RUNOFF ENGINEERING INC.

FLAGSTAFF FAMILY FOOD BANK

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College of Engineering, Forestry & Natural Sciences

BACKGROUND

Flagstaff Family Food Bank transports, stores, and distributes food and commodities to people in need. The staff works with social service agencies, churches, civic organizations, and national hunger relief organizations.

Figure 1: Food Bank Front Entrance

Problem Statement – Food Bank is experiencing significant flooding at the entrance of the building.

Purpose – Find a solution which will alleviate the flooding.

LOCATION

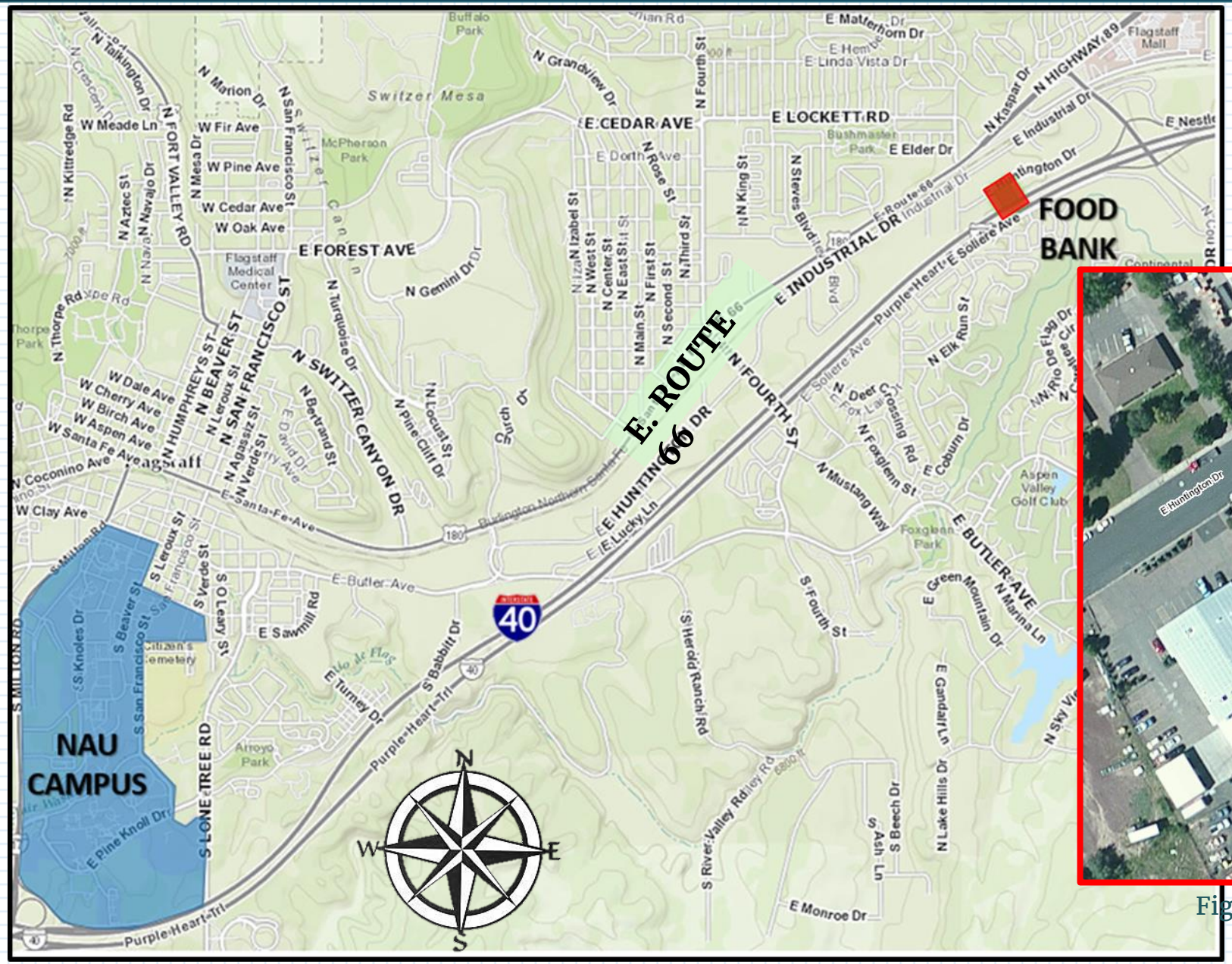


Figure 2: Flagstaff Network

Figure 3: Aerial View of Food Bank Property

COLLABORATION

- Neighboring Companies
  - Neighborhood Survey
    - Past and Present Flooding Issue
- City of Flagstaff
  - Rick Barrett, City Engineer
  - Donna Curry, Engineering Specialist
    - Official Documents
      - City Plans
      - Elevational Data
      - Letters
      - Hydrology Data

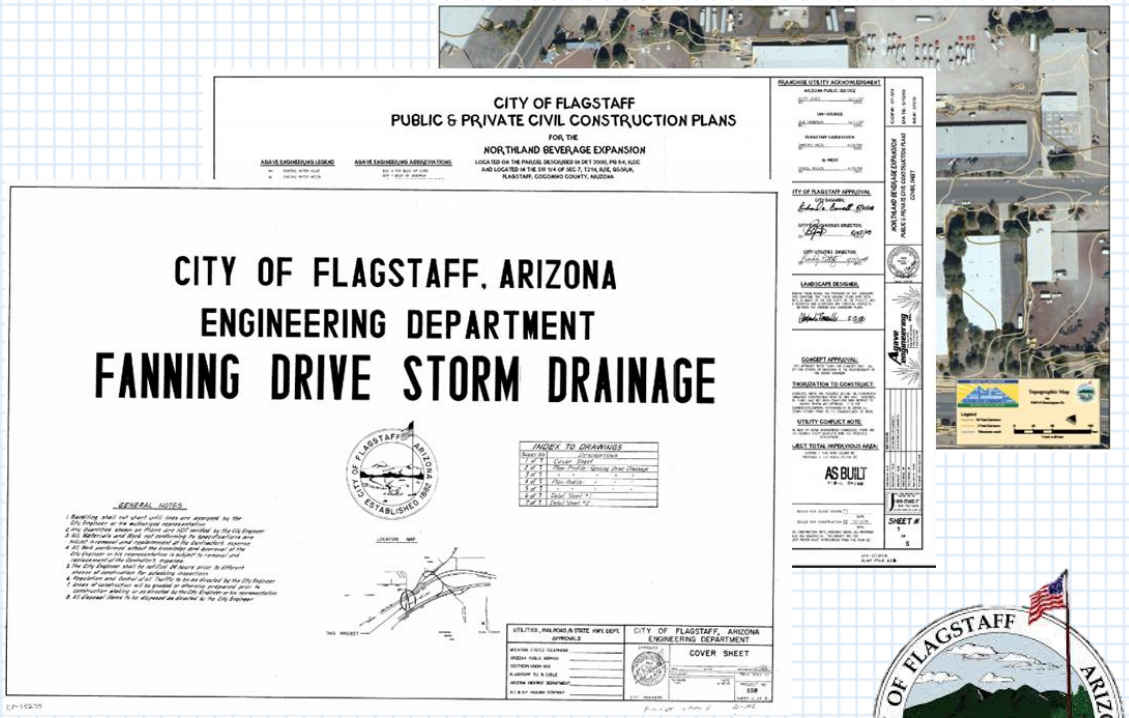


Figure 4: Official Documents Example [2]

[3]

FLOODING

High Intensity Flooding

Figure 7: BEFORE HEAVY RAIN EVENT [1]

Figure 8: DURING HEAVY RAIN EVENT: Monsoon (July and August) [1]

POTENTIAL FLOODING SOURCE

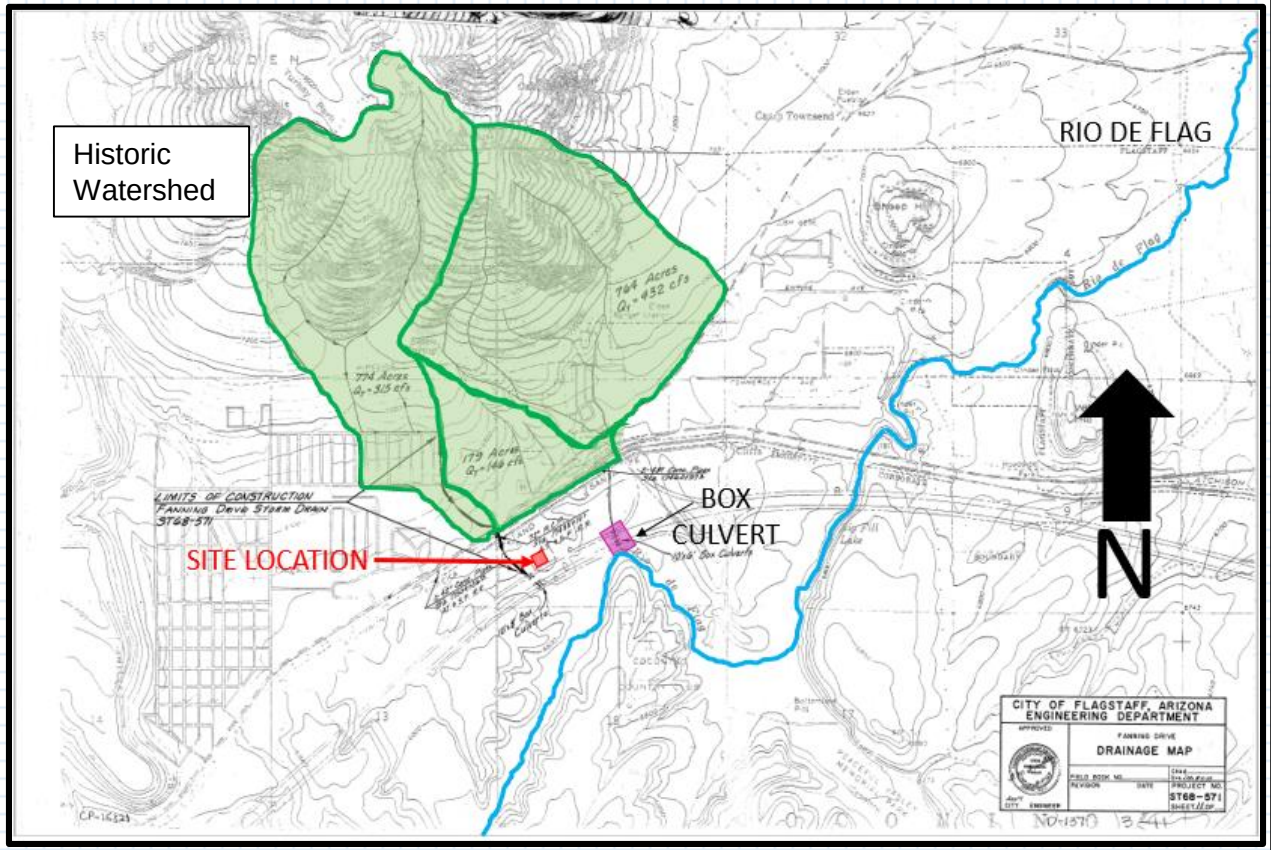


Figure 5: Watershed Near Humphreys Peak [2]

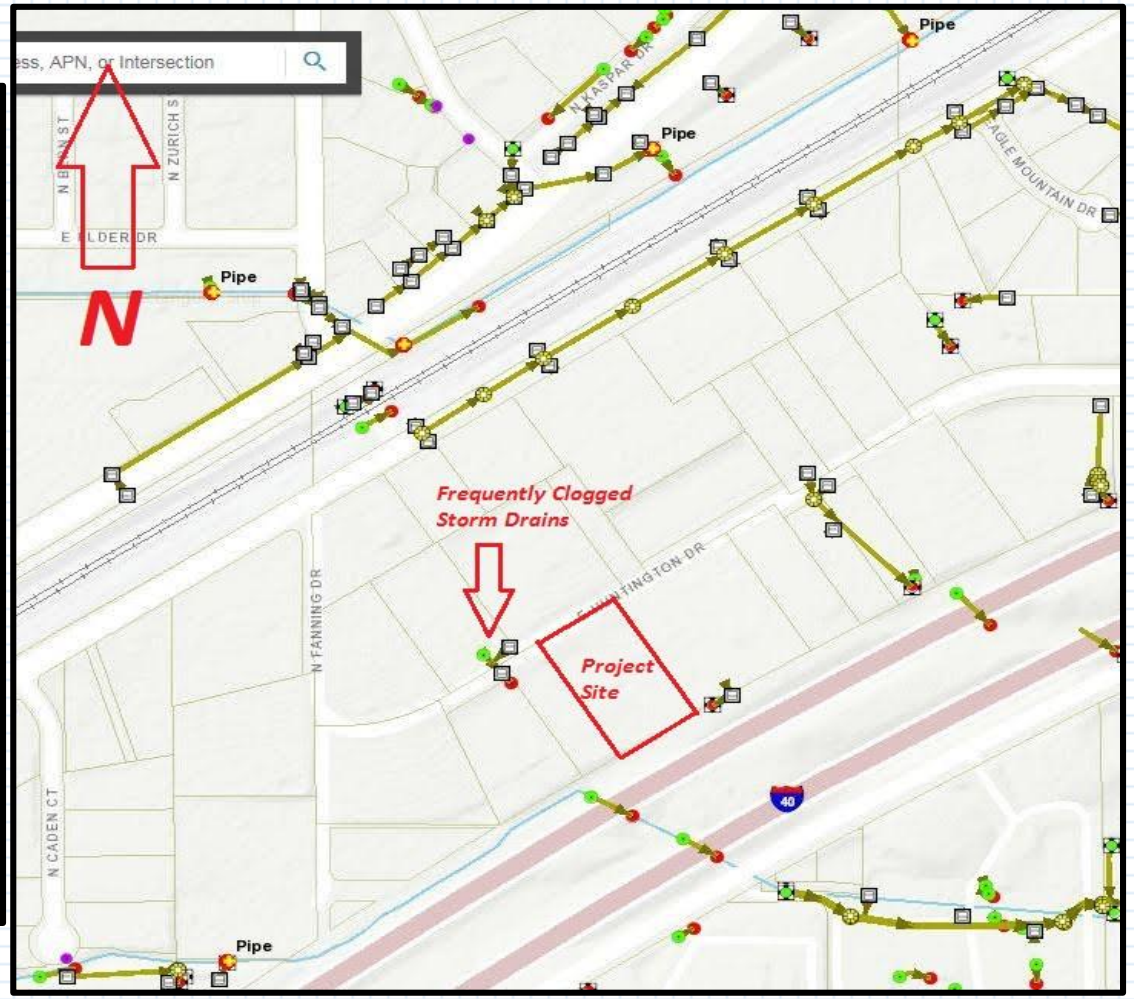


Figure 6: Existing Pipelines Near Food Bank [2]

ON-SITE EVALUATION

Figure 9: North-West Corner of Food Bank Property
(Food Bank Property meets E. Huntington Rd.)

- Understand the physical topography of the property and neighborhood
- Determine how water comes onto property
- Current flooding alleviation
- Determine how water flows off of the property
- E. Huntington Rd. elevation compared to Food Bank Property Elevation.

OBSERVED FLOODING

Low Intensity Flooding

Figure 10: Front Entrance

Figure 11: Front Concrete Barricades

Figure 12: Further Flooding Prevention (Sandbags)

PROJECT EVOLUTION

- **Flooding Area**
  - Neighborhood Assessment
  - Collaboration with the City of Flagstaff
    - Stakeholders
    - Liability
    - Legal Terms: Property rights, right of way, ADOT

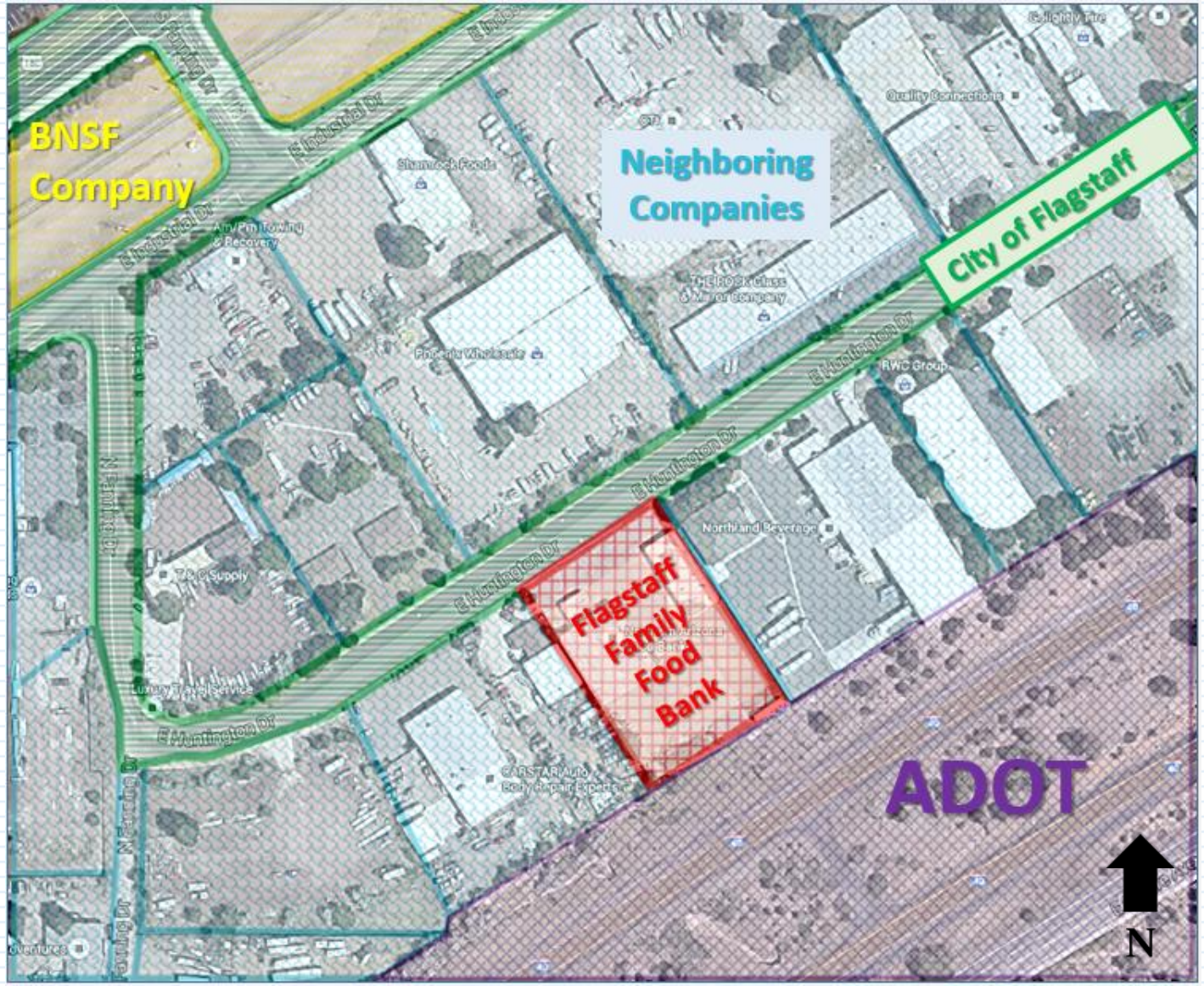


Figure 13: Property Breakdown

SURVEYING: Planning

Figure 14: On-site Evaluation

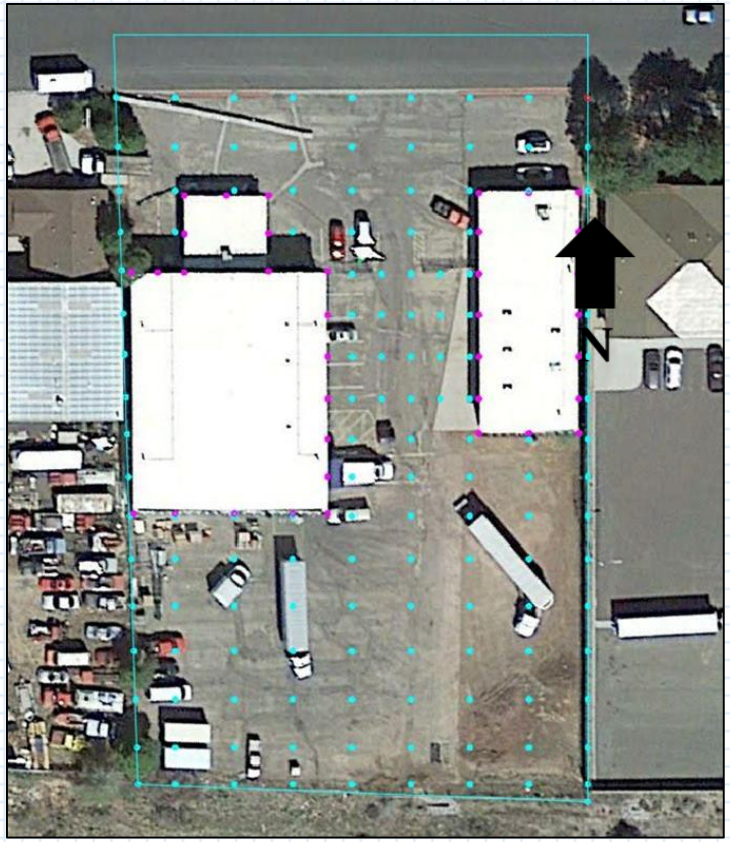


Figure 15: Survey Point Grid

Figure 16: Surveying Property

SURVEYING: Topographical Map

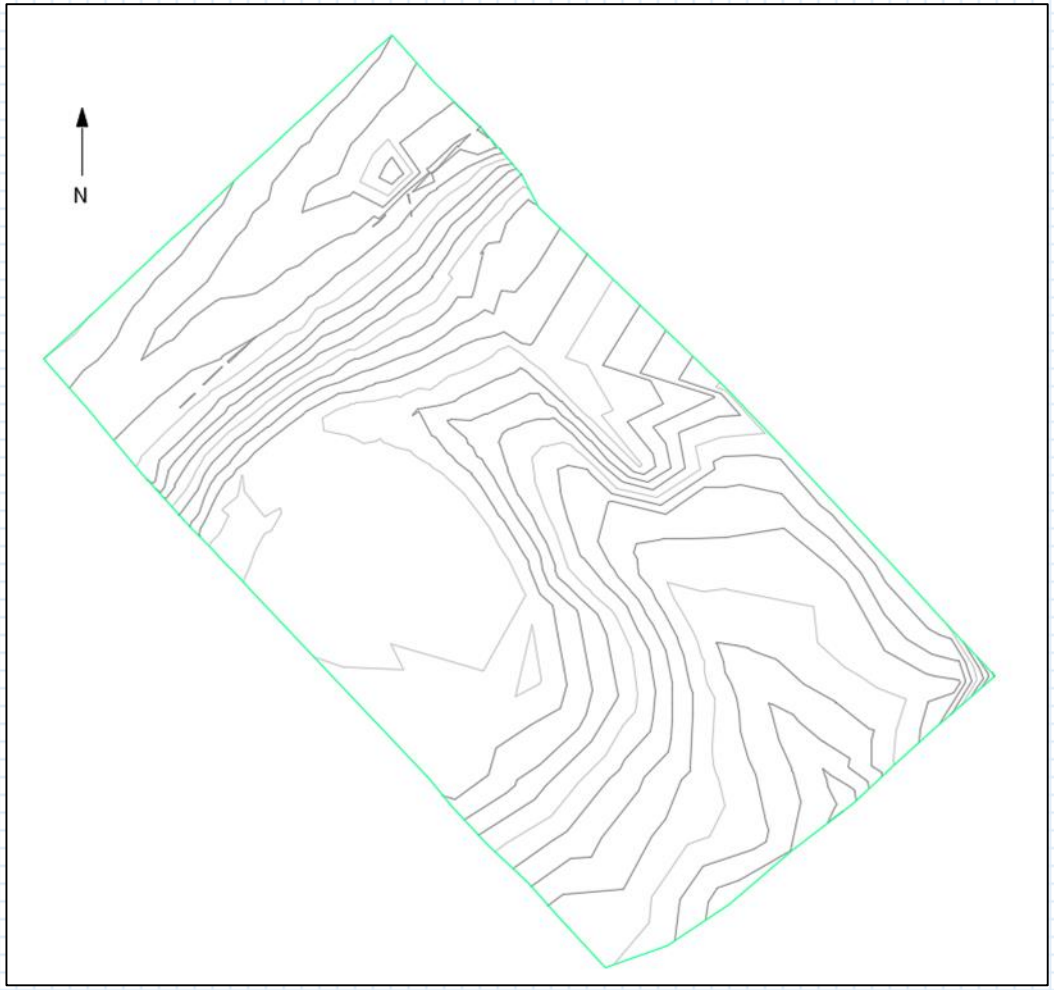


Figure 17: Topographic Map of Property

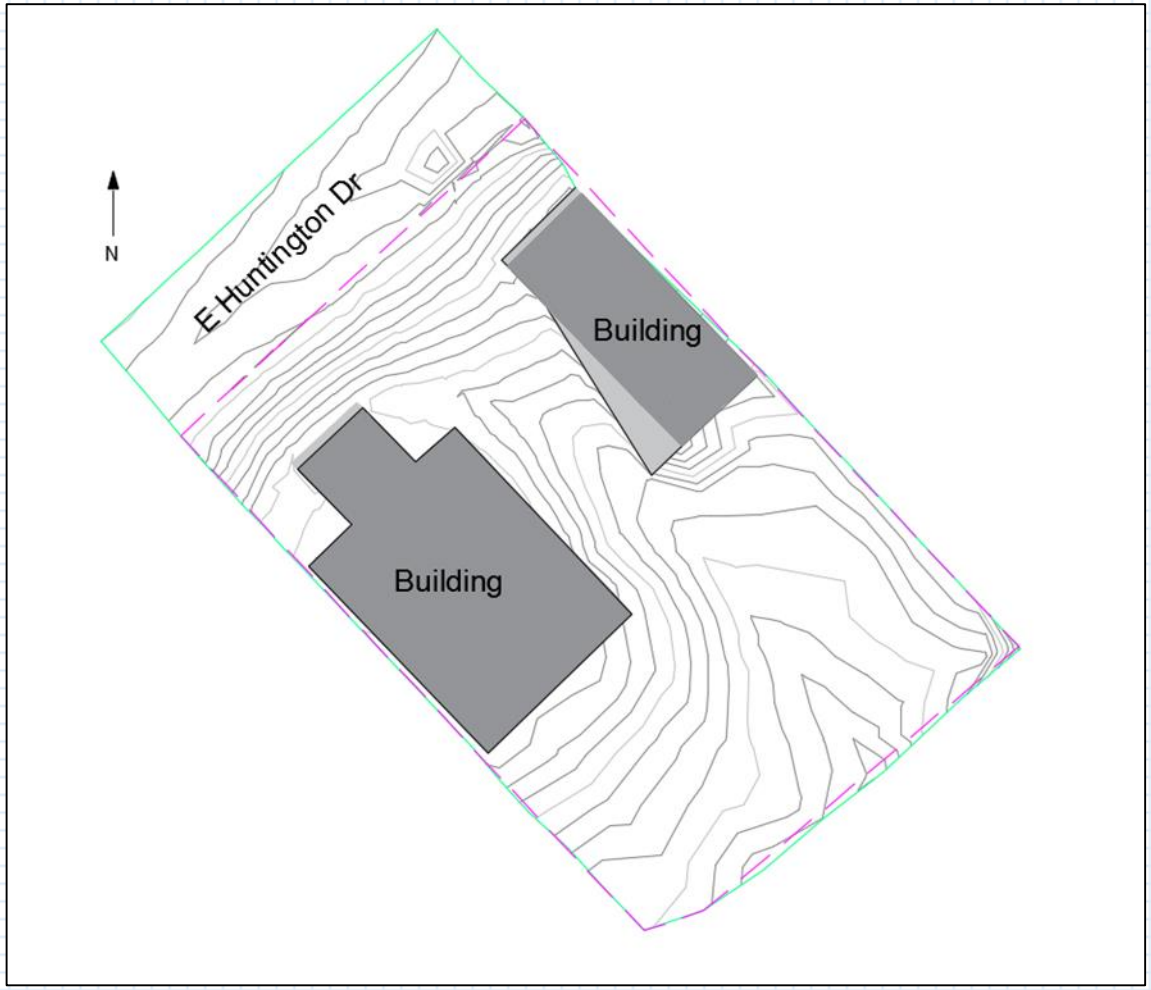


Figure 18: Topographic Map of Property W/ Food Bank Buildings

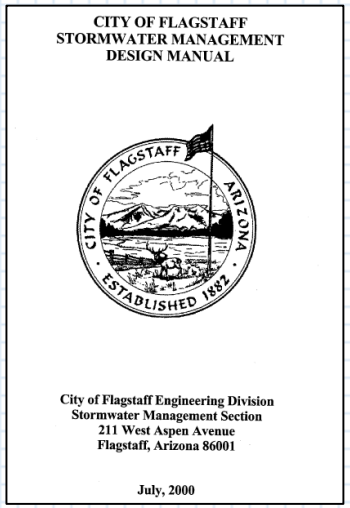
CODES AND STANDARDS

- Title 13 – Engineering Design Standards and Specifications for New Infrastructure [4]

- 13-08-001-0001 STORMWATER MANAGEMENT
  - "The design and construction of all public and private stormwater management facilities shall be in accordance… with the City of Flagstaff Stormwater Management Design Manual and these Standards." [4]

- City of Flagstaff Stormwater Management Design Manual (2000)
  - Chapter 3: Hydrology
  - Chapter 5: Culverts
  - Chapter 6: Pavement Drainage
  - Chapter 7: Storm Drains
  - Chapter 8: Storage and Detention Facilities
  - Chapter 10: Erosion and Sediment Control
  - Chapter 11: Energy Dissipaters [4]

HYDROLOGY ANALYSIS



[4]

City of Flagstaff Stormwater Management Design Manual

Rationale Formula

Partially Full Flowing Pipes Criteria

Runoff Coefficients

[5]

NOAA Atlas 14 Data

Rainfall Intensities

[6]

Coconino County Maps Online

Property Boundaries

STORMWATER RUNOFF EVALUATION

Table 1: Runoff Intensity, NOAA Atlas 14 [5]

PDS-based precipitation frequency estimates with 90% confidence intervals (in inches)[1]

Duration	Average recurrence interval (years)									
	1	2	5	10	25	50	100	200	500	1000
5-min	0.217 (0.189-0.252)	0.282 (0.245-0.325)	0.380 (0.331-0.438)	0.461 (0.398-0.531)	0.578 (0.495-0.663)	0.675 (0.572-0.774)	0.780 (0.653-0.897)	0.895 (0.736-1.03)	1.06 (0.856-1.23)	1.21 (0.951-1.41)
10-min	0.330 (0.288-0.383)	0.428 (0.373-0.495)	0.578 (0.503-0.667)	0.701 (0.605-0.809)	0.879 (0.753-1.01)	1.03 (0.870-1.18)	1.19 (0.993-1.36)	1.36 (1.12-1.57)	1.62 (1.30-1.88)	1.83 (1.45-2.15)
15-min	0.410 (0.357-0.475)	0.531 (0.462-0.614)	0.716 (0.624-0.827)	0.870 (0.750-1.00)	1.09 (0.934-1.25)	1.27 (1.08-1.46)	1.47 (1.23-1.69)	1.69 (1.39-1.94)	2.00 (1.61-2.33)	2.27 (1.79-2.67)
30-min	0.552 (0.481-0.639)	0.715 (0.623-0.827)	0.965 (0.840-1.11)	1.17 (1.01-1.35)	1.47 (1.26-1.68)	1.71 (1.45-1.97)	1.98 (1.66-2.28)	2.27 (1.87-2.62)	2.70 (2.17-3.13)	3.06 (2.42-3.59)
60-min	0.683 (0.595-0.791)	0.885 (0.771-1.02)	1.19 (1.04-1.38)	1.45 (1.25-1.67)	1.82 (1.56-2.08)	2.12 (1.80-2.43)	2.45 (2.05-2.82)	2.81 (2.31-3.24)	3.34 (2.69-3.88)	3.79 (2.99-4.45)
2-hr	0.805 (0.713-0.918)	1.02 (0.900-1.16)	1.34 (1.19-1.53)	1.61 (1.42-1.83)	2.01 (1.75-2.28)	2.34 (2.01-2.66)	2.71 (2.30-3.07)	3.11 (2.59-3.53)	3.69 (3.01-4.22)	4.18 (3.34-4.81)
3-hr	0.888 (0.793-1.01)	1.12 (1.00-1.27)	1.44 (1.28-1.62)	1.71 (1.51-1.93)	(1.		2.79 (2.40-3.16)	3.18 (2.70-3.62)	3.77 (3.13-4.31)	4.27 (3.47-4.92)
6-hr	1.09 (0.987-1.21)	1.35 (1.23-1.50)	1.68 (1.51-1.86)	1.96 (1.76-2.17)	(2.		3.07 (2.69-3.40)	3.46 (2.99-3.86)	4.04 (3.41-4.53)	4.51 (3.74-5.10)
12-hr	1.40 (1.27-1.54)	1.73 (1.57-1.91)	2.11 (1.92-2.33)	2.43 (2.20-2.68)	2.86 (2.58-3.16)	3.20 (2.86-3.53)	3.55 (3.15-3.93)	3.92 (3.44-4.35)	4.46 (3.86-4.99)	4.90 (4.19-5.52)
24-hr	1.65 (1.50-1.82)	2.06 (1.87-2.28)	2.57 (2.32-2.84)	2.98 (2.68-3.29)	3.54 (3.18-3.91)	3.99 (3.56-4.40)	4.46 (3.96-4.91)	4.93 (4.36-5.45)	5.58 (4.89-6.19)	6.10 (5.29-6.78)
2-day	1.94 (1.77-2.15)	2.42 (2.20-2.68)	3.02 (2.74-3.33)	3.50 (3.17-3.86)	4.17 (3.76-4.60)	4.70 (4.23-5.19)	5.25 (4.69-5.80)	5.82 (5.17-6.44)	6.60 (5.80-7.32)	7.22 (6.29-8.04)
3-day	2.11 (1.92-2.33)	2.63 (2.40-2.91)	3.29 (2.99-3.64)	3.83 (3.48-4.23)	4.59 (4.14-5.06)	5.19 (4.67-5.73)	5.83 (5.21-6.43)	6.49 (5.76-7.17)	7.40 (6.50-8.21)	8.13 (7.07-9.05)
4-day	2.28 (2.08-2.51)	2.85 (2.59-3.15)	3.57 (3.25-3.94)	4.17 (3.78-4.60)	5.01 (4.53-5.53)	5.68 (5.11-6.27)	6.40 (5.72-7.07)	7.15 (6.34-7.91)	8.20 (7.19-9.10)	9.04 (7.85-10.1)
7-day	2.74 (2.50-2.99)	3.41 (3.12-3.73)	4.24 (3.88-4.63)	4.93 (4.50-5.38)	5.89 (5.36-6.44)	6.67 (6.04-7.29)	7.48 (6.74-8.18)	8.33 (7.46-9.14)	9.51 (8.42-10.5)	10.4 (9.17-11.6)
10-day	3.11 (2.84-3.40)	3.86 (3.53-4.24)	4.77 (4.36-5.23)	5.49 (5.01-6.02)	6.47 (5.88-7.09)	7.23 (6.55-7.93)	8.01 (7.22-8.79)	8.79 (7.88-9.67)	9.86 (8.76-10.9)	10.7 (9.41-11.8)
20-day	4.18 (3.83-4.58)	5.19 (4.76-5.68)	6.30 (5.77-6.89)	7.15 (6.53-7.80)	8.25 (7.51-9.01)	9.06 (8.23-9.89)	9.86 (8.93-10.8)	10.6 (9.61-11.7)	11.6 (10.4-12.8)	12.4 (11.0-13.6)
30-day	5.14 (4.70-5.64)	6.37 (5.83-6.99)	7.69 (7.03-8.43)	8.70 (7.92-9.52)	9.98 (9.07-10.9)	10.9 (9.89-12.0)	11.8 (10.7-13.0)	12.7 (11.4-14.0)	13.8 (12.4-15.2)	14.6 (13.1-16.2)
45-day	6.17 (5.63-6.81)	7.65 (6.98-8.44)	9.24 (8.43-10.2)	10.5 (9.54-11.6)	12.1 (11.0-13.3)	13.3 (12.0-14.6)	14.4 (13.0-15.9)	15.6 (14.0-17.2)	17.0 (15.2-18.9)	18.1 (16.1-20.1)
60-day	7.23 (6.61-7.96)	8.97 (8.19-9.86)	10.8 (9.82-11.8)	12.1 (11.0-13.3)	13.8 (12.5-15.2)	15.0 (13.6-16.5)	16.2 (14.6-17.8)	17.3 (15.6-19.1)	18.7 (16.8-20.7)	19.7 (17.6-21.8)

1.45 (1.25-1.67)

[1] Precipitation frequency (PF) estimates in this table are based on frequency analysis of partial duration series (PDS).

Numbers in parenthesis are PF estimates at lower and upper bounds of the 90% confidence interval. The probability that precipitation frequency estimates (for a given duration and average recurrence interval) will be greater than the upper bound (or less than the lower bound) is 5%. Estimates at upper bounds are not checked against probable maximum precipitation (PMP) estimates and may be higher than currently valid PMP values.

Please refer to NOAA Atlas 14 document for more information.

Figure 19: Area of Property (Red)

$$Q = CC_tIA$$

- Q = Maximum Rate of Runoff, ft^3/s
- C = Runoff Coefficient
- C_t = Antecedent Precipitation Factor
- I = Rainfall Intensity, in/hr
- A = Drainage Area Tributary to Design Location, acres

$$Q = (0.825)(1.1)\left(1.45\frac{in}{hr}\right)(1.564\ acres) = 2.06\ \frac{ft^3}{s}$$

R.E.I.

DESIGN CALCULATIONS

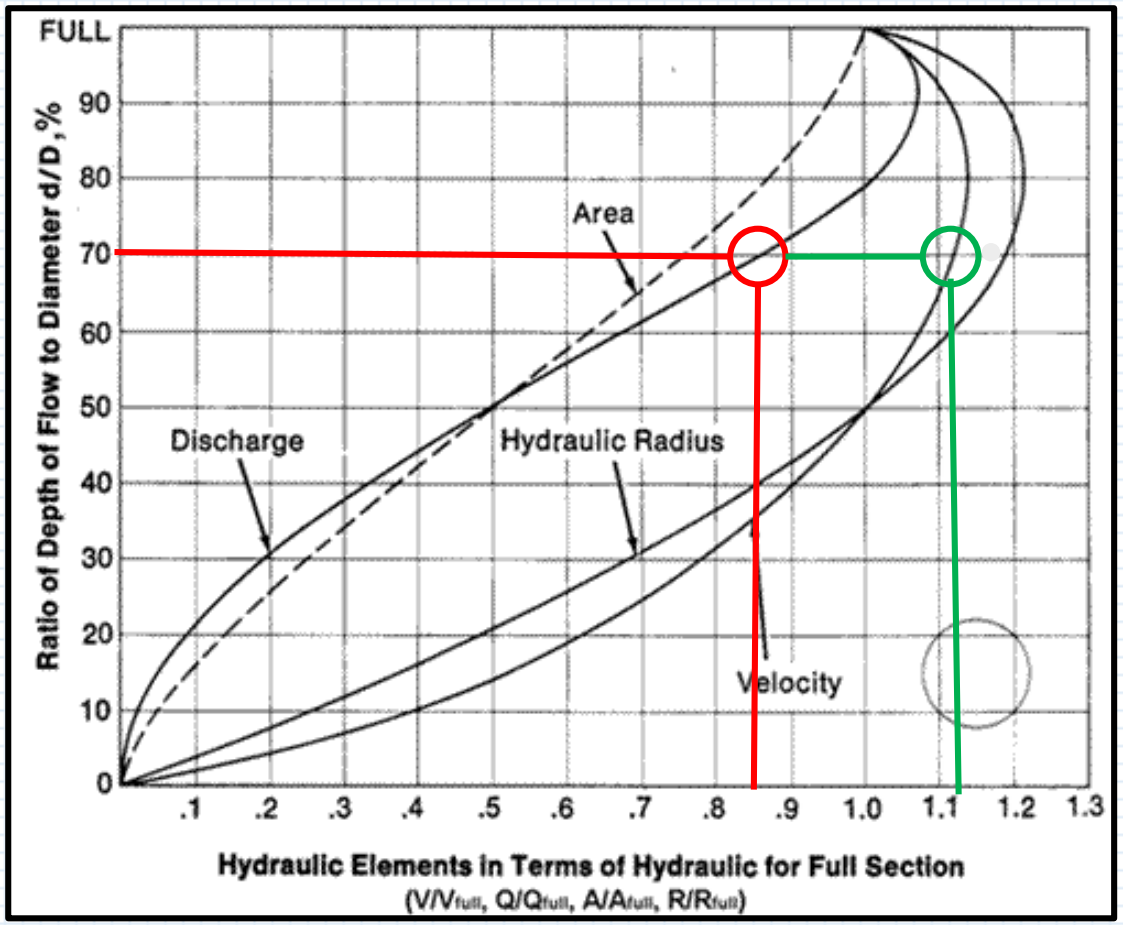


Figure 20: Hydraulic Elements Calculations

Continuity and Manning Equation:

$$Q = VA = A\left(\frac{1}{n}\right)R^{2/3}S^{1/2}$$

$$\frac{Q_{actual}}{Q_{full}} = 0.85$$

$$\frac{V_{actual}}{V_{full}} = 1.12$$

DESIGN CALCULATIONS

Q = 2.06 ft³/s

PIPE SIZING (1% DESIGN SLOPE)

$\frac{d}{D}$=0.70 (CODE)

$\frac{Q_{Actual}}{Q_{full}}$ = 0.85 (CHART)

$$Q_{full} = \frac{2.06\ \frac{ft^3}{s}}{0.85} = 2.42\frac{ft^3}{s}$$

$$Q = VA = A\frac{1}{n}R^{2/3}S^{1/2}$$

$R_{full} = \frac{D}{4}$

n=0.01

Solving for D:

$$2.42\frac{ft^3}{s} = \frac{\pi D^2}{4}\left(\frac{1}{0.01}\right)\left(\frac{D}{4}\right)^{2/3}(0.01)^{1/2}$$

$$2.42\frac{ft^3}{s} = 3.12D^{8/3}$$

$$D = 0.9\ ft \approx 1ft.\ or\ 12\ in$$

Figure 21: Pipe Sizing Calculations Using Q

Verification:

$$\frac{V_{actual}}{V_{full}} = 1.12(Chart)$$

$$V_{full} = \frac{1}{n}R_{full}^{2/3}S^{1/2} = \frac{1}{0.01}\left(\frac{1ft}{4}\right)^{2/3}(0.01)^{1/2}$$

$$V_{full} = 3.97\frac{ft}{s}$$

$$\frac{V_{actual}}{V_{full}} = 1.12(Chart) \rightarrow V_{actual} = 1.12(3.97\ ft/s)$$

$$\frac{V_{actual}}{V_{full}} = 4.44\frac{ft}{s} > 2.0\frac{ft}{s} \therefore Self\ cleaning\ (Code)$$

Figure 22: Verification Calculations

DESIGN CALCULATIONS

Retaining Wall Calculations

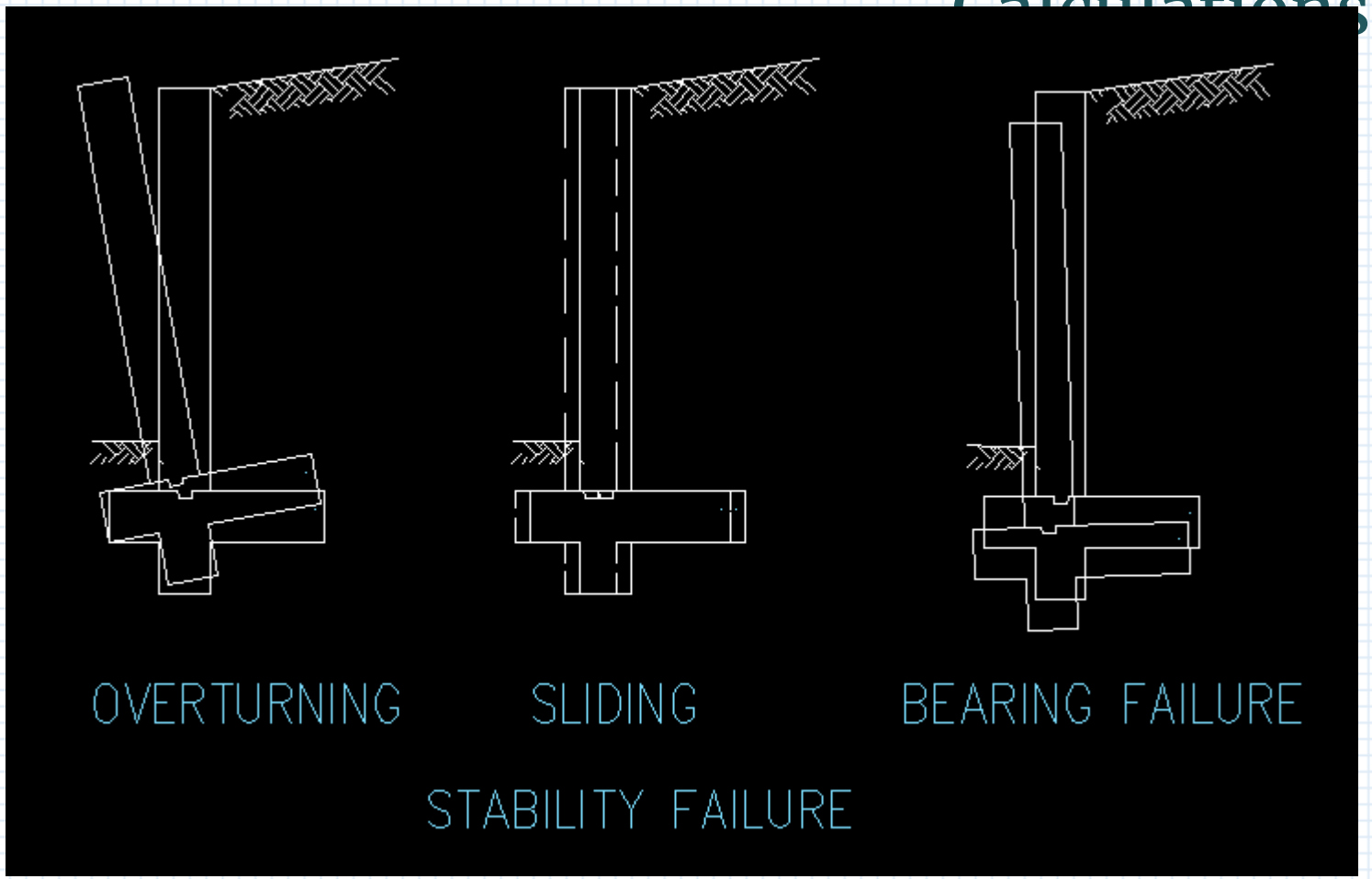


Figure 23 : Stability Failure Checks for Retaining Walls [7]

Table 3: FS for Overturning = 3.3 > 2

M_R	14491.8	lb*ft	
M_O	4384.867	lb*ft	
FS	3.304958	CHECK >2	yes

Table 4: FS for Sliding = 1.73 > 1.5

F'_d	1547.60	plf	
F'_R	2672.268	plf	
FS	1.726718	CHECK>1.5	yes

Table 5: FS for Bearing Capacity = 7.22 > 3

I	13.86	ft^4	
q_{com}	2004.681	psf	
q_{max}	1119.701	psf	
q_{min}	442.4897	psf	
q_u	8086.759	psf	
FS	7.222247	CHECK>3	yes

Design Option 1

Design Option 1: Retaining Wall W/ Commercial Drainage System

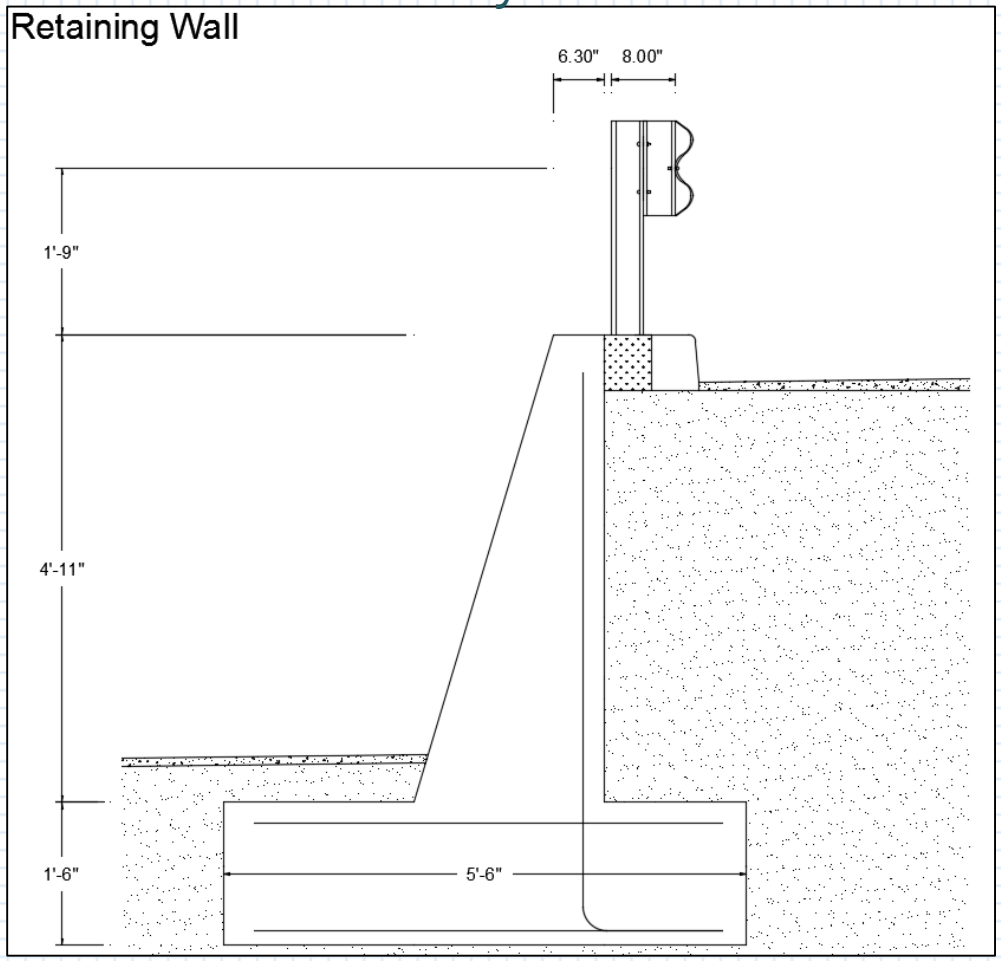


Figure 25: Design Option 1 Retaining Wall Detail

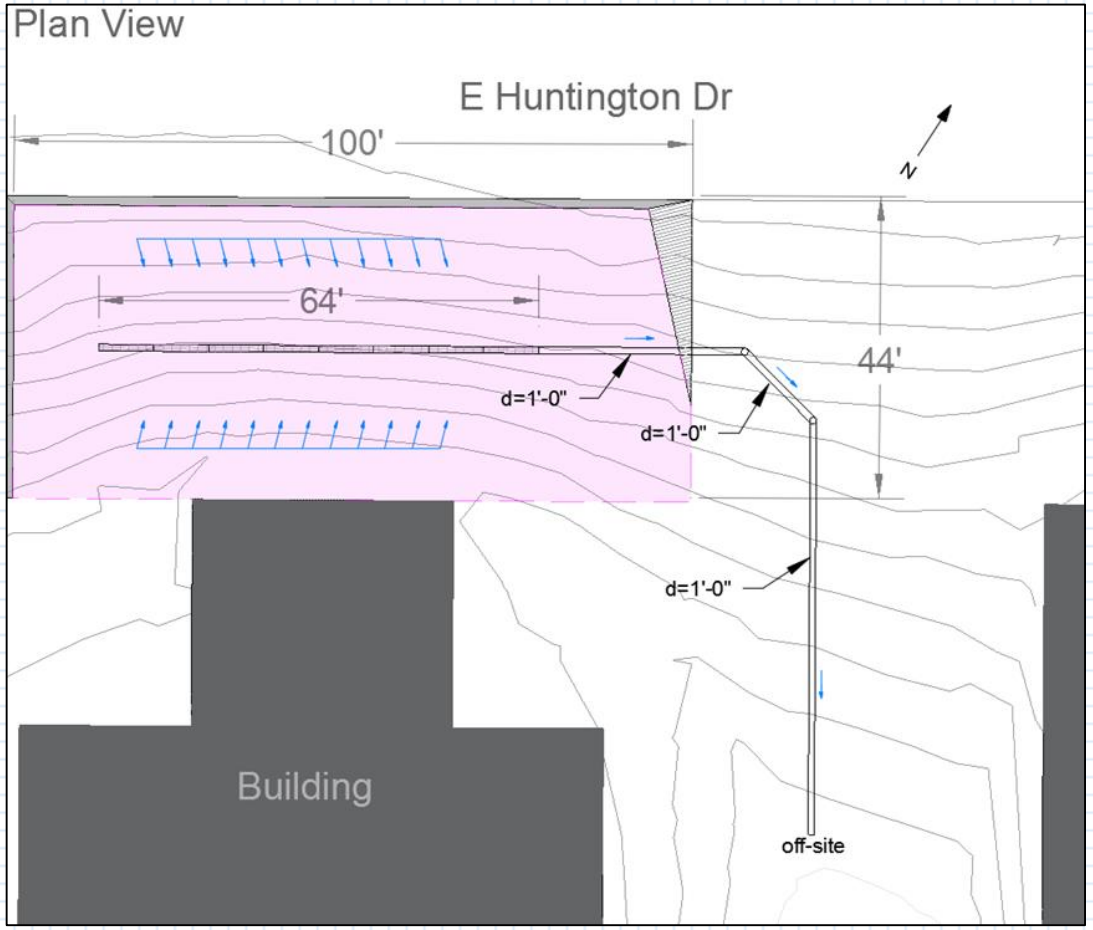
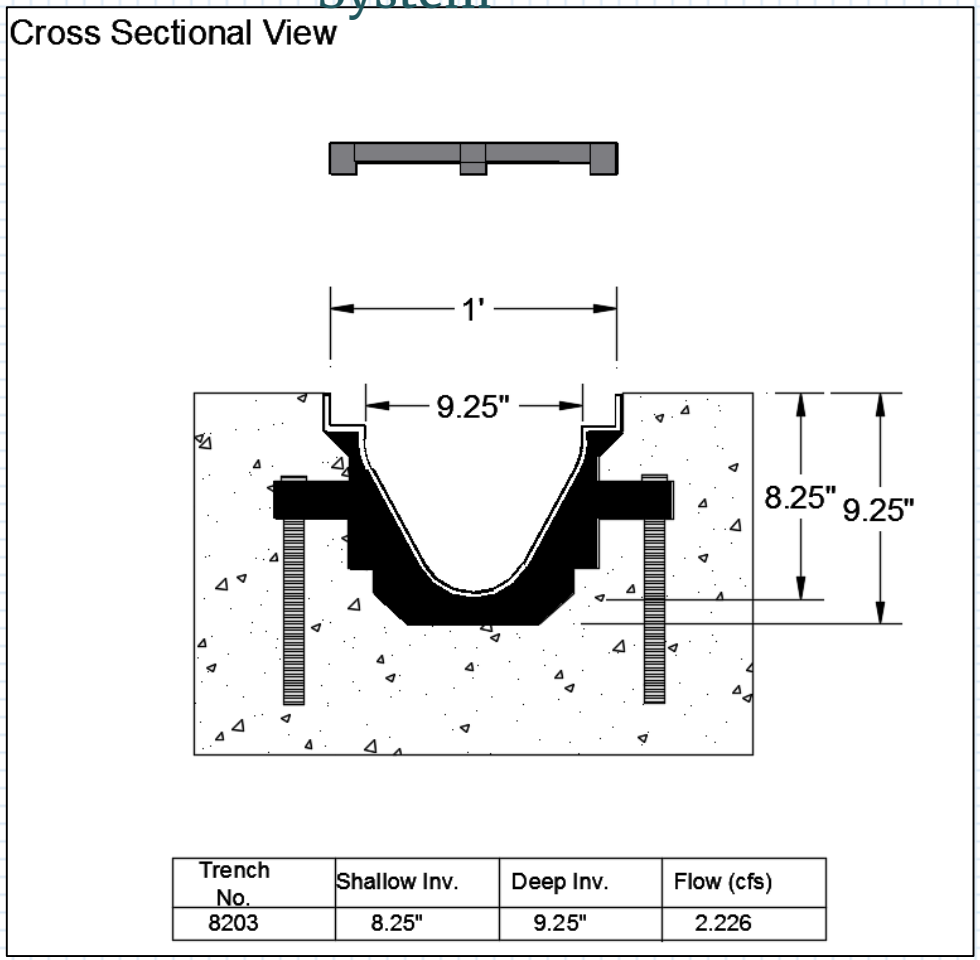


Figure 26: Aerial View of Design Option 1

Design Option 1 Details

Design Option 1: Retaining Wall W/ Commercial Drainage System



Trench No.	Shallow Inv.	Deep Inv.	Flow (cfs)
8203	8.25"	9.25"	2.226

Figure 27: Design Option 1 Cross Sectional View

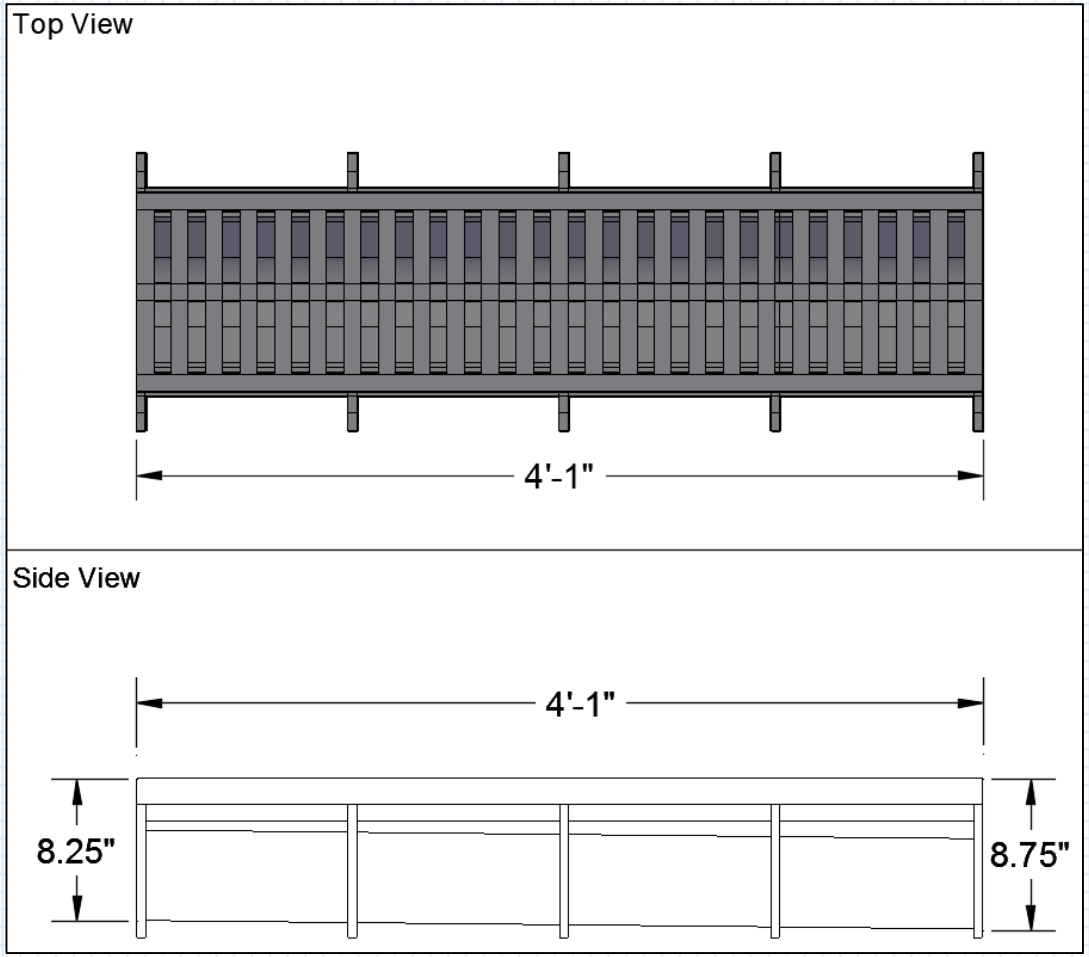


Figure 28: Top and Side View of Commercial Drain

Design Option 2

Design Option 2: Retaining Wall W/ Valley Gutters

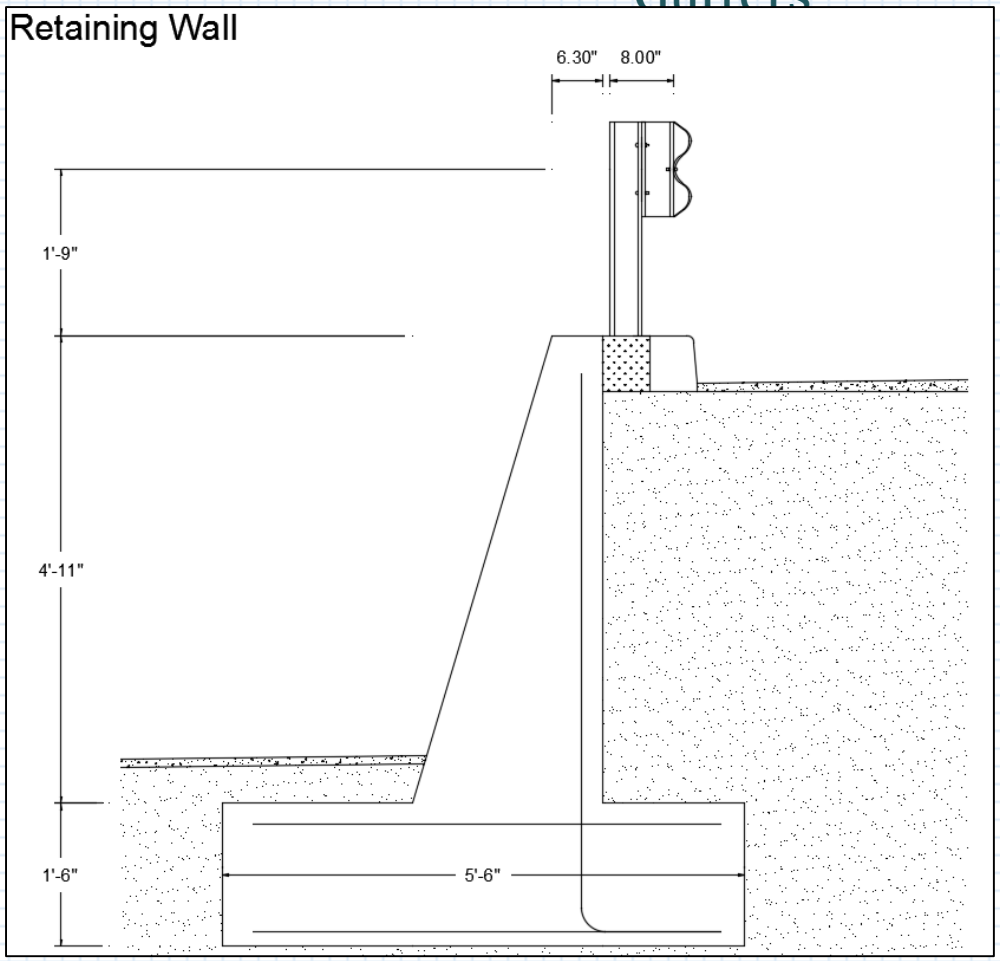


Figure 29: Design Option 2 Retaining Wall Detail

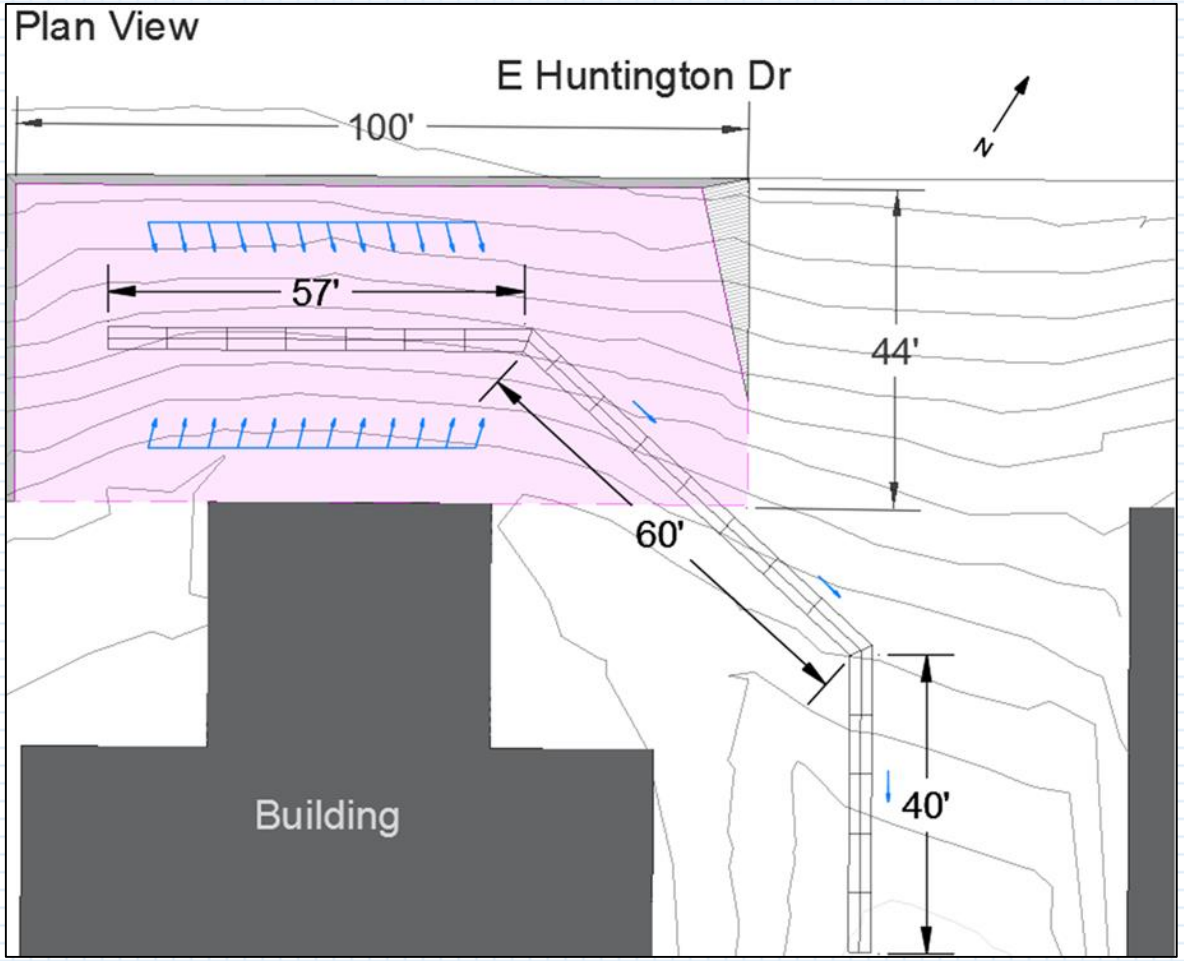


Figure 30: Aerial View of Design Option 2

Design Option 2 Details

Design Option 2: Retaining Wall W/ Valley

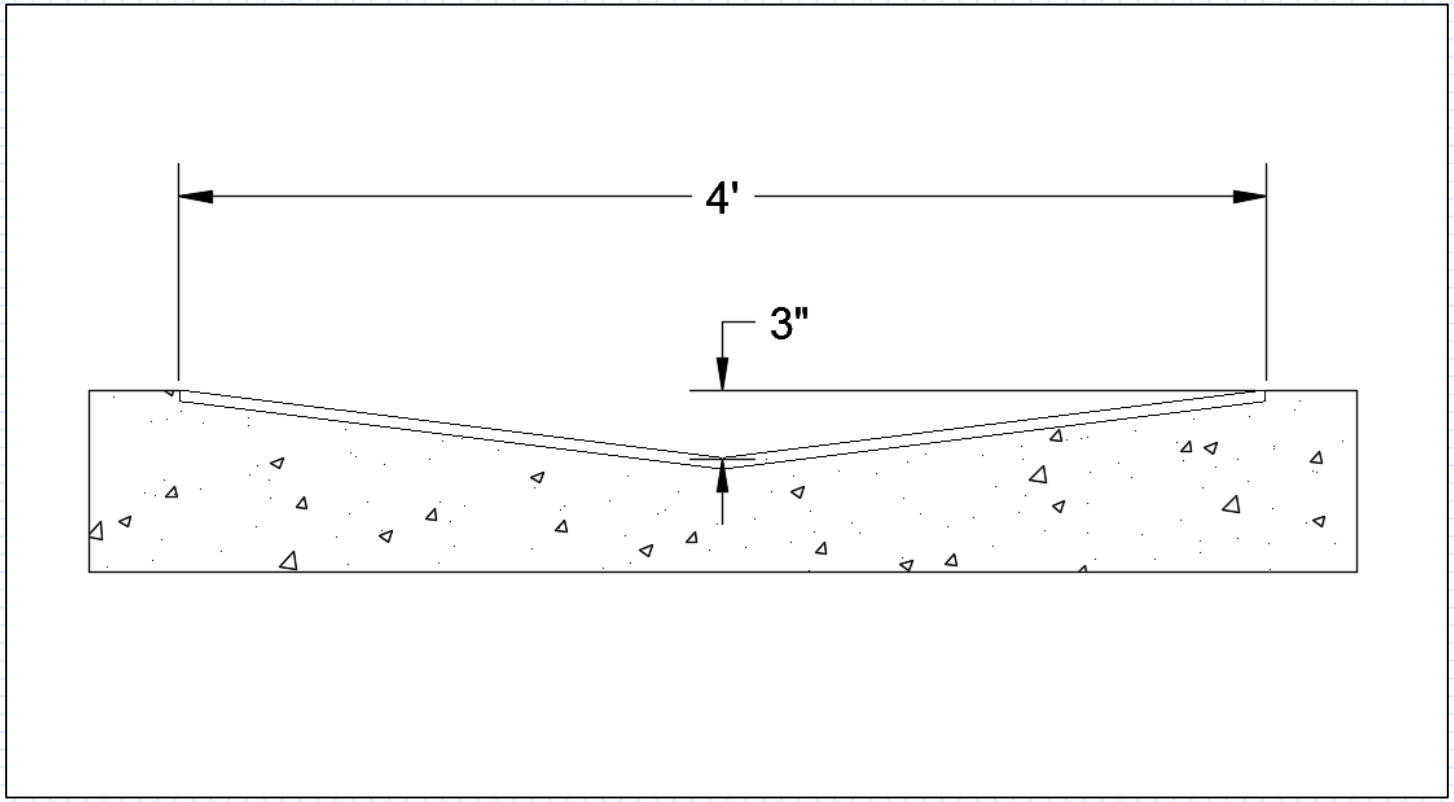


Figure 30: Design Option 2 Valley Gutter Detail

Pros and Cons

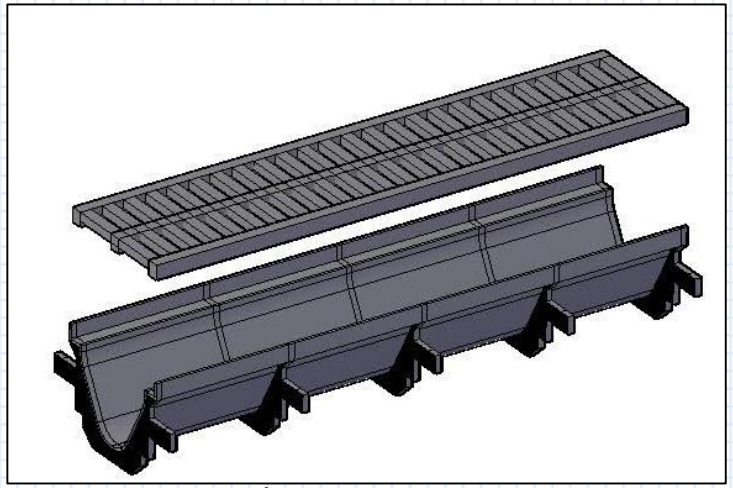


Figure 31:
Design 1

Figure 32:
Design 2

Table 6: Pros and Cons of Designs		
Design	**Pros**	**Cons**
Option 1	1. Meets Conveyance 2.Runoff is Contained 3. Long Design Life	1. Higher Cost 2. Maintenance
Option 2	1. Cost Efficient 2. Constructability	1. Shorter Design Life 2. Does Not Contain Runoff

Offsite Recommendations to City of Flagstaff

- Initiate the Vegetated Swale Design
- Increase Catch Basin Size
- Additional Catch Basins
- Continued Maintenance

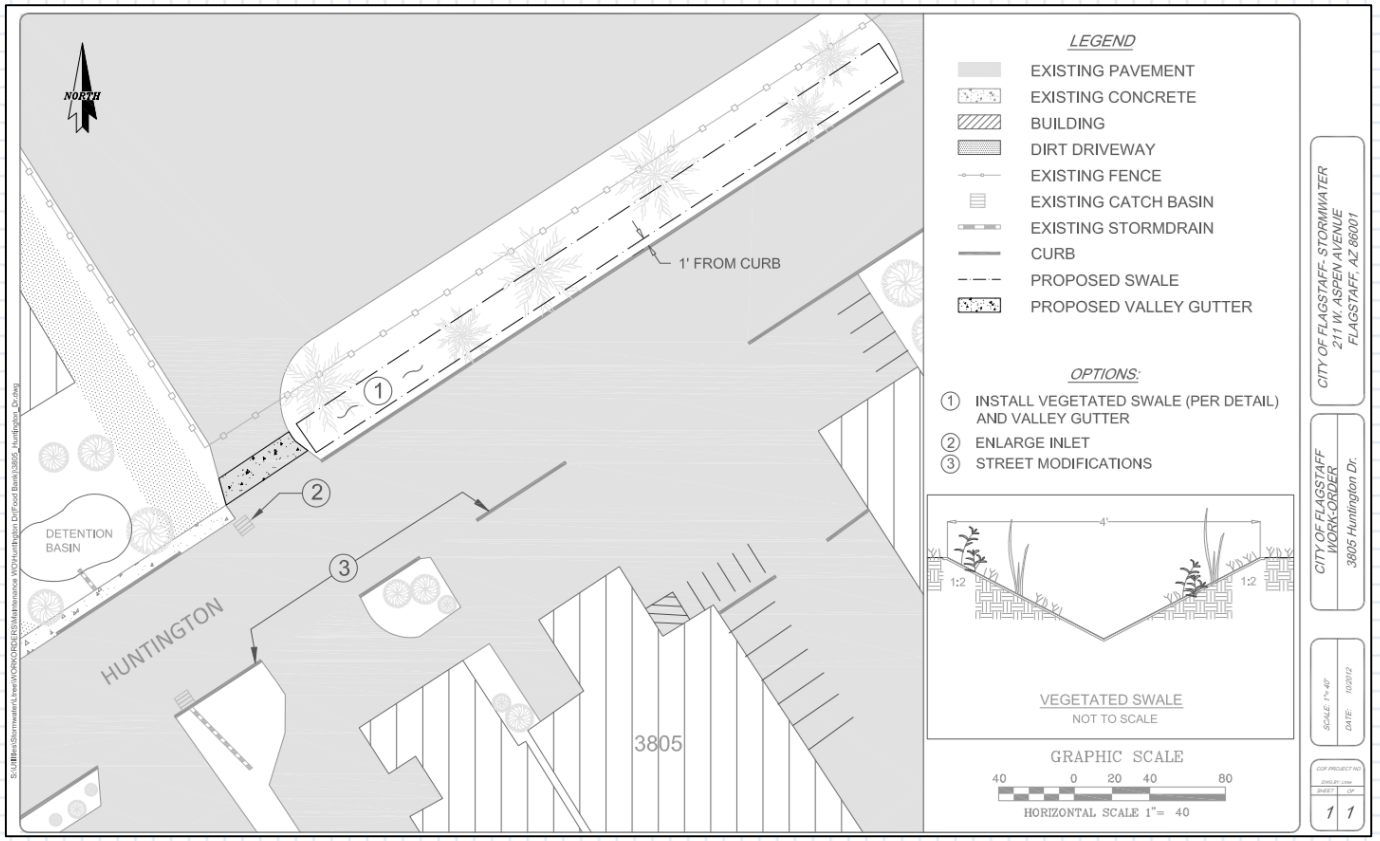


Figure 33: City of Flagstaff Stormwater Division Retention Basin Design

ECONOMICS

Table 6: Economic Analysis for Design 1(Retaining Wall W/ Drainage System

Economic Analysis - Design 1

Task #	Task Describtion	Units	Price/Unit	Total
1	**Excavation**			
	Cut/Fill	8654 ft^3	$2.54 per cub/ft	$22,000
	Repave	3904 ft^2	$3.50 per sq/ft	$13,000
2	**Retaining Wall**			
	Construction	hours		$13,700
	Materials		30-40 per sq/ft	
3	**Drainage Pipes**			
	Commerical	hours	70 plf	$5,600
	Pipe		20 plf	$5,800
4	**Guard Rail**			
	Construction	94.5 ft	$39.00 per ft	$3,666
			TOTAL	**$63,766.00**

Table 7: Economic Analysis for Design 2 (Valley Gutter Design)

Economic Analysis - Design 2

Task #	Task Describtion	Units	Price/Unit	Total
1	**Excavation**			
	Cut/Fill	8654 ft^3	$2.54 per cub/ft	$22,000
	Repave	3904 ft^2	$3.50 per sq/ft	$13,000
2	**Retaining Wall**			
	Construction	hours		$13,700
	Materials		30-40 per sq/ft	
3	**Valley Gutter**			
	Construction	hours		
	Materials		10 plf	$3,600
4	**Guard Rail**			
	Construction	94.5 ft	$39.00 per ft	$3,666
			TOTAL	**$ 55,966.00**

PROJECT IMPACT

Figure 34: Project Impact Flow Chart

STAFFING HOURS

Table 9: Estimated Staffing Hours

Staffing				
Task	SENG	ENG	LAB	AA
Project Management - Meetings - Scheduling - Documentation	22	14	14	20
Research - Site Evaluation - Neighborhood Survey - Codes/Legal Standards	15	65		10
Analysis - Surveying - Geotechnical - Hydrological - Environmental		220	80	
Final Design - Final Proposal - Presentation - Website	160	40		20
Subtotal	197	339	94	50
Total (Hrs)	680			

Table 10: Actual Staffing Hours

Staffing				
Task	SENG	ENG	LAB	AA
Project Management - Meetings - Scheduling - Documentation	26	75	14	20
Research - Site Evaluation - Neighborhood Survey - Codes/Legal Standards	25	75		10
Analysis - Surveying - Geotechnical - Hydrological - Environmental		121	80	
Final Design - Final Proposal - Presentation - Website	160	40		20
Subtotal	211	311	94	50
Total (Hrs)	666			

PROJECT SCHEDULE

Table 11: Estimated Project Schedule

Items			Dates
1.0	Neighborhood Survey (Interviews)		11/2/15 - 11/20/15
	1.1	Interview Neighboring Companies	
	1.2	Observe Surrounding Drainage Conditions	
2.0	Researching Permitting/Standards/Codes		1/25/16 - 2/15/16
	2.1	Obtain Flagstaff City Drainage Codes	
	2.2	Obtain ADOT Drainage Codes for Near Highways	
	2.3	Obtain Property Right Information For Ownership	
3.0	Surveying		2/1/16 - 2/15/16
	3.1	Surveying Property	
	3.2	Generate Topographic Maps of Property	
4.0	Design Alternatives		2/22/16 - 4/11/16
	4.1	Hydrologic and Hydraulic Modeling	
	4.2	Stormwater Runoff Evaluation	
	4.3	Geotechnical Constraints	
	4.4	Economic Analysis	
5.0	Project Management		1/25/16 - 5/12/16
	5.1	Project Schedule	
	5.2	Website	
	5.3	50% Design Report	
	5.4	Final Design Report	
	5.5	Final Presentation	

Table 12: Actual Project Schedule

Items			Dates
1.0	Neighborhood Survey (Interviews)		11/2/15 - 11/20/15
	1.1	Interview Neighboring Companies	
	1.2	Observe Surrounding Drainage Conditions	
2.0	Researching Permitting/Standards/Codes		1/25/16 - 2/15/16
	2.1	Obtain Flagstaff City Drainage Codes	
	2.2	Obtain ADOT Drainage Codes for Near Highways	
	2.3	Obtain Property Right Information For Ownership	
3.0	Surveying		2/1/16 - 2/15/16
	3.1	Surveying Property	
	3.2	Generate Topographic Maps of Property	
4.0	Design Alternatives		2/22/16 - 4/11/16
	4.1	Hydrologic and Hydraulic Modeling	
	4.2	Stormwater Runoff Evaluation	
	4.3	Geotechnical Constraints	
	4.4	Economic Analysis	
5.0	Project Management		1/25/16 - 5/12/16
	5.1	Project Schedule	
	5.2	Website	
	5.3	50% Design Report	
	5.4	Final Design Report	
	5.5	Final Presentation	

COST

Table 13: Estimated Cost

Cost Estimate for Engineering Services				
1.0 Personnel	Classification	Hours	Rate ($/hr)	Cost
	SENG	197	194	$38,218.00
	ENG	339	67	$22,713.00
	LAB	94	48	$4,512.00
	AA	50	56	2,800.00
	Total Personnel			$68,243.00
2.0 Travel	7 Meetings @ 10mi/Meeting	$0.56/mi		$39.00
3.0 Total				$68,282.00

Table 14: Actual Cost

Cost Estimate for Engineering Services				
1.0 Personnel	Classification	Hours	Rate ($/hr)	Cost
	SENG	211	194	$40,934.00
	ENG	311	67	$20,837.00
	LAB	94	48	$4,512.00
	AA	50	56	2,800.00
	Total Personnel			$69,083.00
2.0 Travel	7 Meetings @ 10mi/Meeting	$0.56/mi		$39.00
3.0 Total				$69,122.00

- Within 10% Difference
- Senior Engineer vs. Engineer
- $840.00 Difference

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[5] (August 27, 2014). NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: AZ [NOAA Atlas 14]. Available: http://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html?bkmrk=az.

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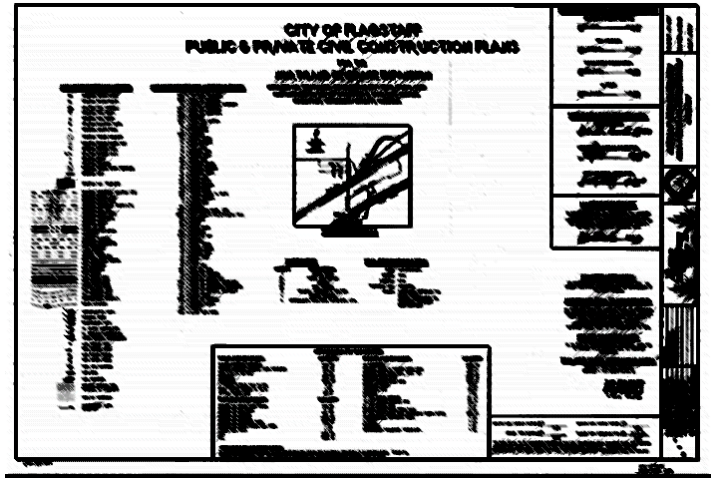
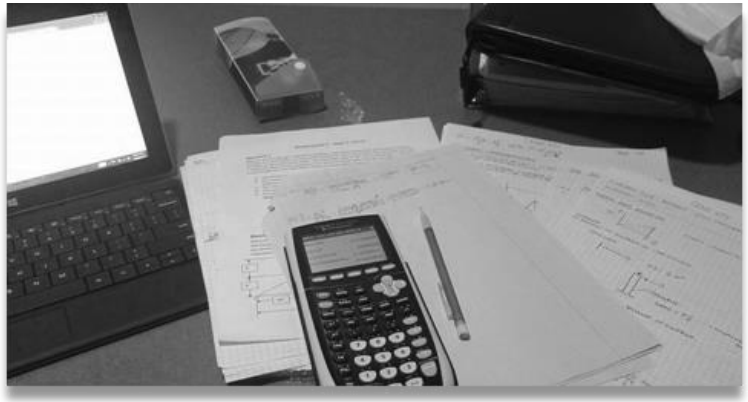
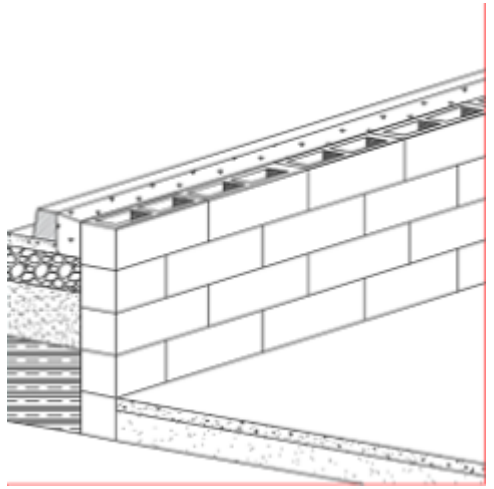
THANK YOU



RESEARCH



ANALYSIS



DESIGN