NAU Flooding Mitigation, Garden Design, and Storm Water Utilization

Final Design Report

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Table of Contents

List of Figures

List of Tables

Abbreviations

APS	Arizona Public Service
CECMEE	Civil Engineering, Construction Management, Environmental Engineering
GIS	Geographic Information System
NAU	Northern Arizona University
WSS	Web Soil Survey
COF	City of Flagstaff

Acknowledgements

ZABS Inc. would like to gratefully acknowledge the following people who have given guidance to us throughout the course of the project. Their constructive comments and suggestions have helped us remain proactive and successful. We are especially grateful for Dianne McDonnell and Jeffrey Heiderscheidt, who are key roles as mentors. Additionally, we would like to thank Arizona Public Service for giving us approval to use their land next to the APS substation.

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1.0 Project Description

Zirotti, Alqaoud, Betoney, and Swearingen (ZABS) Inc. designed a well and sump pump to mitigate flooding from the southeast side of Rolle Activity Center located at Northern Arizona University (NAU). The storm water transports the water across the Pine Knoll Dr. into a designed retention basin to irrigate a possible community garden located between Pine Knoll Dr. and the Arizona Public Service (APS) substation. A state and vicinity map of the project location may be seen in Appendix A.3 [1]. The lowest elevation point of the project site next to the Rolle Activity Center seen as a red circle in Appendix A.2 has insufficient drainage and floods. This increases the chance of damaging the gym floor within the building. The proposed design alternative will eliminate flooding while providing aesthetic benefits to NAU's campus. The design is to withstand a 100 year storm with a duration of one hour to simulate a monsoonal storm in Flagstaff, Arizona.

The department of facility services at NAU are currently preventing flooding damages by placing sand bags a foot high near the southeast doors of Rolle Activity Center (Rolle). A figure showing the sand bags is located in Appendix A.3.

2.0 Methodology

In order to understand the project site's conditions ZABS had to technically consider the following.

2.1 Surveying

Surveying the proposed site would allow the team to have an understanding of the existing topography which calculates the amount water contributing to the flooding at Rolle. The team surveyed the site using both a Topcon R8 GPS unit and a Trimble 5800 Robotic Total Station, both with Trimble Survey Controller software. Groups paired off with each of the units, one team using the GPS to collect information of the P46 parking lot and the south campus soccer fields, and the other using the robotic total station to collect the flooding area in the southwest corner of Rolle and the basin/garden area just south across Pine Knoll Dr. in front of the APS Substation. The robotic total station was used in this area because of the precision of the device, which was vital for the flooding analysis. The robotic total station was also used in this area because of the proximity of the building itself and the overhead trees in the basin/garden area. Items collected included curb and gutter, roadway centerline, basin topography, parking lot striping, culvert inverts, sidewalks, and other miscellaneous items. At the end of the two day surveying session, 1,600 points were collected and exported into two comma delimited .csv files to be used in AutoCAD Civil 3D.

2.2 Topographic Map

The .csv files created in both the GPS and robotic total station data collectors were imported into AutoCAD Civil 3D as a point file. The point descriptions and their corresponding horizontal and vertical information were viewed in Model Space. From here, 3D polylines were drawn to connect the vital landscape and hardscape together. These 3D polylines were then converted into feature lines and these feature lines, combined with the other imported points, were selected to become part of a Surface to be used as the topographic map of the site area. This surface was called Existing Surface to be used as reference in the design.

2.3 Web Soil Survey

The NRCS Web Soil Survey website was used as the source of hydrologic information for the site. The website was accessed and the Web Soil Survey was began. The site area information was given by the website, which showed the design area contained both soil Type 15a and 17 in different amounts, seen in Appendix A.5. This information was used in the hydrology for the site.

2.4 Hydrology

The area of interest, seen below in Figure 1, shows the Rational Method area used in calculations. The area of interest, seen below in Figure 2, shows the SCS TR-55 CN Method area used in calculations, the figure also shows the existing contour delineation contributing to the existing basin/garden volume located in front of the APS Substation marked below in red.

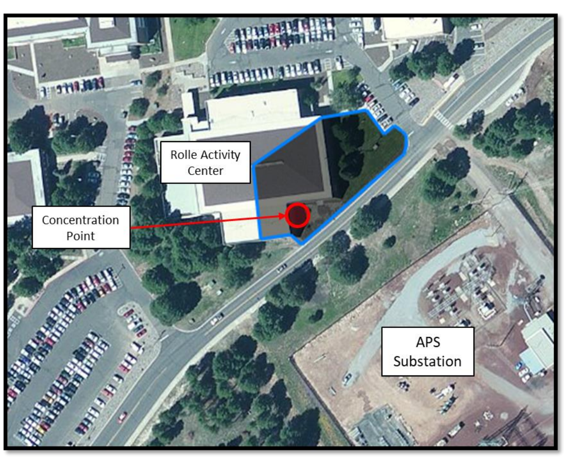

Figure 1. Rational Method Area

Figure 2. SCS TR-55 CN Method Area

This area was analyzed because of the added discharge from the flooding area needed to be accounted for.

2.4.1 Rational Method

The Rational Method from the City of Flagstaff (COF) Stormwater Management Design Manual was used to calculate the flooding area flow based on a 1-hour 100-year storm [4]. This method was used because the area met all of the specified requirement in the Manual. The COF also requires that the Rational Method has an added coefficient, the antecedent precipitation factor, to estimate for the inconsistencies that the Rational Equation itself may not account for. This coefficient is just a multiplier based on the size of storm being designed for, in this case that multiplier, C_f, equaled 1.25 for the 100-year storm.

Equation 1: Rational Equation

$$Q = C_f CIA$$

Q = maximum rate of runoff (cfs)

C_f = antecedent precipitation factor

C = runoff coefficient

2.4.2 SCS TR-55 CN Method

The area of interest was above the 20 acre max for using the Rational Method as described in the COF Stormwater Management Design Manual. The SCS TR-55 CN Method was used instead. The analysis procedure is similar to the Rational Method with some minor differences.

2.5 Pump Selection

Selecting the proper sump pump for the piping system is accomplished by producing a system curve, relating that curve to pump curves, and selecting the pump that meets the projects boundary conditions. A system curve displays the relationship between the flow rate and head losses of a piping system. As the flow rate increases within the system, the head losses will increase. A system curve is plotted using the energy equation to solve for head losses for a certain flow rate. Equation 2 below expresses the energy equation rearranged used in solving for the head of pump.

Equation 2. Energy Equation

$$h_p = \Delta P + \frac{\Delta V^2}{2g} + \Delta z + h_L$$

h_p = *head of pump (ft)*
ΔP = *change in pressure (psi)*
ΔV = *change in velocity (ft/s)*
Δz = *change in elevation (ft)*
h_L = *head losses (ft)*

With a system curve excel spreadsheet, the flow rate is increased to show an increase in head of pump, which is then plotted as the system curve. The system curve is then overlaid onto a pump manufactures pump curve. The intersecting point amongst the two curves shows the pumps operating point for the system. Then one uses their best engineering judgment to select the most efficient pump for the projects boundary conditions.

3.0 Analysis of Results

ZABS will be designing an alternative to mitigate flooding while providing grey water to a proposed community garden for NAU students, faculty, and the surrounding Flagstaff community to enjoy. The goal of the project is to eliminate any chance of flooding in the Rolle Activity Center while bringing life and utility to the selected area for the benefit of the environment and enjoyment of any interested individuals or groups. The results technical sections mandatory in reaching the project's goal are explained below.

3.1 Surveying

ZABS accumulated approximately 1,600 topographic points surveying NAU's parking lot 46 and the east side of Pine Knoll Dr. in front of APS substation. A surface is created using both the survey data and AutoCAD Civil 3D [5]. A topographic map is created and used to understand the hydrology of the surveyed area. The surveyed data points include shots of boulders, trees, and existing infrastructure. In addition, shots were taken on top of curb, end of curb, end of concrete, etc. Figure 1 displays the topographic site layout. See Appendix A.4 for full plan overview of the surveyed area.

3.2 Topographic Map

Using the survey points collected and AutoCAD Civil 3D, a topographic map is created. This involves using polylines to develop the existing infrastructure and landscape. A surface is then produced to show the existing contours.

3.3 Web Soil Survey

With further understanding of the project, the team agreed that a geotechnical analysis of the site is not required. The Web Soil Survey (WSS) website was used to obtain the general soil type in the area. A map showing the area analyzed with WSS is located in Appendix A.4. According to the results, the area contains fine sandy loam and cobbly loam soils, which are labeled as 17 and 15A, respectively. Table 1 below shows that the natural drainage class to be moderately well drained for fine sandy loam and well drained for cobbly loam. Tables 1 and 2 displays the soil type at different depths for 17 and 15A, respectively.

Table 1. Soil Summary [2]

Soil Name	Unit Symbol	Natural Drainage Class
Fine Sandy Loam	17	Moderately well drained
Cobbly Loam	15A	Well drained

Table 2. Profile Summary for Soil Type 17 [2]

17	
Height (inches)	**Soil type**
0-13	fine sandy loam
13-24	clay loam
24-50	clay
50-60	bedrock

Table 3. Profile Summary for Soil Type 15A [2]

15A	
Height (inches)	**Soil type**
0-3	cobbly loam
3-14	very cobbly loam
14-24	bedrock

3.4 Hydrology

3.4.1 Rational Method

The Rational Method, Equation 1 seen below, is used to determine the storm water runoff flowrate of the proposed site. According to the City of Flagstaff Storm Water Management Design Manual, the rational method is used for an area of focus of 20 acres or less. Rainfall intensity data for Flagstaff was taken from NOAA Atlas 14, Volume 1, Version 5 Flagstaff [3]. A table presenting NOAA's point precipitation frequency estimates is located in Appendix A.6. The flooding area near Rolle Activity Center has a basin area of 0.612 acres. The method took into account the impervious and pervious surfaces in the area and calculated a composite runoff coefficient of 0.59. The maximum flow rate calculate is 1.01 $\frac{ft^3}{s}$ for the 100-year one hour duration with a frequency of 2.23 and antecedent precipitation factor of 1.25. These values are displayed in Table 5 and 6 in Appendix A.6. Table 4 summarizes the calculated flow rates for the 25, 50, 100-year one hour and two hour duration storms. The maximum flooding depth is 1.2 feet, thus proving that the water will flow over the placed sand bags and flood Rolle Activity Center.

Table 4. Summary of Rate of Runoffs and Flooding Depths for Flagstaff

Rolle Activity Flooding Area					
Recurrence Interval (yrs)	Duration of Storm (hrs)	Frequency, i (in)[1]	Precipitation Factor, C_f[2]	Flow Rate, Q (ft^3/s)	Flooding Depth (ft)
25	1	1.65	1.1	0.66	0.78
50	1	1.93	1.2	0.84	1.00
100	1	2.23	1.25	1.01	1.20
25	2	1.82	1.1	0.36	0.86
50	2	2.12	1.2	0.46	1.10
100	2	2.44	1.25	0.55	1.32
[1]NOAA Atlas 14 PDS - based point precipitation frequency estimates with 90% confidence intervals					
[2]City of Flagstaff Stormwater Management Design Manual - Antecedent Precipitation Factors based on storm frequency					

3.4.2 SCS TR-55 CN Method

The area of flow of water contributing to the retention basin is approximately 31 acres, thus the SCS TR-55 CN Method is appropriate to use to calculate the flow rate. The area contains soils 15A and 17, thus determining a composite curve number (CN) of 76.02. The flow rates are determined for the 25, 50, 100-year one hour storm duration. The maximum flow rate is 0.538 $\frac{ft^3}{s}$ and the volume of water is 60,553 ft^3 for the 100-year storm. Table 5 summarizes the flow rates for each storm interval.

Table 5. Summary of Rate of Runoffs and volume of water for the retention basin

Retention Basin			
Average Recurrence Interval (yrs)	Rainfall, P (in)	Flow Rate, Q (ft^3/s)	Volume of Water (ft^3)
25	1.65	0.249	28,011
50	1.93	0.379	42,656
100	2.23	0.538	60,553

3.5 Pump Selection

As mentioned before, the type of pump selected is based on the energy equation. The calculated capacity is 890 GPM with a head of pump of 15 feet. Table 6 displays the system properties to appropriately determine the capacity of the pump.

Table 6. System properties to determine type of pump

System Properties	
Δpressure, P_2 - P_1 (psi)	0
Unit Weight of Water, γ_w (lb/ft^3)	62.4
Gravity, g (ft/s^2)	32.2
Elevation of Water Surface, z_1 (ft)	6,879.15
Elevation of Pipe Outlet, z_2 (ft)	6,882.37
Diameter of Pipe A (in)	4
Diameter of Pipe B (in)	6
Length of Pipe A (ft)	1.5
Length of Pipe B (ft)	56.5
$K_{gradual\ expansion}$ [1]	0.72
$K_{90°\ elbow\ flanged}$ [1]	0.3
$K_{swing\ check\ valve}$ [1]	2
$K_{outlet\ grate}$ [1]	0.05
[1]Analysis of Flow in Pipes - minor loss coefficients	

With iteration of calculations of the energy equation, ZABS developed a system curve, in which is compared to the TOYO Pump curves to help select an ideal sump pump for the design. Figure 12 in Appendix A.11 displays the system curve (shown in red) compared to the pump curves of the TOYO Pumps. Based on the compared curves, the ideal selection for the design is the DL-15 TOYO sump pump [6]. The system curve and DL-15 curve interacts at approximately 890 GPM with a head of 15 feet. The efficiency of the pump is determined to be 55 and the power is calculated to be 2.49 kW. Refer to Table 7 below to view results.

Table 7. Components to calculate the power of the pump

Power of Pump	
Unit Weight of Water (lb/ft^3)	62.4
Head of Pump (ft)	15
Pump Flow Rate (ft^3/s)	1.98
Efficiency (%)	55
Power (kW)	2.49

Although the efficiency of the pump is 55, which is low, the pump will not be operating every day throughout the year. The pump will be operating a couple of hours a years, thus the 55 efficiency of the pump does not affect the efficiency of the system. Table 8 summarizes the cost to operate a pump. If the pump functions for 10 hours a year, the cost is $2.54 and the commercial electricity rate is 10.22 ¢/kW-h.

Table 8. Displays the results of the cost to operate a sump pump

Cost to Run Pump	
Power of Pump (kW)	2.49
Commercial Electricity Rate[1] (¢/kW-h)	10.22
Time of Pump Usage (hours)	10
Cost ($)	2.54
[1]Electricity Local - average commercial electricity rates in Flagstaff	

4.0 Design

After understanding the site's boundary conditions and sump pump selected the team was able to design the well, piping system, and retention pond.

4.1 Well Design

The well is designed to be 15'x 5'x 15' in dimension. The bottom of the well has a 2% downgrade toward the south end of the well to allow the water to flow toward the pump. Appendix A.12 displays a plan view of the location of the sump pump well. The well has volume of 1,125 ft^3 and can contain approximately 8,415.6 gallons of water. With the maximum flow rate of 1.01 $\frac{ft^3}{s}$ for the 100-year one hour duration storm, the flow rate to fill the well is 453.3 GPM. The time to fill the well to 75% is 13.9 minutes and the time to drain the well is 14.5 minutes all within the one hour duration. Table 9 displays the well and sump pump characteristics.

Table 9. Well design and drainage results

Well and Sump Pump Characteristics	
Area of Well (gallons)	8415.6
Pump Capacity (gpm)	890
100 Year Storm Flow Rate (ft^3/s)	1.01
100 Year Storm Flow Rate (gpm)	453.3
Initial Time of Detention (min.)	13.9
Well Drainage Rate (gpm)	436.7
Time to Drain Completely (min.)	14.5

4.2 Piping Design

A 1.5 feet long, 4 inch PVC pipe is connected to the sump pump. It expands to a 6 inch PVC pipe for 56.5 feet long. The pipe is constructed to cross under Pine Knoll Dr. roadway with a downward slope of 0.5%. After the expansion from the 4 inch to the 6 inch, a 90 degree elbow is implemented, followed by a swing check valve to prevent back flow issues. The downward slope allows the flow of water to be controlled by gravity after the water is pump passed the check valve. The pipe outlet contains an outlet drainage grain, which is treated as a contraction.

4.3 Retention Basin Design

The retention pond is designed to have a volume of 67,200 ft^3. An additional 7,000 ft^3 is excavated to hold a volume of 60,553 ft^3 of water. The exterior slope of the pond is a 2:1 ratio to display a natural appearance due to the fact that the pond will not always be full of water throughout the year. Appendix A.13 presents the plan view of the retention pond.

5.0 Schedule of Materials

The schedule of materials and costs was determined using prices from home depot, ADOT bid history, and TOYO Pumps manufacturer [6] [7] [8]. Table 10 below displays the materials needed to develop the design and their cost.

Table 10. Schedule of Materials and Cost

Item	Material	Unit	Quantity	Unit Cost ($)	Total Cost ($)
1	4-inch Sch. 40 PVC	feet	1	8.62	8.62
2	6-inch Sch. 40 PVC	feet	7	39.60	277.20
3	6-inch PVC 90 degree elbow	Each	2	10.98	21.96
4	4 in. x 6in. PVC Reducer coupling	Each	1	7.02	7.02
5	6-inch drainage grate cap	Each	1	4.24	4.24
6	TOYO DL-15 Sump Pump	Each	1	8,445.00	8,445.00
				Total	**$8,764.04**
Item	**Services**	**Unit**	**Quantity**	**Unit Cost ($)**	**Total Cost ($)**
1	Horizontal boring	feet	61.5	400	24,600.00
2	Excavation of soil	cubic yard	953.5	30	28,605.00
3	Installation of TOYO DL-15	Each	1	1,022	1,022.00
				Total	**$ 54,227.00**

References

[1] "Google Maps", *Google Maps*, 2017. [Online]. Available: https://www.google.com/maps/search/maps/@35.179423,111.6558083,1528m/data=!3m1!1e3. [Accessed: 07- Feb- 2017].

[2] "Web Soil Survey", *Websoilsurvey.sc.egov.usda.gov*, 2017. [Online]. Available: https://websoilsurvey.sc.egov.usda.gov/App/HomePage.htm. [Accessed: 04- Oct- 2017].

[3] "PF Map: Contiguous US", *Hdsc.nws.noaa.gov*, 2017. [Online]. Available: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html. [Accessed: 13- Oct- 2017].

[4] *"City of Flagstaff Storm Water Management Design Manual", 2000. [Online]. Available: http://www.flagstaffstormwater.com/index.aspx?nid. [Accessed: 13- Oct- 2017]*.

[5] AutoCAD Civil 3D. Autodesk Inc. 2017

[6] "Hevvy Pumps - Toyo Pumps is now Hevvy Pumps", Hevvy Pumps, 2017. [Online]. Available: https://hevvypumps.com/. [Accessed: 27- Nov- 2017].

[7] "Bid Item History", Apps.azdot.gov. [Online]. Available: https://apps.azdot.gov/e2c2/HistoricalPrice.aspx. [Accessed: 29- Nov- 2017].

[8] Homedepot.com,2017. [Online]. Available: https://www.homedepot.com/. [Accessed: 27- Nov- 2017].

Appendix

A.1 State and Vicinity Map

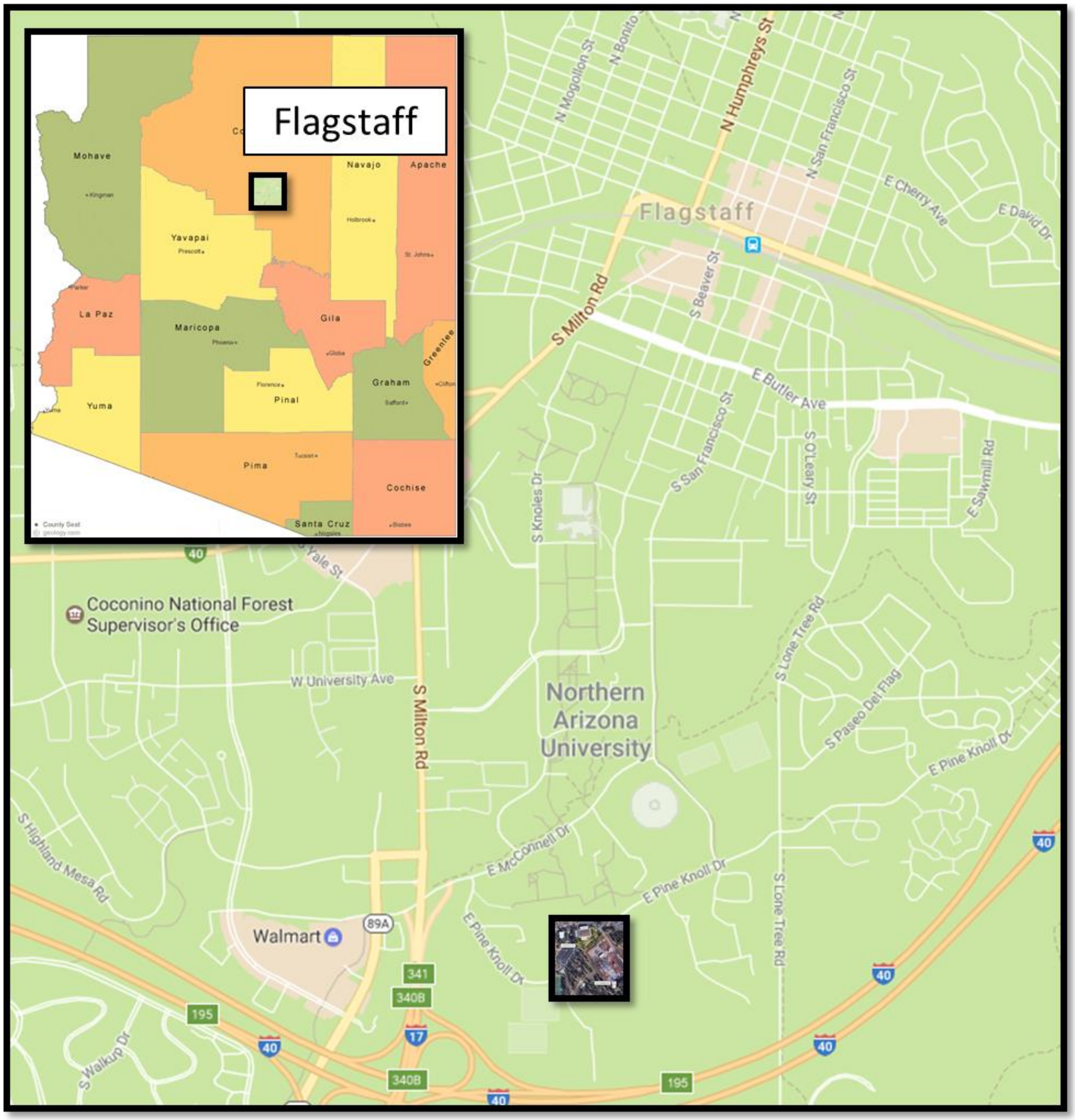

Figure 3. State and vicinity map of proposed site in Flagstaff, Arizona [1]

A.2 Site Map

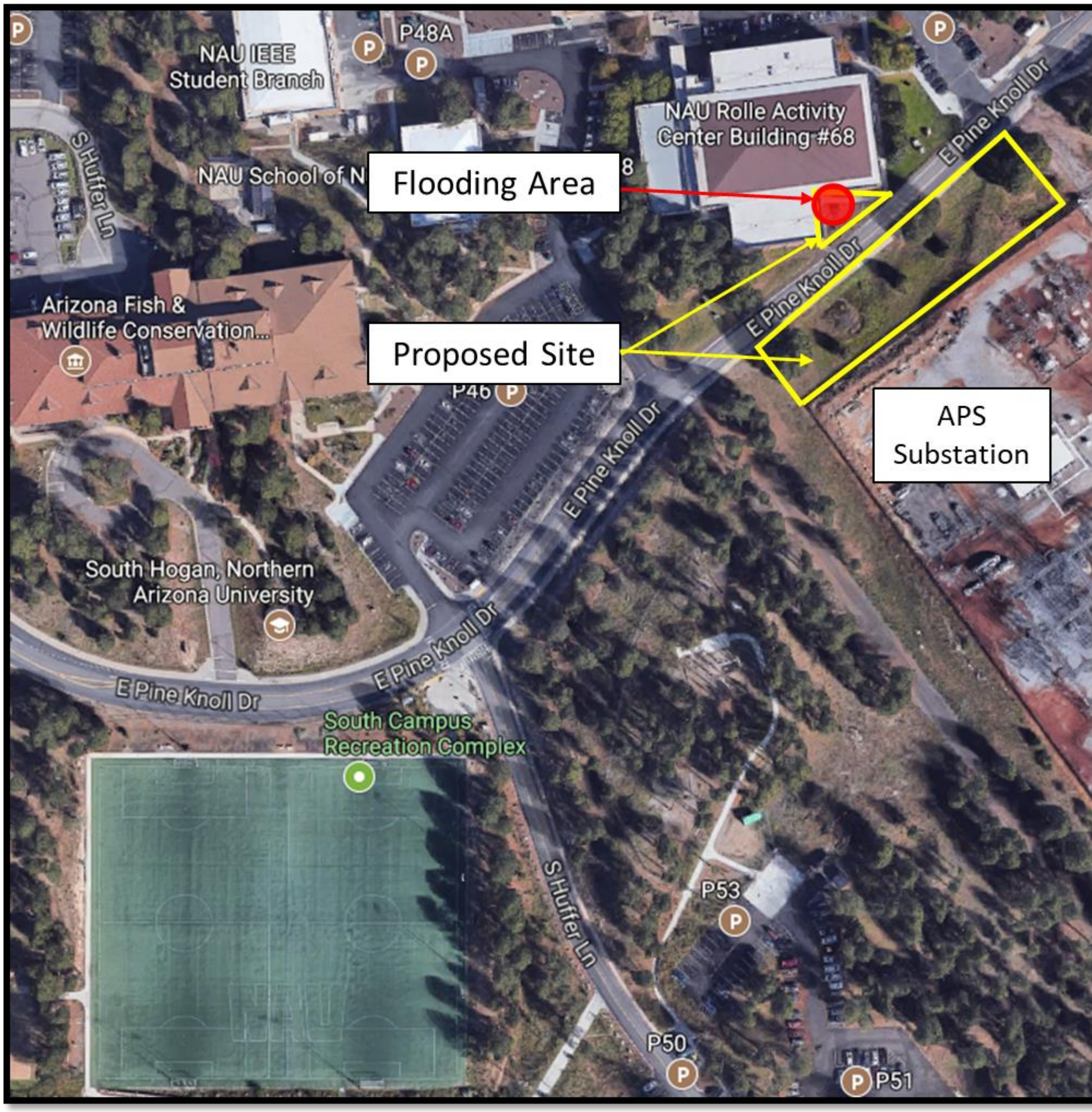

Figure 4. Proposed site (yellow); flooding area (red) [1]

A.3 NAU's Solution to the Flooding Issue

Figure 5. Flooding area behind Rolle Activity Center with sand bags on the Southeast door

A.4 Proposed Overall

(See attached 11”x17”)

A.5 Web Soil Survey Map

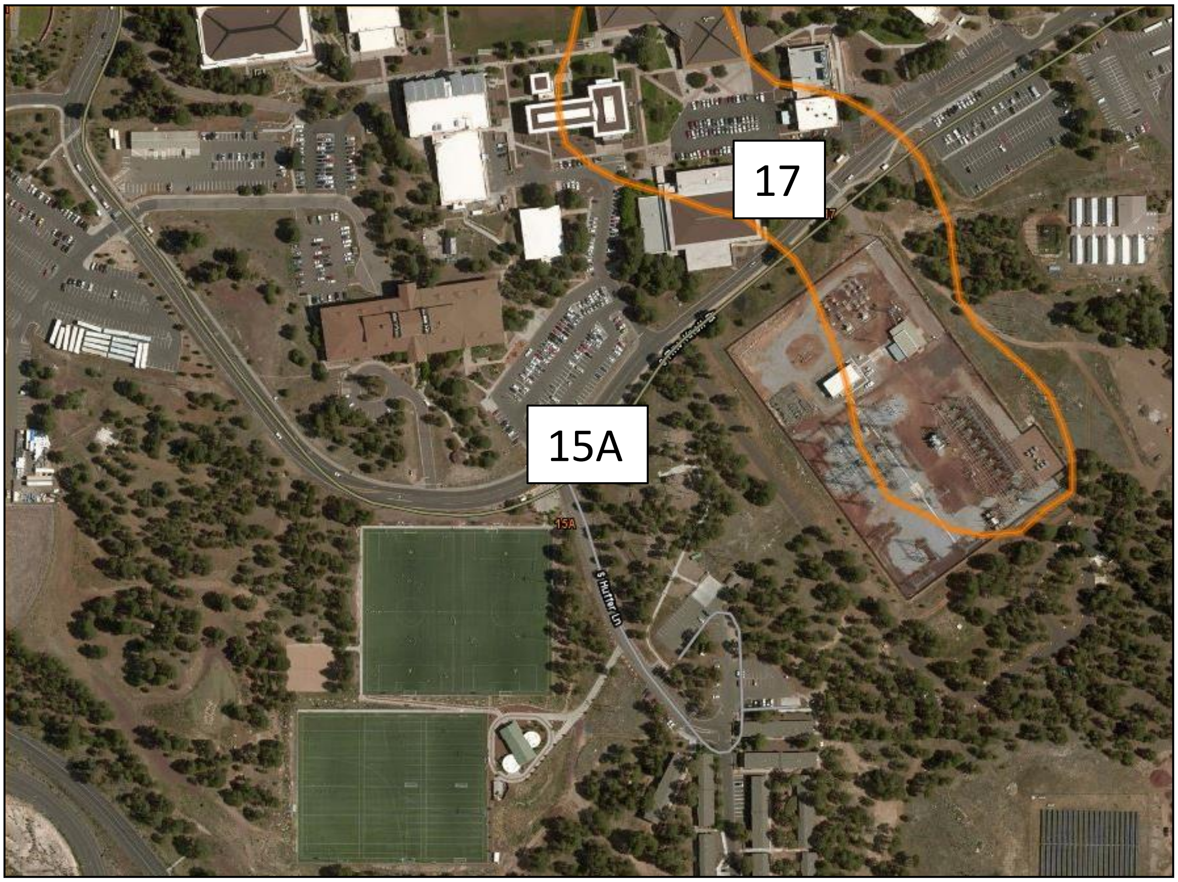

Figure 6. Web Soil Survey of Site [2]

A.6 Point Precipitation Frequency Estimates for Flagstaff, AZ

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	**0.196** (0.174-0.225)	**0.256** (0.227-0.291)	**0.344** (0.306-0.392)	**0.418** (0.366-0.475)	**0.524** (0.457-0.593)	**0.612** (0.527-0.692)	**0.708** (0.602-0.804)	**0.812** (0.677-0.919)	**0.961** (0.786-1.10)	**1.09** (0.873-1.26)
10-min	**0.299** (0.265-0.342)	**0.389** (0.345-0.443)	**0.524** (0.465-0.596)	**0.636** (0.557-0.724)	**0.798** (0.696-0.903)	**0.932** (0.803-1.05)	**1.08** (0.916-1.22)	**1.24** (1.03-1.40)	**1.46** (1.20-1.67)	**1.66** (1.33-1.91)
15-min	**0.370** (0.328-0.424)	**0.482** (0.428-0.550)	**0.649** (0.577-0.739)	**0.788** (0.690-0.897)	**0.989** (0.863-1.12)	**1.16** (0.995-1.31)	**1.34** (1.14-1.52)	**1.53** (1.28-1.74)	**1.81** (1.48-2.07)	**2.06** (1.65-2.37)
30-min	**0.499** (0.442-0.571)	**0.649** (0.576-0.740)	**0.874** (0.776-0.995)	**1.06** (0.930-1.21)	**1.33** (1.16-1.51)	**1.56** (1.34-1.76)	**1.80** (1.53-2.04)	**2.06** (1.72-2.34)	**2.44** (2.00-2.79)	**2.77** (2.22-3.20)
60-min	**0.617** (0.547-0.707)	**0.803** (0.713-0.916)	**1.08** (0.961-1.23)	**1.31** (1.15-1.50)	**1.65** (1.44-1.87)	**1.93** (1.66-2.18)	**2.23** (1.89-2.53)	**2.55** (2.13-2.89)	**3.02** (2.47-3.45)	**3.43** (2.74-3.96)
2-hr	**0.727** (0.658-0.820)	**0.920** (0.826-1.03)	**1.21** (1.09-1.37)	**1.46** (1.30-1.63)	**1.82** (1.60-2.04)	**2.12** (1.84-2.37)	**2.44** (2.10-2.74)	**2.80** (2.37-3.14)	**3.32** (2.74-3.76)	**3.75** (3.03-4.27)
3-hr	**0.794** (0.716-0.897)	**1.00** (0.904-1.13)	**1.29** (1.16-1.44)	**1.53** (1.37-1.72)	**1.89** (1.68-2.11)	**2.17** (1.91-2.43)	**2.49** (2.17-2.80)	**2.84** (2.42-3.20)	**3.36** (2.81-3.81)	**3.80** (3.12-4.34)
6-hr	**0.975** (0.895-1.08)	**1.21** (1.12-1.33)	**1.50** (1.38-1.66)	**1.76** (1.60-1.93)	**2.12** (1.92-2.33)	**2.43** (2.17-2.67)	**2.75** (2.44-3.02)	**3.11** (2.70-3.42)	**3.62** (3.07-4.02)	**4.04** (3.36-4.51)
12-hr	**1.25** (1.16-1.36)	**1.55** (1.43-1.68)	**1.89** (1.75-2.06)	**2.18** (2.01-2.36)	**2.57** (2.35-2.79)	**2.86** (2.60-3.11)	**3.18** (2.86-3.47)	**3.50** (3.12-3.84)	**3.95** (3.46-4.36)	**4.31** (3.72-4.78)
24-hr	**1.73** (1.58-1.88)	**2.16** (1.98-2.35)	**2.68** (2.46-2.92)	**3.11** (2.84-3.39)	**3.70** (3.37-4.03)	**4.16** (3.78-4.52)	**4.65** (4.19-5.05)	**5.14** (4.61-5.60)	**5.82** (5.16-6.36)	**6.36** (5.59-6.97)
2-day	**2.07** (1.90-2.26)	**2.58** (2.37-2.82)	**3.21** (2.95-3.51)	**3.73** (3.41-4.06)	**4.44** (4.05-4.83)	**5.00** (4.55-5.45)	**5.58** (5.04-6.08)	**6.18** (5.55-6.75)	**7.01** (6.22-7.67)	**7.66** (6.75-8.41)
3-day	**2.22** (2.04-2.42)	**2.77** (2.55-3.03)	**3.46** (3.18-3.78)	**4.03** (3.69-4.38)	**4.82** (4.40-5.24)	**5.45** (4.96-5.93)	**6.11** (5.53-6.65)	**6.80** (6.10-7.41)	**7.75** (6.88-8.48)	**8.51** (7.48-9.35)
4-day	**2.38** (2.18-2.59)	**2.96** (2.73-3.23)	**3.71** (3.41-4.04)	**4.33** (3.97-4.71)	**5.21** (4.76-5.66)	**5.90** (5.37-6.41)	**6.64** (6.01-7.23)	**7.41** (6.65-8.07)	**8.49** (7.54-9.29)	**9.35** (8.21-10.3)
7-day	**2.84** (2.61-3.07)	**3.53** (3.25-3.83)	**4.38** (4.03-4.74)	**5.08** (4.67-5.49)	**6.07** (5.55-6.58)	**6.86** (6.23-7.43)	**7.68** (6.95-8.34)	**8.55** (7.67-9.29)	**9.74** (8.66-10.6)	**10.7** (9.41-11.7)
10-day	**3.21** (2.95-3.48)	**3.99** (3.67-4.34)	**4.92** (4.53-5.34)	**5.66** (5.20-6.13)	**6.66** (6.10-7.21)	**7.43** (6.79-8.06)	**8.22** (7.47-8.91)	**9.02** (8.14-9.79)	**10.1** (9.03-11.0)	**10.9** (9.70-11.9)
20-day	**4.30** (3.99-4.62)	**5.33** (4.95-5.74)	**6.45** (5.99-6.95)	**7.31** (6.77-7.86)	**8.42** (7.80-9.06)	**9.24** (8.53-9.94)	**10.0** (9.24-10.8)	**10.8** (9.93-11.7)	**11.8** (10.8-12.8)	**12.6** (11.4-13.6)
30-day	**5.23** (4.87-5.64)	**6.48** (6.03-6.99)	**7.81** (7.26-8.41)	**8.82** (8.18-9.49)	**10.1** (9.34-10.9)	**11.0** (10.2-11.9)	**11.9** (11.0-12.9)	**12.8** (11.7-13.8)	**13.9** (12.7-15.1)	**14.7** (13.4-16.0)
45-day	**6.29** (5.82-6.83)	**7.79** (7.21-8.46)	**9.40** (8.70-10.2)	**10.6** (9.83-11.5)	**12.2** (11.3-13.3)	**13.4** (12.3-14.5)	**14.6** (13.4-15.8)	**15.7** (14.4-17.0)	**17.1** (15.6-18.6)	**18.2** (16.5-19.8)
60-day	**7.34** (6.80-7.95)	**9.08** (8.40-9.84)	**10.9** (10.1-11.8)	**12.2** (11.3-13.2)	**13.9** (12.8-15.0)	**15.1** (13.9-16.4)	**16.3** (14.9-17.7)	**17.4** (15.9-18.9)	**18.7** (17.0-20.4)	**19.7** (17.9-21.5)

[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 7. Point Precipitation Frequency Estimates [3]

A.7 City of Flagstaff Storm Water Management Design Manual: Antecedent Precipitation Factors and Runoff Coefficients

Table 11. Antecedent Precipitation Factors [4]

Storm Frequency	Factor
25 Year	1.1
50 Year	1.2
100 Year	1.25

Table 12. Runoff Coefficients [4]

Surface Description	Runoff Coefficients
Streets	0.95
Asphaltic Concrete	0.95
Concrete	0.95
Brick Pavers	0.90
Compacted ABC roadways/shoulders	0.50 - 0.70
Drives and Sidewalks	0.95
Gravel (open)	0.50
Roofs	0.95

		SLOPE	
Surface Description	Flat < 2%	Avg. 2% - 7%	Steep > 7%
Lawns			
Sandy Soils	0.10	0.20	0.30
Gravelly Soils	0.15	0.25	0.35
Clay Soils	0.20	0.30	0.40
Dense Vegetation			
Sandy Soils	0.07	0.14	0.20
Gravelly Soils	0.11	0.20	0.27
Clay Soils	0.15	0.25	0.35
Woods			
Sandy Soils	0.05	0.10	0.15
Gravelly Soils	0.07	0.12	0.17
Clay Soils	0.10	0.15	0.20

A.8 Rational Method: Basin Area

Figure 8. Rational Method basin area contributing to the flooding at Rolle Activity Center

A.9 Excel Calculations for Runoff Flow Rate and Flooding Depth

$$Q = C * i * A * C_f$$

Basin Area, A (ft^2)	26638
Impervious Surface (ft^2)	11375
Pervious Surface (ft^2)	15263
Runoff Coefficient (Lawn Sandy Soils)	0.10
Runoff Coefficient (Roofs/Concrete)	0.95
Flooding Area (ft^2)	3021
Composite Coefficient, C	0.59

Average Recurrence Interval (yrs)	Duration of Storm (hrs)	Precipitation Frequency (in)	Precipitation Factor	Flow Rate (ft^3)	Flooding Depth (ft)
25	1	1.65	1.1	0.66	0.78
50	1	1.93	1.2	0.84	1.00
100	1	2.23	1.25	1.01	1.20
25	2	1.82	1.1	0.36	0.86
50	2	2.12	1.2	0.46	1.10
100	2	2.44	1.25	0.55	1.32

Figure 9. Excel Data/Calculations for Rate of Runoff and Flooding Depth

A.10 SCS TR-55 CN Method: Basin Area

Figure 10. SCS TR-55 CN Method area of basin contributing to the volume of water to the pond in between Pine Knoll Dr. and the APS Substation

A.11 System Curve vs. DL TOYO Sump Pump Curves

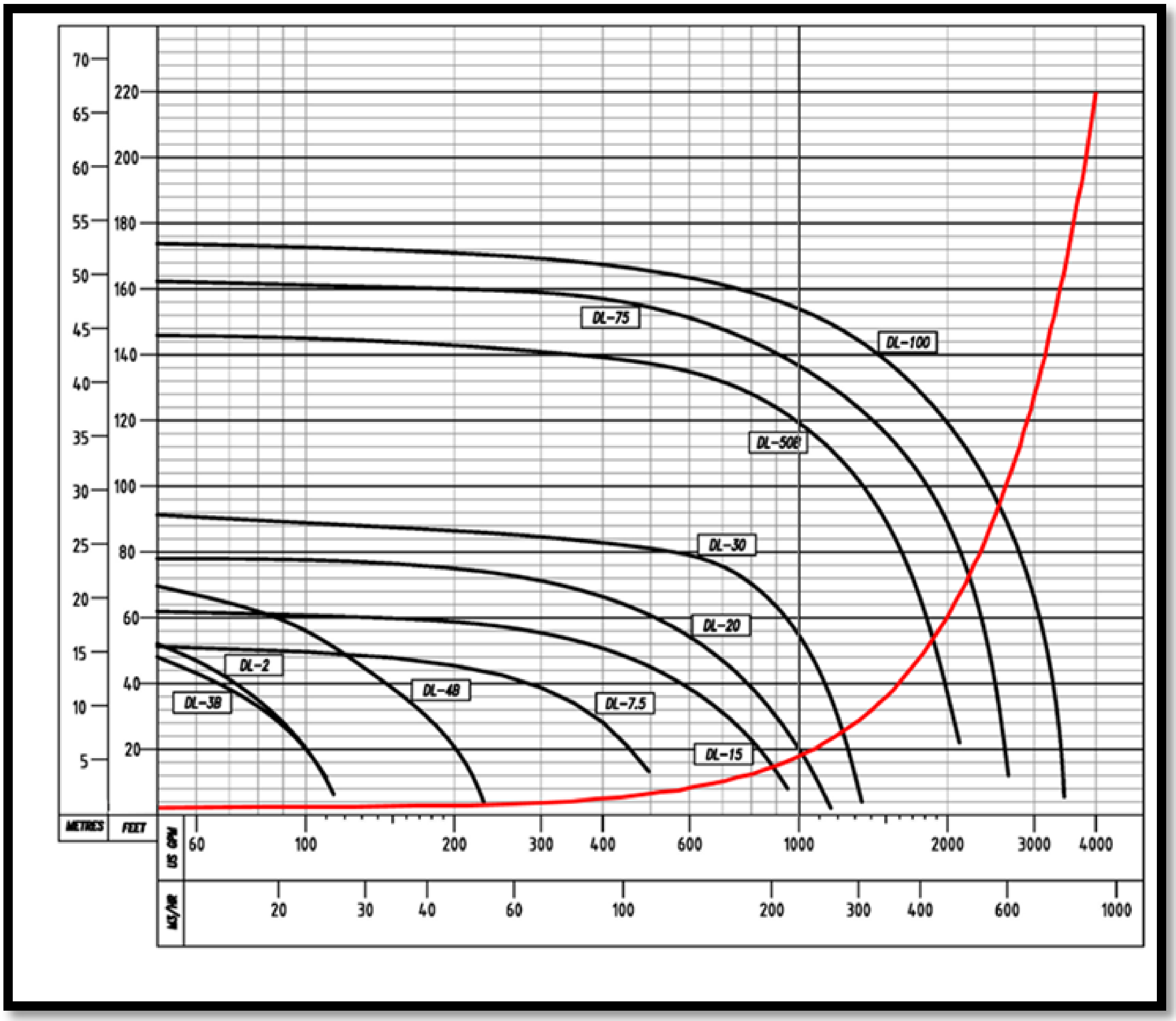

Figure 11. System curve aligned with DL TOYO sump pump curves [6]

A.12 Pipe Profile

(See attached 11”x17”)

A.13 Pond Layout

(See attached 11”x17”)