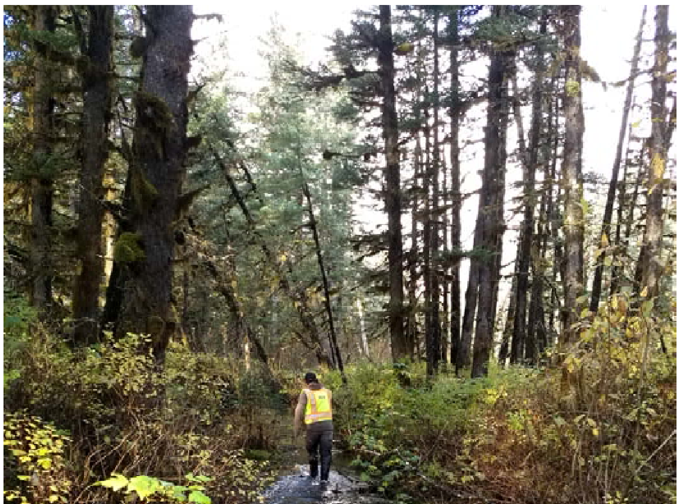

# Hydraulic and Hydrologic Report Draft Final

Copper River Watershed Fish Passage Improvement Project

*Copper River Highway, Cordova, Alaska*

May 24, 2019

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# Acronyms

| | |
|---|---|
| BCE | Bratslavsky Consulting Engineers, Inc. |
| CMP | Corrugated Metal Pipe |
| DOT&PF | Alaska Department of Transportation and Public Facilities |
| cfs | cubic feet per second |
| H&H | Hydraulic and Hydrologic |
| IfSAR | Interferometric Synthetic Aperture Radar |
| O&M | Operations and Maintenance |
| SNAP | Scenarios Network for Alaska + Arctic Planning |
| USFS | U.S. Forest Service |
| USFWS | U.S. Fish and Wildlife Service |
| USGS | U.S. Geological Survey |
| VAP | Variable Adjustment Potential |

# Introduction

The Copper River watershed and delta is an expansive system reaching from its mouth in the Gulf of Alaska to the interior north of Paxson, Alaska, and stretches from the Nelchina River basin into the Yukon Territory, Canada. The delta area encompasses not only the branches of the Copper River but also numerous significant drainages that head in the coastal mountains. It contains many complex, intricate, relict channels with equally complex base flows that support salmon and trout fisheries as well as numerous bird species.

This report provides hydrologic and hydraulic (H&H) analysis for the design of three replacement fish passage culverts along Alaska State Highway 10, between the Mud Hole Smith Airport and the Copper River (see Figure 1). St. Denny Surveying Inc., as contractors for Bratslavsky Consulting Engineers, Inc. (BCE), provided the survey data for the three sites. The U.S. Fish and Wildlife Service (USFWS) provided the flow gaging data for these sites.

This report investigates potential flood flows and fish passage challenges posed by the three crossings and is intended as design guidance for replacement of the culverts. This report will:

- Determine stream slope and profile for long-term channel stability and fish passage
- Investigate roadway grade, fill height, and width
- Create and analyze watershed sizes, analyze peak storm flows, discuss flood plain and routing issues, size conveyance to meet hydraulic and fish passage requirements, and provide scour analysis and stream substrate sizing
- Provide design guidance for the new crossing culvert width, invert elevations, length, structure type, and skew angle
- Design stream substrate and other grade control structures

It is anticipated that stream simulation design will be used for the design of these crossing structures, and low-flow information provided by the USFWS will be used for low-flow channel design within the crossing structures. The structures will be sized to pass the 100-year flood event at 0.9 times the opening height of the culvert, and the low-flow channel will be constructed to simulate the natural creek channel through the crossings. The crossings were modeled using HY-8 to ensure the proposed culvert size will convey the 100-year flood event.

Figure 1 shows the projects location.

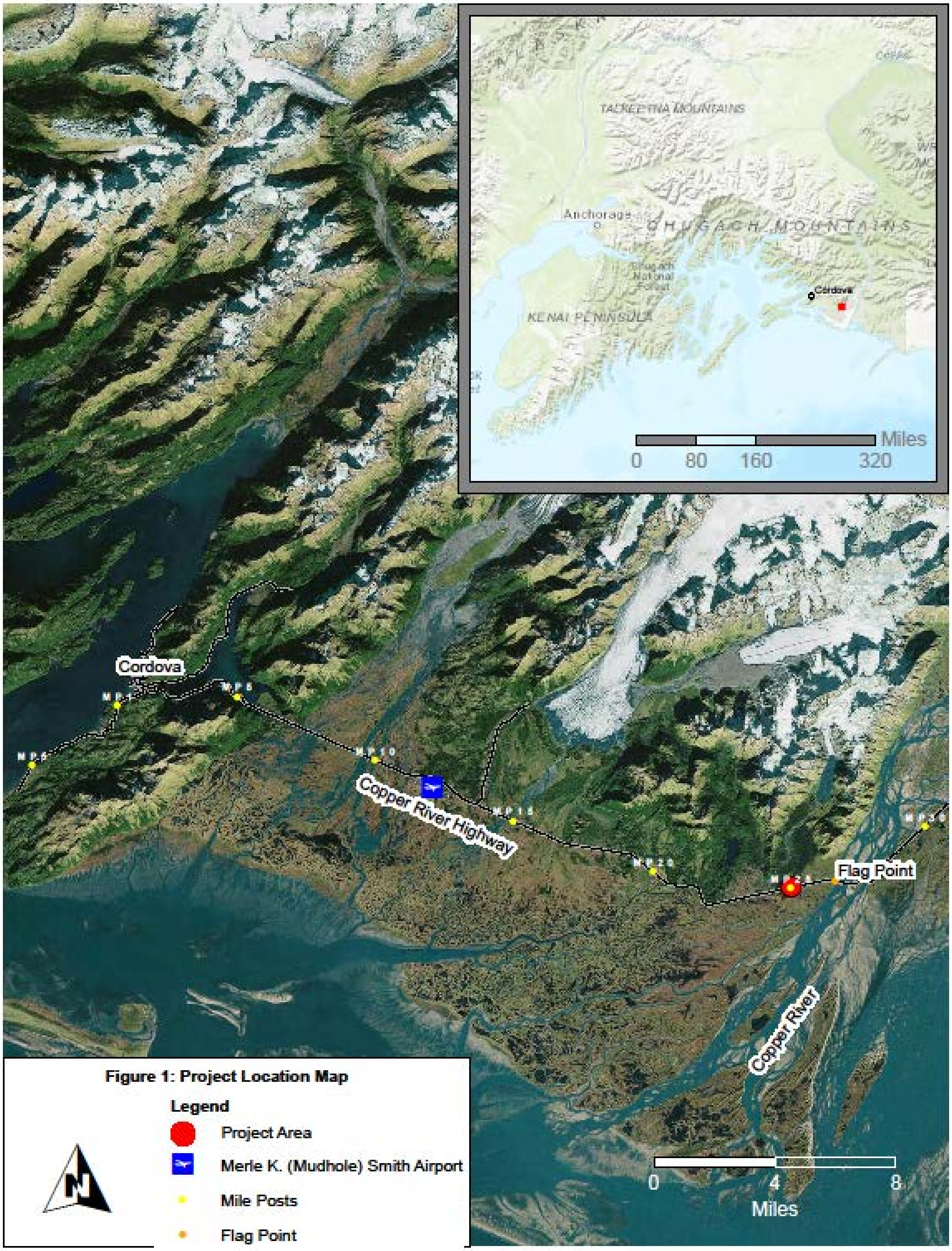


**Figure 1: Project Vicinity Map**

# Site Analysis

To better understand the methodology used in this H&H study, a brief description of the area's history, geomorphology, and their effects is provided below.

## History of the Area

Between 1907and 1911, the Kennecott Corporation constructed the Copper River and Northwestern Railway, extending up the Copper River to access large copper ore deposits in the Chitna River basin. The railway ran for 195 miles from Cordova through Chitina and up the Chitna River to the Kennecott mines. The use of the railway ended in 1938 due to the closure of the Kennecott mines, and the right-of-way was donated to the U.S. government in 1941. At the Cordova end, approximately 51 miles of the railway were converted to the Copper River Highway from 1945 to 1973 (USGS 1997).

The original rail bed cut across the Copper River Delta on its way to Flag Point. Construction methods may have been to simply lay down a gravel rail bed on whatever boggy soils were encountered and to bridge encountered drainages with wooden trestles on closely spaced piles. Historical aerial imagery circa 1950 shows three short railroad trestles in the area of COP 42–46 and a large area of embankment impoundment that remains today. This project's Request for Proposal describes:

> *This two-lane dirt road persists on a remnant rail-bed of the former Copper River and Northwestern Railway. Due to improper culvert design during construction, this 50-mile stretch of road intersecting the Copper River Delta between Cordova and the Copper River now functions similarly to a dike at many of the 73 culverts originally intended to provide drainage. As such, the presence of this road-bed has unintentionally disrupted the Delta's hydrology and led to reduced ecological function as well as expensive road repair following major high water events.*

## 1964 Earthquake

According to the 1997 U.S. Geological Survey (USGS) report (USGS 1997), during the 1964 earthquake:

> *the Copper River Delta was raised about 6 ft. (Plafker, 1969). In the Cordova area, the tidal regime was significantly altered: large areas of subtidal estuary became intertidal and much of the intertidal wetlands became supertidal.*

This may only be significant when viewed in geologic time, recognizing that this uplifting action has been an ongoing process. It is likely that the extensive flats surrounding the rail alignment were once tidal, with fine marine sediment strata underlying the coarser alluvial gravels.

## Drainage Area

The project contains three culvert sites, which are assumed to share a joint drainage basin for the purpose of this report. Low interconnecting marsh and beaver activity frequently redirect flow between the three sites. This co-drainage basin was delineated using historical aerial imagery, USGS Interferometric Synthetic Aperture Radar (IfSAR) data , and field reconnaissance.

The basin is difficult to define precisely due to several factors and may change significantly during flood events. As presented at the time of the field visit, the streams were relatively small even during a significant rain event. Flows were mostly from ground water and local sheet runoff in the remnant channels within one-half mile of the crossing sites. Following these remnant flood channels upslope eventually led to ground water seeps as surface flows transitioned to groundwater in the flat glacial outwash terrain.

Having noted the lack of sustained channel flows from the headwater basins, it was also noted that the streams do occupy remnant flood channels. There is evidence that these channels could and do see larger flood flows as the Saddlebag River overflows its bank into this area.

Looking at the delineated basin as a whole, there are three points of uncertainty where there is either insufficient data to determine drainage flows or alluvial fan features have led to different drainage paths over time. The inclusion or exclusion of drainage above these “tipping points” significantly alters the area of drainage basins and subsequent flows. The Saddlebag River of which these smaller drainages are sub-basins contains a large active glacier, glacial lake, and significant alluvial features. It is these alluvial fan features that, through continued sediment deposition over time, have moved the basins flows between channels and have altered the geometry of the basins feeding the three crossings. Figure 2 shows the larger basin and tipping points. It also shows the complexity of the historic stream channels digitized from available aerial photography dated 1950, 1976, 1983 and the present. The following paragraphs describe the tipping points in more detail.

## Tipping Points

### 1. Saddlebag River

The first tipping point is an outside bend in the Saddlebag River where high flows jump the bank and course into the adjacent wooded area to join channels that cross back into the site basin. A field reconnaissance of the area confirmed that this is a relatively common occurrence but photo records appear to indicate that the Saddlebag River has never been completely rerouted at this point, at least since 1907. Such an event would have washed out the rail bed, and the three small trestles seen in the 1950 aerial would have been replaced with a larger river crossing. The Saddlebag River has not always been contained entirely within its current banks and channel. In fact, these aerial images show that the river has historically had multiple active side channels that run parallel to the existing U.S. Forest Service (USFS) Saddlebag Glacier road that is adjacent to the project area. However, none of these channels have rerouted the river permanently, and it continues to hug the west side of the valley and carry most of the larger flows to the larger existing bridge west of the culvert sites.

The point at the river bend is still active and shows evidence of overtopping in the past summer; however, once the waters subsided, the river went back to its main channel. The following photographs are of this river bend and the sediment deposits in the adjacent forest. Note that there is no high bank for the flood waters to overcome, with high flow events flooding into the forest. Although the forest floor trends downhill toward the east from this point, it appears that the gradient of the existing thalweg is steeper than the alternative routing into the forest, and the river has historically settled back to the westerly channel after significant flood events.

**Photographs 1 and 2: Saddlebag River overtopping point**

Using IfSAR data, the upstream drainage basin for the Saddlebag River at the bend of interest is approximately 11.13 square miles, and would produce an additional 3,680 cubic feet per second (cfs) of flood flow during the 100-year event. A flood of this magnitude would likely wash out the highway and significantly alter the drainages in this valley. Rebuilding would require a bridge or very large box culvert. Because of the high degree of uncertainty for this occurrence and the non-critical nature of the transportation connection, HDR recommends that these flows be ignored until the improbable occurs. The possible inclusion of a high water ford crossing with reinforced road prism was also explored but because of the increased road bed elevation over the new culverts, high flood waters will tend to follow the ditch lines east and west and carry those flows to other cross culverts away from these sites. As the rest of the culverts to the east and west (COP 042 and COR 046) are eventually replaced, the hydraulics of the entire road section should be reevaluated.

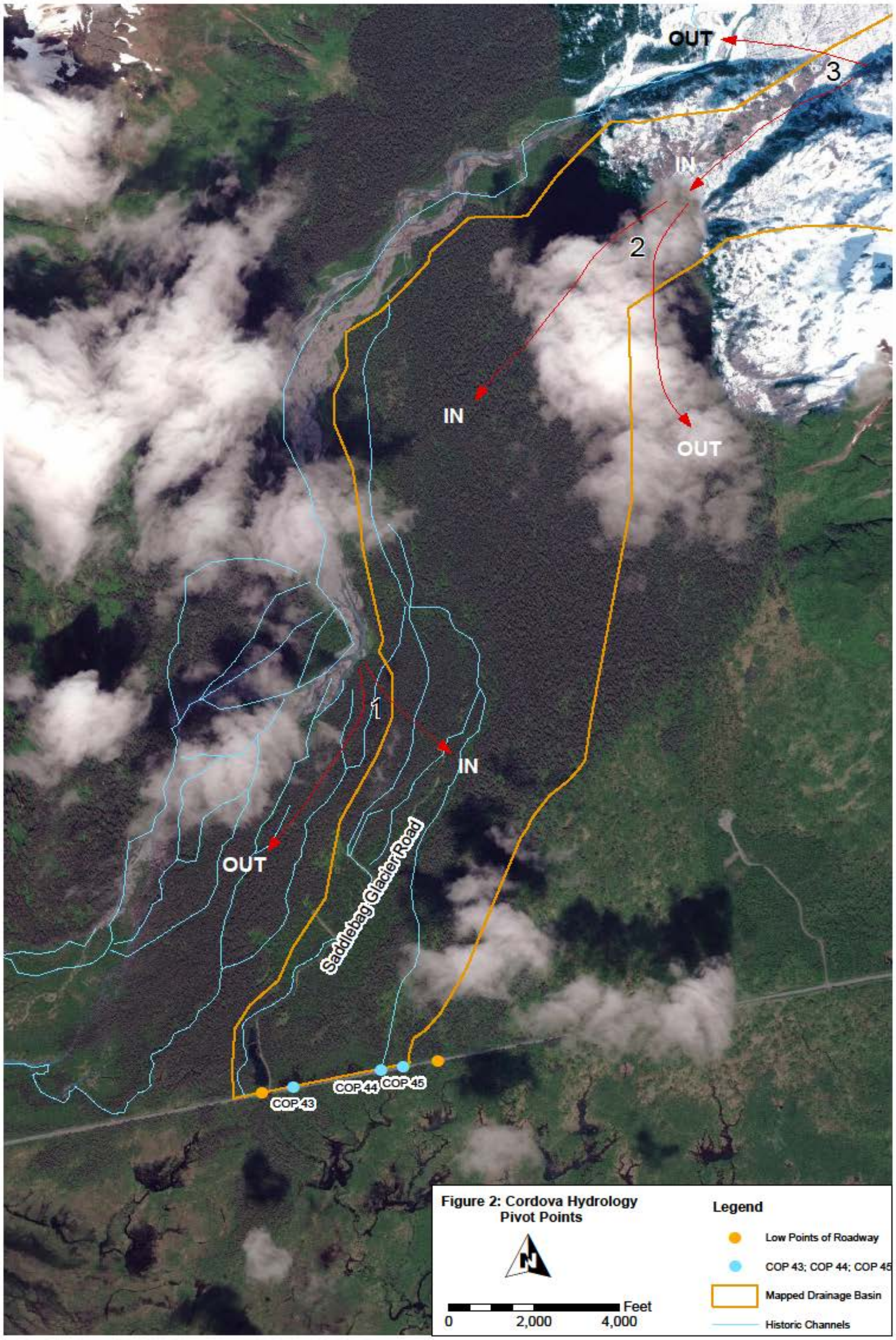


**Figure 2: Drainage Basin Mapping**

### 2. Alluvial Drainage Redirection Along the Eastern Boundary

Site reconnaissance, IfSAR, and historical aerial imagery were used to determine an eastern basin border that is assumed to fall within the forested area near the mountains to the northeast of the project area. It is assumed that surface runoff coming from the eastern wall of the valley flows southeast along the base of the mountains and enters drainages east of the project. At the upper end of this side basin, there is an area where upstream flows traverse an alluvial feature with the ability to course into the project basin or alternatively divert into the more eastern drainages. The basin area upstream of this tipping point is approximately 0.73 square mile. HDR has conservatively included this area in the project basin.

### 3. Headwaters Diversion

Again, based on IfSAR data and aerial imagery, drainage coming from the extreme headwaters of the basin must traverse an area of poorly defined topography to enter the project basin. There is a point at the base of the bowl that can be seen from aerial imagery where flows may flow either into the headwater of the Saddlebag River to the north or enter the project basin between the mountain and a low glacial hill mid valley. The area above this point is approximately 0.53 square mile and has been conservatively included in the watershed.

In summary, for flood flow analysis the delineation of the project basin includes the smaller additions to the basin represented by the two latter unknowns but does not include flood flows from the Saddlebag River. Saddlebag River flows are known to occur, but their frequency and volume have not been included here.

# Consultation with DOT&PF O&M and USFS

Consultation was held with Robbie Matson, Alaska Department of Transportation and Public Facilities (DOT&PF) Operations and Maintenance (O&M), and Luca Adelfio, USFS, pertaining to the frequency of flooding of the Saddlebag River and its effects on the project area.

## USFS

During their site visit, HDR consulted with USFS representative Luca Adelfio regarding Saddlebag River overflow entering the project area. Mr. Adelfio mentioned reports of glacial silt water making its way into the adjacent and hydraulically connected site COP 42.

This is confirmed in the USFS 2018 report, which states:

> *Stormflows from Saddlebag wash through this pond (gravel pit pond adjacent to Saddlebag Road, COP 42) during bankfull events, so I would anticipate a bigger range of flows than COP 44 or COP 45.*

## DOT&PF O&M

Robbie Matson, DOT&PF O&M, reported during consultation that in his time with the DOT&PF he has never seen any silty water enter the COP 43, 44, or 45 areas and that most of the problems in the area are beaver related.

## Summary

The central hydraulic question for these sites is whether or not to include a flood contribution from the Saddlebag River. HDR confirmed that these overbank events happen on a regular basis, but it is unclear how much of this overbank flow gets into the small drainages that end at these sites. An extensive series of channels emanates from the overtopping area but most appear to trend to the west without crossing the USFS Saddlebag Glacier Road into the project basin. Crossing COP 42, which drains the pond just west of the Saddlebag Glacier Road, has seen glacial flows; however, all the overtopping events in COP 43, 44, and 45 are precipitated by beaver activity according to DOT&PF M&O. If flows from these overtopping events are included, even a small percentage of the Saddlebag River flood flows will result in very large structures or inclusion of an armored ford in locations where three less than 4-foot structures have survived for a significant period. This is a cost versus risk call with poorly defined variables and only inferred historic knowledge.

Additionally, the USGS topographic mapping of this area shows a small side channel of the Saddlebag River diverting from the main river even further upstream and making its way to the sites COP 46 east of the project area (Figure 3). HDR found this channel during their field investigation but were unable to walk to its upstream connection point due to time constraints. Field observations show it to be well grown in, and it contained no sustained flow or evidence, in the form of sediment deposition, of recent flooding events.

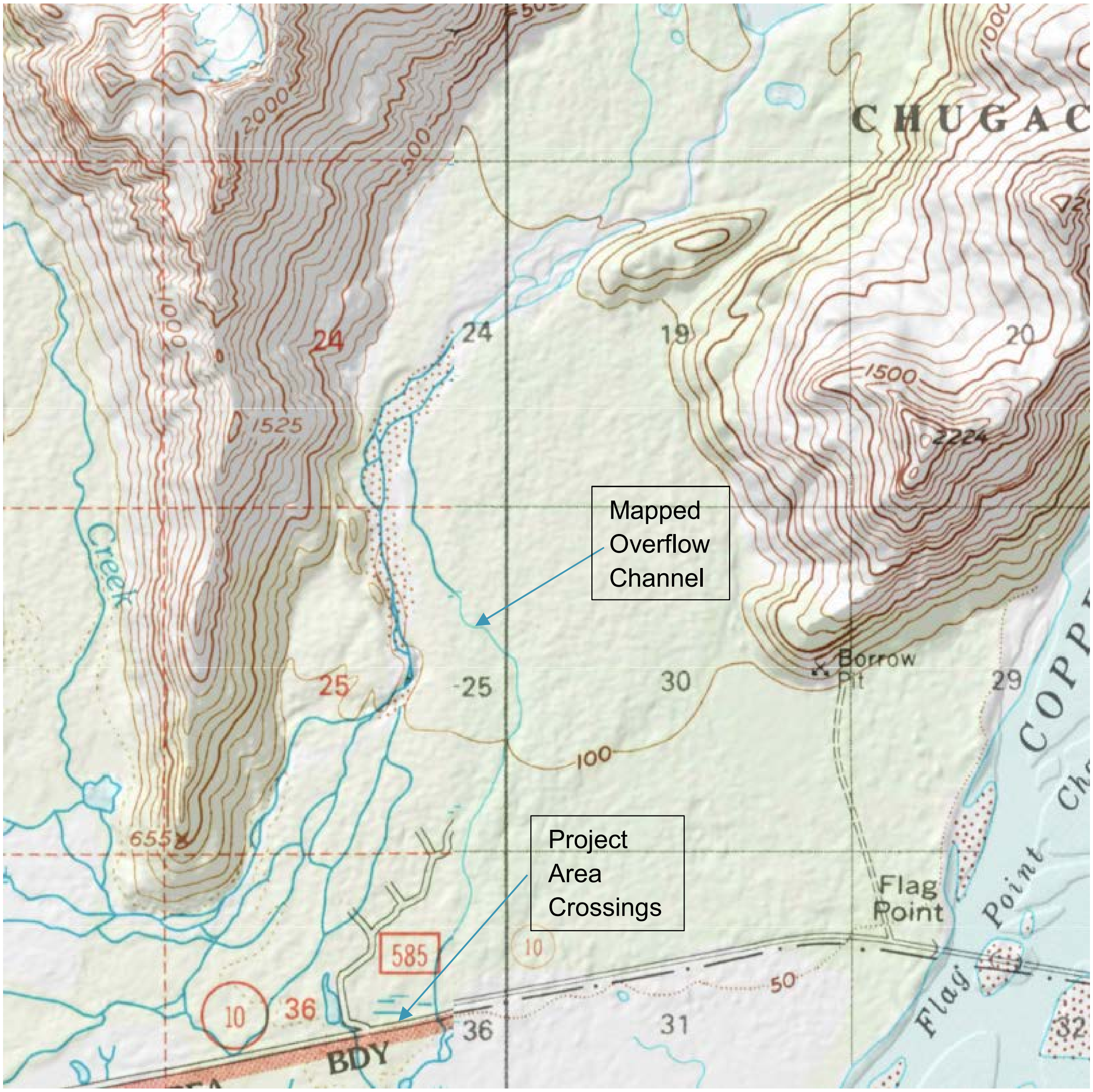


**Figure 3: USGS Drainage Mapping**

# Affecting Factors

## Embankment Impoundment

Due to the raised inlets and small size of existing culverts along this roadway and the backwaters created by beaver dams, water is currently impounded behind the roadway beginning from COP 43 and continuing east almost to COP 45. This creates a man and beaver maintained wetland area spanning the length of the upstream project area. This area contains numerous small side channels and may provide significant fish and wildlife habitat. With improvements to the culverts, the project should set crossing elevations and maintain this wetland area.

### Beaver Activity

An active and robust beaver population inhabits the project area's streams and does not show any signs of leaving. An abandoned gravel pit pond flows into COP 42 (a crossing structure in the Saddlebag Glacier road west of the project area) and then continues into COP 43. Beaver dams at the south end of the pond and within a culvert on the Saddlebag River Road connecting COP 42 to COP 43 currently determine this small pond's elevation. Also, existing beaver dams downstream of the crossing control the tail water elevation at COP 44 and COP 45.

Research suggests that beavers are attracted by the sound of water spilling across threshold features to build dams and that larger structures with quiescent flows are less likely targets. This characteristic should be a design goal of the replacement structures and considered when setting invert elevations and sizing openings. It may be advantageous to create a backwatered condition with a grade control feature downstream of each culvert. This feature would attract the beaver dam building activities and possibly alleviate some of the potential problems within the culverts.

# Hydrology and Flood Flow Analysis

Much of the area surrounding the three culvert locations is relatively flat, and delineation is difficult from aerial photography and available topography. Therefore, the basin has been developed using a conservative approach and has included two of three areas of uncertainty described in the Site Analysis. The resultant flood flows calculated using the 2016 USGS regression equations (USGS 2016) seem large when compared to the observed flows recorded by USFWS. This mismatch is likely due to the unusual configuration of the headwaters. During normal low flow conditions, these channels collect drainage and ground water flows from a relatively small headwater basin and produce the flows seen in the USFWS gauging. During larger events, the much larger Saddlebag drainage and perhaps other parts of the headwater basins start to contribute and the flood flows go up sharply to levels that are not predicted from the low flow data but are supported by bankfull analysis of the channels. Table 1 shows the flow estimates for inclusion and exclusion of the tipping points.

**Table 1: Hydrology Comparison of Basins**

| Basin | Basin Area (sq. mi) | 2-Year Flow (cfs) | 100-Year Flow (cfs) |
|---|---|---|---|
| **With Tipping Points:** | 1.72 | 208 | 679 |
| **Without Tipping Points:** | 0.99 | 145 | 489 |

Bankfull geometries of the upstream reference reach channels for each crossing have been defined using survey information. Their capacities were analyzed using Manning's open channel flow equations and compared to the regression equation calculated 2-year event. The assumption is made that bankfull capacity is approximately equal to the 2-year event and that this geometry calculation will give an indication of historic flood flows. The combined total for all upstream channels bankfull flows (169 cfs) falls between the Q2 for included basin areas (208 cfs) and the less conservative excluded area flows (145 cfs), lending credence to the regression calculated flows. Table 2 lists the Manning's calculated bankfull flow results. Appendix F includes a more thorough analysis of the channels.

**Table 2: Manning's Bankfull Channel Flows**

| Stream | Bankfull Flow (cfs) | Bankfull Velocity (fps) |
|---|---|---|
| **COP 43:** | 69 | 2.58 |
| **COP 44:** | 49 | 2.61 |
| **COP 45:** | 51 | 2.56 |
| **Total:** | **169** | - |

For an additional data point, gage data from a nearby stream was accessed (USGS 15215900 GLACIER R TRIB). This stream has a similar basin size to the project basin, and Log Pearson flows were compared to the 2016 regression flows. While the regression equations underestimated the 2-year event by 30 percent, it overestimated the 100-year event by 59 percent. It should be noted that this stream's basin is predominantly mountainous terrain compared to the flatter nature of the project basin and has only 6 years of recorded data.

# Climate Change Effects:

University of Alaska Fairbanks' Scenarios Network for Alaska + Arctic Planning (SNAP) has predicted an overall increase in annual precipitation of approximately 10.2 percent for the years 2090–2099. This results in an annual precipitation increase from 126 to 138 inches per year. Applying this to the 2016 regression equations increases the 100-year event flow approximately 7.7 percent from 679 to 731 cfs.

Considering this additional data, HDR believes that using the 2016 regression equations without applying any additional factors is sufficiently conservative and in line with the size of the existing channels, as well as the risk and infrastructure impacts associated with the subsequent design recommendations.

# Hydrology Summary/Recommendations

Table 3 shows the values recommended for preliminary design.

- Drainage basin area (square miles): 1.72 square miles
- Annual Precipitation (inches/year): 126 inches/year

| Table 3: USGS Calculated 2016 Regression Equation Flows | |
|---|---|
| **Return Interval** | **Peak Flood Flows (cfs)** |
| 2-year Event | 208 |
| 10-year Event | 317 |
| 50-year Event | 589 |
| 100-year Event | 679 |

## Low Flow Design Values

The USFWS performed stream gaging of the crossing sites during summer-fall 2018 and spring 2019. Appendix G includes the results of this work. The report recommends low flow design numbers range from 0.2 to 1 cfs. The design sketches contained in Appendix H depict a low flow channel 6 inches deep by 2 feet wide. This channel will sustain flow at 6 inch depth at 1 cfs and velocity of 1.3 ft per second.

# Culvert Analysis

## Existing Site Characteristics

The current culverts at the project location include:

- COP 43, a 36-inch, round Corrugated Metal Pipe (CMP) that had debris in its inlet during the site visit but is otherwise in good condition;
- COP 44, is a 48- by 36-inch pipe arch with a partially plugged inlet and rebar beaver debris bars; and
- COP 45 is also a 48-by 36-inch pipe arch with a partially plugged inlet and a damaged outlet.

COP 43 and 44 are connected directly by a roadway impounded pond, and COP 45 is connected to this pond via a roadside ditch. Appendix A includes a copy of the stream geomorphic survey notes. At high flows, the flood waters back up behind the roadway embankment and form a common headwater elevation for all three sites.

Grade control downstream of COP 43 includes small woody debris and grass choked channels (aquatic sedges), with the banks lined with willows and alders. The streambed is predominantly mud/silt. No pebble count was performed.

The downstream reaches of COP 44 and COP 45 are slow moving, backwatered channels (beaver ponds) consisting of deep pools with floating grass mats and beaver dams. The substrate is predominantly gravel and mud.

Due to the complexity of the system, uncertainty of the basin delineation, and the decision to use one basin for all three culverts (described in the Flood Flow Analysis section) the existing culverts were grouped and modeled as one crossing using FHWA HY-8 culvert design software. The objective of this is to find what approximate total flow values will overtop the existing roadway at its lowest point and the magnitude of flows crossing the roadway during the 100 year flood. The capacity of each existing culvert and the flows to overtop the roadway at each individual site were not determined due to the connectivity of the system and the elevation of the existing roadway surface adjacent-to and between the culverts.

Table 4 and Table 5 provide an overview of the existing conditions and results from HY-8 analysis of the existing culverts. All measurements are taken from the recently completed stream and topographic surveys. The roadway surface over the sites and extending east and west form the project area is a nearly consistent 48.5-48.8 feet. See Appendix C for more details.

**Table 4: Existing Culvert and Channel Characteristics**

| Culvert ID | COP 43 | COP 44 | COP 45 |
|---|---|---|---|
| Length (feet): | 40 | 39.9 | 38.5 |
| Shape and Dimensions: | 36” Round CMP | 48” x 36” Pipe Arch | 48” x 46” Pipe Arch |
| Culvert Slope (%): | 1.83 | 2.08 | 1.83 |
| Channel Slope (%): | 1.2 | 1.6 | 1.2 |
| Bankfull Width (feet): | 18 | 19 | 25 |
| Ordinary High Water Width (feet): | 14 | 16 | 20 |

**Table 5: Existing Headwater Elevation and Discharge**

| Culvert ID | Event (Q Yr) | Flow (cfs) | Headwater Elevation (feet) | Culvert Discharge (cfs) | Roadway Discharge (cfs) |
|---|---|---|---|---|---|
| COP 43 | | 94.73 | 48.80 | 23.49 | Overtopping |
| | 2 | 208 | 48.89 | 24.75 | 107.42 |
| | 10 | 317 | 48.94 | 25.47 | 213.78 |
| | 100 | 679 | 49.06 | 27.25 | 568.91 |
| COP 44 | | 94.73 | 48.80 | 33.23 | Overtopping |
| | 2 | 208 | 48.89 | 34.97 | 107.42 |
| | 10 | 317 | 48.94 | 35.96 | 213.78 |
| | 100 | 679 | 49.06 | 38.34 | 568.91 |
| COP-45 | | 94.73 | 48.80 | 38.02 | Overtopping |
| | 2 | 208 | 48.89 | 39.68 | 107.42 |
| | 10 | 317 | 48.94 | 40.61 | 213.78 |
| | 100 | 679 | 49.06 | 42.85 | 568.91 |

Note: The roadway is overtopped at a combined flow of 94.73 cfs.

# Proposed Replacement Structures

The following assumptions/parameters are made for design and modeling the proposed culverts:

- As in the Existing Site Characteristics section, a single drainage basin is defined for the three sites, and all three replacement structures are modeled as a single crossing with three conveyances. The design Q100 uses 679 cfs.
- The low point of the roadway will remain at the same elevation and location as the existing roadway (near the intersection of Copper River Highway and Saddlebag Glacier Road) at approximately 48.80 feet. Note that this elevation is exceeded by the 10-year flow. A 50.19-foot roadway elevation is needed to contain the 100-year flows within the culverts. This contrasts with the HY-8 modeling assumption that the structures will have 2 feet of cover and that the resulting road surface elevation would be maintained beyond the extents of the project area. For modeling purposes, the roadway top elevation is assumed to be an even elevation of 52.6 feet.
- All proposed culverts are sized with beaver activity and stream simulation design as the primary considerations.
- All three culverts are of similar size, length, and slope with identical substrate sizing and embedment. Minor differences in invert elevations are noted to maintain or slightly reduce the backwater elevations as surveyed in 2018.
- Low flow channel geometry will be defined to maintain 6-inch depth in the structures based on USFWS 2018-19 measured flows.
- Substrate is sized for stability during the 100-year event.
- Embedment depths, measured outside the low flow channel, are two times D100 and slightly less below the low flow channel bottoms.
- All culverts will have a minimum of 2 feet of cover.
- Survey stream thalweg data was used to draw Variable Adjustment Potential (VAP) lines, and the vertical location of the new structures are based on a best-fit for the stream thalweg survey and the maintenance of backwater levels.

The proposed design specifies replacing the existing culverts with three 16-foot, 6-inch span by 6-foot, 8-inch aluminum boxes. The proposed configuration places the Q100 back water elevation at approximately 49.7 feet elevation, which is 1.1 feet above the existing roadway (48.8 feet). In this configuration, the water on the upstream side of the road will flow along the upstream ditch lines east and west of the project area to seek out other drainage conveyances or spill across the roadway. These other drainages will eventually receive new fish passage structures and elevated roadway sections, chasing the flows even further east and west.

Table 6 provides a summary of the proposed structures, HY-8 analysis, and substrate sizing. For more details, Appendices C and D include HY-8 analysis documentation. Appendix E includes the substrate sizing spreadsheet. Appendix H includes preliminary design sketches.

| Table 6 Proposed Structure Characteristics | | | |
|---|---|---|---|
| **Site Parameters** | **COP 43** | **COP 44** | **COP 45** |
| **Ordinary High Water Width (ft)** | 14 | 16 | 20 |
| **Bank Full Width (ft)** | 18 | 19 | 25 |
| **Thalweg/VAP slope (%)** | 0.65 | 0.67 | 0.62 |
| **Proposed Structure** | 16'06" x 6'8" Alum Box | 16'06" x 6'8" Alum Box | 16'06" x 6'8" Alum Box |
| **Culvert Rise (in)** | 80 | 80 | 80 |
| **Culvert Span (in)** | 198 | 198 | 198 |
| **Length (ft)** | 58.5 | 58.5 | 58.5 |
| **Culvert Inlet Invert (ft)** | 43.53 | 43.95 | 43.43 |
| **Culvert Outlet Invert (ft)** | 43.13 | 43.55 | 43.03 |
| **Slope (%)** | 0.684% | 0.684% | 0.684% |
| **Substrate Depth (in)** | 30 | 30 | 30 |
| **Low Flow Channel Depth (in)** | 12 | 12 | 12 |
| **Low Flow Inlet Substrate El (ft)** | 46.03 | 46.45 | 45.93 |
| **Low Flow Outlet Substrate El (ft)** | 45.63 | 46.05 | 45.53 |
| **Bank Full Inlet Substrate El (ft)** | 47.03 | 47.45 | 46.93 |
| **Bank Full Outlet Substrate El (ft)** | 46.63 | 47.05 | 46.53 |
| **Tailwater El (ft)** | 45.63 | 46.05 | 45.53 |
| **Top of Culvert CL of Road (ft)** | 50.00 | 50.42 | 49.90 |
| **Opening Height (ft)** | 4.17 | 4.17 | 4.17 |
| **HY-8** | | | |
| **Q2 Headwater (ft)** | 47.77 | 47.76 | 47.77 |
| **Q10 Headwater (ft)** | 48.28 | 48.28 | 48.28 |
| **Q100 Headwater (ft)** | 49.69 | 49.76 | 49.69 |
| **H/D Ratio** | 0.88 | 0.79 | 0.90 |
| **Q100 Outlet Velocity (ft/s)** | 7.89 | 7.4 | 7.93 |
| **Q100 Outlet Depth (ft)** | 2 | 2 | 2 |
| **Q100 Discharge (cfs)** | 236 | 197 | 246 |
| **% Total Discharge** | 34.8 | 29.0 | 36.2 |
| **Substrate Sizing** | | | |
| **Coarse Rock D100 (in)** | 20 | 20 | 20 |
| **Min Embedment (in) 1.5 x D100** | 30 | 30 | 30 |

# References

DOT&PF (Alaska Department of Transportation and Public Facilities) and ADF&G (Alaska Department of Fish and Game). Memorandum of Agreement (MOA) between ADOT and ADF&G, *Design, Permitting and Construction of Culverts for Fish Passage* (8/3/01)

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USGS (U.S. Geological Survey). 1997. Geomorphology of the Lower Copper River, Alaska. U.S. Geological Survey Professional Paper 1581.

USGS. 2003. Estimating the Magnitude and Frequency of Peak Streamflows for Ungaged Sites on Streams in Alaska and Conterminous Basins in Canada. Water-Resources Investigations Report 03-4188.

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# Appendix A: Field Notes

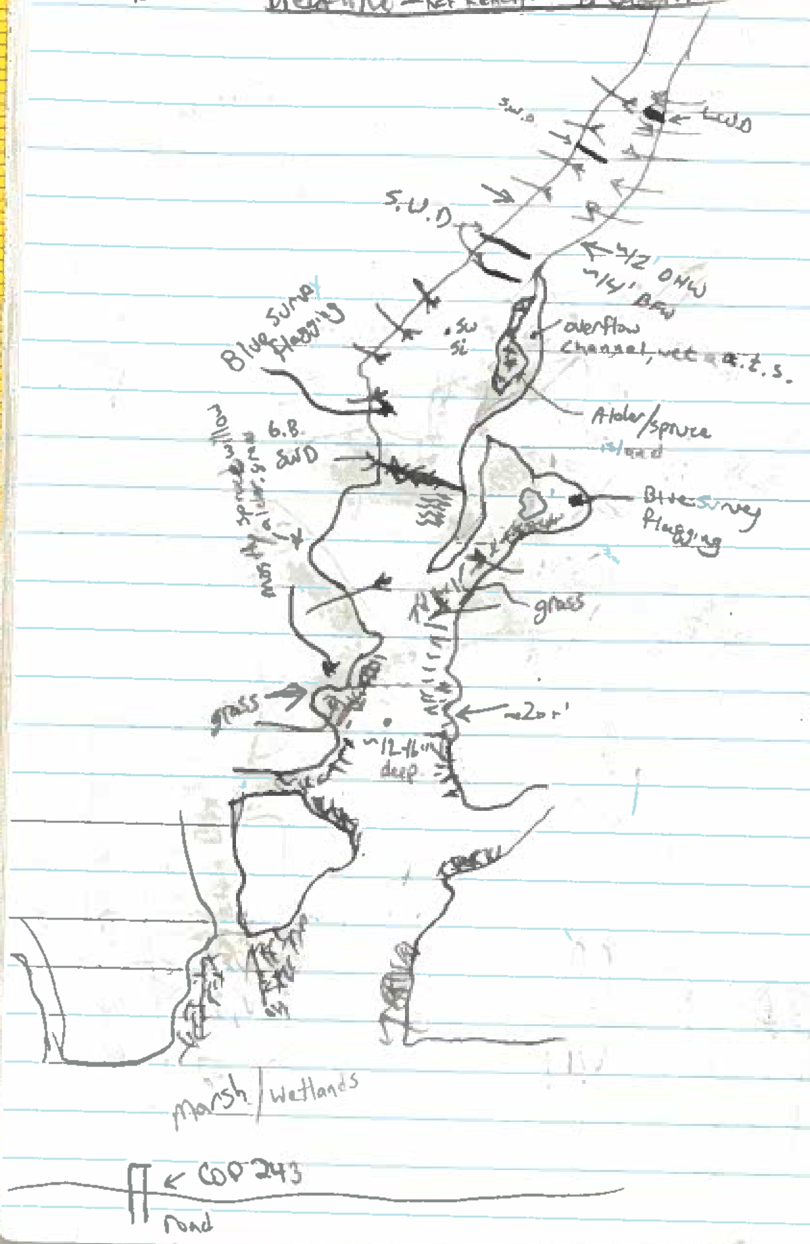
Cordova Fish Passage Project

10/9/18

- 4:00 landed in Cordova picked up rental car, went back to town to pick up snacks.
- Drove to sites and explored headwaters area looking for upstream drainages. Found old stream channel but no evidence of surface flows back to town at 8:00pm
- see mapping of headwater ditches along logging rd.

COP 43 → US SECTION

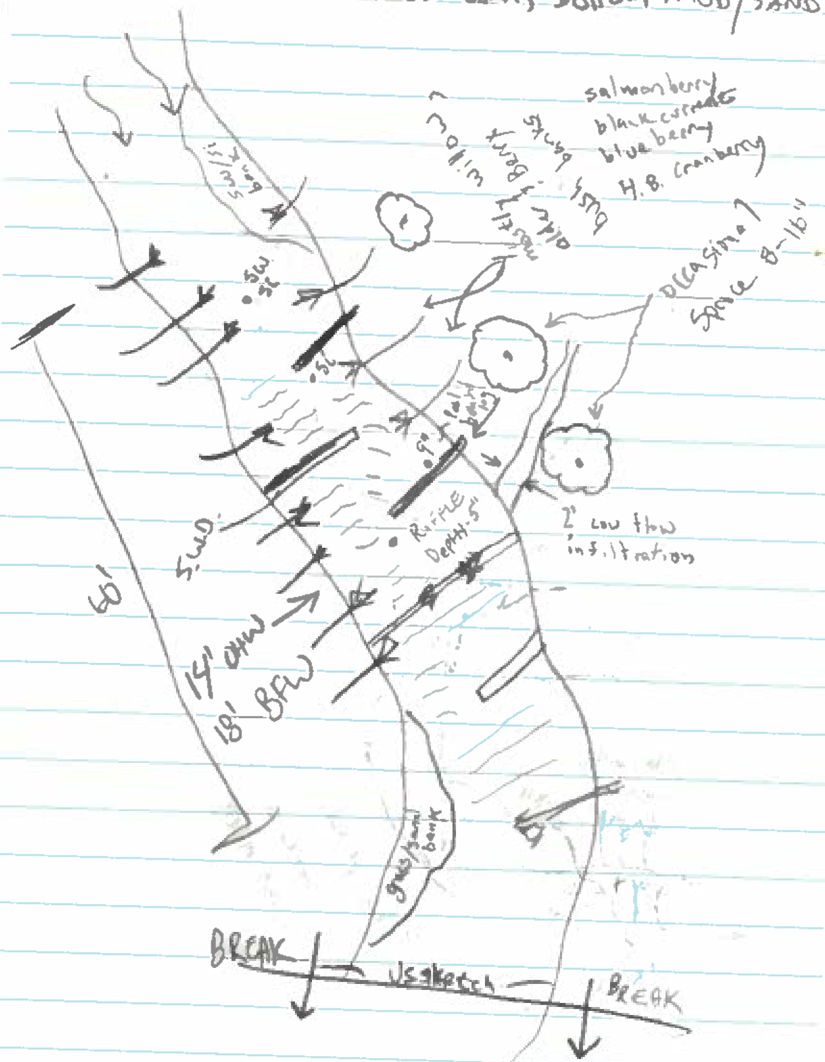
Breakline — Ref Reach — Breakline





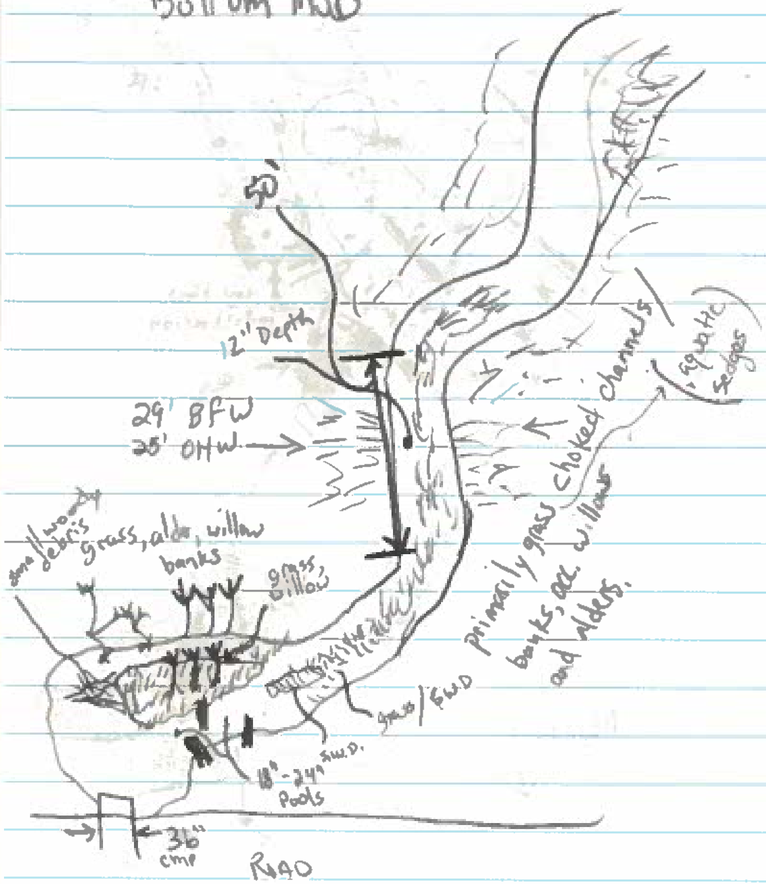

COP 43 Ref Reach Sketch

No Pebble Count, Bottom Mud/Sand



# Cop 43 Downstream Sketch

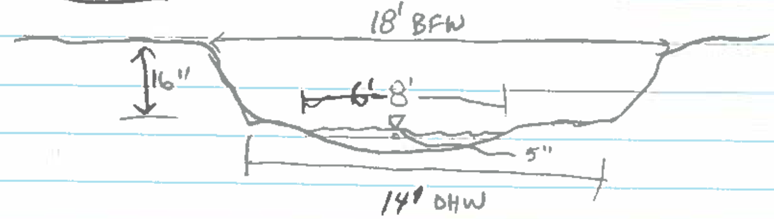
No Pebble Count,
Bottom Mud



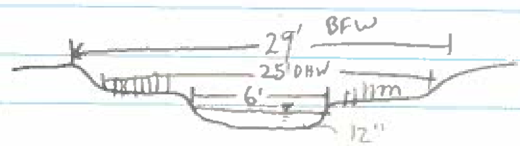



# Cop 243

US X-S




DS XS



Cop 44 US SKETCH - 12:30 p.m.

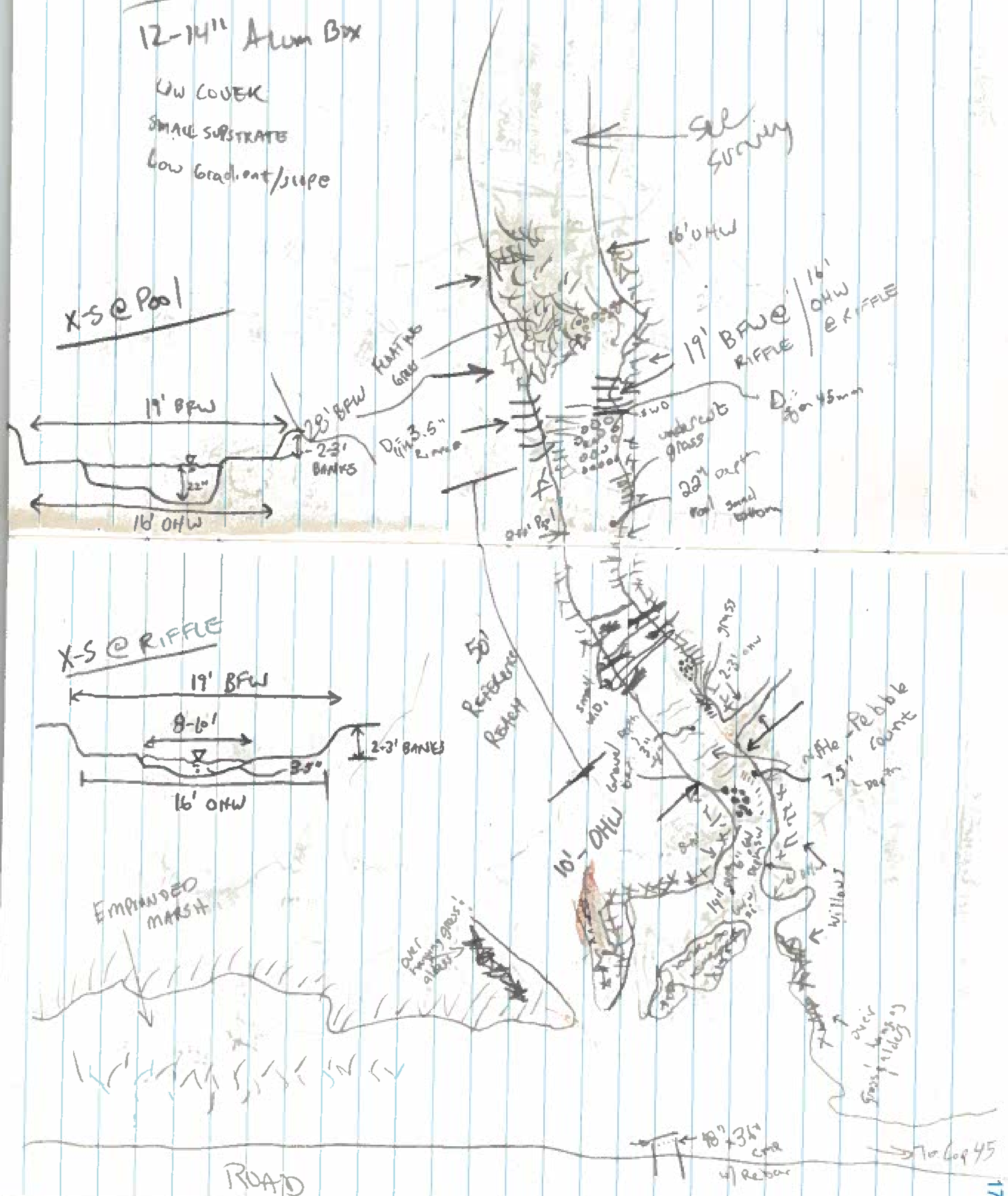
Proposed Crossing Structure:

12-14" Alum Box

w/ cover

Small substrate

Low Gradient/slope



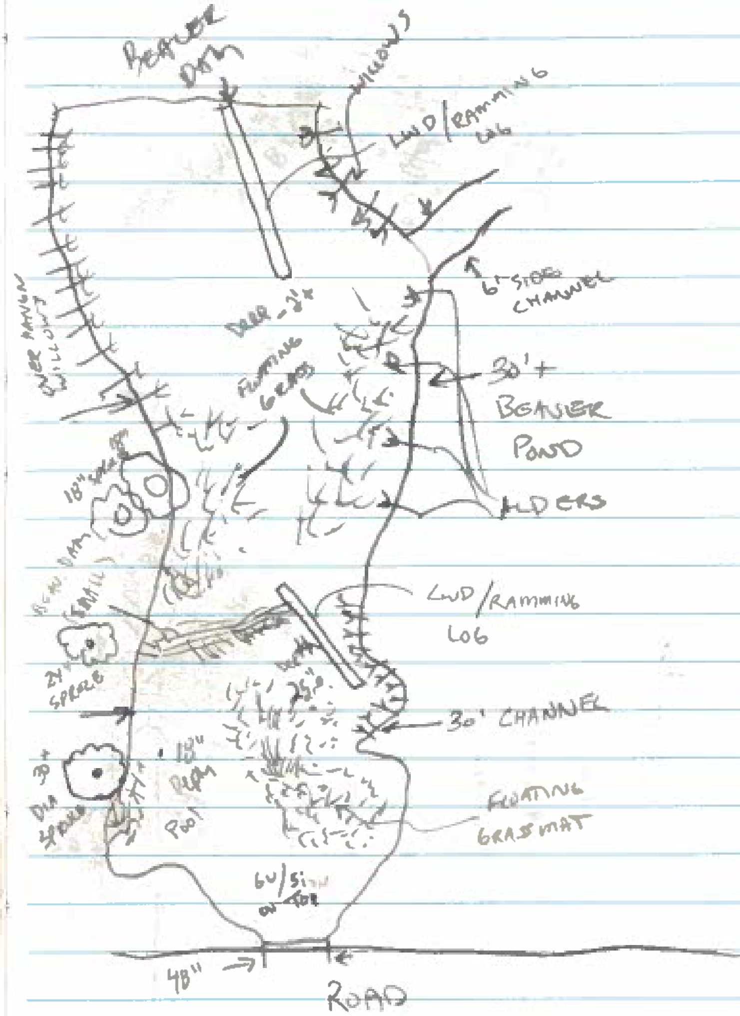
Cop 44 Bill Spencer, Kyle Walker
12:00 - 10/11/18

Pipe : 48" x 36"
Condition : Fair
Cover : 12 - 18"

| | |
|---|---|
| 90 | |
| 64 | |
| 45 | 卌 \|\|\|\| |
| 32 | 卌 卌 \|\| |
| 22.6 | 卌 卌 \| |
| 16 | 卌 卌 \|\| |
| 11 | 卌 \|\|\|\| |
| 8 | 卌 卌 \|\| |
| 5.6 | 卌 卌 \|\|\| |
| 4 | 卌 卌 \|\| |
| 2.8 | 卌 \| |
| 2 | 卌 |
| Fines | 卌 \|\| |



Cop 44 Downstream
10/11/18 - 12:00



10/10/18 9:00 am

- onsite meeting of all stake holders
  - Luka - USFS
    - about yearly event Saddleback creek overflow into pond area above 042 and can cause glacial water flowing across road in this area

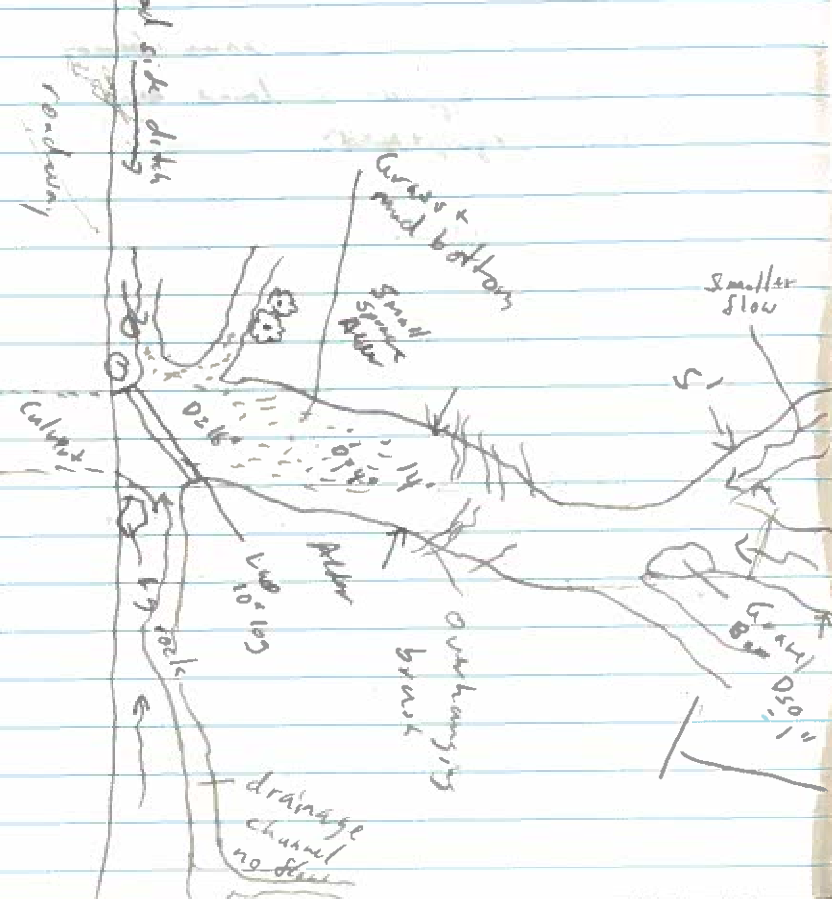


Site COP 45
B. Spencer, Kyle Walker
10:10 am 10/11/18

- culvert is a 36" x 48" pipe-arch
- badly corroded and damaged
- collapsing under road
- cover < 6"
- both upstream and downstream channels appear widened by heavy equipment

COP 45
upstream sketch

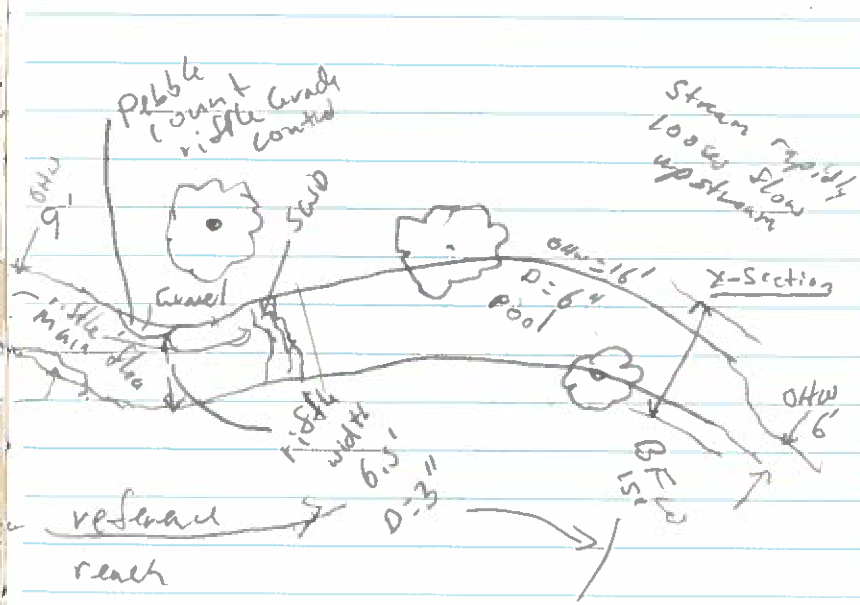
– Ground water stream appears to occupy historic river channel. Channel likely oversized





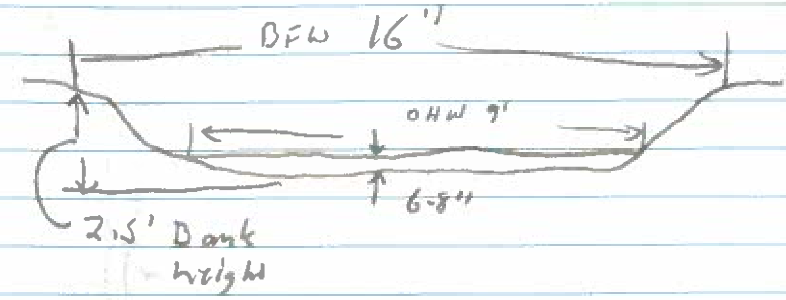

Pebble Count

| | |
|---|---|
| 64 | |
| 45 | \|\|\|\| |
| 32 | \|\|\|\| |
| 22.6 | 卌 \|\|\| |
| 16 | 卌 卌 卌 \|\|\|\| |
| 11 | 卌 卌 \|\| |
| 8 | 卌 卌 \|\| |
| 5.6 | 卌 \|\| |
| 4 | 卌 \|\| |
| 2.8 | 卌 |
| 2 | 卌 \|\|\|\| |
| Fines | 卌 卌 卌 卌 卌 |

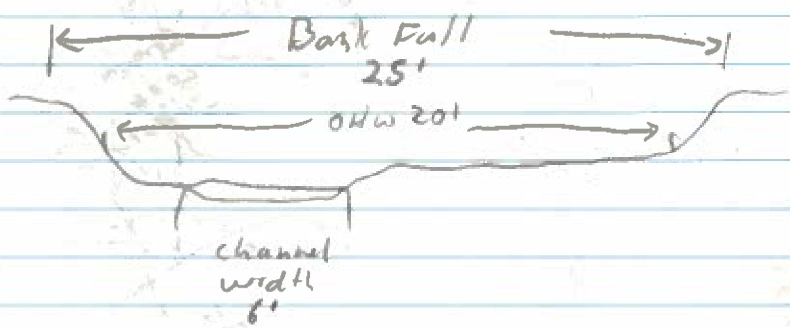


COP 45

X section at Pool



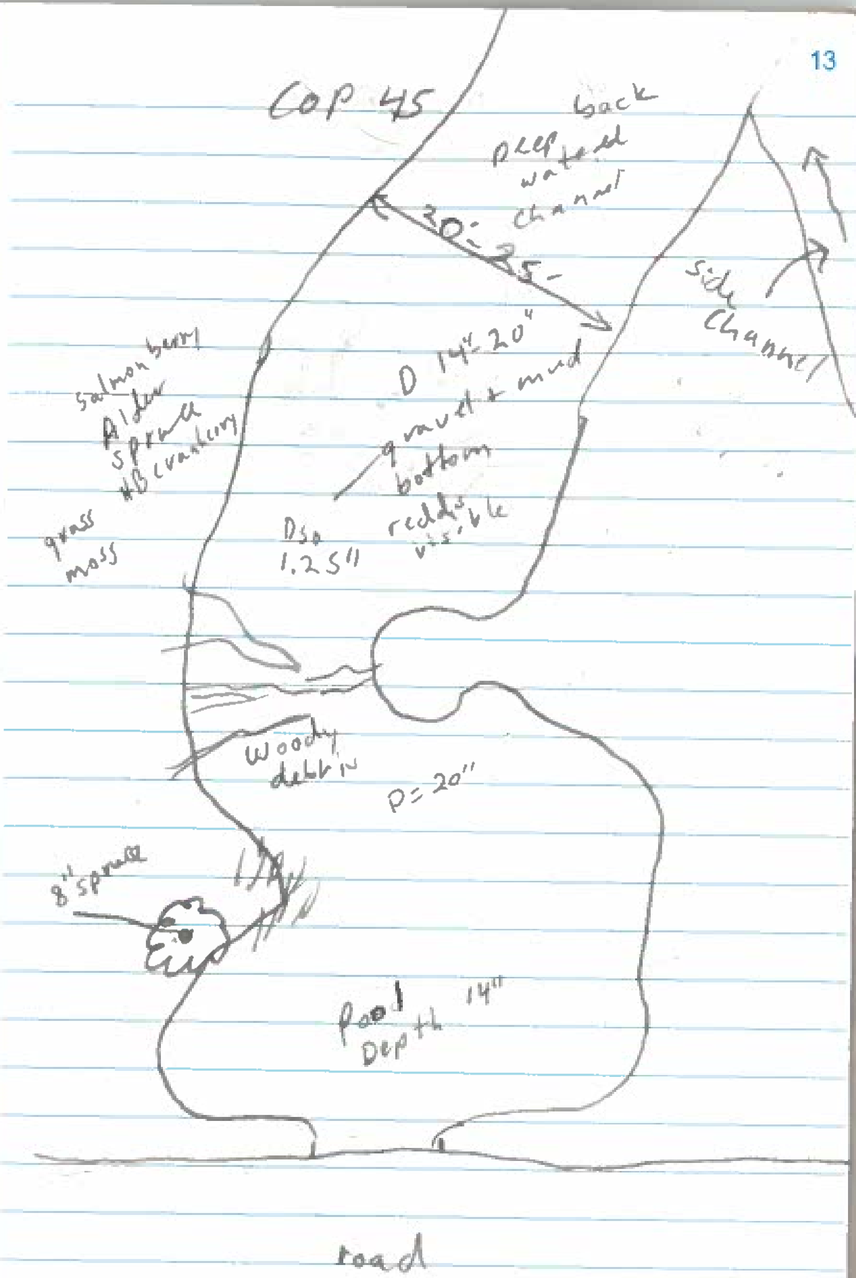

X - section at Riffle



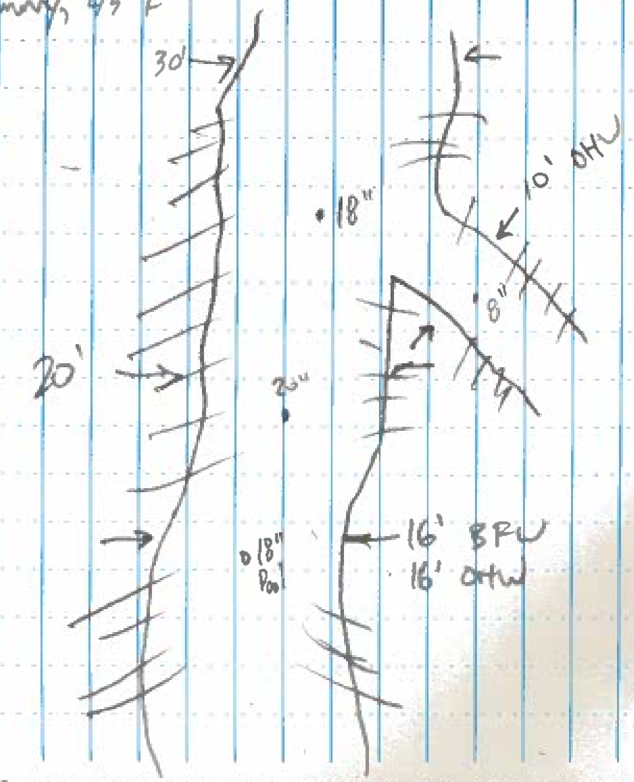

Probable Culvert low bar culvert
8'-10' width



COP 45

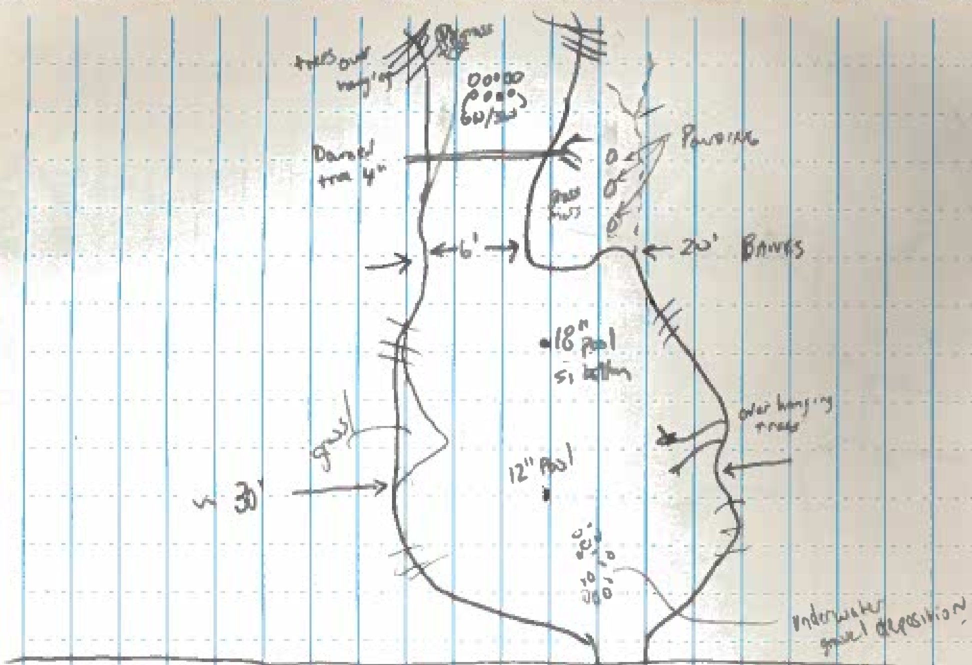


10-11-18 11:30 AM Cor 45 Downstream Sketch
Sunny, 45° F




Rite in the Rain

Scale: 1 square = ______




Scale: 1 square = ______

# Memo

| | |
|---|---|
| Date: | Wednesday, October 17, 2018 |
| Project: | Cordova Fish Passage |
| To: | HDR |
| From: | Kyle Walker, HDR |
| Subject: | Cordova Site Visit Recap |

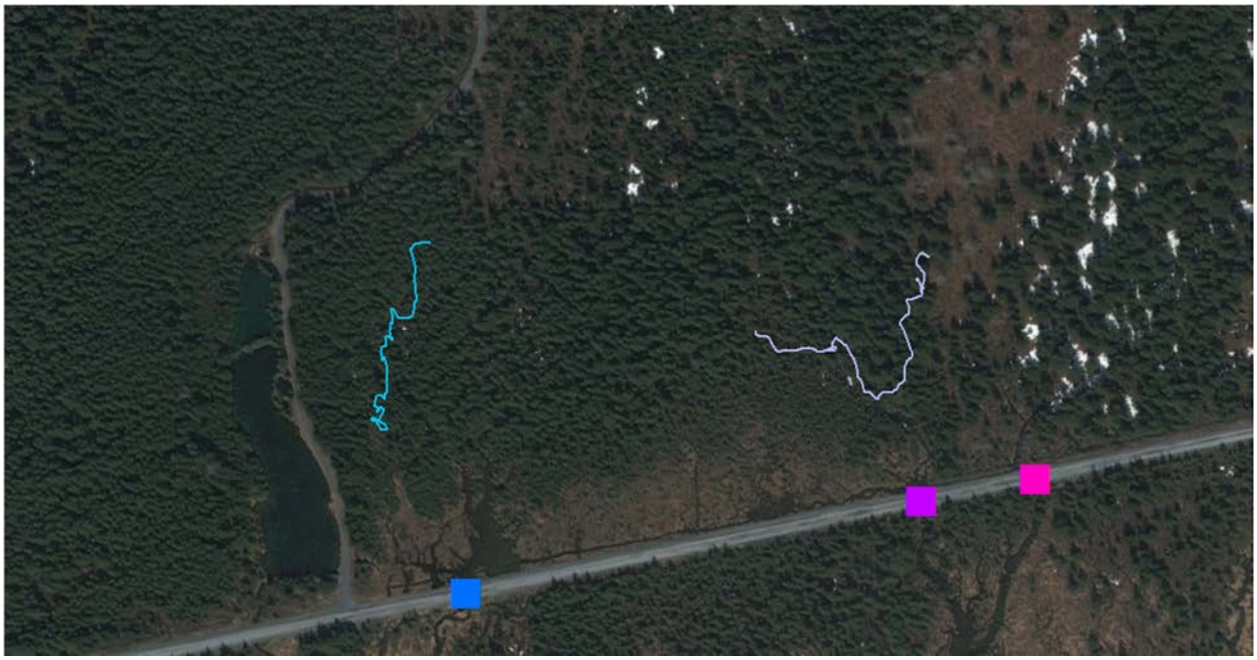
**TUESDAY OCTOBER 9, 2018**

HDR (Bill Spencer, Kyle Walker) arrive in Cordova on Alaska Airlines flight 66, get rental car and head to town to get snack from grocery store and bear spray from Heather Hanson USFWS. Arrive back at project site and proceed up gravel pit road (towards Saddlebag Glacier Trail) and investigated east of trailhead looking for flowing surface water (see screen shot for path), did not find any flowing water. Left site for day


**WEDNESDAY OCTOBER 10, 2018**

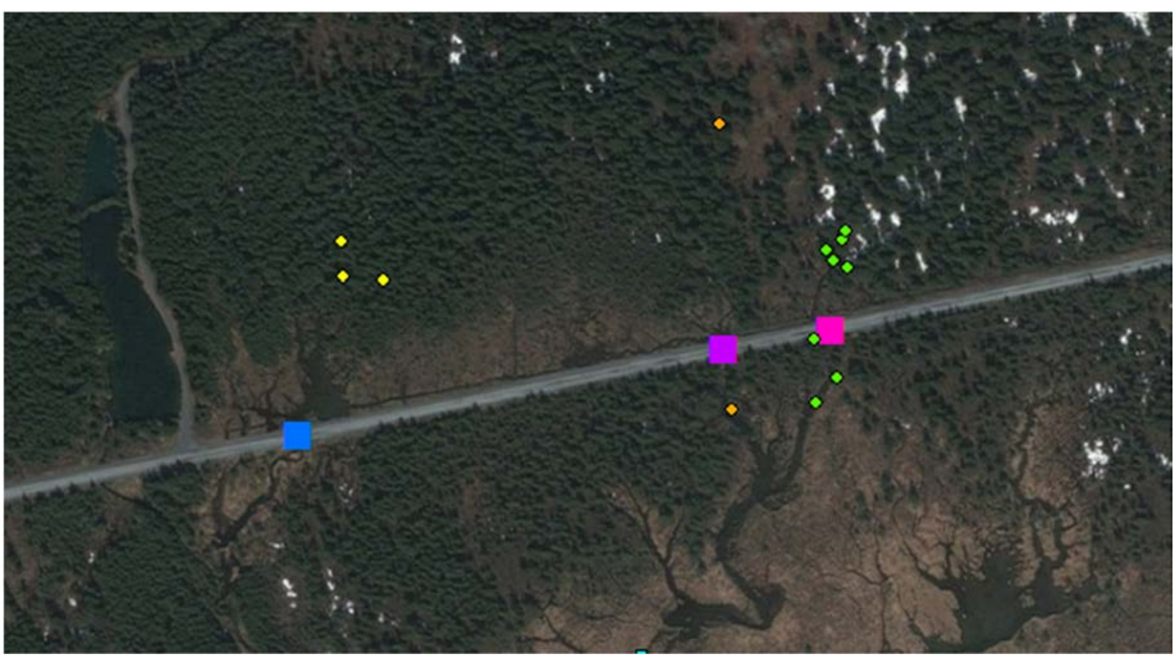
Met at site for site visit (HDR, BCE, USFWS, CRWP, USFS, and St. Denny Surveying), was heavy rain and sustained winds 20-30 MPH, walked all three sites and discussed connectivity of all of the sites, including COP 42 and the road culvert through the road connecting sites to pond (see site visit notes by CRWP for more detail on site visit), went back to town for a dry place to look at information surveyors had already collected (flat tire along the way). Proceeded back to sites and looked for reference reaches with Heather Hanson and Surveyors [see image below for paths taken for COP 43 and COP 44], discussed

COP 42 more. After finished investing reference reaches, proceeded to investigate west of the road to Saddlebag Glacier Trail trailhead for any surface water that might be flowing towards pond, did not find any but found good clear-water gravel-bed stream fed by groundwater from Saddlebag River.



**THURSDAY OCTOBER 11, 2018**

Started day at NAPA to replace tire repair kit used from Ralph, then returned to sites and collected site recon information for each culvert, took lunch at collapsed bridge [Some reference reach and photo locations in image below]. After final site recon was finished, Bill Spencer proceeded to investigate headwaters of clear-water stream found on Wednesday. Determined that main fork of Saddle Bag River could very potentially jump back into clear-water channel with big event which will in hand cause flooding of our culverts during large events.



**FRIDAY OCTOBER 12, 2018**

Met with Sam from City of Cordova Public Works and discussed our work there, returned bear-spray to CRWP, returned rental car and departed Cordova.

# Appendix B: Flood Flow Analysis

## Flood-frequency applications tool for use on unregulated streams in Alaska and conterminous basins in Canada

**This spreadsheet computes the regression estimate of the 50-, 20-, 10-, 4-, 2-, 1-, 0.5-, and 0.2-percent chance exceedance flows for an unregulated stream in Alaska or conterminous basins in Canada. The spreadsheet also includes the 90 percent prediction intervals, the minus and plus standard error of prediction intervals, and the average standard error of prediction. To use the spreadsheet, enter requested information in the yellow cells below.**

**Cordova Fish Passage; COP 43, COP 44, COP 45**

**Enter the explanatory variables:**

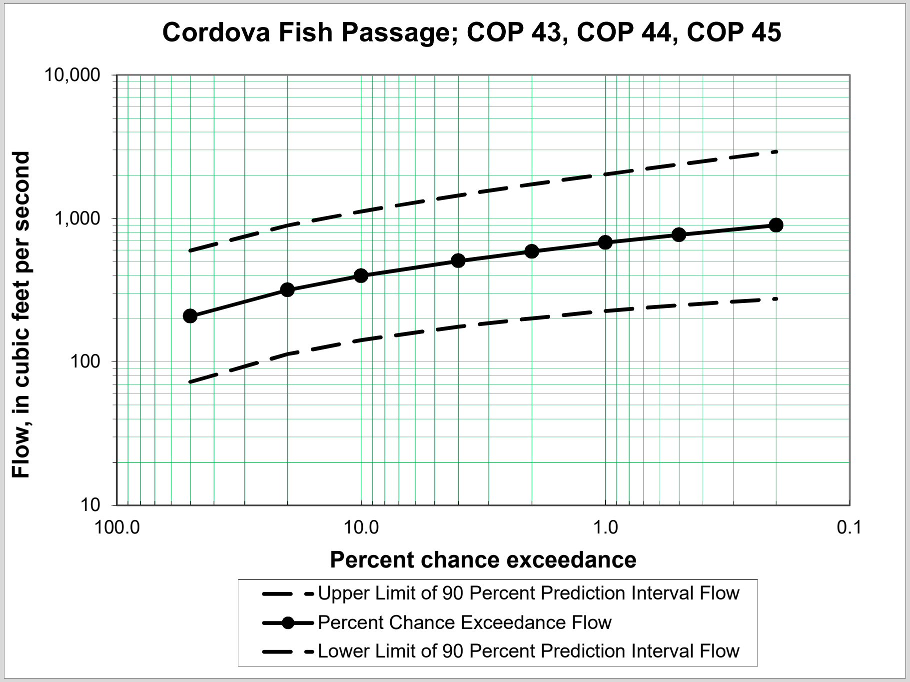
| | | | |
|---|---|---|---|
| Drainage area, in square miles | DRNAREA | 1.715507268 | Equations are valid for DRNAREA between 0.4 and 1,000 $mi^2$ with PRECPRIS00 between 8 and 280 inches, and for DRNAREA greater than 1,000 and less than 31,100 $mi^2$ with PRECPRIS00 between 10 and 111 inches. |
| Mean annual precipitation from 1971-2000 PRISM data, in inches | PRECPRIS00 | 125.5127297 | |

**Results:**

| Percent chance exceedance | Percent chance exceedance flow, in $ft^3/s$ | Lower limit of 90 percent prediction interval flow, in $ft^3/s$ | Upper limit of 90 percent prediction interval flow, in $ft^3/s$ | $-SEP_{P,i}$ (percent) | $+SEP_{P,i}$ (percent) | Average $SEP_{P,i}$ (percent) |
|---|---|---|---|---|---|---|
| 50 | 208 | 72.5 | 597 | -47.2 | 89.4 | 71.0 |
| 20 | 317 | 113 | 892 | -46.5 | 87.1 | 69.3 |
| 10 | 398 | 142 | 1,120 | -46.6 | 87.1 | 69.3 |
| 4 | 506 | 176 | 1,450 | -47.2 | 89.5 | 71.1 |
| 2 | 589 | 201 | 1,730 | -47.9 | 92.0 | 72.8 |
| 1 | 679 | 227 | 2,030 | -48.6 | 94.4 | 74.5 |
| 0.5 | 770 | 249 | 2,380 | -49.6 | 98.3 | 77.3 |
| 0.2 | 895 | 275 | 2,920 | -51.1 | 104.5 | 81.8 |

**Notes**

Differences in rounding of equation parameters can produce minor differences between the results obtained using the regression equations in table 7 and using WREG software. The estimates in this spreadsheet use the regression equations as published in table 7. The regression estimates for streamgages shown in table 4 were computed using WREG during the regression analysis.



# Appendix C: HY-8 Report for Existing Structures

# HY-8 Culvert Analysis Report

## Crossing Discharge Data

Discharge Selection Method: Specify Minimum, Design, and Maximum Flow

Minimum Flow: 20 cfs

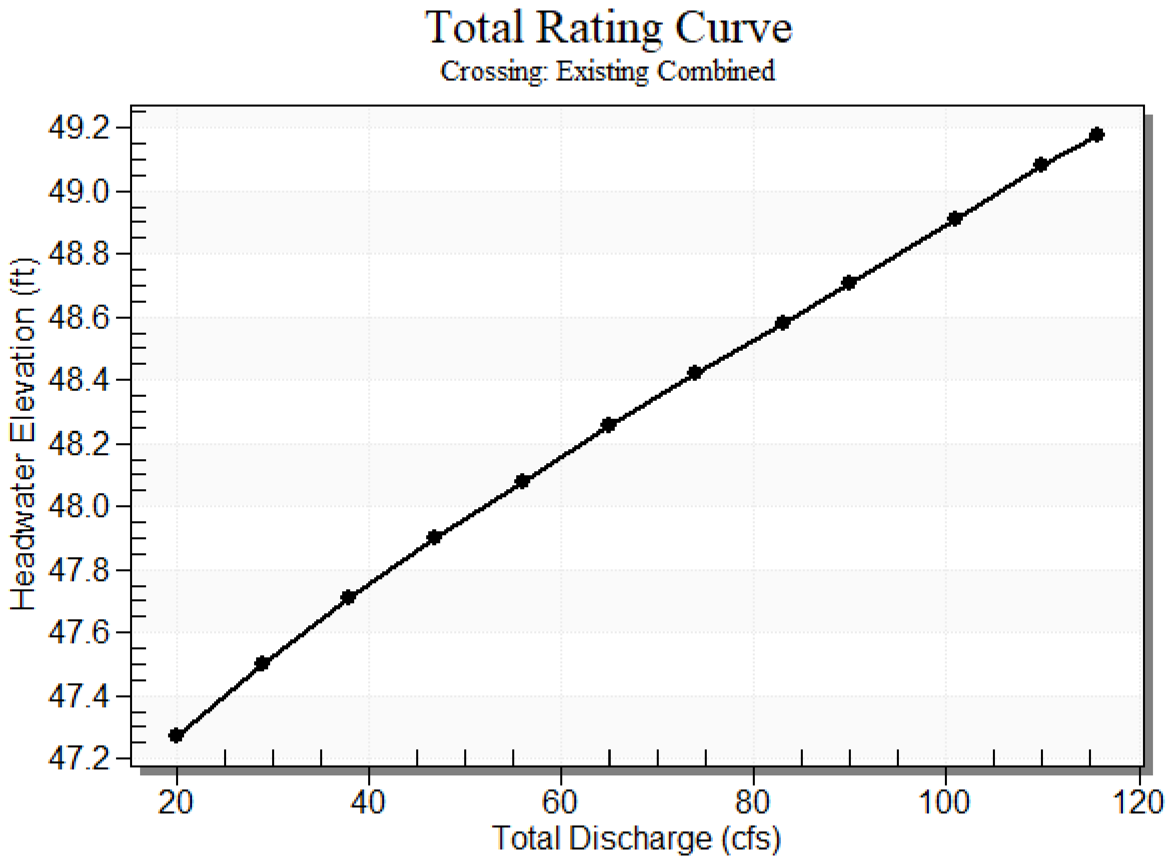
Design Flow: 90 cfs

Maximum Flow: 110 cfs

## Table 1 - Summary of Culvert Flows at Crossing: Existing Combined

| Headwater Elevation (ft) | Total Discharge (cfs) | COP 45 Discharge (cfs) | COP 44 Discharge (cfs) | COP 43 Discharge (cfs) | Roadway Discharge (cfs) | Iterations |
|---|---|---|---|---|---|---|
| 47.27 | 20.00 | 9.67 | 6.21 | 4.10 | 0.00 | 5 |
| 47.50 | 29.00 | 13.32 | 9.41 | 6.27 | 0.00 | 4 |
| 47.71 | 38.00 | 16.76 | 12.67 | 8.56 | 0.00 | 4 |
| 47.90 | 47.00 | 20.17 | 15.89 | 10.93 | 0.00 | 4 |
| 48.08 | 56.00 | 23.62 | 19.06 | 13.29 | 0.00 | 3 |
| 48.25 | 65.00 | 27.07 | 22.28 | 15.65 | 0.00 | 3 |
| 48.42 | 74.00 | 30.42 | 25.53 | 17.97 | 0.00 | 8 |
| 48.58 | 83.00 | 33.71 | 28.80 | 20.30 | 0.00 | 13 |
| 48.71 | 90.00 | 36.25 | 31.39 | 22.15 | 0.00 | 14 |
| 48.91 | 101.00 | 40.13 | 35.46 | 25.11 | 0.00 | 20 |
| 49.08 | 110.00 | 43.21 | 38.72 | 27.54 | 0.00 | 26 |
| 49.20 | 115.63 | 45.35 | 41.01 | 29.27 | 0.00 | Overtopping |

**Rating Curve Plot for Crossing: Existing Combined**



## Table 2 - Culvert Summary Table: COP 45

| 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20.00 | 9.67 | 47.27 | 1.095 | 0.117 | 1-S2n | 0.627 | 0.697 | 0.627 | 0.218 | 4.752 | 1.530 |
| 29.00 | 13.32 | 47.50 | 1.322 | 0.299 | 1-S2n | 0.746 | 0.834 | 0.767 | 0.272 | 5.109 | 1.774 |
| 38.00 | 16.76 | 47.71 | 1.527 | 0.474 | 1-S2n | 0.848 | 0.954 | 0.848 | 0.321 | 5.685 | 1.975 |
| 47.00 | 20.17 | 47.90 | 1.719 | 0.652 | 1-S2n | 0.944 | 1.064 | 0.944 | 0.365 | 6.023 | 2.149 |
| 56.00 | 23.62 | 48.08 | 1.900 | 0.834 | 1-S2n | 1.037 | 1.165 | 1.072 | 0.405 | 6.087 | 2.304 |
| 65.00 | 27.07 | 48.25 | 2.073 | 1.021 | 1-S2n | 1.127 | 1.258 | 1.127 | 0.443 | 6.585 | 2.444 |
| 74.00 | 30.42 | 48.42 | 2.238 | 1.208 | 1-S2n | 1.213 | 1.341 | 1.213 | 0.479 | 6.809 | 2.573 |
| 83.00 | 33.71 | 48.58 | 2.401 | 1.397 | 1-S2n | 1.297 | 1.418 | 1.297 | 0.514 | 7.004 | 2.693 |
| 90.00 | 36.25 | 48.71 | 2.528 | 1.548 | 1-S2n | 1.362 | 1.473 | 1.402 | 0.539 | 6.926 | 2.780 |
| 101.00 | 40.13 | 48.91 | 2.730 | 1.797 | 1-S2n | 1.463 | 1.563 | 1.463 | 0.578 | 7.331 | 2.910 |
| 110.00 | 43.21 | 49.08 | 2.898 | 2.004 | 5-S2n | 1.544 | 1.633 | 1.586 | 0.609 | 7.258 | 3.010 |

*******************************************************************************

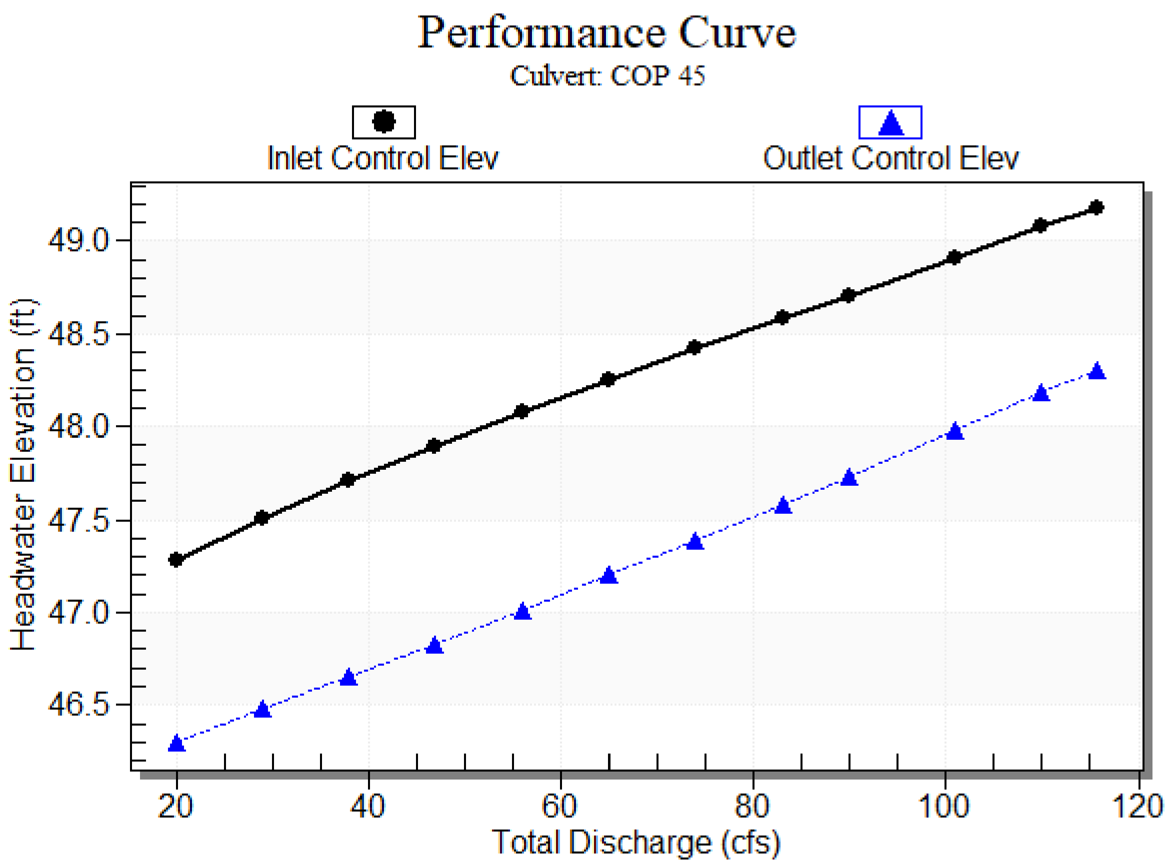
Straight Culvert

Inlet Elevation (invert): 46.18 ft,    Outlet Elevation (invert): 45.55 ft

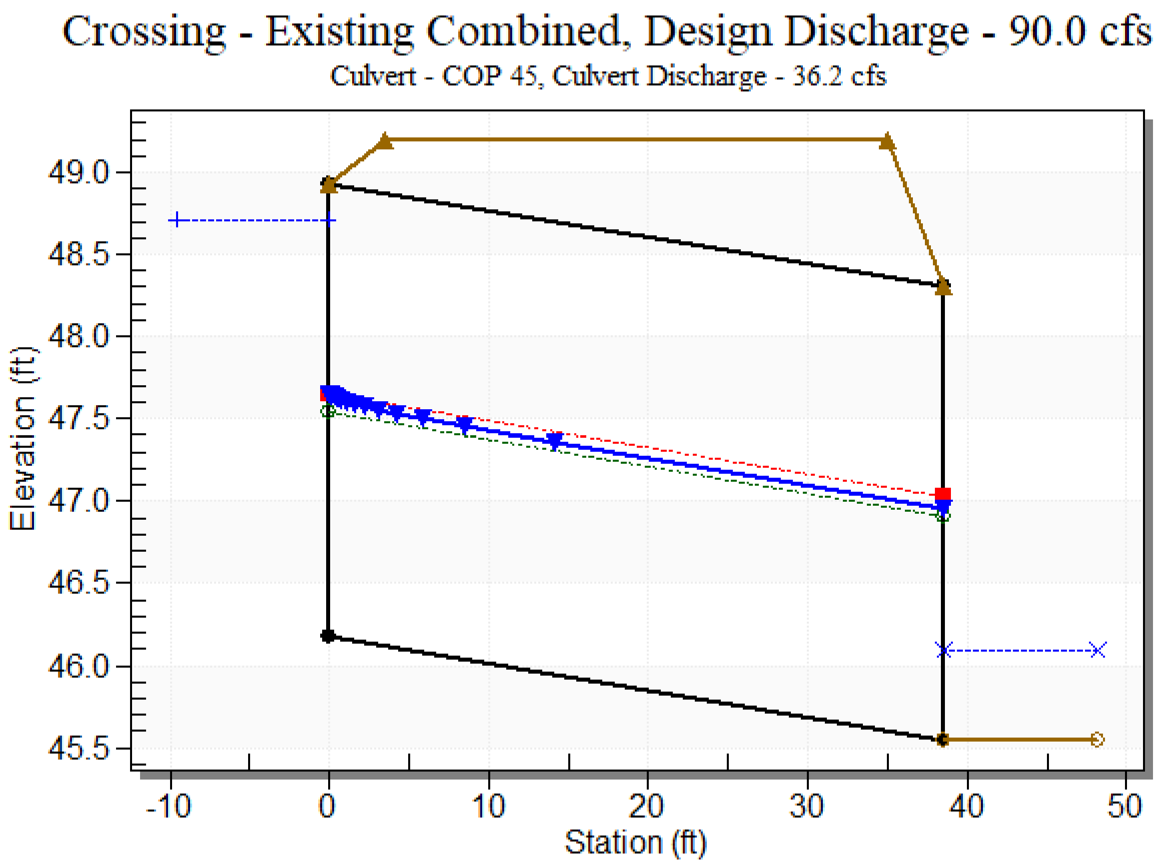
Culvert Length: 38.51 ft,    Culvert Slope: 0.0164

*******************************************************************************

**Culvert Performance Curve Plot: COP 45**



## Water Surface Profile Plot for Culvert: COP 45




## Site Data - COP 45

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 46.18 ft

Outlet Station: 38.50 ft

Outlet Elevation: 45.55 ft

Number of Barrels: 1

## Culvert Data Summary - COP 45

Barrel Shape: Pipe Arch

Barrel Span: 49.00 in

Barrel Rise: 33.00 in

Barrel Material: Steel or Aluminum

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Culvert Type: Straight

Inlet Configuration: Projecting

Inlet Depression: None

## Table 3 - Culvert Summary Table: COP 44

| 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20.00 | 6.21 | 47.27 | 0.845 | 0.0* | 1-S2n | 0.460 | 0.547 | 0.460 | 0.218 | 4.544 | 1.530 |
| 29.00 | 9.41 | 47.50 | 1.073 | 0.0* | 1-S2n | 0.571 | 0.686 | 0.587 | 0.272 | 5.031 | 1.774 |
| 38.00 | 12.67 | 47.71 | 1.278 | 0.017 | 1-S2n | 0.669 | 0.810 | 0.687 | 0.321 | 5.555 | 1.975 |
| 47.00 | 15.89 | 47.90 | 1.469 | 0.179 | 1-S2n | 0.757 | 0.922 | 0.778 | 0.365 | 5.990 | 2.149 |
| 56.00 | 19.06 | 48.08 | 1.650 | 0.346 | 1-S2n | 0.838 | 1.029 | 0.838 | 0.405 | 6.557 | 2.304 |
| 65.00 | 22.28 | 48.25 | 1.823 | 0.517 | 1-S2n | 0.917 | 1.127 | 0.946 | 0.443 | 6.634 | 2.444 |
| 74.00 | 25.53 | 48.42 | 1.989 | 0.691 | 1-S2n | 0.994 | 1.217 | 1.024 | 0.479 | 6.944 | 2.573 |
| 83.00 | 28.80 | 48.58 | 2.151 | 0.872 | 1-S2n | 1.068 | 1.302 | 1.102 | 0.514 | 7.185 | 2.693 |
| 90.00 | 31.39 | 48.71 | 2.278 | 1.020 | 1-S2n | 1.126 | 1.365 | 1.163 | 0.539 | 7.368 | 2.780 |
| 101.00 | 35.46 | 48.91 | 2.481 | 1.258 | 1-S2n | 1.216 | 1.456 | 1.256 | 0.578 | 7.635 | 2.910 |
| 110.00 | 38.72 | 49.08 | 2.648 | 1.466 | 1-S2n | 1.288 | 1.532 | 1.330 | 0.609 | 7.832 | 3.010 |

* Full Flow Headwater elevation is below inlet invert.

********************************************************************************

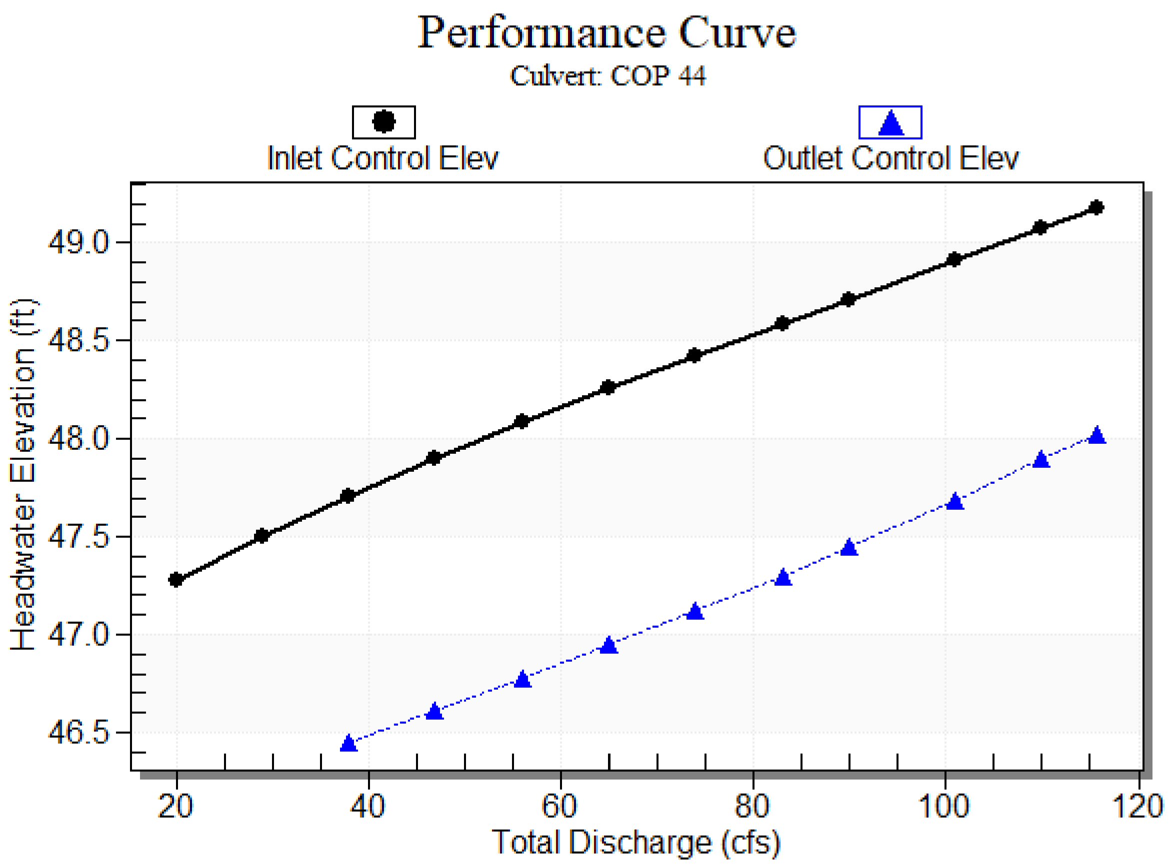
Straight Culvert

Inlet Elevation (invert): 46.43 ft,    Outlet Elevation (invert): 45.55 ft

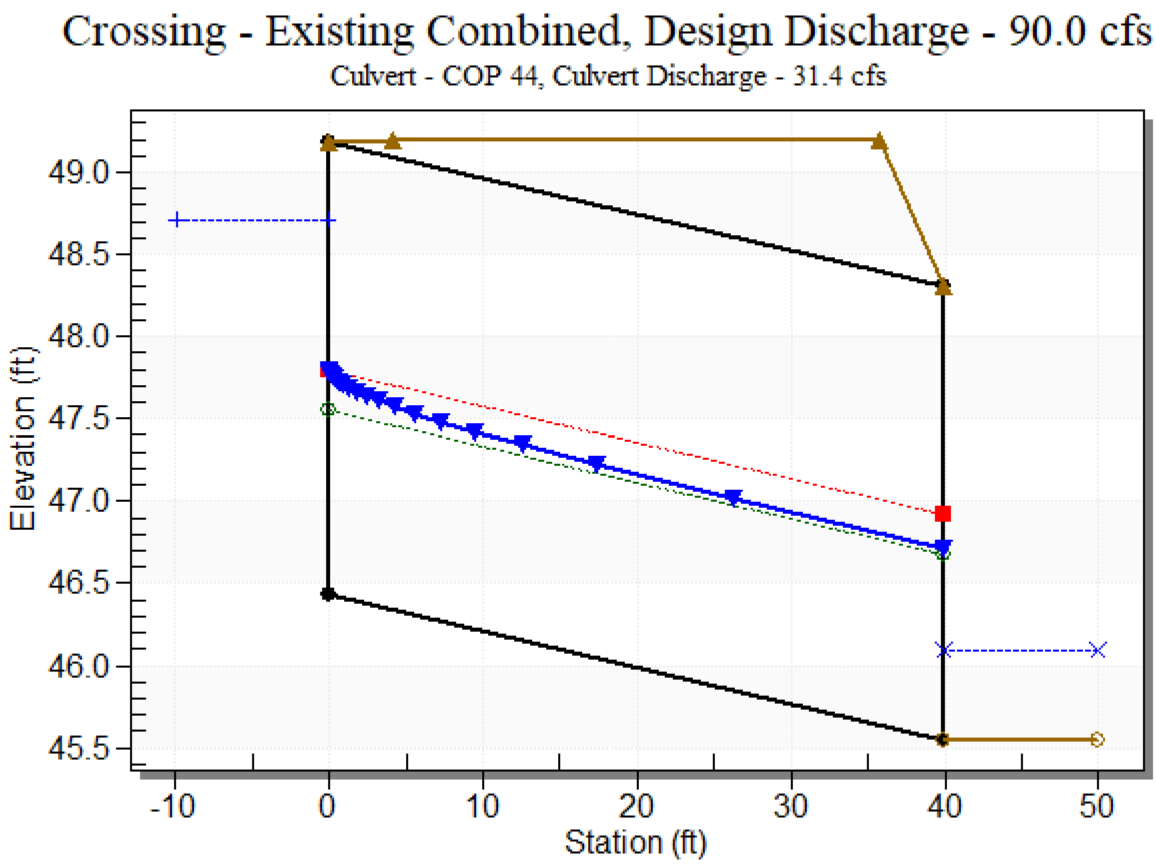
Culvert Length: 39.91 ft,    Culvert Slope: 0.0221

********************************************************************************

**Culvert Performance Curve Plot: COP 44**



**Water Surface Profile Plot for Culvert: COP 44**




## Site Data - COP 44

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 46.43 ft

Outlet Station: 39.90 ft

Outlet Elevation: 45.55 ft

Number of Barrels: 1

## Culvert Data Summary - COP 44

Barrel Shape: Pipe Arch

Barrel Span: 49.00 in

Barrel Rise: 33.00 in

Barrel Material: Steel or Aluminum

Embedment: 0.00 in

Barrel Manning's n: 0.0240

Culvert Type: Straight

Inlet Configuration: Projecting

Inlet Depression: None

## Table 4 - Culvert Summary Table: COP 43

| 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) |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 20.00 | 4.10 | 47.27 | 0.915 | 0.0* | 1-S2n | 0.557 | 0.628 | 0.557 | 0.218 | 4.376 | 1.530 |
| 29.00 | 6.27 | 47.50 | 1.143 | 0.009 | 1-S2n | 0.688 | 0.784 | 0.688 | 0.272 | 4.936 | 1.774 |
| 38.00 | 8.56 | 47.71 | 1.348 | 0.174 | 1-S2n | 0.805 | 0.919 | 0.805 | 0.321 | 5.413 | 1.975 |
| 47.00 | 10.93 | 47.90 | 1.539 | 0.342 | 1-S2n | 0.914 | 1.045 | 0.942 | 0.365 | 5.558 | 2.149 |
| 56.00 | 13.29 | 48.08 | 1.720 | 0.505 | 1-S2n | 1.013 | 1.157 | 1.044 | 0.405 | 5.869 | 2.304 |
| 65.00 | 15.65 | 48.25 | 1.893 | 0.669 | 1-S2n | 1.105 | 1.259 | 1.105 | 0.443 | 6.397 | 2.444 |
| 74.00 | 17.97 | 48.42 | 2.059 | 0.836 | 1-S2n | 1.191 | 1.357 | 1.191 | 0.479 | 6.642 | 2.573 |
| 83.00 | 20.30 | 48.58 | 2.221 | 1.006 | 1-S2n | 1.275 | 1.447 | 1.310 | 0.514 | 6.615 | 2.693 |
| 90.00 | 22.15 | 48.71 | 2.348 | 1.143 | 1-S2n | 1.339 | 1.514 | 1.339 | 0.539 | 7.016 | 2.780 |
| 101.00 | 25.11 | 48.91 | 2.551 | 1.368 | 1-S2n | 1.440 | 1.613 | 1.481 | 0.578 | 6.986 | 2.910 |
| 110.00 | 27.54 | 49.08 | 2.718 | 1.563 | 1-S2n | 1.521 | 1.694 | 1.521 | 0.609 | 7.410 | 3.010 |

* Full Flow Headwater elevation is below inlet invert.

************************************************************************************************

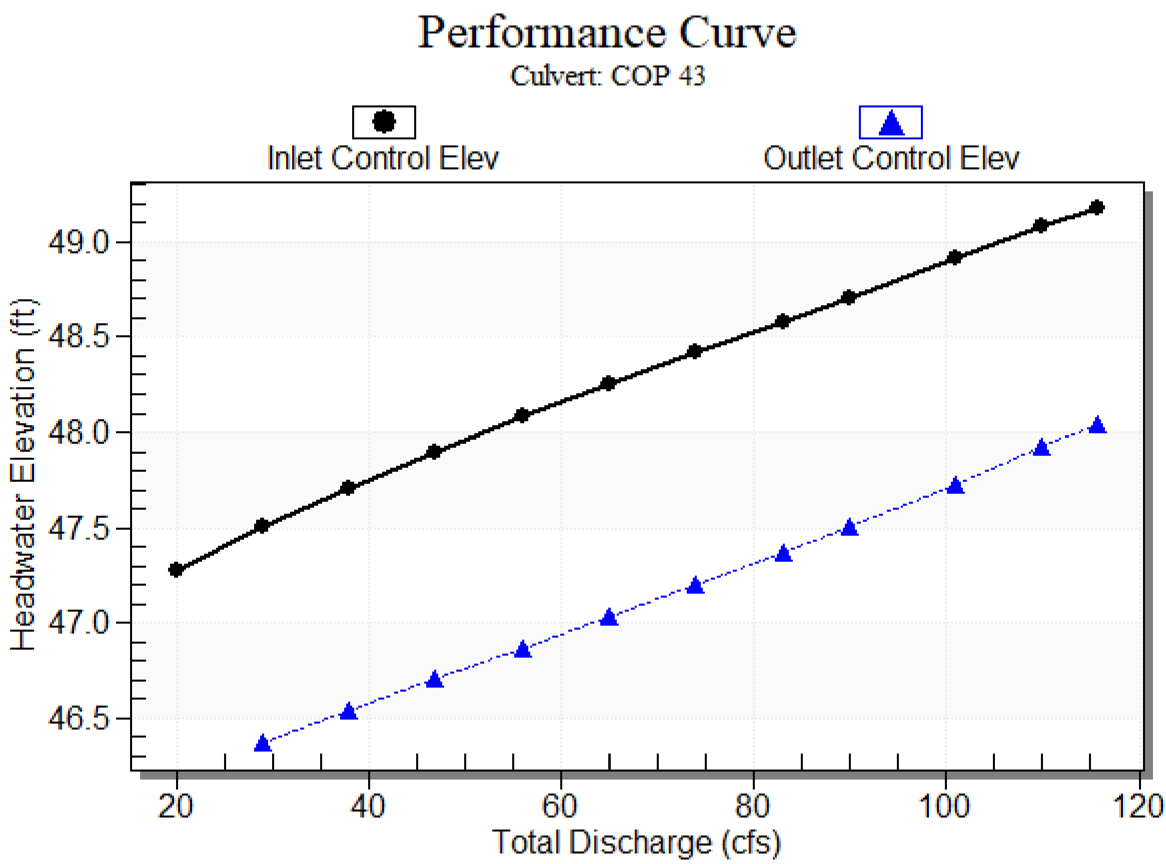
Straight Culvert

Inlet Elevation (invert): 46.36 ft,    Outlet Elevation (invert): 45.55 ft

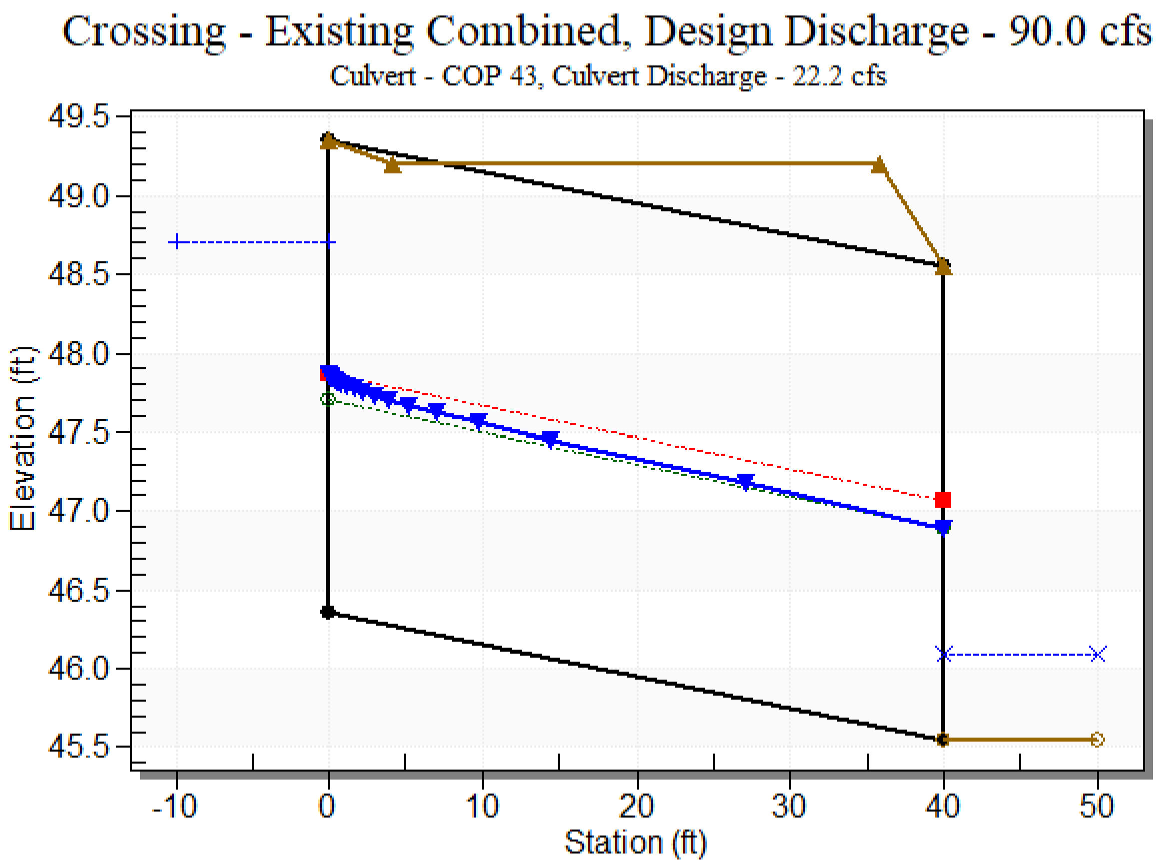
Culvert Length: 40.01 ft,    Culvert Slope: 0.0203

************************************************************************************************

**Culvert Performance Curve Plot: COP 43**



**Water Surface Profile Plot for Culvert: COP 43**




**Site Data - COP 43**

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 46.36 ft

Outlet Station: 40.00 ft

Outlet Elevation: 45.55 ft

Number of Barrels: 1

**Culvert Data Summary - COP 43**

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

Inlet Depression: None

## Table 5 - Downstream Channel Rating Curve (Crossing: Existing Combined)

| Flow (cfs) | Water Surface Elev (ft) | Depth (ft) | Velocity (ft/s) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| 20.00 | 45.77 | 0.22 | 1.53 | 0.14 | 0.58 |
| 29.00 | 45.82 | 0.27 | 1.77 | 0.17 | 0.60 |
| 38.00 | 45.87 | 0.32 | 1.98 | 0.20 | 0.61 |
| 47.00 | 45.91 | 0.36 | 2.15 | 0.23 | 0.63 |
| 56.00 | 45.96 | 0.41 | 2.30 | 0.25 | 0.64 |
| 65.00 | 45.99 | 0.44 | 2.44 | 0.28 | 0.65 |
| 74.00 | 46.03 | 0.48 | 2.57 | 0.30 | 0.66 |
| 83.00 | 46.06 | 0.51 | 2.69 | 0.32 | 0.66 |
| 90.00 | 46.09 | 0.54 | 2.78 | 0.34 | 0.67 |
| 101.00 | 46.13 | 0.58 | 2.91 | 0.36 | 0.67 |
| 110.00 | 46.16 | 0.61 | 3.01 | 0.38 | 0.68 |

## Tailwater Channel Data - Existing Combined

Tailwater Channel Option:  Rectangular Channel

Bottom Width:  60.00 ft

Channel Slope:  0.0100

Channel Manning's n:  0.0350

Channel Invert Elevation:  45.55 ft

## Roadway Data for Crossing: Existing Combined

Roadway Profile Shape:  Constant Roadway Elevation

Crest Length:  1650.00 ft

Crest Elevation:  49.20 ft

Roadway Surface:  Gravel

Roadway Top Width:  31.60 ft

# Appendix D: HY-8 Report for Proposed Structures

# HY-8 Culvert Analysis Report

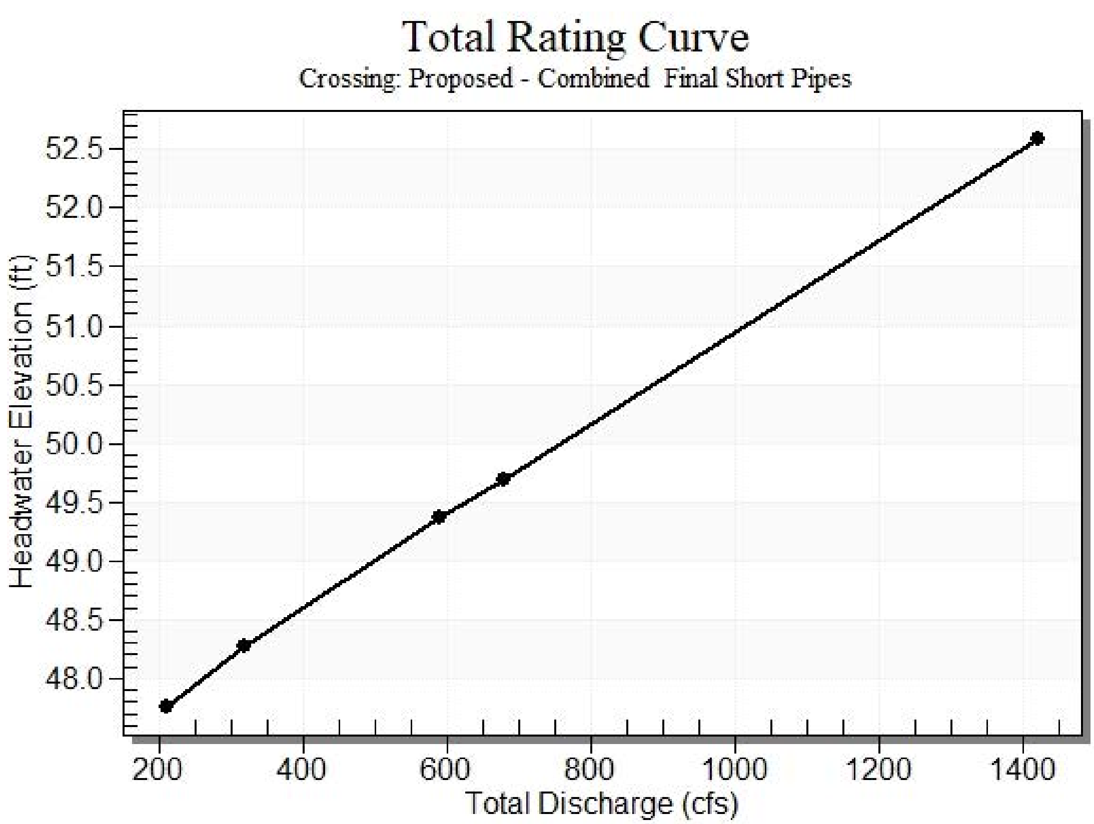
## Crossing Discharge Data

Discharge Selection Method: User Defined

### Table 1 - Summary of Culvert Flows at Crossing: Proposed - Combined Final

| Headwater Elevation (ft) | Discharge Names | Total Discharge (cfs) | COP 43 Discharge (cfs) | COP 44 Discharge (cfs) | COP 45 Discharge (cfs) | Roadway Discharge (cfs) | Iterations |
|---|---|---|---|---|---|---|---|
| 47.77 | 2 Year | 208.00 | 75.95 | 49.35 | 82.55 | 0.00 | 5 |
| 48.28 | 10 Year | 317.00 | 113.43 | 82.26 | 121.29 | 0.00 | 4 |
| 49.36 | 50 Year | 589.00 | 205.77 | 168.19 | 215.00 | 0.00 | 4 |
| 49.69 | 100 Year | 679.00 | 236.15 | 197.09 | 245.71 | 0.00 | 3 |
| 52.60 | Overtopping | 1419.05 | 479.20 | 454.73 | 485.13 | 0.00 | Overtopping |

### Rating Curve Plot for Crossing: Proposed - Combined Final



## Table 2 - Culvert Summary Table: COP 43

| Discharge Names | 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 Year | 208.00 | 75.95 | 47.77 | 1.496 | 1.736 | 2-M2c | 1.361 | 0.915 | 0.915 | 0.972 | 5.357 | 3.568 |
| 10 Year | 317.00 | 113.43 | 48.28 | 1.955 | 2.250 | 2-M2c | 1.758 | 1.192 | 1.192 | 1.256 | 6.142 | 4.207 |
| 50 Year | 589.00 | 205.77 | 49.36 | 3.040 | 3.333 | 2-M2c | 2.637 | 1.767 | 1.767 | 1.834 | 7.515 | 5.351 |
| 100 Year | 679.00 | 236.15 | 49.69 | 3.395 | 3.657 | 2-M2c | 2.941 | 1.932 | 1.932 | 2.002 | 7.894 | 5.652 |

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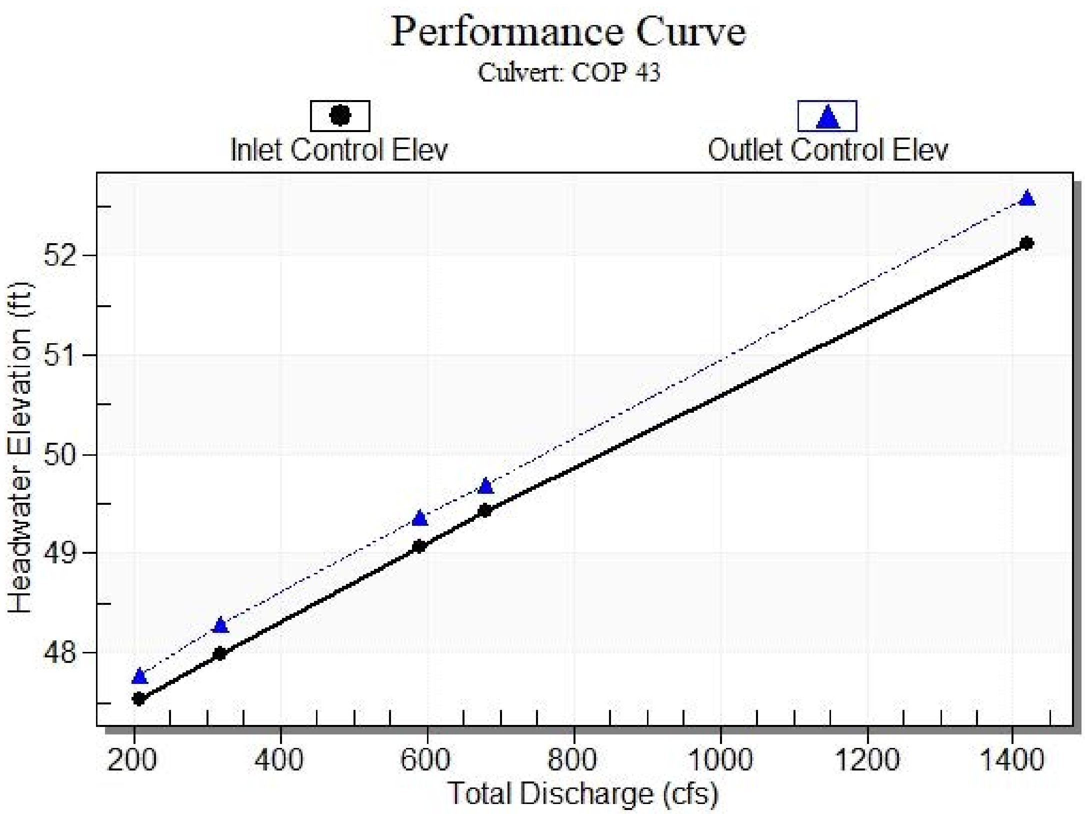
Straight Culvert

Inlet Elevation (invert): 46.03 ft,    Outlet Elevation (invert): 45.63 ft

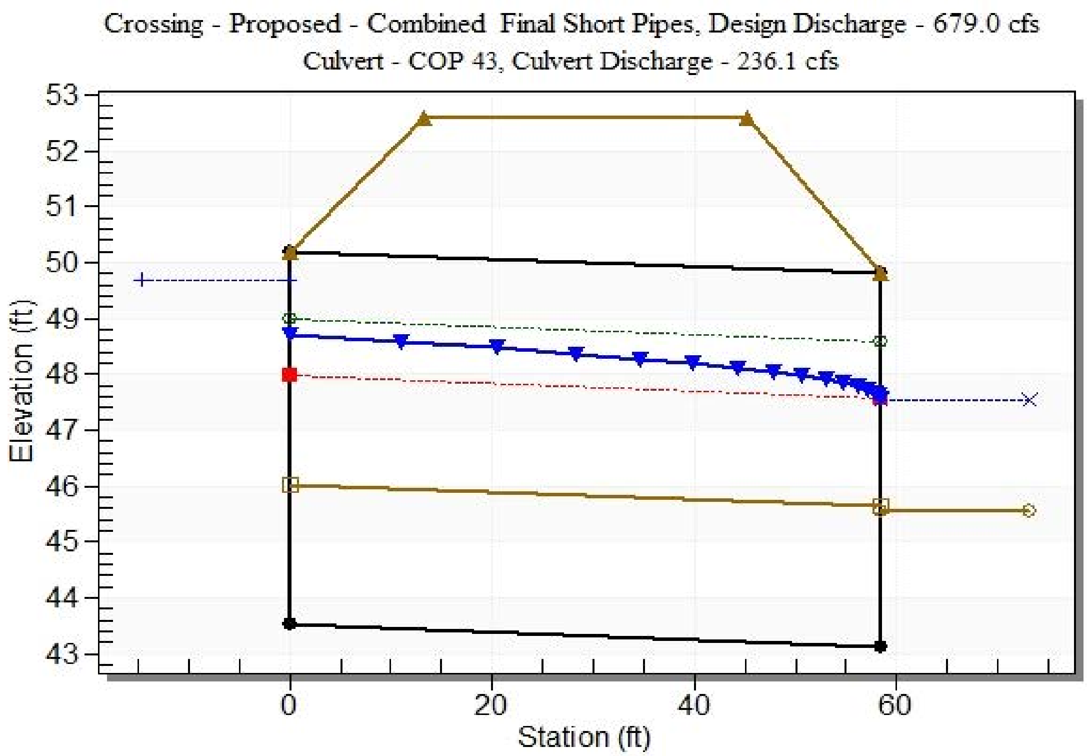
Culvert Length: 58.50 ft,    Culvert Slope: 0.0068

*********************************************************************************

## Culvert Performance Curve Plot: COP 43



## Water Surface Profile Plot for Culvert: COP 43




## Site Data - COP 43

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 43.53 ft

Outlet Station: 58.50 ft

Outlet Elevation: 43.13 ft

Number of Barrels: 1

## Culvert Data Summary - COP 43

Barrel Shape: Metal Box

Barrel Span: 16.50 ft

Barrel Rise: 6.67 ft

Barrel Material: Corrugated Aluminum

Embedment: 30.00 in

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

Manning's n: 0.0400 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

## Table 3 - Culvert Summary Table: COP 44

| Discharge Names | 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 Year | 208.00 | 49.35 | 47.77 | 1.127 | 1.316 | 2-M2c | 1.037 | 0.673 | 0.673 | 0.972 | 4.736 | 3.568 |
| 10 Year | 317.00 | 82.26 | 48.28 | 1.578 | 1.829 | 2-M2c | 1.431 | 0.963 | 0.963 | 1.256 | 5.515 | 4.207 |
| 50 Year | 589.00 | 168.19 | 49.36 | 2.596 | 2.913 | 2-M2c | 2.287 | 1.549 | 1.549 | 1.834 | 7.007 | 5.351 |
| 100 Year | 679.00 | 197.09 | 49.69 | 2.937 | 3.238 | 2-M2c | 2.554 | 1.720 | 1.720 | 2.002 | 7.398 | 5.652 |

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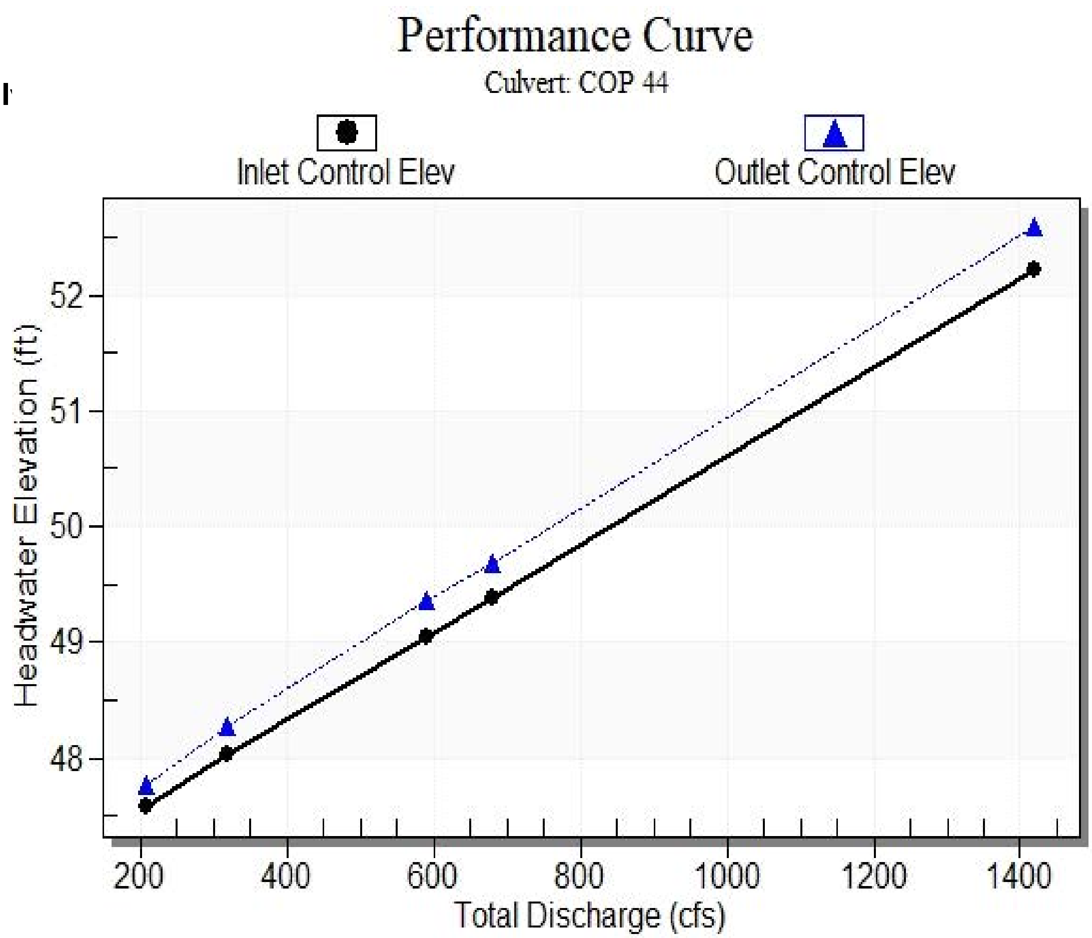
Straight Culvert

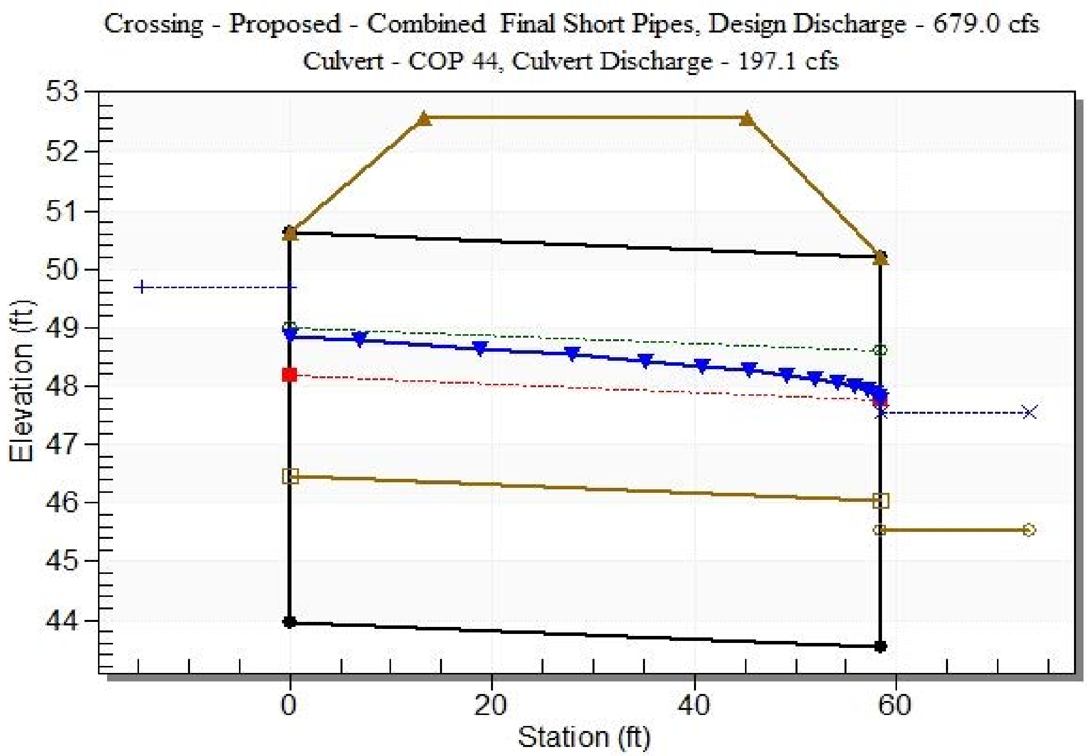
Inlet Elevation (invert): 46.45 ft, Outlet Elevation (invert): 46.05 ft

Culvert Length: 58.50 ft, Culvert Slope: 0.0068

**Cul**



**Water Surface Profile Plot for Culvert: COP 44**




**Site Data - COP 44**

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 43.95 ft

Outlet Station: 58.50 ft

Outlet Elevation: 43.55 ft

Number of Barrels: 1

**Culvert Data Summary - COP 44**

Barrel Shape: Metal Box

Barrel Span: 16.50 ft

Barrel Rise: 6.67 ft

Barrel Material: Corrugated Aluminum

Embedment: 30.00 in

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

Manning's n: 0.0400 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

## Table 4 - Culvert Summary Table: COP 45

| Discharge Names | 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 Year | 208.00 | 82.55 | 47.77 | 1.582 | 1.833 | 3-M2t | 1.434 | 0.965 | 0.972 | 0.972 | 5.484 | 3.568 |
| 10 Year | 317.00 | 121.29 | 48.28 | 2.045 | 2.350 | 3-M2t | 1.836 | 1.247 | 1.256 | 1.256 | 6.234 | 4.207 |
| 50 Year | 589.00 | 215.00 | 49.36 | 3.149 | 3.433 | 3-M2t | 2.728 | 1.817 | 1.834 | 1.834 | 7.566 | 5.351 |
| 100 Year | 679.00 | 245.71 | 49.69 | 3.498 | 3.758 | 3-M2t | 3.040 | 1.980 | 2.002 | 2.002 | 7.931 | 5.652 |

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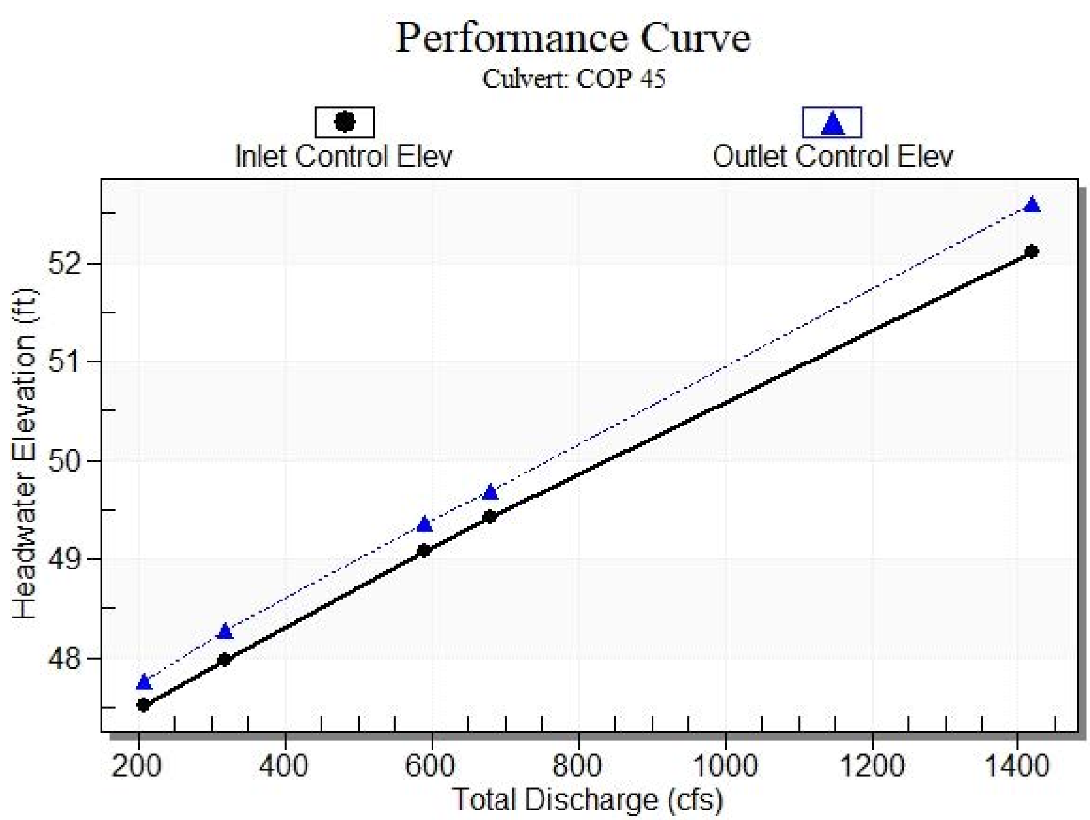
Straight Culvert

Inlet Elevation (invert): 45.93 ft, Outlet Elevation (invert): 45.53 ft

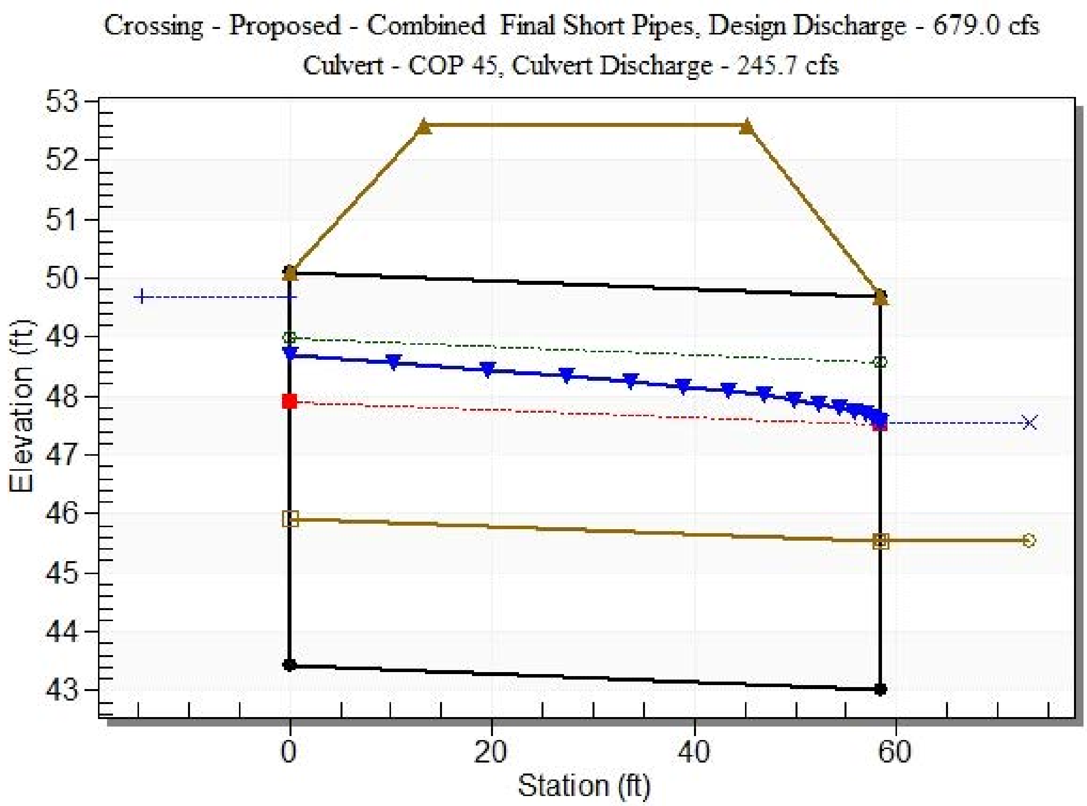
Culvert Length: 58.50 ft, Culvert Slope: 0.0068

*******************************************************************************

## Culvert Performance Curve Plot: COP 45



## Water Surface Profile Plot for Culvert: COP 45




## Site Data - COP 45

Site Data Option: Culvert Invert Data

Inlet Station: 0.00 ft

Inlet Elevation: 43.43 ft

Outlet Station: 58.50 ft

Outlet Elevation: 43.03 ft

Number of Barrels: 1

## Culvert Data Summary - COP 45

Barrel Shape: Metal Box

Barrel Span: 16.50 ft

Barrel Rise: 6.67 ft

Barrel Material: Corrugated Aluminum

Embedment: 30.00 in

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

Manning's n: 0.0400 (bottom)

Culvert Type: Straight

Inlet Configuration: Thin Edge Projecting

Inlet Depression: None

**Table 5 - Downstream Channel Rating Curve (Crossing: Proposed - Combined Final Short Pipes)**

| Flow (cfs) | Water Surface Elev (ft) | Depth (ft) | Velocity (ft/s) | Shear (psf) | Froude Number |
|---|---|---|---|---|---|
| 208.00 | 46.50 | 0.97 | 3.57 | 0.61 | 0.64 |
| 317.00 | 46.79 | 1.26 | 4.21 | 0.78 | 0.66 |
| 589.00 | 47.36 | 1.83 | 5.35 | 1.14 | 0.70 |
| 679.00 | 47.53 | 2.00 | 5.65 | 1.25 | 0.70 |

## Tailwater Channel Data - Proposed - Combined Final

Tailwater Channel Option: Rectangular Channel

Bottom Width: 60.00 ft

Channel Slope: 0.0100

Channel Manning's n: 0.0400

Channel Invert Elevation: 45.53 ft

## Roadway Data for Crossing: Proposed - Combined Final

Roadway Profile Shape: Constant Roadway Elevation

Crest Length: 1650.00 ft

Crest Elevation: 52.60 ft

Roadway Surface: Gravel

Roadway Top Width: 32.00 ft

# Appendix E: Substrate Calculations

**STREAMBED MATERIAL SIZING COP 43,44,45 (Worst Case Velocity/Depth)**

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=2C

| YELLOW ARE INPUTS | | |
|---|---|---|
| **Safety Factor** | **1.5** | |
| Stability Coefficient for Incipient Failure | 0.34 | (0.36 round rock, 0.3 angular rock) |
| Vertical Velocity Distribution Coeff | 1.00 | (1.0 for straight channels) |
| Blanket Thickness Coeff | 1 | (1xD100 or 1.5 or D50 max, whichever is greater) |
| Local depth of flow | 2 | 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 | 7.93 | ft/s from 100-year event avg. velocity in pipe |
| Side Slope correction factor | 1 | |
| Gravitational Acceleration | 32.2 | ft/s^2 |
| D85/D15 | 3.5 | (1.7-5.2) |
| D50/D30 | 2 | |

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

**Coarse Fraction**

| | | | | |
|---|---|---|---|---|
| D15 | 0.3 | ft | 5.0 | inches |
| D30 | 0.5 | ft | 7.0 | inches |
| D50 | 0.8 | ft | 10.0 | inches |
| D85 | 1.4 | ft | 17.0 | inches |
| D100 | 1.6 | ft | 20.0 | inches |

Using D50 size, used FHWA circular for Rip Rap design to spec out D100, D85 and D15.
D100 = 2.0D50
Then, used Fuller-Thompson to spec the fines starting with the D15 of the riprap.

| TABLE 1 | |
|---|---|
| COARSE MATERIAL (2 PARTS) | |
| SIZE | % PASSING |
| 20" | 100% |
| 17" | 80-90% |
| 10" | 45-55% |
| 7" | 25-35% |
| 5" | 10-20% |

**Fine Fraction**

**Fuller-Thompson Estimating for Maximum Density:**
**Method Adapted from US Forest Service Stream Simulation Guidelines**

| Particle Size | | Max. | | Percent |
|---|---|---|---|---|
| Sieve | mm | Size (mm) | Power n | Passing |
| 5 | 127 | 127 | 0.5 | 100.0% |
| 4 | 101.6 | 127 | 0.5 | 89.4% |
| 3 | 76.2 | 127 | 0.5 | 77.5% |
| 2 | 50.8 | 127 | 0.5 | 63.2% |
| 1.5 | 38.1 | 127 | 0.5 | 54.8% |
| 1 | 25.4 | 127 | 0.5 | 44.7% |
| 0.75 | 19.05 | 127 | 0.5 | 38.7% |
| 0.5 | 12.7 | 127 | 0.5 | 31.6% |
| #4 | 4.75 | 127 | 0.5 | 19.3% |
| #10 | 2.00 | 127 | 0.5 | 12.5% |
| #40 | 0.425 | 127 | 0.5 | 5.8% |
| #100 | 0.15 | 127 | 0.5 | 3.4% |
| #200 | 0.075 | 127 | 0.5 | 2.4% |

| TABLE 2 | |
|---|---|
| FINE MATERIAL (1 PART) | |
| SIEVE | % PASSING |
| 5" | 100% |
| 3.5" | 75-85% |
| 2.5" | 65-75% |
| 1.25" | 45-55% |
| 0.5" | 20-30% |
| #10 | 10% |
| #40 | 5% |

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# Appendix F: Bank Full Channel Calculations

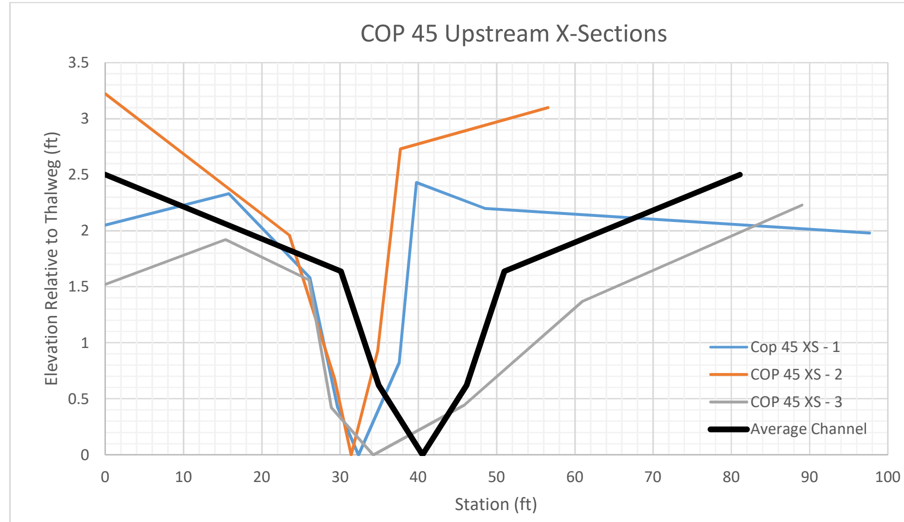
| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | COP 45 US XS-1 Station / Elevation | | | | US Thalweg El | 47.39 |
| PT Type | Length (ft) | Length (in) | Station | Elevation | Adjusted Elevation | DS Thalweg El | 46.63 |
| G | 0 | 0 | 0 | 49.18 | 2.05 | Distance | 123.9275 |
| G | 1 | 3.75 | 15.75 | 49.46 | 2.33 | **AVG Slope** | **0.006133** |
| ToB | 0 | 10.40625 | 26.15625 | 48.71 | 1.58 | | |
| EoW | 0 | 3.5 | 29.65625 | 47.56 | 0.43 | | |
| T | 0 | 2.6875 | 32.34375 | 47.13 | 0 | | |
| EoW | 0 | 5.1875 | 37.53125 | 47.95 | 0.82 | Bankfull Flow El | 1.58 |
| ToB | 0 | 2.21875 | 39.75 | 49.56 | 2.43 | Bankfull Flow (cfs) | 27 |
| G | 0 | 8.71875 | 48.46875 | 49.33 | 2.2 | Bankfull Velocity (fps) | 2.23 |
| G | 4 | 1.1875 | 97.65625 | 49.11 | 1.98 | | |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | COP 45 US XS-2 Station / Elevation | | | | US Thalweg El | 48.34 |
| PT Type | Length (ft) | Length (in) | Station | Elevation | Adjusted Elevation | DS Thalweg El | 47.39 |
| G | 0 | 0 | 0 | 50.78 | 3.22 | Distance | 84.75 |
| ToB | 1 | 11.538462 | 23.53846 | 49.52 | 1.96 | **AVG Slope** | **0.011209** |
| EoW | 0 | 5.75 | 29.28846 | 48.24 | 0.68 | | |
| T | 0 | 2.125 | 31.41346 | 47.56 | 0 | | |
| EoW | 0 | 3.40625 | 34.81971 | 48.49 | 0.93 | Bankfull Flow El | 1.96 |
| ToB | 0 | 2.875 | 37.69471 | 50.29 | 2.73 | Bankfull Flow (cfs) | 52 |
| G | 1 | 6.875 | 56.56971 | 50.66 | 3.1 | Bankfull Velocity (fps) | 3.98 |

| | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | COP 45 US XS-3 Station / Elevation | | | | US Thalweg El | 46.55 |
| PT Type | Length (ft) | Length (in) | Station | Elevation | Adjusted Elevation | DS Thalweg El | 46.24 |
| G | 0 | 0 | 0 | 47.92 | 1.52 | Distance | 40.09375 |
| G | 1 | 3.34375 | 15.34375 | 48.32 | 1.92 | **AVG Slope** | **0.007732** |
| ToB | 0 | 10.6875 | 26.03125 | 47.96 | 1.56 | | |
| EoW | 0 | 2.84375 | 28.875 | 46.82 | 0.42 | | |
| T | 0 | 5.34375 | 34.21875 | 46.4 | 0 | Bankfull Flow El | 1.37 |
| EoW | 0 | 11.5625 | 45.78125 | 46.84 | 0.44 | Bankfull Flow (cfs) | 70 |
| ToB | 1 | 3.1875 | 60.96875 | 47.77 | 1.37 | Bankfull Velocity (fps) | 2.52 |
| G | 2 | 4.0625 | 89.03125 | 48.63 | 2.23 | | |

**COP 45 Average BFW Cross Section**

| | Width | Depth | | Station | Elevation | | |
|---|---|---|---|---|---|---|---|
| | | | | | | **AVG Slope** | **0.008** |
| Ground | 81.09 | 2.50 | G | 0.00 | 2.50 | | |
| BF El | 20.90 | 1.64 | TOB | 30.09 | 1.64 | | |
| EOW | 11.27 | 0.62 | EOW | 34.91 | 0.62 | Bankfull Flow El | 1.64 |
| | | | T | 40.54 | 0 | Bankfull Flow (cfs) | 51 |
| | | | EOW | 46.18 | 0.62 | Bankfull Velocity (fps) | 2.56 |
| | | | TOB | 50.99 | 1.64 | | |
| | | | Ground | 81.09 | 2.50 | | |




Note: Bankfull Flows calculated using HY-8 Tailwater rating curve calculator. Based on Manning's open channel flow with channel n = .05 and overbank n=.08

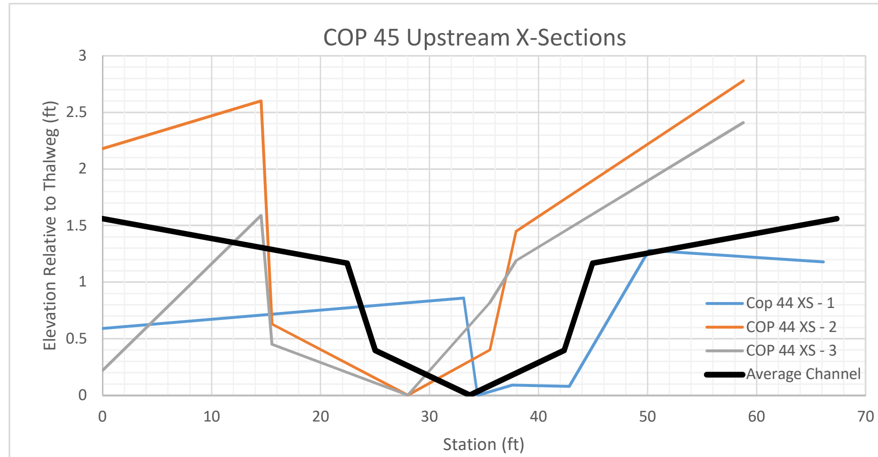
| COP 45 US XS-1 Station / Elevation | | | | | | US Thalweg El | 47.09 |
|---|---|---|---|---|---|---|---|
| PT Type | Length (ft) | Length (in) | Station (ft) | Elevation | Adjusted Elevation | DS Thalweg El | 46.9 |
| G | 0 | 0 | 0 | 48.13 | 0.59 | Distance | 54.28125 |
| ToB | 2 | 9.125 | 33.125 | 48.4 | 0.86 | **AVG Slope** | **0.0035** |
| EoW | 0 | 1.28125 | 34.40625 | 47.54 | 0 | | |
| T | 0 | 3.1875 | 37.59375 | 47.63 | 0.09 | | |
| EoW | 0 | 5.21875 | 42.8125 | 47.62 | 0.08 | | |
| ToB | 0 | 7.3125 | 50.125 | 48.82 | 1.28 | | |
| G | 1 | 4 | 66.125 | 48.72 | 1.18 | | |

| COP 44 US XS-2 Station / Elevation | | | | | | US Thalweg El | 47.2 |
|---|---|---|---|---|---|---|---|
| PT Type | Length (ft) | Length (in) | Station (ft) | Elevation | Adjusted Elevation | DS Thalweg El | 46.8 |
| G | 0 | 0 | 0 | 49.64 | 2.18 | Distance | 27.21875 |
| ToB | 1 | 2.53125 | 14.53125 | 50.06 | 2.6 | **AVG Slope** | **0.014696** |
| EoW | 0 | 1 | 15.53125 | 48.09 | 0.63 | | |
| T | 1 | 0.46875 | 28 | 47.46 | 0 | | |
| EoW | 0 | 7.53125 | 35.53125 | 47.86 | 0.4 | | |
| ToB | 0 | 2.40625 | 37.9375 | 48.91 | 1.45 | | |
| G | 1 | 8.84375 | 58.78125 | 50.24 | 2.78 | | |

| COP 45 US XS-3 Station / Elevation | | | | | | US Thalweg El | 47.97 |
|---|---|---|---|---|---|---|---|
| PT Type | Length (ft) | Length (in) | Station (ft) | Elevation | Adjusted Elevation | DS Thalweg El | 47.2 |
| G | 0 | 0 | 0 | 47.87 | 0.22 | Distance | 70.84375 |
| ToB | 1 | 3.9375 | 15.9375 | 49.24 | 1.59 | **AVG Slope** | **0.010869** |
| EoW | 0 | 0.71875 | 16.65625 | 48.1 | 0.45 | | |
| T | 0 | 11.21875 | 27.875 | 47.65 | 0 | | |
| EoW | 1 | 0.46875 | 40.34375 | 48.47 | 0.82 | | |
| ToB | 0 | 2.78125 | 43.125 | 48.84 | 1.19 | | |
| G | 2 | 10.03125 | 77.15625 | 50.06 | 2.41 | | |

**COP 44 Average BFW Cross Section**

| | Width | Depth | | Station | Elevation | | |
|---|---|---|---|---|---|---|---|
| | | | | | | **AVG Slope** | **0.010** |
| Ground | 67.35 | 1.56 | G | 0.00 | 1.56 | | |
| BF El | 22.53 | 1.17 | TOB | 22.41 | 1.17 | | |
| EOW | 17.36 | 0.40 | EOW | 24.99 | 0.40 | Bankfull Flow El | 1.17 |
| | | | T | 33.68 | 0 | Bankfull Flow (cfs) | 49 |
| | | | EOW | 42.36 | 0.40 | Bankfull Velocity (fps) | 2.61 |
| | | | TOB | 44.94 | 1.17 | | |
| | | | Ground | 67.35 | 1.56 | | |




Note: Bankfull Flows calculated using HY-8 Tailwater rating curve calculator. Based on Manning's open channel flow with channel n = .05 and overbank n=.08

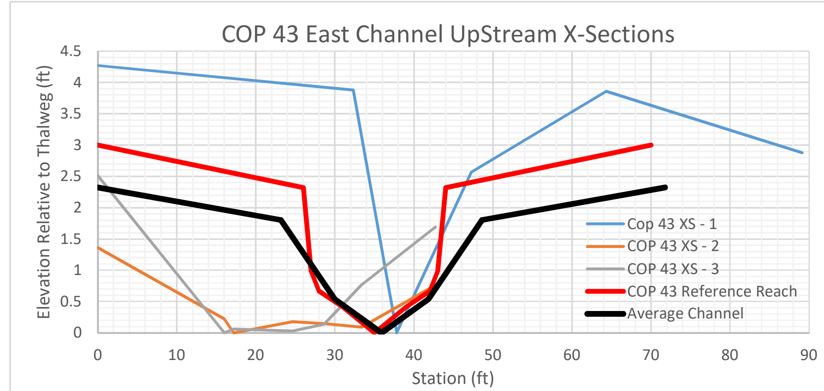
| COP 43 US XS-1 Station / Elevation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | US Thalweg El | 47.47 |
| PT Type | Length (ft) | Length (in) | Station (ft) | Elevation | Adjusted Elevation | DS Thalweg El | 46.81 |
| G | 0 | 0 | 0 | 48.73 | 4.27 | Distance | 91.90625 |
| EoV | 2 | 8.34375 | 32.34375 | 48.34 | 3.88 | **AVG Slope** | **0.007181** |
| CH | 0 | 5.5 | 37.84375 | 44.46 | 0 | | |
| CH | 0 | 9.46875 | 47.3125 | 47.03 | 2.57 | | |
| EoV | 1 | 5.03125 | 64.34375 | 48.32 | 3.86 | | |
| G | 2 | 0.78125 | 89.125 | 47.34 | 2.88 | | |

| COP 43 US XS-2 Station / Elevation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | US Thalweg El | 47.47 |
| PT Type | Length (ft) | Length (in) | Station (ft) | Elevation | Adjusted Elevation | DS Thalweg El | 46.81 |
| G | 0 | 0 | 0 | 48.51 | 1.36 | Distance | 91.90625 |
| EoV | 1 | 4.03125 | 16.03125 | 47.37 | 0.22 | **AVG Slope** | **0.007181** |
| CH | 0 | 1.15625 | 17.1875 | 47.15 | 0 | | |
| CH | 0 | 7.4375 | 24.625 | 47.33 | 0.18 | | |
| CH | 0 | 4.03125 | 28.65625 | 47.3 | 0.15 | | |
| CH | 0 | 4.78125 | 33.4375 | 47.24 | 0.09 | | |
| EoV | 0 | 9.28125 | 42.71875 | 47.91 | 0.76 | | |
| G | 1 | 11.84375 | 66.5625 | 48.38 | 1.23 | | |

| COP 43 US XS-3 Station / Elevation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | US Thalweg El | 47.47 |
| PT Type | Length (ft) | Length (in) | Station (ft) | Elevation | Adjusted Elevation | DS Thalweg El | 46.81 |
| G | 0 | 0 | 0 | 49.95 | 2.51 | Distance | 91.90625 |
| EoV | 1 | 8.65625 | 20.65625 | 47.44 | 0 | **AVG Slope** | **0.007181** |
| CH | 0 | 4.1875 | 24.84375 | 47.5 | 0.06 | | |
| CH | 0 | 3.40625 | 28.25 | 47.47 | 0.03 | | |
| CH | 0 | 6.4375 | 34.6875 | 47.58 | 0.14 | | |
| EoV | 0 | 3.6875 | 38.375 | 48.21 | 0.77 | | |
| G | 1 | 9.28125 | 59.65625 | 49.13 | 1.69 | | |

| COP 43 US Reference Reach Station / Elevation | | | | | | | |
|---|---|---|---|---|---|---|---|
| | | | | | | US Thalweg El | 47.47 |
| | Width | Depth | | Station | Elevation | DS Thalweg El | 46.81 |
| Ground | 70.00 | 3.00 | Ground | 0.00 | 3.00 | Distance | 91.90625 |
| BFW | 18.00 | 2.32 | BFW | 26.00 | 2.32 | **AVG Slope** | **0.007181** |
| TOE | 16.00 | 0.99 | TOE | 27.00 | 0.99 | | |
| HW | 14.00 | 0.67 | OHW | 28.00 | 0.67 | | |
| CH | 8.00 | 0.42 | CH | 31.00 | 0.42 | Bankfull Flow El | 2.32 |
| T | | 0.00 | T | 35.00 | 0.00 | Bankfull Flow (cfs) | 111 |
| | | | CH | 39.00 | 0.42 | Bankfull Velocity (fps) | 3.49 |
| | | | OHW | 42.00 | 0.67 | | |
| | | | TOE | 43.00 | 0.99 | | |
| | | | BFW | 44 | 2.32 | | |
| | | | Ground | 70 | 3.00 | | |

| **COP 43 Average BFW Cross Section** | | | | | | | |
|---|---|---|---|---|---|---|---|
| | Width | Depth | | Station | Elevation | **AVG Slope** | **0.007** |
| Ground | 71.78 | 2.32 | G | 0.00 | 2.32 | | |
| EOV | 25.47 | 1.80 | EoV | 23.16 | 1.80 | | |
| CH | 11.85 | 0.54 | EOW | 29.96 | 0.54 | Bankfull Flow El | 1.80 |
| | | | T | 35.89 | 0 | Bankfull Flow (cfs) | 69 |
| | | | EOW | 41.82 | 0.54 | Bankfull Velocity (fps) | 2.58 |
| | | | TOB | 48.63 | 1.80 | | |
| | | | Ground | 71.78 | 2.32 | | |




Note: Bankfull Flows calculated using HY-8 Tailwater rating curve calculator. Based on Manning's open channel flow with channel n = .05 and overbank n=.08

# Appendix G: USFWS Stream Gauging Findings

**Summary of Hydrology Data Collected for Cop 42, 43, 44 & 45 To date**
4/22/2019
Franklin Dekker, USFWS

Between 9/5/2018 to 3/18/2019, USFWS and Copper River Watershed Project collected flow measurements at sites COP42, 43, 44 and 45 and two pressure transducer gages recorded stage at COP42 and 44 (Table 1). This data summary report includes low flow observations and very tentative peak streamflow estimates. Prior to using the numbers in this report it should be noted that all correlations used are tentative at this point, especially for peak flow. A total of 6 flow measurements were used and a single high flow measurement collected on 12/7/2018 heavily influences all relationships. Confidence in low flow values is much greater than peak flow values.

**Low Flow Conditions**

The flow record from The COP42 gage proved useful for low flow observations, while the COP44 gage experienced a falling base level that resulted in considerable uncertainty in discharge (Figure 3, 4 & 5). The COP44 gage may have behaved differently due to downstream beaver activity or ice diverting flow away from this pipe. Given the issues with the COP44 gage, the flow measurements from the ungaged sites, COP 43 and COP45, were correlated to the COP42 gage to create a record of daily flow for all sites (Figure 6 ,7 & 8).

The lowest flows were observed in January, February and March (Figure 1) where flows <0.1 cfs were observed at all four sites (Figure 2). The lowest mean daily flows for the months of September and October may be a good low design flow for fish movement (Figure 2). Between COP42, 43 and 45 the lowest daily mean flow for the months of September and October ranged from 0.2 - 1 cfs, while COP44 had a higher low flow during those months at 1.2 cfs. Low flow fish passage channel design could potentially be 0.2 cfs for COP 45, and approximately 1 cfs for both COP43 and COP44.

**Peak flow Estimates**

To develop peak flow estimates, I took the sum of discharge for the 3 sites slated for replacement (COP43, 44, & 45) and correlated their combined flow to the USGS "Glacier River Trib" gage # 15215900 record (Figure 9, Table 2). Summing the 3 sites was meant to eliminate the problems caused by the shifting flow between sites. For comparison I also made peak flow estimates by summing all 4 sites investigated (COP42, 43, 44, 45) as it appears they are all related (Table 2). The USGS gage record provides 7 years of peak flows. I have low confidence in the peak flow estimates until data is collected on additional high flow events.

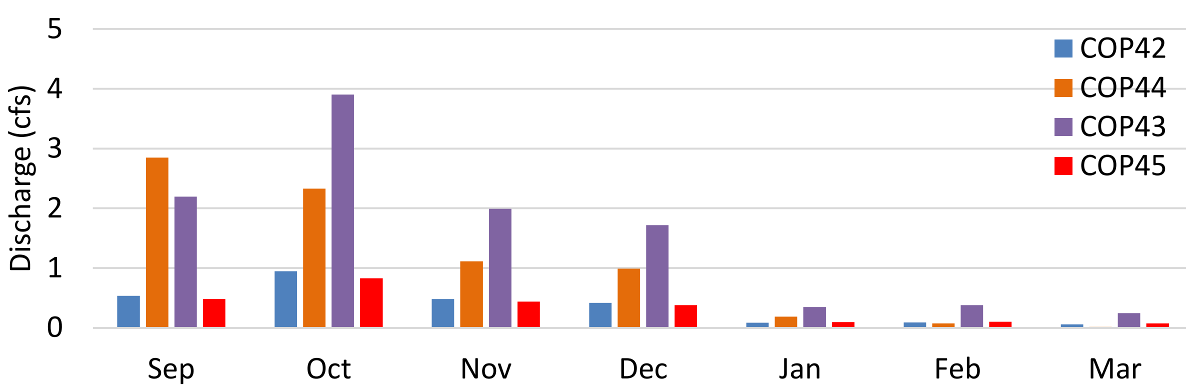


Figure 1. Average monthly discharge at COP 42, 43, 44 and 45 from mean daily discharge data.

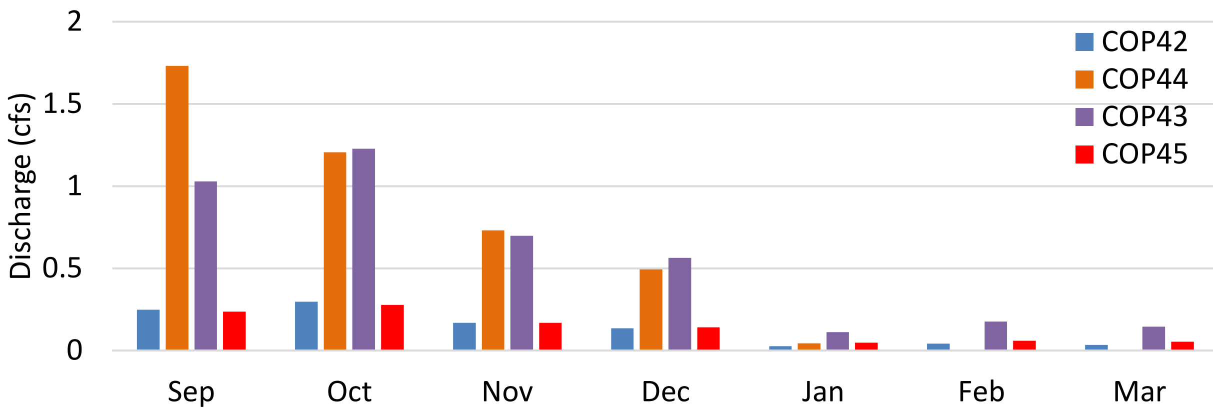
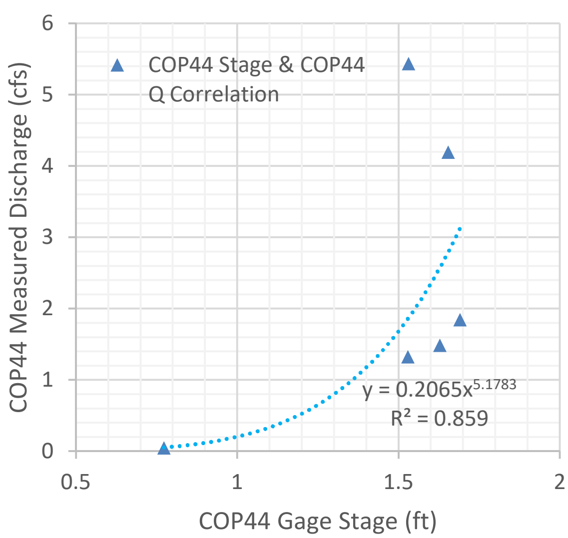


Figure 2. Lowest mean daily discharge at sites COP42, 43, 44 and 45 in each month.



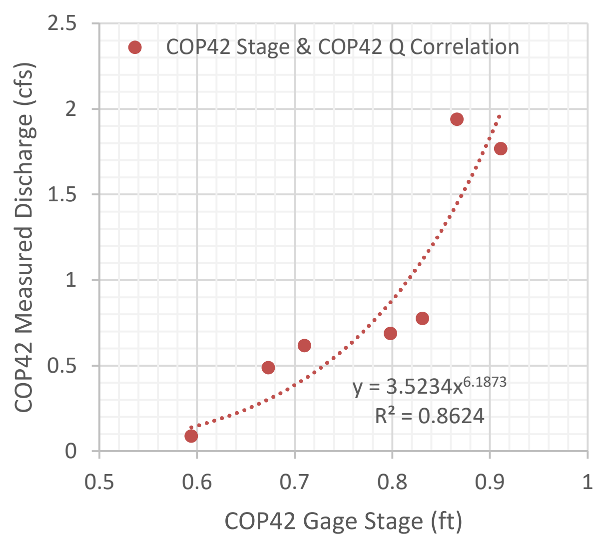



Figure 3. Correlations between the COP 42 and COP 44 gage stage (ft) to the measured discharge (cfs) at each site to create a record of continuous discharge (Figure 4 & 5).

Table 1. Flow measurements taken to date at COP 42, 43, 44 ,45.

| Site number | Measure # | Date | Time | Area (ft) | Width (ft) | Flow (cfs) | Gage Stage (COP42) | Gage Stage (COP44) | Method | # of stations | Team |
|---|---|---|---|---|---|---|---|---|---|---|---|
| COP44 | 1 | 9/5/2018 | 10:52 | 7.4 | 4.8 | 4.2 | | 1.65 | OTT | 17 | FD |
| COP44 | 2 | 10/9/2018 | 19:00 | 4.04 | 3.9 | 1.33 | | 1.53 | pygmy | 12 | FD |
| COP44 | 3 | 10/10/2018 | 17:33 | 4.39 | 3.55 | 1.85 | | 1.69 | pygmy | 18 | FD |
| COP44 | 4 | 10/11/2018 | 10:49 | 4.39 | 3.8 | 1.49 | | 1.63 | pygmy | 14 | FD |
| COP44 | 5 | 12/7/2018 | 10:00 | 5.21 | 3.94 | 5.44 | | 1.53 | OTT | 14 | KJ |
| COP44 | 6 | 3/18/19 | 10:00 | 1 | 3.94 | 0.05 | | 0.77 | estimate | | FD |
| COP42 | 1 | 9/5/2018 | 11:24 | 1.741 | 4 | 0.49 | 0.67 | | OTT | 12 | FD |
| COP42 | 2 | 10/9/2018 | 18:02 | 0.99 | 2.4 | 0.69 | 0.80 | | pygmy | 12 | FD |
| COP42 | 3 | 10/10/2018 | 16:34 | 1.06 | 2.55 | 0.78 | 0.83 | | pygmy | 14 | FD |
| COP42 | 4 | 10/11/2018 | 11:31 | 0.97 | 2.35 | 0.62 | 0.71 | | pygmy | 12 | FD |
| COP42 | 5 | 12/7/2018 | 11:15 | 4.52 | 3.28 | 1.77 | 0.91 | | OTT | 11 | KJ |
| COP42 | 6 | 12/7/2018 | 11:45 | 3.99 | 4.59 | 1.94 | 0.87 | | OTT | 15 | KJ |
| COP42 | 7 | 3/18/2019 | 10:23 | 0.15 | 1.5 | 0.09 | 0.59 | | pygmy | 3 | FD |
| COP43 | 1 | 9/5/2018 | 10:00 | | | 0 | | | estimate | | FD |
| COP43 | 2 | 10/9/2018 | 18:42 | 1.02 | 2.4 | 1.27 | 0.85 | 1.85 | pygmy | 14 | FD |
| COP43 | 3 | 10/10/2018 | 17:06 | 1.54 | 3.35 | 1.74 | 0.78 | 3.17 | pygmy | 17 | FD |
| COP43 | 4 | 10/11/2018 | 11:14 | 1.09 | 2.6 | 1.39 | 0.44 | 2.56 | pygmy | 12 | FD |
| COP43 | 5 | 12/7/2018 | 10:45 | 3.24 | 3.12 | 9.99 | 2.03 | 1.88 | OTT | 11 | KJ |
| COP43 | 6 | 3/18/2018 | 9:45 | 1.03 | 3.28 | 0.71 | 0.13 | 0.05 | OTT | 10 | KJ |
| COP45 | 1 | 9/5/2018 | 10:27 | 8.139 | 8.99 | 0.74 | 0.29 | 2.64 | OTT | 15 | FD |
| COP45 | 2 | 10/9/2018 | 19:18 | 0.54 | 3.2 | 0.10 | 0.87 | 1.86 | pygmy | 7 | FD |
| COP45 | 3 | 10/10/2018 | 18:11 | 1.15 | 2.2 | 0.34 | 0.80 | 3.13 | pygmy | 12 | FD |
| COP45 | 4 | 10/11/2018 | 11:52 | 1.13 | 2.3 | 0.21 | 0.44 | 2.58 | pygmy | 11 | FD |
| COP45 | 5 | 11/28/2018 | 10:15 | 4.24 | 3.61 | 0.71 | 0.65 | 1.52 | OTT | 11 | KJ |
| COP45 | 6 | 11/28/2018 | 10:45 | 2 | | 1.17 | 0.67 | 1.56 | OTT | 14 | KJ |
| COP45 | 7 | 12/7/2018 | 9:30 | 1.97 | 4.27 | 2.08 | 2.22 | 1.81 | OTT | 13 | KJ |
| COP45 | 8 | 3/18/2019 | 10:00 | | | 0.03 | 0.13 | 0.05 | estimate | | FD |

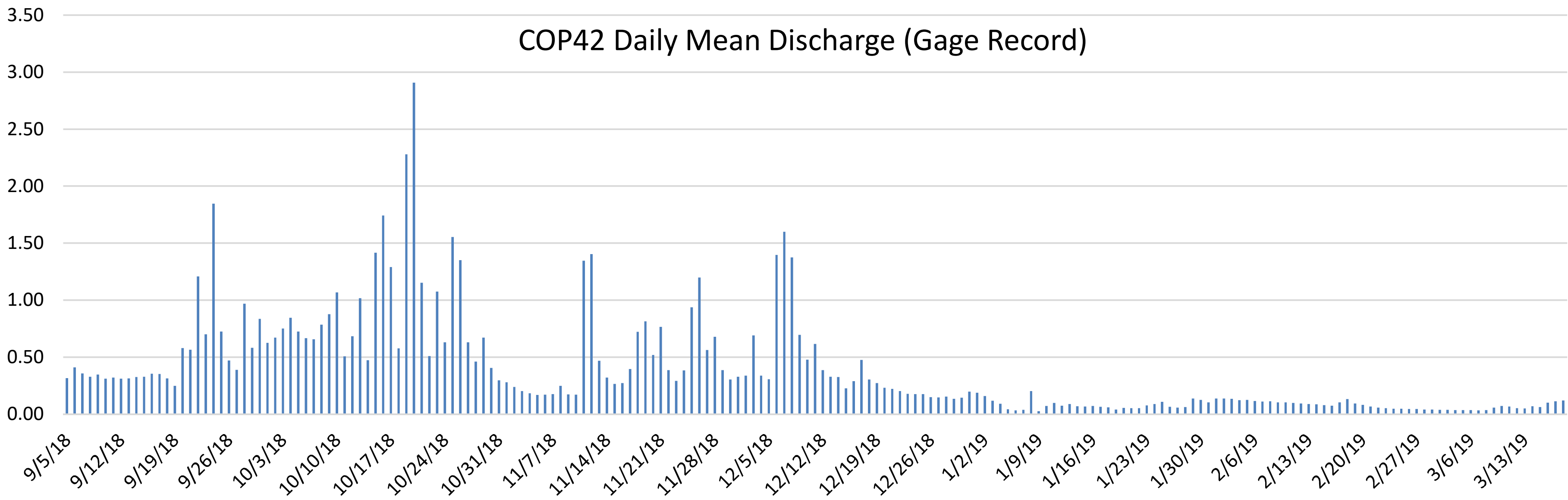



Figure 4. Mean daily discharge for COP42 derived from the COP42 pressure transducer gage and seven flow measurements. The gage indicated the highest daily mean flow was on 10/20/2018 (2.91 cfs) and the lowest was on 1/6/2019 (0.03 cfs).

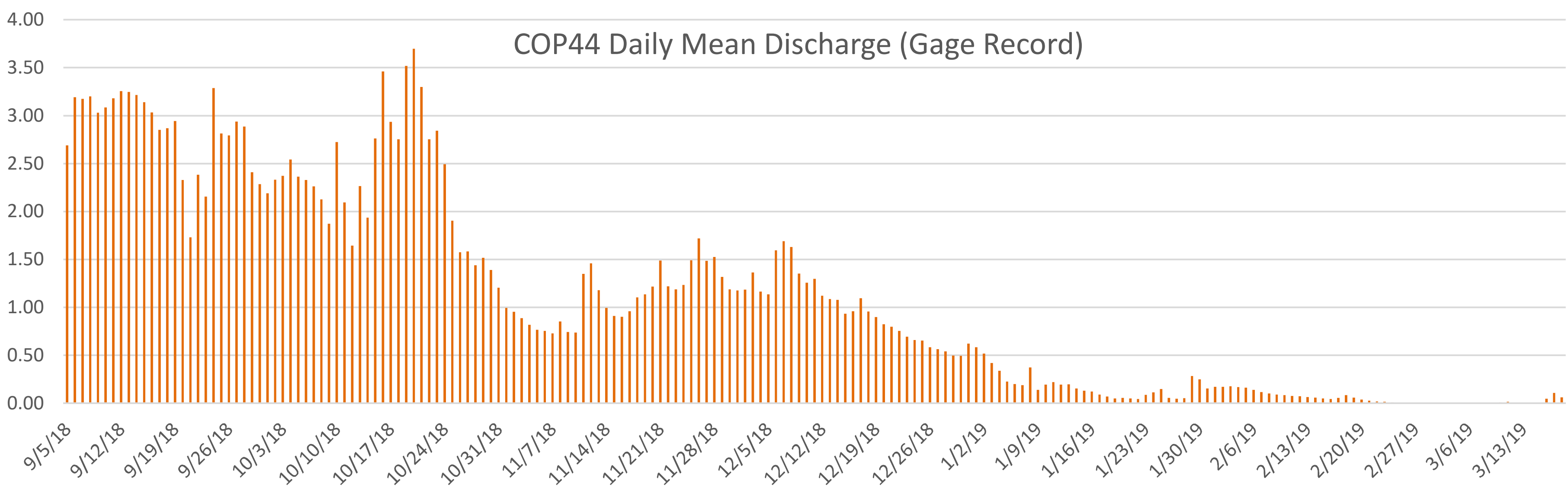



Figure 5. Mean daily discharge for COP44 derived from the COP44 pressure transducer gage and six flow measurements. The gage indicated the highest daily mean flow was on 10/20/2018 (3.70 cfs) and the lowest were in February and March (0.0 cfs).

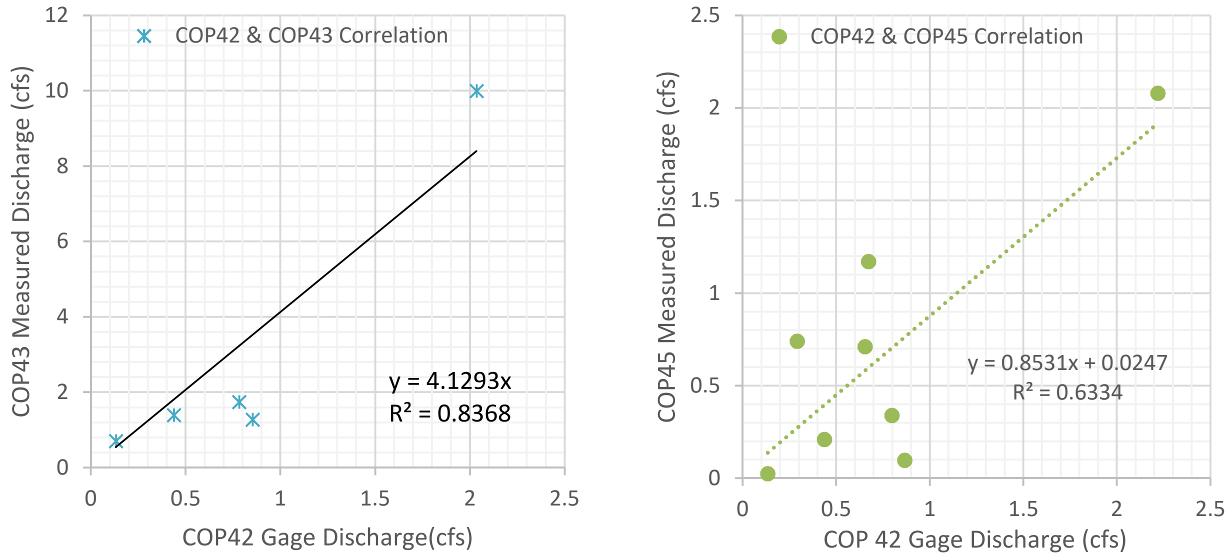



Figure 6. Correlations between the COP 42 gage discharge record and the flow measurements collected at COP43 and COP45. The regression equations were used to create continuous flow records for both ungaged sites (Figure 7 & 8).

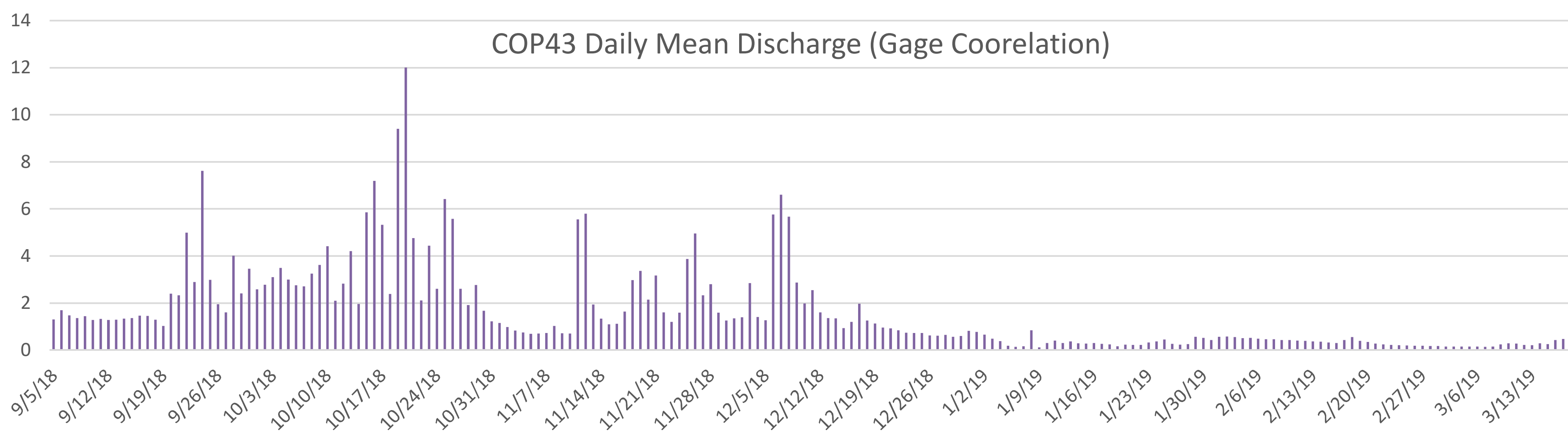



Figure 7. Mean daily discharge for COP43 derived from the COP42 pressure transducer gage record and the 6 flow measurements taken at COP43. Flow measurements ranged from 1.5 to 9.99 cfs (when flow was not blocked by beaver activity), but the gage correlation indicated the highest daily mean flow was on 10/20/2018 (11.8 cfs) and the lowest was on 1/9/2019 (0.6 cfs).

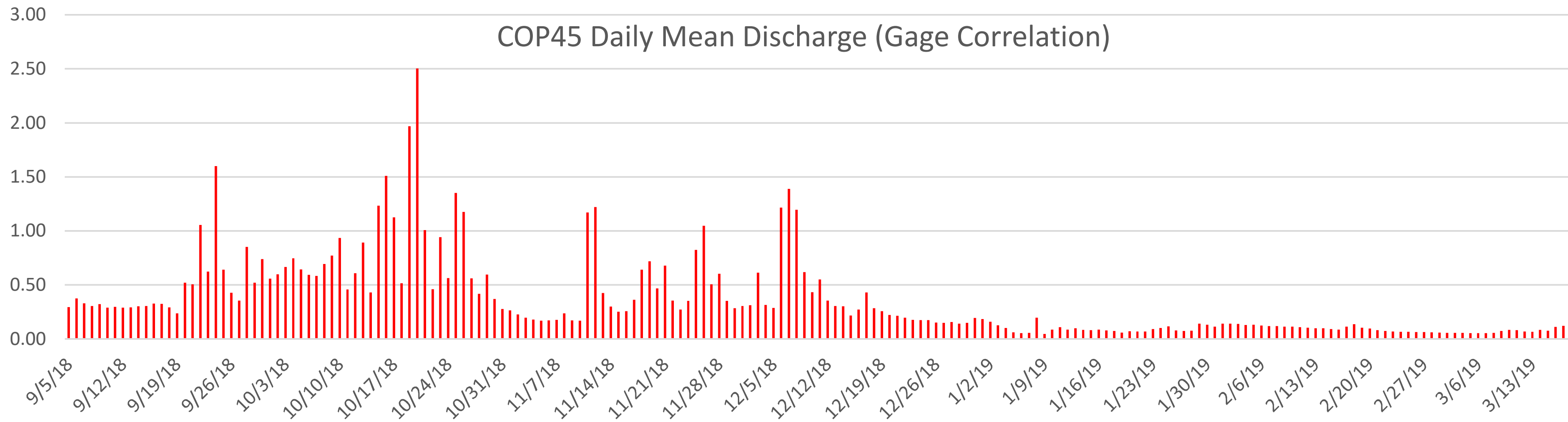



Figure 8. Mean daily discharge for COP45 derived from the COP42 pressure transducer gage record and the 8 flow measurements taken at COP45. Flow measurements ranged from 0.025 to 2.08 cfs, but the gage correlation indicated the highest daily mean flow was on 10/20/2018 (2.5 cfs) and the lowest was on 3/7/2019 (0.05 cfs).

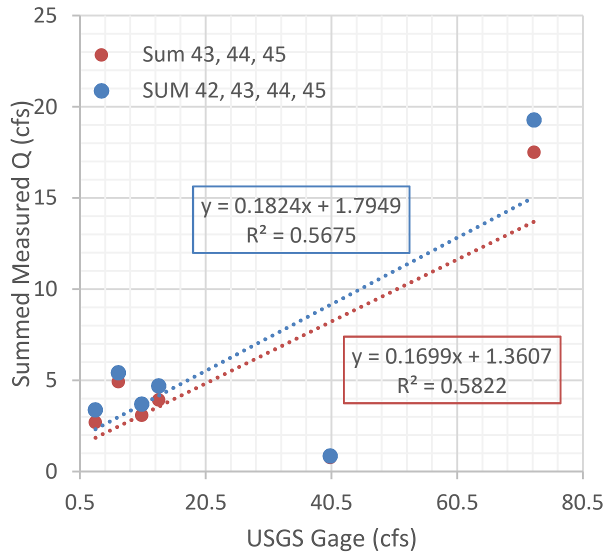


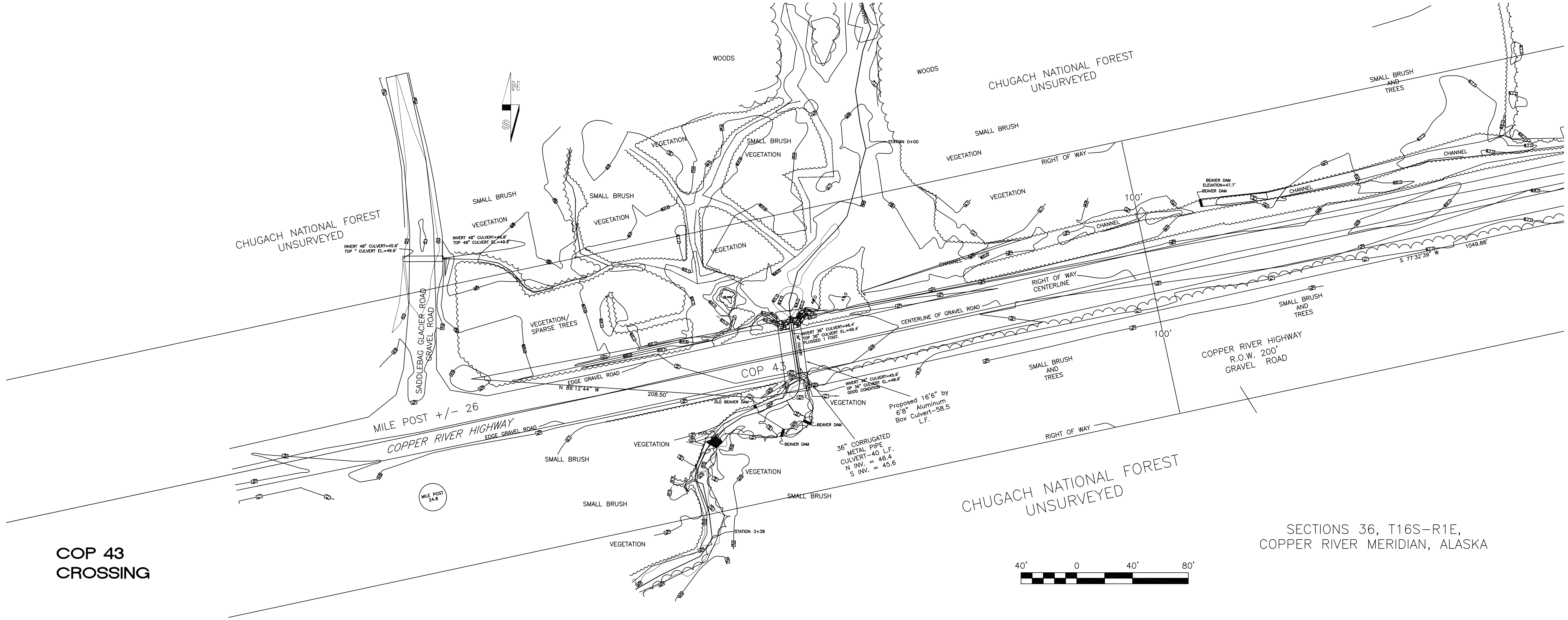

Figure 9. The correlation between the summed site discharges and the USGS Gage. Six flow measurements were included between 9/5/2018 to 3/18/2019. The relationship is strongly influenced by the single large flow measured on 12/7/2018. Also, if the observation from 3/18/2019, which plots below the trend line, is removed the $R^2$ improves to 0.9.

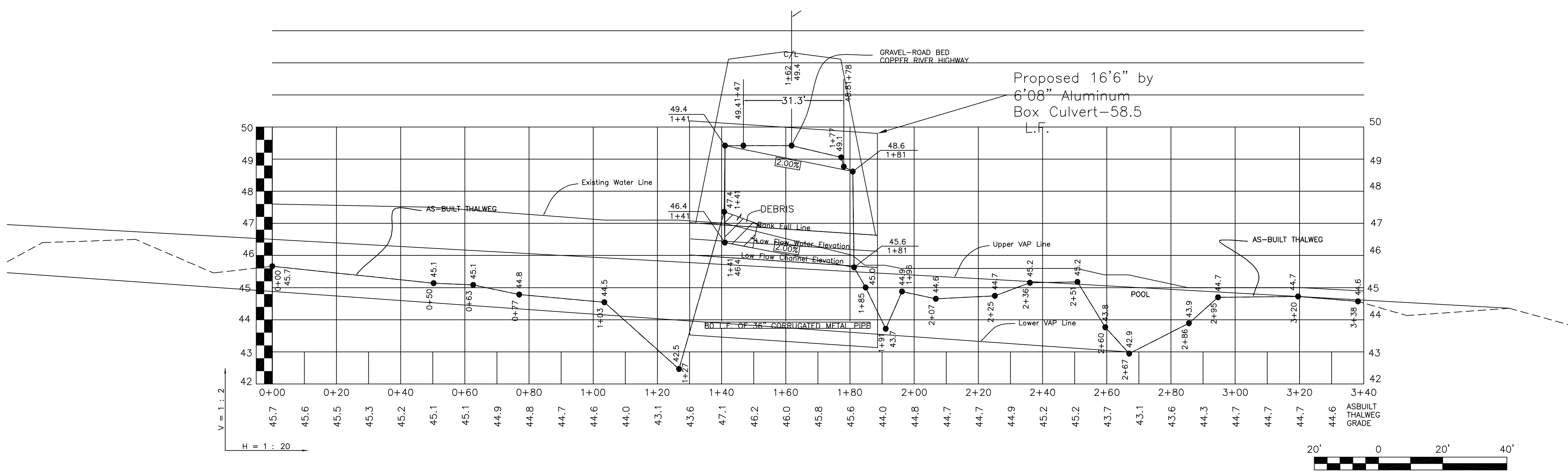
Table 2. Peak streamflow magnitude and frequency estimates based on the correlation between the sum of flow measurements to the USGS "Glacier River Trib" Gage # 15215900. The gage relationship is strongly influenced by the single large flow measured on 12/7/2018. Also, if the flow measurement from 3/18/2019 is removed from the gage correlation, the peak flow magnitudes increase by approximately 25%.

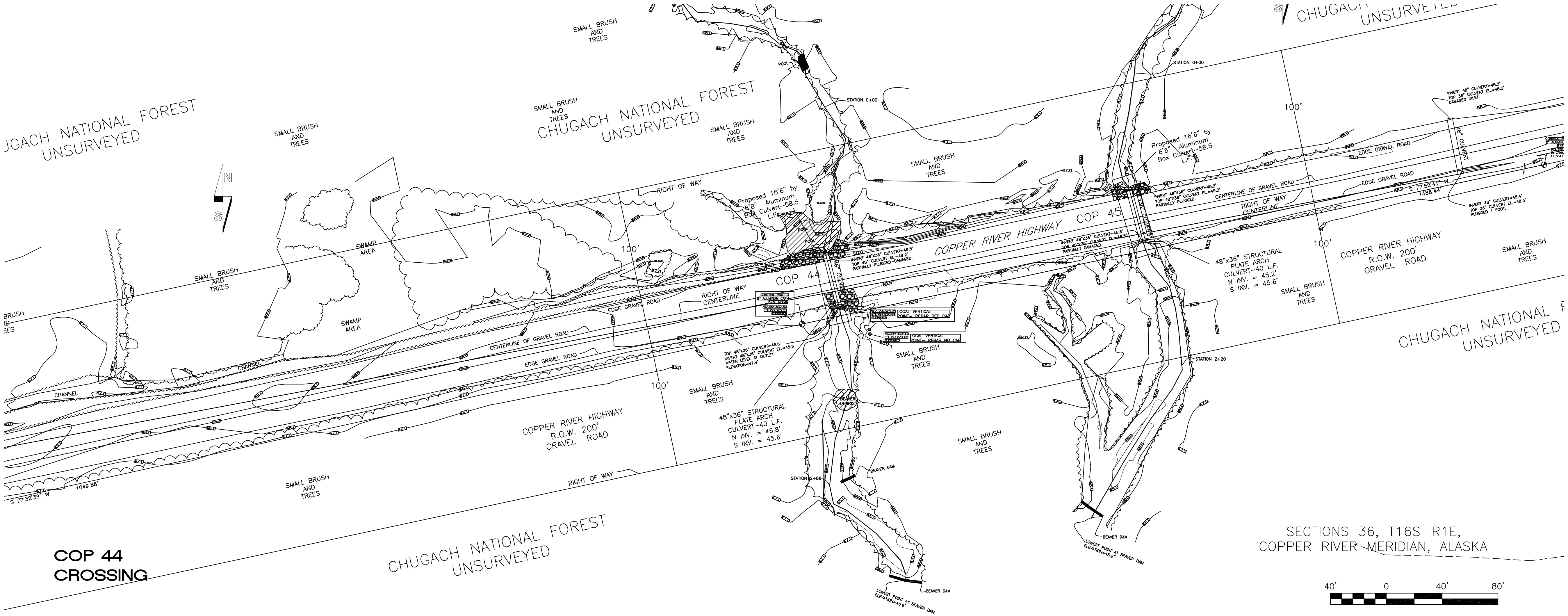
| RI | Sum of COP 43, 44, & 45 Q (cfs) | Sum of COP 42, 43, 44, & 45 Q (cfs) |
|---|---|---|
| 1.0001 | 45 | 48 |
| **2** | **73** | **79** |
| 5 | 82 | 89 |
| 10 | 88 | 95 |
| 20 | 93 | 100 |
| 25 | 94 | 101 |
| 40 | 97 | 104 |
| 50 | 98 | 106 |
| **100** | **102** | **110** |
| 200 | 106 | 114 |

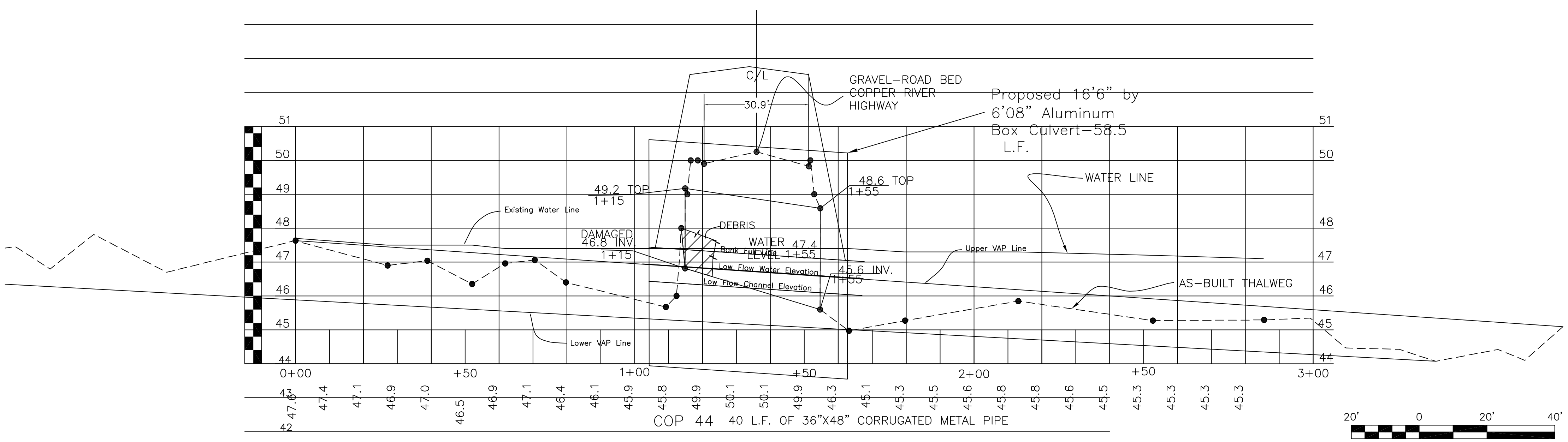
# Appendix H: Design Sketches

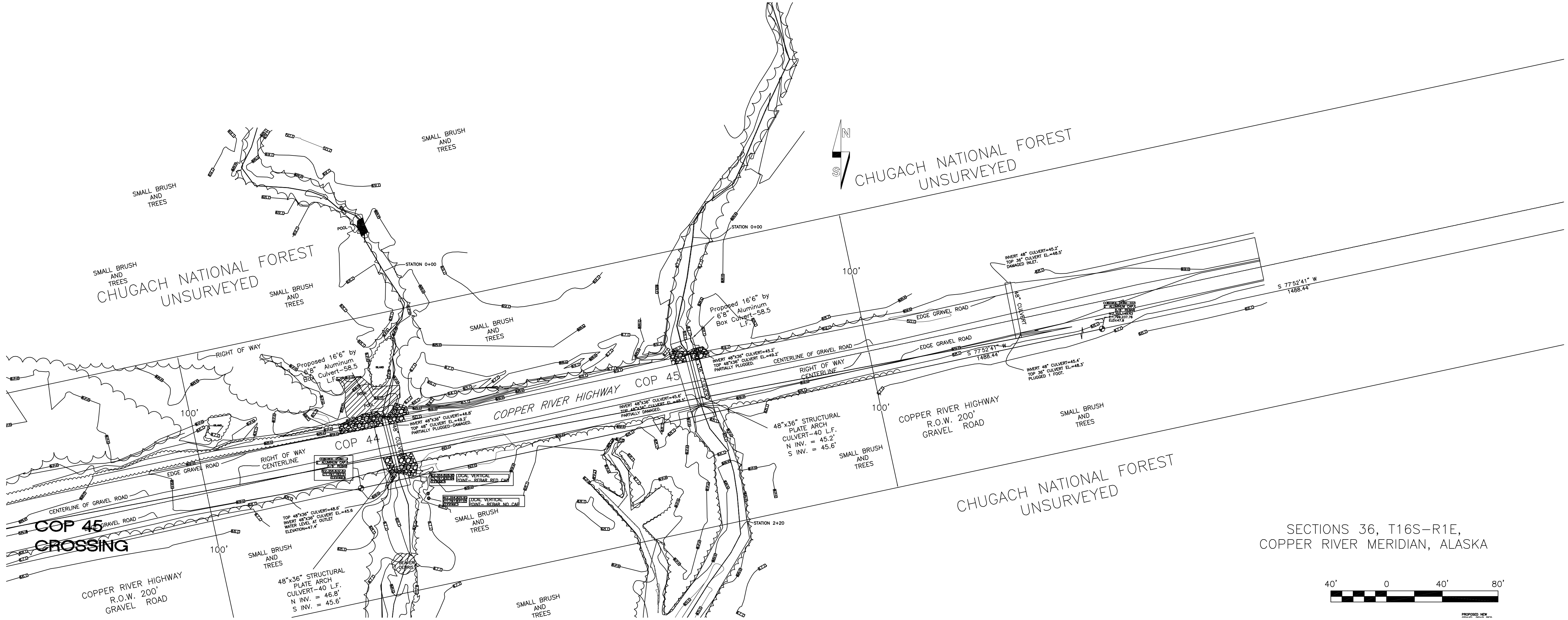
## COP 43 CROSSING

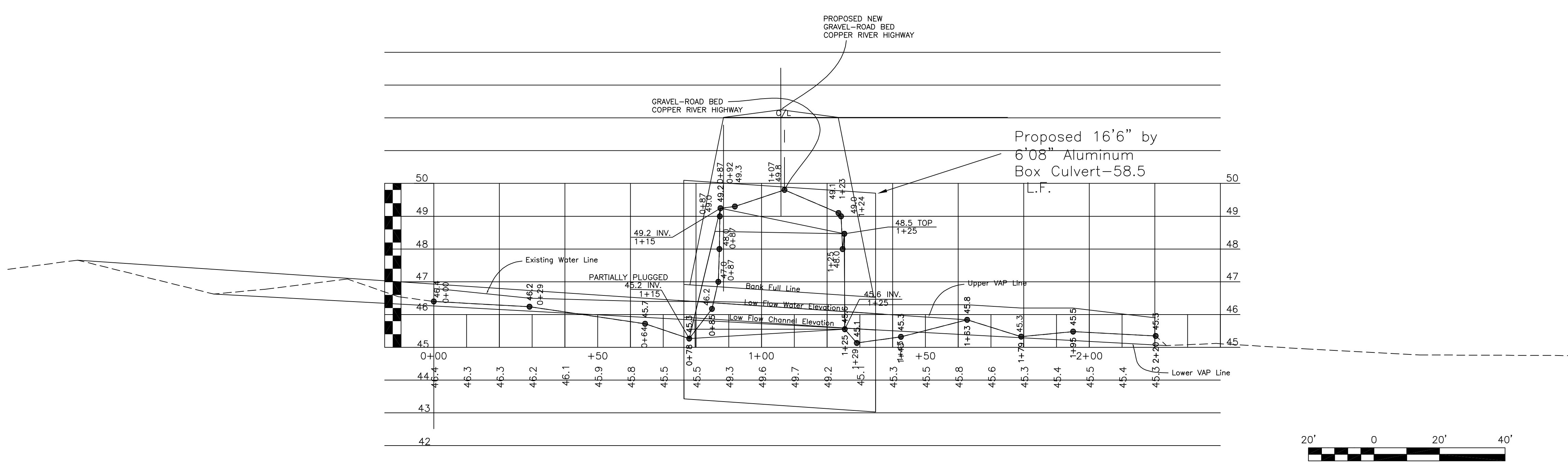


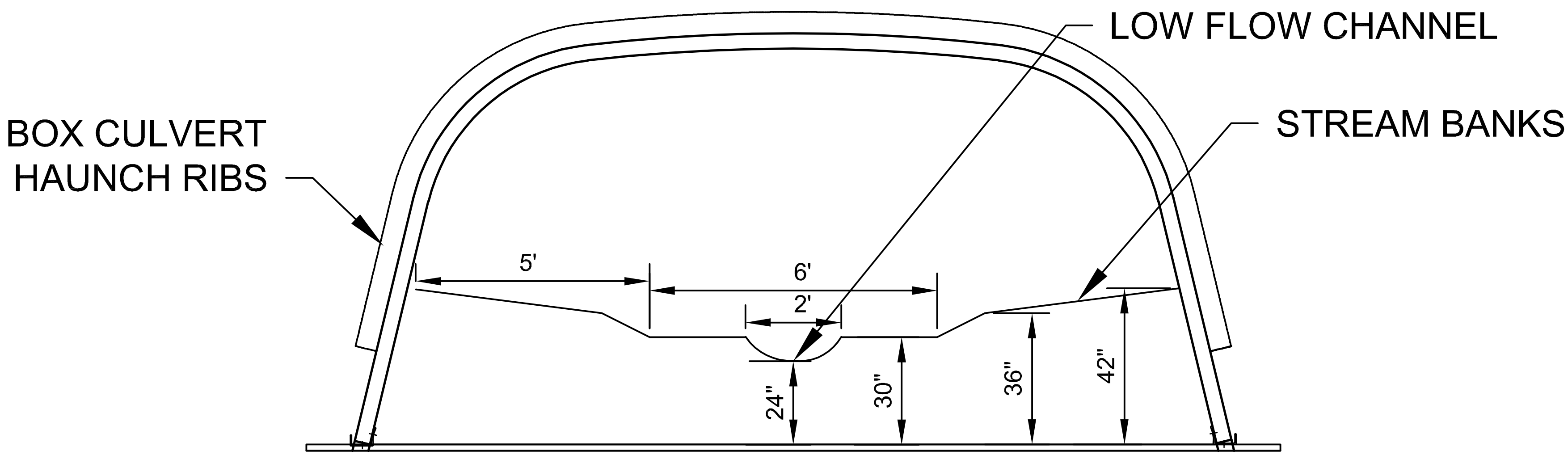




CHUGACH NATIONAL FOREST
UNSURVEYED
SMALL BRUSH AND TREES
SWAMP AREA
CHANNEL
COPPER RIVER HIGHWAY COP 45
COP 44
RIGHT OF WAY
RIGHT OF WAY CENTERLINE
EDGE GRAVEL ROAD
CENTERLINE OF GRAVEL ROAD
COPPER RIVER HIGHWAY
R.O.W. 200'
GRAVEL ROAD
100'
Proposed 16'6" by 6'8" Aluminum Box Culvert-58.5 L.F.
48"x36" STRUCTURAL PLATE ARCH CULVERT-40 L.F.
N INV. = 46.8'
S INV. = 45.6'
48"x36" STRUCTURAL PLATE ARCH CULVERT-40 L.F.
N INV. = 45.2'
S INV. = 45.6'
STATION 0+00
STATION 2+20
BEAVER DAM
LOCAL VERTICAL POINT- REBAR RED CAP
LOCAL VERTICAL POINT- REBAR NO CAP
S 77°32'39" W 1049.86
COP 44
CROSSING
SECTIONS 36, T16S-R1E,
COPPER RIVER MERIDIAN, ALASKA
40' 0 40' 80'


C/L
30.9'
GRAVEL-ROAD BED
COPPER RIVER HIGHWAY
Proposed 16'6" by 6'08" Aluminum Box Culvert-58.5 L.F.
WATER LINE
49.2 TOP 1+15
48.6 TOP 1+55
DEBRIS
DAMAGED 46.8 INV 1+15
WATER LEVEL 47.4 1+55
45.6 INV. 1+55
Existing Water Line
Bank Full Line
Low Flow Water Elevation
Low Flow Channel Elevation
Upper VAP Line
Lower VAP Line
AS-BUILT THALWEG
51
50
49
48
47
46
45
44
43
42
0+00
+50
1+00
+50
2+00
+50
3+00
47.6 47.4 47.1 46.9 47.0 46.5 46.9 47.1 46.4 46.1 45.9 45.8 49.9 50.1 50.1 49.9 46.3 45.1 45.3 45.5 45.6 45.8 45.8 45.6 45.5 45.3 45.3 45.3 45.3
COP 44 40 L.F. OF 36"X48" CORRUGATED METAL PIPE
20' 0 20' 40'


CHUGACH NATIONAL FOREST
UNSURVEYED
CHUGACH NATIONAL FOREST
UNSURVEYED
CHUGACH NATIONAL FOREST
UNSURVEYED
SMALL BRUSH AND TREES
COPPER RIVER HIGHWAY
COP 44
COP 45
COP 45 CROSSING
RIGHT OF WAY
CENTERLINE OF GRAVEL ROAD
EDGE GRAVEL ROAD
100'
STATION 0+00
STATION 2+20
Proposed 16'6" by 6'8" Aluminum Box Culvert-58.5 L.F.
48"x36" STRUCTURAL PLATE ARCH CULVERT-40 L.F. N INV. = 45.2' S INV. = 45.6'
48"x36" STRUCTURAL PLATE ARCH CULVERT-40 L.F. N INV. = 46.8' S INV. = 45.6'
COPPER RIVER HIGHWAY R.O.W. 200' GRAVEL ROAD
S 77°52'41" W 1488.44'
SECTIONS 36, T16S-R1E,
COPPER RIVER MERIDIAN, ALASKA
40' 0 40' 80'


PROPOSED NEW GRAVEL-ROAD BED COPPER RIVER HIGHWAY
GRAVEL-ROAD BED COPPER RIVER HIGHWAY
Proposed 16'6" by 6'08" Aluminum Box Culvert-58.5 L.F.
49.2 INV. 1+15
48.5 TOP 1+25
PARTIALLY PLUGGED 45.2 INV. 1+15
45.6 INV. 1+25
Existing Water Line
Bank Full Line
Low Flow Water Elevation
Low Flow Channel Elevation
Upper VAP Line
Lower VAP Line
0+00 +50 1+00 +50 2+00
42 43 44 45 46 47 48 49 50
20' 0 20' 40'


LOW FLOW CHANNEL
STREAM BANKS
BOX CULVERT
HAUNCH RIBS
5'
6'
2'
24"
30"
36"
42"