SINCLAIR WASH RIPARIAN HABITAT ENHANCEMENT FEASIBILITY STUDY

Agassiz Consulting Engineers 100% Design Report

May 12, 2016

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The completion of this project could not have been accomplished without the provision and guidance of our client, David McKee, City of Flagstaff Stormwater Manager.

Our team of engineers would like to thank Mark Lamer, P.E. for his continued support throughout this project and his role as our technical adviser during the entirety of this feasibility study.

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1.0 PROJECT DESCRIPTION

1.1 PROJECT BACKGROUND

This report details the second phase of the Sinclair Wash Riparian Habitat Enhancement Study. The second phase is essentially a feasibility study on how the function of Sinclair Wash can be improved upon. Sinclair wash is an artificial ephemeral stream constructed to convey storm water from the Sinclair Wash watershed area and transport runoff to the Rio De Flag. Located along the channel is the Flagstaff Urban Trail system, which is used for recreationally by the local community in Flagstaff. The purpose of the project is to evaluate current stream conditions and issues with the stream and current infrastructure and to provide enhancement alternatives to the City of Flagstaff to return the channel to a functional, healthy state.

The project will focus on a stream reach evaluation and redesign, an evaluation of current infrastructure and stream crossings, and a focus on implementation of low impact development to reduce peak flows and improve the quality of water. Alternative designs will be provided to the City of Flagstaff to assess the feasibility for improvement of the function of the channel.

1.2 LOCATION AND SPAN

Figure 1 below shows the seven-mile span of Sinclair Wash in relation to the Flagstaff City Limits. Located in Flagstaff, Arizona, Sinclair Wash originates near Woody Mountain and runs east through Fort Tuthill Park along the Flagstaff Urban Trail System. The wash travels northeast past Walmart, through Northern Arizona University (NAU), and continues until it combines with the Rio De Flag on the east side of Lone Tree Road.

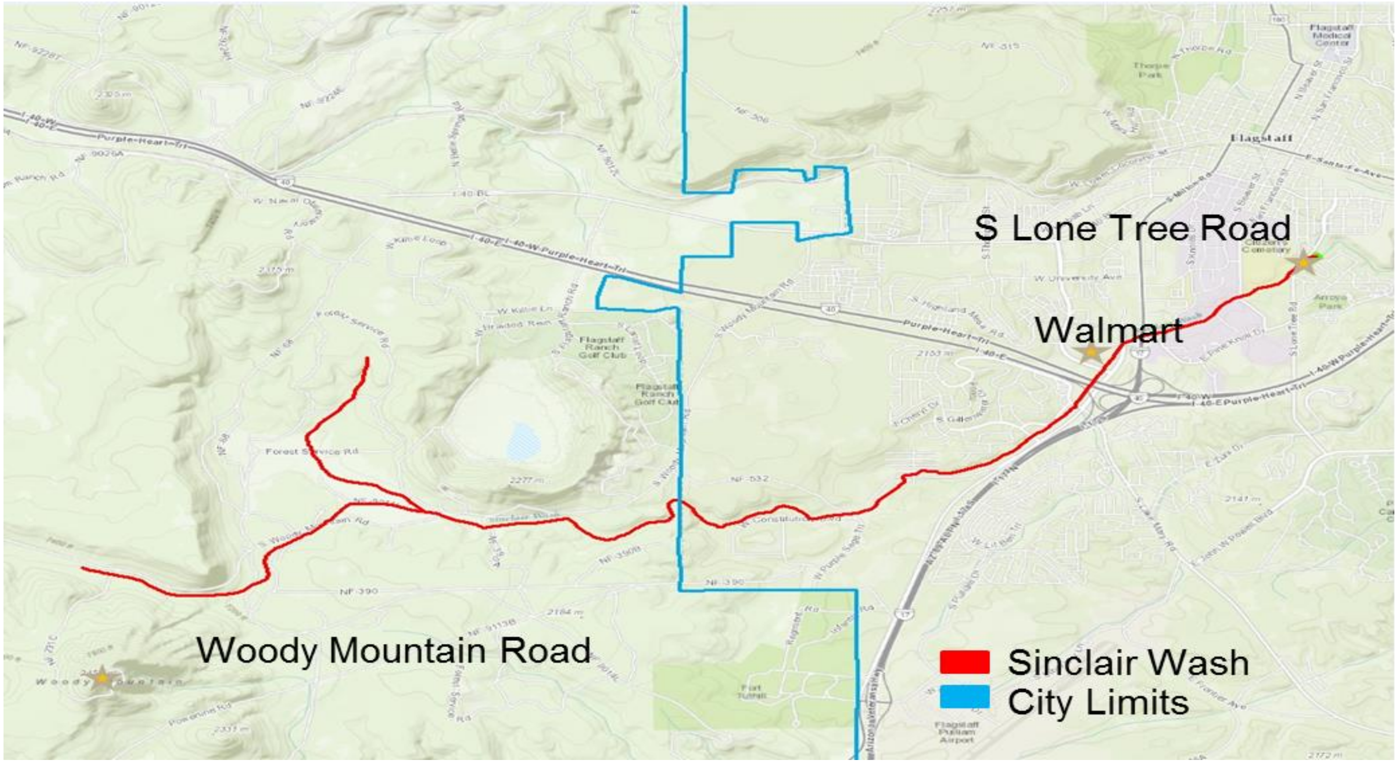

Figure 1: Map of the extents of Sinclair Wash

1.3 CURRENT CONDITIONS OF SITE

The health and function of the wash has greatly diminished since first constructed. Some stream reaches are encroached upon by the urban development surrounding it, particularly through the campus of Northern Arizona University. Many areas of the stream experience detrimental flooding during heavy flood storm events. Invasive plant species have rapidly grown throughout the wash and have affected the vigor of the wash's riparian habitat and inhibited healthy flows. Invasive species cause a lack of stability along channel banks and change the energy of the flow throughout the channel, leading to detrimental changes in geomorphology.

Many of the stream crossing infrastructure in the channel attenuate flows or are lacking maintenance and will be evaluated for redesign and replacement. Sedimentation buildup from low flows as well as erosion and scouring from flood flows have changed the geomorphology and stability of the channel. Sinclair Wash east of San Francisco Street has shown signs of flooding during major storm events and has a tendency to overflow the Flagstaff Urban Trail System, creating a hazard to trail users. This is shown in Figure 2 below. Some of the reaches of Sinclair Wash have been reported to show signs of over sedimentation by the existing trail system. Garbage has piled up in front of and behind culverts and is affecting the water flow in the wash. The pooling of water creates an environment for harmful bacteria to grow and mosquitos to breed. An example of this is shown below in Figure 3.

Figure 2: Flooding of FUTS Trail by Lone Tree Road

Figure 3: Culvert under South Knoles Drive

1.4 REACH EVALUATION / ENHANCEMENT

Sinclair Wash spans 8 miles from west Flagstaff and travels Northeast, through NAU campus, and drains into the Rio De Flag near Lone Tree Road. The team conducted a field reach evaluation, where the entire wash was evaluated for current conditions and problematic areas. Agassiz Consulting Engineers has identified three critical sections of the channel for further analysis and redesign; Reach 2, Reach 4, and Reach 11. A map of Sinclair Wash with the identified areas of interest is shown in Appendix A.

The first area of interest for design implementation is Reach 2 (Appendix B) located between San Francisco Street and Lone Tree Road. The culverts in this reach show signs of scour pools and sediment deposition. The crossings do not support high flood events, considering the detrimental signs of erosion to the urban trail crossing over the culverts. Further analysis will be completed on the current infrastructure to redesign the crossing in order to mediate the issues. There are also signs of sedimentation buildup, steep side slopes, and unwanted ponding.

The second area of interest is Reach 4, located at east McConnell Drive and South Milton road (Appendix C). This section of the wash has very steep side slopes and signs of erosion. The urban development surrounding this section of the reach yields high runoff of low quality water directly into the stream. The team hopes to develop a design to mitigate detrimental effects of storm events in this area.

The third area of interest is reach 11, near the mountain Dell neighborhood (Appendix D). This area of the stream is located in the 100-year floodplain, and because of this, the residential area deals with flooding of the neighborhood during flood events. The culverts in the reach near Mountain Dell are filled with sediment and are partially crushed by the soil above them. The team will aim to mitigate the effects of residential flooding through this area with design alternatives.

Invasive species in the channel were previously identified prior to this project, and options for the revegetation of native species in order to enrich the riparian habitat will be assessed for the entirety of the stream. A geomorphic assessment of the reach will be completed to find entrenchment ratios and sinuosity values, and the feasibility of redesigning the stream geomorphology to enhance the function of the channel will be evaluated. Geomorphic improvements to the reach will enhance the stability of the reach, support the riparian habitat, and convey the 2-year storm event without sediment deposition or damage to geomorphology. Sinclair Wash has the potential to become a designated wetland area that welcomes wildlife and biodiversity and provides ecological education to the surrounding community.

1.5 LOW IMPACT DEVELOPMENT

The implementation of Low Impact Development (LID) designs is a priority for this project. Low Impact Development aims to mitigate detrimental effects of stormwater runoff from new development and provide treatment to the first flush rainfall. LID design options include vegetated buffer strips, vegetated/rock swales, bioretention, and extended detention basins. The team will determine the most feasible LID designs for based on technical analysis and engineering judgment, and provide final designs for implementation.

1.6 LOW WATER CROSSINGS

Many of the current stream crossings show signs of scouring downstream, are filled with sediment, or are simply crushed due to years of lack of maintenance. Areas where the FUTS trail crosses sections of the wash will be analyzed for current issues and alternative design ideas. The team aims to implement new stream crossings to help convey the 2-year flow, reduce the amount of erosion and scouring through the channel, and provide crossings that reduce maintenance requirements. The new crossings will be designed to provide more stability for recreation as well. Design alternatives may include a low water crossing, vented fjord, or culvert redesign. The final design will depend on results of analysis that show an improvement of the function of the wash, the crossings aesthetics, as well as cost.

1.7 CONSTRAINTS / LIMITATIONS

Surveying the channel in the timeframe that our design team had presented a potential challenge. Flagstaff winter conditions were a concern, and at the beginning of this project we were aware of the predicted large snowfall this year. In order to avoid waiting for the snow to melt to complete the topographic survey, the channel was surveyed in the early fall/winter, prior to the point in which snow might stay on the ground.

The biggest constraint that our team of engineers will face is the amount of space that we have to work with when proposing new stream reach designs. As Sinclair Wash runs directly through Flagstaff, and more specifically through the university campus, there is a large amount of urban development surrounding it, encroaching upon the stream. Because of preexisting development, the sinuosity of the channel cannot be changed, and potential widening recommendations will not be suggested.

Another challenge of our project is the funding needed for the proposed designs to be implemented. In order for changes to be made to Sinclair Wash, the City of Flagstaff will need the financial involvement of NAU and other stakeholders in the project. The proposed designs for Sinclair Wash will only include channel improvements that will yield economically sensible results and are practical for the city to carry out.

2.0 STREAM ASSESSMENT AND ANALYSIS

2.1 FIELD ASSESSMENT/SURVEYING

2.1.1 STREAM REACH DETERMINATION

The reaches of Sinclair Wash within the city of Flagstaff limits were determined with the guidance of the City of Flagstaff (COF) map delineation. Reaches two through seventeen were the designated project scope throughout the entirety of this feasibility study. The reaches were delineated as Reach 2 starting just west of Lone Tree Road through Reach 17 just east of the COF limits. The delineation of reaches can be viewed in Appendix E. The reaches of specific focus will include Reach 2, located in between Lone Tree Road and San Francisco Street, Reach 4 at E. McConnell Drive and S. Milton Road, and Reach 11, located in the Mountain Dell neighborhood.

2.1.2 FIELD INVENTORY FORMS

Stream Reach Field Inventory Forms were completed for each reach within our scope of work. These forms detail the average channel reach conditions, descriptions of current disturbances, invasive species identification, and recommendations for action. The forms were helpful in the initial assessment of the reach and helped the team determine the areas of priority. The forms are located in Appendix F.

2.1.3 TOTAL STATION SURVEYING

The team conducted topographic survey of the Reach 2 and Reach 11 using local coordinates 5000N, 5000E, 1000Z and setting magnetic north. All survey work was performed using the total station survey equipment.. The survey data were used to create a topographic map of each area using AutoCAD Civil 3D (design set 1&2). The topographic surveys show existing conditions, and will be merged with proposed surfaces to determine cut and fill values and compare existing to proposed features. The geometry from the surveys was utilized in hydraulic analysis.

The following is a list of abbreviations used in the data collector during surveying

- OCP = Occupation Point
- CP = Control Point
- LBB = Left Bottom Bank
- LTB = Left Top Bank
- RBB = Right Bottom Bank

- RTB = Right Top Bank
- FT = Foots Trail
- CVT = Culvert Top
- CVB = Culvert Bottom
- TFT = Toe of Foots Trail
- TWG = Thalweg
- DLB = Downstream left bottom
- DRB = Downstream right bottom
- DLT = Downstream left top
- DRT = Downstream right top
- DRC = Downstream right culvert
- DLC = Downstream left culvert
- ULF = Upstream left foot
- URF = Upstream right foot
- ULT = Upstream left toe
- URT = Upstream right toe
- FP = Floodplain
- CUL = Culvert upstream left
- CUM = Culvert upstream middle
- CUR = Culvert upstream right

2.2 HYDRAULIC ANALYSIS

2.2.1 HYDRAULIC ENGINEERING CENTER - RIVER ANALYSIS SYSTEM

Hydraulic Analysis was performed for two areas of interest, Reach 2 and Reach 11, to obtain values such as channel velocities and normal depths of flow. The areas were surveyed and the geometry was input into HEC-RAS (Hydraulic Engineering Center's -Rivers Analysis System) with the discharge values from the 2, 25, and 100-year flows for the specific areas.

The results for reach 2 can be viewed in Appendix G showed that the normal depth of flow for the 2-year, 25-year, and 100-year storm flow pass over the existing stream crossing elevation. This is visually apparent due to the erosion of the FUTs crossing over the stream crossing. The maximum velocity for erosion of fine gravel, according to the City of Flagstaff storm water Drainage Manual, is 5ft/s. The channel velocities for the 25 and 100-year flows show speeds that erode fine gravel (Reference storm water drainage manual). The team used the values obtained in the results and aimed to mitigate these issues in the final design.

Results from the hydraulic analysis of reach 11 is shown in Appendix H. The analysis showed a similar result, in that the flows for the 2, 25, and 100-year flows are topping over the road and completely flooding the existing culverts. Velocities in reach 11 were relatively normal and not an area of concern, except for one outlier that has not been mitigated.

The values obtained from HEC-RAS were helpful during the design phase for a comparison of critical values.

2.3 HYDROLOGIC ANALYSIS

2.3.1 LIDAR (LIGHT RADAR)

For the hydrologic analysis of the entire reach of Sinclair Wash LiDAR data is being used. The team has imported the LiDAR data into Civil 3D as a point cloud in order to work with the amount of points. The ground points of the point cloud were then created into a TIN surface in order to extract elevation data. The surface was useful in determining channel and valley slopes and channel sinuosity. This surface will be used for analysis and any proposed design alternatives will be included. By modifying this surface to include the changes to geomorphology of the channel, another hydrologic analysis will be done to guarantee the channel will still flow at optimal conditions after the design changes are made.

2.4 GEOMORPHOLOGY

2.4.1 FIELD WORK

Steams are in a constant state of change, as they try to reach a state of equilibrium. Channel geomorphology describes the shape of the channel, including "channel entrenchment, dimensions, patterns, profiles, and bed materials" [1]. The geomorphology of a channel can yield a stable, healthy, functional stream that flows as it would as an undisturbed channel. Poor geomorphology of a stream can lead to erosion, deposition, scouring, head cutting, patches of bare ground, vertical banks, and a variety of other technical issues.

To assess the geomorphic conditions of Sinclair wash, the team walked the length of the wash and took measurements on a cross section that accurately represented each reach. The team filled out worksheets for stream classification for each reach that can be viewed in Appendix I. The top width of the bankfull channel, the bankfull depth, maximum depth, and the bottom channel width were measured using a 100 foot measuring tape. From these values, the bankfull cross sectional area, the width to depth ratio, the width of the flood-prone area, and the entrenchment ratio were calculated. LiDAR was used to accurately measure the sinuosity (stream length divided by valley length) and the slope of the water surface. Using the values from the geomorphic assessment, the reaches can be classified and used for comparison to reference reaches. Appendix L shows the geomorphic values gathered throughout the entirety of the wash.

2.4.2 STREAM CLASSIFICATION

After the team gathers all of the values from the geomorphic assessment, the Rosgen Stream Classification flowchart will be used to classify each reach [1] See Appendices J and K for the Rosgen Stream classification charts. The Rosgen Classification system is widely used for the classification of streams based on the shape of the channel geomorphology [2]. Benefits of classifying streams include the ability to predict the behavior of a stream based on how it looks, provide a consistent way to compare streams with similar characteristics, and provide a way to easily communicate stream morphology across different disciplines [2].

2.5 RIPARIAN HABITAT ASSESSMENT

Riparian habitats along streams are crucial in to maintaining the stability and function of the channel. Invasive species have the tendency to degrade soil stability, reproduce and spread quickly, and eliminate native species in the area. When invasive species occupy an area quickly and grow out of control, Manning's values change in the channel, which has the ability to alter the energy of the flows through the channel from the initial design. It has been reported that the spread of invasive plant species around a wash channel causes many changes like bed and bank erosion, channel widening and narrowing, in-channel deposition, bar formation and channel migration [7]. If the channel is not revegetated with native species of ephemeral streams in Northern Arizona, the channel of the wash will continue to become more unstable over the years, not only increasing soil erosion around the banks, but also affecting the natural flora and fauna species of the area, leading to even higher level of instability. Native plants yield a more vital riparian habitat as well as an enhancement of water quality by aiding in the filtration of storm water runoff.

Figure 4: Toadflax found in Sinclair vs Example Picture Comparison

2.5.1 INVASIVE VEGETATION IDENTIFIED

The previous Sinclair Wash capstone team 2014-2015 identified invasive species in the wash which included diffuse knapweed, yellow starthistle, dalmation toadflax, prickly lettuce, kochia, cheatgrass, and diffuse knapwweed. These invasive species have been detrimental to the health of the channel and need to be mitigated in order to preserve the native wildlife along Sinclair Wash.

2.5.2 METHOD FOR REMOVAL

For removal and mitigation of the invasive species, three methods can be adopted as per requirement. The methods are physical removal, chemical removal, and biological removal [3]. Physical removal involves identifying weeds and pulling them out of the ground by hand or heavy machinery. Chemical removal involves the use of chemicals like herbicides, which will kill the weeds and herbs and ensure their control. Biological removal can be done be introducing a specific plant disease targeting the invasive plants only or by introducing specific insect species which make the survival of invasive plants difficult (e.g. nematodes) [4].

2.5.3 IMPORTANCE OF REMOVAL

It is vital to remove invasive plants in order to re-establish Sinclair Wash to its natural path. Invasive plants grow uncontrollably and reproduce on a very high rate, hindering the channel of the wash. They affect the velocity of the channel which is the main reason that the wash changes the direction and the path in which it was flowing before. Some primary effects of invasive plants are bioturbation, bioerosion, and bioconstruction [6]. All these processes have long lasting effects on the soil textures and hinder the evolving plant and animal species in the region. They majorly affect the stability and health of the wash by directly obstructing its path which brings pressure on the micro as well as macro evolution of the natural habitats of many plants and animals living along Sinclair Wash. This is due to the fact that they alter the natural geomorphic process of the land. It has been reported that the spread of invasive plant species around a wash channel causes many changes like bed and bank erosion, channel widening and narrowing, in-channel deposition, bar formation and channel migration [7]. This indicates that if not revegetated with native species of Sinclair Wash, the channel of the wash will continue to become more unstable over the years, not only increasing soil erosion around the banks, but also affecting the natural flora and fauna species of the area, leading to even higher level of natural instability.

2.5.4 REVEGETATION OF NATIVE SPECIES

Once the invasive species are removed from Sinclair Wash, native vegetation can be reintroduced to the area. Appendix M shows a list plants and trees that are native to Northern Arizona and that thrive along ephemeral streams. Native species that may be recommended include willow, cattail, narrowleaf cottonwood, sedge, and deergrass. The team suggests maintenance of the riparian habitat along Sinclair Wash every one to two years.

3.0 FEASIBILITY OF ALTERNATIVES

3.1 STREAM EVALUATION

3.1.1 GEOMORPHOLOGY ALTERATION

The geomorphology of Sinclair wash was one of the primary concerns and issues found when the project began. The team decided to look into the feasibility of changing the geomorphology of the stream, and designing a low flow channel in order to pass low flows and reduce the occurrence of sedimentation and erosion in certain areas.

A low flow channel was a design consideration for the restoration for Sinclair Wash. The data gathered from the geomorphic survey and hydraulic analysis using the 2-year flow illuminated the fact that a low flow channel was not actually feasible with the amount of space in the surrounding area. The general requirements for a low flow channel is a maximum depth of about 2 feet, and the ability to convey the 2- year storm. When a 2-year flow channel was sized out for the 2-year flow in reach 2 and reach 11, it was clear that the low flow channel would need to be larger than the maximum width the channel. Appendix N shows geometric values for the channels as well as widths required for the low flow channel. Because changing the geometry of the channel was no longer a feasible design alternative, the team moved on to consider other design alternatives.

3.1.2 SINUOSITY ALTERATION

The optimal sinuosity of natural channels is 1.2 [site mark lamer]. The average sinuosity in Sinclair Wash is approximately 1.04 as seen in Appendix L. The team considered creating meanders through Sinclair Wash to achieve this sinuosity and slow the flows through the channel. Because the channel is encroached upon by urban development, the team did not see this design alternative as feasible.

3.2 LOW IMPACT DEVELOPMENT

In order to mitigate detrimental downstream affects caused by runoff from urban development, and to improve the quality of water flowing through Sinclair Wash, the team considered design alternatives that incorporated Low Impact Development.

3.2.1 BIOREMEDIATION BASIN / POND

A bioremediation basin would be designed to hold a certain volume of water and support the riparian wildlife in and around the pond. The design would contain a low-lying vegetated area on top of a layer of bioretention soil, and an underdrain gravel system. The underdrain system gradually drains into the downstream area of the wash. The pond would provide an aesthetic area that supports the riparian habitat vitality. This design was determined to be feasible for the project, and further consideration of this design was taken.

3.2.2 DETENTION BASIN

A detention basin aims to capture the first flush rainfall off from impervious surfaces and release the captured volume slowly back into the stream. A detention basin should be placed in an area of the wash that requires an enhancement of water quality and a reduction of peak flows. The detention basin design alternative was a feasible design alternative and further consideration was taken for implementation.

3.2.3 VEGETATED SWALE / ROCK SWALE

Vegetated and rock swales are open drainage channels that are designed to “detain, evaporate, or infiltrate” [LID Manual reference] the runoff from a storm event. These designs reduce the imperviousness of an area and can reduce peak flows through the channel. This design alternative was feasible for the restoration of Sinclair wash, but due to time constraints and other alternatives taking priority, it was not used in the final design selection. It is recommended that they be considered for the next phase of restoration for Sinclair Wash.

3.3 STREAM CROSSINGS

The current infrastructure for stream crossings through Sinclair Wash were one of the main concerns seen through initial analysis. Because of the issue they pose, the team has considered design alternatives for new infrastructure.

3.3.1 LOW WATER CROSSINGS

Low water crossings can take alternative forms, such as vented fjords, low water bridges, and dams. The low water crossing should be able to convey low flows through the channel, and be unusable during high storm events. The design team is considering the implementation of low water crossings to replace existing stream crossings in the channel.

3.3.2 CULVERT REDESIGN

An analysis was done on the current culverts in Sinclair Wash located in the Mountain Dell area (reach 11). The results for this analysis are shown in Appendix O. The current culverts in the stream were found to be too small to convey the 2-year flows, and should be resized. The design team is considering the recommendation of box culverts, or a resizing of existing culverts.

4.0 DESIGN RECOMMENDATIONS

4.1 REACH 2 (BETWEEN LONE TREE RD. AND SAN FRANCISCO ST.)

The following designs are recommendations for the stream restoration of reach 2.

4.1.1 BIOREMEDIATION POND WITH LOW WATER CROSSING

Because of spacing restraint, the team was not able to change the geomorphology for reach 2. The team is proposing implementation of a bioremediation pond that would have a maximum ponding depth of 2-3 feet and will support the riparian habitat vitality, while also improving the aesthetics of the reach. The existing stream crossing and culverts are recommended for removal, and a concrete dam is proposed to replace the stream crossings, where the FUTS trail crosses Sinclair Wash. The dam is designed to tie into existing elevations of the Flagstaff Urban Trail, and will provide a crossing for recreational users when floods are not imminent, and a low-water crossing for storm events. The implementation of the dam will yield an aesthetic pond in Reach 2, and is designed to handle the large flows through the area without erosion. The pond was not designed to handle a certain storm event, but with the space available, we estimate it will hold approximately 50,000 cubic feet of water. The dam will be lined with riprap up and downstream, to slow high flows and protect the concrete walls of the dam.

The bioretention pond will be designed with a topsoil layer of native vegetation, a 3-inch minimum mulch layer, a 3-foot layer of bioretention soil, and a 3-inch minimum layer of pea gravel for drainage into the downstream section. The team recommends enhancing this area with recreational benches for wildlife viewing, and ecological signs for the educational enhancement of recreational users. A rendering of the pond design and a to-scale drawing of the dam are shown in the attached plan set.

4.1.2 SEDIMENT TRAP

A sediment trap will be implemented on the upstream side of the bioretention pond to capture sediment and potential trash from high flows before the water enters the pond. The goal of the sediment trap is to keep the pond from filling with sediment from large storm events.

The sediment trap was designed with a catchment basin for sediment and an overflow weir that will convey the cleaner water into the pond. The design of the sediment trap is shown in the plan set.

4.2 REACH 4 (BETWEEN SOUTH KNOLES DR. AND INTERSTATE 17)

The following designs are recommendations for the stream restoration of reach 4.

4.2.1 DETENTION BASIN

The second focus area is located on the north east corner of East McConnell Drive and South Milton Road. This area was specifically requested by the client to help reduce flows as well as help with sediment buildup and treat the water running through the channel. A plan view of the proposed detention basin can be seen in the plan set attached.

The detention basin located in Focus Area 2 was designed in accordance with Flagstaff Low Impact Development (LID) standards. The watershed north of the proposed detention basin was delineated using the AutoCAD software to determine the design volume of the basin. The surrounding contributing area was determined to be 7,552 ft^2. The design volume was calculated using an equation from the LID design standards.

Equation for LID Detention Basin Design Volume:

$$Design\ Volume = \frac{1"}{12} x\ Area$$

Using this equation and a contributing area of 7,552 ft^2, the design volume was calculated to be 629.4 ft^3. The dimensions of the detention basin were determined by the trapezoidal top layer of the basin needing to hold the required design volume with 4:1 side slopes. Using a top layer of 10' by 80' at a 1' depth, the volume of the top and bottom layers of the trapezoid were determined to be 800 $ft^2$and 460 ft^2, respectively. The volumes were averaged to be 630 ft^2, which is capable of holding the required design volume. Flagstaff LID required that a 4" diameter perforated pipe be spaced ever 20' on center. Since the detention basin has a width of 10', only one pipe was required in the middle of the detention basin running the length of the basin.

The detention basin has a foot of top soil, on top of 18" of C-33 gravel, which is stacked on top of a layer of geotextile fabric, which lies above a final layer of AASHTO #67, #3, or #4 type material, which is where the 4" perforated pipe is located. The transition of flow from the channel to the detention basin takes place through a concrete V-notched 2' curb opening with a 2" minimum drop feeding into the detention basin. Both the concrete inlet and the cross section are standard LID designs outlined in the Flagstaff LID Manual. All design specifications are shown in the attached plan set.

4.3 REACH 11 (MOUNTAIN DELL NEIGHBORHOOD)

The following designs are recommendations for the stream restoration of reach 11.

4.3.1 CULVERT REDESIGN

The team proposed replacing the current 48" circular culverts in the Mountain Dell area because they cannot properly convey the 2, 25, or 100-year flows. The proposed alternatives are two 7' x 4' reinforced concrete culverts placed as a double-boxed culvert with a 1:2 side slope. The team chose reinforced concrete because after analysis it was found that reinforced concrete culverts have the longest life expectancy of up to 100 years. The box culvert designs are shown in the attached plan set.

4.4 ENTIRE REACH OF SINCLAIR WASH

Appendix P shows a map of Sinclair Wash with the locations of design recommendations delineated. The following recommendations are for the entirety of Sinclair Wash and should be considered for current and future restoration of the channel.

4.4.1 RIPARIAN HABITAT ENHANCEMENT

The design team recommends removing invasive species from the channel via heavy machinery. Native vegetation for Northern Arizona ephemeral streams, such as willow, cattail, and deergrass should be planted along the wash to increase soil stability, enhance water quality, and provide a stable flow through the channel. It is expected to take two to three years for the channel to reach equilibrium with the newly implemented vegetation.

The vegetation removal our team proposes is a physical application. This was chosen over the two alternative solutions, which were biological and chemical removal. The parameters to create our decision matrix were feasibility, cost, and environmental impact. The physical removal held better results in all three categories. The need to purchase varying chemicals, is necessary due to the diversity of invasive species from reach to reach and is a main reason why a chemical application would be too expensive. In addition, if we decide to put in chemicals to kill invasive species, a later impact could affect the water table in the subsurface, wild life, and other native plants species.

To implement the physical method in an efficient manner we devised measures to adhere too. While out in the field it is imperative to avoid or at the bare minimum not to disturb wildlife. Due to the weather conditions in Flagstaff we advise to only work during dry seasons to ensure the safety of the workers. While removing the invasive plants it is important to minimize the soil disturbance because it could alter the flow patterns. To actually remove the plants just pull. If there is difficulty in extracting the plant then we advise to cut the roots.

4.4.2 RECREATIONAL ENHANCEMENT

For the recreational enhancement of Sinclair Wash, the team recommends looking into implementing low water stream crossings at any FUTs trail crossing. The team also suggests the implementation of public benches, and ecological signage for the educational enhancement of recreational users in the area.

4.4.3 MAINTENANCE

Stream restoration projects are ongoing, and require maintenance in order to continue to function as a stable channel. Because invasive species are merciless, they will require maintenance every one or two years for removal. Native species should equilibrate and thrive, but yearly maintenance should be completed to ensure the vitality of stream vegetation. The sedimentation trap at the upstream section of the bioretention pond should be maintained every six months or after large storm events. The box culverts should be cleaned every two to three years to prevent sedimentation buildup.

4.4.4 FUTURE NAU CAPSTONE WORK

The restoration of Sinclair Wash does not end with the current design team. For the future capstone teams that will take on this project, the design team has provided suggestions of the potential projections that would benefit and build on the base of the feasibility study.

Changes to the geomorphology of Sinclair Wash will be difficult due to the encroached areas through Northern Arizona University and the high flows through the channel, but this aspect of redesign should be investigated. The implementation of Low Impact Development should be continued in future years to enhance the health of the stream. Further examination of the invasive species in the channel and a more in depth suggestion of implementation of native species should be explored. A priority of the design is to provide education to local recreational users of the necessity of stream restoration as well as information on the biodiversity of the riparian habitat. It is suggested to re-evaluate the hydrologic data from this project. The current hydrologic data used yielded very high flows through the channel and lead the design team to the conclusion that a low flow channel would be infeasible. If new hydrological data is used, this may not be the case. Finally, the redesign of other stream crossings should be assessed for the overall improvement of the function of the channel.

5.0 PROJECT SCHEDULE

Table 1 represents a schedule which compares the predicted task completion date to the scheduled task completion date. The tasks that are highlighted blue were finished earlier or on time and the tasks left white represent tasks that were completed behind schedule. Tasks including: design enhancement alternatives, survey identified problematic areas, and geomorphic assessment were delayed due to weather conditions. The hydrologic assessment-incorporate LiDAR/GIS, hydraulic analysis, and impact analysis were delayed because they were dependent on the previous tasks.

Sinclair Wash Schedule	Predicted Complete Date	Actual Complete Date
1.0 Field Assessment	11/5/2015	11/5/2015
2.0 Design Enhancement Alternatives	4/22/2016	4/24/2016
3.0 Survey Identified Problematic Areas	1/29/2016	2/23/2016
4.0 Geomorphic Assessment	3/10/2016	3/20/2016
5.0 Riparian Habitat Assessment	3/4/2016	3/4/2016
6.0 Hydrologic Assessment-Incorporate LiDAR/GIS	3/10/2016	3/10/2016
7.0 Hydraulic Analysis	3/2/2016	4/22/2016
8.0 Low Impact Development	4/3/2016	4/4/2016
9.0 Cost of Implementation	4/29/2016	4/23/2016
10.0 Impact Analysis	4/3/2016	4/23/2016
11.0 Project Management	5/6/2016	5/6/2016
12.0 Client Communication	5/6/2016	5/6/2016
13.0 Technical Adviser Communication	5/6/2016	5/6/2016
14.0 Budget Management	4/22/2016	4/22/2016
15.0 Project Submittals	5/12/2016	5/12/2016
16.0 50% Design Report	3/10/2016	3/8/2016
17.0 Final Presentation	4/29/2016	4/29/2016
18.0 Website Development	5/12/2016	5/12/2016
19.0 100% Design Report	5/12/2016	5/12/2016

Table 1: Project Schedule

6.0 SUMMARY OF PROJECT COSTS

6.1 COST OF SERVICES

When the Agassiz Consulting Engineers team finished the design proposal for the project, the price estimate was determined to be $77,139, as seen in Table 2 below. When the project design was completed, the logged hours came out to a cost of $62,326, as seen in Table 3 below. The greatest difference in costs came from the difference in hour's logged verse the hours that were expected. In addition, the biggest difference in logged hours came from the Project Engineering and Project Management positions, which have the two most expensive hourly rates. The type spent doing Project Management was minimal. The majority of the time spend on the project was doing Engineer-in-Training (EIT) design work. The team also spend more time surveying than was expected. This resulted from a surveying learning curve, as well as weather conditions that gave the team a constant struggle and restricted the ability to survey at different times during the year.

Expense				
Personnel	**Classification**	**Hours**	**Rate ($/hour)**	**Cost**
	Project Manager	176	$158	$27,808
	Project Engineer	217	$78	$16,926
	Engineer-in-Training	214	$62	$13,268
	Lab Technician	171	$75	$12,825
	Intern	163	$24	$3,912
Surveying		16	$150	$2,400
TOTAL				**$77,139**

Table 2: Predicted Cost of Services

Expense				
Personnel	**Classification**	**Hours**	**Rate ($/hour)**	**Cost**
	Project Manager	107	$158	$16,906
	Project Engineer	158	$78	$12,324
	Engineer-in-Training	222	$62	$13,764
	Lab Technician	146	$75	$10,950
	Intern	193	$24	$4,632
Surveying		25	$150	$3,750
TOTAL				**$62,326**

Table 3: Actual Cost of Services

6.2 COST OF IMPLEMENTATION

After finishing all of the designs, the team conducted research to estimate how much the designs would cost. Table 5 represents the specific overall cost of each proposed design. A more detailed breakdown of the earthwork and material cost is included in Appendix Q.

Design	Area	Cost ($)
Detention Basin	E. McConnell Dr.	$10,130.80
Box Culverts	Mountain Dell	$24,000.00
Pond	Lone Tree Rd.	$8,741.80
Dam	Lone Tree Rd.	$23,011.60
Sedimentation Trap	Lone Tree Rd.	$929.90
Vegetation Enhancement	Sinclair wash	$1,200.00
Total Cost		$68,014.10

Table 4: Cost of Implementation

The design costs listed in the tables were taken from the Arizona Department of Transportation Historical Bid Unit Price Lookup [8]. The Sinclair Wash team attempted to find historical bid prices for projects that were in the Flagstaff area, which is where the majority of the earthwork costs came from as well as the erosion control riprap material. If historical bid prices were not available for Flagstaff, the search was expanded to Prescott and Phoenix. The concrete box culvert designs were estimated based off of prefabricated concrete box culverts that were available online, however 4' by 7' boxes are not a standard size, so the costs were estimated based off of pricing for the 4' by 8' boxes. The costs for vegetation removal were estimated off of renting a backhoe with an operator for eight hours [9]. Eight hours of labor for vegetation removal was estimated based off the judgment of the team.

7.0 IMPACT ANALSIS

Before beginning design of any engineering project, an implication of the broader impacts of the design should be considered. There is an understanding that any design project has an affect and a broader impact on the physical world around us, which is a responsibility that should not be taken lightly. The triple bottom line recognizes that there are three stakeholders in all design, which include society, the economy, and the environment. For the stream enhancement of Sinclair Wash, the engineering design team tried to recognize these broader impacts before designing in order to maximize the quality of the proposals.

7.1 ECONOMIC IMPACTS

Before designing, it was noticed that the restoration of the ephemeral stream was not going to be economically based. Initially, implementation of the design will not have a positive economic impact due to excavation, construction, and operation and maintenance costs. However, in the long-term, enhancing the stream through Flagstaff and through the Northern Arizona University campus will likely attract more tourism as well as incur a greater number of NAU students, which will increase the amount of money going to the University and to the local businesses around Flagstaff.

7.2 SOCIAL IMPACTS

The social impacts for this project include an increase in the recreational use of the local community. On a short-term scale, the construction process of new infrastructure may anger or disturb the local community, but we would aim to be as helpful as possible about getting information to the community of the positive impacts that the construction will have. An improvement of the water quality could yield a positive correlation in the health of people living around the wash. An objective of the project was to also enhance the ecological educational of users of the channel. With signage lining the stream about the advancements of the restoration, the community that uses the channel may become more aware of the necessity of stream restoration and be more socially involved in future city projects.

7.3. ENVIRONMENTAL IMPACTS

The most impactful aspect of the design project was the enhancement of environmental quality. Short-term impacts were considered, such as the negative environmental impacts of new construction in the area as well as potentially detrimental maintenance impacts. In the long-term, however, the project will have an overall positive impact on the surrounding environment. The implementation of Low Impact Development aims to enhance water quality while reducing detrimental affects of stormwater from urban runoff, as well as preserving the natural tendencies of the channel. An enhancement of water quality will provide a more vital riparian wetland habitat and enhance biodiversity in and around the stream. The design team hopes that the environmental enhancement from the proposed design will encourage other restoration projects along Sinclair Wash, as well as other channels around Northern Arizona.

8.0 REFERENCES

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[9] "How Much Does A Backhoe Cost? - Costhelper.Com". *CostHelper*. 2016. Web. 11 Apr. 2016.

APPENDIX A: MAP OF SINCLAIR WASH WITH AREAS OF INTEREST IDENTIFIED

APPENDIX B: CONCEPTUAL MAP OF REACH 2

APPENDIX C: CONCEPTUAL MAP OF REACH 4

APPENDIX D: CONCEPTUAL MAP OF REACH 11

APPENDIX E: MAP OF SINCLAIR WASH WITH REACHES DELINEATED

APPENDIX F: STREAM REACH FIELD INVENTORY FORMS FOR REACHES 2-17

APPENDIX G: HEC-RAS REACH 2 (LONE TREE) RESULTS

APPENDIX H: HEC-RAS REACH 11 (MOUNT DEL) RESULTS

APPENDIX I: STREAM CLASSIFICATION WORKSHEETS USED FOR GEOMORPHOLOGY

APPENDIX J: ROSGEN MAJOR STREAM TYPE

APPENDIX K: ROSGEN MAJOR STREAM TYPE CLASSIFICATION

APPENDIX L: GEOMORPHIC FIELD VALUES

APPENDIX M: PLANT LIST FOR EPHEMERAL STREAMS

APPENDIX N: FEASIBILITY TO ALTER GEOMORPHOLOGY OF CHANNEL

APPENDIX O: HEC-RAS RESULTS FOR EXISTING CULVERTS

APPENDIX P: COST OF IMPLEMENTATION BREAK DOWN

APPENDIX Q: MAP OF SINCLAIR WASH WITH PROPOSED DESIGNS INDICATED