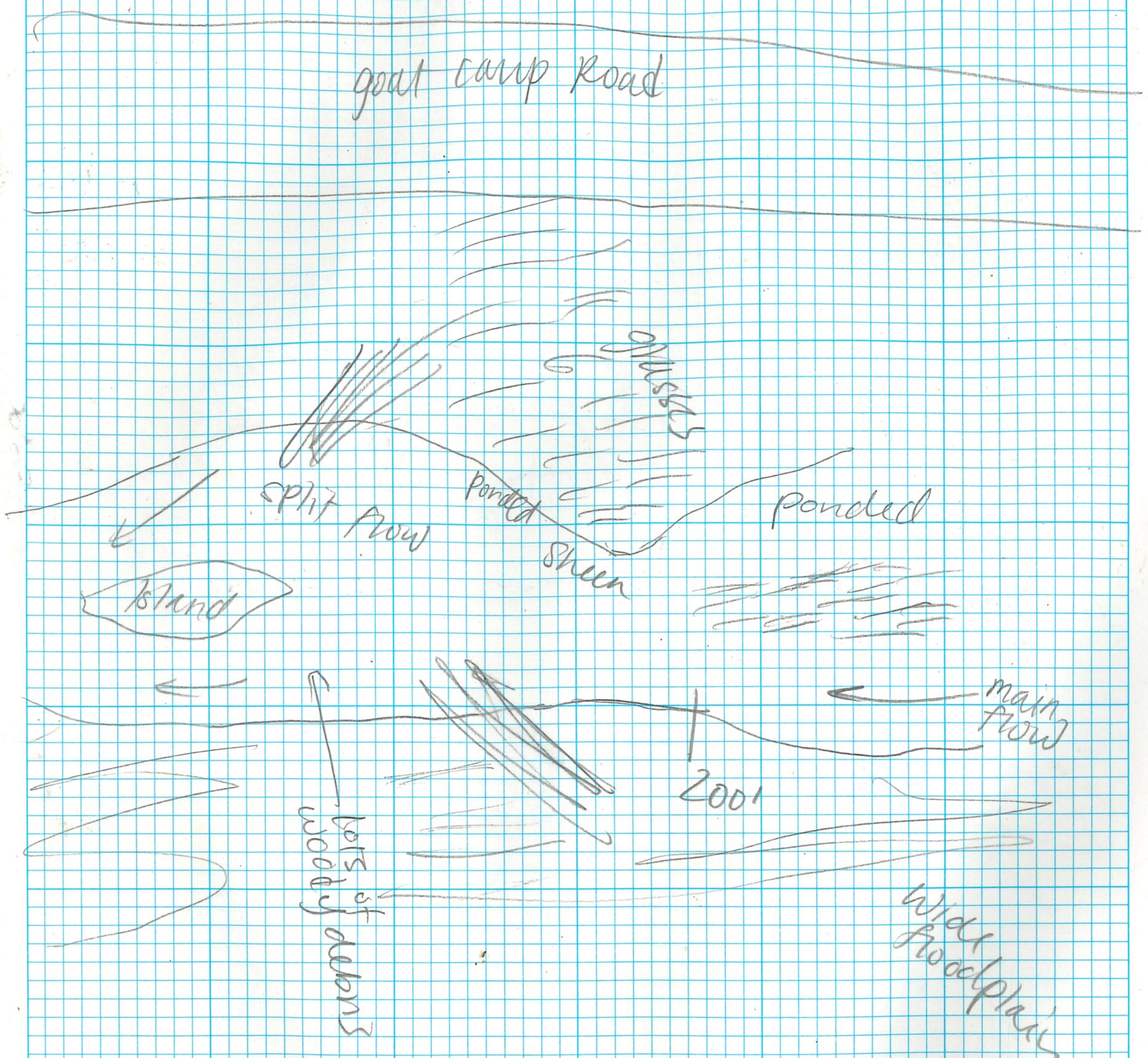
7/20/21 SHER01

~5.5' cover at inlet

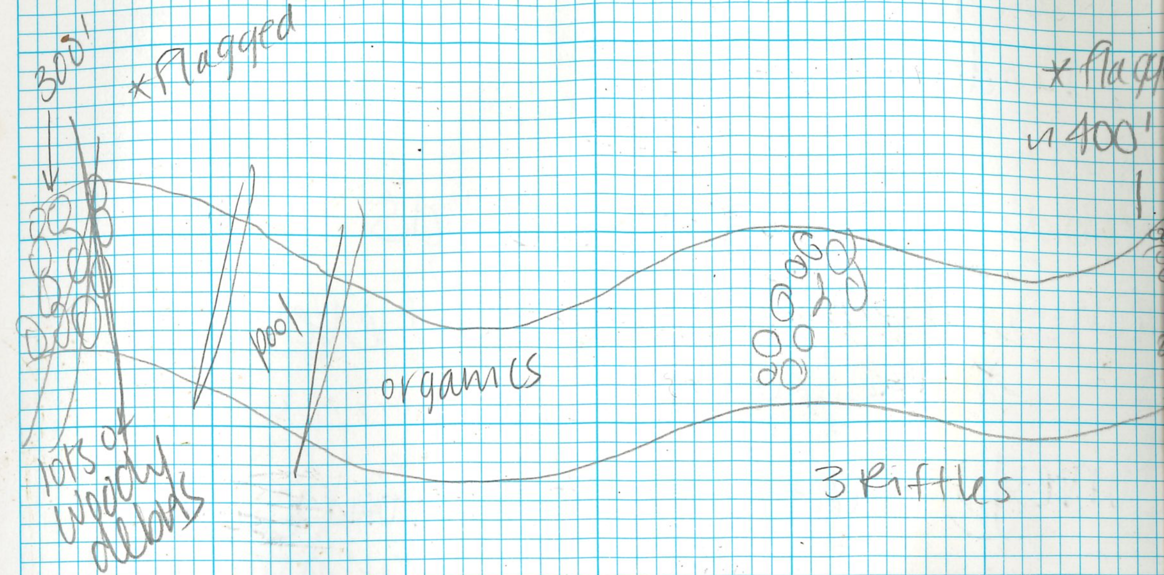
US




goat camp Road
grasses
split flow
ponded
ponded
sheen
Island
main flow
200'
lots of woody debris
wide floodplain

# Ref Reach


300'
*Flagged
*Flagged
~400'
pool
organics
lots of woody debris
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

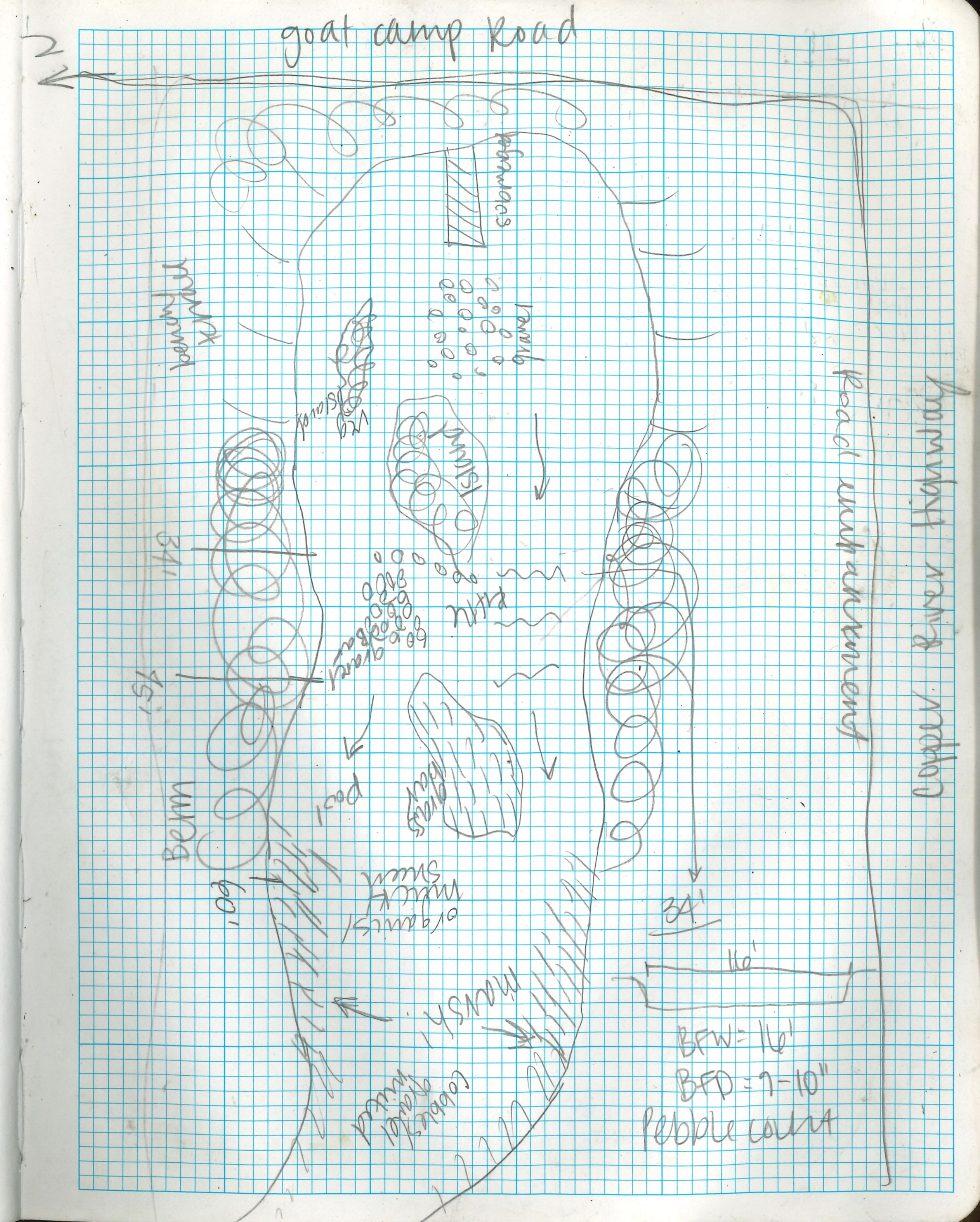
Survey: goat camp Road from crown of copper River highway to 200'-300' (old large culvert)

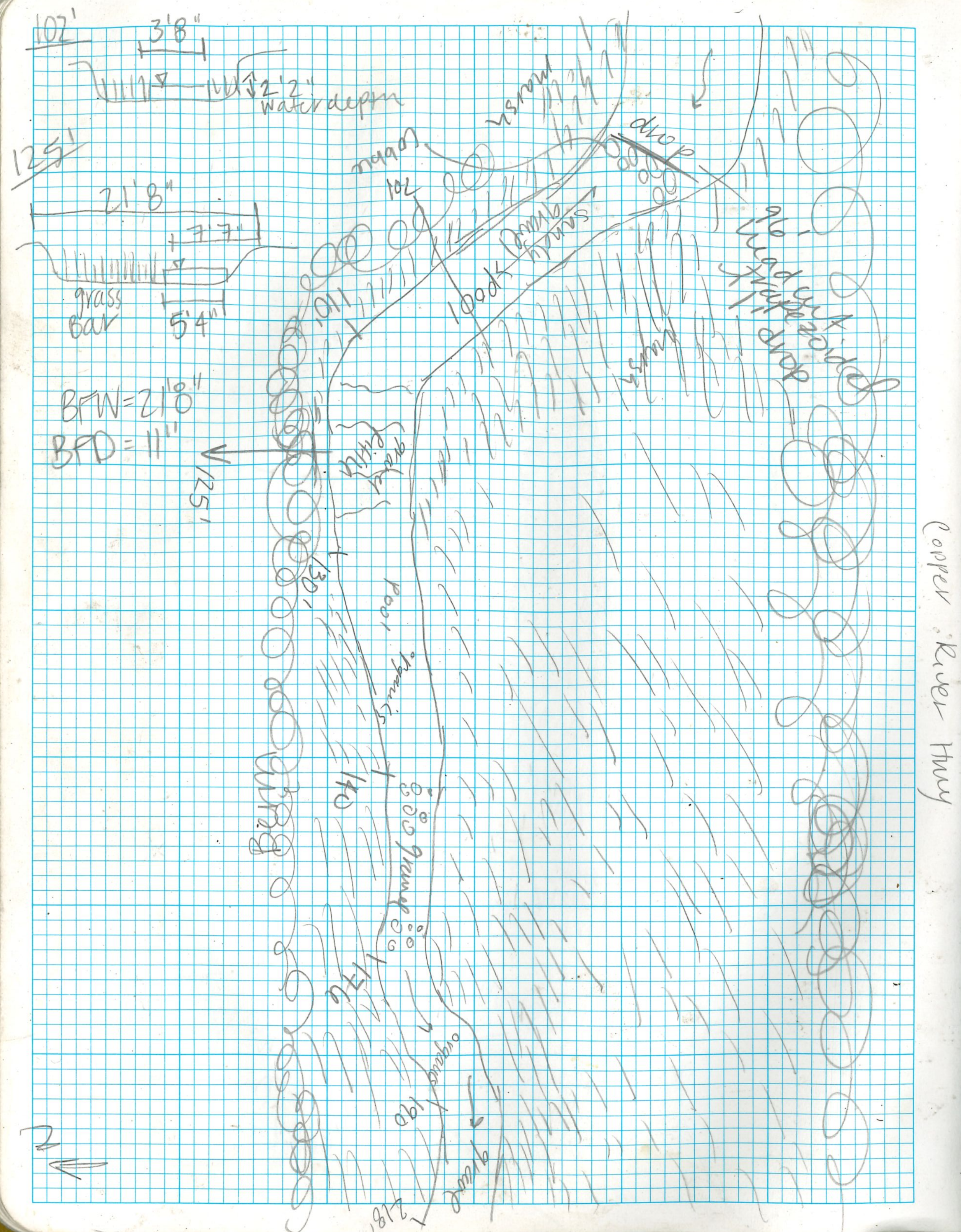
ds: ~300' to where streams connect
Big drop @ ~290'

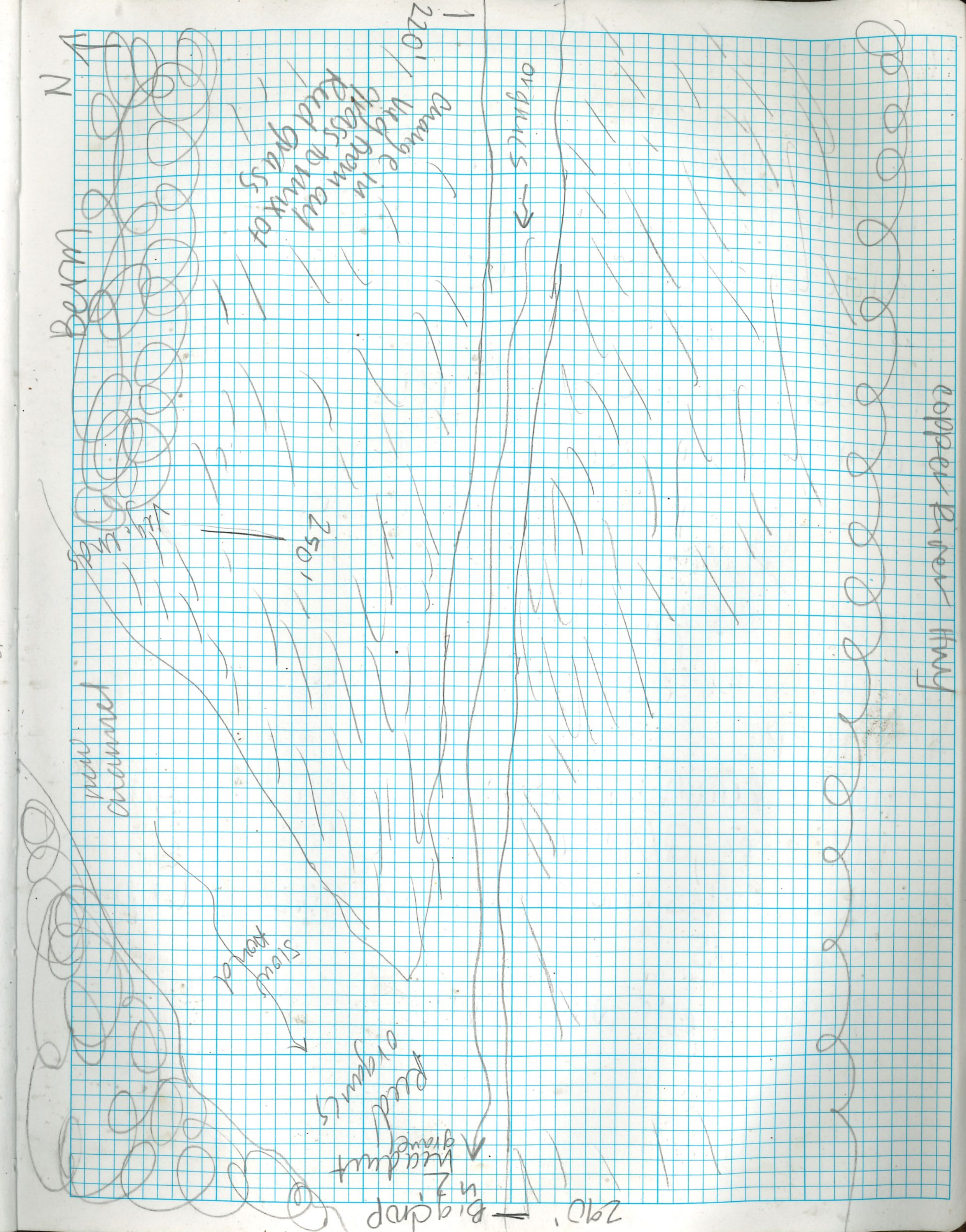
2: Riffle/pool/ & marsh

4: confined by Road and bench N

6: no Rif. Rach




102'
3'8"
2'2"
water depth
125'
21'8"
7'7"
grass bar
5'4"
BFW=21'8"
BFD=11"
125'
drop
Berm
130'
140
170
190
218'
N
Copper River Hwy


N
220'
Berm
250'
new channel
240'
Big dip
Copper River Hwy

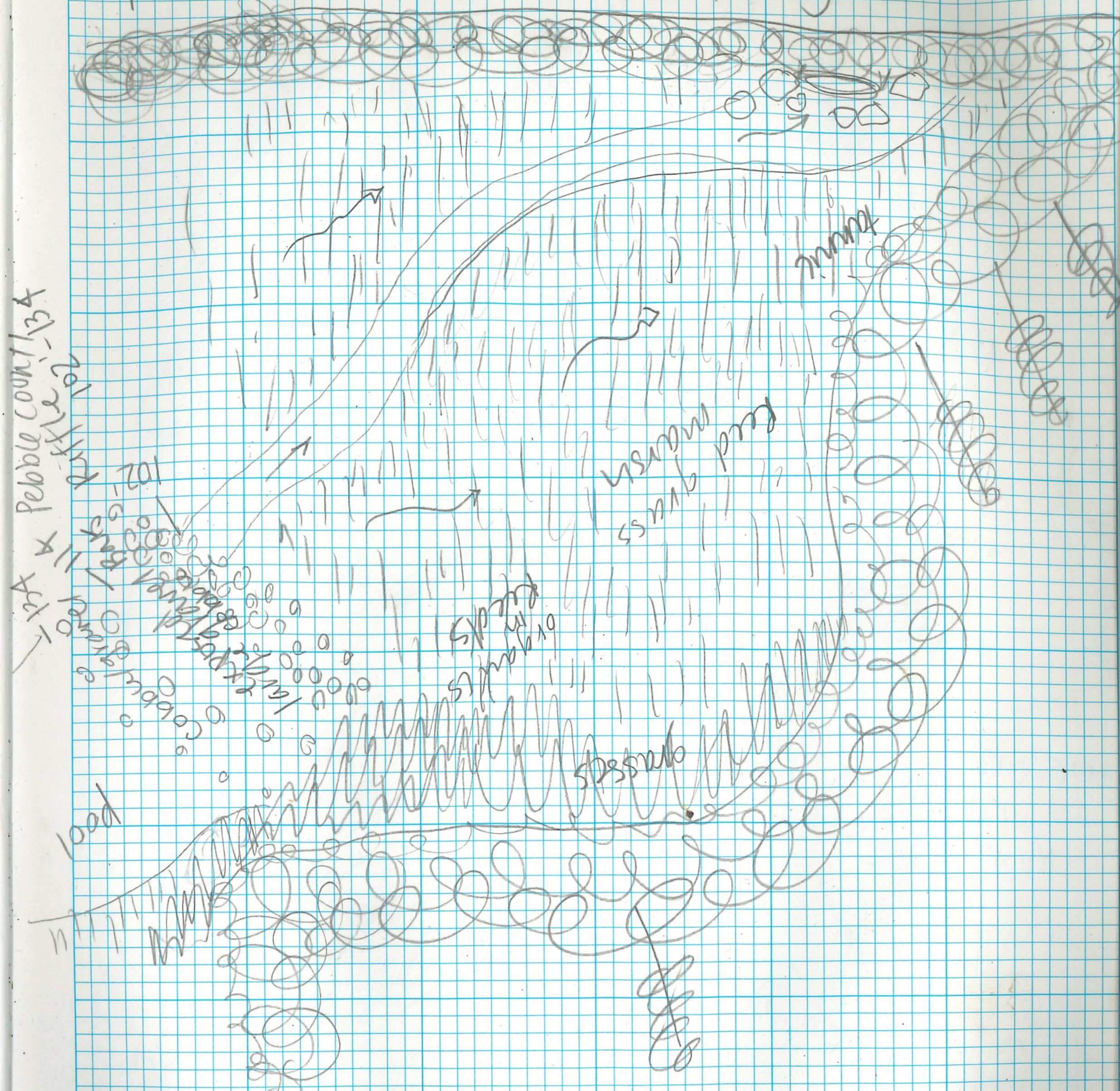
COP 9 7/21/21 US

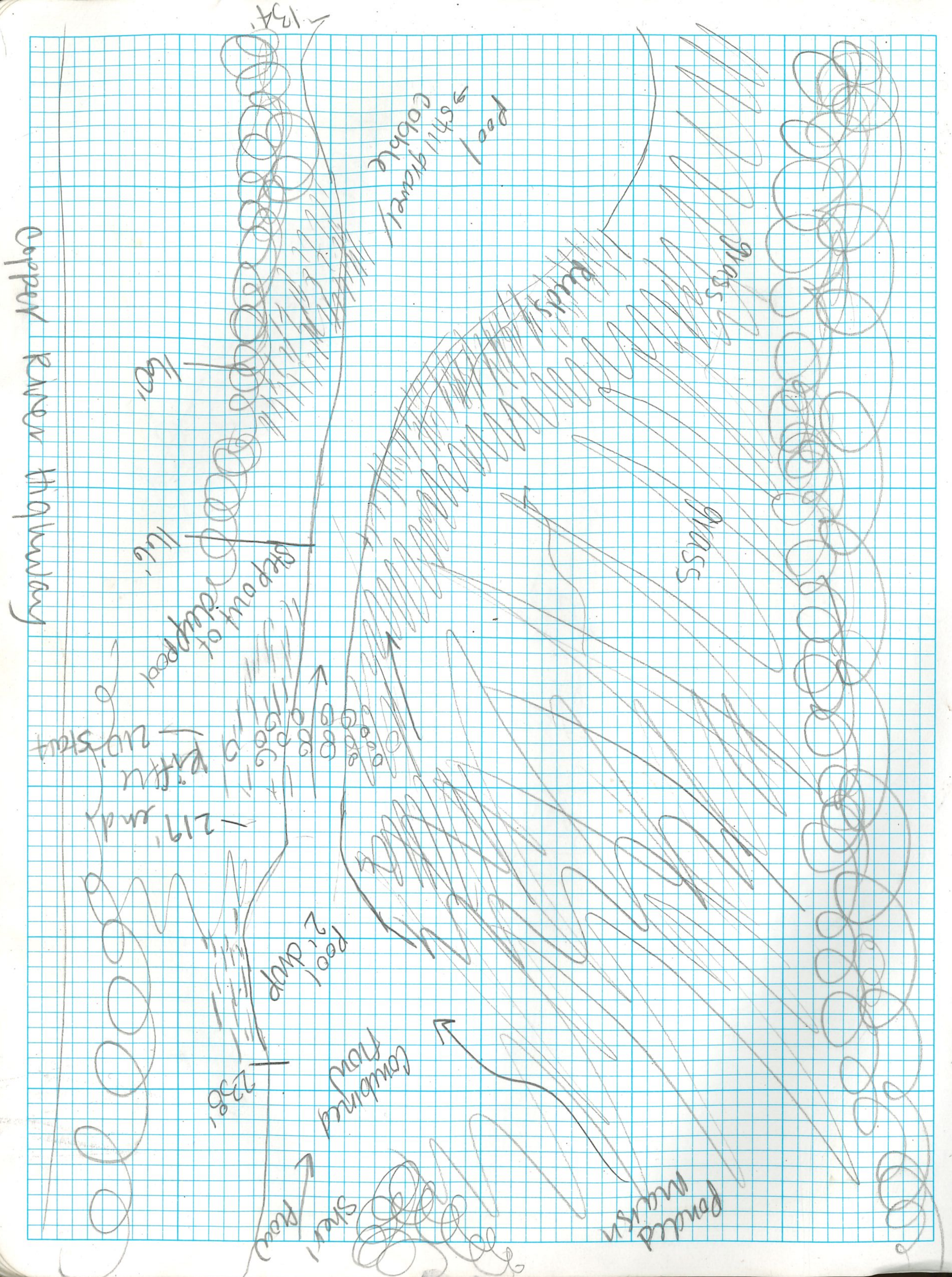
- 4' existing culvert
- Rust mark @ half Barrel
- WSE ~ 1/4 Barrel
- large boulder inside
- 4'-5' cover @ inlet
- Pebble count @ 102' Riffle

Survey: US ~ 300' to Sheri 1 tie in
go up new channel for
Remaining

2: Riffle/pools & marsh
3: gravel-cobble & organics/tannic
4: wide FP
6: no Ref Reach use Sheri 1 Ref. Reach & do syn.
width or Q/A method
all marsh US. no culvert on goat camp
Road US
7: grasses, Reeds, willow/Alder

COP9US Copper River Highway



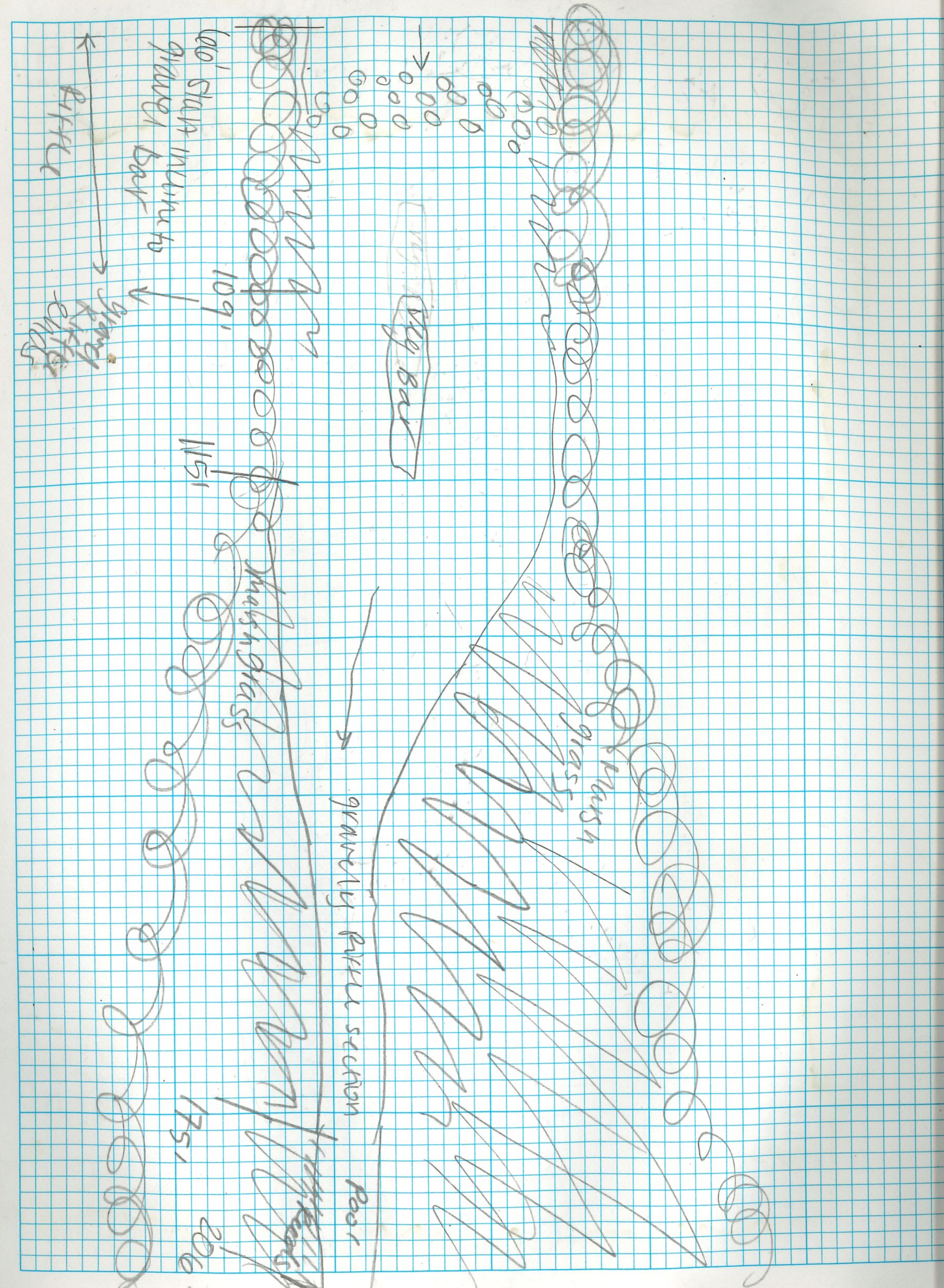


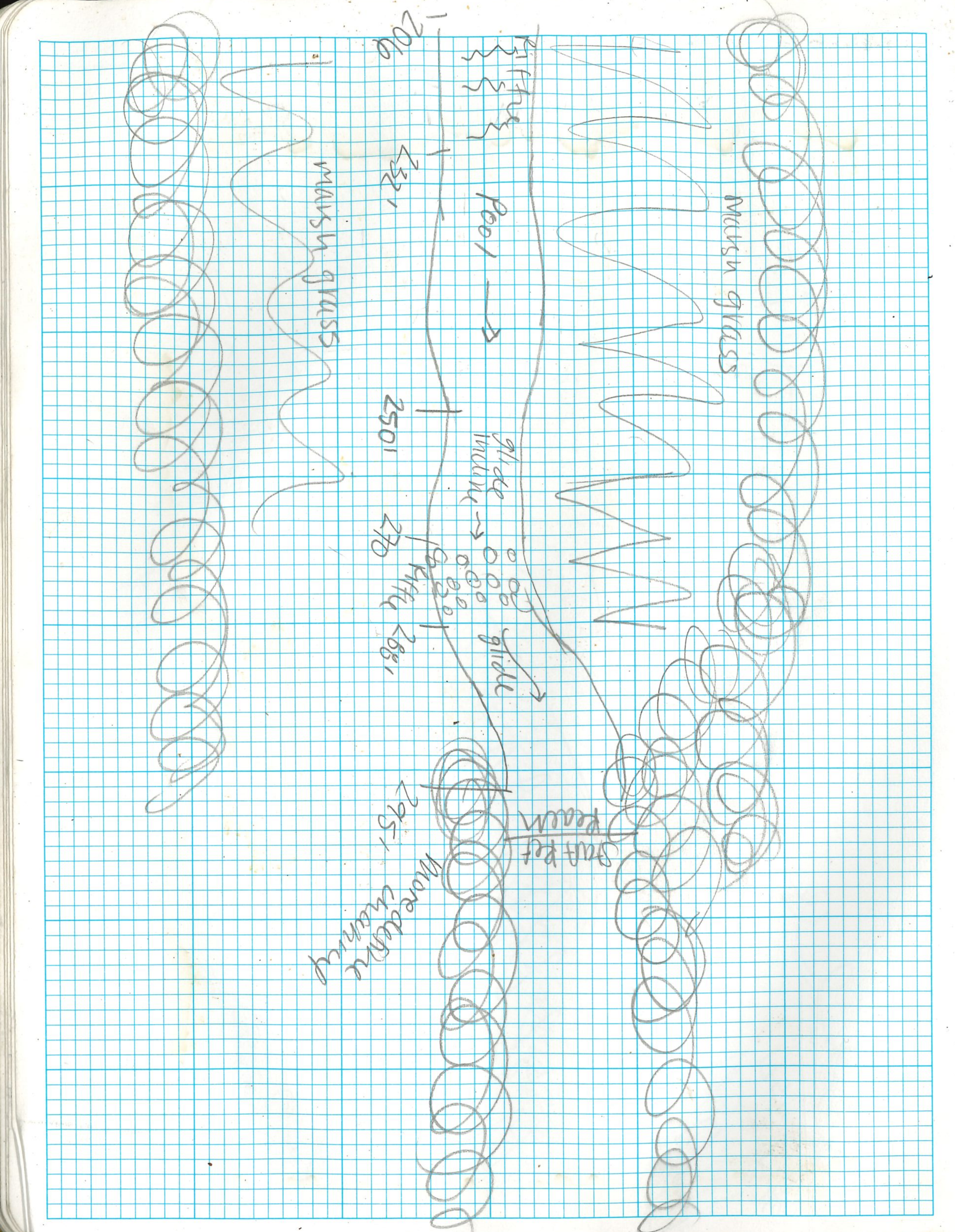

COP 9 DS 7/21/21

- placed rock @ outlet ~ Riprap Class I
- ~4' cover @ outlet
- Reference Reach DS ~300' to 400'
  approx. 100' ~ 3 riffle section
  flagged @ top/bottom

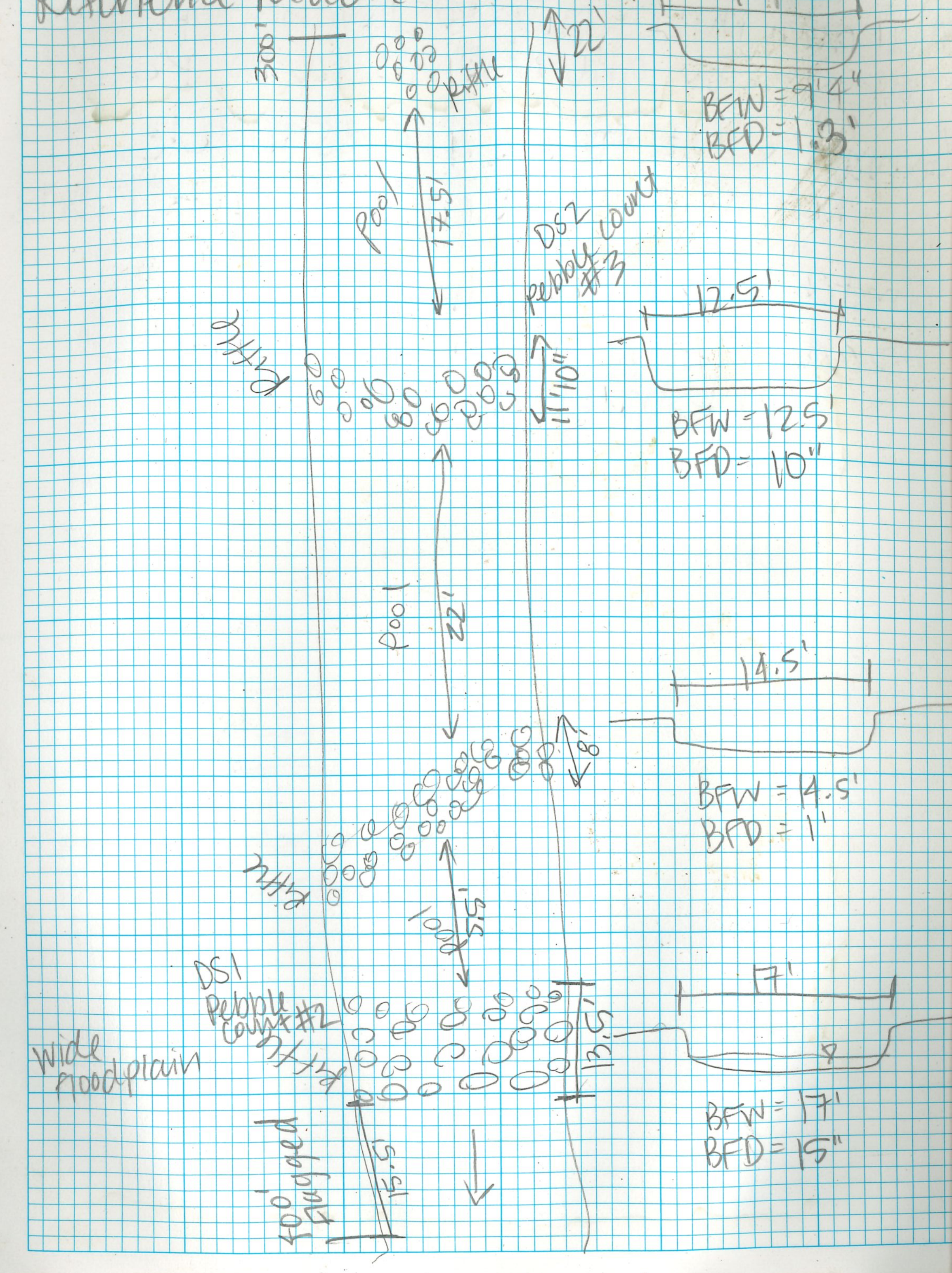
Pebble count #2 @ DS riffle


Copper River Highway
grasses
Riffle
open pool
small Riffle
grasses
Woody debris
Island Bar
Veg Bar
slow pool


Veg Bar
gravelly Riffle section
grasses
Pool




# 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

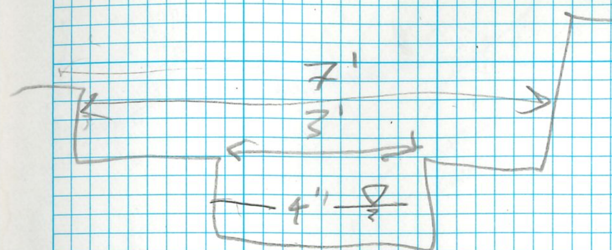
Forester COP20-25 advice:

→ add removal of structures and obstruction

7/22/21

CAB1/2 US

- APPROX 1FT COVER. ON PIPE
- ↳ SURVEY TIMBER WEIR
- CONSTRUCTION ACCESS FOR CAB1 VIA ROAD/RAIL PATH
- CULTURAL RESOURCE FOR TIMBER WEIR
- POTENTIAL UPWELLING
  ↳ WATER NOT WARM
- CAB1 APPEARS TO OVERFLOW
  ↳ FLOW PATH EVIDENT

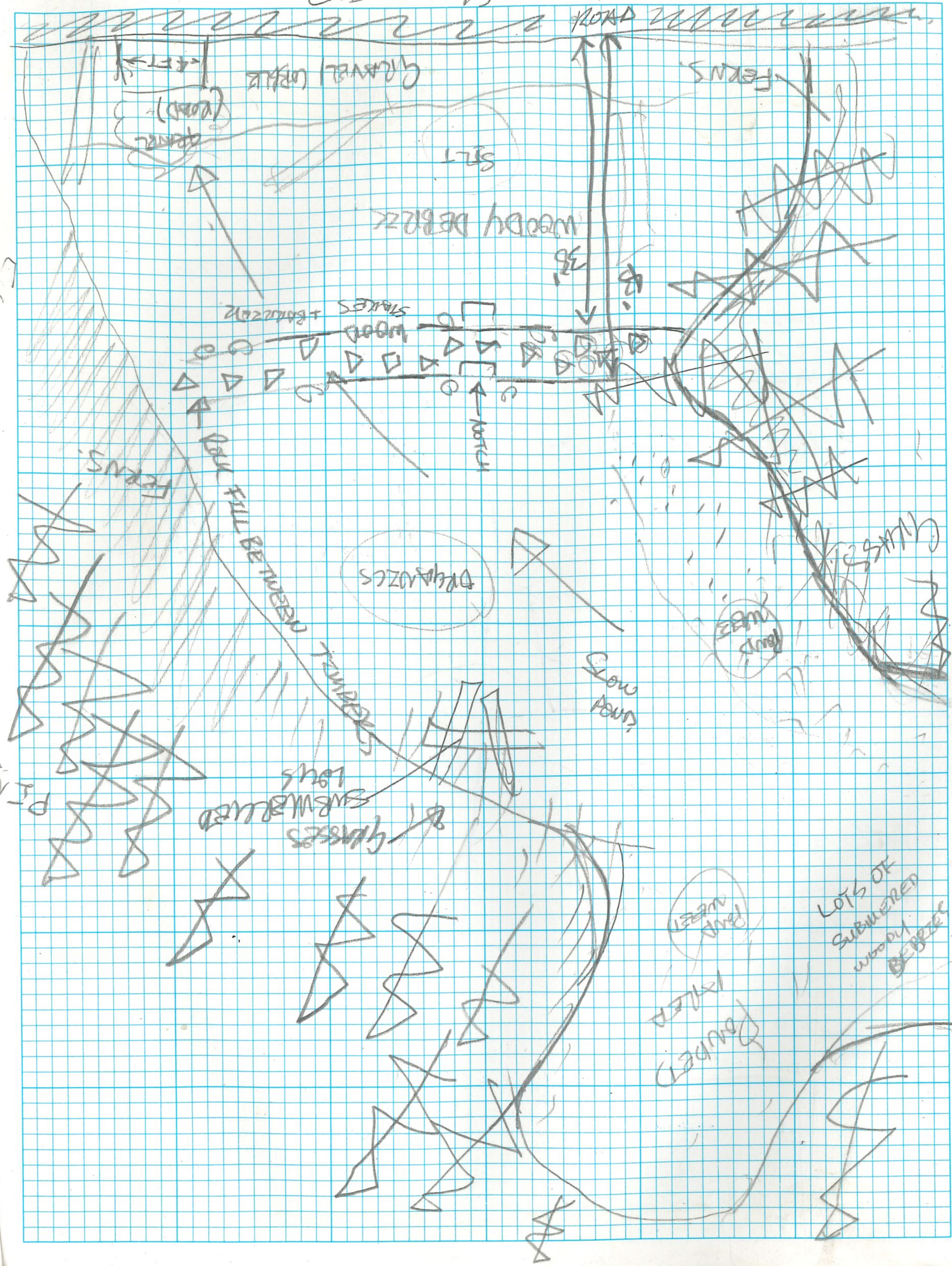


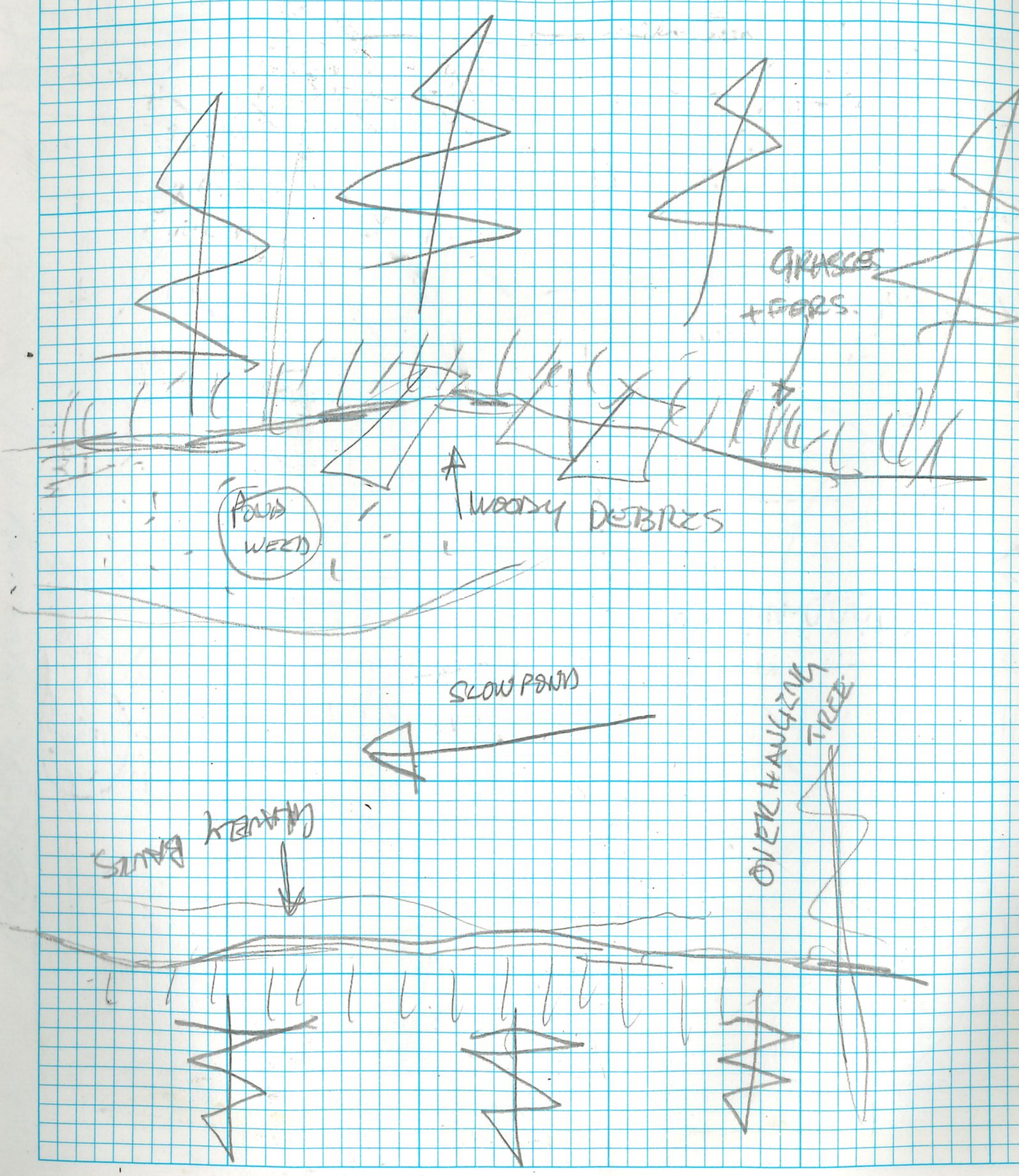

- ASK FRANKLIN FOR PRESSURE TRANSDUCER DATA.

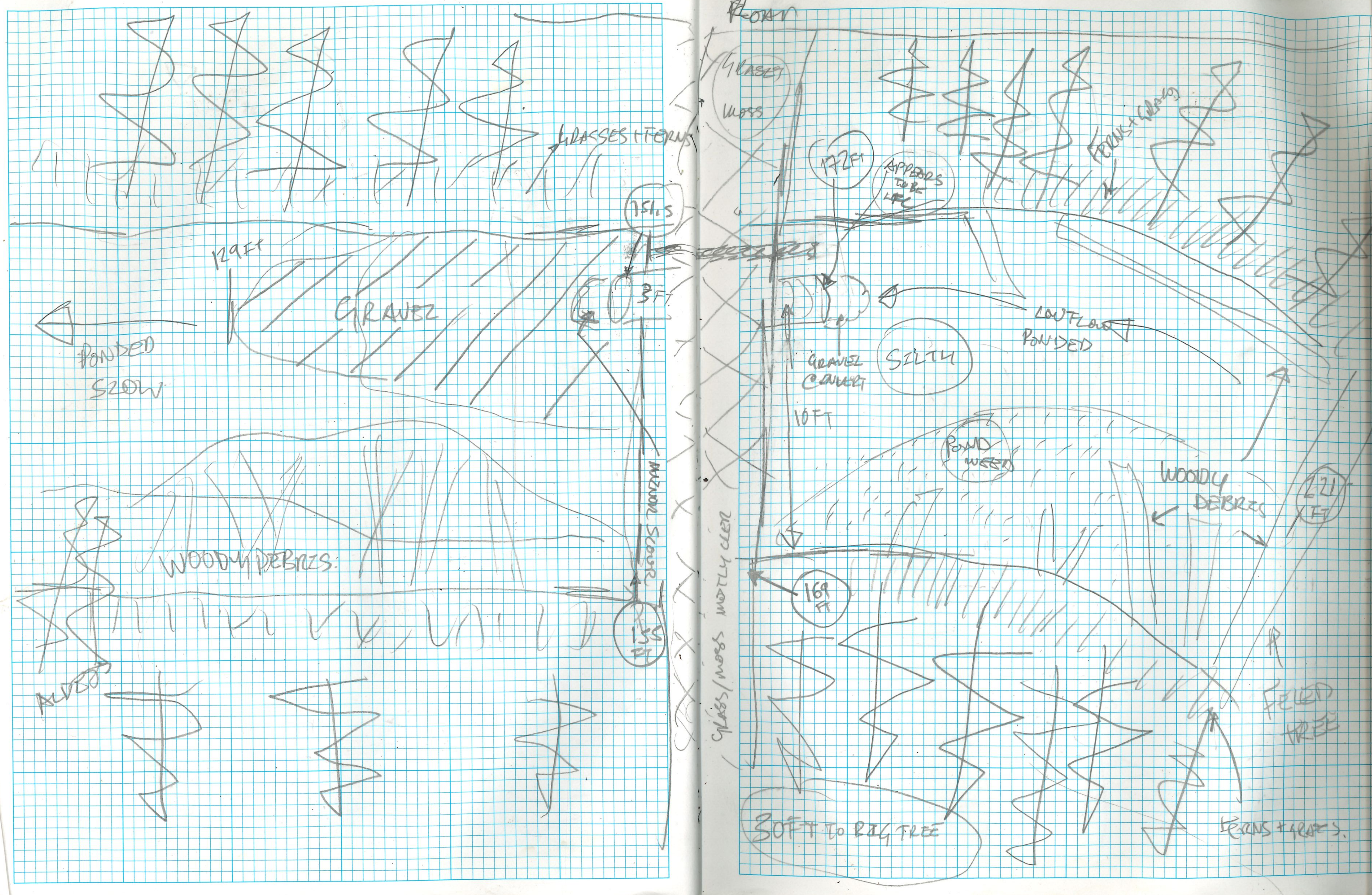
SURVEY

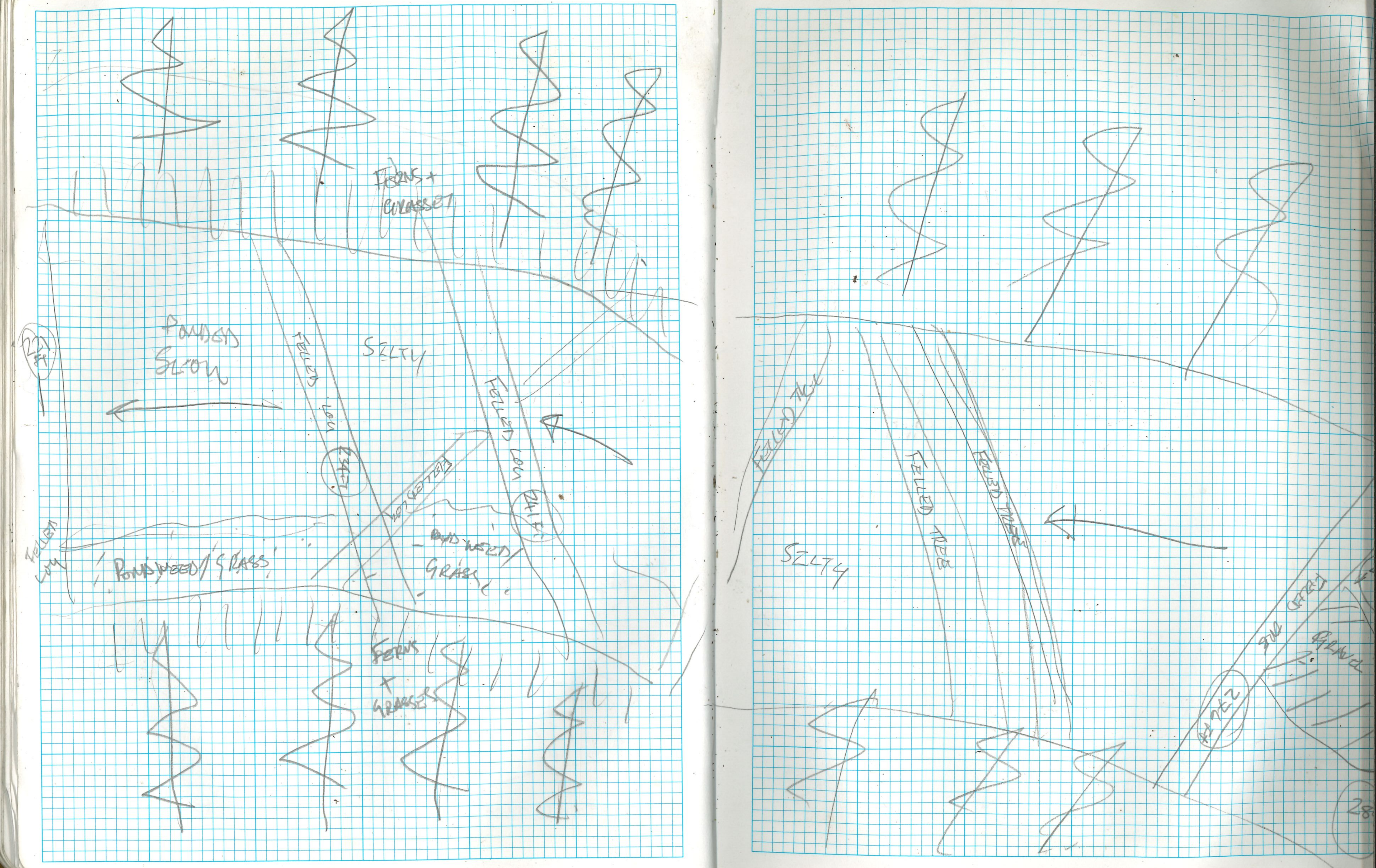
- GET WSE
- GET LIP OF PIPE INVERT
- 300' upstream/DS not flagged

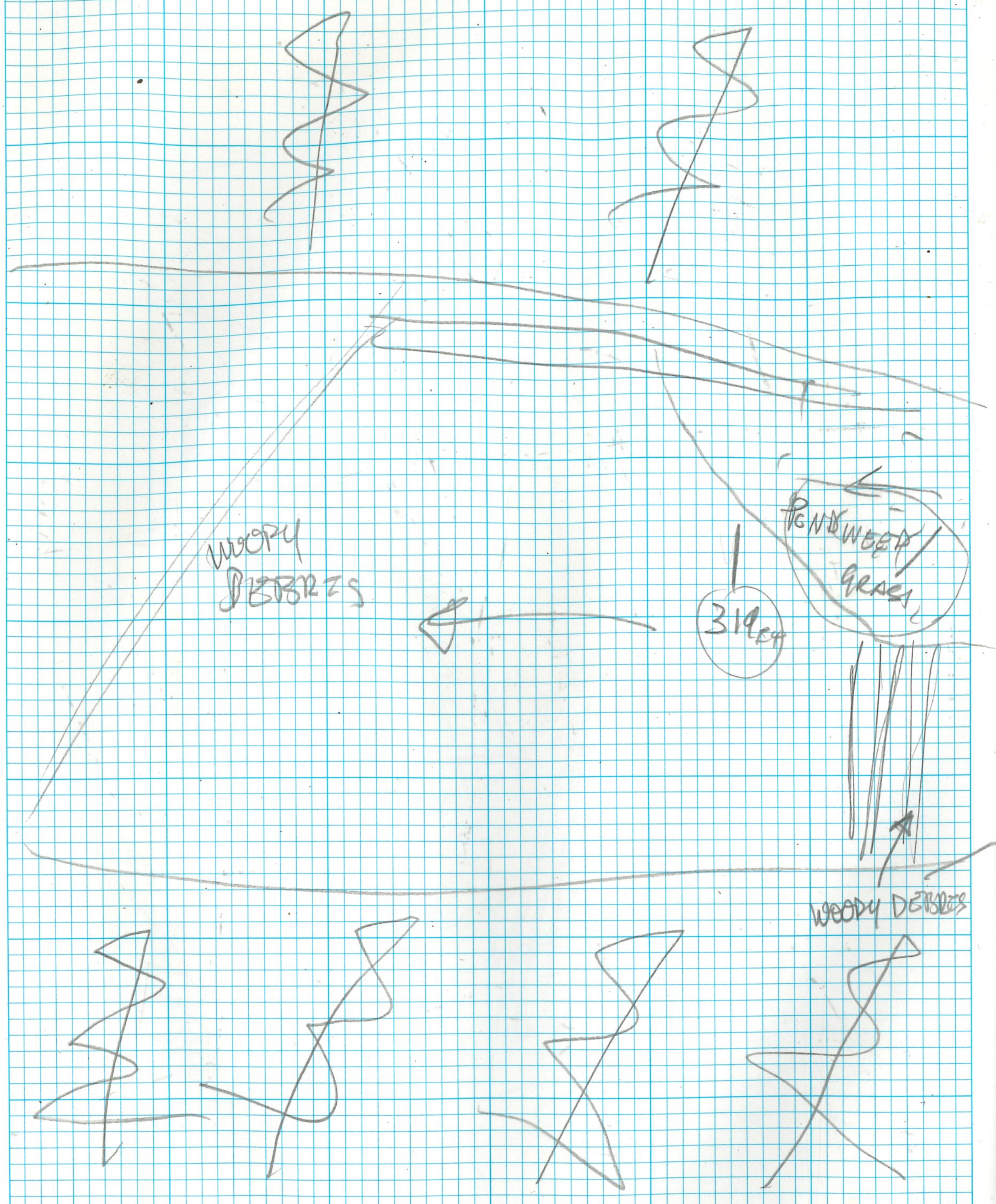
CAB 2 U/S

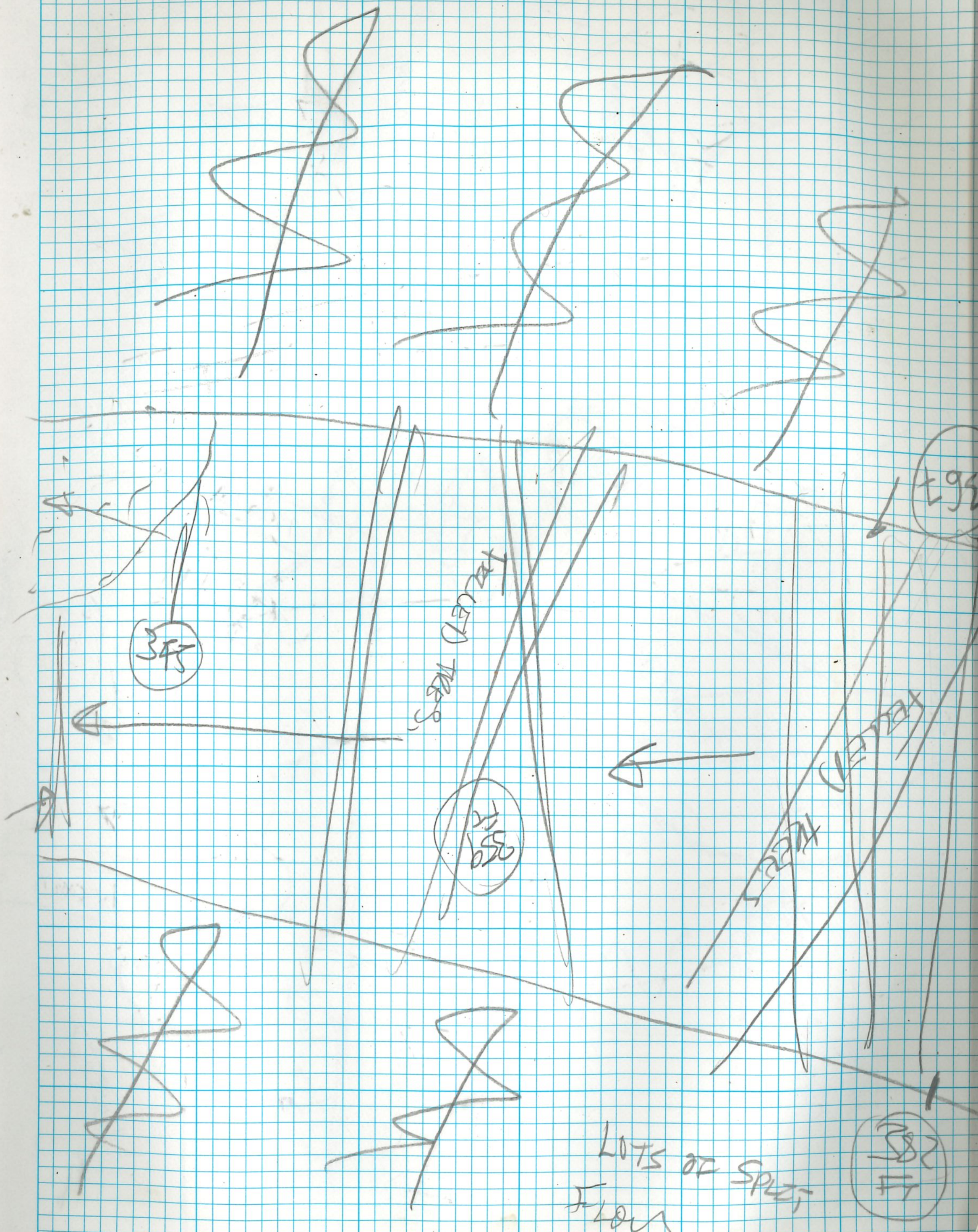

ROAD
FERNS
SILT
WOODY DEBRIS
BULK FILL BETWEEN
LOTS OF SUBMERGED WOODY DEBRIS

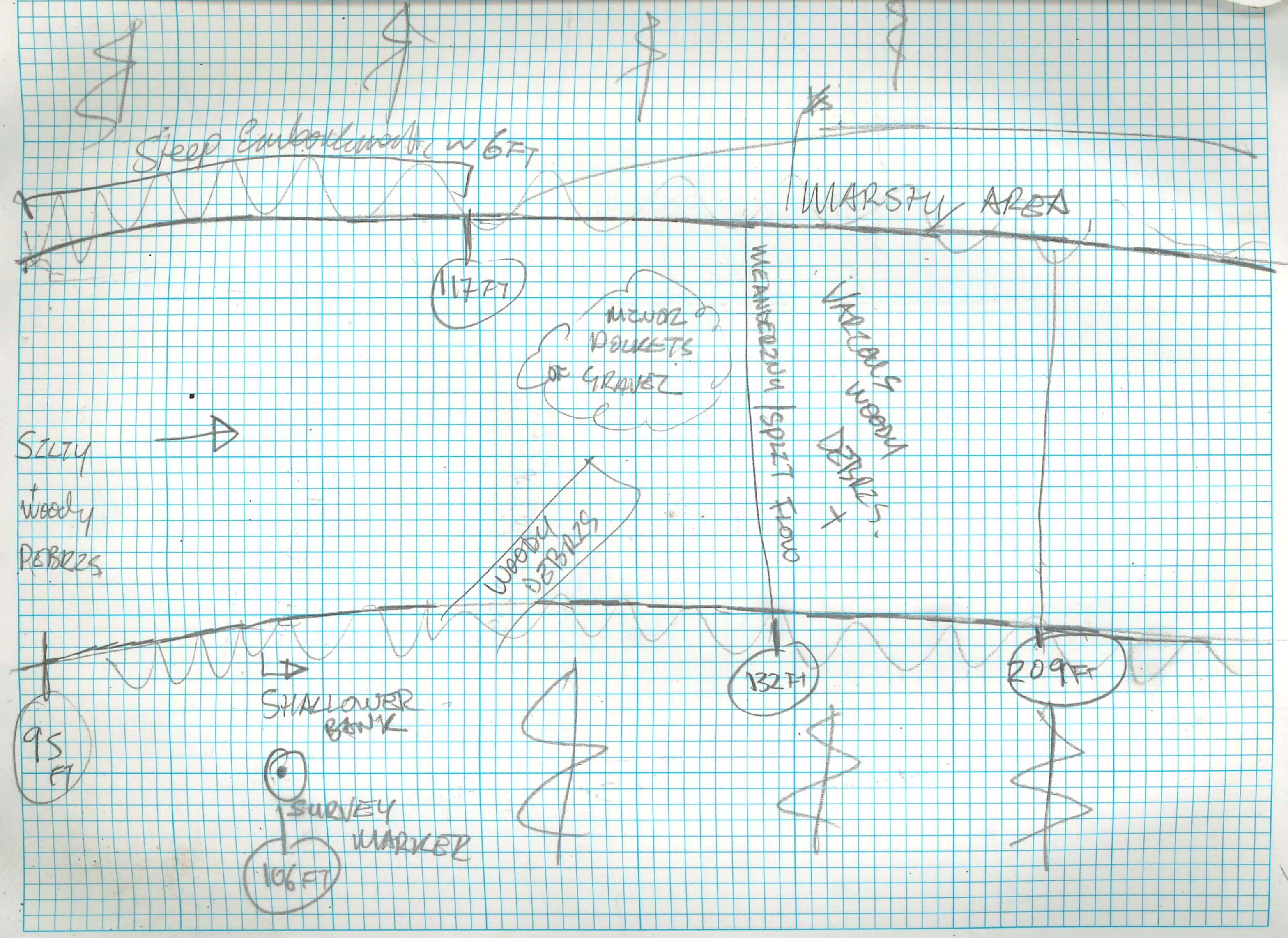
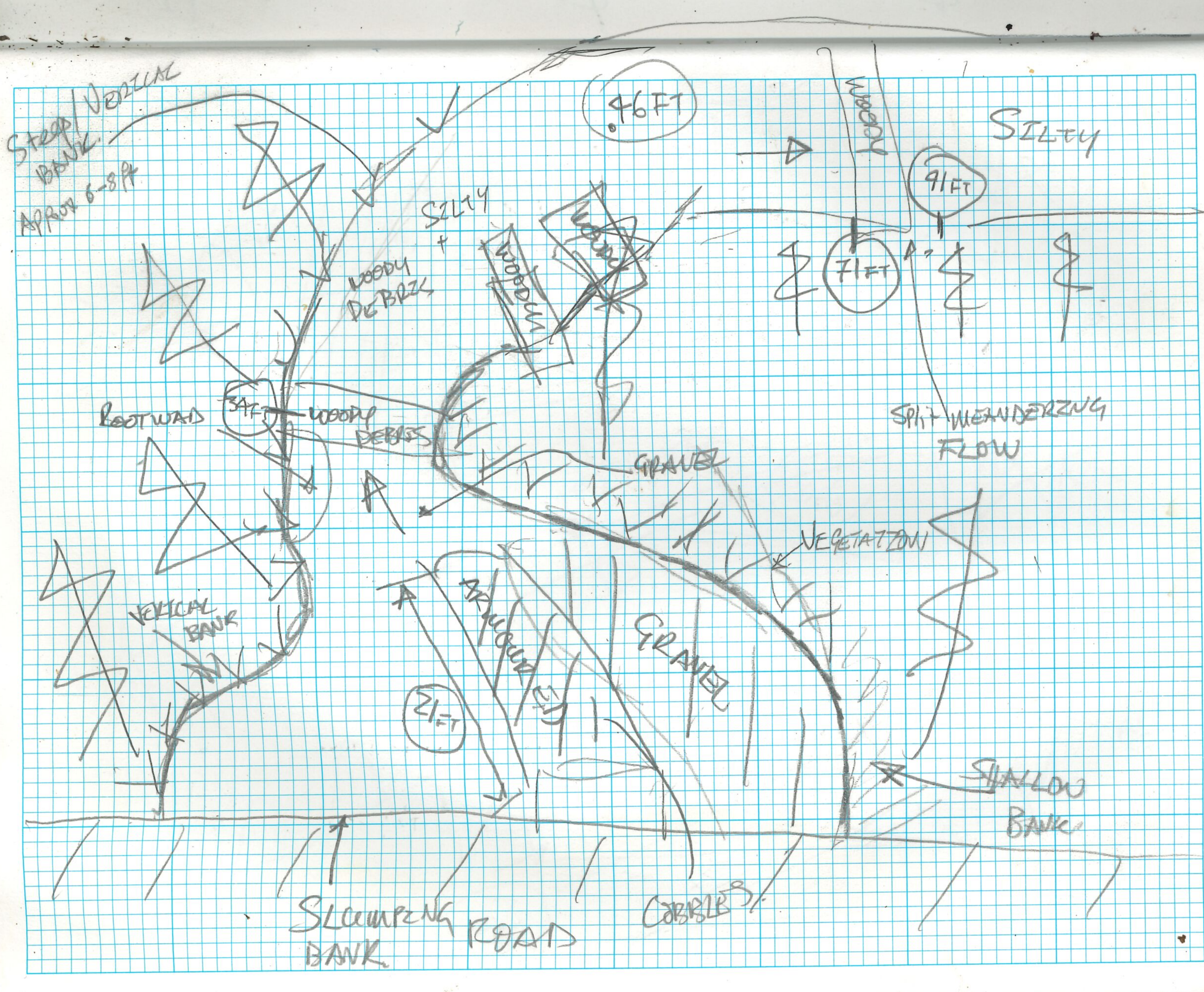

GRASSES + FERNS
POND WEED
WOODY DEBRIS
SLOW POND
OVERHANGING TREE

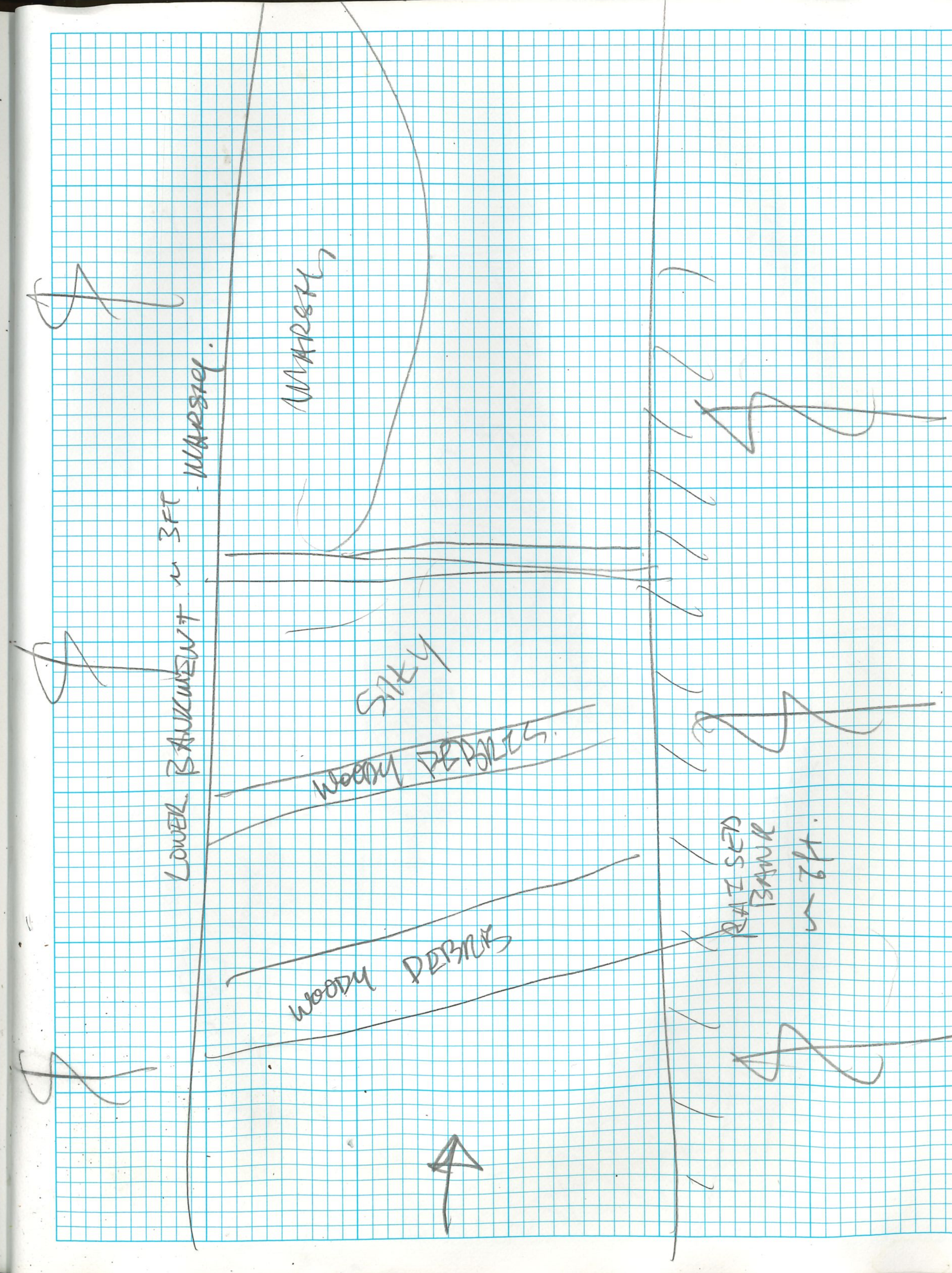

ROAD
GRASSES + FERNS
151.5
129 FT
GRAVEL
PONDED SLOW
3 FT
MINOR SCOUR
WOODY DEBRIS
ALDERS
155 FT
GRASS/MOSS MOSTLY CLEAR
GRASSES MOSS
172 FT
FERNS + GRASS
OUTFLOW
PONDED
GRAVEL CULVERT
SILTY
10 FT
POND WEED
WOODY DEBRIS
221 FT
169 FT
FELLED TREE
30 FT TO BIG TREE
FERNS + GRASS


FERNS + GRASSES
PONDED SLOW
SILTY
FELLED LOG
FELLED LOG
FELLED LOG
POND WEED / GRASS
POND WEED / GRASS
FERNS + GRASSES
FELLED TREE
FELLED TREE
FELLED TREE
SILTY
GRAVEL


WOODY DEBRIS
POND WEED GRASS
319 FT
WOODY DEBRIS


345
LOTS OF SPLIT FLOW
382 FT


Steep Embankment w 6FT
MARSHY AREA
117FT
MINOR POCKETS OF GRAVEL
MEANDERING SPLIT FLOW
VARIOUS WOODY DEBRIS +
SILTY + WOODY DEBRIS
WOODY DEBRIS
95 FT
SHALLOWER BANK
132FT
209FT
SURVEY MARKER
106FT

Steep/VERTICAL BANK
APPROX 6-8FT
46FT
WOODY
SILTY
91FT
SILTY +
WOODY DEBRIS
WOODY
WOODY
71FT
ROOTWAD
34FT
WOODY DEBRIS
SPLIT MEANDERING FLOW
GRAVEL
VEGETATION
VERTICAL BANK
ARMOURED
GRAVEL
21FT
SHALLOW BANK
SLUMPING BANK
ROAD
COBBLES


Lower embankment ~ 3ft
Marshy.
Marshy
Silty
Woody debris.
Woody debris
Raised bank ~6ft.

# APPENDIX B: SUBSTRATE DESIGN

**New Stream Channel Design (Culvert, Rock Ramp) - CAB 1**

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 | 0.3 | (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 | 1.15 | 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 | 1.2 | ft/s from 100-year event avg. velocity in pipe | Approximate depth-average flow for outlet velocities |
| Side Slope correction factor | 1 | | |
| Gravitational Acceleration | 32.2 | ft/s^2 | |
| D85/D15 | 5 | (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 | 0.0 | ft | 1.0 | inches |
| D30 | 0.0 | ft | 1.0 | inches |
| D50 | 0.0 | ft | 1.0 | inches |
| D85 | 0.0 | ft | 1.0 | inches |
| D100 | 0.0 | ft | 1.0 | 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 (inches) **12.0**

**Method Adapted from US Forest Service Stream Simulation Guidelines** D30 5.0 | Stability (D30): **OK**

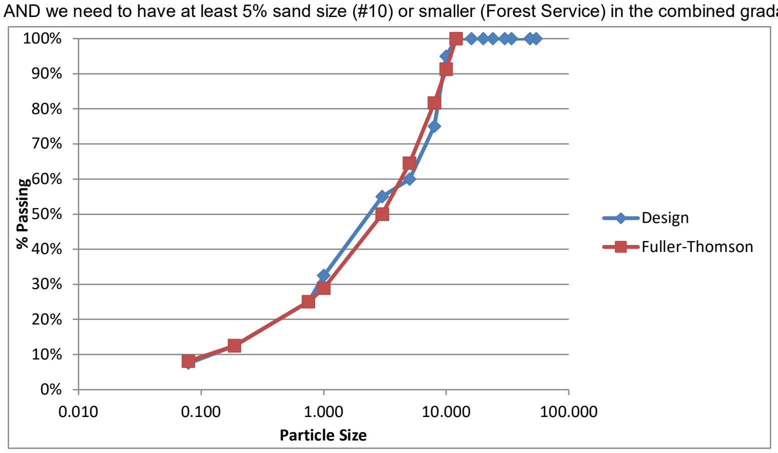
D30 Req'd 1.0

YELLOW ARE INPUTS

| | | COARSE MATERIAL | | | | | FINES | |
|---|---|---|---|---|---|---|---|---|
| | | Type IV Rip Rap | Type III Rip Rap | Type II Rip | Type I Rip R | FA | Combined % | F-T EQN |
| | RELATIVE % = | 0 | 0 | 0.0000 | 0.5000 | 0.5000 | 1.0000 | |
| Size (inches) | Sieve Size | % Passing | % Passing | % Passing | % Passing | % Passing | % Passing | % Passing |
| 54 | 54 in | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 100% | 212% |
| 48 | 48 in | 0.90 | 1.00 | 1.00 | 1.00 | 1.00 | 100% | 200% |
| 34 | 34 in | 0.50 | 1.00 | 1.00 | 1.00 | 1.00 | 100% | 168% |
| 30 | 30 in | 0.35 | 0.90 | 1.00 | 1.00 | 1.00 | 100% | 158% |
| 24 | 24 in | 0.25 | 0.50 | 1.00 | 1.00 | 1.00 | 100% | 141% |
| 20 | 20 in | 0.15 | 0.15 | 0.90 | 1.00 | 1.00 | 100% | 129% |
| 16 | 16 in | 0.00 | 0.00 | 0.50 | 1.00 | 1.00 | 100% | 115% |
| 12 | 12 in | 0.00 | 0.00 | 0.15 | 1.00 | 1.00 | 100% | 100% |
| 10 | 10 in | 0.00 | 0.00 | 0.00 | 0.90 | 1.00 | 95% | 91% |
| 8 | 8 in | 0.00 | 0.00 | 0.00 | 0.50 | 1.00 | 75% | 82% |
| 5 | 5 in | 0.00 | 0.00 | 0.00 | 0.20 | 1.00 | 60% | 65% |
| 3 | 3 in | 0.00 | 0.00 | 0.00 | 0.10 | 1.00 | 55% | 50% |
| 1 | 1 in | 0.00 | 0.00 | 0.00 | 0.00 | 0.65 | 33% | 29% |
| 0.75 | 0.75 in | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 25% | 25% |
| 0.187 | #4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 13% | 12% |
| 0.0787 | #10 Sand | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 8% | 8% |

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 Eqn

| Size (in) | Combined % pa | F-T equation |
|---|---|---|
| 54.000 | 100% | 212% |
| 48.000 | 100% | 200% |
| 34.000 | 100% | 168% |
| 30.000 | 100% | 158% |
| 24.000 | 100% | 141% |
| 20.000 | 100% | 129% |
| 16.000 | 100% | 115% |
| 12.000 | 100% | 100% |
| 10.000 | 95% | 91% |
| 8.000 | 75% | 82% |
| 5.000 | 60% | 65% |
| 3.000 | 55% | 50% |
| 1.000 | 33% | 29% |
| 0.750 | 25% | 25% |
| 0.187 | 13% | 12% |
| 0.079 | 8% | 8% |

**New Stream Channel Design (Culvert, Rock Ramp) - CAB 2**

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 | 0.3 | (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 | 0.5 | 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 | 2 | ft/s from 100-year event avg. velocity in pipe | | Approximate depth-average flow for outlet velocities |
| Side Slope correction factor | 1 | | | |
| Gravitational Acceleration | 32.2 | ft/s^2 | | |
| D85/D15 | 5 | (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 | 0.0 | ft | 1.0 | inches |
| D30 | 0.0 | ft | 1.0 | inches |
| D50 | 0.0 | ft | 1.0 | inches |
| D85 | 0.1 | ft | 1.0 | inches |
| D100 | 0.1 | ft | 1.0 | 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 (inches) **12.0**

**Method Adapted from US Forest Service Stream Simulation Guidelines** D30 5.0

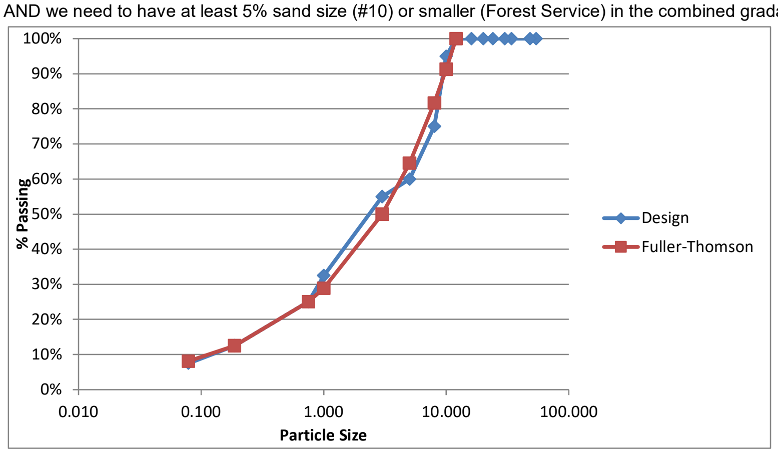
Stability (D30): **OK**

D30 Req'd 1.0

| YELLOW ARE INPUTS | | COARSE MATERIAL | | | | | FINES | |
|---|---|---|---|---|---|---|---|---|
| | | Type IV Rip Rap | Type III Rip Rap | Type II Rip | Type I Rip R | FA | Combined % | F-T EQN |
| | RELATIVE % = | 0 | 0 | 0.0000 | 0.5000 | 0.5000 | 1.0000 | |
| Size (inches) | Sieve Size | % Passing | % Passing | % Passing | % Passing | % Passing | % Passing | % Passing |
| 54 | 54 in | 1.00 | 1.00 | 1.00 | 1.00 | 1.00 | 100% | 212% |
| 48 | 48 in | 0.90 | 1.00 | 1.00 | 1.00 | 1.00 | 100% | 200% |
| 34 | 34 in | 0.50 | 1.00 | 1.00 | 1.00 | 1.00 | 100% | 168% |
| 30 | 30 in | 0.35 | 0.90 | 1.00 | 1.00 | 1.00 | 100% | 158% |
| 24 | 24 in | 0.25 | 0.50 | 1.00 | 1.00 | 1.00 | 100% | 141% |
| 20 | 20 in | 0.15 | 0.15 | 0.90 | 1.00 | 1.00 | 100% | 129% |
| 16 | 16 in | 0.00 | 0.00 | 0.50 | 1.00 | 1.00 | 100% | 115% |
| 12 | 12 in | 0.00 | 0.00 | 0.15 | 1.00 | 1.00 | 100% | 100% |
| 10 | 10 in | 0.00 | 0.00 | 0.00 | 0.90 | 1.00 | 95% | 91% |
| 8 | 8 in | 0.00 | 0.00 | 0.00 | 0.50 | 1.00 | 75% | 82% |
| 5 | 5 in | 0.00 | 0.00 | 0.00 | 0.20 | 1.00 | 60% | 65% |
| 3 | 3 in | 0.00 | 0.00 | 0.00 | 0.10 | 1.00 | 55% | 50% |
| 1 | 1 in | 0.00 | 0.00 | 0.00 | 0.00 | 0.65 | 33% | 29% |
| 0.75 | 0.75 in | 0.00 | 0.00 | 0.00 | 0.00 | 0.50 | 25% | 25% |
| 0.187 | #4 | 0.00 | 0.00 | 0.00 | 0.00 | 0.25 | 13% | 12% |
| 0.0787 | #10 Sand | 0.00 | 0.00 | 0.00 | 0.00 | 0.15 | 8% | 8% |

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 Eqn

| Size (in) | Combined % pa | F-T equation |
|---|---|---|
| 54.000 | 100% | 212% |
| 48.000 | 100% | 200% |
| 34.000 | 100% | 168% |
| 30.000 | 100% | 158% |
| 24.000 | 100% | 141% |
| 20.000 | 100% | 129% |
| 16.000 | 100% | 115% |
| 12.000 | 100% | 100% |
| 10.000 | 95% | 91% |
| 8.000 | 75% | 82% |
| 5.000 | 60% | 65% |
| 3.000 | 55% | 50% |
| 1.000 | 33% | 29% |
| 0.750 | 25% | 25% |
| 0.187 | 13% | 12% |
| 0.079 | 8% | 8% |

# APPENDIX C: HYDROLOGIC ANALYSIS

| Cordova Hydrology - CAB 1 & 2 | | | | | | | |
|---|---|---|---|---|---|---|---|
| **Percent chance exceedance** | **Recurrence interval** | **2016 Regression (cfs)** | **2003 Regression (cfs)** | **Win TR-55 (cfs)** | CAB3 Gage Record | Peak Q Coorelated to USGS Gage 15min | Peak Q from coorelation to daily rainfall 10 day sum |
| | Q2D2 | **5.04** | 9.37 | 6.53 | 1.88 | 2.51 | 1.09 |
| 50 | 2 | **12.6** | 23.4 | 16.3 | 4.7 | 6.3 | 2.7 |
| 20 | 5 | **22.3** | 31.6 | 23.8 | 5.8 | 8.0 | 3.5 |
| 10 | 10 | **30.0** | 37.1 | 30.0 | 6.5 | 9.0 | 4.0 |
| 4 | 25 | **41.0** | 44.0 | 38.9 | 7.4 | 10.1 | 4.6 |
| 2 | 50 | **49.8** | 49.1 | 46.2 | 8.0 | 10.9 | 5.0 |
| 1 | 100 | **59.7** | 54.1 | 53.9 | 8.7 | 11.7 | 5.4 |
| 0.5 | 200 | **69.8** | 59.3 | | 9.4 | 12.4 | 5.8 |
| 0.2 | 500 | **84.4** | 66.0 | | | | |

| 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

Existing Culvert

| CAB 1 - 36" CMP | |
|---|---|
| | Existing Culvert |
| Culvert Inlet Invert Elevation | 55.1 |
| Culvert Inlet Thalweg Elevation | 55.1 |
| Culvert Height(ft) | 3.0 |
| Embedment (ft) | 0.0 |
| D (Depth to top of embedment, ft) | 3.0 |
| Q2D2 = 2.51 | |
| Headwater Elevation | 55.9 |
| HW (to embedment, ft) | 0.8 |
| **HW/D (to top of embedment)** | **0.27** |
| Q2 = 6.3 | |
| Headwater Elevation | 56.4 |
| HW (to embedment, ft) | 1.3 |
| **HW/D (to top of embedment)** | **0.43** |
| Q5 = 8.0 | |
| Headwater Elevation | 56.6 |
| HW (to embedment, ft) | 1.5 |
| **HW/D (to top of embedment)** | **0.49** |
| Q10 = 9 | |
| Headwater Elevation | 56.7 |
| HW (to embedment, ft) | 1.6 |
| **HW/D (to top of embedment)** | **0.52** |
| Q25 = 10.1 | |
| Headwater Elevation | 56.8 |
| HW (to embedment, ft) | 1.7 |
| **HW/D (to top of embedment)** | **0.56** |
| Q50 = 10.9 | |
| Headwater Elevation | 56.8 |
| HW (to embedment, ft) | 1.7 |
| **HW/D (to top of embedment)** | **0.58** |
| Q100 = 11.7 | |
| Headwater Elevation | 56.9 |
| HW (to embedment, ft) | 1.8 |
| **HW/D (to top of embedment)** | **0.60** |

| | |
|---|---|
| **Overtopping (cfs)** | **45.09** |

65% Proposed

| CAB 1 - 72" CMP | |
| --- | --- |
| | Proposed Culvert (Embedded) |
| Culvert Inlet Invert Elevation | 50.9 |
| Culvert Inlet Thalweg Elevation | 53.8 |
| Culvert Height(ft) | 6.0 |
| Embedment (ft) | 2.9 |
| D (Depth to top of embedment, ft) | 3.1 |
| Q2D2 = 2.51 | |
| Headwater Elevation | 54.2 |
| HW (to embedment, ft) | 0.4 |
| **HW/D (to top of embedment)** | **0.11** |
| Q2 = 6.3 | |
| Headwater Elevation | 54.5 |
| HW (to embedment, ft) | 0.7 |
| **HW/D (to top of embedment)** | **0.21** |
| Q5 = 8.0 | |
| Headwater Elevation | 54.6 |
| HW (to embedment, ft) | 0.8 |
| **HW/D (to top of embedment)** | **0.26** |
| Q10 = 9 | |
| Headwater Elevation | 54.7 |
| HW (to embedment, ft) | 0.9 |
| **HW/D (to top of embedment)** | **0.28** |
| Q25 = 10.1 | |
| Headwater Elevation | 54.8 |
| HW (to embedment, ft) | 0.9 |
| **HW/D (to top of embedment)** | **0.31** |
| Q50 = 10.9 | |
| Headwater Elevation | 54.8 |
| HW (to embedment, ft) | 1.0 |
| **HW/D (to top of embedment)** | **0.32** |
| Q100 = 11.7 | |
| Headwater Elevation | 54.9 |
| HW (to embedment, ft) | 1.1 |
| **HW/D (to top of embedment)** | **0.34** |

| | |
| --- | --- |
| **Overtopping (cfs)** | **67.51** |

# HY-8 Culvert Analysis Report

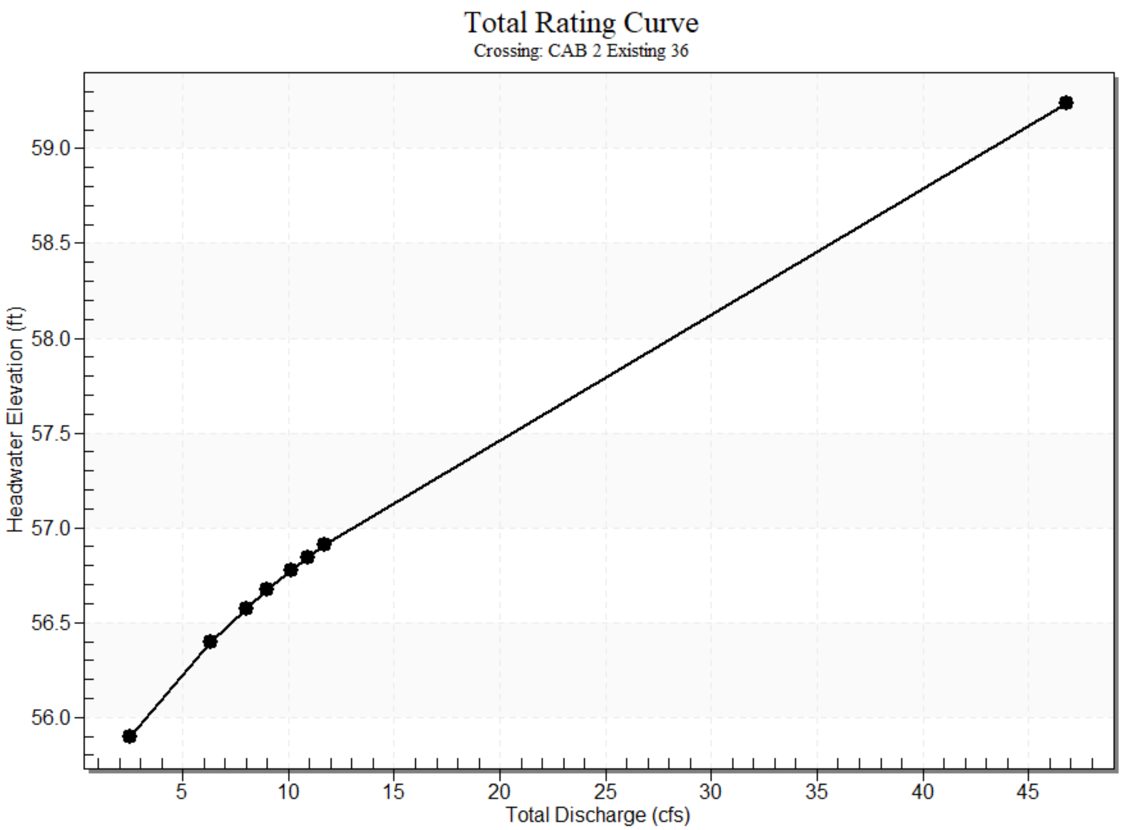
## Crossing Discharge Data

Discharge Selection Method: User Defined

### Table 1 - Summary of Culvert Flows at Crossing: CAB 2 Existing 36

| Headwater Elevation (ft) | Total Discharge (cfs) | Existing 36 Discharge (cfs) | Roadway Discharge (cfs) | Iterations |
|---|---|---|---|---|
| **55.90** | 2.51 | 2.51 | 0.00 | 1 |
| **56.40** | 6.30 | 6.30 | 0.00 | 1 |
| **56.58** | 8.00 | 8.00 | 0.00 | 1 |
| **56.67** | 9.00 | 9.00 | 0.00 | 1 |
| **56.77** | 10.10 | 10.10 | 0.00 | 1 |
| **56.84** | 10.90 | 10.90 | 0.00 | 1 |
| **56.91** | 11.70 | 11.70 | 0.00 | 1 |
| **59.22** | 45.09 | 45.09 | 0.00 | Overtopping |

### Rating Curve Plot for Crossing: CAB 2 Existing 36



## Culvert Data: Existing 36

### Table 1 - Culvert Summary Table: Existing 36

| Total Discharge (cfs) | Culvert Discharge (cfs) | Headwater Elevation (ft) | Inlet Control Depth (ft) | Outlet Control Depth (ft) | Flow Type | Normal Depth (ft) | Critical Depth (ft) | Outlet Depth (ft) | Tailwater Depth (ft) | Outlet Velocity (ft/s) | Tailwater Velocity (ft/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.51 cfs** | 2.51 cfs | 55.90 | 0.71 | 0.799 | 2-M2c | 0.52 | 0.49 | 0.49 | 0.40 | 3.31 | 2.10 |
| **6.30 cfs** | 6.30 cfs | 56.40 | 1.16 | 1.299 | 2-M2c | 0.82 | 0.79 | 0.79 | 0.74 | 4.25 | 2.84 |
| **8.00 cfs** | 8.00 cfs | 56.58 | 1.31 | 1.475 | 2-M2c | 0.93 | 0.89 | 0.89 | 0.87 | 4.55 | 3.05 |
| **9.00 cfs** | 9.00 cfs | 56.67 | 1.40 | 1.572 | 2-M2c | 0.98 | 0.95 | 0.95 | 0.95 | 4.70 | 3.16 |
| **10.10 cfs** | 10.10 cfs | 56.77 | 1.49 | 1.672 | 2-M2c | 1.05 | 1.01 | 1.01 | 1.03 | 4.86 | 3.26 |
| **10.90 cfs** | 10.90 cfs | 56.84 | 1.55 | 1.743 | 2-M2c | 1.09 | 1.05 | 1.05 | 1.09 | 4.97 | 3.34 |
| **11.70 cfs** | 11.70 cfs | 56.91 | 1.61 | 1.811 | 2-M2c | 1.13 | 1.09 | 1.09 | 1.15 | 5.07 | 3.40 |

### Culvert Barrel Data

Culvert Barrel Type Straight Culvert

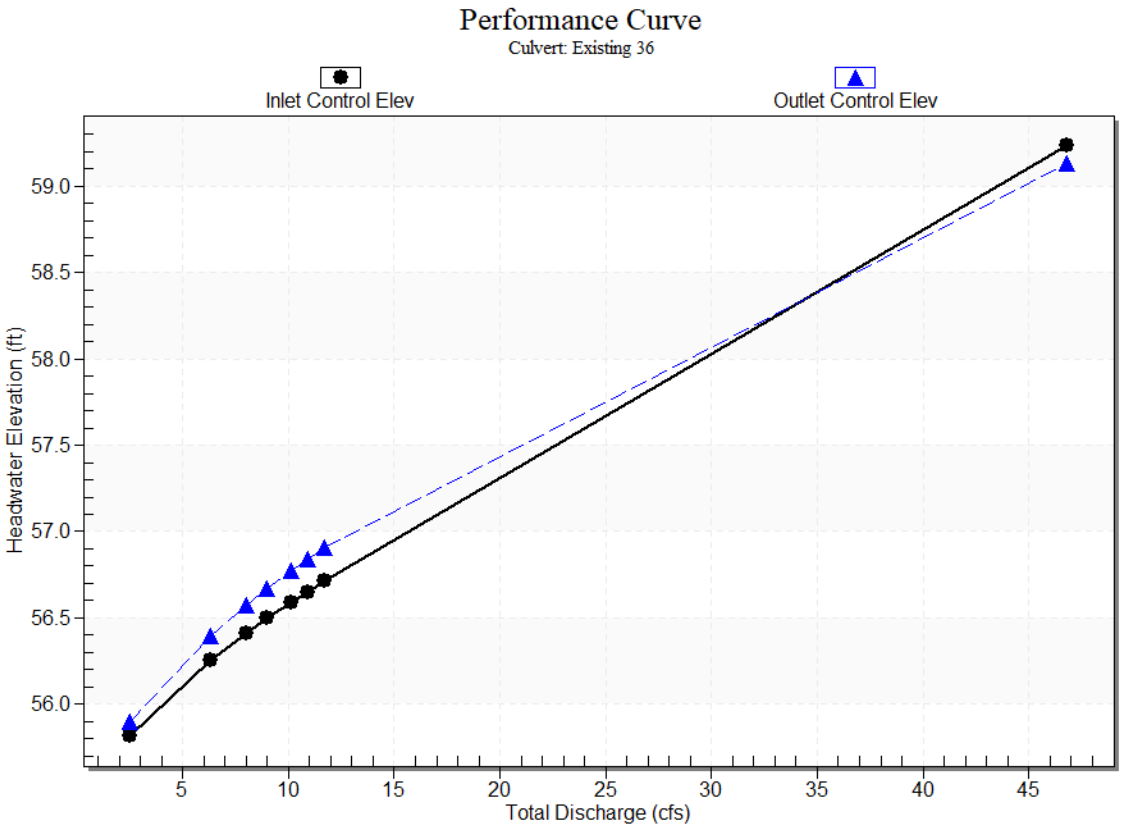
Inlet Elevation (invert): 55.10 ft,

Outlet Elevation (invert): 54.70 ft

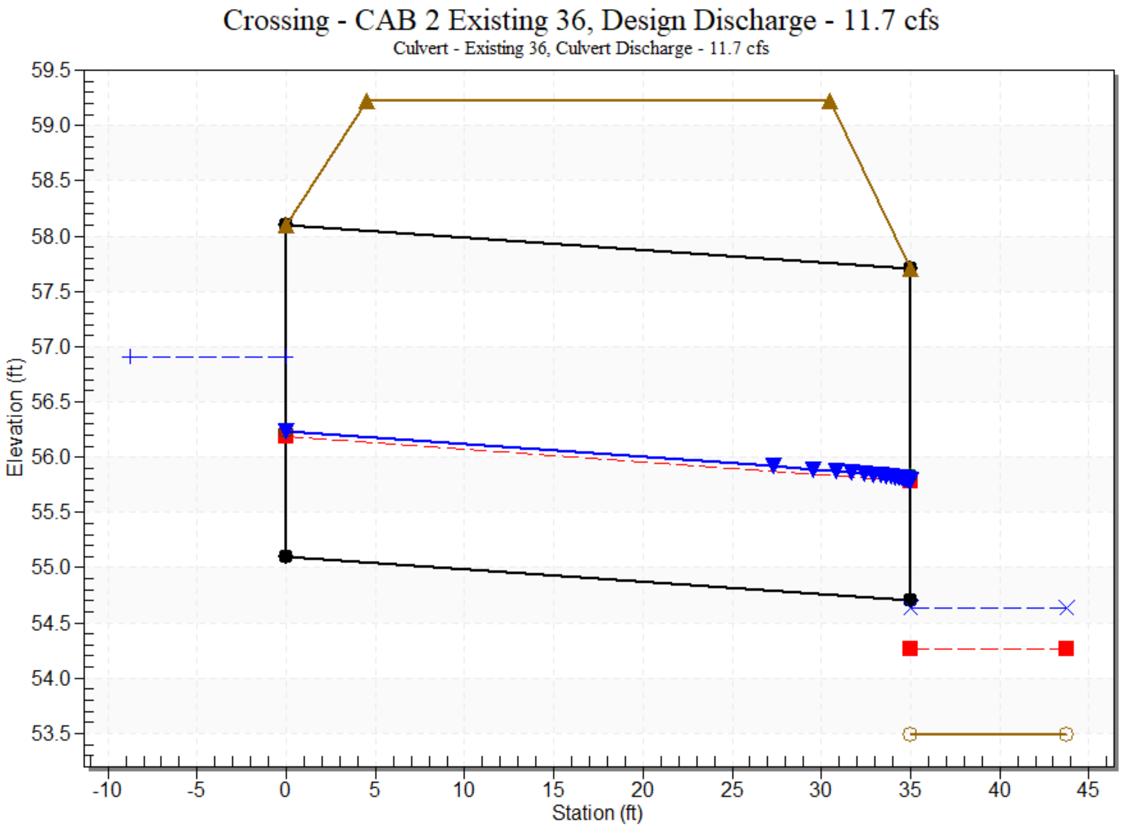
Culvert Length: 35.00 ft,

Culvert Slope: 0.0114

## Culvert Performance Curve Plot: Existing 36



## Water Surface Profile Plot for Culvert: Existing 36




## Site Data - Existing 36

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 55.10 ft

Outlet Station: 35.00 ft

Outlet Elevation: 54.70 ft

Number of Barrels: 1

## Culvert Data Summary - Existing 36

Barrel Shape: Circular

Barrel Diameter: 3.00 ft

Barrel Material: Corrugated Steel

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting (Ke=0.9)

Inlet Depression: None

## Tailwater Data for Crossing: CAB 2 Existing 36

### Table 2 - Downstream Channel Rating Curve (Crossing: CAB 2 Existing 36)

| Flow (cfs) | Water Surface Elev (ft) | Velocity (ft/s) | Depth (ft) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| **2.51** | 53.89 | 0.40 | 2.10 | 0.28 | 0.59 |
| **6.30** | 54.23 | 0.74 | 2.84 | 0.53 | 0.58 |
| **8.00** | 54.36 | 0.87 | 3.05 | 0.62 | 0.58 |
| **9.00** | 54.44 | 0.95 | 3.16 | 0.68 | 0.57 |
| **10.10** | 54.52 | 1.03 | 3.26 | 0.73 | 0.57 |
| **10.90** | 54.58 | 1.09 | 3.34 | 0.77 | 0.56 |
| **11.70** | 54.64 | 1.15 | 3.40 | 0.82 | 0.56 |

## Tailwater Channel Data - CAB 2 Existing 36

Tailwater Channel Option: Rectangular Channel

Bottom Width: 3.00 ft

Channel Slope: 0.0114

Channel Manning's n: 0.0350

Channel Invert Elevation: 53.49 ft

## Roadway Data for Crossing: CAB 2 Existing 36

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 59.22 ft

Roadway Surface: Paved

Roadway Top Width: 26.00 ft

## Crossing Discharge Data

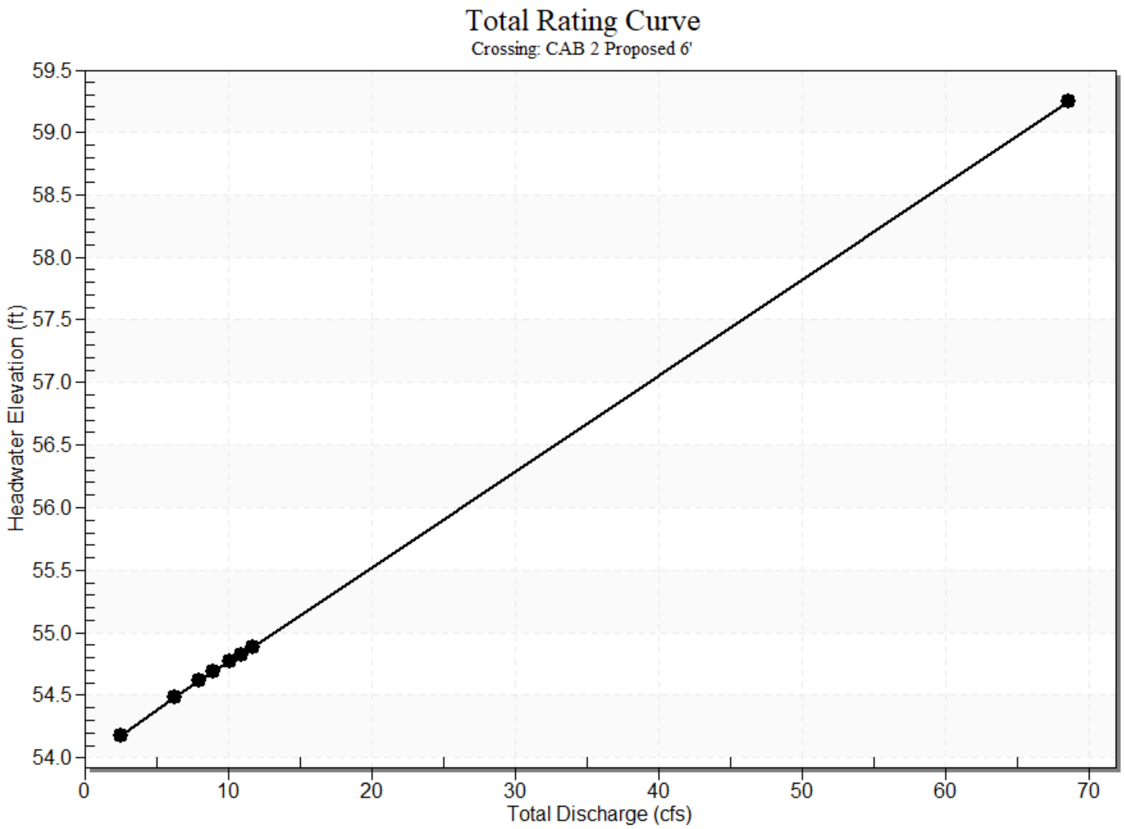
Discharge Selection Method: User Defined

### Table 3 - Summary of Culvert Flows at Crossing: CAB 2 Proposed 6'

| Headwater Elevation (ft) | Total Discharge (cfs) | Proposed 6' Discharge (cfs) | Roadway Discharge (cfs) | Iterations |
|---|---|---|---|---|

| | | | | |
|---|---|---|---|---|
| **54.18** | 2.51 | 2.51 | 0.00 | 1 |
| **54.49** | 6.30 | 6.30 | 0.00 | 1 |
| **54.62** | 8.00 | 8.00 | 0.00 | 1 |
| **54.69** | 9.00 | 9.00 | 0.00 | 1 |
| **54.77** | 10.10 | 10.10 | 0.00 | 1 |
| **54.83** | 10.90 | 10.90 | 0.00 | 1 |
| **54.88** | 11.70 | 11.70 | 0.00 | 1 |
| **59.22** | 67.51 | 67.51 | 0.00 | Overtopping |

### Rating Curve Plot for Crossing: CAB 2 Proposed 6'




## Culvert Data: Proposed 6'

### Table 2 - Culvert Summary Table: Proposed 6'

| Total Discharge (cfs) | Culvert Discharge (cfs) | Headwater Elevation (ft) | Inlet Control Depth (ft) | Outlet Control Depth (ft) | Flow Type | Normal Depth (ft) | Critical Depth (ft) | Outlet Depth (ft) | Tailwater Depth (ft) | Outlet Velocity (ft/s) | Tailwater Velocity (ft/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.51 cfs** | 2.51 cfs | 54.18 | 0.26 | 0.351 | 3-M1t | 0.28 | 0.18 | 0.40 | 0.40 | 1.05 | 2.10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **6.30 cfs** | 6.30 cfs | 54.49 | 0.53 | 0.660 | 3-M1t | 0.49 | 0.33 | 0.74 | 0.74 | 1.43 | 2.84 |
| **8.00 cfs** | 8.00 cfs | 54.62 | 0.65 | 0.787 | 3-M1t | 0.57 | 0.38 | 0.88 | 0.87 | 1.54 | 3.05 |
| **9.00 cfs** | 9.00 cfs | 54.69 | 0.71 | 0.861 | 3-M1t | 0.62 | 0.41 | 0.95 | 0.95 | 1.60 | 3.16 |
| **10.10 cfs** | 10.10 cfs | 54.77 | 0.78 | 0.941 | 3-M1t | 0.66 | 0.45 | 1.03 | 1.03 | 1.66 | 3.26 |
| **10.90 cfs** | 10.90 cfs | 54.83 | 0.83 | 0.998 | 3-M1t | 0.70 | 0.47 | 1.09 | 1.09 | 1.70 | 3.34 |
| **11.70 cfs** | 11.70 cfs | 54.88 | 0.87 | 1.055 | 3-M1t | 0.73 | 0.49 | 1.15 | 1.15 | 1.74 | 3.40 |

## Culvert Barrel Data

Culvert Barrel Type Straight Culvert

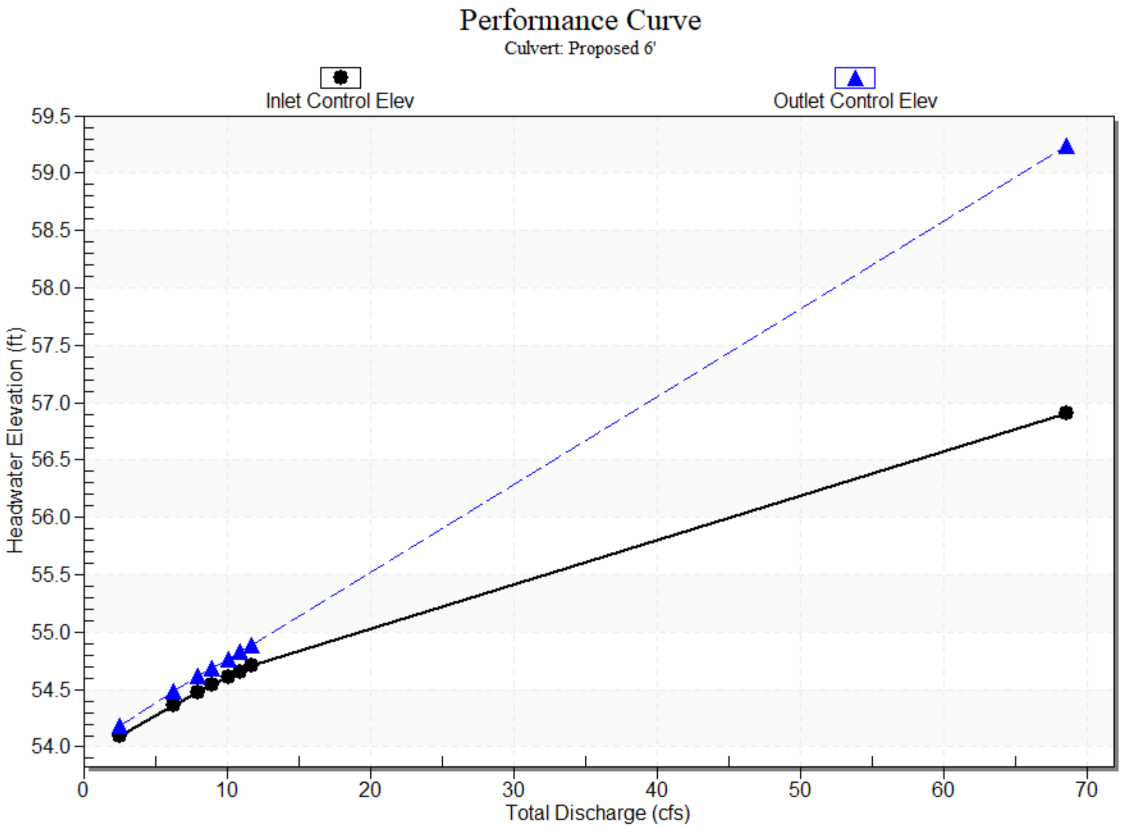
Inlet Elevation (invert): 53.83 ft,

Outlet Elevation (invert): 53.49 ft

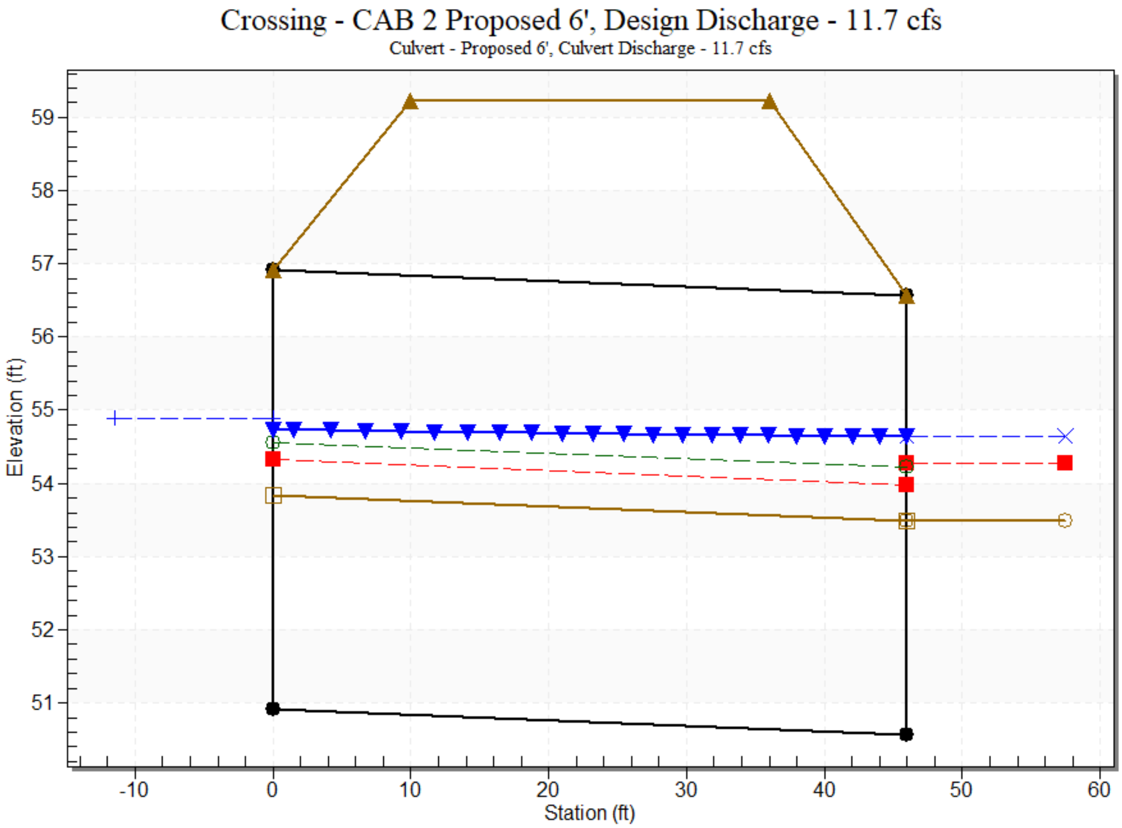
Culvert Length: 46.00 ft,

Culvert Slope: 0.0074

## Culvert Performance Curve Plot: Proposed 6'



## Water Surface Profile Plot for Culvert: Proposed 6'




## Site Data - Proposed 6'

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 50.91 ft

Outlet Station: 46.00 ft

Outlet Elevation: 50.57 ft

Number of Barrels: 1

## Culvert Data Summary - Proposed 6'

Barrel Shape: Circular

Barrel Diameter: 6.00 ft

Barrel Material: Corrugated Steel

Embedment: 35.02 in

Barrel Manning's n: 0.0240 (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: CAB 2 Proposed 6'

**Table 4 - Downstream Channel Rating Curve (Crossing: CAB 2 Proposed 6')**

| Flow (cfs) | Water Surface Elev (ft) | Velocity (ft/s) | Depth (ft) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| **2.51** | 53.89 | 0.40 | 2.10 | 0.28 | 0.59 |
| **6.30** | 54.23 | 0.74 | 2.84 | 0.53 | 0.58 |
| **8.00** | 54.36 | 0.87 | 3.05 | 0.62 | 0.58 |
| **9.00** | 54.44 | 0.95 | 3.16 | 0.68 | 0.57 |
| **10.10** | 54.52 | 1.03 | 3.26 | 0.73 | 0.57 |
| **10.90** | 54.58 | 1.09 | 3.34 | 0.77 | 0.56 |
| **11.70** | 54.64 | 1.15 | 3.40 | 0.82 | 0.56 |

## Tailwater Channel Data - CAB 2 Proposed 6'

Tailwater Channel Option: Rectangular Channel

Bottom Width: 3.00 ft

Channel Slope: 0.0114

Channel Manning's n: 0.0350

Channel Invert Elevation: 53.49 ft

## Roadway Data for Crossing: CAB 2 Proposed 6'

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 59.22 ft

Roadway Surface: Paved

Roadway Top Width: 26.00 ft

## Crossing Discharge Data

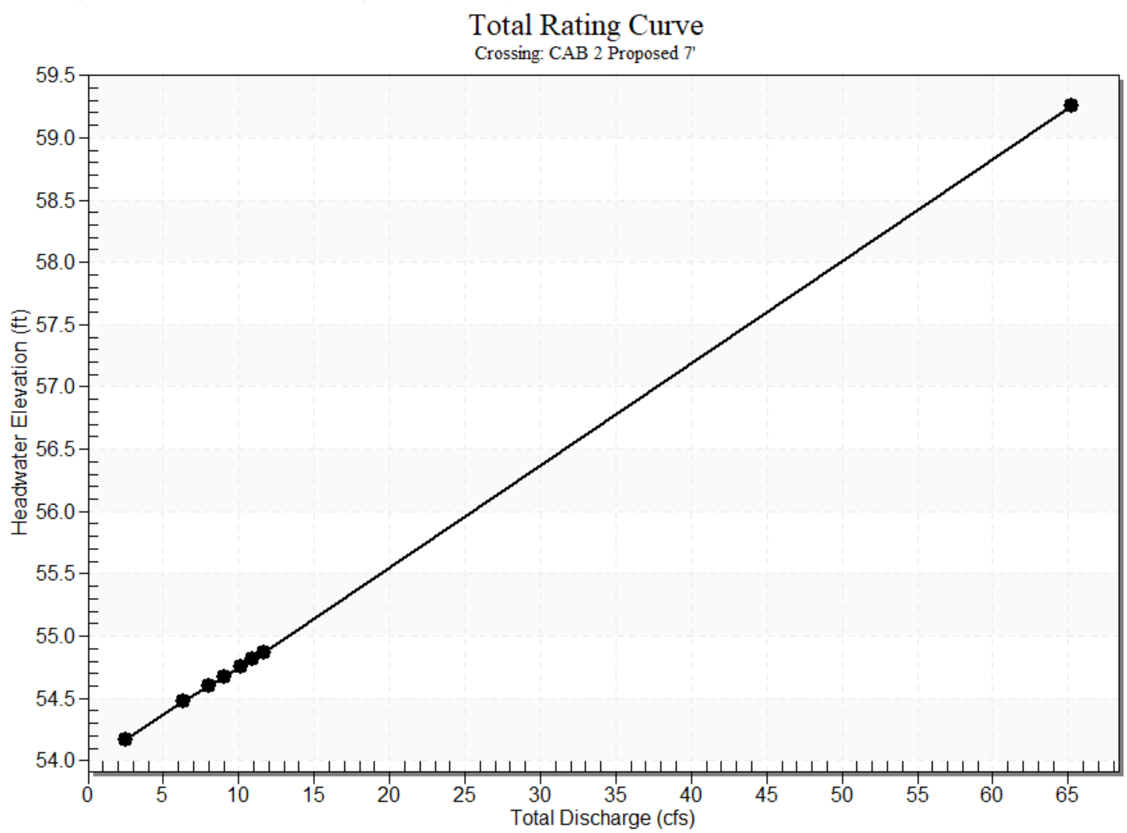
Discharge Selection Method: User Defined

**Table 5 - Summary of Culvert Flows at Crossing: CAB 2 Proposed 7'**

| Headwater | Total | Proposed 7' | Roadway | Iterations |
|---|---|---|---|---|

| Elevation (ft) | Discharge (cfs) | Discharge (cfs) | Discharge (cfs) | |
|---|---|---|---|---|
| **54.17** | 2.51 | 2.51 | 0.00 | 1 |
| **54.48** | 6.30 | 6.30 | 0.00 | 1 |
| **54.60** | 8.00 | 8.00 | 0.00 | 1 |
| **54.68** | 9.00 | 9.00 | 0.00 | 1 |
| **54.76** | 10.10 | 10.10 | 0.00 | 1 |
| **54.81** | 10.90 | 10.90 | 0.00 | 1 |
| **54.87** | 11.70 | 11.70 | 0.00 | 1 |
| **59.22** | 63.30 | 63.30 | 0.00 | Overtopping |

### Rating Curve Plot for Crossing: CAB 2 Proposed 7'




## Culvert Data: Proposed 7'

### Table 3 - Culvert Summary Table: Proposed 7'

| Total Discharge (cfs) | Culvert Discharge (cfs) | Headwater Elevation (ft) | Inlet Control Depth (ft) | Outlet Control Depth (ft) | Flow Type | Normal Depth (ft) | Critical Depth (ft) | Outlet Depth (ft) | Tailwater Depth (ft) | Outlet Velocity (ft/s) | Tailwater Velocity (ft/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.51** | 2.51 | 54.17 | 0.26 | 0.34 | 3- | 0.27 | 0.17 | 0.4 | 0.40 | 1.01 | 2.10 |

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **cfs** | cfs | | | 1 | M1t | | | 0 | | | |
| **6.30 cfs** | 6.30 cfs | 54.48 | 0.54 | 0.646 | 3-M1t | 0.48 | 0.32 | 0.74 | 0.74 | 1.38 | 2.84 |
| **8.00 cfs** | 8.00 cfs | 54.60 | 0.65 | 0.773 | 3-M1t | 0.56 | 0.37 | 0.88 | 0.87 | 1.50 | 3.05 |
| **9.00 cfs** | 9.00 cfs | 54.68 | 0.72 | 0.847 | 3-M1t | 0.60 | 0.40 | 0.95 | 0.95 | 1.55 | 3.16 |
| **10.10 cfs** | 10.10 cfs | 54.76 | 0.78 | 0.927 | 3-M1t | 0.65 | 0.44 | 1.03 | 1.03 | 1.61 | 3.26 |
| **10.90 cfs** | 10.90 cfs | 54.81 | 0.83 | 0.985 | 3-M1t | 0.68 | 0.46 | 1.09 | 1.09 | 1.66 | 3.34 |
| **11.70 cfs** | 11.70 cfs | 54.87 | 0.88 | 1.043 | 3-M1t | 0.71 | 0.48 | 1.15 | 1.15 | 1.70 | 3.40 |

## Culvert Barrel Data

Culvert Barrel Type Straight Culvert

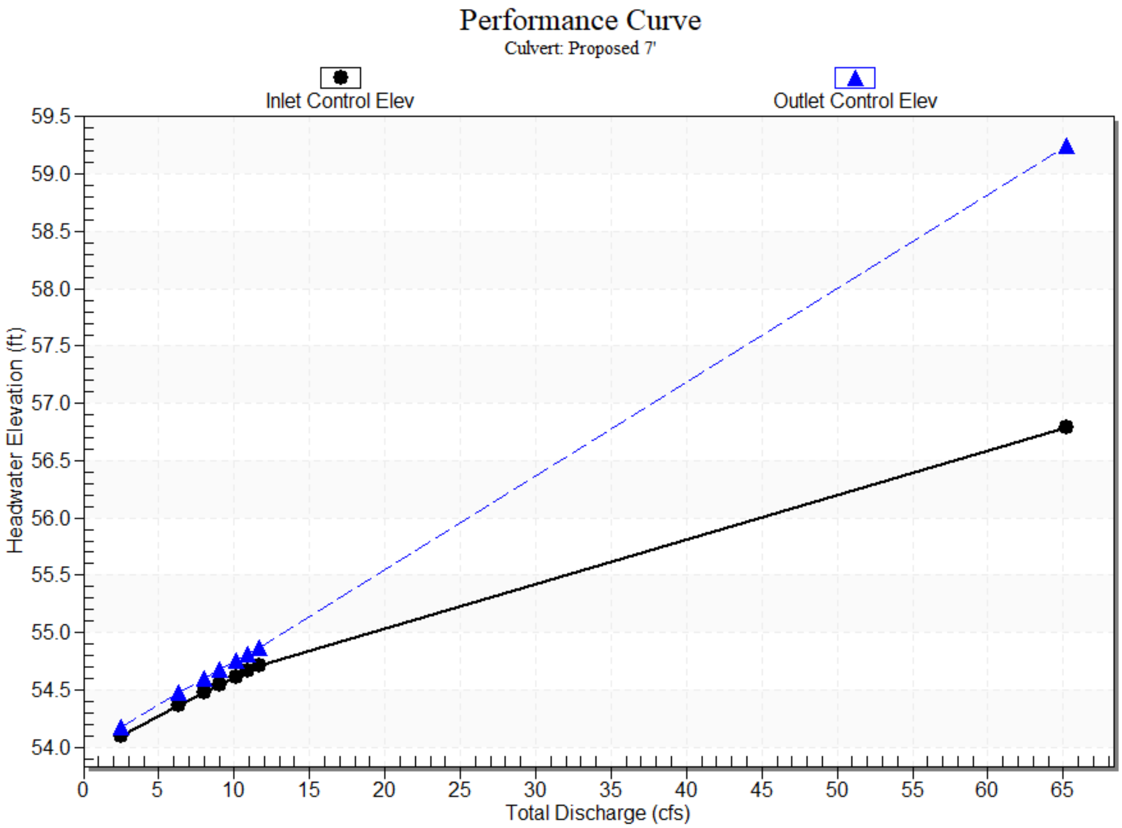
Inlet Elevation (invert): 53.83 ft,

Outlet Elevation (invert): 53.49 ft

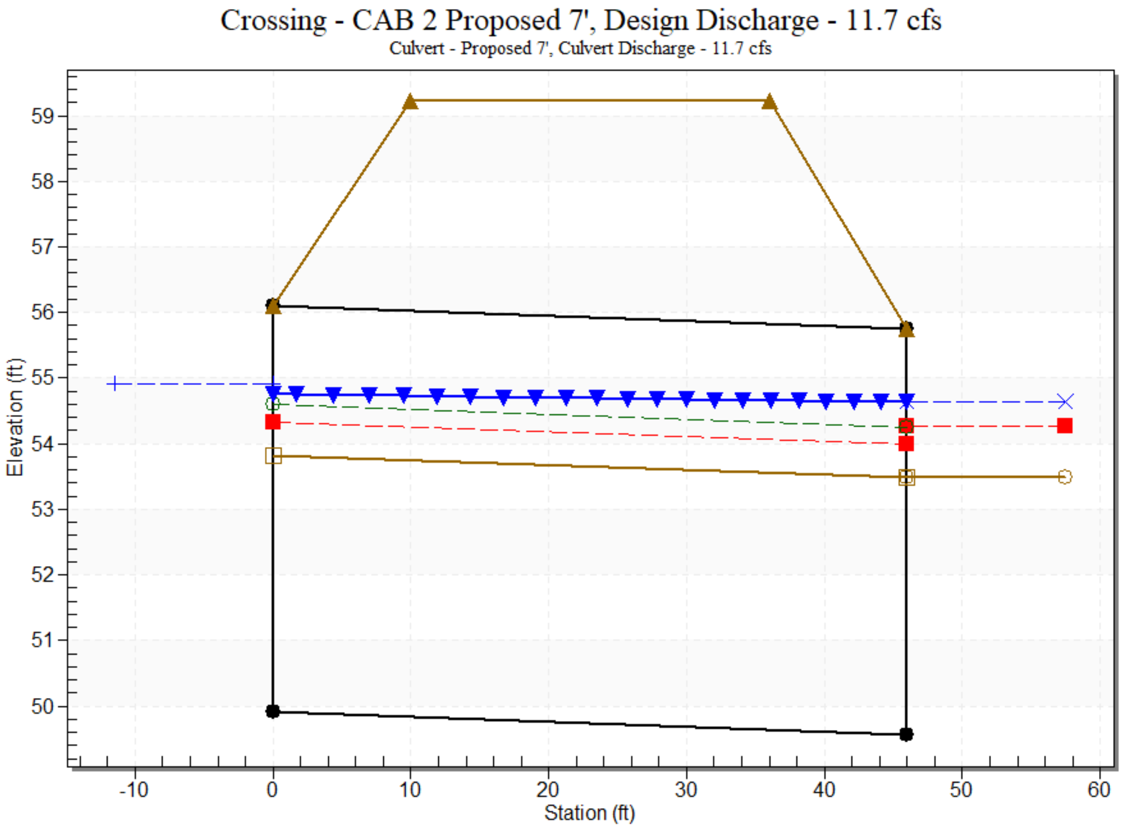
Culvert Length: 46.00 ft,

Culvert Slope: 0.0074

## Culvert Performance Curve Plot: Proposed 7'



## Water Surface Profile Plot for Culvert: Proposed 7'




## Site Data - Proposed 7'

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 49.91 ft

Outlet Station: 46.00 ft

Outlet Elevation: 49.57 ft

Number of Barrels: 1

## Culvert Data Summary - Proposed 7'

Barrel Shape: Circular

Barrel Diameter: 5.81 ft

Barrel Material: Corrugated Steel

Embedment: 47.03 in

Barrel Manning's n: 0.0240 (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: CAB 2 Proposed 7'

### Table 6 - Downstream Channel Rating Curve (Crossing: CAB 2 Proposed 7')

| Flow (cfs) | Water Surface Elev (ft) | Velocity (ft/s) | Depth (ft) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| **2.51** | 53.89 | 0.40 | 2.10 | 0.28 | 0.59 |
| **6.30** | 54.23 | 0.74 | 2.84 | 0.53 | 0.58 |
| **8.00** | 54.36 | 0.87 | 3.05 | 0.62 | 0.58 |
| **9.00** | 54.44 | 0.95 | 3.16 | 0.68 | 0.57 |
| **10.10** | 54.52 | 1.03 | 3.26 | 0.73 | 0.57 |
| **10.90** | 54.58 | 1.09 | 3.34 | 0.77 | 0.56 |
| **11.70** | 54.64 | 1.15 | 3.40 | 0.82 | 0.56 |

## Tailwater Channel Data - CAB 2 Proposed 7'

Tailwater Channel Option: Rectangular Channel

Bottom Width: 3.00 ft

Channel Slope: 0.0114

Channel Manning's n: 0.0350

Channel Invert Elevation: 53.49 ft

## Roadway Data for Crossing: CAB 2 Proposed 7'

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 59.22 ft

Roadway Surface: Paved

Roadway Top Width: 26.00 ft

## Crossing Discharge Data

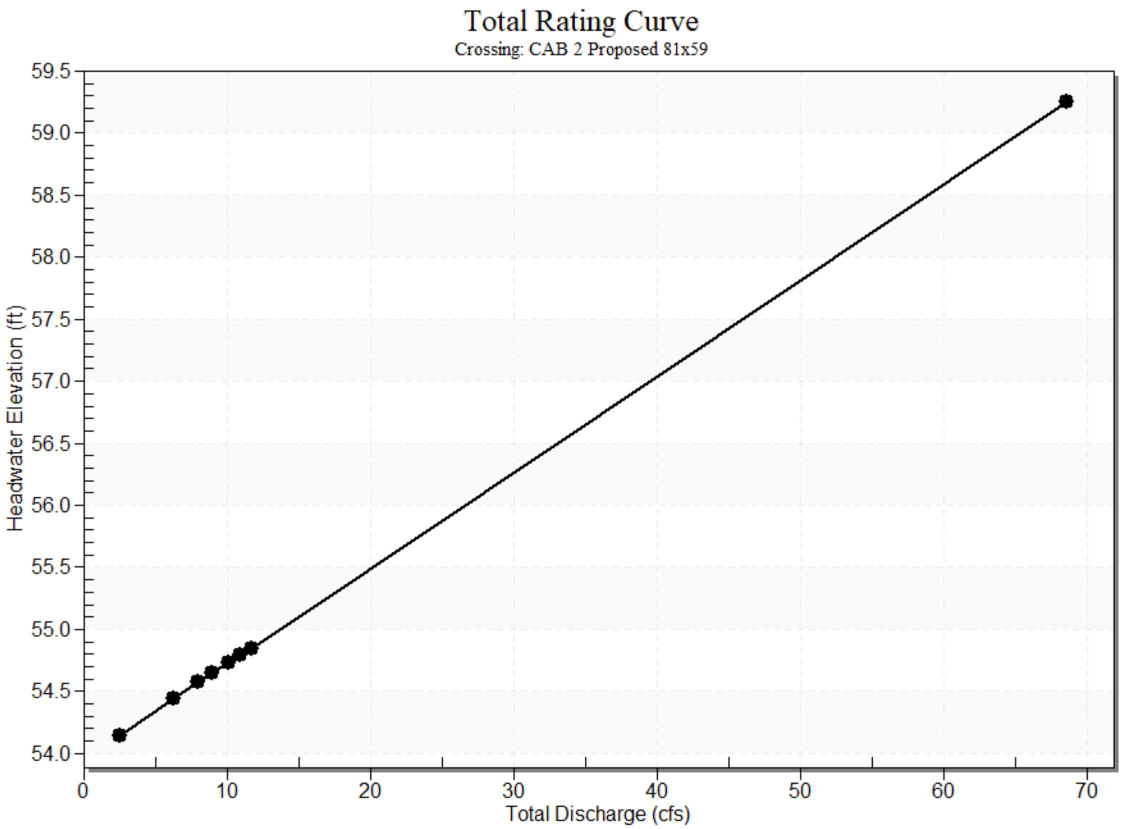
Discharge Selection Method: User Defined

### Table 7 - Summary of Culvert Flows at Crossing: CAB 2 Proposed 81x59

| Headwater | Total | Proposed | Roadway | Iterations |
|---|---|---|---|---|

| Elevation (ft) | Discharge (cfs) | 81x59 Discharge (cfs) | Discharge (cfs) | |
|---|---|---|---|---|
| **54.15** | 2.51 | 2.51 | 0.00 | 1 |
| **54.45** | 6.30 | 6.30 | 0.00 | 1 |
| **54.57** | 8.00 | 8.00 | 0.00 | 1 |
| **54.65** | 9.00 | 9.00 | 0.00 | 1 |
| **54.73** | 10.10 | 10.10 | 0.00 | 1 |
| **54.79** | 10.90 | 10.90 | 0.00 | 1 |
| **54.85** | 11.70 | 11.70 | 0.00 | 1 |
| **59.22** | 67.15 | 67.15 | 0.00 | Overtopping |

### Rating Curve Plot for Crossing: CAB 2 Proposed 81x59




## Culvert Data: Proposed 81x59

### Table 4 - Culvert Summary Table: Proposed 81x59

| Total Discharge (cfs) | Culvert Discharge (cfs) | Headwater Elevation (ft) | Inlet Control Depth (ft) | Outlet Control Depth (ft) | Flow Type | Normal Depth (ft) | Critical Depth (ft) | Outlet Depth (ft) | Tailwater Depth (ft) | Outlet Velocity (ft/s) | Tailwater Velocity (ft/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.51 cfs** | 2.51 cfs | 54.15 | 0.27 | 0.325 | 3-M1t | 0.26 | 0.16 | 0.40 | 0.40 | 0.94 | 2.10 |
| **6.30 cfs** | 6.30 cfs | 54.45 | 0.54 | 0.626 | 3-M1t | 0.47 | 0.30 | 0.74 | 0.74 | 1.30 | 2.84 |
| **8.00 cfs** | 8.00 cfs | 54.57 | 0.64 | 0.755 | 3-M1t | 0.55 | 0.35 | 0.87 | 0.87 | 1.41 | 3.05 |
| **9.00 cfs** | 9.00 cfs | 54.65 | 0.69 | 0.829 | 3-M1t | 0.59 | 0.38 | 0.95 | 0.95 | 1.47 | 3.16 |
| **10.10 cfs** | 10.10 cfs | 54.73 | 0.75 | 0.910 | 3-M1t | 0.64 | 0.41 | 1.03 | 1.03 | 1.53 | 3.26 |
| **10.90 cfs** | 10.90 cfs | 54.79 | 0.79 | 0.968 | 3-M1t | 0.67 | 0.43 | 1.09 | 1.09 | 1.57 | 3.34 |
| **11.70 cfs** | 11.70 cfs | 54.85 | 0.83 | 1.026 | 3-M1t | 0.70 | 0.45 | 1.15 | 1.15 | 1.61 | 3.40 |

## Culvert Barrel Data

Culvert Barrel Type Straight Culvert

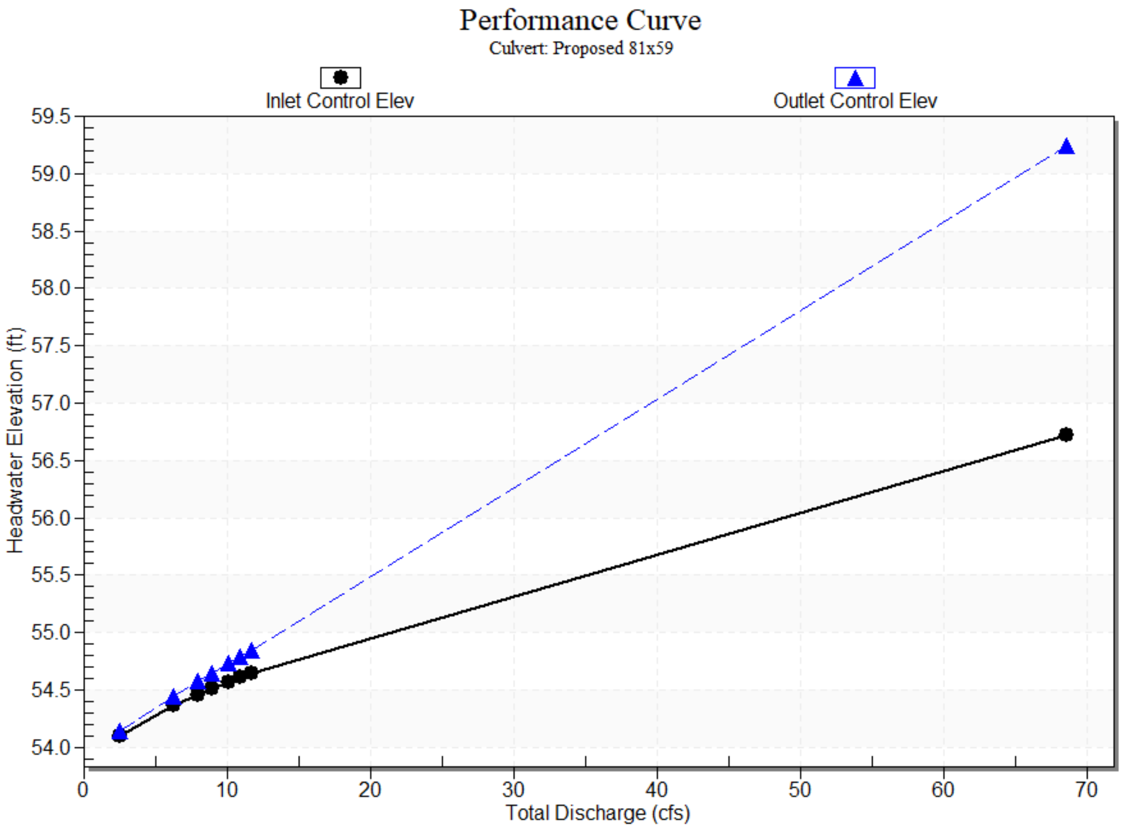
Inlet Elevation (invert): 53.82 ft,

Outlet Elevation (invert): 53.49 ft

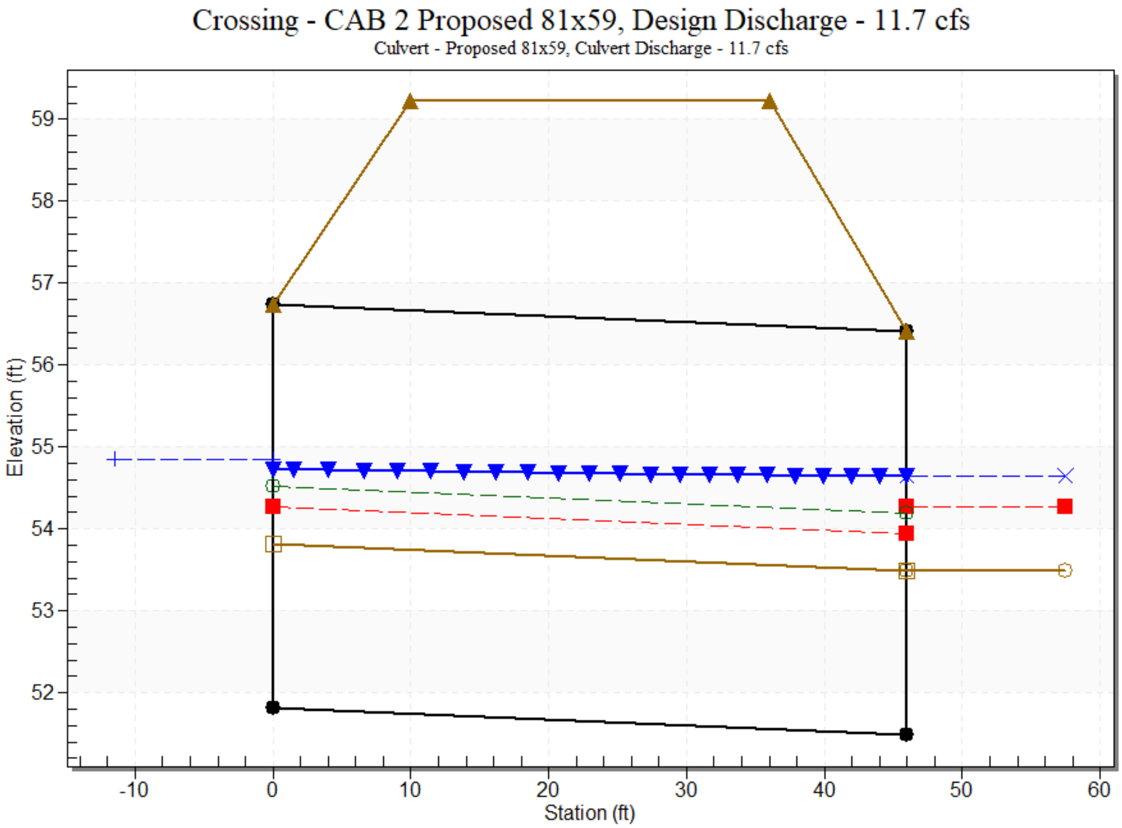
Culvert Length: 46.00 ft,

Culvert Slope: 0.0072

## Culvert Performance Curve Plot: Proposed 81x59



## Water Surface Profile Plot for Culvert: Proposed 81x59




## Site Data - Proposed 81x59

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 51.82 ft

Outlet Station: 46.00 ft

Outlet Elevation: 51.49 ft

Number of Barrels: 1

## Culvert Data Summary - Proposed 81x59

Barrel Shape: Pipe Arch

Barrel Span: 80.37 in

Barrel Rise: 59.00 in

Barrel Material: Steel or Aluminum

Embedment: 24.00 in

Barrel Manning's n: 0.0280 (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: CAB 2 Proposed 81x59

Table 8 - Downstream Channel Rating Curve (Crossing: CAB 2 Proposed 81x59)

| Flow (cfs) | Water Surface Elev (ft) | Velocity (ft/s) | Depth (ft) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| **2.51** | 53.89 | 0.40 | 2.10 | 0.28 | 0.59 |
| **6.30** | 54.23 | 0.74 | 2.84 | 0.53 | 0.58 |
| **8.00** | 54.36 | 0.87 | 3.05 | 0.62 | 0.58 |
| **9.00** | 54.44 | 0.95 | 3.16 | 0.68 | 0.57 |
| **10.10** | 54.52 | 1.03 | 3.26 | 0.73 | 0.57 |
| **10.90** | 54.58 | 1.09 | 3.34 | 0.77 | 0.56 |
| **11.70** | 54.64 | 1.15 | 3.40 | 0.82 | 0.56 |

## Tailwater Channel Data - CAB 2 Proposed 81x59

Tailwater Channel Option: Rectangular Channel

Bottom Width: 3.00 ft

Channel Slope: 0.0114

Channel Manning's n: 0.0350

Channel Invert Elevation: 53.49 ft

## Roadway Data for Crossing: CAB 2 Proposed 81x59

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 59.22 ft

Roadway Surface: Paved

Roadway Top Width: 26.00 ft

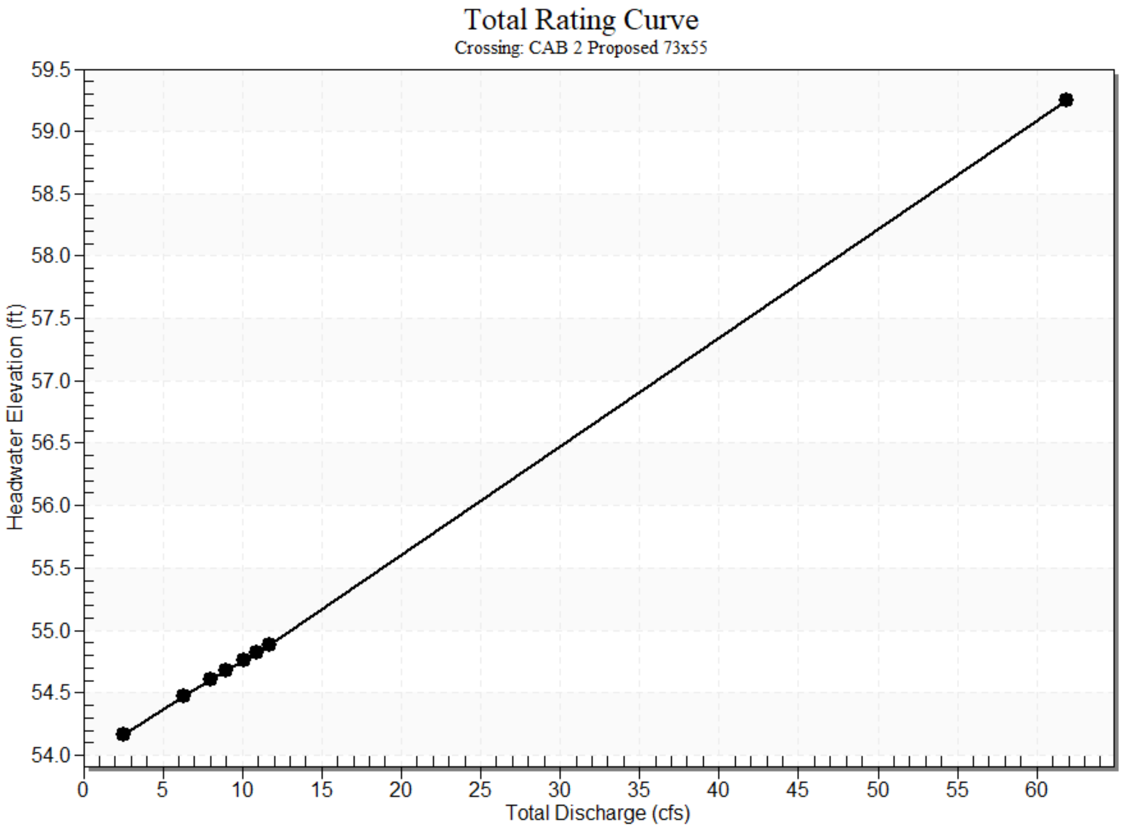
## Crossing Discharge Data

Discharge Selection Method: User Defined

Table 9 - Summary of Culvert Flows at Crossing: CAB 2 Proposed 73x55

| Headwater Elevation (ft) | Total Discharge (cfs) | Proposed 73x55 Discharge (cfs) | Roadway Discharge (cfs) | Iterations |
|---|---|---|---|---|
| **54.17** | 2.51 | 2.51 | 0.00 | 1 |
| **54.48** | 6.30 | 6.30 | 0.00 | 1 |
| **54.61** | 8.00 | 8.00 | 0.00 | 1 |
| **54.68** | 9.00 | 9.00 | 0.00 | 1 |
| **54.76** | 10.10 | 10.10 | 0.00 | 1 |
| **54.82** | 10.90 | 10.90 | 0.00 | 1 |
| **54.88** | 11.70 | 11.70 | 0.00 | 1 |
| **59.22** | 60.77 | 60.77 | 0.00 | Overtopping |

Rating Curve Plot for Crossing: CAB 2 Proposed 73x55




## Culvert Data: Proposed 73x55

Table 5 - Culvert Summary Table: Proposed 73x55

| Total Discharge (cfs) | Culvert Discharge (cfs) | Headwater Elevation (ft) | Inlet Control Dep | Outlet Control Dep | Flow Type | Normal Depth (ft) | Critical Depth (ft) | Outlet Depth (ft) | Tailwater Depth (ft) | Outlet Velocity (ft/s | Tailwater Velocity (ft/s) |
|---|---|---|---|---|---|---|---|---|---|---|---|

| | | | th (ft) | th (ft) | | | | | | ) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| **2.51 cfs** | 2.51 cfs | 54.17 | 0.30 | 0.347 | 3-M1t | 0.28 | 0.17 | 0.40 | 0.40 | 1.04 | 2.10 |
| **6.30 cfs** | 6.30 cfs | 54.48 | 0.58 | 0.656 | 3-M1t | 0.50 | 0.32 | 0.74 | 0.74 | 1.42 | 2.84 |
| **8.00 cfs** | 8.00 cfs | 54.61 | 0.69 | 0.785 | 3-M1t | 0.58 | 0.38 | 0.87 | 0.87 | 1.53 | 3.05 |
| **9.00 cfs** | 9.00 cfs | 54.68 | 0.74 | 0.860 | 3-M1t | 0.63 | 0.41 | 0.95 | 0.95 | 1.60 | 3.16 |
| **10.10 cfs** | 10.10 cfs | 54.76 | 0.80 | 0.942 | 3-M1t | 0.67 | 0.44 | 1.03 | 1.03 | 1.66 | 3.26 |
| **10.90 cfs** | 10.90 cfs | 54.82 | 0.84 | 1.001 | 3-M1t | 0.71 | 0.46 | 1.09 | 1.09 | 1.71 | 3.34 |
| **11.70 cfs** | 11.70 cfs | 54.88 | 0.88 | 1.060 | 3-M1t | 0.74 | 0.49 | 1.15 | 1.15 | 1.75 | 3.40 |

## Culvert Barrel Data

Culvert Barrel Type Straight Culvert

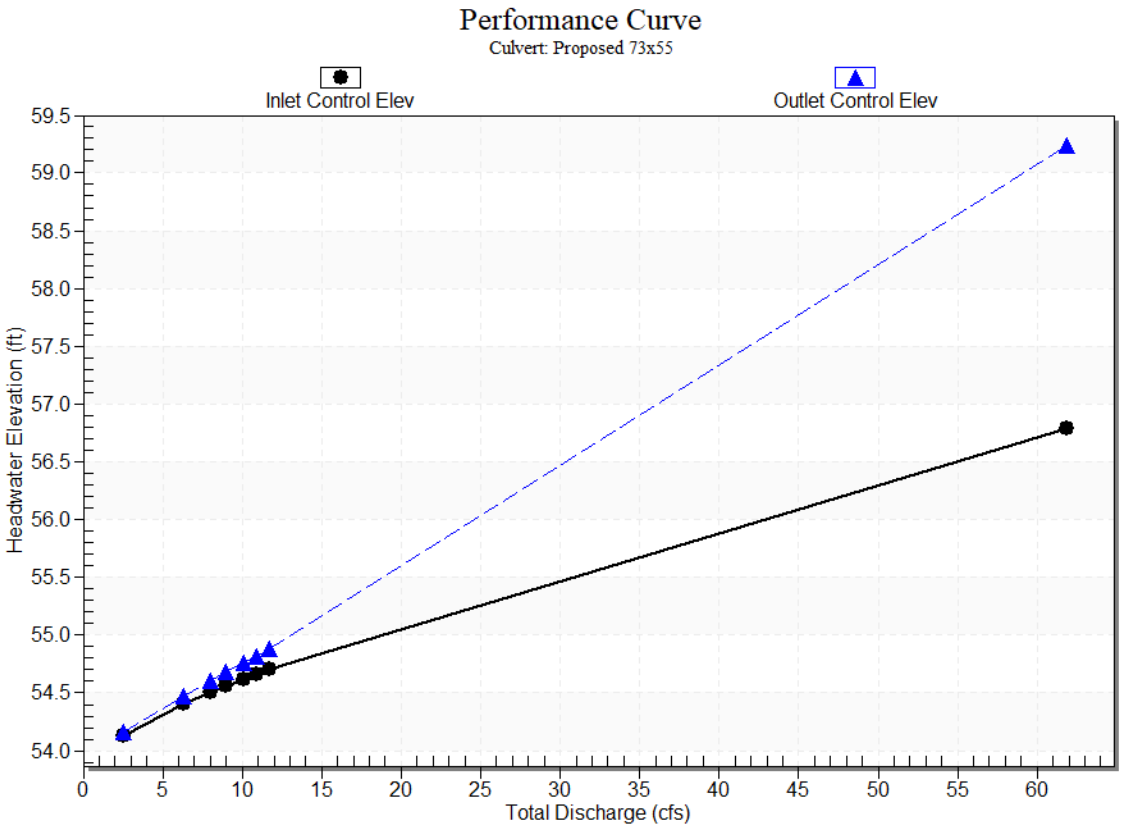
Inlet Elevation (invert): 53.82 ft,

Outlet Elevation (invert): 53.49 ft

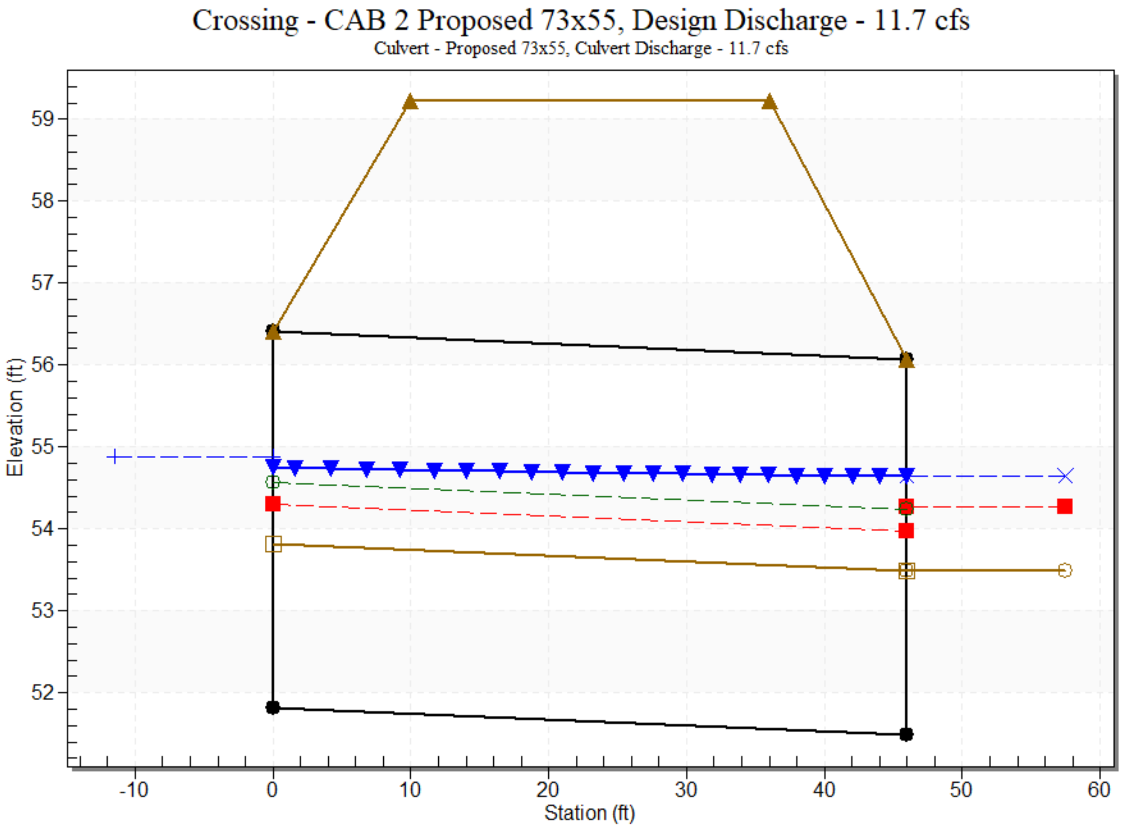
Culvert Length: 46.00 ft,

Culvert Slope: 0.0072

## Culvert Performance Curve Plot: Proposed 73x55



## Water Surface Profile Plot for Culvert: Proposed 73x55




## Site Data - Proposed 73x55

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 51.82 ft

Outlet Station: 46.00 ft

Outlet Elevation: 51.49 ft

Number of Barrels: 1

## Culvert Data Summary - Proposed 73x55

Barrel Shape: Pipe Arch

Barrel Span: 73.00 in

Barrel Rise: 55.00 in

Barrel Material: Steel or Aluminum

Embedment: 24.00 in

Barrel Manning's n: 0.0280 (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: CAB 2 Proposed 73x55

### Table 10 - Downstream Channel Rating Curve (Crossing: CAB 2 Proposed 73x55)

| Flow (cfs) | Water Surface Elev (ft) | Velocity (ft/s) | Depth (ft) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| **2.51** | 53.89 | 0.40 | 2.10 | 0.28 | 0.59 |
| **6.30** | 54.23 | 0.74 | 2.84 | 0.53 | 0.58 |
| **8.00** | 54.36 | 0.87 | 3.05 | 0.62 | 0.58 |
| **9.00** | 54.44 | 0.95 | 3.16 | 0.68 | 0.57 |
| **10.10** | 54.52 | 1.03 | 3.26 | 0.73 | 0.57 |
| **10.90** | 54.58 | 1.09 | 3.34 | 0.77 | 0.56 |
| **11.70** | 54.64 | 1.15 | 3.40 | 0.82 | 0.56 |

## Tailwater Channel Data - CAB 2 Proposed 73x55

Tailwater Channel Option: Rectangular Channel

Bottom Width: 3.00 ft

Channel Slope: 0.0114

Channel Manning's n: 0.0350

Channel Invert Elevation: 53.49 ft

## Roadway Data for Crossing: CAB 2 Proposed 73x55

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 200.00 ft

Crest Elevation: 59.22 ft

Roadway Surface: Paved

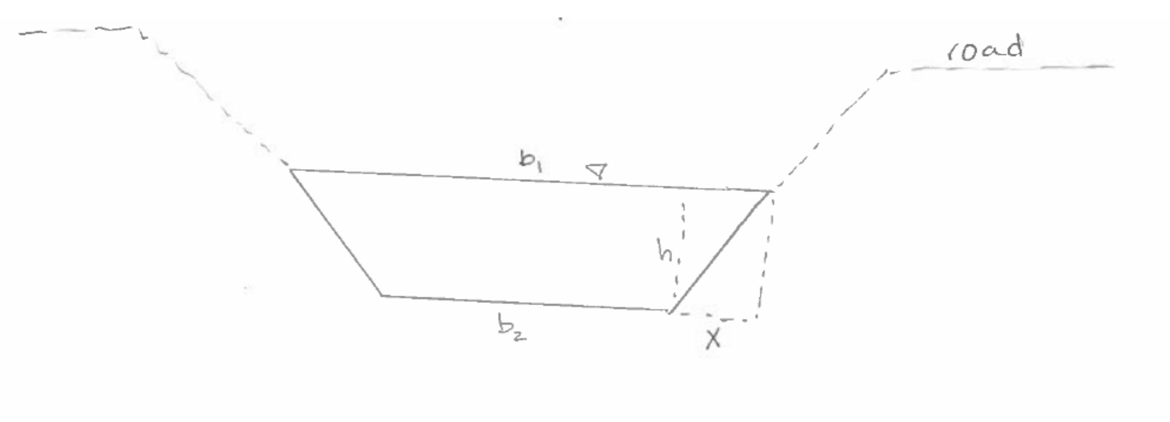
Roadway Top Width: 26.00 ft

| Low Flow Depths | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STA** | **IDENTIFIER** | **Qfish (cfs)** | **Shape** | **A (ft2)** | **R (ft)** | **S** | **n** | **b2 (ft)** | **h (ft)** | **h(in)** | **b1 (ft)** | **x** | **side slope (H:V)** | | **RHS equation** | **Equilibrate** | **V (fps)** |
| 53+24.00 | Design | 2.510 | Trapezoid | 1.560696 | 0.30989 | 0.005 | 0.0300 | 4 | 0.35 | 4.15 | 5.036286 | 0.518143 | 1.5:1 | 0.67 | 2.51 | 0.000 | 1.61 |
| 53+24.00 | Design | 2.510 | Trapezoid | 1.898978 | 0.23089 | 0.005 | 0.0300 | 7.5 | 0.24 | 2.90 | 8.224589 | 0.362295 | 1.5:1 | 0.67 | 2.51 | 0.000 | 1.32 |
| 53+24.00 | Design | 2.510 | Trapezoid | 2.102784 | 0.19815 | 0.005 | 0.0300 | 10 | 0.20 | 2.45 | 10.6121 | 0.306051 | 1.5:1 | 0.67 | 2.51 | 0.000 | 1.19 |
| 53+24.00 | Design | 2.510 | Trapezoid | 2.445673 | 0.157975 | 0.005 | 0.0300 | 15 | 0.16 | 1.93 | 15.48141 | 0.240705 | 1.5:1 | 0.67 | 2.51 | 0.000 | 1.03 |

| Bankfull Flow Depths | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STA** | **IDENTIFIER** | **Q2 (cfs)** | **Shape** | **A (ft2)** | **R (ft)** | **S** | **n** | **b2 (ft)** | **h (ft)** | **h(in)** | **b1 (ft)** | **x** | **side slope (H:V)** | | **RHS equation** | **Equilibrate** | **V (fps)** |
| 53+24.00 | Design | 6.300 | Trapezoid | 2.860229 | 0.496689 | 0.005 | 0.0300 | 4 | 0.59 | 7.03 | 5.758591 | 0.879296 | 1.5:1 | 0.67 | 6.30 | 0.000 | 2.20 |
| 53+24.00 | Design | 6.300 | Trapezoid | 3.381019 | 0.386469 | 0.005 | 0.0300 | 7.5 | 0.42 | 4.99 | 8.748492 | 0.624246 | 1.5:1 | 0.67 | 6.30 | 0.000 | 1.86 |
| 53+24.00 | Design | 6.300 | Trapezoid | 3.713169 | 0.335791 | 0.005 | 0.0300 | 10 | 0.35 | 4.23 | 11.05798 | 0.528992 | 1.5:1 | 0.67 | 6.30 | 0.000 | 1.70 |
| 53+24.00 | Design | 6.300 | Trapezoid | 4.28659 | 0.270718 | 0.005 | 0.0300 | 15 | 0.28 | 3.34 | 15.83413 | 0.417063 | 1.5:1 | 0.67 | 6.30 | 0.000 | 1.47 |

| 50 Year Flood Flow | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STA** | **IDENTIFIER** | **Q50 (cfs)** | **Shape** | **A (ft2)** | **R (ft)** | **S** | **n** | **b2 (ft)** | **h (ft)** | **h(in)** | **b1 (ft)** | **x** | **side slope (H:V)** | | **RHS equation** | **Equilibrate** | **V (fps)** |
| 53+24.00 | Design | 10.900 | Trapezoid | 4.143721 | 0.64823 | 0.005 | 0.0300 | 4 | 0.80 | 9.57 | 6.392365 | 1.196182 | 1.5:1 | 0.67 | 10.90 | 0.000 | 2.63 |
| 53+24.00 | Design | 10.900 | Trapezoid | 4.797861 | 0.520287 | 0.005 | 0.0300 | 7.5 | 0.57 | 6.89 | 9.22156 | 0.86078 | 1.5:1 | 0.67 | 10.90 | 0.000 | 2.27 |
| 53+24.00 | Design | 10.900 | Trapezoid | 5.234176 | 0.456607 | 0.005 | 0.0300 | 10 | 0.49 | 5.85 | 11.4632 | 0.731602 | 1.5:1 | 0.67 | 10.90 | 0.000 | 2.08 |
| 53+24.00 | Design | 10.900 | Trapezoid | 6.004303 | 0.371639 | 0.005 | 0.0300 | 15 | 0.39 | 4.63 | 16.15629 | 0.578147 | 1.5:1 | 0.67 | 10.90 | 0.000 | 1.82 |

| 100 Year Flood Flow | | | | | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| **STA** | **IDENTIFIER** | **Q100 (cfs)** | **Shape** | **A (ft2)** | **R (ft)** | **S** | **n** | **b2 (ft)** | **h (ft)** | **h(in)** | **b1 (ft)** | **x** | **side slope (H:V)** | | **RHS equation** | **Equilibrate** | **V (fps)** |
| 53+24.00 | Design | 11.700 | Trapezoid | 4.349413 | 0.67036 | 0.005 | 0.0300 | 4 | 0.83 | 9.95 | 6.48818 | 1.24409 | 1.5:1 | 0.67 | 11.70 | 0.000 | 2.69 |
| 53+24.00 | Design | 11.700 | Trapezoid | 5.021869 | 0.540326 | 0.005 | 0.0300 | 7.5 | 0.60 | 7.18 | 9.294149 | 0.897075 | 1.5:1 | 0.67 | 11.70 | 0.000 | 2.33 |
| 53+24.00 | Design | 11.700 | Trapezoid | 5.473272 | 0.474879 | 0.005 | 0.0300 | 10 | 0.51 | 6.10 | 11.52561 | 0.762804 | 1.5:1 | 0.67 | 11.70 | 0.000 | 2.14 |
| 53+24.00 | Design | 11.700 | Trapezoid | 6.272669 | 0.387057 | 0.005 | 0.0300 | 15 | 0.40 | 4.82 | 16.20605 | 0.603024 | 1.5:1 | 0.67 | 11.70 | 0.000 | 1.87 |



**Worksheet 2-2.** Computations of bankfull mean velocity and bankfull discharge using various methods.

## Bankfull VELOCITY & DISCHARGE Estimates

| | | | |
|---|---|---|---|
| Stream: | **Elsner Creek** | Location: | **Cordova, AK** |
| Date: | | Stream Type: | |
| Landscape Type: | | | |
| Observers: | | HUC: | __ __ __ __ __ __ __ __ __ __ __ |

| INPUT VARIABLES | | | OUTPUT VARIABLES | | |
|---|---|---|---|---|---|
| Bankfull Riffle Cross-Sectional Area | 3.3 | $A_{bkf}$ ( $ft^2$ ) | Bankfull Riffle Mean Depth | 1.1 | $d_{bkf}$ ( ft ) |
| Bankfull Riffle Width | 3 | $W_{bkf}$ ( ft ) | Wetted Perimeter $\approx (2 * d_{bkf}) + W_{bkf}$ | 5.2 | $W_p$ ( ft ) |
| $D_{84}$ Particle Size at Riffle | 55 | $D_{84}$ ( mm ) | $D_{84}$ Particle Size in Feet $D_{84}$ (mm) / 304.8 | 0.18045 | $D_{84}$ ( ft ) |
| Bankfull Slope | 0.005 | $S_{bkf}$ ( ft / ft ) | Hydraulic Radius $A_{bkf} / W_p$ | 0.63462 | R ( ft ) |
| Gravitational Acceleration | 32.2 | g ( ft / $sec^2$ ) | Relative Roughness R (ft) / $D_{84}$ (ft) | 3.51692 | $R / D_{84}$ ( ft / ft ) |
| Drainage Area | 0.08 | DA ($mi^2$) | Shear Velocity $u^* = (gRS)^{1/2}$ | 0.31965 | u* ( ft / sec) |

| ESTIMATION METHODS | | Bankfull VELOCITY | | Bankfull DISCHARGE | |
|---|---|---|---|---|---|
| **1. Friction Factor / Relative Roughness** | $\bar{u} = [\,2.83 + 5.66 * Log\,\{ R / D_{84} \}\,]\,u^*$ | 1.89 | ft / sec | 6.25 | 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 | 1.73 | ft / sec | 5.71 | cfs |
| **2. Roughness Coefficient: b) Manning's *n* from Stream Type** (Fig. 2-31) | $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$   $n =$ | | ft / sec | | cfs |
| **2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS):** **Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 | $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$   $n = 0.39 * S^{0.38} * R^{-0.16}$   $n =$ | | ft / sec | | cfs |
| **3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)** | | | ft / sec | | cfs |
| **3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)** | | | ft / sec | | cfs |
| **4. Continuity Equations: a) USGS Gage Data** **Return Period for Bankfull Q** | $\bar{u} = Q / A$   **Q =** ____ **year** | | ft / sec | | cfs |
| **4. Continuity Equations: b) Regional Curves** | $\bar{u} = Q / A$ | | ft / sec | | cfs |

**Protrusion Height Options for the $D_{84}$ Term in the Relative Roughness Relation ($R/D_{84}$) – Estimation Method 1**

| | |
|---|---|
| Option 1. | For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the $D_{84}$ sand dune protrusion height in ft for the $D_{84}$ term in method 1. |
| Option 2. | For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the $D_{84}$ boulder protrusion height in ft for the $D_{84}$ term in method 1. |
| Option 3. | For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the $D_{84}$ bedrock protrusion height in ft for the $D_{84}$ term in method 1. |
| Option 4. | For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the $D_{84}$ protrusion height in ft for the $D_{84}$ term in method 1. |

**Worksheet 2-2.** Computations of bankfull mean velocity and bankfull discharge using various methods.

## Bankfull VELOCITY & DISCHARGE Estimates

| | | | |
|---|---|---|---|
| Stream: | **Elsner Creek** | Location: | **Cordova, AK** |
| Date: | | Stream Type: | |
| Landscape Type: | | | |
| Observers: | | HUC: | __ __ __ __ __ __ __ __ __ __ __ |

| INPUT VARIABLES | | | OUTPUT VARIABLES | | |
|---|---|---|---|---|---|
| Bankfull Riffle Cross-Sectional Area | **4.4** | $A_{bkf}$ ( $ft^2$ ) | Bankfull Riffle Mean Depth | **1.1** | $d_{bkf}$ ( ft ) |
| Bankfull Riffle Width | **4** | $W_{bkf}$ ( ft ) | Wetted Perimeter $\approx (2 * d_{bkf}) + W_{bkf}$ | **6.2** | $W_p$ ( ft ) |
| $D_{84}$ Particle Size at Riffle | **55** | $D_{84}$ ( mm ) | $D_{84}$ Particle Size in Feet $D_{84}$ (mm) / 304.8 | **0.18045** | $D_{84}$ ( ft ) |
| Bankfull Slope | **0.005** | $S_{bkf}$ ( ft / ft ) | Hydraulic Radius $A_{bkf} / W_p$ | **0.70968** | R ( ft ) |
| Gravitational Acceleration | **32.2** | g ( ft / $sec^2$ ) | Relative Roughness R (ft) / $D_{84}$ (ft) | **3.9329** | $R / D_{84}$ ( ft / ft ) |
| Drainage Area | **0.08** | DA ($mi^2$) | Shear Velocity $u^* = (gRS)^{1/2}$ | **0.33802** | u* ( ft / sec) |

| ESTIMATION METHODS | Bankfull VELOCITY | | Bankfull DISCHARGE | |
|---|---|---|---|---|
| **1. Friction Factor / Relative Roughness** $\bar{u} = [2.83 + 5.66 * Log\{R / D_{84}\}] u^*$ | **2.09** | ft / sec | **9.22** | 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** | **1.86** | ft / sec | **8.20** | cfs |
| **2. Roughness Coefficient: b) Manning's *n* from Stream Type** (Fig. 2-31) $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ $n =$ | | ft / sec | | cfs |
| **2. Roughness Coefficient: c) Manning's *n* from Jarrett (USGS):** $\bar{u} = 1.49 * R^{2/3} * S^{1/2} / n$ $n = 0.39 * S^{0.38} * R^{-0.16}$ $n =$ <br>**Note:** This equation is applicable to **steep, step/pool, high boundary roughness, cobble- and boulder-dominated stream systems**; i.e., for Stream Types A1, A2, A3, B1, B2, B3, C2 & E3 | | ft / sec | | cfs |
| **3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)** | | ft / sec | | cfs |
| **3. Other Methods (Hey, Darcy-Weisbach, Chezy C, etc.)** | | ft / sec | | cfs |
| **4. Continuity Equations: a) USGS Gage Data** $\bar{u} = Q / A$ <br>**Return Period for Bankfull Q** Q = ___ year | | ft / sec | | cfs |
| **4. Continuity Equations: b) Regional Curves** $\bar{u} = Q / A$ | | ft / sec | | cfs |

**Protrusion Height Options for the $D_{84}$ Term in the Relative Roughness Relation ($R/D_{84}$) – Estimation Method 1**

| | |
|---|---|
| Option 1. | For **sand-bed** channels: Measure 100 **"protrusion heights"** of sand dunes from the downstream side of feature to the top of feature. Substitute the $D_{84}$ sand dune protrusion height in ft for the $D_{84}$ term in method 1. |
| Option 2. | For **boulder-dominated** channels: Measure 100 **"protrusion heights"** of boulders on the sides from the bed elevation to the top of the rock on that side. Substitute the $D_{84}$ boulder protrusion height in ft for the $D_{84}$ term in method 1. |
| Option 3. | For **bedrock-dominated** channels: Measure 100 **"protrusion heights"** of rock separations, steps, joints or uplifted surfaces above channel bed elevation. Substitute the $D_{84}$ bedrock protrusion height in ft for the $D_{84}$ term in method 1. |
| Option 4. | For **log-influenced** channels: Measure "**protrustion heights**" proportionate to channel width of log diameters or the height of the log on upstream side if embedded. Substitute the $D_{84}$ protrusion height in ft for the $D_{84}$ term in method 1. |