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NAU Water Buffalo Engineering

DRAINAGE STUDY OF NAU'S CLINE LIBRARY, EASTBURN EDUCATION, AND GAMMAGE BUILDINGS

FINAL DESIGN REPORT

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1.0 Project Description

The NAU department of Engineering and inspection has indicated that the Gammage, Cline Library, and Eastburn Education buildings have been experiencing flooding and resulting water damage. These building sites are susceptible to poor drainage conditions and can consequently suffer moderate flood damage during relatively minor flood events. In response, NAU's Facility Services has re-graded and constructed a concrete channel in the parking lot behind Gammage this past summer (July 2016), in an attempt to alleviate flood damage at the given site, while the Cline Library and Eastburn Education sites are still in their original conditions. Accordingly, the new hydraulic infrastructure at Gammage will be analyzed for effectiveness while the existing drainage plan for the Eastburn Education and Cline Library buildings will be researched and revised to minimize flood impacts and drain the site area as efficiently as possible. Although the site area lies within the Federal Emergency Management Agency (FEMA) designated floodplain for the Rio De Flag, this drainage study will not include an analysis of the Rio De Flag's 100-year flood plain.

1.1 Project Background

1.1.1 Gammage, Cline Library and Eastburn Education Drainage Issues

The Eastburn Education, Cline Library, and Gammage buildings are located in Northern Arizona's (NAU) northern campus in a heavily urbanized area of Flagstaff, Arizona. According to a previous drainage study on NAU's campus performed by "Coe and Van Loo LLC", six buildings on NAU's north campus were marked individually for concern due to flooding risk (Gammage, Bury Hall, Eastburn Education, Babbit Administration, Peterson, and Cline Library) [1]. Of the six sites designated as "high drainage concern", only Eastburn Education/Cline Library and Gammage have not received any flood mitigation design work or recently received hydraulic infrastructure upgrades that have yet to be analyzed accordingly. The drainage report lists the primary causes of flooding to be parking lot drainage and roof runoff, resulting in small-scale localized flooding concerns for the site areas.

1.1.2 Location within Rio De Flag's Floodplain

NAU's campus is located south of the confluence of the Rio de Flag and Clay Avenue wash, two ephemeral streams draining over 67 square miles of watershed. According to FEMA [2], the Rio De Flag's 100-year storm floodplain will overflow into a significant portion of NAU's campus. As shown in Figure 1, FEMA's map of the 100-year floodplain of the Rio de Flag, 106 of the 490 acres of NAU's campus currently lies within the floodplain.

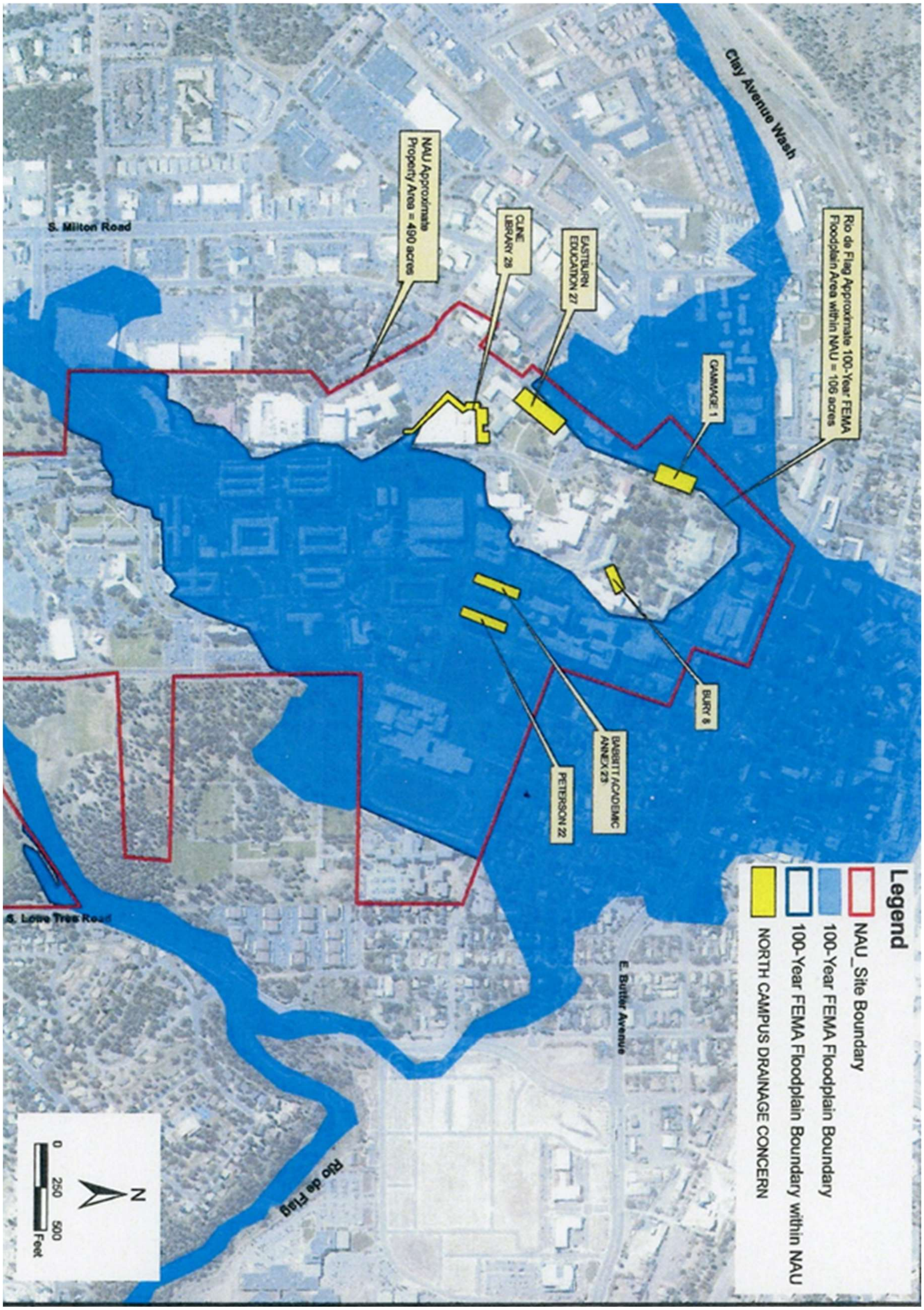

Figure 1: FEMA 100-year floodplain map of Flagstaff, with the 6 buildings that have been identified as areas of concern [2].

1.2 Technical Considerations

1.2.1 Site Surveying

In order to perform hydrologic analysis on the site, a land survey will be needed to determine site topography. Topographic maps allow for 3-Dimensional data points of land surface elevation to be used for delineating drainage basins, and this topography data can only be gathered through a land survey. The team will conduct the topographic surveys with a Total Station rented from NAU's College of Civil and Environmental Engineering (CENE).

1.2.2 Site Mapping

On completion of the topographic survey, the team will input the survey data points into Civil-3D, where a 3-Dimensional topographic map will be created. The topographic map will be used to delineate drainage basins that will be used in the hydrologic analysis of the sites.

1.2.3 Hydrologic Analysis

In order to complete a drainage study, the team must determine the peak surface runoff that can be generated at the site. Calculation of surface runoff can be done in a variety of ways, and the hydrologic analysis will be performed in compliance with the City of Flagstaff Storm Water Management Design Manual, Chapter 3[3], described in more detail later in the report. By using a topographic map to determine exact area, implementing a weighted curve number/runoff coefficient to various surfaces, and using rainfall intensity gathered from National Oceanic and Atmospheric Administration's (NOAA) Atlas 14 on rainfall data; the surface runoff flow generated will be accurate enough to use for performing all hydraulic analysis on the site areas. The volumes gathered from these calculations will serve as the basis for the sizing and designing of all hydraulic infrastructure.

1.2.4 Hydraulic Analysis of Current Hydraulic Infrastructure

Upon completion of the hydrologic analysis of the given site areas, the team will conduct a hydraulic analysis of the existing drainage configurations and determine its adequacy against the design flow for the target storm frequency. The hydraulic analysis will be conducted in accordance with the methods outlined in the City of Flagstaff Storm Water Management Design Manual, Chapter 4 [3] as is discussed more thoroughly later in the report. Based upon the calculations to determine hydraulic capacity of the sites, the team will then decide to maintain or upgrade all pieces of hydraulic infrastructure based on upon its current adequacy.

1.2.5 Hydraulic Design of Proposed Solutions

In areas determined to be inadequate by the hydraulic analysis, the team will formulate a suite of design alternatives for the problem locations, designed to accommodate the targeted flow. All new designs will adequately convey the targeted surface runoff flow and be in compliance with the standards set in the City of Flagstaff Storm Water Management Design Manual, Chapter 4 [3].

2.0 Technical Sections

This project will perform a drainage study the targeted buildings; Cline Library, Eastburn Education, and Gammage, located on NAU's north campus. The conducted drainage study will include the following elements:

- Site Surveying
- Site Mapping
- Hydrologic Analysis
- Hydraulic Analysis
- Design Solutions
- Proposed Solution
- Cost Analysis
- Project Management
- Impacts

2.1 Site Surveying

2.1.1 Site Inspection

This task included visiting the site area and determining what surface types lie within the basins, what areas will be needed to be surveyed, and locations of current hydraulic infrastructure within the sites. The locations of these buildings in relationship to NAU's campus are shown in Figure 2.

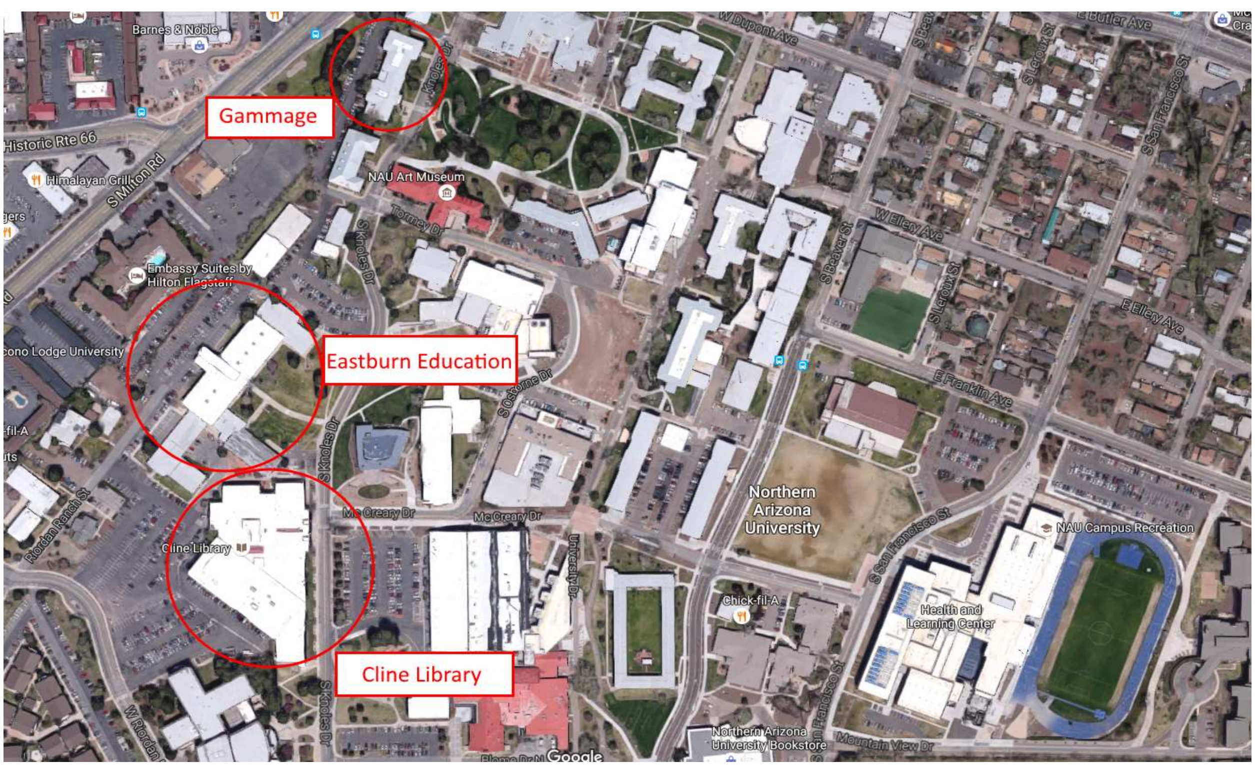

Figure 2: Location of Cline Library, Eastburn Education, and Gammage within NAU's campus

It is from this site inspection, that the team determined that there are 2 separate watersheds that encompass the Three building sites. The first drainage basin contains only the Gammage building and its accompanying parking lot with the newly constructed drainage channel lying within, while the second drainage basin contains both the Cline Library and Eastburn Education Buildings, along with a large stretch of parking lot separating the 2 structures with an existing storm drain located near its centroid.

2.1.2 Site Survey

Upon completion of the preliminary site inspection, the team acquired a Total Station, Data Collector, and Prism Pole from NAU's CENE lab. This survey equipment was used to gather surface elevation data for over 500 points surrounding Cline Library, Eastburn Education, and Gammage. In addition to surface elevation data, the team also marked all locations of roof gutter outlets, and the position of the existing concrete channel (Gammage drainage basin) and storm drain (Cline Library/Eastburn Education drainage basin) within the watersheds. All survey points for the Gammage and Cline Library/Eastburn Education watersheds are attached in appendices A and B respectively.

2.2 Site Mapping

2.2.1 Creation of Topographic Map

Using the data gathered from the site survey, the team imported all survey data points into Civil-3D where a surface with corresponding topography contours was created. The topographic map for the Gammage drainage basin is shown in Figure 3, and the topographic map for the Cline Library/Eastburn Education building is shown in Figure 4, on the following pages.

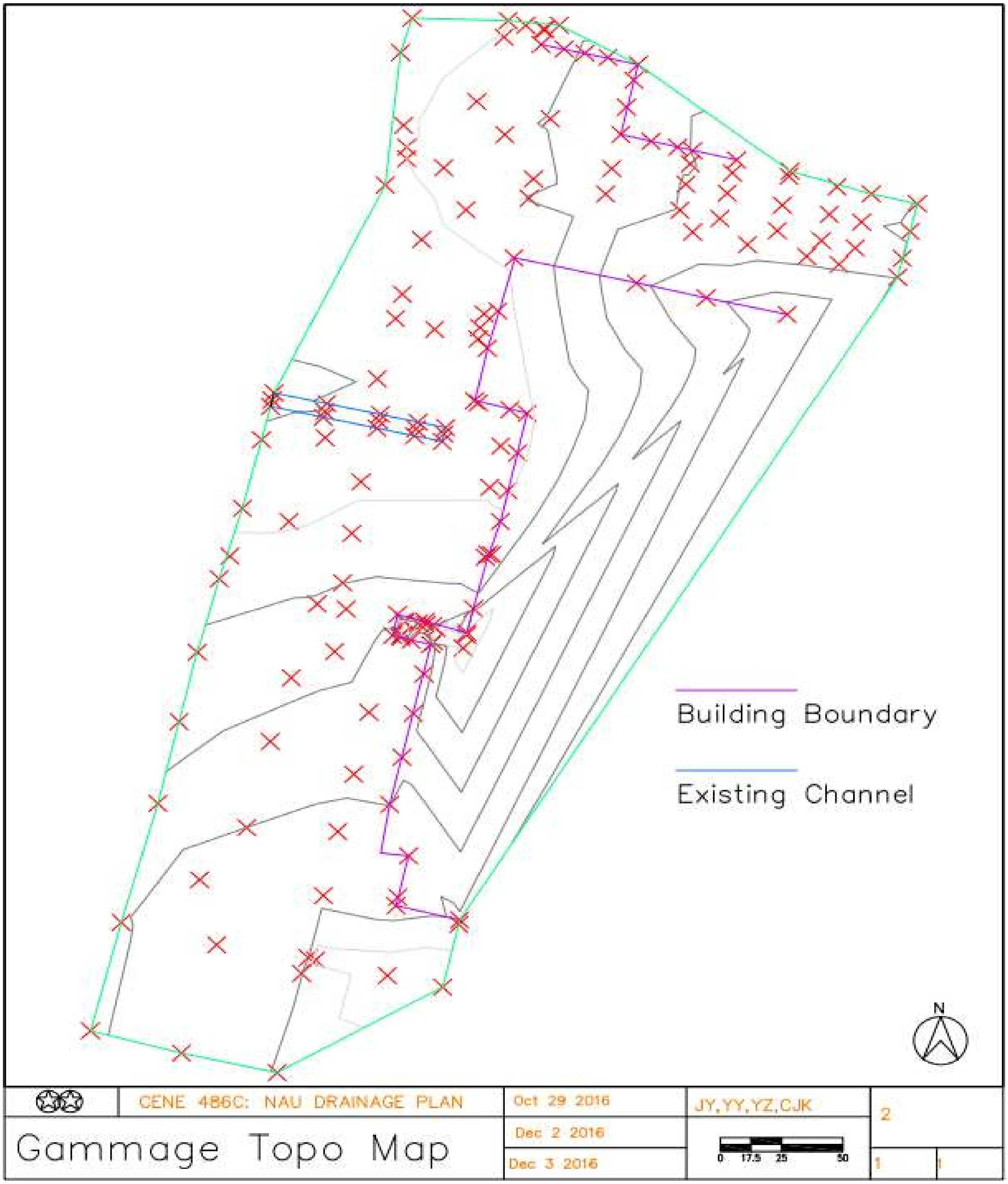

Figure 3: Topographic Map of Gammage Watershed

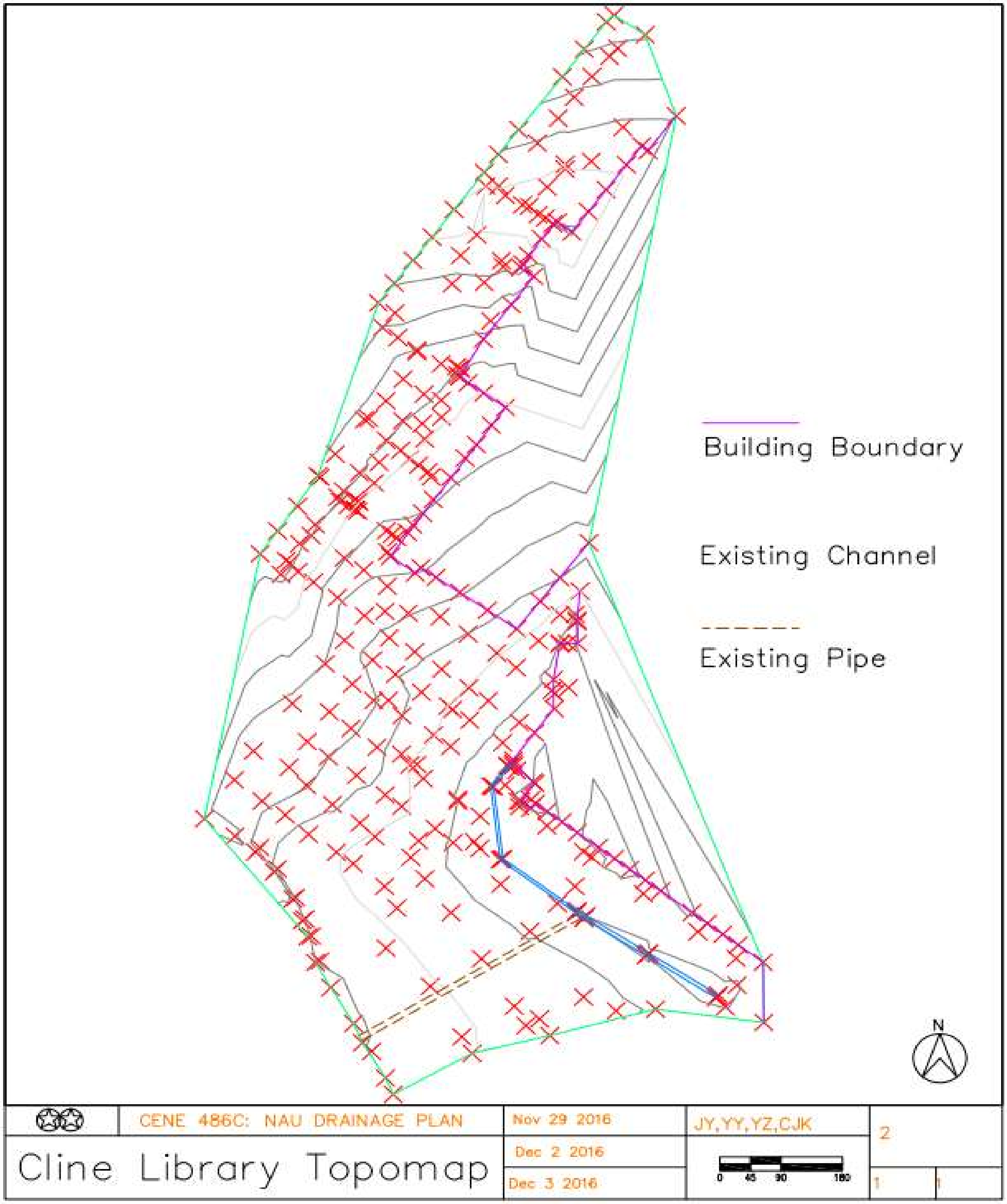

Figure 4: Topographic Map of Cline Library/Eastburn Education Watershed

2.3 Hydrologic Analysis

2.3.1 City of Flagstaff Stormwater Management Design Manual

The City of Flagstaff Stormwater Management Design Manual, Chapter 3, requires that all hydrologic analysis within its city limits be performed by way of Rational Method, SCS TR-55 Method, or HEC-1 method [3].

2.3.2 Method of Hydrologic Analysis Used

In compliance with the City of Flagstaff Stormwater Management Design Manual, the team decided to perform the hydrologic analysis using the Rational Method. According to The City of Flagstaff Stormwater Management Design Manual, Section 3.1.3, the Rational Method's limitations are shown in Table 1 [3].

Table 1: Rational Method Limitations Taken From the City of Flagstaff Stormwater Management Design Manual [3].

The following limitations shall apply to the Rational Method in the City of Flagstaff	
1.	The total drainage area must be less than or equal to 20 acres
2.	The time of concentration cannot be less than 5 minutes or greater than 60 minutes
3.	The land use of the contributing watershed must be fairly consistent over the entire drainage area and uniformly distributed throughout the area. That is, the contributing area should not consist of a large percentage of two or more land uses (e.g. 50% commercial and 50% undeveloped forest)
4.	The contributing watershed cannot have drainage structures or facilities which would require flood routing to estimate the discharge at the point of interest.
5.	If it is important to locate a specific land use within the drainage area then another hydrologic method should be used where hydrographs can be generated and routed through the drainage system.

Given that the drainage basins for Gammage and Cline Library/Eastburn Education are roughly 1 and 3 acres accordingly, the size limitation for analysis isn't exceeded satisfying limit One. The time of concentration calculated further ahead in the chapter was found to be 10 minutes, greater than the 5-minute minimum satisfying limit Two. The site inspection revealed that each drainage basin was predominantly impervious surfaces satisfying limit Three. All current drainage structures within the watershed do not route flow satisfying limit Four. And finally, being that there is no need to locate a specific land use within the drainage basin, limit Five is satisfied. Due to all Five mandated limit states being met, the team finalized the decision to use the

Rational Method for analysis.

2.3.3 Rational Method Analysis for Runoff Volume

As defined by the City of Flagstaff Stormwater Management Design Manual, the Rational Method of analysis is shown in Equation 1.

Equation 1

$$Q = C_f * C * I * A$$

Q= Maximum rate of runoff (ft^3/s)

C_f= Antecedent precipitation factor

C= Runoff Coefficient

I= Rainfall Intensity (in/hr)

A= Drainage Area Tributary to Design Location (Acres)

2.3.4 Runoff Coefficients (C)

When using the Rational Method, different surfaces possess varying abilities to convert how much rainfall falls upon it into sheet flow runoff. In order to determine how much runoff will develop from each surface type, a "C" factor is used to specify what percentage of precipitation will become surface runoff. Table 3-4 from the City of Flagstaff Stormwater Management Design Manual, Section 3.1.7. [3] is used to determine runoff coefficient for various surface types and is displayed in the report as Table 2.

Table 2: Table 3-4 from City of Flagstaff Stormwater Management Design Manual, Summary of Runnof Coefficients "C"

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

2.3.5 Rainfall Intensity (I)

Using information taken from NOAA Atlas 2, provided in the City of Flagstaff Stormwater Management Design Manual as Table 3-2 [3], and shown in the report as Table 3, rainfall intensities for any given storm event can be found dependent upon its Duration, which is equal to its Time of Concentration (T_c).

Table 3:NOAA Atlas 2 Rainfall Intensities "i" for the City of Flagstaff

Duration	Frequency, In Years					
	2	5	10	25	50	100
5-min.	3.96	5.04	5.76	6.84	7.68	8.52
10-min.	3.06	3.90	4.50	5.34	6.00	6.66
15-min.	2.48	3.20	3.48	4.40	4.92	5.48
30-min.	1.58	2.06	2.40	2.86	3.22	3.58
1-hour	0.95	1.25	1.46	1.76	1.98	2.21
2-hour	0.56	0.73	0.85	1.02	1.15	1.28
3-hour	0.41	0.53	0.62	0.74	0.83	0.92
6-hour	0.24	0.31	0.36	0.43	0.48	0.53
12-hour	0.14	0.19	0.21	0.26	0.29	0.32
24-hour	0.08	0.11	0.12	0.15	0.17	0.19

2.3.5.1 Time of Concentration (T_c)

The T_c of a drainage basin can be found using Equation 2, T_c for overland sheet flow, which is the only kind present in the designated site areas.

Equation 2

$$T_c = \frac{.007 * (nL)^{.8}}{(2.0)^{.5} S^{.4}}$$

T_c= Sheet flow travel time (hr)

n= Manning's Roughness Coefficient

L= Flow Length(ft)

S=Land Slope (ft/ft)

Using an "n" value provided in the City of Flagstaff Stormwater Management Design Manual as Table 3-3 [3], and shown in the report as Table 4, and taking values for Flow Length "L" and Land Slope "S" from measurements from the basin's corresponding topography map, the final calculations for Time of Concentration (T_c) using Equation 2, are shown for Gammage and Cline Library/Eastburn Education in Tables 5 and 6 respectively.

Table 4: Manning's "n" for Overland/Sheet Flow

Surface Description		'n' value
Concrete		0.012
Asphalt		0.011
Fallow (no residue)		0.05
Cultivated soils:	Residue cover $\leq$ 20%	0.06
	Residue cover > 20%	0.17
Grass:	Short grass, prairie	0.15
	Dense grasses	0.24
	Bermuda grass[1]	0.41
	Bluegrass sod	0.45
Range (natural)		0.13
Woods[2]:	Light underbrush	0.40
	Dense underbrush	0.80

Table 5: Time of Concentration (T_c) for Gammage Watershed

n	L (ft)	S (ft/ft)	T_c (min)
0.0012	300	.0001	**5.22**

Table 6: Time of Concentration (T_c) for Cline Library/Eastburn Education Watershed

n	L (ft)	S (ft/ft)	T_c (min)
0.0012	975	.0002	**10.16**

2.3.6 Antecedent Precipitation Factor (C_f)

In order to accurately reflect the decreasing effects of infiltration during heavy storm events, the The City of Flagstaff Stormwater Management Design Manual, Section 3.1.1, gives the Rational Method a factor that increases the surface runoff proportionally to the severity of the storm event. The "C_f" factors are summarized with their corresponding storm event in Table 7. However, it is important to note that the product of C_f and C can never be greater than 1.

Table 7: C_f Factors

Storm Frequency	**C_f**
<25 Year	1
25 Year	1.1
50 Year	1.2
100 Year	1.25

2.3.7 Drainage Area (A)

To find the boundaries of the area that is tributary to the site (i.e. drains towards the study location), the basin must be delineated by its surrounding drainage divides. Using the topographic map created in Civil-3D, the drainage divides can easily be found by locating where the map contours change from ascending to decreasing. Once all surrounding drainage divides are discovered, the Drainage Area "A" can be calculated by finding the area between all of the divides. The basins for Gammage and Cline Library have been delineated in Figures 5 and 6 respectively.

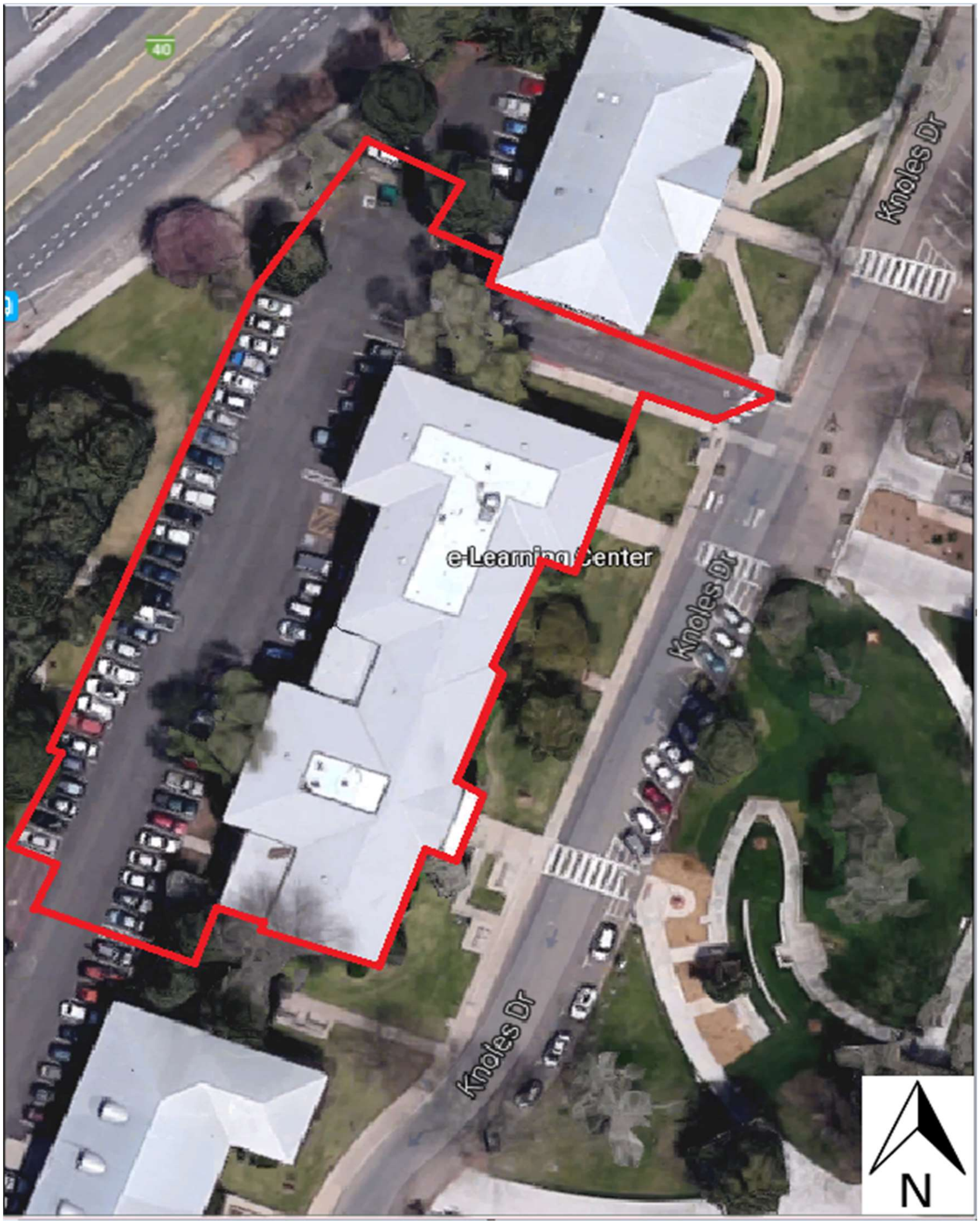

Figure 5: Basin Delineation for Gammage Watershed

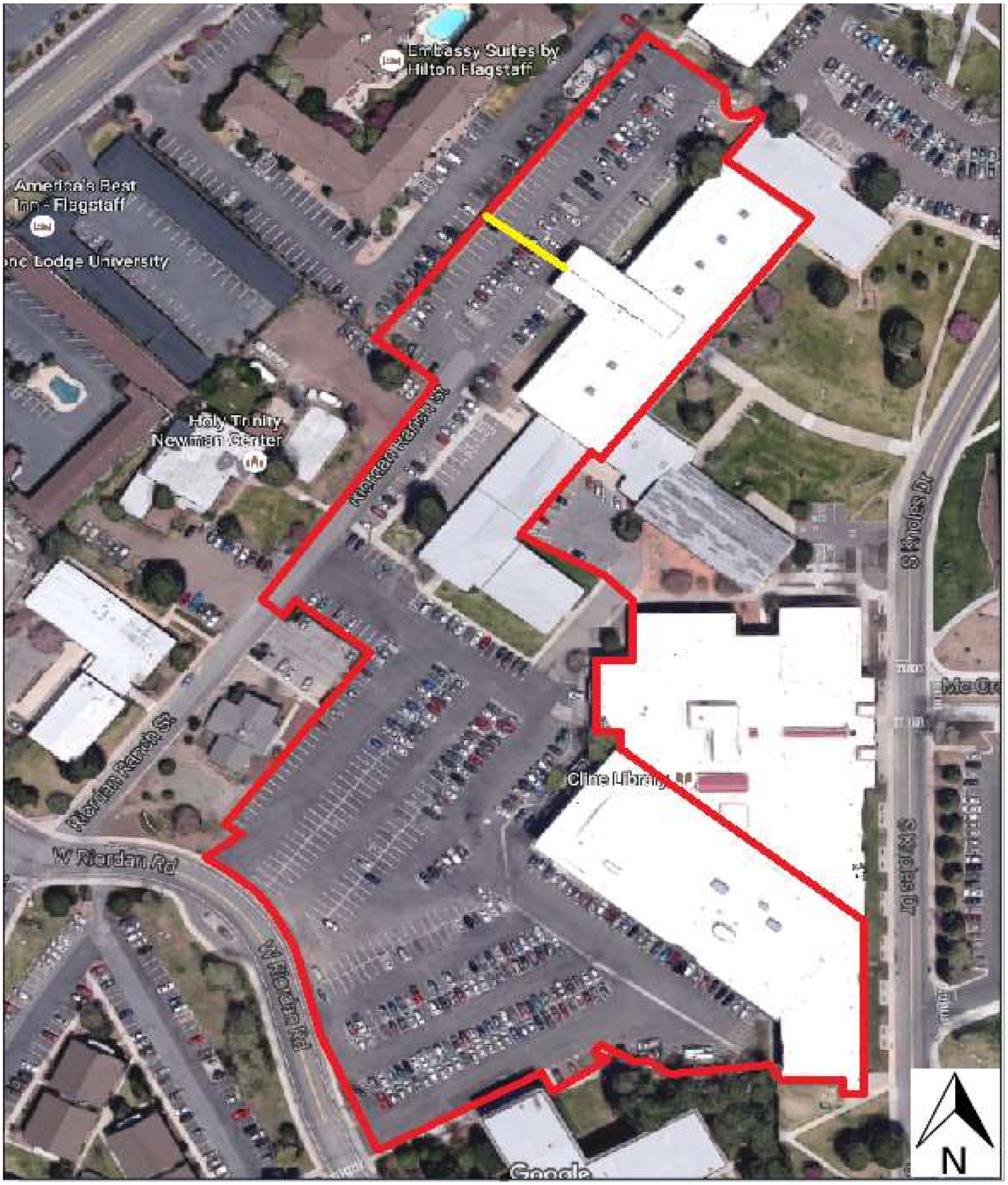

Figure 6: Basin Delineation for Cline Library/Eastburn Education Watershed

2.3.8 Final Surface Runoff Calculations "Q"

Using Equation 1, and values gathered from sections 2.3.4 to 2.3.7, the Rational Method was used to determine a peak surface runoff volume. The peak flow calculations for Gammage and Cline Library/Eastburn Education are shown in Tables 8 and 9 respectively.

Table 8: Rational Method of Analysis for Gammage Drainage Basin

	Surface Type 1	Runoff Coefficient "C"	Area 1 (acres)	Surface Type 2	Runoff Coefficient "C"	Area 2 (acres)	Rainfall Intensity (in/hr)	Cf	Total Flow "Q" (cfs)
10 year	Asphalt Parking Lot	0.95	0.47	Building Roof	0.95	0.42	5.76	1	**4.87**
25 year	Asphalt Parking Lot	0.95	0.47	Building Roof	0.95	0.42	6.84	1.05	**6.07**
50 year	Asphalt Parking Lot	0.95	0.47	Building Roof	0.95	0.42	7.68	1.05	**6.82**
100 year	Asphalt Parking Lot	0.95	0.47	Building Roof	0.95	0.42	8.52	1.05	**7.56**

Table 9: Rational Method of Analysis for Cline Library/Eastburn Education Drainage Basin

	Surface Type 1	Area 1 (acres)	Surface Type 2	Area 2 (acres)	Surface Type 3	Area 3 (acres)	Weighted Runnoff Coefficient "C"	Rainfall Intensity (in/hr) "i"	C_f	Total Flow "Q" (cfs)
10 year	Cline/Eastburn Roof	2.89	Cline/Eastburn Parking Lot	4.64	Gravel Parking Lot	0.26	0.93	4.50	1	**32.78**
25 year	Cline/Eastburn Roof	2.89	Cline/Eastburn Parking Lot	4.64	Gravel Parking Lot	0.26	0.93	5.34	1.07	**41.62**
50 year	Cline/Eastburn Roof	2.89	Cline/Eastburn Parking Lot	4.64	Gravel Parking Lot	0.26	0.93	6.00	1.07	**46.77**
100 year	Cline/Eastburn Roof	2.89	Cline/Eastburn Parking Lot	4.64	Gravel Parking Lot	0.26	0.93	6.66	1.07	**51.91**

2.4 Hydraulic Analysis

On completion of the hydrologic analysis, the next step is to determine what storm frequency the hydraulic infrastructure will be evaluated for capacity against. The City of Flagstaff Stormwater Management Design Manual, Section 4.3, states that all artificial open channel drainage systems shall be designed for the 25-year design storm at minimum [3]. Although NAU has no legal obligation to adhere to this code, the team has decided to adopt this standard for capacity of the drainage structures. Table 10 summarizes the 25-year storm flows calculated in the previous section from the Rational Method.

Table 10: Peak Flows for 25-year storms for Gammage and Cline Library/Eastburn Education

Storm Frequency	**Gammage Peak Flow (cfs)**	**Cline Library/Eastburn Education Peak Flow (cfs)**
25-year Storm	6.07	41.62

2.4.1 Open Channel Capacity Calculation

The City of Flagstaff Stormwater Management Design Manual states that all open channel flow calculations must be done with Manning's Equation [3], pictured in Equation 3.

Equation 3

$$Q = \frac{k}{n} R_h^{2/3} S^{1/2} \mathrm{A}$$

Q= Maximum Flow (ft^3/s)
K= conversion factor (1.49 for English Units, 1 for SI)
n= Manning's Roughness Coefficient
R= Hydraulic Radius (ft)
S= Slope (ft/ft)
A=Cross-Sectional Area of Flow (ft^2)

2.4.2 Current Hydraulic Infrastructure at Gammage Capacity

This past July, the NAU Facility Services department authorized the construction of an open top concrete drainage channel to be laid in the parking lot behind Gammage, pictured in Figure 7. This current channel will be evaluated to determine capacity with Manning's Equation in order to determine its ability to convey a 25-year storm. Manning's roughness coefficient "n" was determined using Table 11, taken from the City of Flagstaff Stormwater Management Design Manual [3]. Values for Slope, Hydraulic Radius (R_h), and Cross-Sectional Area can all be gathered from onsite measurements.

Figure 7: Drainage Channel in Gammage Parking lot

Table 11: Manning's "n" Value for Open Channel Flow

Surface Description		'n' value
Concrete		0.012
Asphalt		0.011
Fallow (no residue)		0.05
Cultivated soils:	Residue cover ≤ 20%	0.06
	Residue cover > 20%	0.17
Grass:	Short grass, prairie	0.15
	Dense grasses	0.24
	Bermuda grass[1]	0.41
	Bluegrass sod	0.45
Range (natural)		0.13
Woods[2]:	Light underbrush	0.40
	Dense underbrush	0.80

2.4.3 Manning's Equation Analysis of Gammage Channel

Table 12 is complete summary of the Mannning's Equation analysis to determine capacity of the channel behind Gammage.

Table 12: Manning's Equation Analysis to Determine Capacity of Drainage Channel Behind Gammage

k	n	Channel Hydraulic Radius (ft)	Channel Slope	Channel Cross-Sectional Area (ft^2)	Max Channel Flow (Q) (ft^3/s)
1.49	0.015	0.30	0.012	1.25	**6.10**

The results of this hydraulic analysis reveal that the current channel behind Gammage is sufficient in that it can convey a 25-year storm (6.10 ft^3/s capacity > 6.07 ft^3/s 25-year storm)

2.4.4 Current Hydraulic Infrastructure at Cline Library/Eastburn Education Capacity

The entire drainage basin of the Cline Library/Eastburn Education watershed is currently graded into a storm drain with a 2-ft diameter corrugated metal pipe in place to convey flow, pictured in Figure 8. The max capacity of this current storm drain is found using Manning's equation, with the analysis displayed in Table 13.

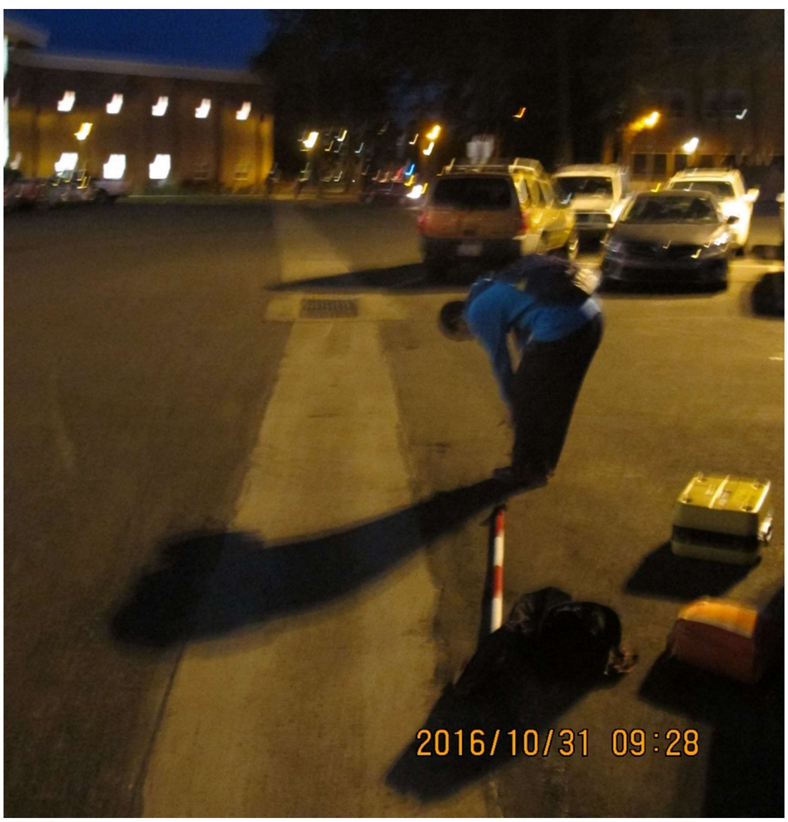

Figure 9: Current Storm Drain at Cline Library/Eastburn Education Watershed

Table 13: Manning's Equation Analysis to Determine Capacity for 2 ft Diameter Pipe at Cline Library/Eastburn Education

k	n	Channel Hydraulic Radius (ft)	Channel Slope	Channel Cross-Sectional Area (ft^2)	Max Channel Flow (Q) (ft^3/s)
1.49	0.027	0.50	0.005	3.14	**7.72**

The results of this hydraulic analysis reveal that the current storm drain serving the Cline Library/Eastburn Education watershed is severely over capacity (7.72 ft^3/s capacity < 41.62 ft^3/s 25-year storm).

2.5 Proposed Solutions

Due to the drainage channel at Gammage's ability to convey a 25-year storm, there is no need to design any new drainage infrastructure at that given site location; however, the severely inadequate storm drain at Cline Library/Eastburn Education will need remediation.

2.5.1 Design Solution #1(Enlarge Pipe)

The first solution to the Cline Library/Eastburn Education storm drain would be to increase the size of the pipe to accommodate the 25-year storm. This process can be achieved through Manning's Equation (Equation 3), using the Rational Method's 25-year storm as the design flow, and then back calculating minimum pipe diameter, through the Hydraulic Radius and Cross-Sectional Area (both functions of pipe diameter). The resulting calculations are displayed in Table 14.

Table 14: Minimum Pipe Diameter for Cline Library Storm Drain to Convey 25-year Storm

Storm Event Flow (ft^3/s)	k	n	Channel Hydraulic Radius (ft)	Channel Slope	Channel Cross-Sectional Area (ft^2)	Min Diameter
41.62	1.49	0.027	0.94	0.005	11.11	**3.76' or 48"**

As a result of this analysis, if a 48" pipe were to be installed at the Cline Library/Eastburn Education drainage basin, the area would no longer flood during a 25-year storm.

2.5.2 Design Solution #2 (Green-roof)

The second solution to the Cline Library/Eastburn Education would be to reduce the surface runoff the storm drain receives. One possible design that could achieve that would be installing a green-roof [5] onto the Cline Library and Eastburn Education buildings. The installation of a green-roof can reduce surface runoff exponentially (Runoff Coefficient "C" reduction of .95 to .2) [5]. The resulting decrease in surface runoff is displayed in Table 15, which is a recalculation of the Rational Method with a decreased "C" value.

Table 15: Rational Method Calculations for Cline Library/Eastburn Education with Runoff Reduction for Green-roofs

	Surface Type 1	**Area 1 (acres)**	**Surface Type 2**	**Area 2 (acres)**	**Surface Type 3**	**Area 3 (acres)**	**Weighted Runoff Coefficient "C"**	**Rainfall Intensity (in/hr) "i"**	**C_f**	**Total Flow "Q" (ft^3/s)**
25 year	Cline/Eastburn Roof (with green-roof installed)	2.89	Cline/Eastburn Parking Lot	4.64	Gravel Parking Lot	0.26	.66	5.34	1.1	**30.06**

When analyzing Table 15, one notices a difference of peak flow from the original conditions that is reduced by more than 25% (41.62 cfs to 30.06 cfs). In order to find the minimum pipe size for the storm drain after the green-roof runoff reduction, the same methodology is applied as earlier in Table 14, where Manning's Equation is used to back calculated diameter, however, this instance the design flow is the newly reduced "Q". The resulting calculations are displayed in Table 16.

Table 16: Minimum Pipe Diameter for Cline Library Storm Drain to convey 25-year storm after Green-roof reduction

Storm Event Flow (ft^3/s)	k	n	Channel Hydraulic Radius (ft)	Channel Slope	Channel Cross-Sectional Area (ft^2)	Min Diameter
30.06	1.49	0.027	0.94	0.005	11.11	**3.33' or 42"**

As a result of this analysis, one can see that the green-roof decrease in surface runoff would still result in a pipe being needed at only 6 inches less in diameter than under the original conditions.

2.5.3 Design Solution #3 (Porous Pavement)

The third solution to the Cline Library/Eastburn Education storm drain would again be to reduce the surface runoff, but this time through the installation of porous pavement in the parking lot. Porous pavement can reduce runoff significantly (Runoff Coefficient "C" reduction of .95 to .5) at a much cheaper price than a green-roof [6]. The resulting decrease in surface runoff is displayed in Table 17, which is a recalculation of the Rational Method with a decreased "C" value.

Table 17: Rational Method Calculations for Cline Library/Eastburn Education with Runoff Reduction for Porous Pavement

	Surface Type 1	**Area 1 (acres)**	**Surface Type 2**	**Area 2 (acres)**	**Surface Type 3**	**Area 3 (acres)**	**Weighted Runoff Coefficient "C"**	**Rainfall Intensity (in/hr) "i"**	**C_f**	**Total Flow "Q" (ft^3/s)**
25 year	Cline/Eastburn Roof	2.89	Cline/Eastburn Parking Lot (with Porous Pavement Installed)	4.64	Gravel Parking Lot	0.26	.67	5.34	1.1	**30.53**

Analysis of Table 17 reveals that peak runoff flow is reduced by an amount almost identical to that of the green-roof reduction (41.62 cfs to 30.53 cfs). Table 18 shows the results of the minimum necessary pipe diameter to convey the 25-year storm after the porous pavement reduction through the same technique as the green-roof.

Table 18: Minimum Pipe Diameter for Cline Library Storm Drain to convey 25-year storm after porous pavement reduction

Storm Event Flow (ft^3/s)	k	n	Channel Hydraulic Radius (ft)	Channel Slope	Channel Cross-Sectional Area (ft^2)	Min Diameter
30.53	1.49	0.027	0.94	0.005	11.11	**3.35' or 42"**

Just as with the green-roof reduction, the porous pavement solution would still require the installation of a 42" pipe.

2.5.4 Cost of Implementation for Designs

A cost analysis of the 3 design alternatives for the Cline Library storm drain is presented in Table 19.

Table 19: Cost of Implementation for All Designs

Cost analysis - Design 1					
Building	**Item**	**Unit Cost**	**Unit**	**Quantity**	**Cost ($)**
EastBurn-Cline Library	Cut/Fill	$2.58	Cubic ft	10452.0	$26,966.2
	Repave	$1.67	Square ft	1608.0	$2,685.4
	Pipe (D 48")	$65.00	ft	268.0	$17,420.0
				Total Cost	$48,596

Cost analysis - Design 2					
Building	**Item**	**Unit Cost**	**Unit**	**Quantity**	**Total Cost ($)**
EastBurn-Cline Library	Cut/Fill	$2.58	Cubic ft	9648.0	$24,891.8
	Repave	$1.67	Square ft	1608.0	$2,685.4
	Pipe (D 42")	$55.00	ft	268.0	$14,740.0
	Green Roof	$10.00	Square ft	125888.4	$1,258,884.0
				Total Cost	$1,485,678

Cost analysis - Design 3					
Building	**Item**	**Unit Cost**	**Unit**	**Quantity**	**Total Cost ($)**
EastBurn-Cline Library	Cut/Fill	$2.58	Cubic ft	9648.0	$24,891.8
	Repave	$1.67	Square ft	1608.0	$2,685.4
	Pipe (D 42")	$55.00	ft	268.0	$14,740.0
	Porous Asphalt (PA)	$0.75	Square ft	213444.0	$160,083.0
				Total Cost	$219,279.6

2.5.5 Final Design Recommendation

Based upon the cost and feasibility of the 3 possible designs, the team has recommended the first Design Solution (Enlarged Pipe) to remedy the drainage issues at Cline Library/Eastburn Education. The simple installation of a larger pipe is a very quick and relatively inexpensive fix to the problem at hand, while the costs of constructing green-roofs or repaving parking lots is far too high to be feasible.

2.5.6 Final Design Impacts

As a result of the possible implementation of the enlarged pipe design, the team has analyzed the design's social, economic, and environmental impacts (the Triple Bottom Line or "TBL"). The social impact of this design would simply be the improved living conditions around the site area that comes with a properly drained site. Economically speaking, the proposed design would require some basic construction, which would provide some economic activity in the construction industry, albeit a minor one. The environmental impacts from this project are the largest, because flood mitigation can heavily effect the surrounding environment in a positive or negative way. Because the flow from our surface runoff is being diverted into a storm drain that will eventually end up in designated drainage for overflow, our design will actually have a positive influence on the riparian environment around Flagstaff.

3.0 Summary of Project Costs

3.1 Comparison of Schedule Pre and Post Project

The projected project schedule that was given in the proposal is presented in Appendix C, while the actual project schedule is presented in Appendix D. The main difference between the two Gantt charts is the increased length of time spent surveying that was not predicted in the original schedule, while the "Model Creation" task was eliminated from the project after the team determined it was not necessary.

3.2 Comparison of Cost/Budget Pre and Post Project

The projected personnel cost that was given in the proposal is pictured in Table 20, while the actual personnel cost is shown in Table 21. The increase in hours billed to the Engineer and Land Surveyor were due to the unexpected amount of time the team spent surveying and performing hydraulic analysis. The complete man hour break down for each individual task for the proposal and the final project is attached in Appendices E and F respectively.

Table 20: Projected Project Personnel Costs

1.0 Personnel	Classification	Hours	Rate ($/Hr)	Cost
	SENG	173	135	*$23,355*
	ENG	372	75	*$27,900*
	LSVR	40	65	*$2,600*
	AA	38	50	*$1,900*
	Total Personnel			***$55,755***
2.0 Equipment	**Hours Used**	**Renting Charge**		**Cost**
	24	$50/hr		***$1200***
Total Cost				***$56,955***

Table 21: Actual Project Personnel Costs

3.0 Personnel	Classification	Hours	Rate ($/Hr)	Cost
	SENG	206	135	*$27,810*
	ENG	423	75	*$31,725*
	LSVR	60	65	*$3,900*
	AA	38	50	*$1,900*
	Total Personnel			***$65,335***
4.0 Equipment	**Hours Used**	**Renting Charge**		**Cost**
	50	$50/hr		***$2500***
Total Cost				***$67,835***

4.0 References

[1] COE AND VAN LOO L.L.C., "Northen Arizona University North Campus Drainage Concerns - Phase I", Flagstaff, 2013.

[2] US ARMY CORPS OF ENGINEERS, FEMA flood plain map, 100-year flood of Rio De Flag

[3] City of Flagstaff Engineering Division Stormwater Management Section, "CITY OF FLAGSTAFF STORMWATER MANAGEMENT DESIGN MANUAL", *Flagstaffstormwater.com*, 2016. [Online]. Available: http://www.flagstaffstormwater.com/DocumentCenter/View/16. [Accessed: 11- Feb- 2016].

[4] Uhl, M., & Schiedt, L. (n.d.). Green Roof Storm Water Retention. Retrieved from https://web.sbe.hw.ac.uk/staffprofiles/bdgsa/11th_International_Conference_on_Urban_Drainage_CD/ICUD08/pdfs/317.pdf.

[5] 2011, A. R. R. (2011). : Pervious pavement: Pervious concrete for green, sustainable porous and permeable Stormwater drainage: Retrieved December 13, 2016, from http://www.perviouspavement.org/design/hydrologicaldesign.htm

Appendix A- Survey Points for Gammage

Attached to back of page

Appendix B- Survey Points for Cline Library/Eastburn Education

Attached to back of page

Appendix C- Gantt Chart Schedule From Proposal

Attached to back of page

Appendix D- Actual Gantt Chart Schedule From Final Project

Attached to back of page

Appendix E- Man Hour Breakdown From Proposal

Task	SENG Hours	ENG Hours	LSVR Hours	AA Hours	Total Hours
1.0 Site Surveying					***40***
1.1 Preliminary Site Evaluation		8			
1.2 Current Hydraulic Infrastructure		8			
1.3 Field Survey			24		
2.0 Site Mapping					***75***
2.1 Topography Map Creation		75			
3.0 Hydrologic Analysis					***150***
3.1 Basin Delineation	14	35			
3.2 Time of Concentration (T_c)	6	8			
3.3 Weighted Curve Number	6	10			
3.4 Rainfall	6	10			
3.5 Model Creation	12	35			
4.0 Hydraulic Analysis					***101***
4.1 Existing Hydraulic Infrastructure Adequacy	8	24			
4.2 Storm Drain Analysis	24	45			
5.0 Proposed Solution					***120***
5.1 Design Creation	50	30			
5.2 Design Analysis	8	24			
5.3 Final Design Recommendation	8				
6.0 Cost Analysis					***24***
6.1 Materials Cost	2	10			
6.2 Cost of Implementation	2	10			
7.0 Impacts					***8***
7.1 Social, Economic, and Environmental	2	8			
8.0 Project Management					***76***
8.1 Scheduling & Meetings	1			8	
8.2 50% Design Report	4	8		8	
8.3 Final Design Report	8	12		16	
8.4 Final Design Presentation	4	4			
8.5 Website				4	
Total (Hours)					***599***

Appendix F- Man Hour Breakdown From Final Project

Task	SENG Hours	ENG Hours	LSVR Hours	AA Hours	Total Hours
1.0 Site Surveying					***84***
1.1 Preliminary Site Evaluation		20			
1.2 Current Hydraulic Infrastructure		14			
1.3 Field Survey			50		
2.0 Site Mapping					***30***
2.1 Topography Map Creation		20	10		
3.0 Hydrologic Analysis					***116***
3.1 Basin Delineation	20	40			
3.2 Weighted Curve Number	16	20			
3.3 Rainfall	10	10			
4.0 Hydraulic Analysis					***115***
4.1 Existing Hydraulic Infrastructure Adequacy	14	60			
4.2 Storm Drain Analysis	10	31			
5.0 Proposed Solution					***171***
5.1 Design Creation	58	47			
5.2 Design Analysis	18	40			
5.3 Final Design Recommendation	8				
6.0 Cost Analysis					***56***
6.1 Materials Cost	10	20			
6.2 Cost of Implementation	10	16			
7.0 Impacts					***32***
7.1 Social, Economic, and Environmental	2	30			
8.0 Project Management					***123***
8.1 Scheduling & Meetings	4			12	
8.2 50% Design Report	6	12		8	
8.3 Final Design Report	10	27		16	
8.4 Final Design Presentation	4	16			
8.5 Website				8	
Total (Hours)					***727***