# NAU Stormwater Runoff Quality & Quantity Mitigation

RainRoots Consulting

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CENE 486

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# Introduction

**Client:** Erin McAnaly-Trejo, NAU Sustainability

**Project Location:** NAU Mountain Campus

**Purpose:** Identify best locations for Low Impact Development (LID) implementation & provide a design for one chosen location

- Decrease flooding and erosion due to stormwater runoff
- Promote groundwater infiltration
- Save NAU costs on stormwater credits

**Additional Goal:**
- Analyze the effects of stormwater runoff on downstream areas

Figure 1: Vegetated Swale Example [1]

# Project Constraints/Limitations

**Constraints for LID Implementations:**

- Cannot interfere with existing infrastructure including utilities or concrete
- Cannot interfere with existing landscaping including native vegetation and trees
- Keep construction costs low
  - Design should not require an underdrain
- Avoid highly trafficked locations such as the student pedway
- Should not affect historic aesthetics, such as Old Main

Figure 2: Example of Poor Location

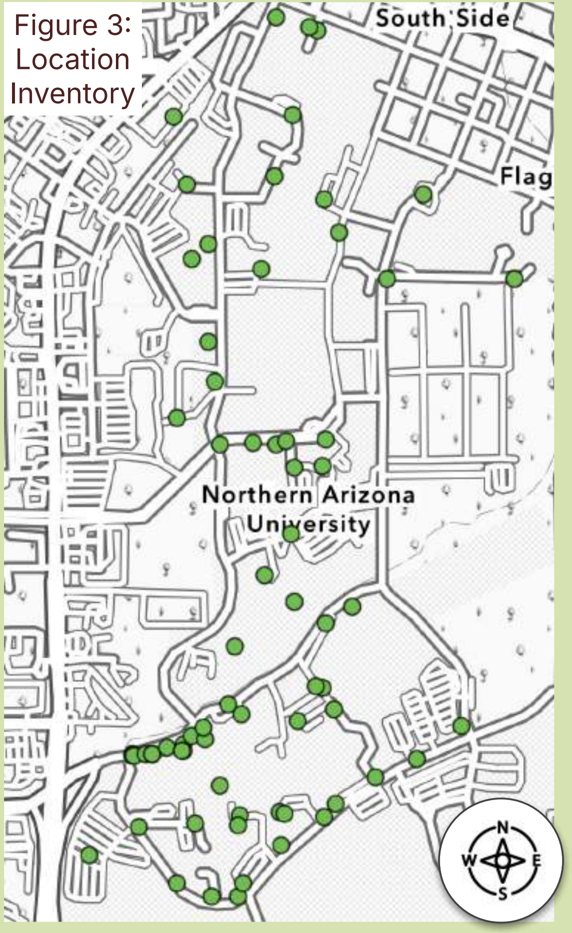
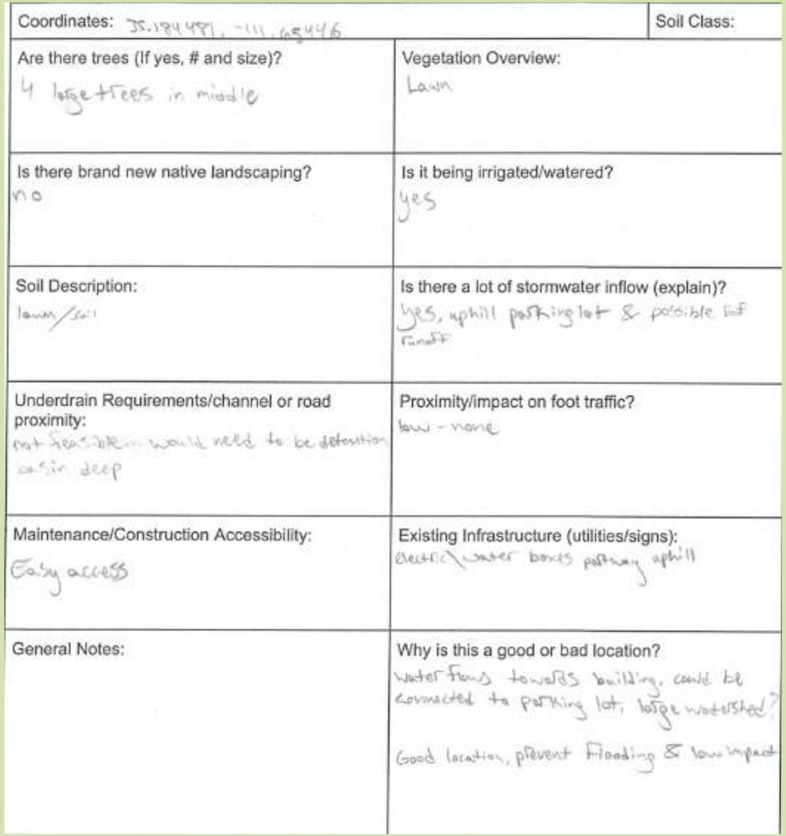



Figure 3: Location Inventory



| Coordinates: 35.184481, -111.65446 | Soil Class: |
|---|---|
| Are there trees (If yes, # and size)? 4 large trees in middle | Vegetation Overview: Lawn |
| Is there brand new native landscaping? no | Is it being irrigated/watered? yes |
| Soil Description: lawn/soil | Is there a lot of stormwater inflow (explain)? yes, uphill parking lot & possible roof runoff |
| Underdrain Requirements/channel or road proximity: not feasible would need to be detention basin deep | Proximity/impact on foot traffic? low - none |
| Maintenance/Construction Accessibility: Easy access | Existing Infrastructure (utilities/signs): electric\water boxes pathway uphill |
| General Notes: | Why is this a good or bad location? water flows towards building, could be connected to parking lot, large watershed? Good location, prevent flooding & low impact |

Figure 4: C-7 Field Notes

# Site Investigation

- 70 potential locations
- Uploaded Coordinates to ArcGIS Online
- Digitized Field Notes

# Watershed Delineation



Figure 5: C-7 Watershed Delineation

# ADOTRational: Peak Flow Calculations

$Q = C_f CiA$, [2]

Where:

**Q** = Peak flow rate of runoff (cubic feet per second)

$C_f$ = Antecedent precipitation factor

**C** = Runoff coefficient

**i** = Rainfall intensity (in/hr), for a duration equal to time of concentration

**A** = watershed area (acres) that drains to the design location

$T_c = 11.4 L^{0.5} K_b^{0.52} S^{-0.31} i^{-0.38}$, [3]

Where:

$T_c$ = Time of concentration (hours)

**L** = Length of the longest flow path (miles)

$K_b$ = Watershed resistance coefficient

**S** = Slope of the longest flow path (ft/mile)

**i** = Rainfall intensity (in/hr), for a duration equal to time of concentration

| Duration | | | | |
|---|---|---|---|---|
| | 1 | 2 | 5 | 10 |
| 5-min | 0.242 (0.206-0.285) | 0.313 (0.266-0.367) | 0.424 (0.358-0.496) | 0.513 (0.432-0.599) |
| 10-min | 0.369 (0.313-0.433) | 0.476 (0.405-0.559) | 0.645 (0.545-0.755) | 0.780 (0.657-0.912) |
| 15-min | 0.457 (0.388-0.537) | 0.591 (0.502-0.693) | 0.799 (0.676-0.935) | 0.967 (0.815-1.13) |
| 30-min | 0.616 (0.523-0.723) | 0.795 (0.675-0.933) | 1.08 (0.911-1.26) | 1.30 (1.10-1.52) |

Figure 6: NOAA Rainfall Intensity [4]

# Stormwater Runoff Sampling Methods

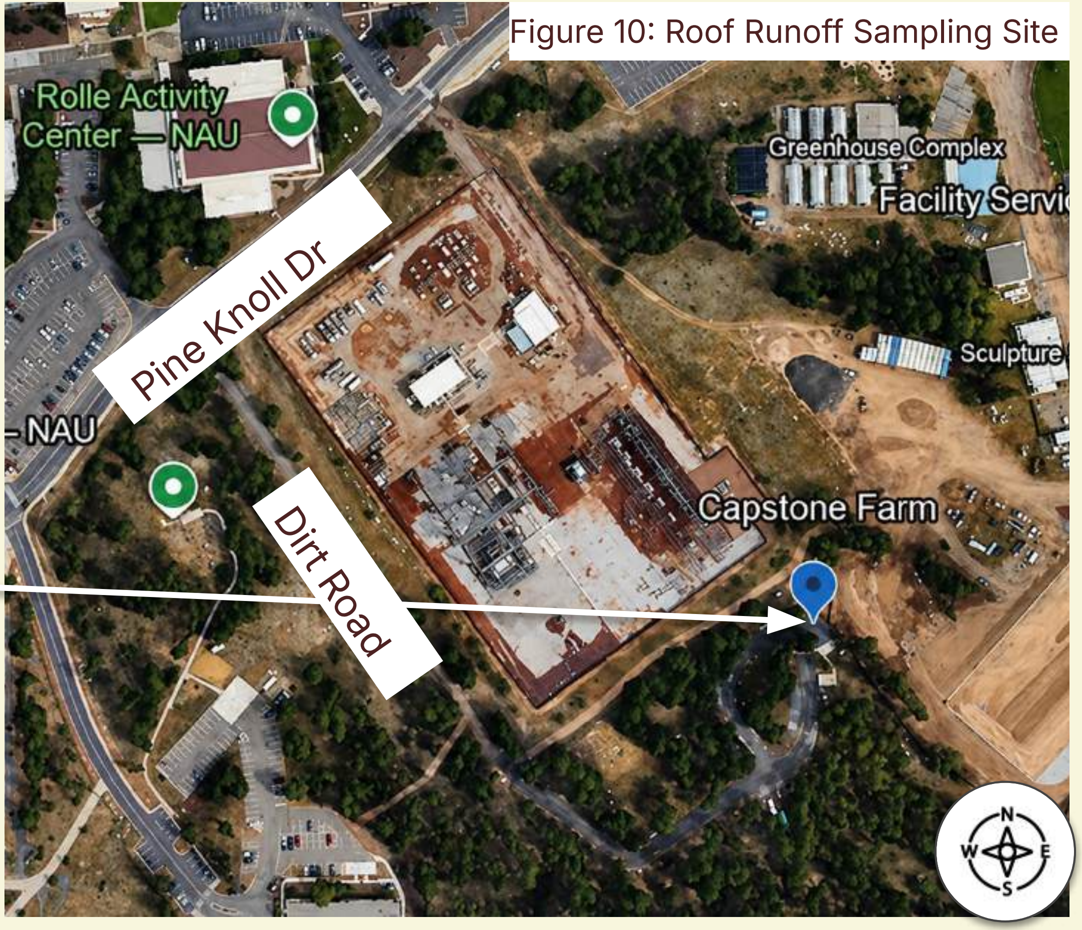
Figure 7: Simulated Storm

Figure 8: Water Pump

Figure 9: Water Pump Siphon

# Roof Runoff Sampling

Figure 10: Roof Runoff Sampling Site



# Field Runoff Sampling

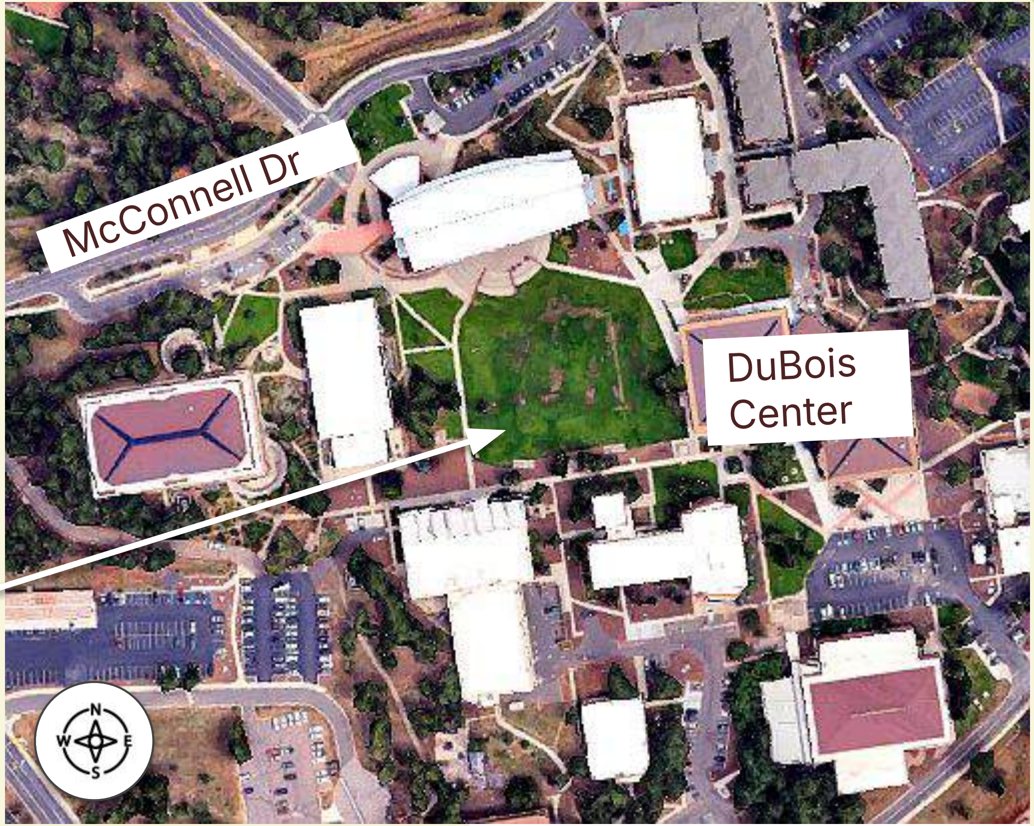



Figure 11: Field Runoff Sampling Site

# Parking Lot Runoff

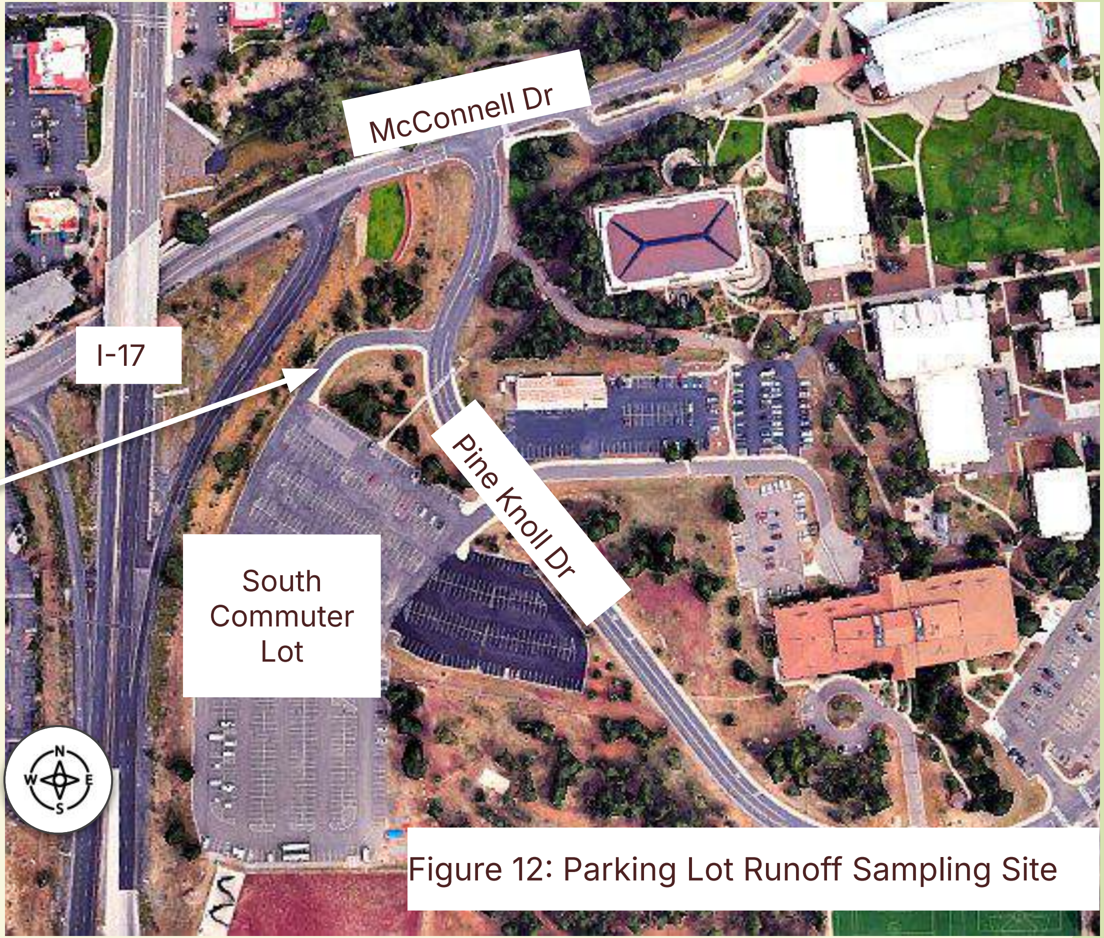



Figure 12: Parking Lot Runoff Sampling Site

# Stormwater Quality Testing

Figure 13: Total Suspended Solids Method [5]

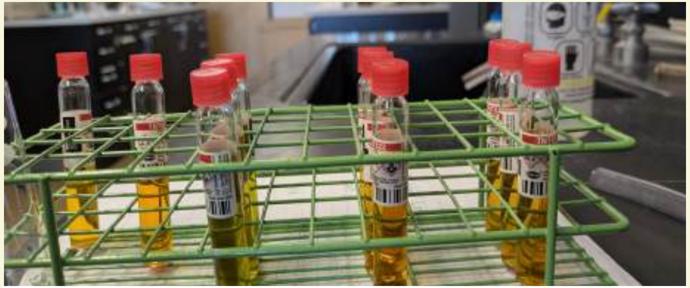


Figure 14: Chemical Oxygen Demand  Method [6]

Figure 15: Nitrate Method [7]

# Stormwater Quality Results

| Nitrate Results | |
|---|---|
| **Sample ID** | **mg/L NO3-N** |
| **ParkingLot1** | 3.6 |
| **ParkingLot2** | 3.2 |
| **ParkingLot3** | 2.5 |
| **Roof1** | 1.3 |
| **Roof2** | 3 |
| **Roof3** | 2.1 |
| **Field1** | 1.7 |
| **Field2** | 3.1 |
| **Field3** | 3.9 |

Table 1: Nitrate Results

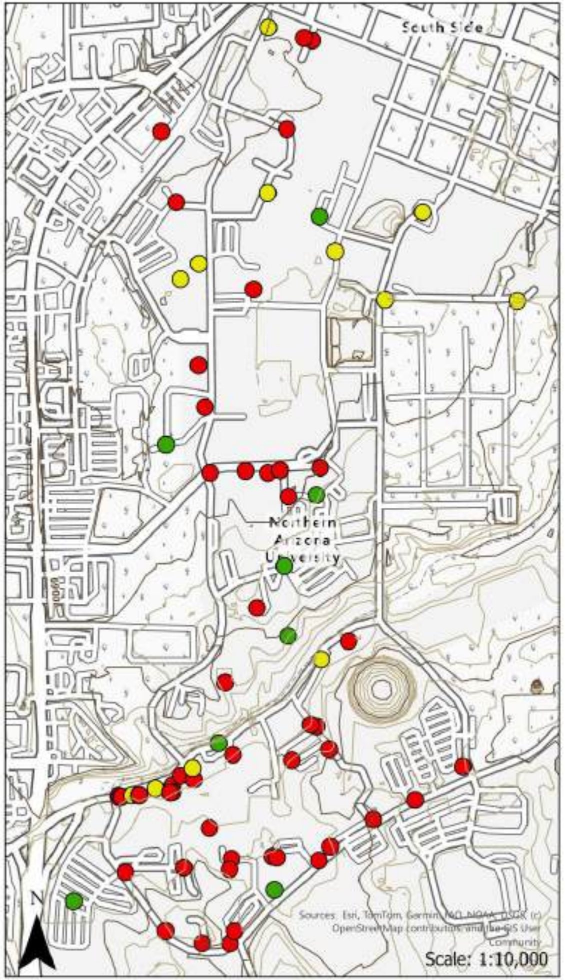
| Total Suspended Solids (TSS) Results | |
|---|---|
| **Sample ID** | **TSS (g/L)** |
| **ParkingLot1** | 0.6308 |
| **ParkingLot2** | 0.6474 |
| **ParkingLot3** | 0.614 |
| **Roof1** | 0.4357 |
| **Roof2** | 0.5571 |
| **Roof3** | 0.4067 |
| **Field1** | 1.177 |
| **Field2** | 0.881 |
| **Field3** | 1.8141 |

Table 2: TSS Results

| Chemical Oxygen Demand (COD) Results | |
|---|---|
| **Sample ID** | **mg/L COD** |
| **ParkingLot1** | 346 |
| **ParkingLot2** | 261 |
| **ParkingLot3** | 333 |
| **Roof1** | 309 |
| **Roof2** | 206 |
| **Roof3** | 260 |
| **Field1** | 865 |
| **Field2** | 788 |
| **Field3** | 1053 |

Table 3: COD Results

## Figure 16: Stormwater Score




Stormwater Mitigation Potential

**Stormwater Score**

A score of 1 was given to locations with a flow rate of less than 0.45cfs.

A score of 2 was given to lacations with a flow rate between 0.45cfs and 0.9cfs.

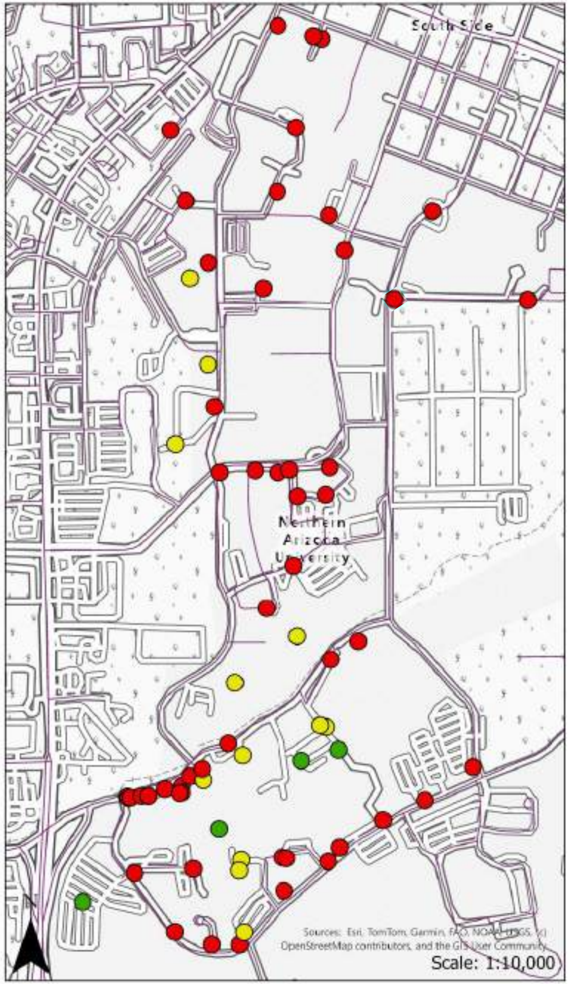
A score of 3 was given to locations with a flow rate greater than or equal to 0.9cfs.

This category was weighted 45%

**Stormwater Score**

- 1
- 2
- 3

## Figure 17: Visibility Score




Visibility from Roads & Pedways

**Visibility Score**

A score of 1 was given to locations that were within 100 feet of a public road.

A score of 2 was given to locations that were between 100 and 300 feet of a public road.

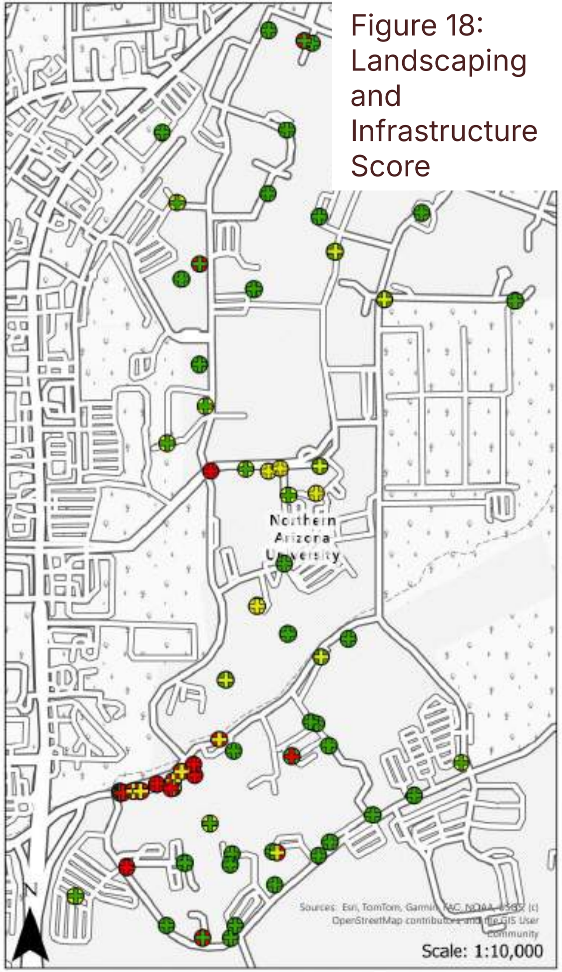
A score of 3 was given to locations that were more than 300 feet away from a public road.

This category was weighted 9.5%

**Visibility Score**

- 1
- 2
- 3

Figure 18: Landscaping and Infrastructure Score




Impact on Landscaping & Infrastructure

**Infrastructure Score**

A score of 1 means that there was existing infrastructure that cannot be moved or removed.

A score of 2 means that there was existing infrastructure that could be moved or removed.

A score of 3 means that there was no existing infrastructure.

This category was weighted 18%

**Infrastructure Score**

- 1 (red circle)
- 2 (yellow circle)
- 3 (green circle)

**Landscaping Score**

A score of 1 means that there were medium to large trees or brand-new native landscaping that would have to be removed.

A score of 2 means that there were small trees or shrubs that would have to be removed.

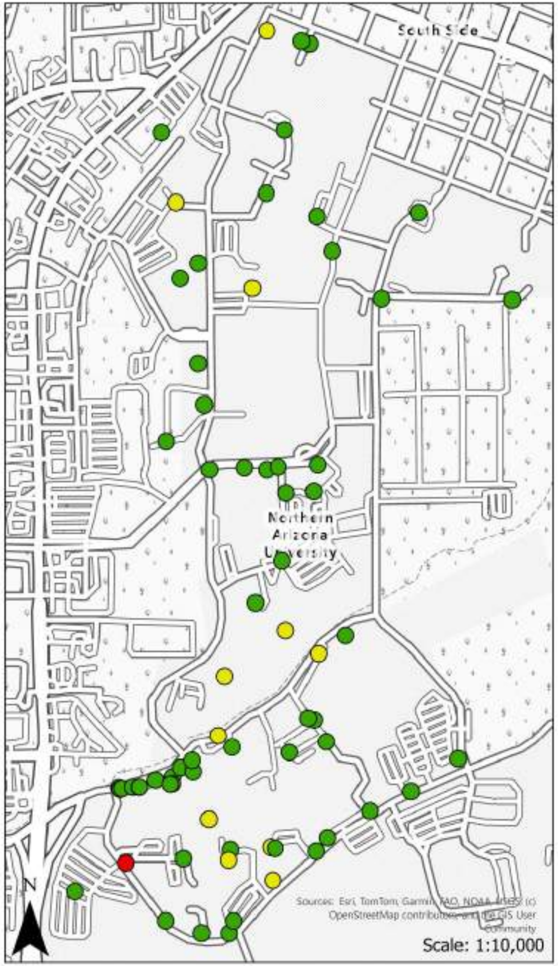
A score of 3 means that there was no landscaping or vegetation besides grass or lawn that would need to be removed.

This category was weighted 18%

**Landscaping Score**

- 1 (red cross)
- 2 (yellow cross)
- 3 (green cross)

Figure 19: Access Score




Ease of Access for Maintenance & Construction

**Access Score**

A score of 1 means that the location was not easily accessible for small construction or maintenance equipment and larger.

A score of 2 means that the location was easily accessible to small construction and maintenance equipment.

A score of 3 means that the location was easily accessible to large construction and maintenance equipment.

This category was weighted 9.5%

**Access Score**

- 1 (red circle)
- 2 (yellow circle)
- 3 (green circle)

| Decision Matrix | |
|---|---|
| **Criteria** | **Weight** |
| Stormwater Mitigation Potential | 45% |
| Presence of Existing Infrastructure | 18% |
| Presence of Existing Landscape | 18% |
| Ease of Access for Construction and Management | 9.5% |
| Visibility | 9.5% |

Table 4: Decision Matrix Scoring

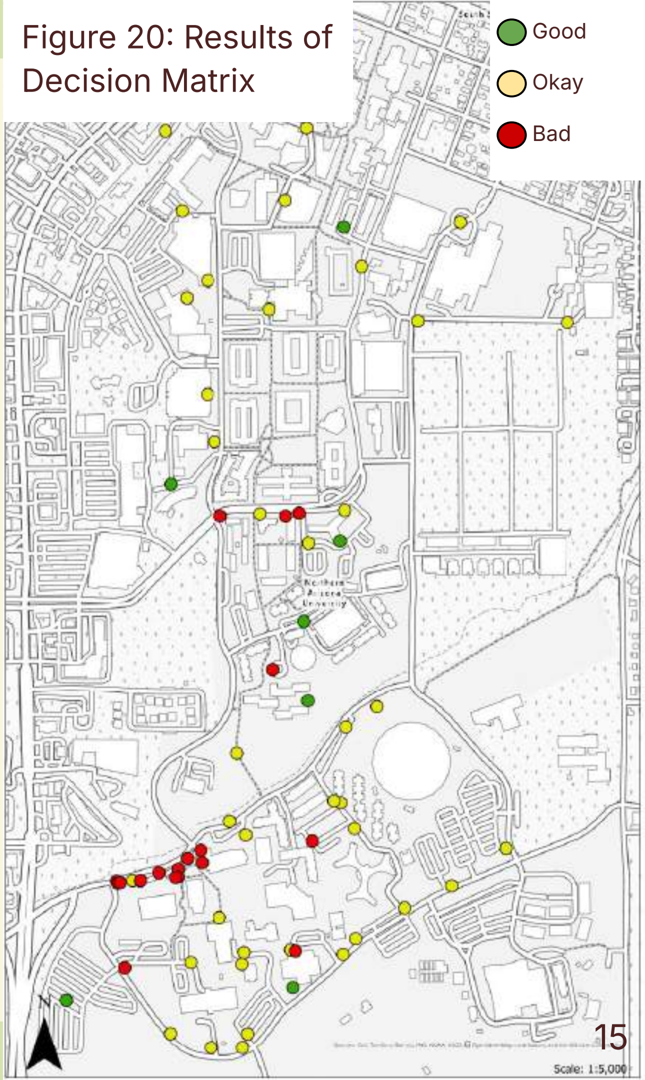



Figure 20: Results of Decision Matrix

# Top Five Locations

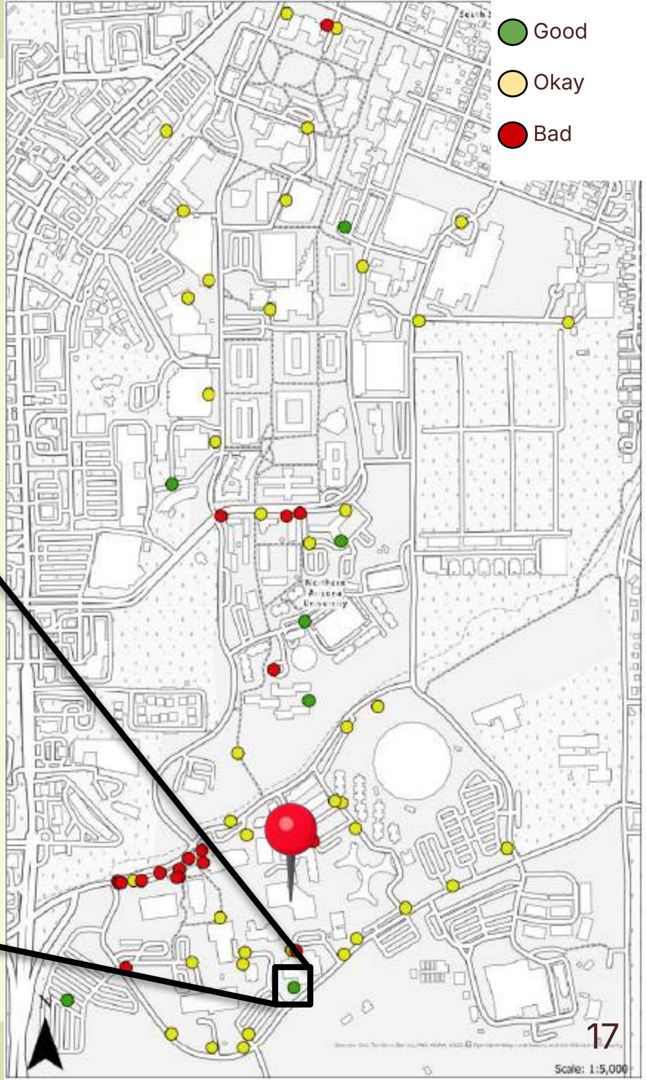
| Plot Numbers | Stormwater Mitigation Potential | Presence of Existing Infrastructure | Presence of Existing Landscaping | Ease of Access for Construction and Maintenance | Visibility | Unweighted Score | Weighted Score |
|---|---|---|---|---|---|---|---|
| N-17 | 3 | 3 | 3 | 3 | 2 | 14 | 32 |
| C-10 | 3 | 3 | 3 | 2 | 3 | 14 | 32 |
| C-12 | 3 | 3 | 3 | 3 | 2 | 14 | 32 |
| S-22 | 3 | 3 | 3 | 2 | 2 | 13 | 31 |
| N-1 | 3 | 2 | 3 | 3 | 2 | 13 | 30 |

Table 5: Top 5 Locations for LID Implementation

**Legend:**

| | |
|---|---|
| 1= Poor | N= North Campus |
| 2= Average | C= Central Campus |
| 3= Great | S= South Campus |

Figure 21: Selected Location


# Selected Location

# Points of Interest


Figure 22: Points of Interest

1. Pine Knoll Curb Cut
2. Parking Lot Culvert Outlet
3. Parking Lot Curb Cuts
4. Stormwater Pipe Inlet
5. Pedestrian Path Culvert
6. Pooling/Flooding
7. Central Basin

# Design Location Survey

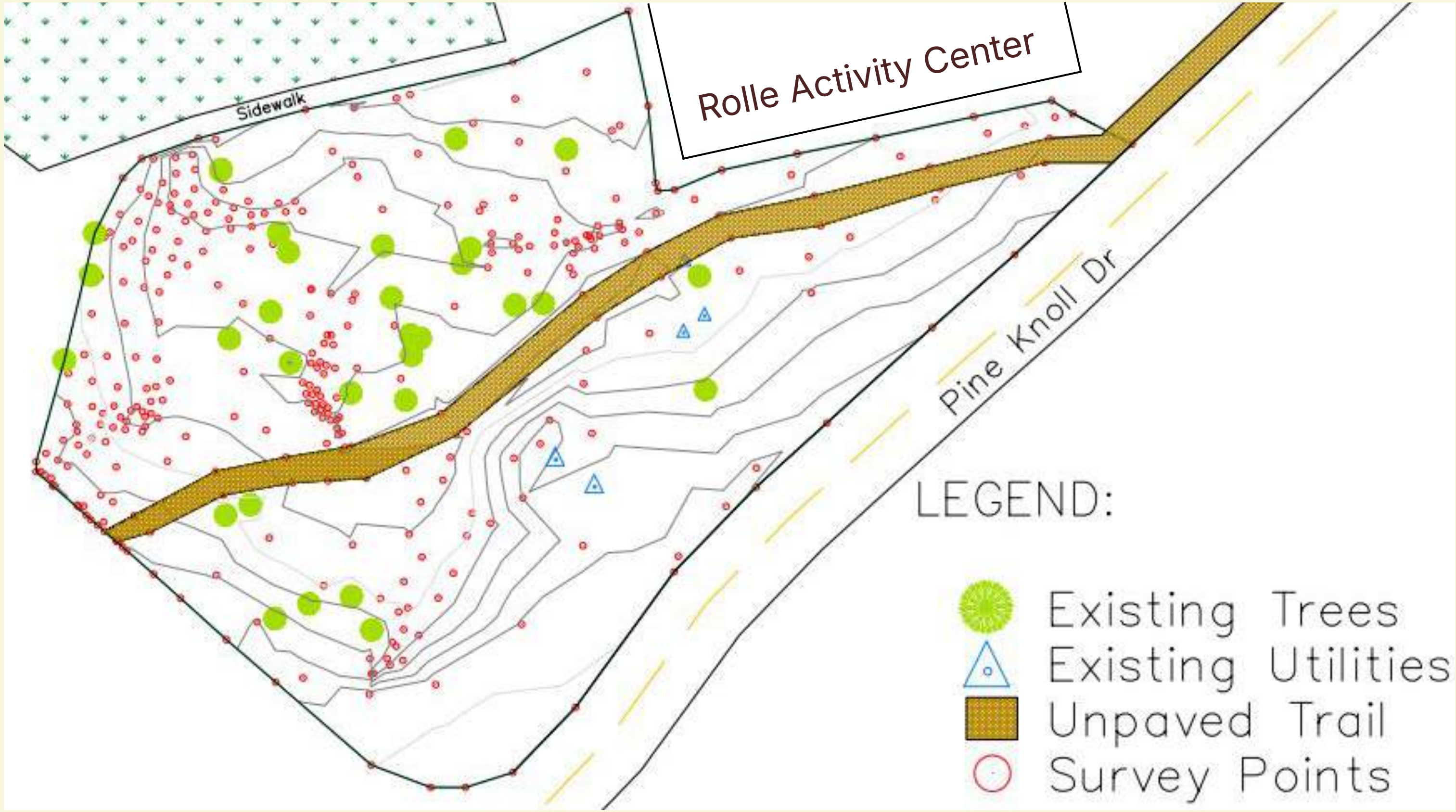



Figure 23: Topographic Map

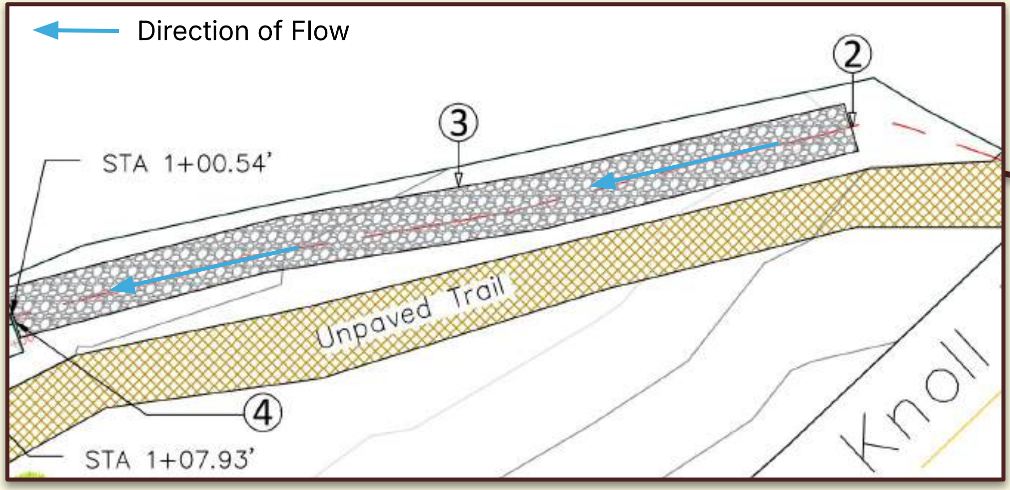
# Location Field Assessment

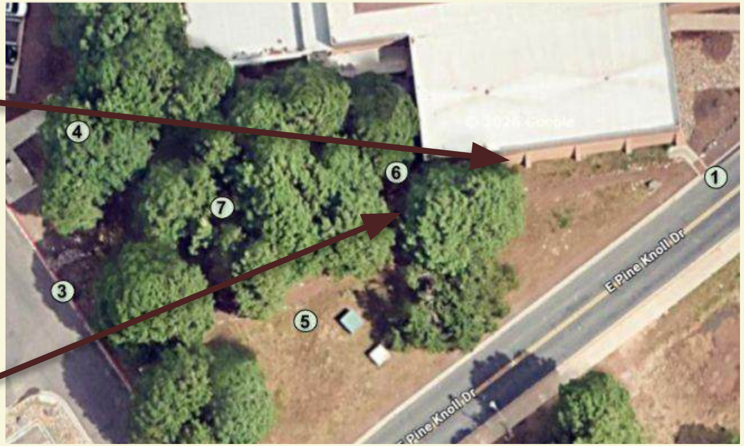
Figure 24: Inlet 1

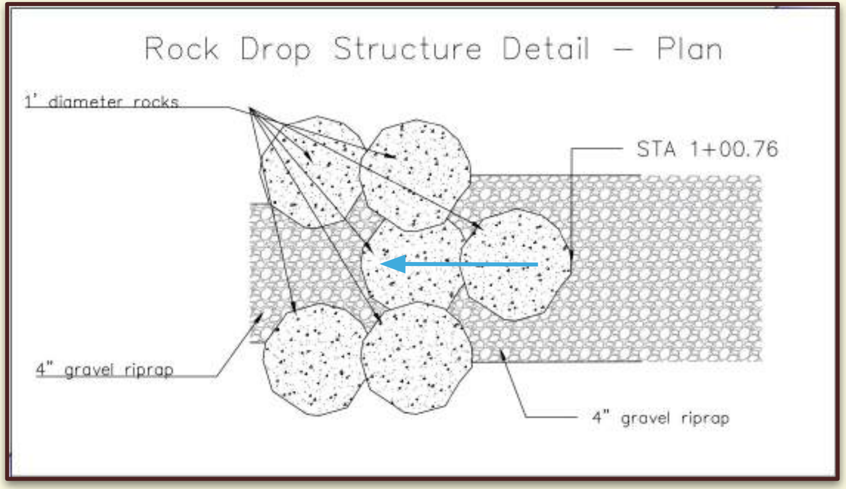
Figure 25: Inlet Channel Erosion

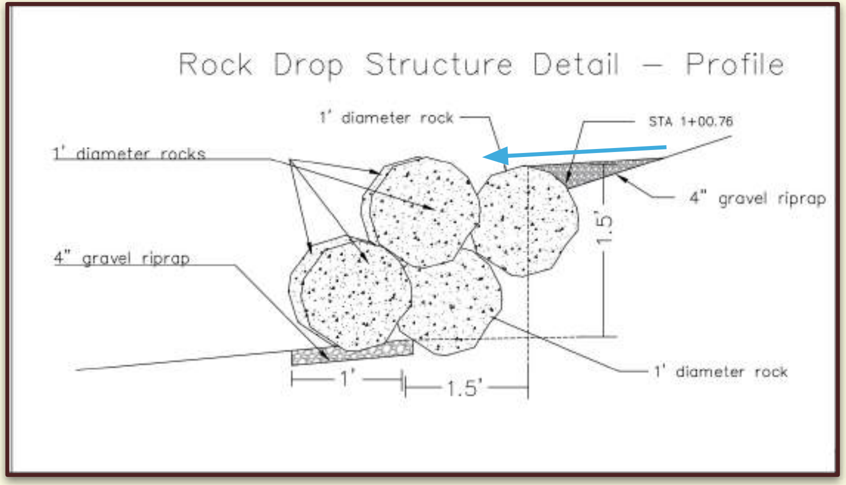
Figure 26: Existing Flooding

# Figure 27: Channel Lining and Drop Structure Details

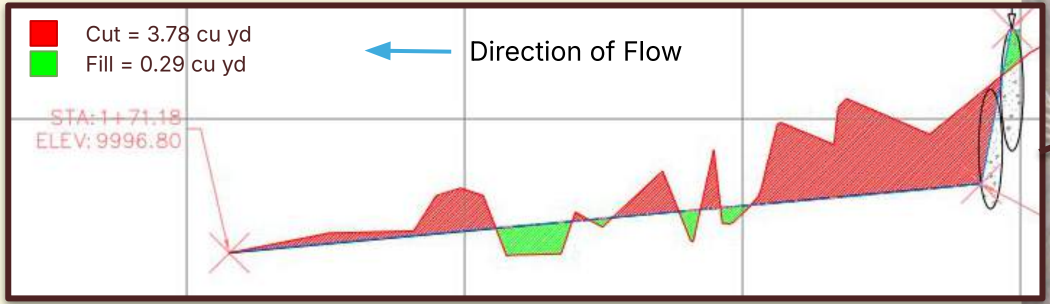


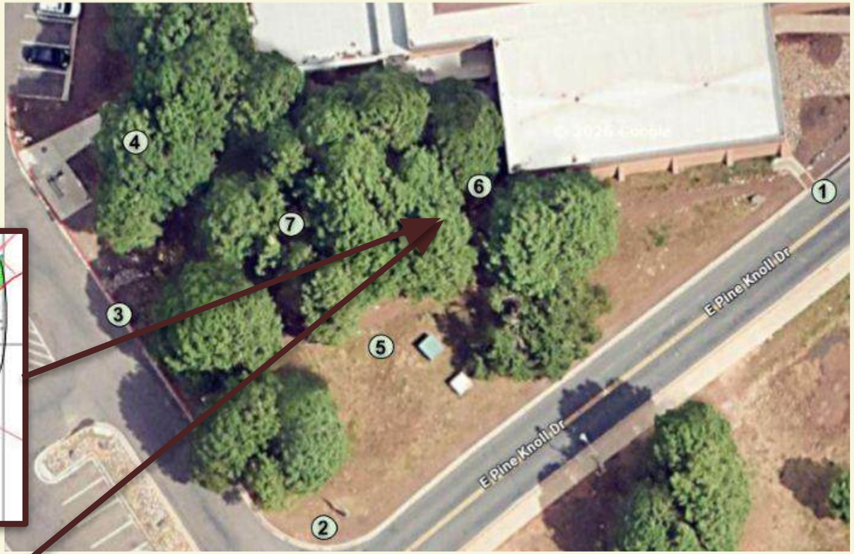



# Proposed Design



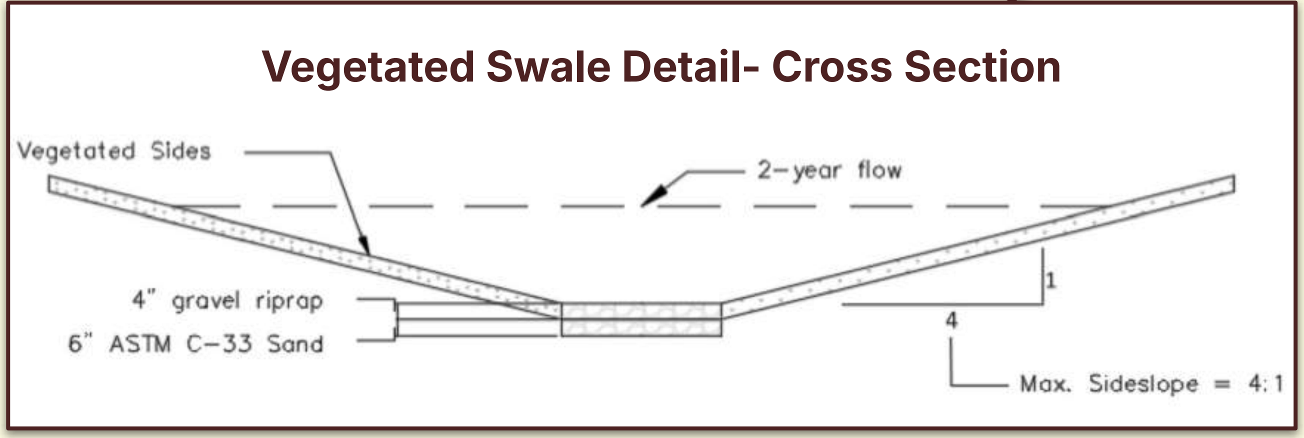




Figure 28: Vegetated Swale Design & Location

# Hydraulic Analysis

| | | Existing FlowMaster Results | | Proposed FlowMaster Results | |
|---|---|---|---|---|---|
| Cross Section | Station # | Velocity (ft/s) | Normal Depth (ft) | Velocity (ft/s) | Normal Depth (ft) |
| 1 | 24.55’ | 0.29 | 0.017 | 0.02 | 0.075 |
| 2 | 75.3’ | 0.00 | 0.075 | 0.01 | 0.083 |
| 3 | 100.54’ | 0.95 | 0.025 | 0.17 | 0.05 |
| 4 | 107.93’ | 0.23 | 0.108 | 0.74 | 0.025 |
| 5 | 116.8’ | 0.80 | 0.083 | 0.27 | 0.058 |
| 6 | 123.18’ | 0.70 | 0.033 | 0.27 | 0.058 |
| 7 | 126.58’ | 3.03 | 0.067 | 0.59 | 0.033 |
| 8 | 129.7’ | 0.60 | 0.125 | 0.22 | 0.058 |
| 9 | 137.5’ | 0.64 | 0.108 | 0.24 | 0.058 |
| 10 | 141.45’ | 0.51 | 0.075 | 0.19 | 0.042 |

Table 6: Existing vs Proposed Hydraulic Analysis

- The existing channel has high velocity flow near or above 1 ft/s.
- The proposed design:
  - Reduces channel velocity below 1 ft/s
  - Maintains subcritical flow
  - Keeps channel depth below 1 ft
- This prevents further channel erosion

# Total Cost of Construction

| Component | Quantity | Unit | Cost per Unit | Total Cost |
|---|---|---|---|---|
| **Cut and Fill** | | | | |
| **Channel Cut Volume** | 5.01 | cy | $23 | $118 |
| **Clay-Loam Backfill** | 0.29 | cy | $23 | $7 |
| **ASTM C-33 Sand [8]** | 1.23 | cy | $84 | $103 |
| **Materials For Construction** | | | | |
| **4" gravel (Proposed Design) [9]** | 3.29 | cy | $80 | $263 |
| **1' rocks [10]** | 6 | ea | $9 | $54 |
| **Native Plants/grass seed [11]** | 1 | ea | $37 | $37 |
| **Service Labor Costs** | | | | |
| **Excavation and Install (Proposed Design)** | 13 | hr | $47 | $611 |
| **Staking** | 1 | LS | $500 | $500 |
| | | | Projected Total Costs | $1,693 |

Table 7: Estimated Cost of Construction

# Flagstaff Stormwater Discounts

1 Equivalent Rate Unit (ERU) = 1,500 sq ft [12]

| Effective Date | Rate per ERU |
|---|---|
| **April 1, 2023** | $4.19 |
| **January 1, 2024** | $4.69 |
| **January 1, 2025** | $5.25 |
| **January 1, 2026** | $5.88 |
| **January 1, 2027** | $6.59 |
| **January 1, 2028** | $7.38 |

Table 8: Projected ERU Rates

**ERU Discounts [12]**

- LID and Rainwater Harvesting = 10%
- Detention Basins = 20%

**Years Until Project Pays for Itself**

- 56,000 sq ft
- 43.27 ERU's get a 10% discount
- Save $32 annually at the 2028 fee rate or $65 annually if fees continue to increase at their current rate (12%)
- Project pays for itself in 32-65 years

# Future Site Recommendations


Figure 29: Culvert Outlet


Figure 30: Parking Lot Curbcuts


Figure 1: Culvert Beneath Trail

# Scaling up for Campus Implementation

- 3 additional locations from our top 5
- 80,000 sq ft
- 53.33 ERU's get a 20% discount

- Combined, save $80 annually at the 2028 fee rate or $160 annually if fees continue to increase at their current rate.

Figure 32: N-1

Figure 33: C-10

Figure 34: C-12

❖ Detention Basin projects completed for under $750 each are profitable in 14-28 years on fee discounts alone.

# Questions?

# Citations


[1]https://anrweb.vt.gov/PubDocs/DEC/WSMD/Lakes/Docs/LP_BMPVegetatedSwales.pdf
[2] City of Flagstaff Utilities Division, “2025 STORMWATER MANAGEMENT DESIGN MANUAL,” 2025. COF_Manual.pdf
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