John Wesley Powell West Road Extension

Final Presentation

CELS ENGINEERING

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– CENE 486C - 5/3/2024 –

Project Introduction

JWP West Assessment and Design

- Located between South Pulliam Dr. & Lake Mary Rd.
  - *1.5 miles*
  - *Rugged and forested terrain*

Design Goals

- Connect South Pulliam Dr. to Lake Mary Rd.
  - *Enhance accessibility to local communities*

Client

- Jeff Bauman (*PE, PTOE, Traffic Engineer with C.O.F*)

Figure 1: View from S. Pulliam Dr. (West)

Figure 2: View from Lake Mary Rd. (East)

Project Location

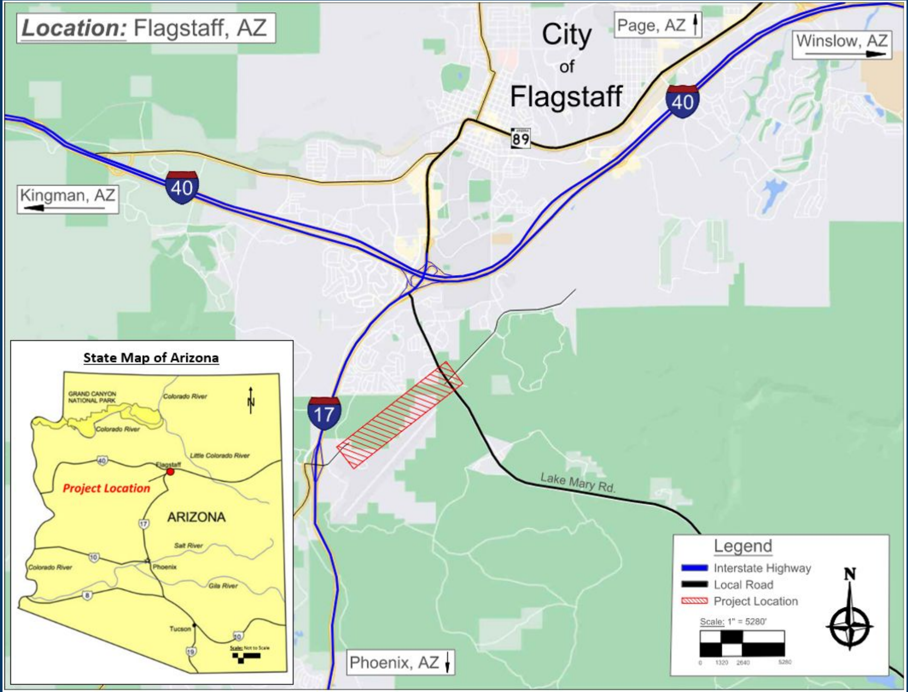

Figure 3: State map of Arizona (Google Maps)

Figure 4 Project vicinity map (Google Maps)

Traffic Counts - West Intersection

S. Pulliam Drive and JWP

- JAMAR Board
- Identified traffic volumes and turning count movements
- West intersection AM total volume: 213 vehicles
- West intersection PM total volume: 237 vehicles

Photo by Elijah Begay

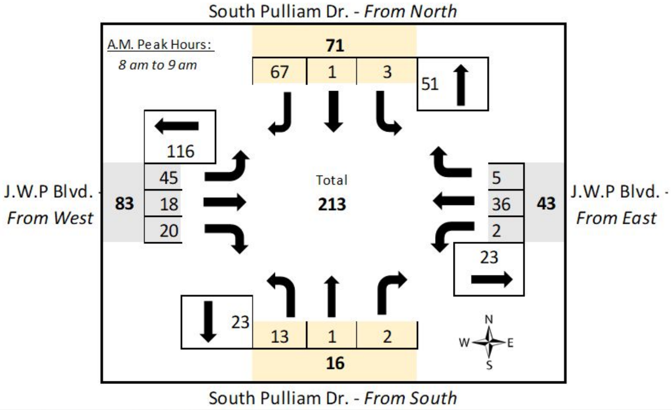

Figure 5: AM traffic volume - West intersection

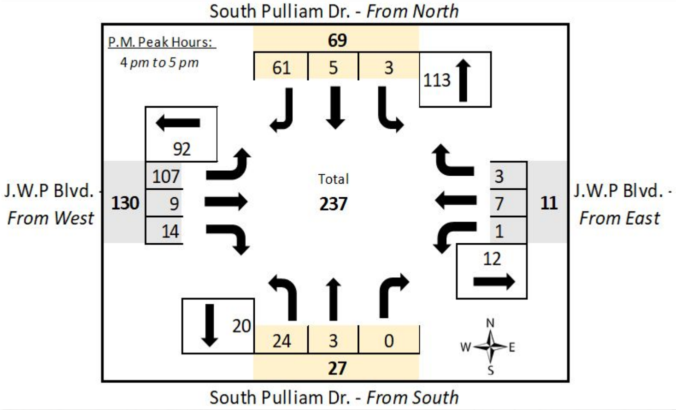

Figure 6 PM traffic volume - West intersection

Traffic Counts - East Intersection

Lake Mary Road and JWP

- East intersection AM total volume: 368
- East intersection PM total volume: 397

Photo by Elijah Begay

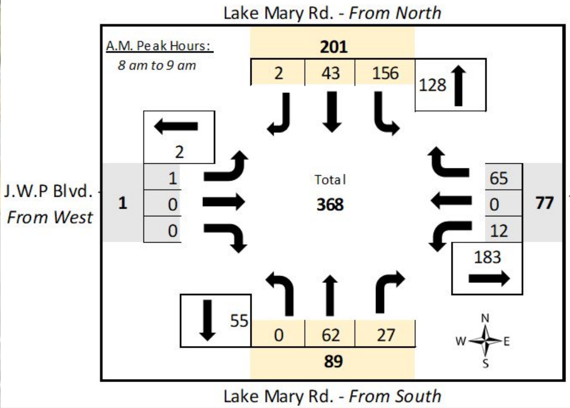

Figure 7: AM traffic volume - East intersection

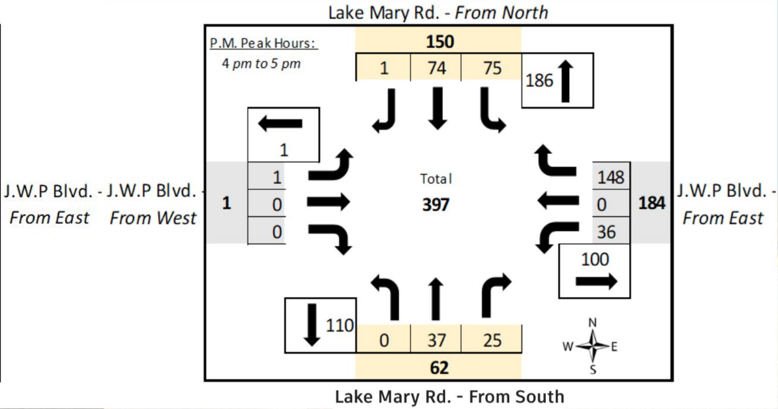

Figure 8: PM traffic volume - East intersection

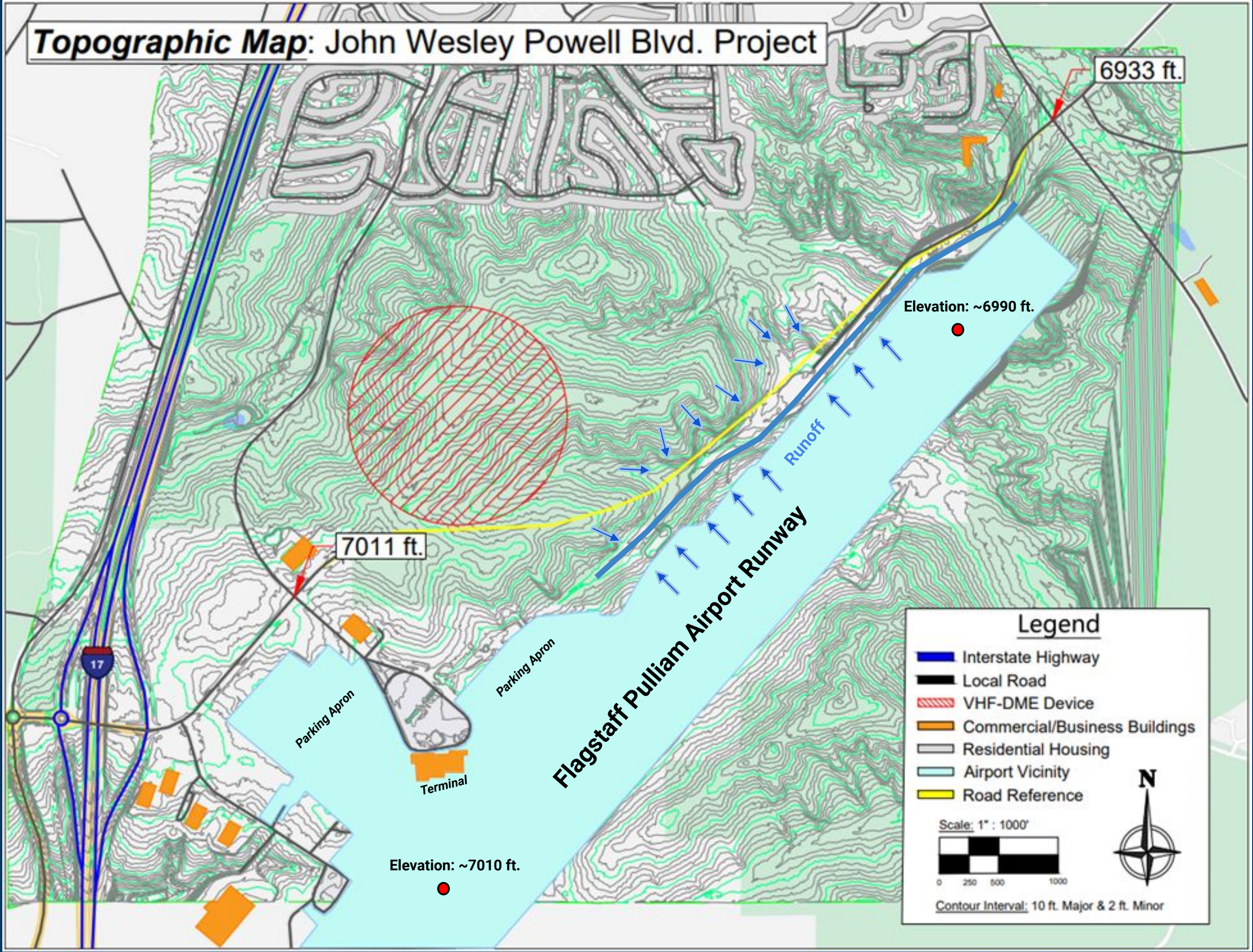

Figure 9: Topographic Map

Roadway Geometry

- Two Lane Road
- LOS B
- Bike Lane/Shoulder
- Vertical Grade from 0.66-1.17%
- Sidewalk on North End
- 40 MPH Speed Limit

Figure 10: Roadway alignment

Roadway Cross Section

- Lane
  Width: 12 ft
  Slope: 2%

- Shoulder
  Width: 5.5 ft
  Slope: 4%

- Sidewalk
  Width: 6 ft
  Thickness: 4 in

- Curb
  Width: 1.5 ft
  Thickness: 8 in
  Slope: 4%

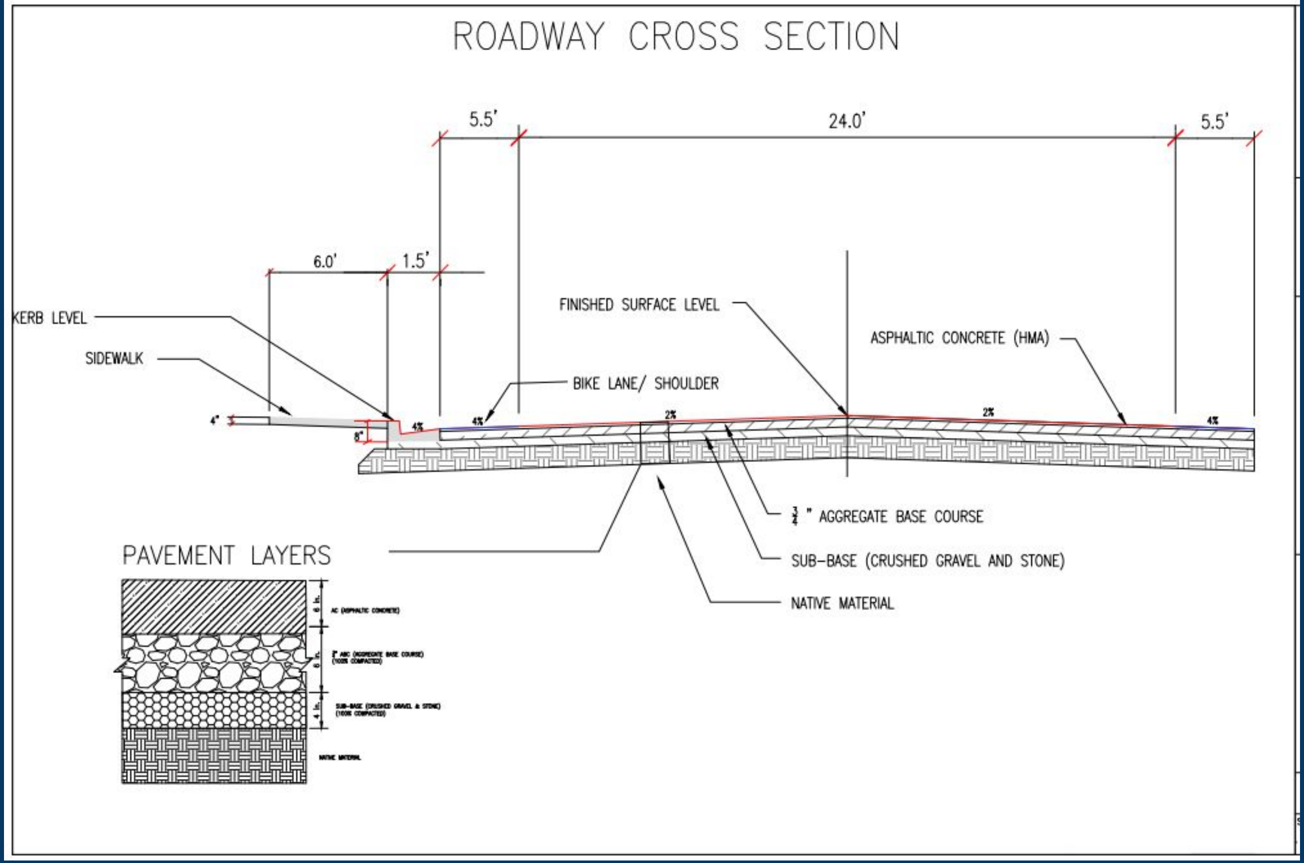

Figure 11: Cross-section of roadway

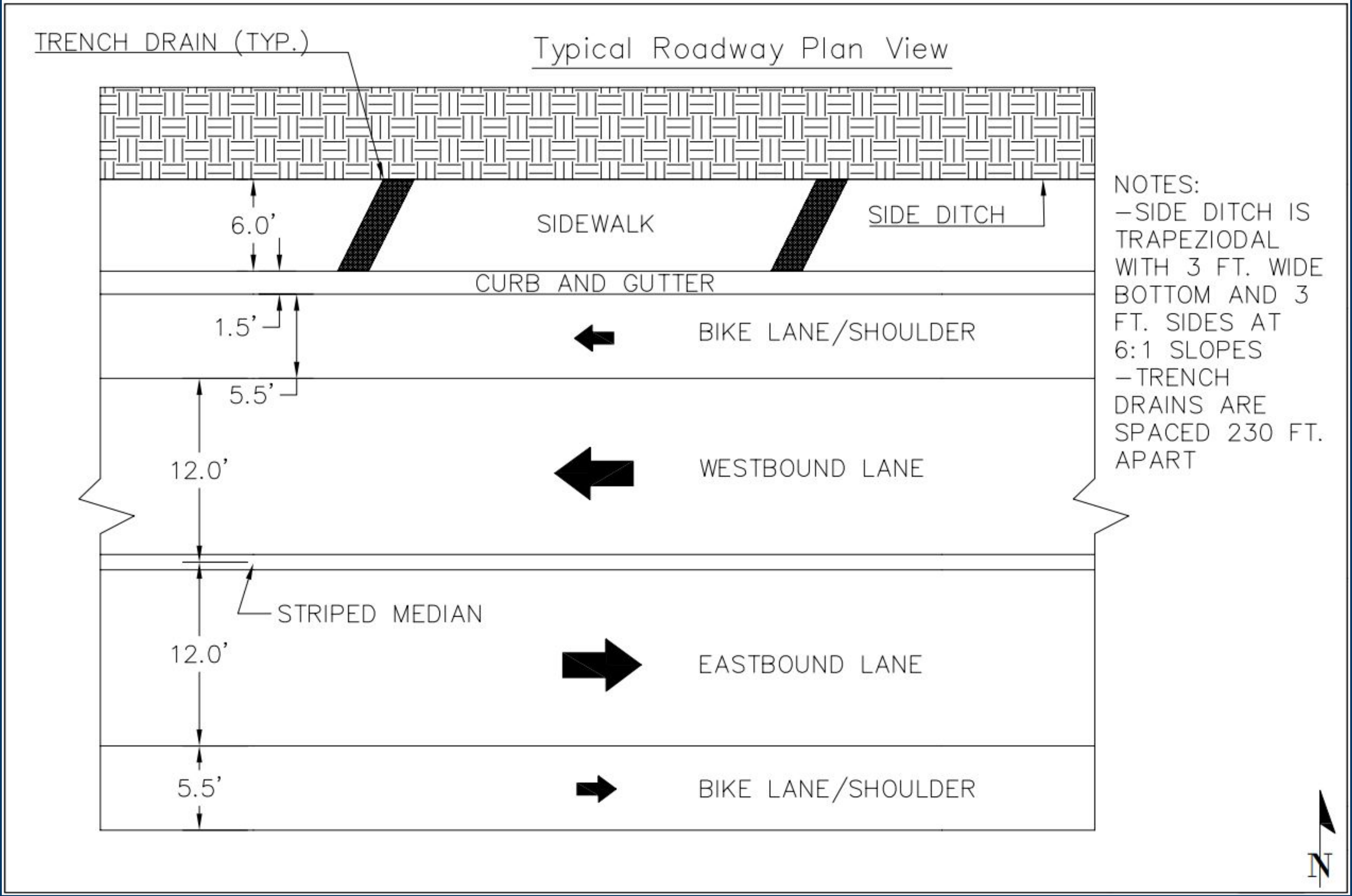

Figure 12: Plan view of roadway

Horizontal Alignment

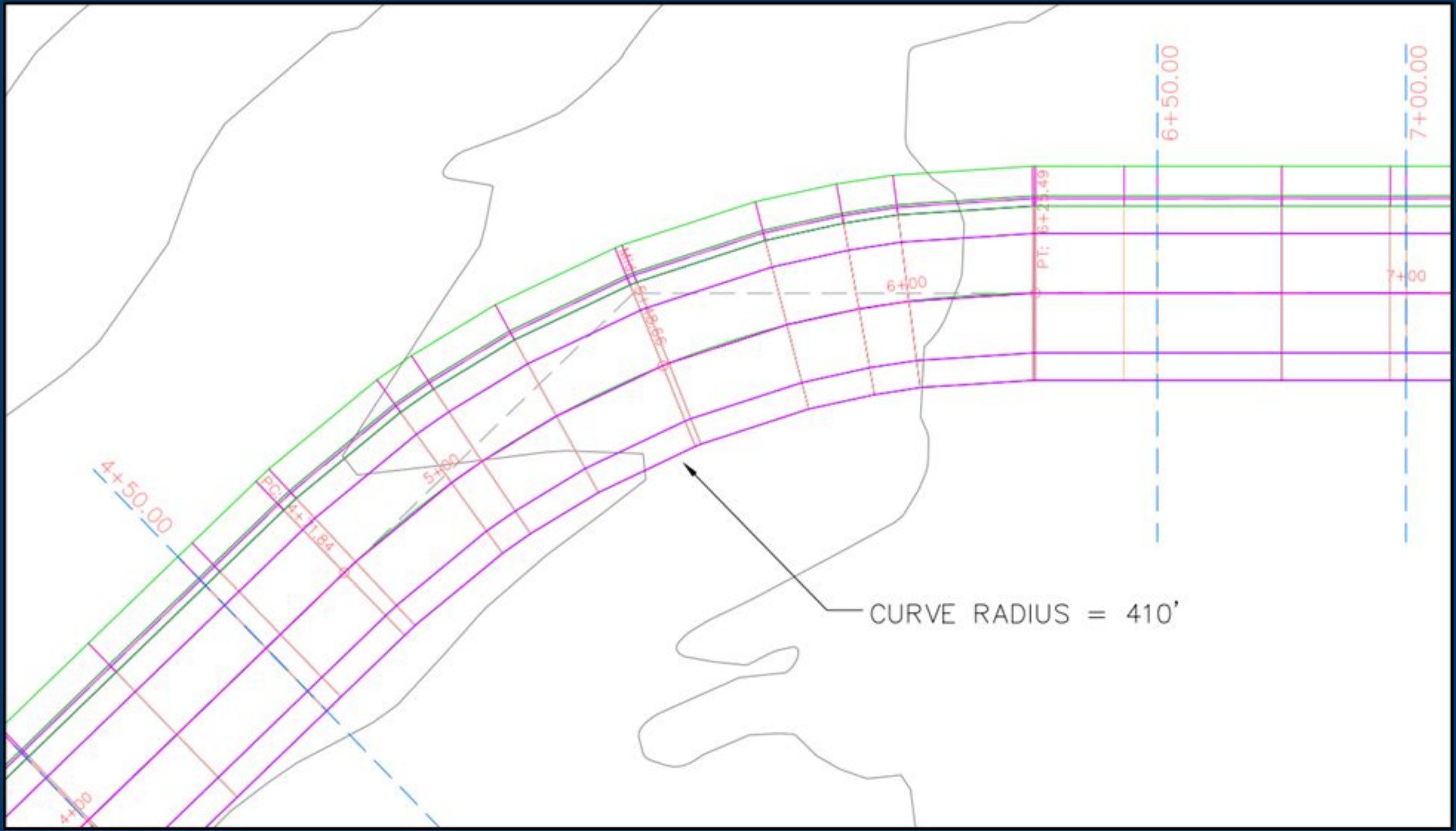

Figure 13: Horizontal alignment

Vertical Alignment

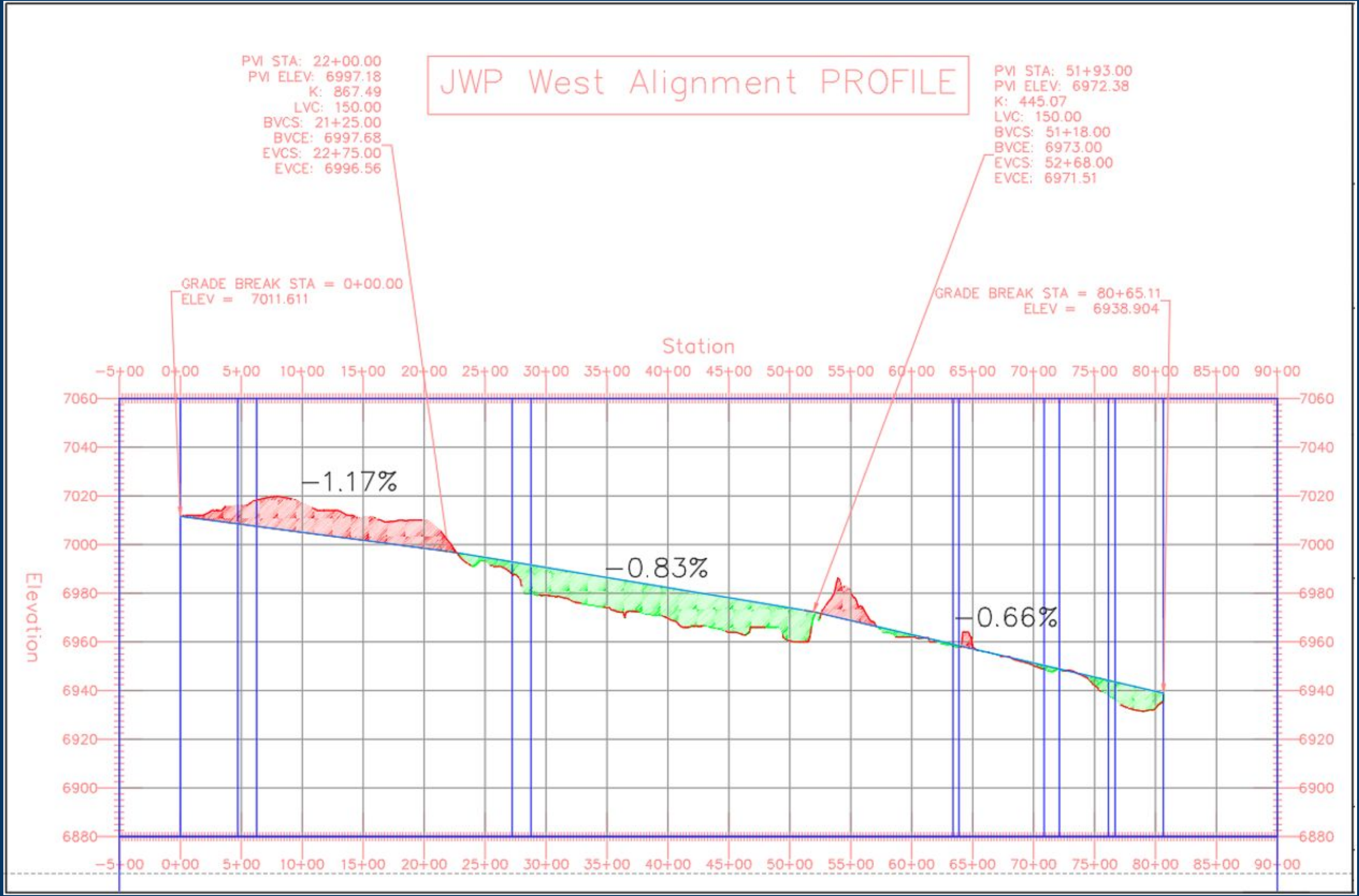

Figure 14: Profile of roadway

Decision Matrix - Pavement Design

Criteria

- Cost: cubic yd. construction, maintenance
- Durability: lifespan, withstand wear and tear
- Effectiveness: permeability, performance under road volume

Scoring Description for Pavement Design			
Criteria	1 (Worst)	2 (Neutral)	3 (Good)
Cost	highest upfront cost	moderate upfront cost	lowest upfront cost
Durability	shorterst lifespan, continuous maintenance necessary	moderate lifespan, moderate maintenance necessary	longest lifespan, minimal maintenance necessary
Effectiveness	not permeable, cannot withstand heavy traffic load	moderately permeable, lower ability to withstand heavy traffic load	permeable, can withstand heavy traffic load

Table 1: Scoring Description for pavement design

Material Options:

Figure 15: Concrete vs Asphalt [5]

Decision Matrix					
Material Options:		Asphaltic Concrete		Concrete	
Criteria	Weight (%)	Avg Score (1-3)	Weighted Score	Avg Score (1-3)	Weighted Score
Cost	35	3	1.05	1	0.35
Durability	35	2	0.7	3	1.05
Effectiveness	30	2	0.6	1	0.3
Weighted Score	100		2.35		1.7

Table 2: Pavement type decision matrix

Pavement Design: Layers

- Top Layer
  Asphaltic Concrete
- Base
  ¾” Aggregate Base Course
- Sub-base
  Crushed Gravel and Stone
- Lower Layer
  Native Material

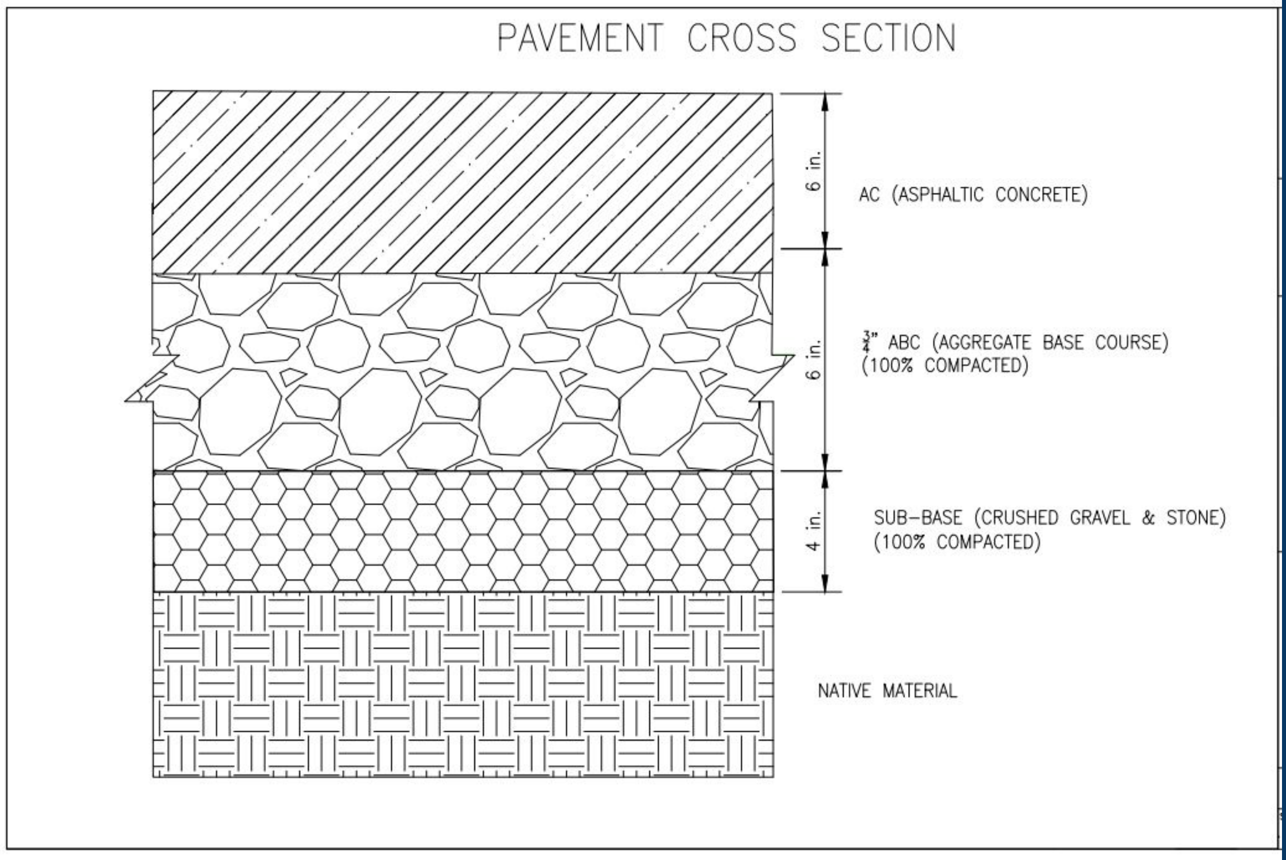

Figure 16: Pavement cross section

Decision Matrix - Intersection Design (Lake Mary Rd.)

- Projected 2045 Data from COF
- Used Traffic Counts to Estimate Turn Volumes
- Two-Way Stop, Four-Way Stop, Roundabout, Signalized Intersection
- Used Vistro to analyze LOS, Delay, Signal Phasing, etc.

Table 3: Intersection scoring descriptions

Scoring Description for Intersection			
Criteria	1 (Worst)	2 (Neutral)	3 (Good)
Cost	Design is very costly	Design applies to categories 1 and 3	Design is not very costly
Efficiency	LOS E-F	LOS C-D	LOS A-B
Constructability	Challenging installation, requires additional labor & equipment	Requires adequate construction	Less labor & equipment
Pedestrians	LOS E-F	LOS C-D	LOS A-B

Table 4: JWP and Lake Mary Intersection Decision Matrix

Decision Matrix									
Lake Mary Road and JWP Intersection:		Signalized		2-Way Stop		4-Way Stop		Roundabout	
Criteria	Weight (%)	Avg Score (1 -3)	Weighted Score	Avg Score (1 -3)	Weighted Score	Avg Score (1 -3)	Weighted Score	Avg Score (1 -3)	Weighted Score
Cost	20	2	0.40	3	0.60	3	0.60	1	0.20
Efficiency	45	2	0.90	1	0.45	1	0.45	2	0.90
Constructability	15	2	0.30	3	0.45	3	0.45	1	0.15
Pedestrians	20	3	0.60	1	0.20	2	0.40	1	0.20
Weighted Score	100		2.20		1.70		1.90		1.45

JWP & Lake Mary - East Intersection

- LOS C
- Added right turn lane on JWP Eastbound
- Fixed Timing
- 100 Second Cycle Lengths
- Delay of 23.8 s/veh

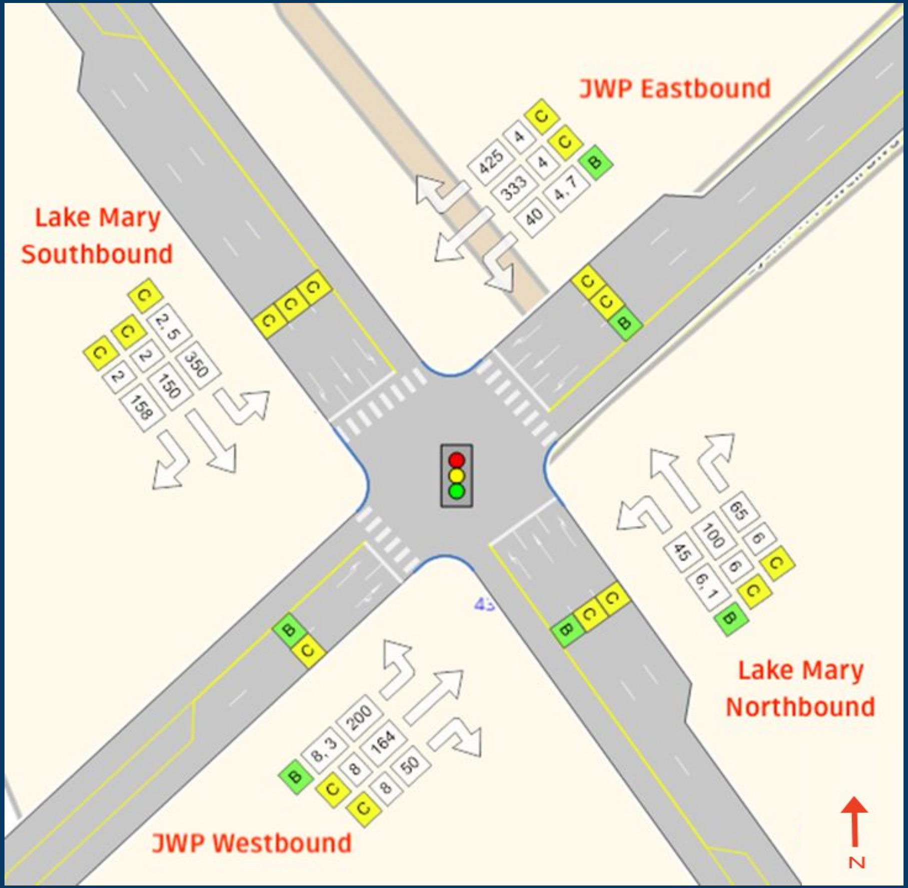

Figure 17: JWP and Lake Mary intersection [1]

Decision Matrix - Intersection Design (S Pulliam Dr.)

Table 5: JWP and Pulliam intersection decision matrix

Decision Matrix										
S Pulliam and JWP		Signalized		2-Way Stop		4-Way Stop		Roundabout		
Criteria	Weight (%)	Avg Score (1 -3)	Weighted Score	Avg Score (1 -3)	Weighted Score	Avg Score (1 -3)	Weighted Score	Avg Score (1 -3)	Weighted Score	
Cost	20	2	0.40	3	0.60	3	0.60	1	0.20	
Efficiency	45	3	1.35	2	0.90	1	0.45	3	1.35	
Constructability	15	2	0.30	3	0.45	3	0.45	2	0.30	
Pedestrians	20	3	0.60	2	0.40	2	0.40	1	0.20	
Weighted Score	100		2.65		2.35		1.90		2.05	

JWP & Pulliam Intersection

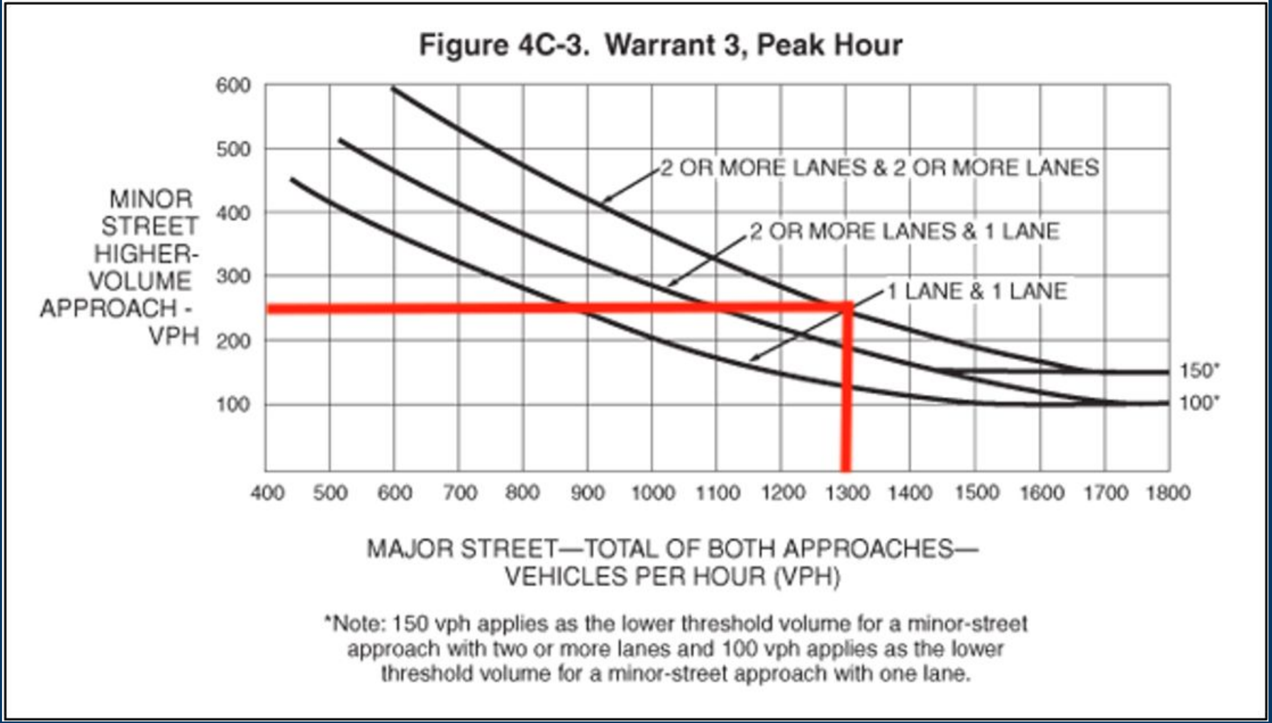

Figure 18: JWP and Pulliam intersection signal warrant

JWP & Pulliam - West Intersection

- LOS B
- Semi-Actuated
- Full Cycle Length of

  60 Seconds
- Delay of 12.1 s/veh

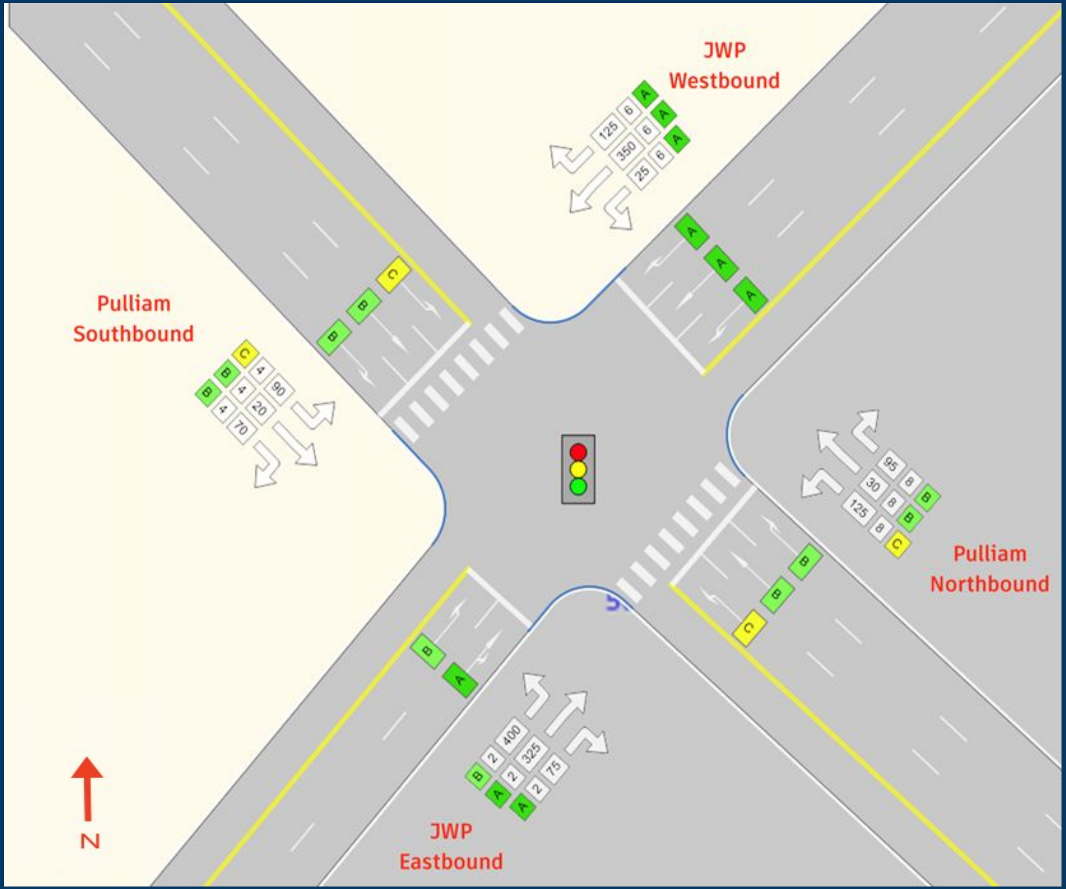

Figure 19: JWP and Pulliam intersection [1]

Signage and Striping

- Designed according to the Manual on Uniform Traffic Control Devices (MUTCD)
- White lines for right side of road, indicating shoulder and bike lane
- Yellow lines for left side of the road, median
- Speed limit signs after intersection and along road
- “Do Not Pass” signs along the road
- Turning arrows, stopping lines, and crosswalks at intersections

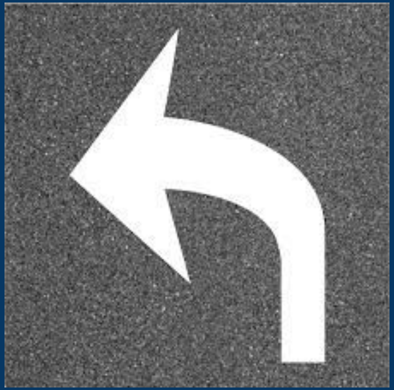

Figure 20: Left turn arrow [3]

Figure 21: Do Not Pass sign [2]

Figure 22: Continental crosswalk [4]

Geotechnical Analysis

- 19
  - Rocky sandy soil
  - Occurs on hills
- 19A
  - Soil series combination
  - Steep hillslope soil

Map Unit Symbol	Map Unit Name	Acres in AOI	Percent of AOI
8	Paymaster family fine sandy loam, 0 to 3 percent slopes	8.2	7.1%
19	Telephone gravelly sandy loam, 0 to 15 percent slopes	32.8	28.60%
19A	Telephone-Daze complex, 0 to 8 percent slopes	73.8	64.30%
Totals for Area of Interest		**114.8**	**100.0%**

Figure 23: Site soil type description

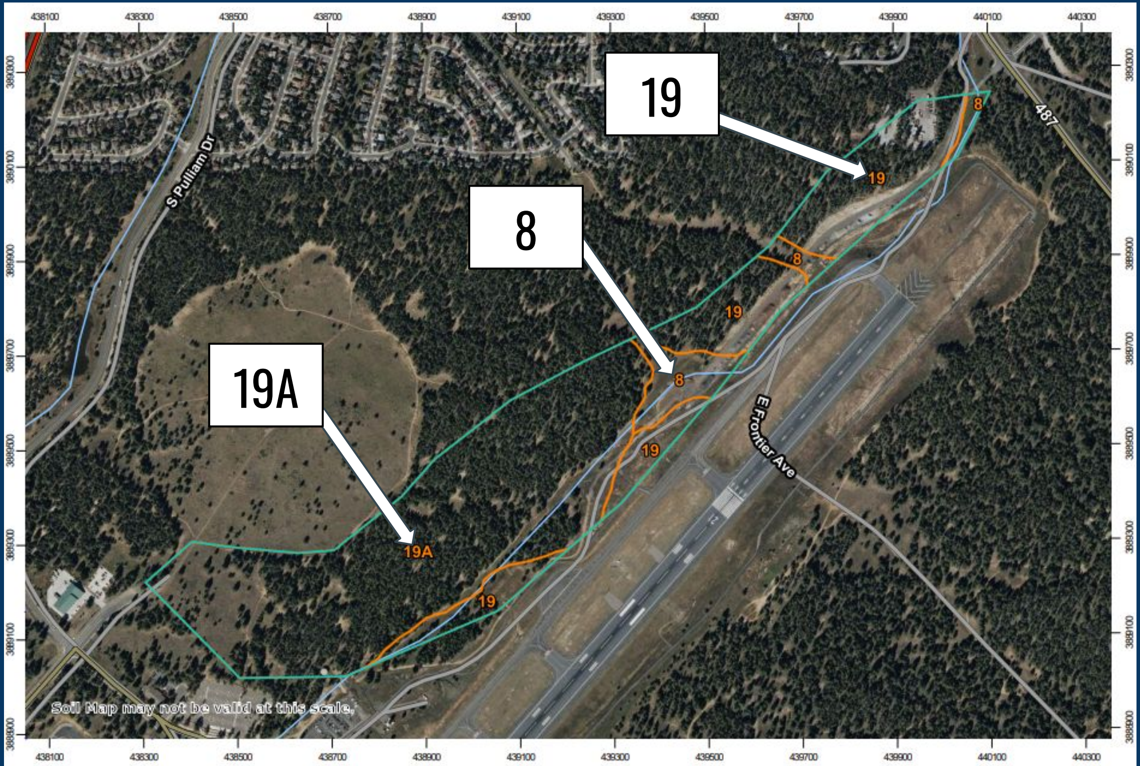

Figure 24: Site soil map from USDA Web Soil Survey [6]

Site Investigation

Land Surveying

- Auto Level
- Profile: 6 shots upstream, 10 shots down stream, 10 ft intervals
- Cross section: Flood plain, left bank, bottom bank, thalweg, bottom bank, right bank, flood plain, 30 ft intervals

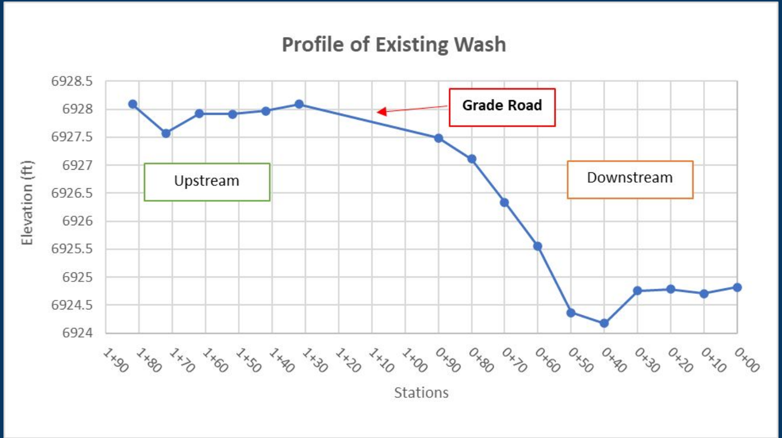

Figure 25: Channel profile

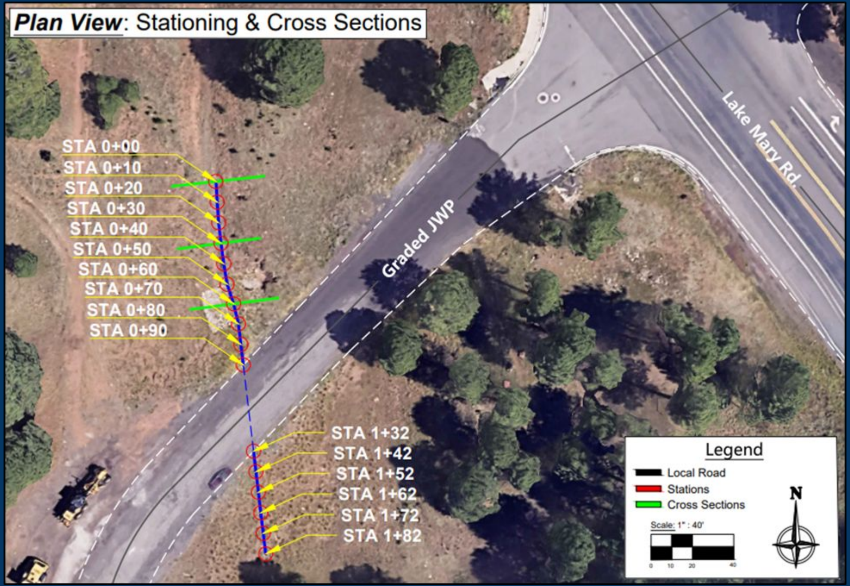

Figure 26: Plan view of stationing & channel cross sections

Photographs

Photo by Elijah Begay

Figure 27: Auto level

Photo by Logan McFarland

Figure 28: Image of channel looking downstream

Photo by Elijah Begay

Figure 30: Surveying the typical cross section

Photo by Logan McFarland

Figure 29: Downstream typical cross section

Hydrologic Analysis

Watershed Delineation

- StreamStats uses a Digital Elevation Model (DEM) grid
- Automatically creates GIS layers through basins

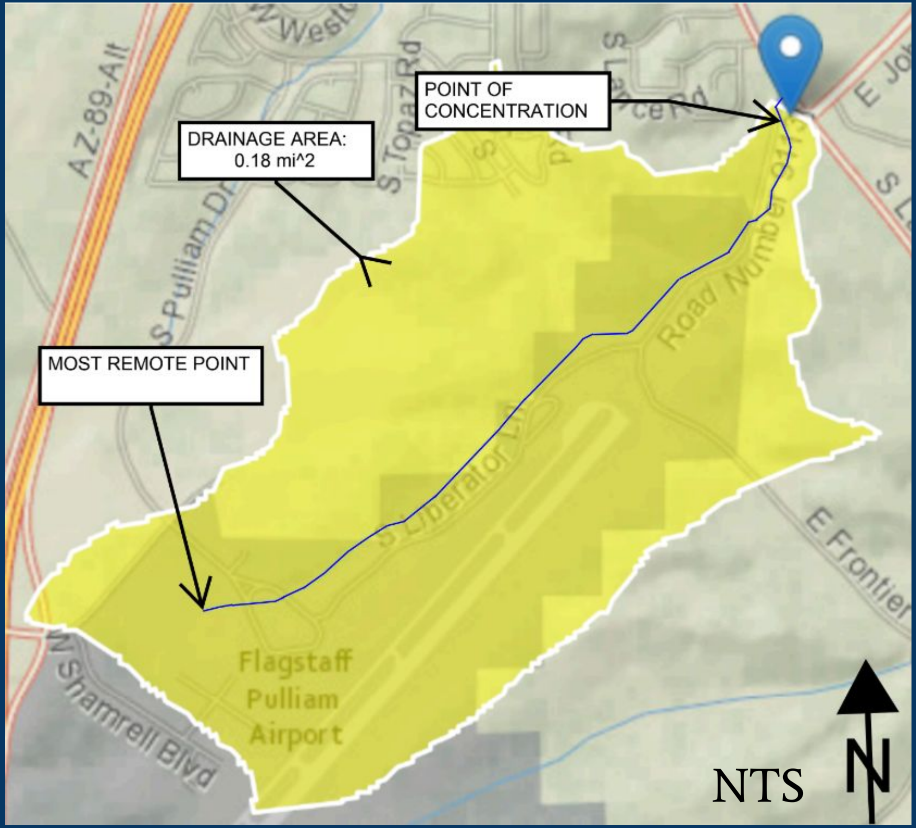

Figure 31: Watershed of project site

Time of Concentration

USDA TR-55 Method [4]

- *Sheet flow*, a thin uniform flow of water across a surface
- *Shallow concentrated flow*, a flow of water in defined channels across uneven terrain
- *Channel flow*, a flow of water in hydraulically made channels

Equation 1: Sheet flow [4]

$$T_t = \frac{0.007(nL)^{0.8}}{P_2^{0.5} s^{0.4}}$$

Equation 2: Shallow concentrated flow [4]

$$T_t = \frac{L}{3600\,V}$$

Equation 3: Channel flow [4]

$$T_t = \frac{L}{3600\,V}$$

Table 6: Travel time for sheet flow

USDA TR-55: Travel Time, Sheet Flow	
Manning's roughness, n	0.15
Flow length, L (ft)	292
Rainfall, P_2 (2-yr)	2.13
Land slope, s (ft/ft)	0.0103
Travel time, T_t (hr)	0.616

Table 7: Travel time for shallow concentrated flow

USDA TR-55: Travel Time, Shallow Concentrated Flow	
Surface Description	Unpaved
Flow length, L (ft)	292
Average velocity, V (ft/s)	2.13
Slope, s (ft/ft)	0.0083
Travel time, T_t (hr)	1.34

Table 8: Travel time for channel flow

USDA TR-55: Travel Time, Channel Flow	
Surface Description	0.025
Flow length, L (ft)	320
Average velocity, V (ft/s)	16.5
Slope, s (ft/ft)	0.0125
Travel time, T_t (hr)	0.00539

$\sum$= 1.96 hours

Peak Discharge

Storm Intensity

- “Roadway classifications shall be designed for the 50-yr storm event.”-SWMDM [5]

Calculate Peak Flow

- Used for future hydraulic design

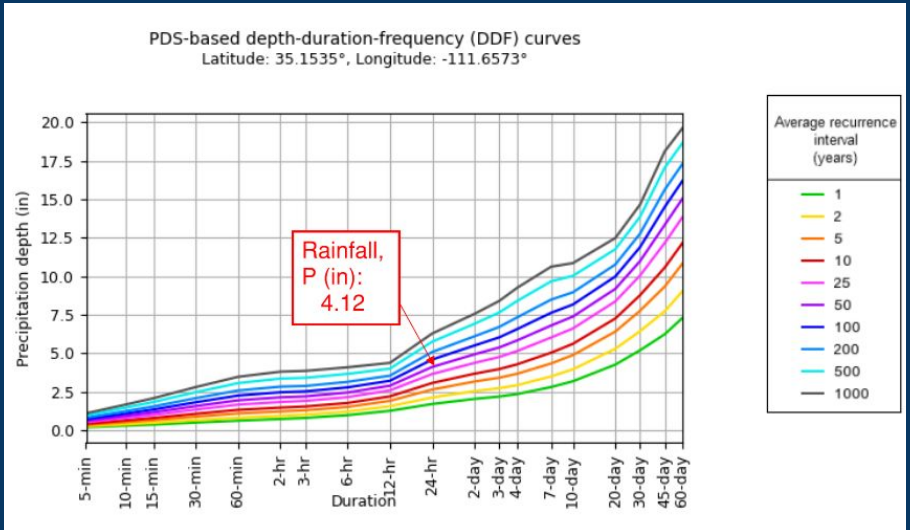

Figure 32: NOAA Atlas 14 PDS-DDF curves [6]

Table 9: Peak flow rate

	USDA TR-55 Method		
Storm Event (yr)	10	50	100
Rainfall, P (24-hr)	3.08	4.12	4.60
Runoff, Q (in)	1.58	2.48	2.91
Drainage Area, Am (mi^2)	0.18	0.18	0.18
Peak Discharge, qp (cfs)	65.4	103	121

Equation 4: Peak discharge formula [6]

$$q_p = q_u A_m Q F_p$$

Existing Channel

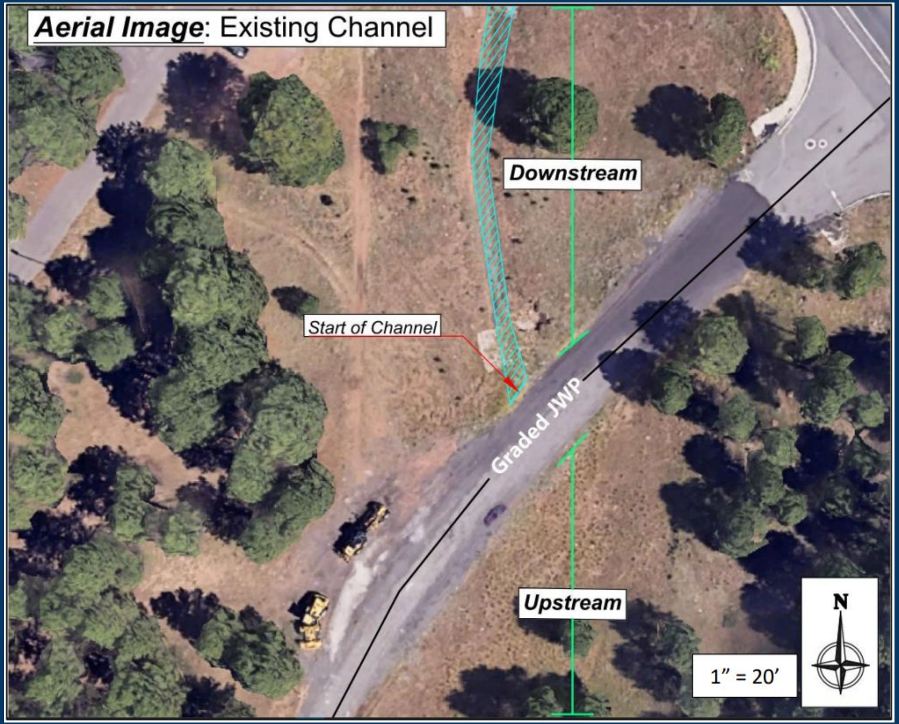

Figure 33: Aerial image of existing channel

Figure 34: Looking upstream of existing channel

Existing Channel Analysis

Purpose

- Evaluated current state of the channel
  - *Flow rates*, *velocities*, & *water surface elevations*
- Understood hydraulic behavior near east intersection
  - Currently overtopping designed road

Work

- Developed 1-D HEC-RAS model
- Evaluated cross-sectional data, flow characteristics, and compliance with CoF's SWMDM

Table 10: General overview of compliance

Existing Conditions of Cross-Sections HEC-RAS	
Variables	*Compliance*
Flow rate (cfs)	Yes
Velocity (ft/s)	Yes
Water surface elevation (ft)	No
Freeboard (ft)	No
Flow regime	Yes

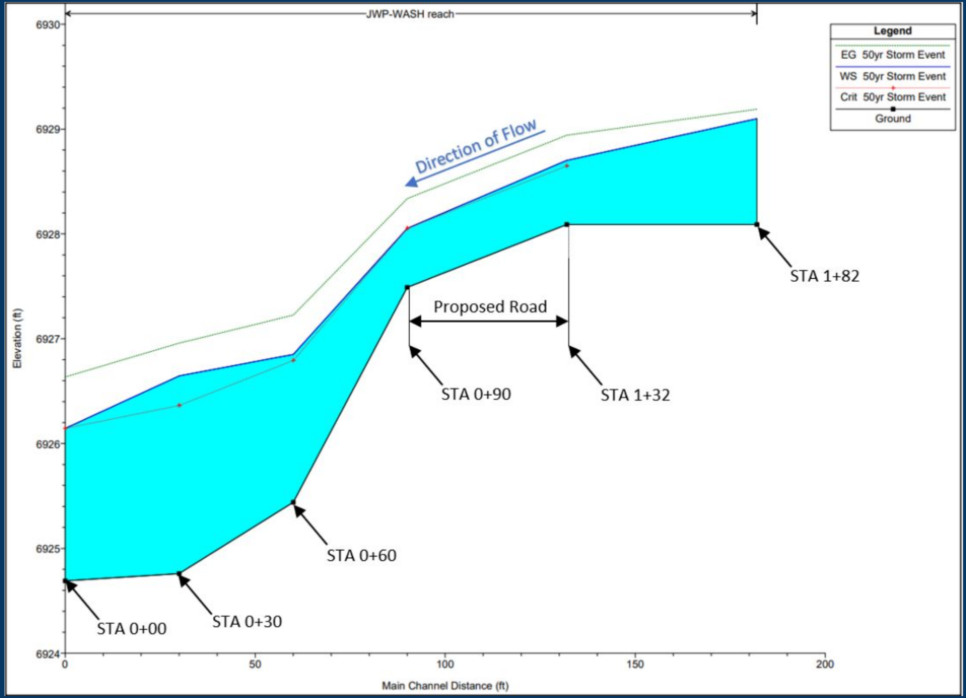

Figure 35: Profile view of existing channel

Decision Matrix - Hydraulic

Criteria

- Cost: initial expenses and long-term maintenance
- Efficiency: maximizing hydraulic efficiency
- Constructability: ease of construction/installation
- Aesthetics: enhance visual appeal

Table 11: Culvert scoring description

Scoring Description for Culvert			
Criteria	1 (Worst)	2 (Neutral)	3 (Good)
Cost	Structure is very costly & not economical (>$70,000)	Is costly nor economical	Structure is economical, very sufficient (<$30,000)
Efficiency	Does not meet conveyance & allowable freeboard	Able to either convey or have resonable freeboard	Able to channel design flow & has adequate amount of freeboard
Constructability	Challenging installation, requires additional labor & equipment	Structure requires adequate construction	Less labor & equipment
Aesthetics	Not eye-appealing; does not fit into surrounding background	Has normal appeal	Structure appears to fit into terrain

Table 12: Culvert-shape decision matrix

Decision Matrix									
Culvert Entrance Design:		Concrete Box		Corrugated Metal Pipe		Concete Arch		Ellipse	
		 ~ $6,600 per section - x10 (Total: $66,370)		 ~ $860 per 2' dia. pipe-x16 (Total: $13,800)		 ~ $370 per foot 3' dia. (Total: $79,000)		 ~ $1,010 per foot -3' dia. (Total: $76,800)	
Criteria	Weight (%)	Avg Score (1-3)	Weighted Score	Avg Score (1-3)	Weighted Score	Avg Score (1-3)	Weighted Score	Avg Score (1-3)	Weighted Score
Cost	35	2	0.70	3	0.89	1	0.35	1	0.35
Efficiency	35	3	0.95	1	0.35	2	0.79	1	0.47
Constructability	20	2	0.40	3	0.60	1	0.27	1	0.21
Aesthetics	10	2	0.24	1	0.10	3	0.30	2	0.20
Weighted Score	100		2.29		1.94		1.71		1.23

Proposed Hydraulic Design

- **2 Barrel *8’ x 3’* Box Culvert**
  - Concrete Material
  - Typical run length of 7’- 8”
  - Beveled corners
- 10 sections needed (total length of 76’ 8”) to connect upstream and downstream
- Structure will be sloped at 0.5%
- A headwall and wingwalls will be installed at both ends

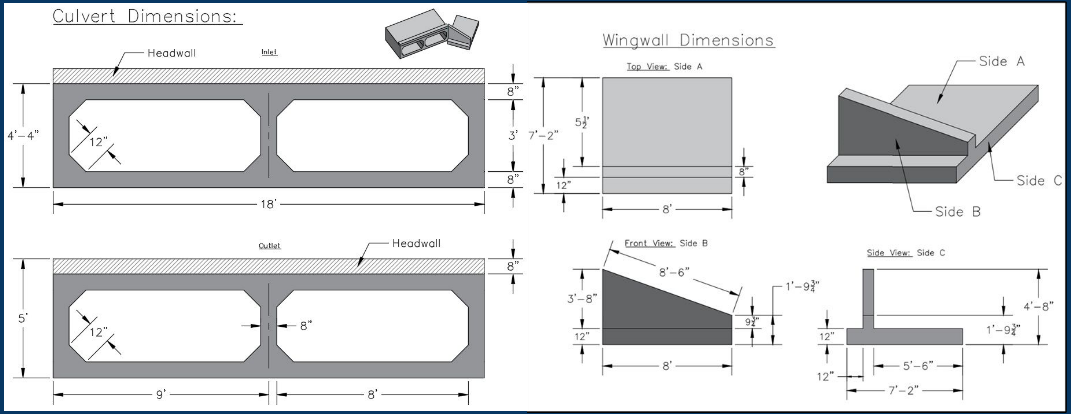

Figure 36: Typical culvert & wingwall dimensions

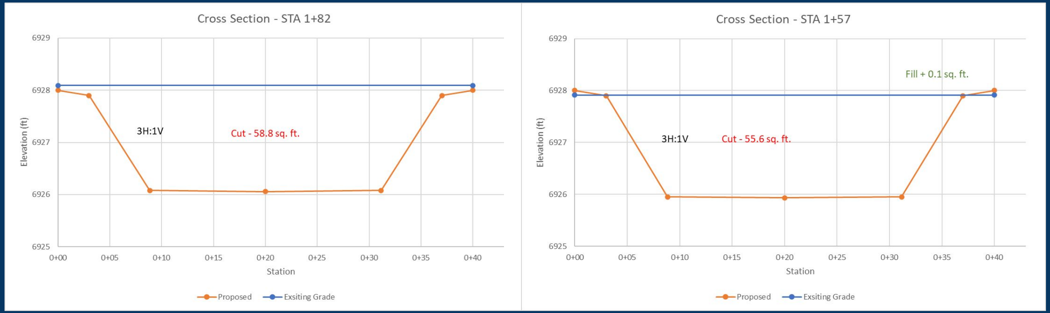

Figure 37: Upstream cross sections

Post-Improvement Hydraulic Analysis

Table 13: Evaluation of proposed culvert

Culvert Conditions HEC-RAS				
Culvert 8x3 (2)	Inlet	Compliance	Outlet	Compliance
Variables	**50 years**		**50 years**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	5.9	Yes	4.5	Yes
Water surface elevation (ft)	6927.5	Yes	6927.0	N/A
HW/D ≤ 1.2	0.47	Yes	N/A	N/A
Freeboard (ft)	1.4	Yes	1.6	Yes
Flow Regime	Supercritical	Yes	Supercritical	Yes

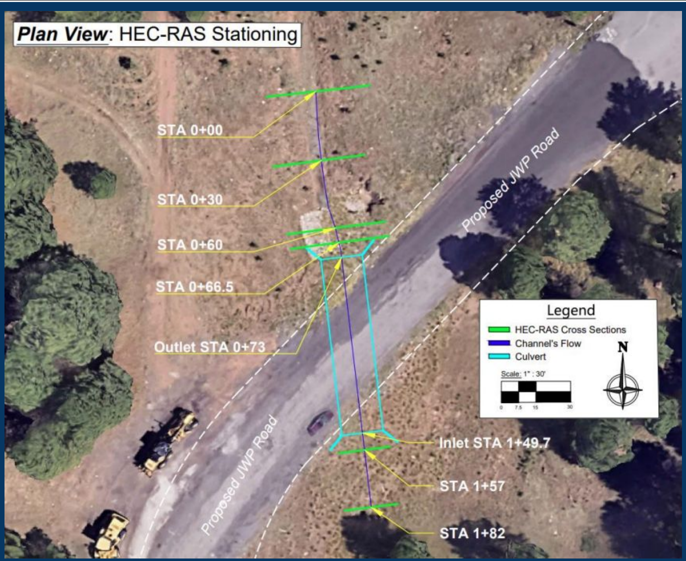

Figure 38: Plan view of proposed channel

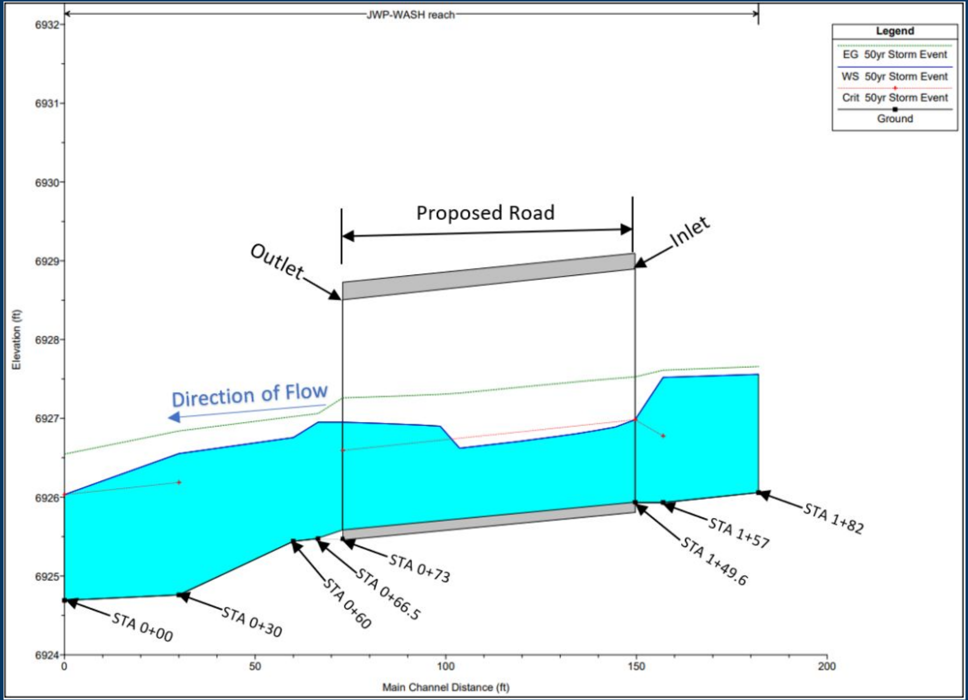

Figure 39: Profile view of proposed channel

Final Hydraulic Design

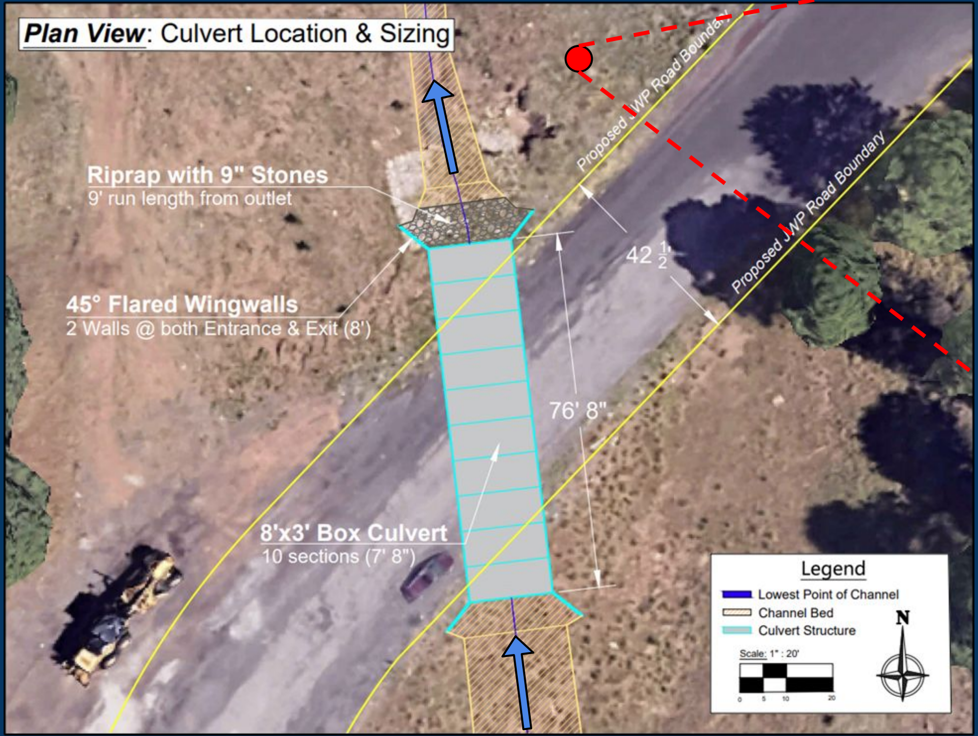

Figure 40: Plan view of final hydraulic design

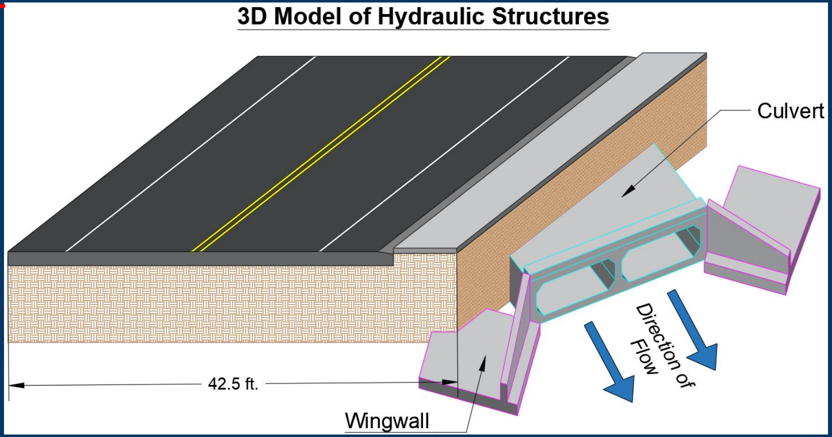

Figure 41: 3D model of roadway and culvert

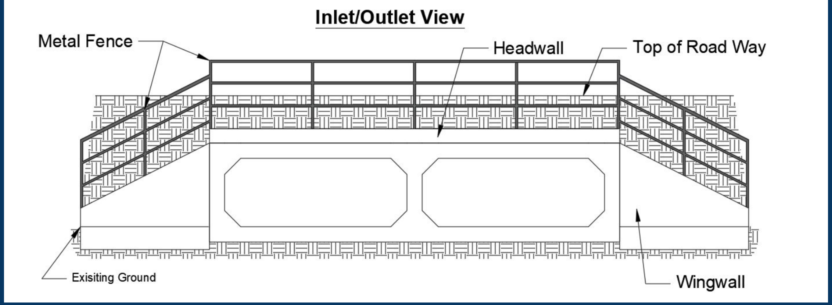

Figure 42: Cross-section view of culvert

Construction Cost Estimate

Roadway Cost:
- $4,366,334

Hydraulic Structure Cost:
- $99,688

Table 14: General material cost of project

Roadway and Hydraulic Structure				
ITEM	Quantity	Unit	Unit Price	Cost
Roadway:				
6" Asphatic Concrete over 10" MSL ABC Layer	30800	SY	$65	$2,002,000
Traffic Signal Installation	2	EA	$442,345	$884,690
Concrete Sidewalk	47520	SF	$16	$760,320
Streetlight	52	EA	$6,850	$356,200
Vertical Curb and Gutter	7920	LF	$25	$198,000
Remove Existing Tree	120	EA	$610	$73,200
White Bike Lane Striping	15840	LF	$2	$31,680
6" Double Yellow Stripe Marking	7920	LF	$4	$31,680
Roadway Earthwork (Cut & Fill)	1212	CY	$21	$25,452
40 MPH Speed Limit Sign	2	EA	$750	$1,500
Do Not Pass Sign	2	EA	$550	$1,100
Pavement Arrow Marking	4	EA	$125	$500
Crosswalk Marking	6	LF	$2	$12
Hydraulic Structure:				
Precast Concrete Box Culvert	1	EA	$66,375	$66,375
Flared Wingwalls	4	EA	$3,750	$15,000
Outlet Protection (RipRap)	121.5	CY	$75	$9,113
Inlet/Outlet Headwall	2	EA	$2,500	$5,000
Hydraulic Earthwork (Cut & Fill)	200	CY	$21	$4,200
TOTAL				$4,466,022

Project Impacts

Social

- Enhanced accessibility for local residents and businesses
- Initial disruption in traffic pattern within the immediate project vicinity

Economic

- Increase in property values and business traffic in adjacent area
- Heightened noise pollution

Environmental

- Reduced erosion along roadside
- Runoff from road surface during and after construction

Figure 43: Impacts Icon [7]

References

[1] “PTV VISTRO.” *Traffic Engineering Software PTV Vistro | PTV Group*, www.ptvgroup.com/en-us/products/traffic-engineering-software-ptv-vistro. Accessed 17 Mar. 2024.

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[4] “UrbanReview: Saint Louis.” – *St. Louis Fails At Crosswalks, Part 2UrbanReview | ST LOUIS*, www.urbanreviewstl.com/2016/02/st-louis-fails-at-crosswalks-part-2/. Accessed 17 Mar. 2024.

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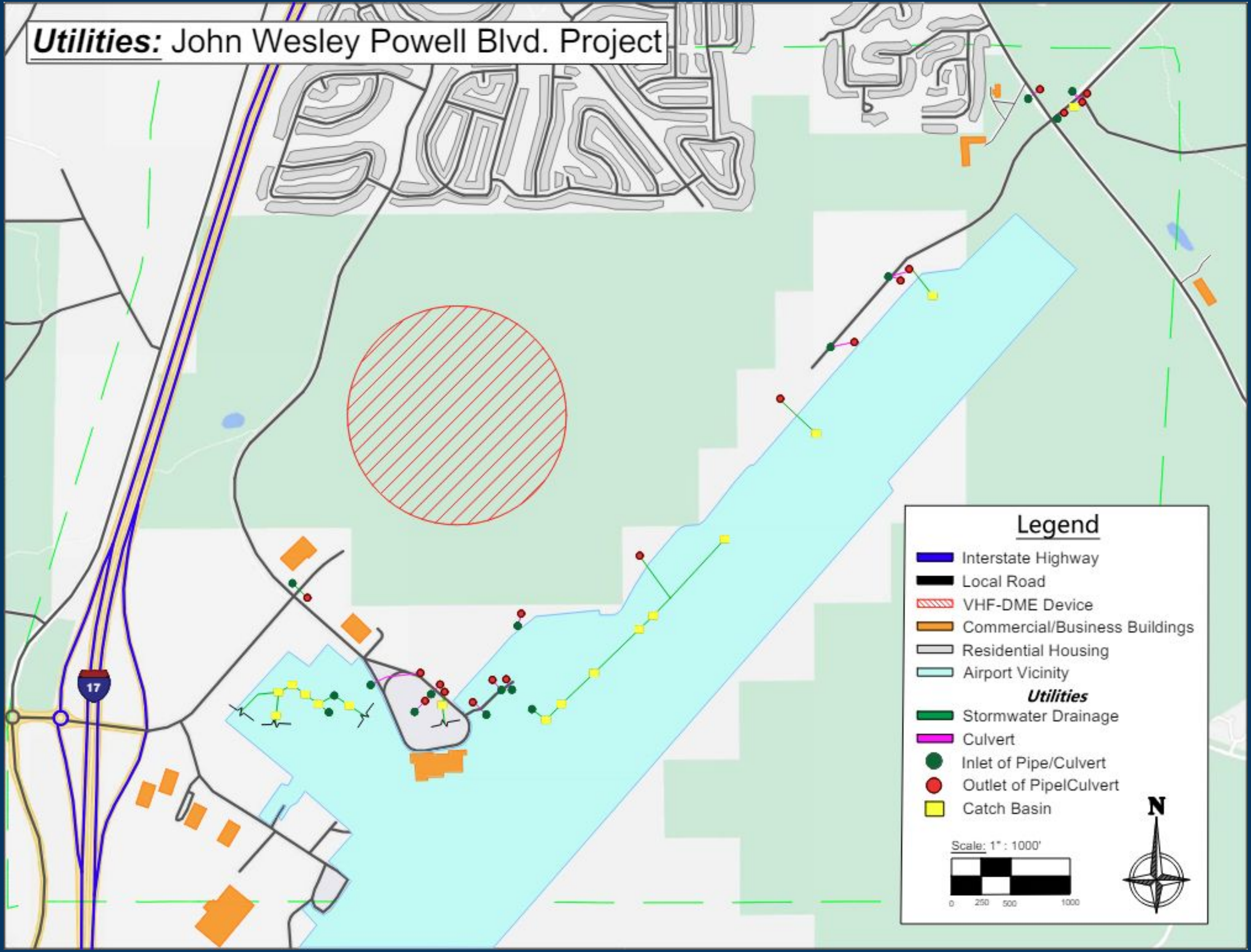
[6] United States Department of Agriculture , "Web Soil Survey," 31 July 2019. [Online]. Available: https://websoilsurvey.nrcs.usda.gov/app/. [Accessed 20 January 2024].

[7] “Impacts Icon.” *Master Recycler Program*, https://www.masterrecycler.org/news/2019/11/6/triple-bottom-line-applied-in-portland . Accessed 17 Mar. 2024

Appendix

See the following slides for additional information


Utilities: John Wesley Powell Blvd. Project
17
Legend
Interstate Highway
Local Road
VHF-DME Device
Commercial/Business Buildings
Residential Housing
Airport Vicinity
Utilities
Stormwater Drainage
Culvert
Inlet of Pipe/Culvert
Outlet of PipelCulvert
Catch Basin
N
Scale: 1" : 1000'
0 250 500 1000

Worksheet 2: Runoff curve number and runoff

Project	By	Date
JWP West	Logan McFarland	2/7/24
Location	**Checked**	**Date**
Flagstaff, Az	Logan McFarland	2/8/24

Check one: ☒ Present ☐ Developed

1. Runoff curve number

Soil name and hydrologic group (appendix A)	Cover description (cover type, treatment, and hydrologic condition; percent impervious; unconnected/connected impervious area ratio)	CN [1] Table 2-2	CN [1] Figure 2-3	CN [1] Figure 2-4	Area ☒ acres ☐ mi² ☐ %	Product of CN x area
B	Paymaster family fine Sandy loam, 0 to 3 percent Slopes	86			8.2	705
D	Telephone gravely Sandy loam, 0 to 15 percent Slopes	84			32.8	2755
D	Telephone – Daze Complex, 0 to 8 Percent Slopes	84			73.8	6199

[1] Use only one CN source per line

Totals ➡ 114.8 | 9659

CN (weighted) = $\frac{\text{total product}}{\text{total area}} = \frac{9659}{114.8} = 84.14$; Use CN ➡ 84

2. Runoff

		Storm #1	Storm #2	Storm #3
Frequency	yr	10	50	100
Rainfall, P (24-hour)	in	3.08	4.12	4.60
Runoff, Q (Use P and CN with table 2-1, figure 2-1, or equations 2-3 and 2-4)	in	1.58	2.48	2.91

$S = \frac{1000}{84} - 10 = 1.9$

Worksheet 3: Time of Concentration (T_c) or travel time (T_t)

Project	By	Date
JWP West	Logan McFarland	2/7/24
Location	**Checked**	**Date**
Flagstaff, AZ	Logan McFarland	2/8/24

Check one: ☒ Present ☐ Developed

Check one: ☒ T_c ☐ T_t through subarea

Notes: Space for as many as two segments per flow type can be used for each worksheet. Include a map, schematic, or description of flow segments.

Sheet flow (Applicable to Tc only)

Segment ID			Comments
1. Surface description (table 3-1)		Grass	
2. Manning's roughness coefficient, n (table 3-1)		0.15	
3. Flow length, L (total L † 300 ft)	ft	292	
4. Two-year 24-hour rainfall, P_2	in	2.13	
5. Land slope, s	ft/ft	0.01027	
6. $T_t = \frac{0.007\,(nL)^{0.8}}{P_2^{0.5}\,s^{0.4}}$ Compute T_t	hr	0.6158	+ = 0.6158

Shallow concentrated flow

Segment ID			Comments
7. Surface description (paved or unpaved)		unpaved	Paved areas
8. Flow length, L	ft	7,214	
9. Watercourse slope, s	ft/ft	0.0083	
10. Average velocity, V (figure 3-1)	ft/s	1.5	
11. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr	1.336	+ = 1.336

Channel flow

Segment ID			Comments
12. Cross sectional flow area, a	ft²	105.22	
13. Wetted perimeter, p_w	ft	27	
14. Hydraulic radius, $r = \frac{a}{p_w}$ Compute r	ft	3.897	
15 Channel slope, s	ft/ft	0.0125	
16. Manning's roughness coefficient, n		0.025	Rubble bottom
17. $V = \frac{1.49\,r^{2/3}\,s^{1/2}}{n}$ Compute V	ft/s	16.50	
18. Flow length, L	ft	320	
19. $T_t = \frac{L}{3600\,V}$ Compute T_t	hr	0.00539	+ = 0.00539

20. Watershed or subarea T_c or T_t (add T_t in steps 6, 11, and 19) Hr 1.957

Worksheet 4: Graphical Peak Discharge method

Project	By	Date
JWP West	Logan McFarland	2/7/24
Location	**Checked**	**Date**
Flagstaff, Az	Logan McFarland	2/8/24

Check one: ☒ Present ☐ Developed

1. Data

- Drainage area .... A_m = 0.18 mi² (acres/640)
- Runoff curve number .... CN = 84 (From worksheet 2)
- Time of concentration .... T_c = 1.957 hr (From worksheet 3)
- Rainfall distribution .... = II (I, IA, (II), III)
- Pond and swamp areas sprea throughout watershed .... = 0 percent of A_m (0.00 acres or mi² covered)

		Storm #1	Storm #2	Storm #3
2. Frequency	yr	10	50	100
3. Rainfall, P (24-hour)	in	3.08	4.12	4.60
4. Initial abstraction, I_a (Use CN with table 4-1)	in	0.381	0.381	0.381
5. Compute I_a/P		0.124	0.092	0.083
6. Unit peak discharge, q_u (Use T_c and I_a/P with exhibit 4– ____)	csm/in	230	230	230
7. Runoff, Q (From worksheet 2) Figure 2-6	in	1.58	2.48	2.91
8. Pond and swamp adjustment factor, F_p (Use percent pond and swamp area with table 4-2. Factor is 1.0 for zero percent pond ans swamp area.)		1.0	1.0	1.0
9. Peak discharge, q_p (Where $q_p = q_u A_m Q F_p$)	ft³/s	65.4	102.3	120.5

Existing Conditions vs. Proposed Improvements of Cross-Sections HEC-RAS				
Variables	**Existing Conditions**	**Compliance**	**Proposed Improvements**	**Compliance**
STA	**1+82**		**1+82**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	2.5	Yes	2.5	Yes
Water surface elevation (ft)	6929.1	N/A	6927.6	N/A
Freeboard (ft)	0.0	No	0.3	No
Flow Regime	Subcritical	Yes	Subcritical	Yes
STA	***1+32***		**1+57**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	4.0	Yes	2.4	Yes
Water surface elevation (ft)	6928.7	N/A	6927.5	N/A
Freeboard (ft)	0.0	No	0.4	No
Flow Regime	Subcritical	Yes	Subcritical	Yes
STA	**0+90**		**0+66.5**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	4.3	Yes	2.67	Yes
Water surface elevation (ft)	6927.5	N/A	6927.0	N/A
Freeboard (ft)	0.0	No	0.7	No
Flow Regime	Supercritical	No	Subcritical	Yes
STA	**0+60**		**0+60**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	4.9	Yes	4.13	Yes
Water surface elevation (ft)	6926.8	N/A	6926.8	N/A
Freeboard (ft)	0.0	No	0.0	No
Flow Regime	Subcritical	Yes	Subcritical	Yes
STA	**0+30**		**0+30**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	4.5	Yes	4.3	Yes
Water surface elevation (ft)	6926.6	N/A	6926.6	N/A
Freeboard (ft)	0.0	No	0.0	No
Flow Regime	Subcritical	Yes	Subcritical	Yes
STA	**0+00**		**0+00**	
Flow rate (cfs)	103	Yes	103	Yes
Velocity (ft/s)	5.6	Yes	5.8	Yes
Water surface elevation (ft)	6926.1	N/A	6926.0	N/A
Freeboard (ft)	0.2	No	0.3	No
Flow Regime	Supercritical	No	Critical	Yes

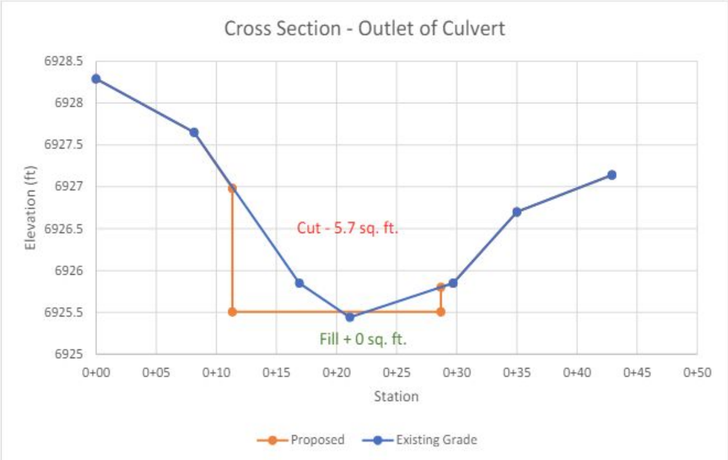
Channel Requirements		**Section of SWMDM**
Flow Rate	Shall be designed for the 25-year design storm at a minimum	4.3
Water Surface Elevation	Shall be consistent with maintaining a minimum freeboard of 1-foot throughout the channel	4.3.4
Velocity	Maximum velocity of 18 ft/s	4.3.3
Freeboard	Minimum freeboard of 1-foot	4.3.4
Flow Regime	Earth lined channels should *not* be operating at supercritical flow	4.3.3

Culvert Requirements		**Section of SWMDM**
Flow Rate	Culverts near a collector/arterial street should convey a 50-year storm event without overtopping (103 cfs)	5.2.1
Water Surface Elevation	Minimum freeboard of 2-feet at inlet with respect to the low chord	5.4.2.2
Velocity	Minimum velocity of 3 ft/s	5.2
Headwater	HW/D ratio must be ≤ 1.2 for cross sectional area greater than 30 sq. ft.	5.2.3.1
Freeboard	Minimum freeboard of 1-foot	4.3.4
Flow Regime	Avoid Froude number in the range of 0.86-1.13	4.3.3

Channel Cut/Fill Analysis (cu. ft.)				
Cross-Section	*Cut (-)*		*Fill (+)*	
STA 0+00				
STA 0+30	326		99	
STA 0+60		85		21
STA 0+66.5	81		21	
Outlet				
Inlet	329		0	
STA 1+57		1429		1
STA 1+82				
Total Cut:	**- 78 cu.yd.**			

Earth Work Calculations for Culvert		
Type	*Description*	*Cut/Fill Total (cu. yd.)*
Cut (-)	Excavation to place culvert	221.5
Cut (-)	Wingwall installation	8.4
Fill (+)	Fill wingwalls	19.3
Fill (+)	Fill above culvert to road	61.7
Fill (+)	Fill other parts of culvert	28
Total Cut:		**- 120.9 cu. yd.**

Cut/Fill Summary for Hydraulic	
Total Cut for Culvert	- 120.9 cu. yd.
Total Cut for Channel	- 78 cu.yd.
Summation of Total Cut	**- 198.9 cu.yd.**



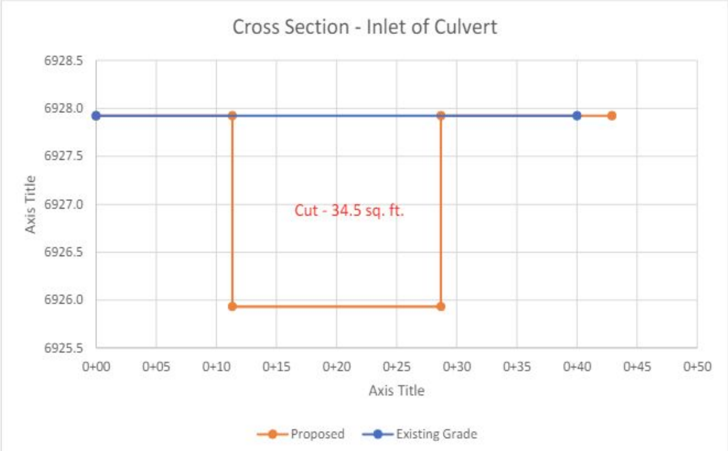
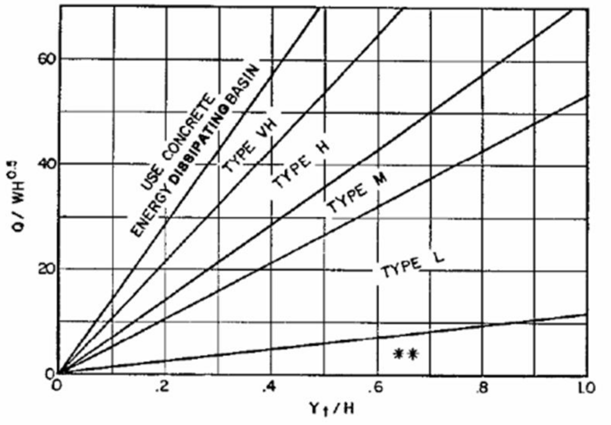


Table 11.4 Classification and Gradation Of Ordinary Riprap	
Riprap Classification	**D_{50} (inches)**
Type VL	6
Type L	9
Type M	12
Type H	18
Type VH	24

Figure 11.3 Riprap Protection at Rectangular Conduit Outlets

(from UDFCD, 2001)



Use H_a instead of H whenever culvert has supercritical flow in the barrel.
**Use Type L for a distance of 3H downstream.

Rectangular culvert:

$$\frac{\left(\frac{d_{50}}{H}\right)\left(\frac{Y_t}{H}\right)}{\frac{Q}{WH^{1.5}}} = 0.014 \quad \textbf{11.3}$$

Solving for d_{50}:

$$d_{50} = \frac{0.014QH^{0.5}}{WY_t} \quad \textbf{11.4}$$

where:

- ***W*** = width of rectangular culvert, in feet, and
- ***H*** = height of rectangular culvert, in feet.

Q (cfs)	W (ft)	H (ft)	Yt (ft)	Yn (ft)
103	16	3	1.48	1.48

d50 (ft)	0.105

$$H_a = \frac{(H + Y_n)}{2} \quad \textbf{11.6}$$

in which the maximum value of H_a shall not exceed H, and

where:

- ***D_a*** = parameter to use in place of D_c in Figure 11.2 when flow is supercritical,
- ***D_c*** = diameter of circular culvert, in feet,
- ***H_a*** = parameter to use in place of *H* in Figure 11.3 when flow is supercritical,
- ***H*** = height of rectangular culvert, in feet, and
- ***Y_n*** = normal depth of supercritical flow in the culvert.

Ha	2.24
Yt/H	0.660714
Q/WH^0.5	3.716692
Run length (ft)	9
Type L, D50 (in)	9