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ACKNOWLEDGEMENTS

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1.0 SUMMARY

This report discusses the initial conditions of an ephemeral stream called the Sinclair Wash. An assessment including site visits, surveying and, performing a hydrologic and hydraulic analysis ultimately proved the Sinclair Wash does not meet city specifications when conveying the 100-year and 50-year floods.

2.0 BACKGROUND

2.1 Site Information

The Sinclair Wash is located in Northern Arizona and is a part of the Little Colorado River Watershed; more specifically it is a part of the Canyon Diablo Drainage Area [1]. Its headwaters reside at the base of Woody Mountain. Flowing east, Sinclair Wash ultimately ends at South Lone Tree Road where it connects to the Rio De Flag (See Appendix A for site map).

This study will only focus on portions of the Sinclair Wash that are within the city of Flagstaff limits; however, a hydrologic model was created for the entire wash to accurately depict worst case flow scenarios (see Appendix B for watershed boundary).

The Sinclair Wash sees two types of precipitation throughout the year; rainfall in the summer monsoon months and snow fall during the winter. According to NOAA, the long term rainfall average for Flagstaff is about 23 inches, with the average snowfall of 77 inches annually [2].

2.2 Existing Conditions

Sinclair Wash is the product of human encroachment. Physically, the wash has been straightened and narrowed due to construction on both sides of the banks. This has affected the steam health negatively because sinuosity and a wider bed help prevent a supercritical flow, which in turn prevents scouring, plant life depletion and excess sedimentation deposits.

Figure 1: Pooling at CMPs [3]

Biologically, invasive plant species reside along the stream. Pooling water is present at all of the corrugated metal pipes at trail crossings as well as at the double box culverts, creating breading grounds for insects like mosquitos. Garbage and other debris along the wash facilitate harmful bacteria that eventually end up downstream.

Figure 2: Sinclair Wash along McConnell Drive [3]

Figure 3: DBC Crossing Under Knoles Drive [3]

The head of the stream is fairly undisturbed therefore, seems to follow natural conditions. The sinuous bankfull conditions and the plant life would ideally be modeled from this area throughout the wash.

3.0 METHODOLOGY

3.1 Inventory

An inventory for all reaches of the wash within the boundary was completed (See Appendix C for a Sample Inventory Sheet). Inventories on reaches within the upstream portion of the boundary are especially important because bad areas of the wash will be modeled after them. Inventory items include the location, measurements and abundance of the following: inlet structures, culverts and, invasive plant species. The location of each item is determined via a GPS handheld device and imported into georeferenced maps to create a visual representation key areas in the wash.

3.1.1 Inlet Structures and Culverts

All inlets and culverts were located pictured and then identified according to shape and material. From there, each structure was measured. Inlet structures were classified as anything that would ultimately convey water into the wash.

3.1.2 Invasive Plant Species

Invasive plants were identified via the Common Invasive Plants in N. AZ Streams visual (See Appendix C) provided by the client.

3.2 Surveying

For the duration of this project, the TOPCOM GR-3 GPS unit was used to survey areas in the wash. The beginning and end of every culvert within the wash was logged to get an accurate slope for culvert analysis. Five sections of the wash channel were selected to survey. The team focused on areas that were very straight as well as sections that seemed over designed based on size of the cross-sectional area (See Appendix D-1 for a map of surveyed section locations).

3.2.1 Cross-Section Development

All point data from the GPS unit was inserted as point cloud data in Civil 3D 2015. From there, a surface was created for each of the five sections depicting an aerial topographic view in 5-foot contours (Appendix D-2: Civil 3D Sectional Outputs). This data would later be used to model each area's current conditions via HEC-RAS (see section 3.5.1: Channel Cross-Section Analysis for more information).

3.3 Soil Analysis

The ultimate goal of the soil analysis was to gather accurate data to ultimately determine Manning's Coefficients within the Sinclair Wash. Soil classifications based on results were compared to the United States Department of Agriculture (USDA) soil group classifications.

3.3.1 Collecting Soil Samples

Sinclair Wash was separated into 11 reaches. At least eight soil samples, about the size of a quart size freezer bag, were taken from random places within each section. Each sample was then taken back to the lab to analyze the moisture content and then to classify the soil via the United States Soil Conservation Method (USCS).

3.3.2 Moisture Content

Before completing the sieve analysis, a portion of each sample was taken to discover the moisture content. This was done to determine what areas of wash were more susceptible to pooling. Since the samples were all taken within the same 2 days it was reasonable to infer the more saturated the sample, the more likely water will pool in the area. A can was first weighed, the small sample was placed in the can and reweighed, and then the sample was dried in an oven overnight. The dried sampled was again weighed to determine the moisture content via the following equation:

$$[Equation\ 1]\ Moisure\ Content\ (\%) = \frac{W - D}{W} * 100\ [4]$$

Where:

-W is the wet soil weight in grams

-D is the dry soil weight in grams

3.3.3 Sieve Analysis

A sieve analysis was performed in order to classify the soil type by the USCS method [4] in the Sinclair Wash. Samples were then dried in an oven overnight in order to have a dry soil to put through a sieve stack. Once samples were dried they were laid out by reach and similar samples, within the same reach, based on color and consistency were grouped together to get a bigger sample size. The sample were then broken down with a rubber mallet and/or rubber mortar and pestle so as not to destroy the sample. The sample was then weighed. A stack or sieves containing numbers 4, 10, 20, 40, 60, 140 and 200, were cleaned and prepared for each sample. Each sieve was weighed after cleaner and prior to shaking. The sieves were cleaned and blown out with air and washed before a new sample was put through the sieve. The samples were shaken for 10 minutes to get all the particles through the proper sieve. After the stack was finished each sieve was weighed again in order to create a percent finer curve.

3.3.4 Pebble Count

In random sections of each reach, a modified Wolman Method pebble count was performed. A pebble was thrown along the edge of the wash. Where ever it landed, a 3.3ft x 3.3ft wooden frame with a 6ft x 6ft grid (pictured below) was placed. At every grid crossing, a pebble was picked up and measured length and width wise. This data was used to create a percent larger curve [5].

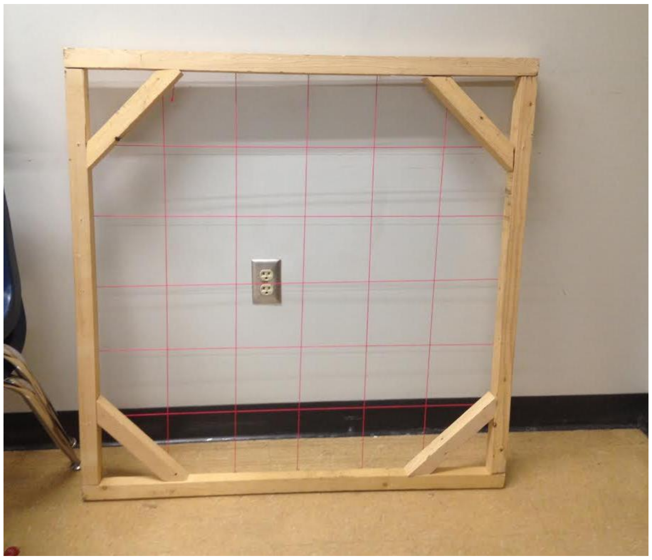

Figure 4: Device Used for Modified Wolman Method Pebble Count

3.4 Hydrologic Analysis

A hydrologic model was created to get an accurate flow through Sinclair Wash for the 100-year and 50-year flood in accordance with the City of Flagstaff Stormwater Management Design Manual, FSMDM [6].

3.4.1 Watershed Delineation

The most current topographic data of Flagstaff (2013) was overlaid on an aerial map of the city to get an accurate view of the wash. From there, the polyline tool was used to create watershed boundaries based on the two foot contour intervals provided. After the whole watershed was determined, it was further sectioned into 18 sub-basins as can be seen in Appendix F: Sinclair Wash Sub-Basin Map.

3.4.2 Hydrologic Model

For watersheds greater than 3 square miles the city of Flagstaff requires that HEC-1 or HEC-HMS software be used. For this project, HEC-HMS was the chosen to model the current conditions of the wash. A 24-hour storm duration was used in junction with the SCS unit hydrograph and SCS curve number methodology, and the SCS Type II rainfall distribution to create the model in accordance with FSMDM standards. The Muskingum-Cunge method was used for reach routing. The model required all 18 sub-basins, 9 junctions, and 8 reaches to accurately depict the physical characteristics of the watershed.

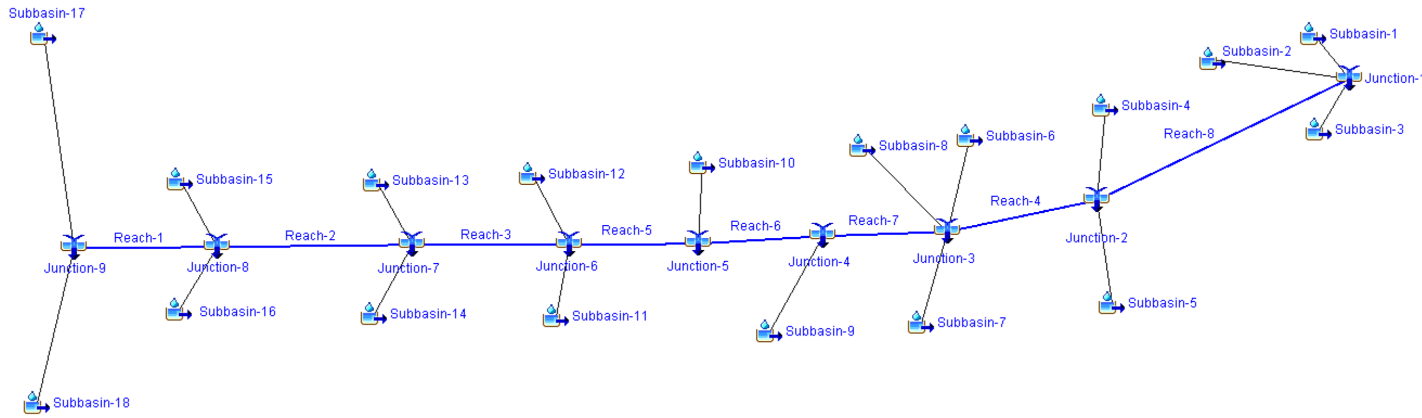

Figure 5: Sinclair Wash HEC-HMS Basin Model

3.4.2.1 Modeling Losses Method: SCS Curve Number

The area of each sub-basin was first calculated in square miles using the ArcMap tool: Polygon. A curve number was assigned to each sub-basin based on tables provided by the United States Department of Agriculture Natural Resources Conservation Service, NRCS (See Appendix E-1: Runoff Curve Numbers)[7]. The soil type was determined in the soil analysis section and confirmed by a soil survey completed by the NRCS. The percent impervious was based off of the classification of each sub-basin and then determined using the tables mentioned above. The initial abstraction values were based on the equation:

$$[Equation\ 1]\ \ I_a = 0.2 * \left(\frac{1000-10CN}{CN}\right)$$

Where:

-I_a is the initial abstraction

-CN is the Curve Number of the sub-basin

3.4.2.2 Transform Method: SCS Unit Hydrograph

The total length of flow path in each sub-basin was determined by choosing the point that was furthest away from the end of the basin. From there, contour lines were followed to mimic the path water would take down to the wash. From there, the path was split into two sections: sheet flow and shallow flow. In accordance with the city of Flagstaff, sheet flow was only acceptable for the first 200ft [6]. See Figure 6 for an example of how the flow length was determined.

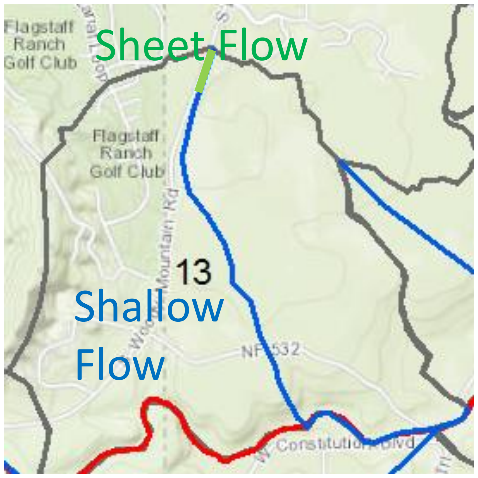

Figure 6: Sub-Basin 13 Path of Flow

The precipitation depth for the 100-year and 50-year 24 hour storm was found using NOAA Atlas 14 precipitation frequency data. From there, the following equations were used to calculate the total time of sheet flow and shallow flow for each sub-basin:

Sheet flow:

$$[Equation\ 2]\ \ ln t_{sheet} = a + b ln(N) + c(\ln N)^{2}\ [8]$$

$$[Equation\ 3]\ a = 1.94 - (4.09\, ln(P_{24})) - (.0049(ln P_{24})^{2})\ [8]$$

$$[Equation\ 4]\ N = \frac{nL_{sheet}}{C^{\frac{2}{3}}\sqrt{S}}\ [8]$$

Where:

-t_{sheeet} is the time it takes for the flow to travel the first 200ft

-b is 0.545 for a Type II rainfall distribution

-c is .0216 for a Type II rainfall distribution

-n is the Manning's Coefficient for overland flow (Appendix E-2)

-L_{sheet} is the length of sheet flow in meters (60.96 meters or 200ft)

-C is the runoff coefficient for the 100-year or 50-year storm (Appendix E-3: Runoff Coefficients, C)

-S is the slope of the basin in %

Shallow flow:

$$[Equation\ 5]\ V_{sc} = kS^{1/2}[8]$$

$$[Equation\ 6]\ t_{shallow} = \frac{L - 60.96}{V_{sc}}\ [8]$$

Where:

-V_{sc} is the velocity of flow when it is in the shallow phase

-k is the Intercept Coefficient (Appendix E-4: Intercept Coefficient for Overland Flow)

-$t_{shallow}$ is the amount of time the flow was considered to be shallow before exiting the sub-basin

-L is the total length of flow from the top of the basin to the end in meters

The sheet and shallow flow times were then added together to define total time the flow remains in the sub-basin, t_{lag}.

3.4.2.3 Reach Routing Method: Muskingum-Cunge

Here, the total length of each reach was input into HEC-HMS along with the slope and the basic dimensions of an average channel cross-section (side slope and bottom width when applicable. All of this information was based on aerial maps and inferences from pictures when compared to reaches that were actually surveyed. The required Manning's Coefficient was calculated based on the soil analysis completed earlier.

The model was ran in 5 minute increments for a 24 hour duration. The precipitation depth chosen was 4.16in and 4.65in respectively for the 50-year and 100-year 24hr storm.

3.5 Hydraulic Analysis

3.5.1 Channel Cross-Section Analysis

The thalweg of each of the five cross-sections was created based off of the surface made during the surveying task. It was turned into an alignment and sample lines, perpendicular to the thalweg, were drawn through the wash to get cross-sectional data. From there, the sample lines and alignment of each surveyed area were imported into HEC-RAS. Again, the Manning's Coefficient determined from the soil analysis was used for each reach. The boundary conditions were based on normal depth. The normal depth slope inputted was based on the thalweg elevation at the beginning and end of the section. A steady flow analysis was ran with only the 100-year flow (found during the Hydrologic Analysis) per the city of Flagstaff specifications.

3.5.2 Culvert Analysis

All culverts that impede on the flow through the Sinclair Wash were analyzed to see if they were compliant with the City of Flagstaff Storm Water Management Specifications. All trail crossings were required to pass the 50-year storm and all street crossings were required to pass the 100-year storm. Dimensions of culverts and elevations taken during the surveying task, along with the culvert material and inlet type were input into Bentley CulvertMaster to determine maximum flow capacity. Hand calculations based on Manning's Equation were used to check results.

$$[Equation\ 7]\ Q = \frac{k}{n} R^{2/3} S^{1/2} A$$

Where:

-Q is the maximum flow through the culvert in cfs

-k is 1.49 for English units

-n is the Manning's Coefficient for open channel flow (Appendix E-5)

-R is the hydraulic radius in ft

-S is the slope in ft/ft

-A is the area in ft^2

Any culverts not meeting the specifications were flagged in the final map layout (Appendix F-1: Final Map Inventory of Sinclair Wash).

4.0 RESULTS

4.1 Inventory Results

The following table shows the total amount of inlets and culverts in Sinclair Wash starting within the city limits.

Type/Structure	Culvert	Inlet	*Open Inlets
PVC		3	
1-CMP		11	
2-CMP	1		
3-CMP	5	1	
DBC	6		
Concrete		4	4
Total	12	19	4

Table 1: Water Structures within Sinclair Wash

*Note, open inlets for the purpose of this inventory were gutters that lead to the wash in a small, shallow concrete channel-like structure as pictured below.

Figure 7: "Open Inlet" After Pedestrian Bridge on McConnell Drive

Locations of all of the structures can be seen in Appendix F-2: Inlet and Culvert Structures Along Sinclair Wash.

Invasive Plant Species	Number of Occurrences in Sinclair Wash
Yellow Starthistle	18
Dalmation Toadlflax	11
Prickly Lettuce	30
Kochia	15
Cheatgrass	28

Table 2: Invasive Plants in Sinclair Wash

Diffuse Knapweed	15

Again, inventory was limited to the city limits of Sinclair Wash. The location of each occurrence can be seen in Appendix F-3: Invasive Plant Species along Sinclair Wash.

4.2 Soil Analysis Results

4.2.1 Moisture Content

The average moisture content of each surveyed reach can be seen in the table below. A full analysis of each sample can be seen in Appendix G-1: Moisture Content Analysis.

Reach	Average Moisture Content
1	12.88%
2	26.62%
3	21.46%
4	21.16%
5	15.03%
6	17.51%
7	18.34%

Table 3: Average Moisture Content in Sinclair Wash

4.2.2 Sieve Analysis

All soil samples had more than 50% retained soil on the number 200 sieve meaning that none of the soil classified as just a clay or silt. However, all samples had more than 50% passing the number 4 sieve meaning that all of them were sandy. Samples with greater than 12% fines (passing the 200 sieve) could be classified as a clayey or silty sand while the rest are classified as a clean sand. This only occurred for samples 6.5 and6.6. All percent finer graphs can be seen in Appendix G-2: Sieve Analysis Results. All the soil in the channel bottom is a clean sand or a clayey/silty sand.

4.2.3 Pebble Count

4.3 Hydrologic Analysis Results

For the 100-year storm, the peak flow was 1200cfs, occurring at "Reach 8" in the model; the section of Sinclair Wash between San Francisco Street. Sub-basin 10 provided the greatest flow to the system at 318cfs. "Junction 1", the double-box culvert at S Lone Tree Rd, conveyed the largest flow at 1211cfs. For the 50-year each of the location of the peak flows;

however, the values were 1040cfs, 280cfs and 1050cfs respectively. See Appendix H for a summary of each hydrologic section.

4.4 Hydraulic Analysis Results

4.4.1 Channel Cross-Section Analysis Results

All channels surveyed could convey the 100 year storm the free-board left during the storm can be seen in the table below.

Section Surveyed	Location	Average Free-Board for 100-Year Storm (ft)
1	South part of University Drive	1.5
2	Big 5	3.5
3	Walmart	3.5
4	East of I-40	3
5	West of San Francisco	2

HEC-RAS results can be seen in Appendix I-1: Channel Analysis Results

4.4.2 Culvert Analysis Results

The table below shows the capacity of all of the culverts along with the flow of the storm they must convey. The red indicatites that the culvert fails to meet storm flow requirements.

Type	Reach	Crossing Type	Year Storm Requirement	Flow Capacity (cfs)	Storm Flow (cfs)	Pass/Fail
T1-CMP	3	Trail	50	40.99	644.1	Fail
T2-CMP	3	Trail	50	93.02	644.1	Fail
T-3CMP	3	Trail	50	4.98	644.1	Fail
T-4CMP	3	Trail	50	49.08	644.1	Fail
R-1 CMP	5	Road	100	219.48	891.6	Fail
R-2 Box	5	Road	100	718.07	939.9	Fail
R-3 CMP	6	Road	100	1503.49	938.4	Pass
R- 4 CMP	6	Road	100	2521.6	938.4	Pass
R-5 CMP	6	Road	100	1193.57	993.9	Pass
T-5 CMP	7	Trail	50	31.58	993.8	Fail
R-6 Box	7	Road	100	879.63	1176	Fail
R-7 Box	4	Road	100	1198.77	1199.9	Fail
T-6 CMP	8	Trail	50	5.68	1199.7	Fail
T-7 CMP	8	Trail	50	43.76	1199.7	Fail
R-8 Box	8	Road	100	1513.44	1210.9	Pass

5.0 DISCUSSION

5.1 Inventory

Most of the invasive species in the wash resided on campus in reaches 5,6 and 7. This seems to be consistent with a lot of pooling in the area. This creates a marsh like environment allowing species that are not native in arid environments to grow.

5.2 Soil Analysis

The majority of the soil in the wash was classified as sand with gravel or sand with clay/silt. This matches the USDA's soil classification C and D for the area. This means that the soil has a slow infiltration rate when wet, leading to more runoff and ultimately a greater flow for large storms. This also explains why pools remain in the wash for long periods of time. The small slope is unable to carry the water through, while the infiltration rate prevents the water from absorbing.

5.3 Hydrologic and Hydraulic Results

All of the trail crossings fail in the event of a 50-year storm event. This is due to the poorly maintained and undersized CMPs. Many of them have been warped and the slopes lessened, again, encouraging pooling at the entrance and exit of each pipe. This could also explain why some of the capacities were so low. With weeds impeding in the pipes with little slope, only a small amount of water actually heads through the pipe, instead, going over the trail. Some of the road crossings fail at the 100-year storm event. This seems to be due to a lack of slope, not necessarily an under design of the size. The whole wash seems to lack slope. The channels, however, are over designed in some areas. Near the Big 5 and Walmart parking lots, the channels have a free-board of about three feet even when conveying the 100-year storm. Because such a deep channel was dredged in these areas, it took some potential elevation away from areas downstream again lessening the slope.

6.0 CONCLUSION/ SUGGESTED ALTERNATIVES

Many of the culverts in the Sinclair Wash failed to convey the 100-year and 50-year storm events. This is ultimately due to a lack of slope throughout the wash. Flat areas and even dips in the slope in junction with a poorly infiltrating soil ultimately cause pooling and allow for invasive species to thrive. The team suggests a rework of the overall slope of the wash before considering redesigning any culverts passing under roads. All of the culverts at trail crossings fail. Since these do not require a redesign of current roads, it would be ideal to remove the culverts completely, leaving an open dip at each crossing. This would allow water to flow freely through the channel. Side slopes could even be altered to prevent potential safety issues when people are using the trail.

7.0 SUMMARY OF PROJECT COSTS

7.1 Gantt Chart Comparison

The schedule for the Sinclair Wash Feasibility Analysis changed dramatically throughout the course of the project. This is mainly due to the scope change on the 2nd of March, 2015. The team just finished troubleshooting problems with the surveying equipment, but then was forced to go out again to inventory and survey all areas outside of the original scope. This pushed back the completion of the Hydrologic Analysis Part 2 and the Hydraulic Analysis. The Hydrologic Analysis task needed to be restarted in order to re-delineate the watershed to match the new constraints. The hydrologic model was ultimately wrong upon completion, so a significant amount of time was used troubleshooting until the team ultimately went out to survey again to get cross-sections for previously undefined reaches. Last, the Restoration Planning and Limitation Planning tasks were completely removed from the Gantt Chart because those were no longer within the scope of the project.

7.2 Cost Proposal Comparison

Besides task deletions discussed in 7.2 Gantt Chart Comparison, one team member did not complete his/her share of work. Therefore, those hours needed to be allocated between the other team members. The project manager also had to take the lead on two of the technical tasks. Troubleshooting did occur during the Hydrologic Analysis, increasing the hours dramatically. Surveying times also increased due to the change in scope. Overall, the Cost of Engineering services were about the same; however, the hours changed significantly because the team meeting hours were originally over estimated.

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