Smokerise/Penstock Wash Stream Capacity & Stabilization

Final Presentation

CENE 486

Harth Beaty, Briana Pilling, Haile Nelson, Qixuan Yang

5/1/26

Figure 1: Project Location Map

Introduction

Location

Flagstaff, AZ

Forest Service, US HWY-89 & E Trails End Drive

Client

Chase McLeod (City of Flagstaff Stormwater Engineer)

Technical Advisor

Owen Allen (Remal Consulting)

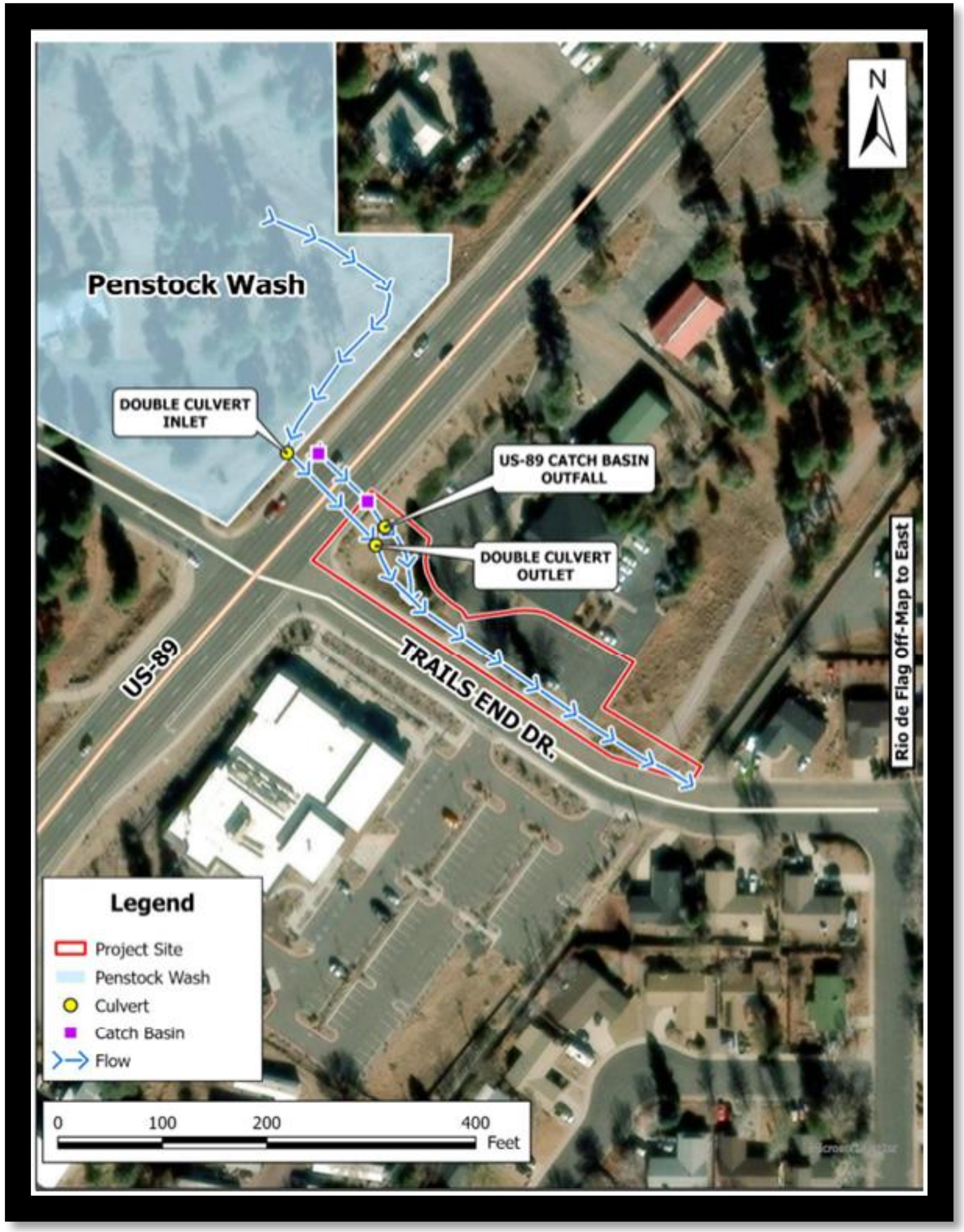


Figure 2: Project Site Map

Problem Statement

Problem

- Recurring flooding at East Trails End Drive
- Sediment buildup in the culverts and overtopping at the parking lot crossing
- Overgrown vegetation and channel instability reduce capacity

Project Objectives

- Improve stormwater conveyance
- Reduce flooding risk
- Improve hydraulic performance and channel stability
- Meet City of Flagstaff, Coconino County, and FEMA criteria

Figure 3: Penstock Wash Data

Due Diligence

Research

- Compiled all available background information
  - City of Flagstaff Stormwater Management Design Manual, FEMA Flood Maps, Drainage Documentation
- Identification of Known Issues
  - Drainage deficiencies
  - Flooding concerns
  - Sediment accumulation

Requirement Category	Design Criteria	Technical Specifications	Regulatory Standard	Maintenance Considerations
Open Channel Design	Conveyance of 25-year and 100-year storm events.	Min 0.5% slope; Max velocity 18 ft/s; Min 1 ft freeboard; Side slopes 3H:1V (natural) or 2H:1V (riprap).	City of Flagstaff 2025 Stormwater Management Design Manual Section 5.3.7	12-ft min maintenance access road; soil-cement linings prohibited for public channels.
Hydrologic Modeling	Selection of modeling method based on area and routing needs.	Rational Method or Unit Hydrograph for larger catchments.	City of Flagstaff 2025 Stormwater Management Design Manual Section 4.0 and SCS (NRCS) Standards	Accounting for land use changes and soil hydrologic groups.

Table 1: Regulatory Requirements [1]

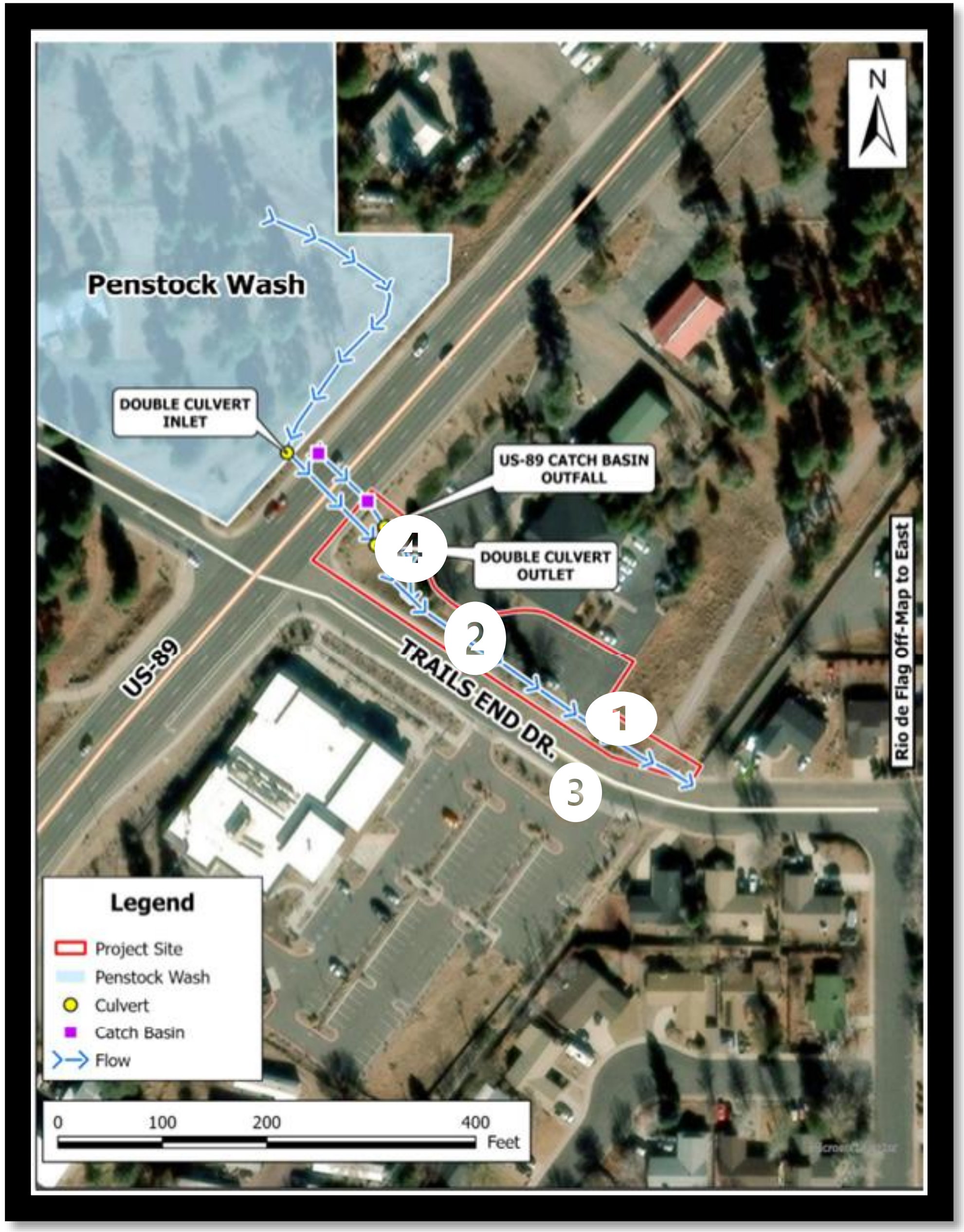


Figure 4: Site Investigation Photo Locations

Site Investigation

Site Investigation

- Verify existing conditions
  - Conveying runoff inadequately
    - Document drainage features
    - Field observations
    - Foliage & debris buildup along direct runoff of HWY 89

- #1 shows sediment buildup at the culvert entrance
- #2 shows the deteriorated state of the culvert under the parking lot
- #3 shows the area where the survey station was placed
- #4 shows the overrun condition of the drainage path in-between Highway 89 and the Parking Lot

Photos & Survey Data Collection

1 **Culvert Condition**
Sediment buildup

2 **Culvert Under Parking Lot**

3 **Survey Data Collection**
GPS/Total Station

4 **Existing Channel & Drainage Path**

Figure 5: Site Visit

Survey Data Collection

- Channel Geometry
- Culvert Inlets and Outlets
- Roadway Crossings
- Drainage Paths

Survey Tools

- Total Station
- GPS Data Collection

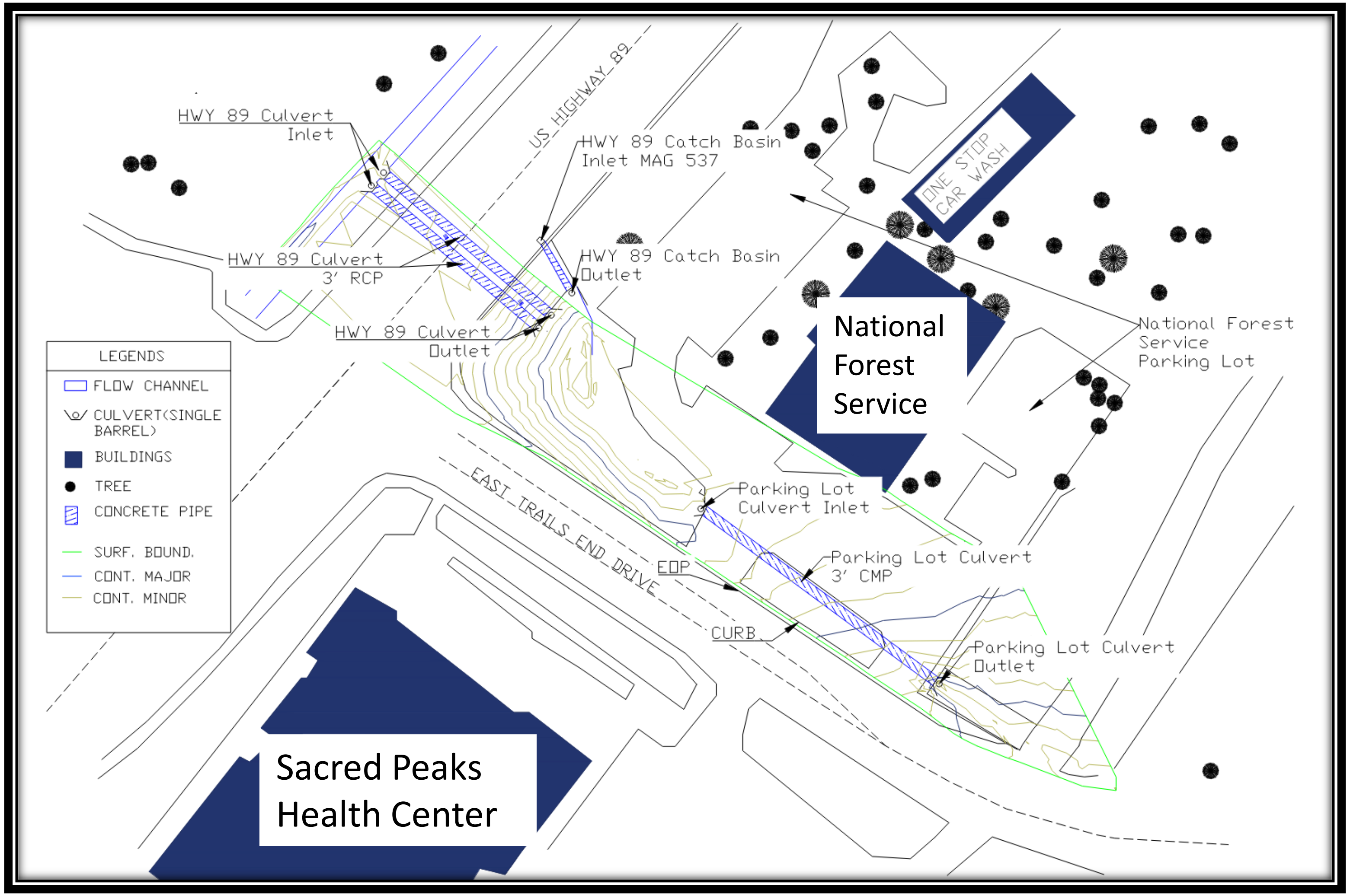


Figure 6: Smokerise Neighborhood Topographic Map

Data Processing & Base Mapping

- Field and survey data processed in Civil 3D
- Preliminary topographic base map was developed
  - Delineated watershed boundaries
  - Identify drainage divides
  - Locate existing infrastructure
  - Define channel alignments
- Geometric foundation for later modelling and development of alternatives

Hydrologic Analysis

- Watershed Delineation
  - HEC-HMS to identify flow paths & contributing area (NRCS TR-55)
- Hydrologic Parameters
  - Land-Use Classifications
- Time of Concentration
  - Manning's Roughness Coefficients
- Design Storm and Rainfall Data
  - NOAA Atlas 14 and Stream Stats, 10-year and 100-year storm events selected

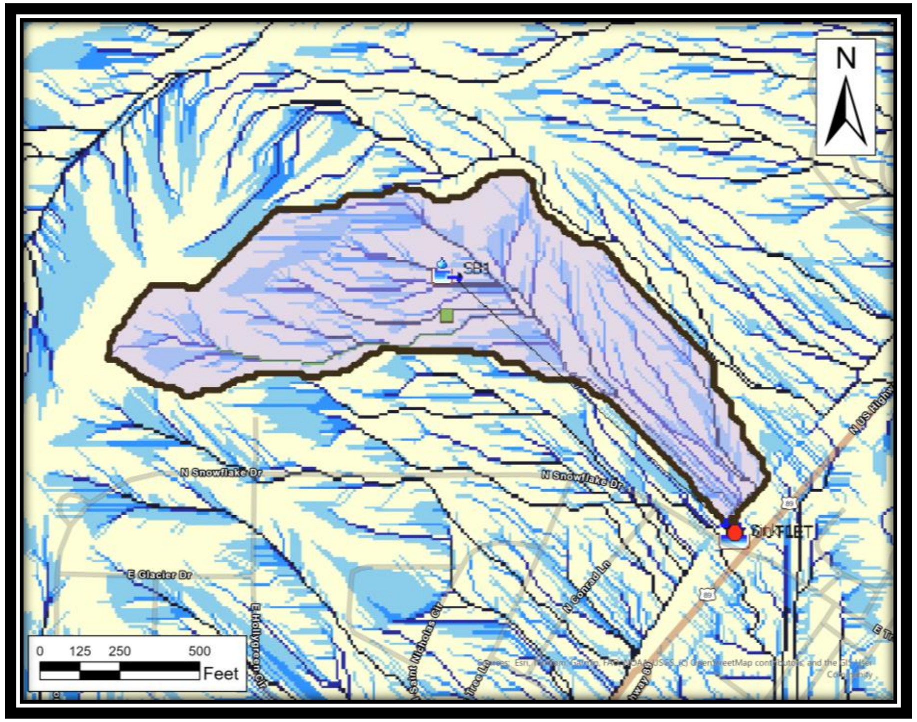


Figure 7: Delineated Penstock Watershed

Equation 1: Time of Concentration

$$T_c = C_t * (\frac{L * L_c}{\sqrt{S}})^{0.3}$$

Where:

T = Time of Concentration
L = Length of Flow Path
L_c= Length of Centroidal Flow Path
S = 10-85 Flow Path Slope
C_t= Empirical Coefficient of 2.2

Soil Type / Description	% of Area	Slope	Drainage Class	Soil Group	Infiltration	Flooding Potential	Considerations
Paymaster fine sandy loam	0.30%	0–3%	Well drained	B	Moderate to high	Rare	Minimal influence due to small coverage
Mixed mountainous soils	21.90 %	0–55%	Well drained	B&C/D	Very low to moderate	None to rare	Some areas promote runoff due to shallow soils and slope
Mountain slope soils	77.80 %	8–75%	Well drained	C/D	Very low to moderate	None	Increase runoff potential

Table 2: Soil Parameters [3]

Hydrologic Analysis

Figure 8: Different Basins of Smokerise Neighborhood

Table 3: Culvert Master Inputs

Culvert Master Inputs	Value
Manning's	0.024
Ke	0.50
Invert Upstream (ft)	6905.31
Invert Downstream (ft)	6901.72
Length (ft)	122.07
Allowable HW (ft)	6911.19
Tailwater Elevation (ft)	6901.72

Table 4: Culvert Master Outputs

Culvert Master Outputs	Value
Slope	0.029
Discharge (cfs)	53.71
Velocity (ft/s)	9.00
Depth (ft)	1.81

Additional Flow Calculations

- Highway 89 runoff contributes 4-6 cfs that was added to existing flow rates
- Full watershed flow doesn't go to Smokerise Neighborhood
- Majority of the flow continues downstream along highway
- Culvert Master analysis
  - Better idea of existing double barrel culvert capacity
  - Convey 53 cfs without overtopping 89
- 10- & 100-year storm decreased

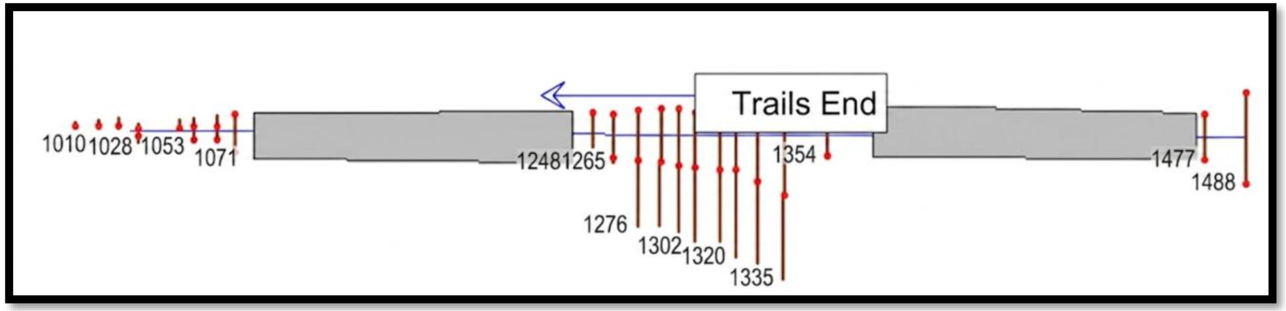
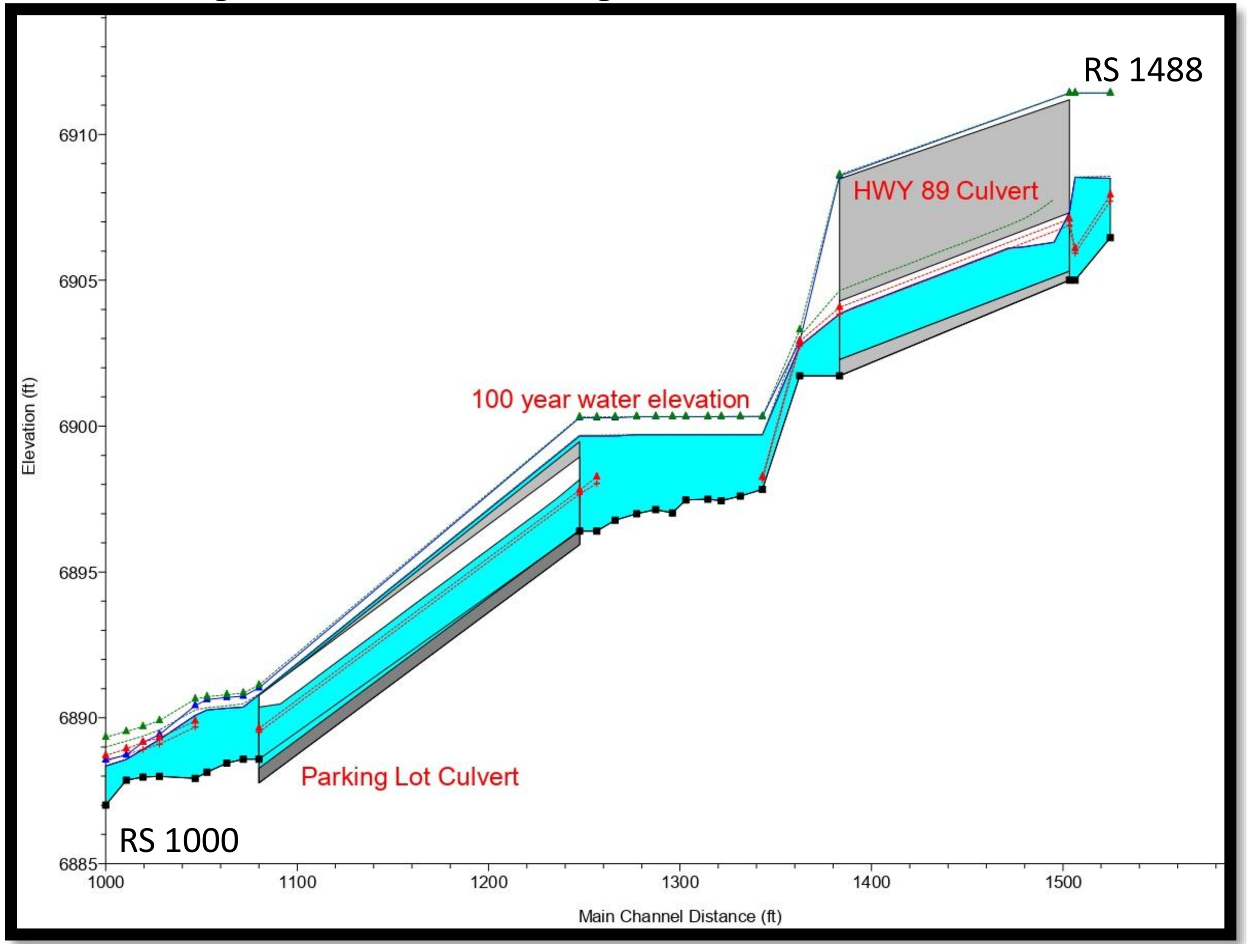


Figure 9: River Stationing of East Trails End Drive



Hydraulic Analysis

Existing Drainage Infrastructure Overview

- Combination of engineered conveyance structures and natural drainage features
- Multiple roadway culverts conveying flow near East Trails End Dr and National Park Service Parking Lot
- Open, unlined channel transitions through vegetated and overgrown areas
- Project focused on double barrel culverts under HWY 89 and single barrel culvert under parking lot
- First cross section is labelled 1488 near the church and the last cross section is 1000 where gravel road ends

Figure 10: Penstock Wash Full Profile

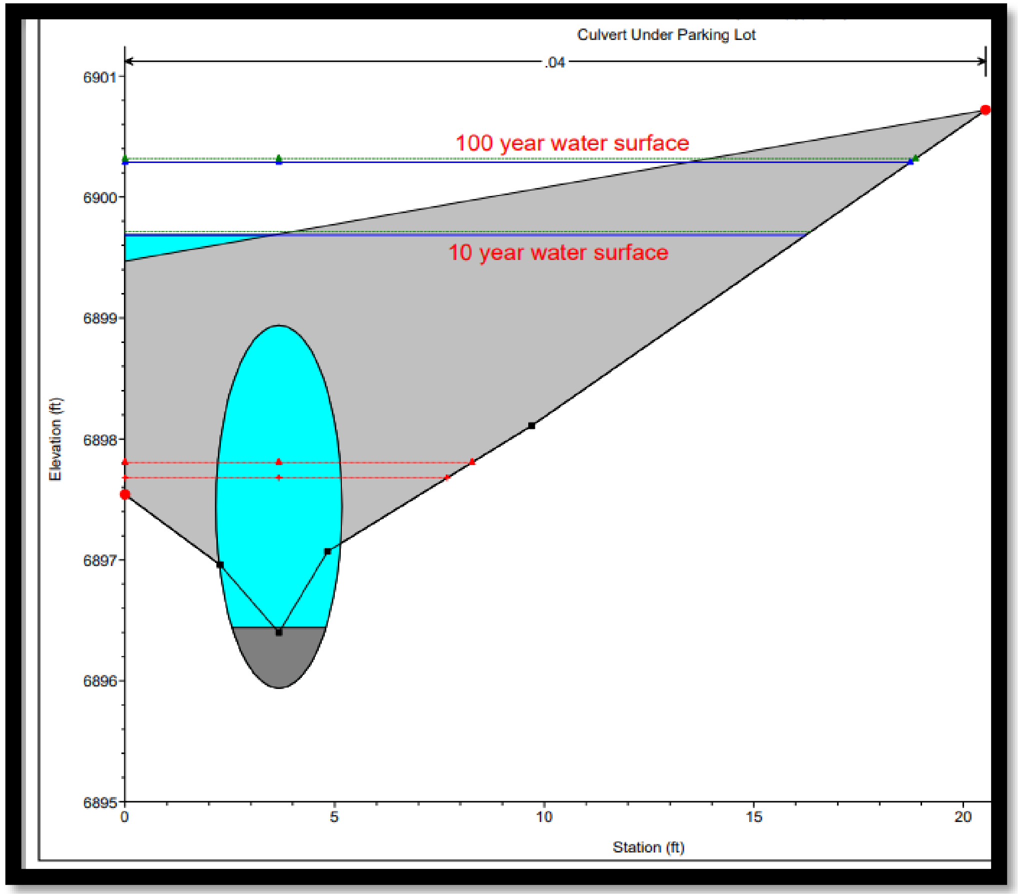


Figure 11: Parking Lot Culvert Inlet Condition

Hydraulic Analysis

Culvert Hydraulic Evaluation

- Capacity and performance under 10- & 100- year storms
- Overall overtopping, varied velocities, and upstream backwater effects
- Culvert underneath HWY 89 is an inlet control for a 10-year event and an outlet control for a 100-year event
- The culvert under the National Park Service is overtopping the parking lot
- Nearly a foot of water in the 100-year storm

River Station	Profile	Water Surface Upstream	Min Weir Elevation	Flow Culvert	Flow Weir	Change Water Surface	Culvert Velocity US	Culvert Velocity DS
		(ft)	(ft)	(cfs)	(cfs)	(ft)	(ft/s)	(ft/s)
1473	10	6908.56	6911.2	38.35	0.00	5.81	6.10	7.22
1473	100	6911.42	6911.2	52.07	0.93	8.51	8.29	8.79
1248	10	**6899.69**	6899.48	37.89	**0.46**	9.30	7.76	6.58
1248	100	**6900.29**	6899.48	43.06	**9.94**	9.55	6.84	6.85

Table 5: Culvert Analysis Results

Hydraulic Analysis

Open Channel Hydraulic Evaluation

- Capacity and performance under 10- & 100-year storms
- Inadequate freeboard, overtopping, stability deficiencies
- Flooding of the channel and parking lot
  - Majority of water going over the left bank station

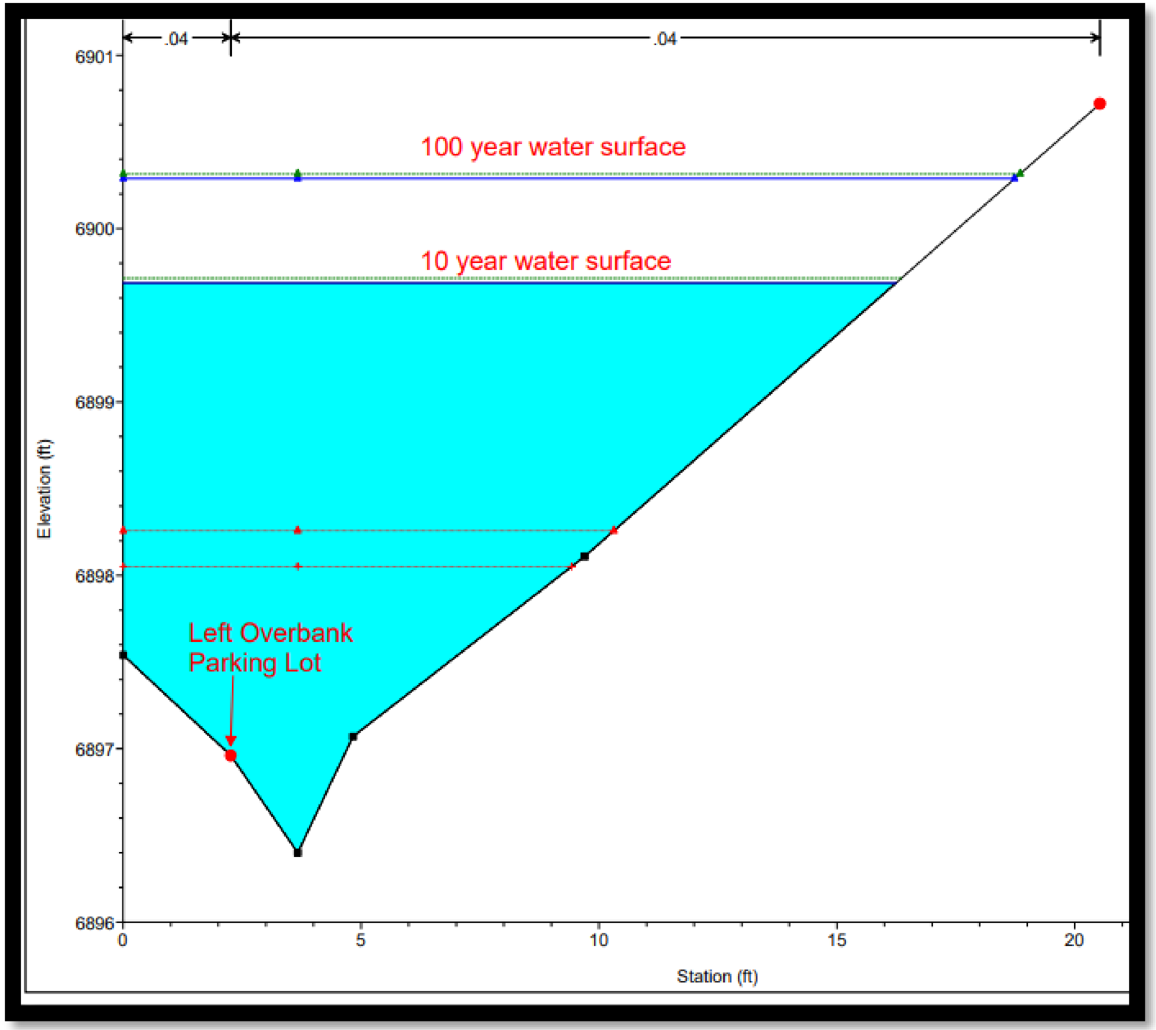


Figure 12: River Station 1256 Current Conditions

River Station	Profile	Water Surface Elevation (ft)	Energy Grade Slope	Velocity Channel (ft/s)	Flow Area (ft^2/s)	Top Width (ft)
1329	10	6899.70	0.000139	0.51	72.83	50.95
1329	100	6900.30	0.000086	0.47	103.93	53.29
1256	10	**6899.70**	0.000756	1.39	28.52	16.24
1256	100	**6900.30**	**0.000623**	1.41	38.94	18.71
1019	10	6888.90	**0.012074**	5.57	7.17	8.08
1019	100	6889.20	0.011484	6.13	9.00	8.08

Table 6: Cross Section Data

Alternatives Development

- **Alternative #1**: Channel Improvements and Stabilization
  - Pros: Lower cost and conveyance improvements
  - Cons: Large environmental impact
- **Alternative #2**: Channel Geometry Modification
  - Pros: Better hydraulic performance
  - Cons: Higher complexity of design
- **Alternative #3**: Full Channel Redesign and Box Culvert Implementation
  - Pros: Gravel road intact
  - Cons: Extremely high cost

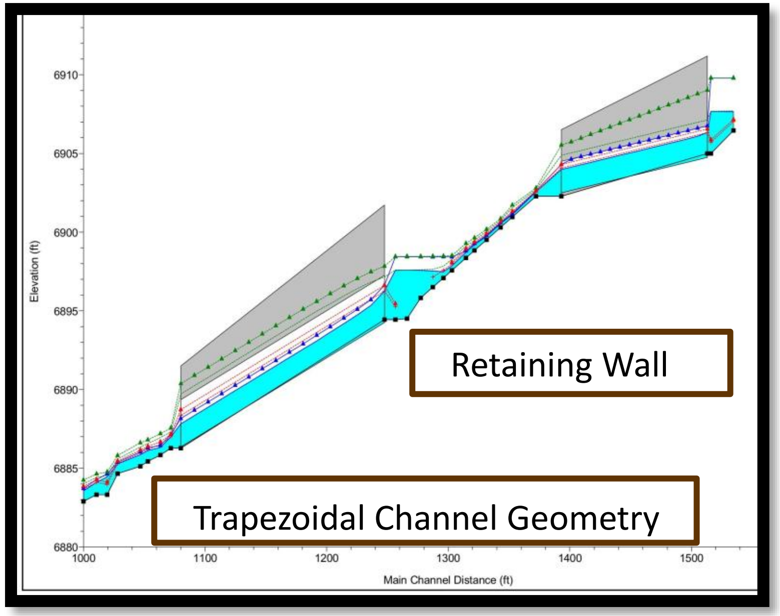


Figure 13: Alternative #1

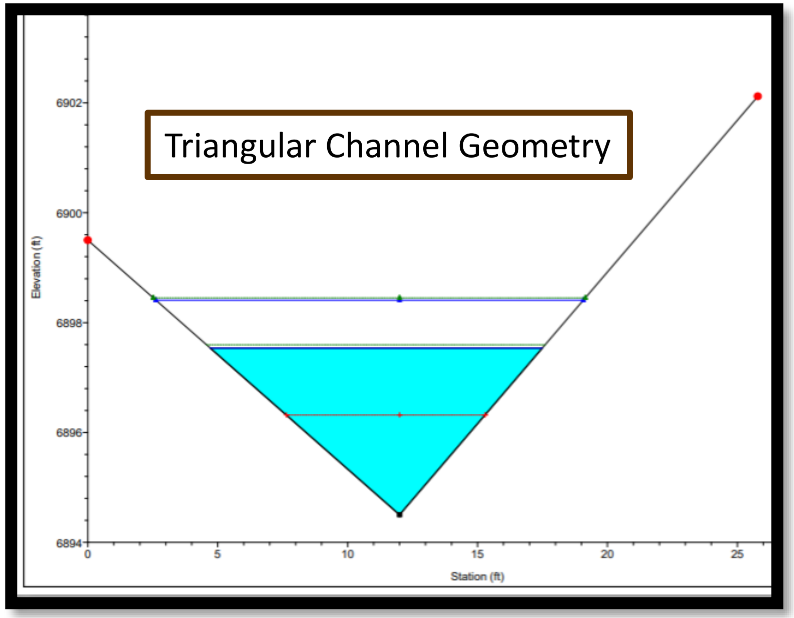


Figure 14: Alternative #2

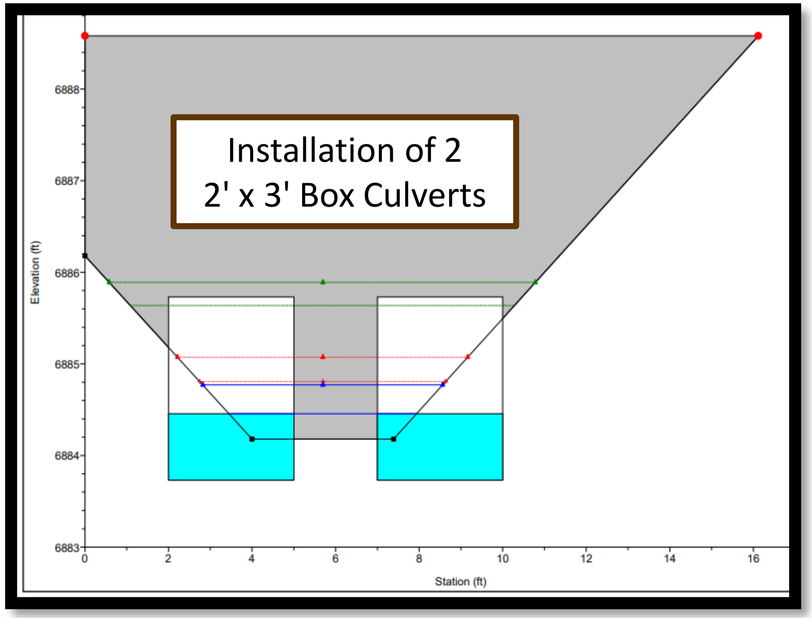


Figure 15: Alternative #3

Alternatives Matrix

Evaluation Criteria:

- Hydraulic Efficiency
- Regulatory Compliance
- Cost
- Constructability
- Durability
- Environmental / Social Impact

The Selected Final Alternative:

- Alternative #1
- Channel Improvements and Stabilization
- Best Overall Hydraulic Efficiency
- Most Durable
- Lost in Environmental and Social Impact
- Highest Weighted Score – 7.2

Penstock Wash Decision Matrix							
Alternatives	Hydraulic Efficiency (40%)	Regulatory Compliance (15%)	Cost (10%)	Constructability (10%)	Durability (15%)	Environmental/Social Impact (10%)	Weighted Score
1 – Trapezoidal & Retaining Wall	3.2	1.2	0.5	0.6	1.2	0.5	**7.2**
2 - Triangular	2.4	0.45	0.4	0.5	0.6	0.7	**5.1**
3 – Trapezoidal & Box Culvert Addition	1.6	0.9	0.2	0.4	0.75	0.3	**4.2**

Table 7: Penstock Wash Decision Matrix

Design Challenges and Engineering Judgment

Sensible, Accurate Modeling

- Rational Method Calculations
  - Mt. Elden Watershed
- Cross-Sectional Area Comparison
  - Highway 89 Culvert Inlet
  - First Cross Section (1488)
- HEC-HMS Issues
  - Accurate Flow Rate
- HEC-RAS Overtopping
  - Backflow Effects
- Culvert Master Analysis
  - 50 CFS

Figure 16: Upstream Side of Highway 89 Culvert

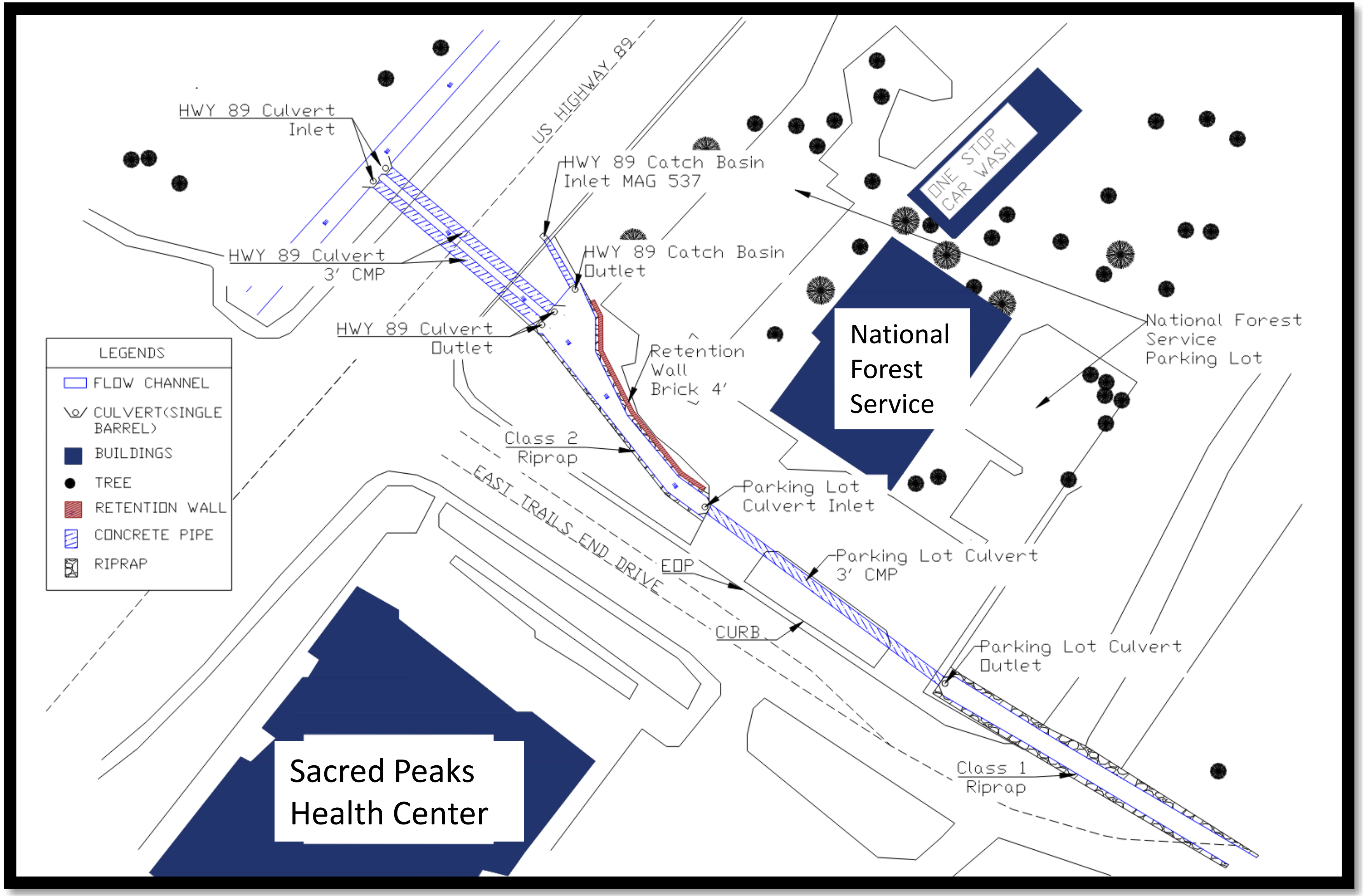


Figure 17: Final Design

Final Design

- Culvert Cleaning for both HWY 89 and Parking Lot
- Channel Geometry Reshaped From 'Natural' to Trapezoidal.
- 4' Brick Retaining Wall
  - 2:1 slopes
- Installation of Riprap for Erosion Protection
  - High Velocity Areas

Engineer's Opinion of Probable Cost

- EOPC developed to estimate construction costs of proposed improvements
- Estimate based on typical unit costs for materials, contract and hidden costs, and contingency costs
- Material costs represent the largest portion of the total cost

- Driven by earthwork operations, installation of channel lining materials, construction of structural elements
- Contract and hidden include mobilization, traffic control, erosion control, profit
- Contingency costs are approximately 15-20% of subtotal construction costs

Item	Cost
Material Costs	$271,460
Contract & Hidden Costs	$76,009
Contingency Costs	$75,466
	Total
	$422,935

Table 8: Overall Costs

Material Cost Totals		Contract and Hidden Costs		Contingency Costs	
Description	**Cost**	**Description**	**Cost**	**Description**	**Cost**
Site Setup	$64,000	**Mobilization Adjustment**	$13,573	**Engineering Design**	$7,601
Earthwork	$46,260	**Traffic Control**	$13,573	**Contingency (Concept Level)**	$67,865
Material Installation	$56,200	**Additional Erosion Control**	$8,144		
Geomorphic Restoration	$87,000	**Contractor OHP**	$40,719		
Site Restoration	$18,000				
	Total		**Total**		**Total**
	$271,460		**$76,009**		**$75,466**

Table 9: Engineer's Opinion of Probable Cost

Future Project Recommendations

Phase 2 Systems-Level Improvements

- Evaluate diverting peak flow parallel to US-89 to reduce neighborhood loading
- Assess downstream storm sewer capacity and potential upgrades
- Integrate design with existing drainage network to improve overall system performance

Additional Considerations

- Perform detailed downstream hydraulic analysis
- Explore more channel solutions
- Conduct environmental and permitting studies for long-term implementation

References

[1] USGS, “StreamStats,” [Online]. Available: https://www.usgs.gov/streamstats. [Accessed 15 January 2026].

[2] United States Department of Agriculture, “Web Soil Survey,” [Online]. Available: https://websoilsurvey.nrcs.usda.gov/app/. [Accessed 15 January 2026].

[3] Coconino Country Arizona, “Coconino Country Drainage Design Criteria Manual,” 2025. [Online]. Available: https://www.coconino.az.gov/DocumentCenter/View/67366/2025-Drainage-Design-Criteria-Manual. [Accessed 18September 2025].

[4] NOAA, “Precipitation Frequency Data Server (PFDS),” National Weather Service, [Online]. Available: https://hdsc.nws.noaa.gov/pfds/. [Accessed 18 September 2025].

[5] City of Flagstaff, “2025 Stormwater Management Design Manual,” 2025. [Online]. Available: https://www.flagstaff.az.gov/DocumentCenter/View/88520/2025-Stormwater-Management-Design-Manual. [Accessed 18September 2025].

[6] “FEMA,” U.S. Department of Homeland Security, [Online]. Available: https://www.fema.gov/floodplain-management.

[7] “Natural Resources Conservation Service,” U.S. Department of Agriculuture, [Online]. Available: https://www.nrcs.usda.gov/.

Questions?

THANK YOU!

Haile Nelson, Briana Pilling, Harth Beaty, Qixuan Yang