34th Annual WERC Environmental Design Contest:

Task 1 - Stormwater Management for EJ/CJ Community Resilience

Northern Arizona University – Task #1

Department of Civil Engineering, Construction Management, and Environmental Engineering

Aguatierra Engineering

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LIST OF ABBREVIATIONS

ADEQ	Arizona Department of Environmental Quality
ADOSH	Arizona Division of Occupational Safety and Health
ADOT	Arizona Department of Transportation
AZPDES	Arizona Pollutant Discharge Elimination System
BNSF	Burlington Northern Santa Fe
CAPEX	Capital Expenses
CWA	Clean Water Act
DEM	Digital Elevation Model
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
FIRM	Flood Insurance Rate Map
FIS	Flood Insurance Study
HSG	Hydrologic Soil Group
JCW	Joseph City Wash
NOAA	National Oceanic and Atmospheric Administration
OPEX	Operating Expenses
OSHA	Occupational Health and Safety Administration
PPE	Personal Protective Equipment
RPE	Reinforced Polyethylene
SCS	Soil Conservation Service
USGS	United States Geological Survey
USDA	United States Department of Agriculture

ACKNOWLEDGEMENTS

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EXECUTIVE SUMMARY

Task 1 of the 34th WERC Environmental Design Contest is to design a solution for an underserved community that has historic stormwater flooding issues, which are getting worse with climate change. The solution is to be cost efficient, applicable, innovative, manage storm flows, and include community co-benefits. A 50-year design storm was chosen based on the knowledge that climate change will increase the frequency of higher intensity storms.

Hydrologic and hydraulic modeling was used to assess the existing flooding conditions for the selected community, Joseph City, Arizona. After analysis, it was determined that the 50-year storm event will cause an estimated 2.4 feet of flooding at the residential houses, east of the Joseph City Wash. Multiple design alternatives were developed and discussed to determine the best solution to meet the needs of the community and mitigate flooding; including watershed modification via gabions, cross-vane weirs, and a re-deployable barrier. The watershed gabion modifications were determined to disperse storm flows over a long period of time, reducing flooding and requiring low maintenance, however very costly. The cross-vane weirs were determined to mitigate flooding cost-effectively but were ultimately determined to be less effective due to the maintenance involved from frequent sediment build up and lack of community co-benefits. The selected final design was the re-deployable liner, which operates as a storm barrier. This solution is cost-effective, innovative, applicable to numerous sites, provides flood mitigation, and community co-benefits. The chosen design introduces a community green space and new fence infrastructure that will support the liner. The fence structure can support a 4-foot depth of water and live wave loads, using steel posts, a reinforced polyethylene liner, and Douglas fir sideboards. The total capital design cost is estimated to be $260,000 and can mitigate all storm events more frequent than the 50-year storm. The 50-year storm is estimated to incur a flood depth of 2.4-feet, which would result in approximately $2.1 million in property damages, indicating a high return on investment.

The implementation of this design shall begin at the beginning of the fiscal year and be completed the following fiscal year in time for the upcoming monsoon season. A community outreach plan will be utilized to understand and meet the needs of Joseph City. The construction phase will be in accordance with all local, state, and federal regulations for environmental health and safety reasons.

The re-deployable liner will make a major impact for Joseph City by mitigating all flooding under the 50-year storm event. This design can positively impact additional sites, as it is easy to implement on existing structures. This design will revolutionize stormwater management practices.

PROJECT INTRODUCTION

Joseph City is a small and underserved community in northeastern Arizona. It is located in Navajo County, with a population of 1,307 and a poverty rate of 14.5%, which is higher than the state of Arizona[1]. Historical flooding from the Joseph City Wash (JCW) has impacted residents, with the most recent major storm event dating back to 1998, as depicted in Figure 1. The JCW is an ephemeral stream, meaning water only flows through it during precipitation events.

Figure 1: 1998 Flooding. Image from Navajo County Public Works

Joseph City currently lacks any major stormwater infrastructure to manage current major storm events for residents. The only existing infrastructure for stormwater is intended to protect the interstate and the BNSF railroad. This creates issues for smaller storm events -those less than the 100-year storm event- which are able negatively impact Joseph City residents. Increased storm events due to climate change will disproportionately affect the community. The Joseph City community is impacted by large storm events (100-yr storm) as well as smaller yet more frequent storm events like the (50-yr storm), see existing conditions Table 8. The goal of this report is to address the flooding issues by providing a cost-effective stormwater management solution that will best protect the residents, while providing additional community co-benefits.

Figure 2 depicts a Federal Emergency Management Agency (FEMA) 100-yr flood map overlain on an aerial image of identified site within Joseph City and provides a visual extent of the project flooding. JCW reach. The Flood Insurance Study (FIS) and Flood Insurance Rate Map (FIRM) map #04017C3304E[2] effective September 2008, were used to gather the 100-yr flood designation. Figure 2 indicates the residential houses on the east side of the wash, just beyond the artistical fields, that is within the 100-year storm and has been heavily impacted from frequent storms.

Figure 2: Site Location

Existing Conditions

The watershed for JCW is primally undeveloped land with minimal vegetation and a soil classification in the hydrologic soil group (HSG) of sandy loam[3]. This unvegetated and undeveloped land results in substantial amounts of sediment transport to the wash during storm events. The resulting in sediment buildup at underpasses, obstructs water flow, causing the water to back cut and results in flooding. The main area of sediment buildup is under the BNSF railroad bridge, which causes flooding in the residential area and fields adjacent to the JCW.

To characterize typical existing topographic conditions in the wash and site area as depicted in Figure 2, a land survey was performed. Manually collected land survey data, along with United States Geological Survey (USGS) digital elevation modeling (DEM) data, was used to create a robust topographic map in Civil3D, which can be found in Appendix A.

Hydrology.

A hydrologic analysis was performed to determine watershed size and design storm flows. The watershed that contributes to the flooding was delineated according to high points and the estimated path of water, using USGS 20' contour maps. Google Earth Pro was used to determine watershed areas and verify the delineated watershed with aerial imagery, as seen outlined in red in Figure 3. Outlined in blue are the additional watershed boundaries that contribute to JCW after confluences.

Figure 3: Watershed Delineation

These computed watershed areas were compared with FEMA values gathered during the Flood Insurance Study (FIS) in 1999[2], as depicted in Table 1.

Table 1: Watershed Area Comparisons

	Mesa Wash (mi^2)	Joseph City Wash (mi^2)	Mesa & JC Wash Confluence (mi^2)	Highway I-40 (mi^2)	Santa Fe Railroad (mi^2)
NAU Watershed Areas	6.54	23.50	30.04	30.82	32.40
FEMA Watershed Areas	6.37	23.34	29.71	30.64	32.50

The comparison validified the watershed values from the FEMA study for future analysis, as it's assumed the study was more robust and accurate. 32.50 mi^2 is the watershed areas used which is the farthest point south of the watershed at the Santa Fe (BNSF) Railroad, see Table 1.

The determined watershed was used to develop a 1D model (HEC-HMS[4]) of the watershed, because the flooding at the site along the JCW is a volume issue rather than a discharge issue, meaning a 1D or 2D model that can simulate the effects of the stored volume is necessary to accurately determine flood stage.

To accurately model with HEC-HMS, a unit hydrograph was estimated using the Soil Conservation Service (SCS) Type II method. This method analyzes soil data in the entire watershed to produce a soil curve number -dimensionless number that indicates the amount of loss that will occur due to runoff. The watershed for JCW was assumed to be an arid rangeland with fair desert shrub cover (between 30-70%)[5]. The watershed soil composition was found using the United States Department of Agriculture (USDA) Web Soil Survey[3] and translated into USDA hydrologic soil groups. This soil data was also used to gather a percent impervious area which accounts for losses due to lack of infiltration; loss characteristics were found from Arizona Department of Transportation (ADOT) rainfall loss parameters[6]. The storm of interest was determined to be a 100-yr storm, with a 24-hour duration which is assumed to produce the controlling discharge amount. The National Oceanic and Atmospheric Administration (NOAA) precipitation frequency data server[7] was used to find the general centroid of the watershed and gather data. All the above data, other assumptions, and outputs are shown below in Table 2.

Table 2: HEC-HMS Inputs, Assumptions, and Outputs 100-yr Storm

HEC-HMS Model – 100-year 24-hour storm					
Inputs		Assumptions		Outputs	
Curve Number	66	Depth-Area Reduction	TP40 of whole watershed	Peak Rainfall Excess Volume (in)	0.68
Impervious Area (%)	2.083	Breakouts	Ignored due to lack of data		
Point Depth (in)	2.83	Hydrograph	Single basin approach	Peak Discharge (cfs)	1,430
Lag Time (min)	313	SCS Method	Type II 24-hour rainfall distribution using NOAA Atlas 14		
Watershed Area (mi^2)	32.5				

The outputs were gathered from running a 1-minute interval simulation run over 3 days. The associated hydrograph is seen below in Figure 4. The hydrograph is for the 24-hour duration 100-year storm. The top viewport is the precipitation excess accumulation over the duration and the bottom viewport is the flow rate during the simulation.

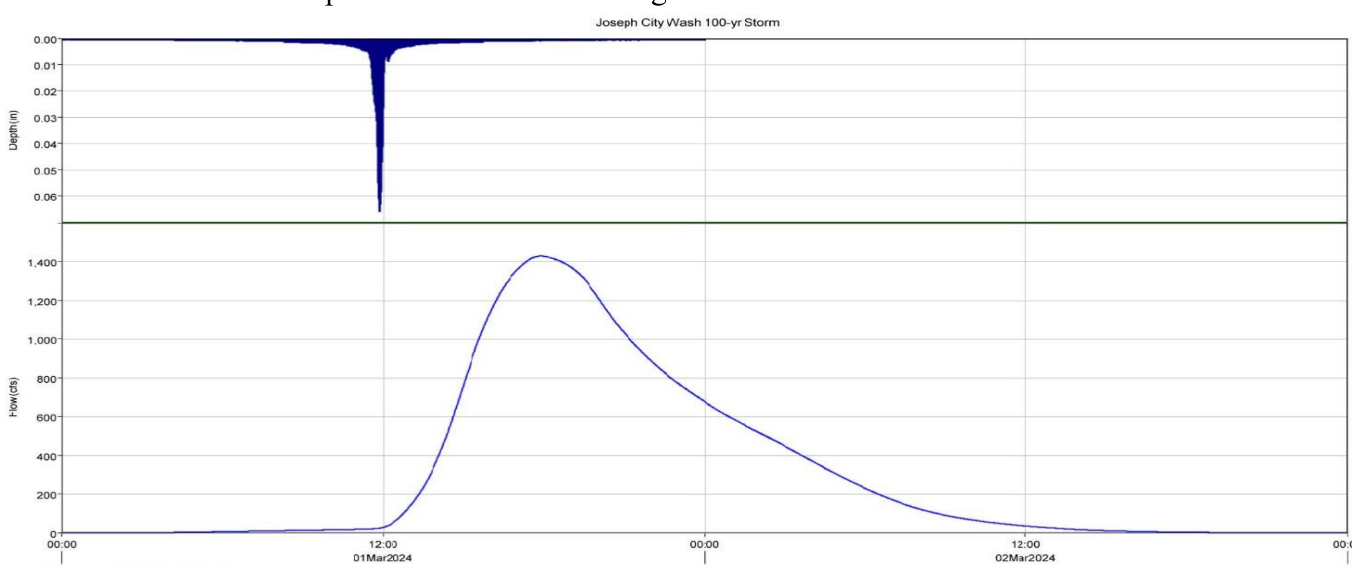

Figure 4: 100-yr Storm Hydrograph

To certify storm flows, USGS Regional Regression Equations were used to estimate peak storm flows discharges[8]. Joseph City is in the Colorado Plateau Region (region 2), which was determined based on physical and climatic characteristics. The following equation shows the utilized 100-yr equation.

$$Q = 778(DRNAREA)^{0.421} \quad (1)$$

Where:
Q is the flow rate, ft^3/s
$DRNAREA$ is the drainage area of the watershed, 32.50 mi^2

This method does not account for breakout flows; where water leaves the watershed due to distributary flows non-conveyance to the main path of water. This means that the calculated USGS Discharge flows are an overestimate for this watershed.

This discharge was compared to HEC-HMS and the FEMA study value. Table 4 shows all 100-yr storm discharges estimates, in cubic feet per second (cfs), indicating the disparities between each method.

Table 3: Storm Flow Discharge Comparisons

Method	Discharge (cfs)
FEMA	5,657
HEC-HMS	1,430
USGS	3,369

The results from HEC-HMS are lower than the other methods. The most accurate storm flow was determined to be the USGS discharge flow -which is conservative due to exclusion of discharge flows- and was therefore used in future hydraulic analysis. To use the USGS discharge flow and a hydrograph, the HEC-HMS time series hydrograph data was linearly scaled up by dividing the two peak flows to fit the USGS peak discharge. While a linear scale is not typical, a hydrograph was necessary to accurately represent the unsteady flow volume that occurs in JCW. Additionally, scaling up to the USGS peak flow is conservative because the USGS regression model does not account for breakout flows in the watershed. In short, this study was conducted using USGS peak flow but using the hydrograph data from a HEC-HMS 1D model to estimate time distribution of runoff volume.

Hydraulics.

A hydraulic assessment was conducted using HEC-RAS[9] to conduct a hydraulic model of the extend of the flooding at the site and for future modeling of the final design. To accurately conduct the HEC-RAS modeling assessment, channel alignment and detailed cross sections were created using the topographic map. The fields were modeled as storage areas to best model the pondage and storage of overbanking channel flows into the fields. Below, in Figure 5, is the JCW river reach and the most average cross section.

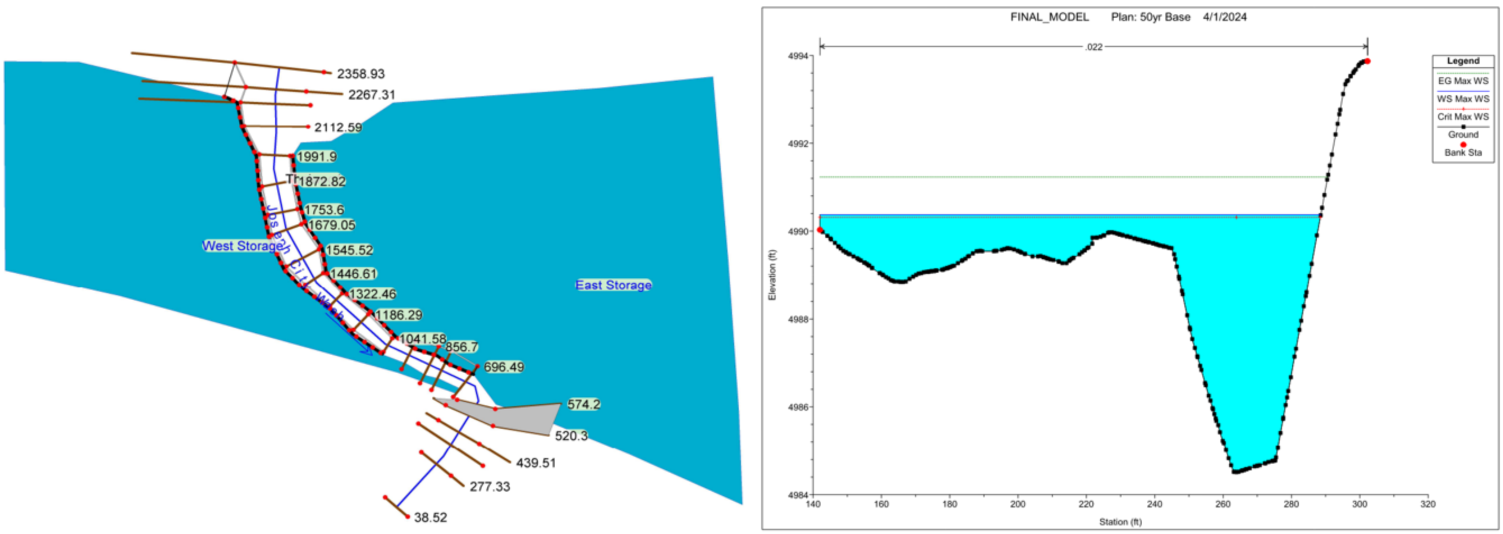

Figure 5: Joseph City Wash River Reach (left) and Average Cross Section (right)

The BNSF bridge was modeled as a major constriction zone with contraction and expansion coefficients of 0.6 and 0.8, respectively. As seen in Figure 6, the BNSF bridge inhibits flow from the excavated sediment trap underneath, which causes water to pool and slows the flow under the bridge.

Figure 6: BNSF Railroad Crossing

All other cross sections were modeled with typical contraction and expansion coefficients of 0.1 and 0.3, respectively. Manning's values for the channel and overbank floodplains were determined following the guidelines from the Flood Control District of Maricopa County drainage design manual[10]. Existing flood conditions were estimated using the HEC-RAS model and the scaled hydrograph from the hydrologic analysis. The three scaled hydrographs (25-,50,100-yr) modeled unsteady flow in HEC-RAS, to best represent the volume of flooding. The 50-year storm is the highest potential flood frequency that will impact residents.

DESIGN ALTERNATIVES

Design alternatives were developed to address flooding using different techniques for management: modifying the watershed, amending the channel, and including a storm water blockade near the houses. All ideas were ranked using the following criteria categories:

- Stormwater Management Effectiveness: An evaluation of how well the alternative manages storm flows.
- Cost: Consideration of the alternative's cost effectiveness with lower costs being better.
- Innovativeness: Consideration of how new and different the alternative is from traditional stormwater management practices and designs.
- Operation and Maintenance: Extent of maintaining and operating the alternative for it to successfully manage storm flows and the overall lifetime of the design.
- Community Co-Benefits: Evaluates the design's impact on community co-benefits such as social, environmental, economic, and community living aesthetics.

Table 6 depicts the list of viable design alternatives considered for the project and their assigned ranking using a plus, minus, neutral scale to eliminate reduce the impact of human bias.

Table 4: Decision Matrix

Alternative	Stormwater Management Effectiveness	Cost	Innovativeness	Operation and Maintenance	Community Co-Benefits	TOTAL
Watershed Modification	+	--	+	+	0	**+1**
Re-deployable Liner	+	+	+	-	+	**+3**
Cross Vane Weir	0	+	+	-	0	**+1**

The table indicates that the re-deployable liner was the best alternative. The discussion evaluating each alternative and supporting the decisions made in Table 6, can be seen below.

Watershed Modifications: The concept behind the gabion watershed modification was to utilize gabions, rocks encased in wire cages, to help dissipate storm water energy further north in the watershed. This would disperse the storm flow over a longer duration and reduce the sediment transported into the Joseph City Wash. A major drawback of this alternative is the total project cost. Gabions cost approximately $10-15 per square foot[11] and the number of gabions needed to manage a 32.50 mi^2 watershed would be unrealistic and extremely costly. The deployment of the gabions would be labor intensive. However, gabions have a long-life cycle, 50 years or more, and minor maintenance after initial installation, posing to be a major benefit over the other alternative[11]. This design also doesn't provide any signification community co-benefits outside of flood prevention.

Re-deployable Liner: This alternative includes using a pond liner to operate as a storm barrier, by deploying it on a structure, such as a fence. The liner is to be stored on site to allow for easy access and quick deployment, and for it to only be in use during storm events. This alternative provides a cost effective solution to manage storm flows, putting this design ahead of the other alternatives, as pond liner is ~$1 a square foot[12]. This alternative, however, requires deployment prior to each major storm event demonstrating a major weakness. Additionally, this design requires existing infrastructure, which will add to costs but is still quite minimal compared to traditional stormwater management designs. This design also includes the use of a community garden that ties into the fence structure, proving community co-benefits such as a social gathering area, partial substitute for grocery costs, and increased community aesthetics.

Cross-Vane Weir: The cross-vane weir alternative involves placing rocks in a "v" shape with the point facing upstream which redirects flow to the center of the channel. Cross-vane weir's direct stream flow to the center of the channel provides channel stability, dissipates flow energy, and creates ponding downstream of the weir[13]. This alternative encompasses using several cross-vane weirs to control storm flow and keep it within the channel. This alternative was determined to be cost efficient due to the low amount of rocks required, while helping with the conveyance of channel flow. However, after further analysis of these weirs, it was determined that these are not applicable for streams with large sediment transport loads[14], which is the major pollutant in the JCW. The sediment would bury the cross-vane weirs and require continuous maintenance to remove sediment and allow the weir to perform efficiently. Additionally, the cross-vane weir alternative doesn't provide any co-benefits to the community.

SOLUTION & FINAL DESIGN

The re-deployable liner was determined to be the best alternative. It can manage storm volumes, is cost efficient, innovative, applicable to additional sites, and provides opportunities for community co-benefits. The liner consists of a 40 mil (0.040 inches) reinforced polyethylene (RPE) liner that is rolled up and attached near the top of a fence, allowing it to be rolled down 4 feet and anchored 3 feet out from the fence along the ground prior to a storm event, see Figure 9. The additional 3 feet of liner along the ground allows water to flow on top and generate a pressure on the ground sealing the liner to prevent water from flowing under the liner. The liner will be attached to the HSS Steel posts and side boards every 1 foot using grommets, washers, and bolts. The end of the liner furthest from the fence is anchored to the ground using steel rebar stakes every 6 feet. The RPE liner is UV resistant; to increase the liner's life span, a roof design was included to provide cover when it's not in use. Figure 7, below, illustrates the liner and its components when rolled up.

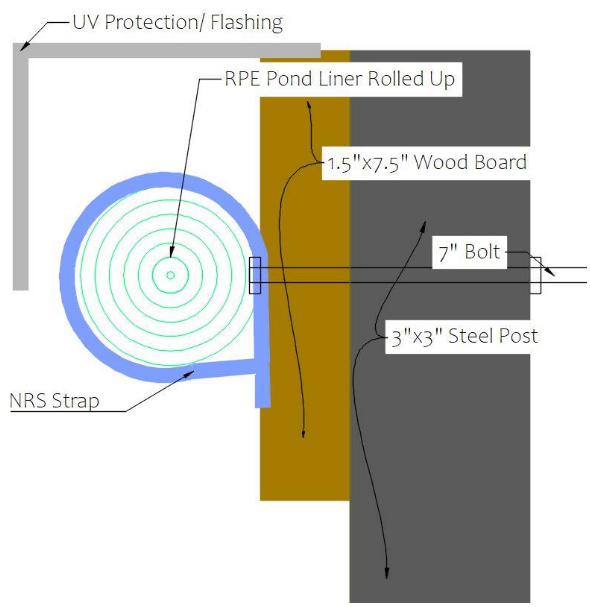

Figure 7: Liner Components

Figure 8, the liner before and after deployment is shown with the maximum water surface elevation it can withstand.

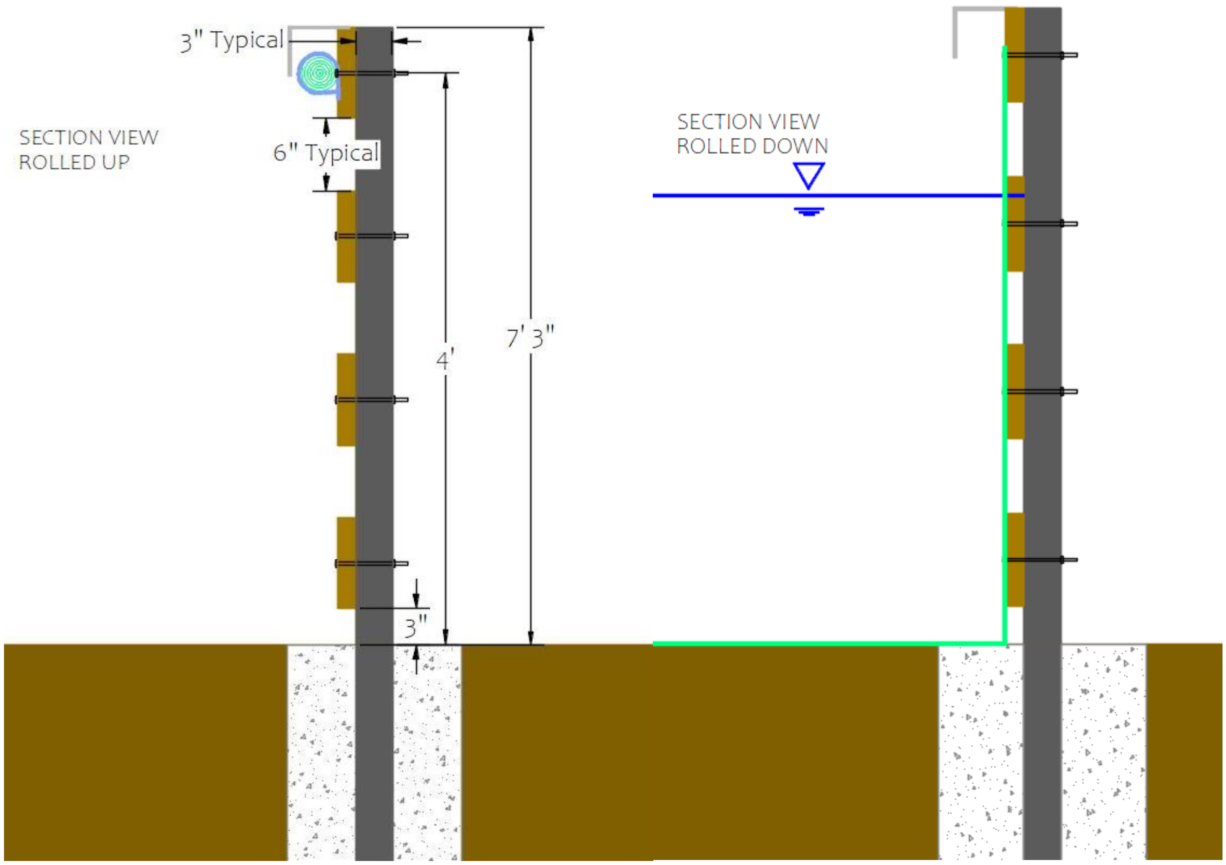

Figure 8: Section View; Rolled Up (left) & Deployed (right)

Site-Specific Full-Scale Design

The selected Joseph City site contains no existing infrastructure in the flood zone that the liner can be attached to, therefore a fence structure was designed for the device. The fence will delineate a new community space for Joseph City; Figure 9 highlights the liner location and the community space. The new space is proposed to be a community garden, but Joseph City will decide as outlined in the community relations and involvement plan. The device will be installed on the east side of the fence (wash facing side) to maximize community space. The implemented fencing will run parallel to the Joseph City Wash and end at the high point along the BNSF railroad, resulting in a total approximate length of 2,600 feet. A total of 1,300 fence posts will be needed for this project, each spaced 2 feet apart with a concrete fill of 430 lbs (0.12 yd^3). Between each fence post, four 2"x8" wood sideboards will provide a structurally stable framework for the liner to be deployed on.

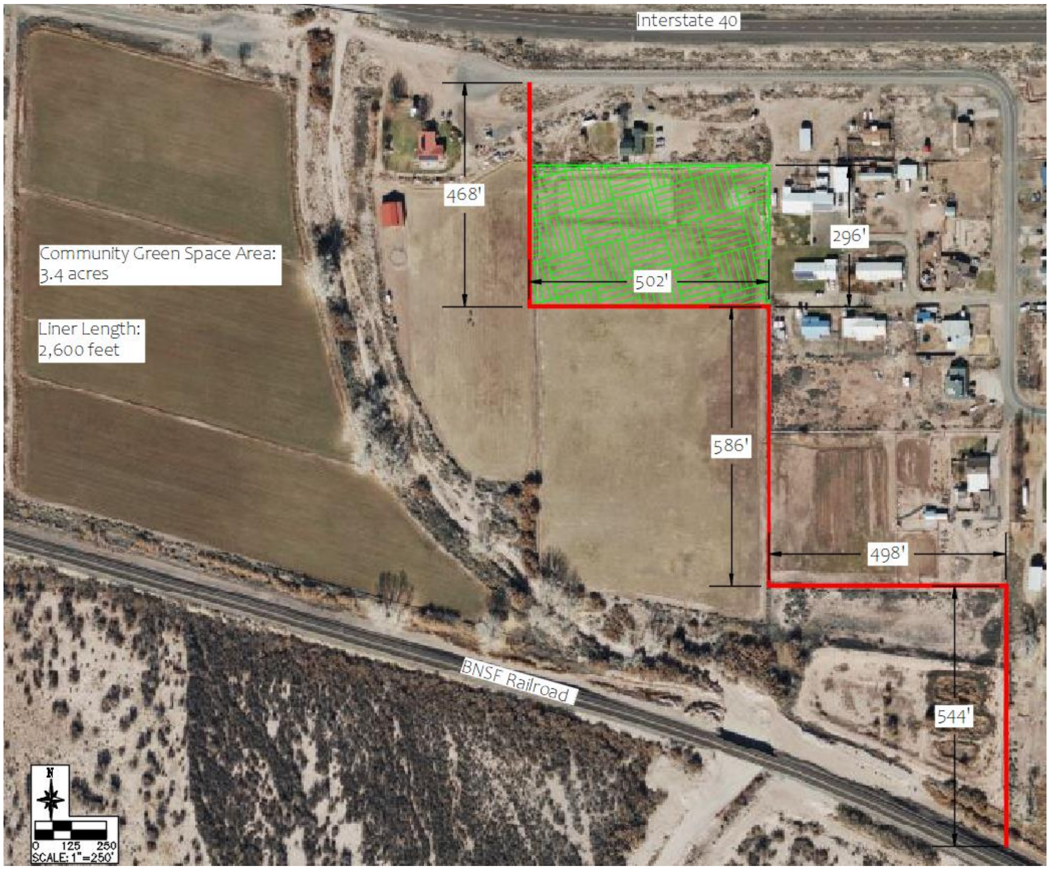

Figure 9: Approximate Liner Location

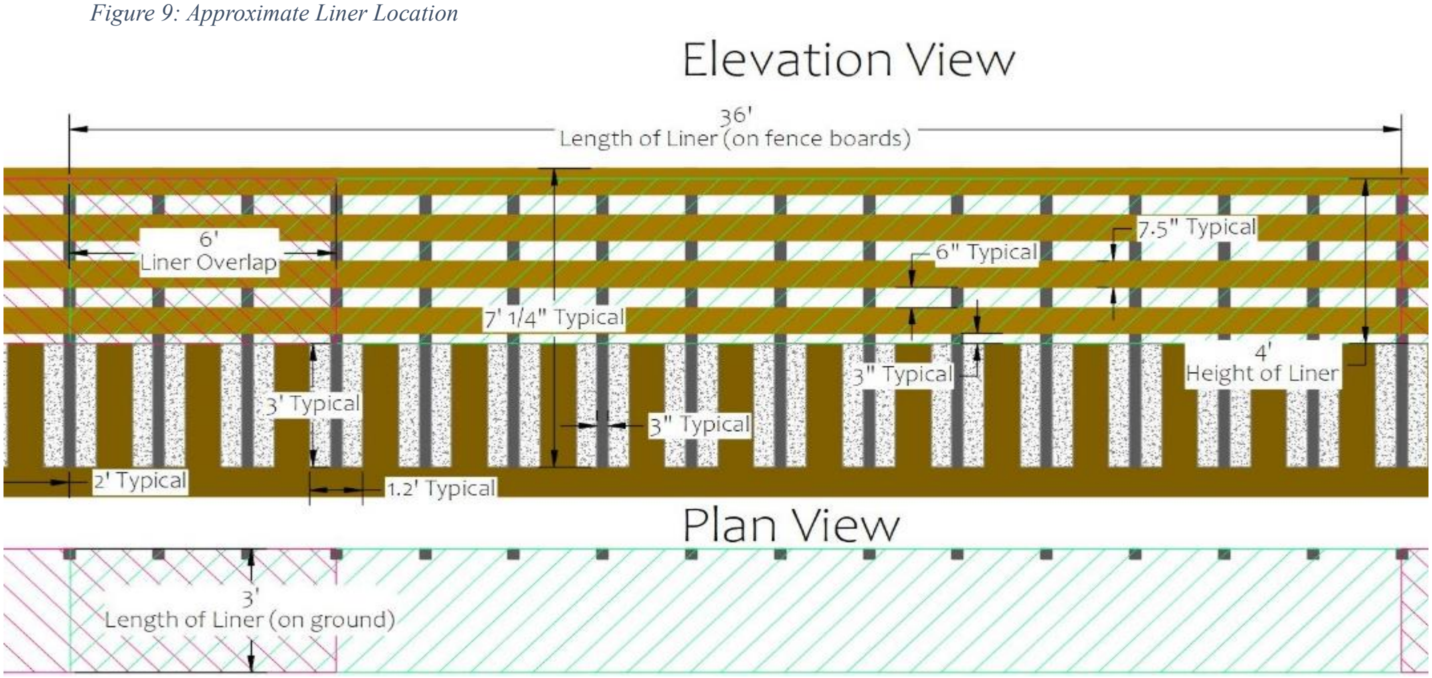

Figure 10: Elevation and Plan View

In the figure above, the red and green indicate the different liner sections with 6 feet of overlap to prevent leakage. Each liner is 36-feet long against the fence board. The liner will be bolted to the top fence board every foot and staked to the ground every 6 feet. This solution will also incorporate adding rain gauges and a flood warning system. The warning system will consist of a tipping bucket rain gauge and transmitter to collect and distribute data. The transmitter will send data to existing telephone poles and emergency notifications will be sent via the Ready Navajo County Notification System[15]. Notifications will be sent with 0.4 inches of precipitation, which is the minimum amount of rainfall needed to cause runoff in the wash.

Final Design Shortcomings

While this design meets the requirements and needs of the residents of Joseph City, it has its shortcomings. A major shortcoming is the deployment time for the liner. Deploying the liner over 2,600 feet of fence will take an estimate of 2-4 people around 2-6 hours to properly deploy and secure the entire liner. Alternatives such as watershed modifications and cross-vane weirs do not require deployment before a flooding event. According to the HEC-RAS model, the liner cannot withstand the volume of the 100-year storm, as its structural capacity is 4 feet of water. The watershed amendment alternatives can manage the 100-year storm by distributing the volume over an extended period, resulting in lower peak storm flows which is something that the liner cannot do.

Community Co-Benefits

This design provides economic, environmental, and social community co-benefits in addition to flood mitigation. Through flood mitigation, Navajo County will spend less on flood repairs and Joseph City citizens will be spared from the emotional distress that follows a flooding event. The green space will add a gathering area for Joseph City to increase community connection. The proposed community garden will provide local produce that can offset grocery costs and be an event space. The green space will also increase outdoor activity spaces, leading to more education and involvement for conserving the local environment.

Additional Site Applicability

This design is applicable to other areas, both rural and urban, that face flooding issues, particularly those related to volume stormwater issues. The liner can easily attach to any structurally sound infrastructure to provide a usable stormwater barrier. This device can replace or reduce the dependency of sandbag use. The liner will revolutionize small scale and large-scale stormwater management, by scaling the device to meet the needs of the project.

Process Flow Diagrams

To display how the final design works from deployment to redaction, a process flow diagram illustrates the proper way to use the deployable liner from the fence.

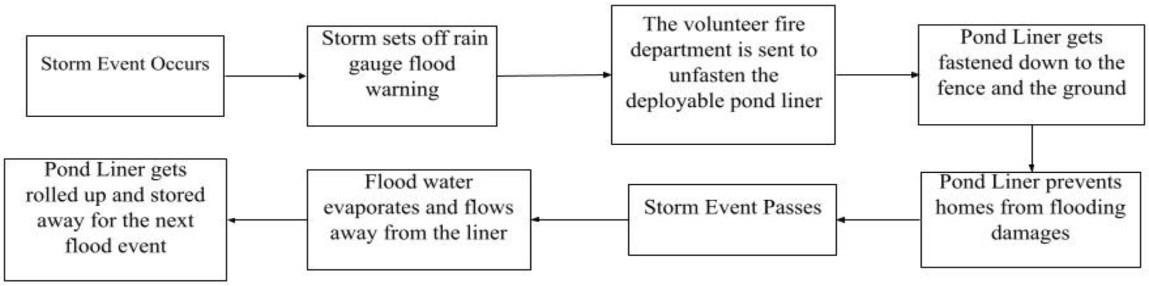

Figure 11: Process Flow Diagram

Technical Evaluation

Structural Analysis.

A structural analysis was performed for a maximum 4-foot water depth, with additional wave forces to account for live loads during storm conditions. Conservatively, the live wave load was directed at the highest point on the structure, a low soil bearing pressure capacity was assumed, and a design safety factor of 2 for each component was used – excluding soil bearing pressure. Each component was assessed in phases to determine the resulting force on each component. This force progression path includes the RPE liner transferring forces to the side boards and the side boards transferring forces to the steel posts. This process results in more concentrated forces, building in total force magnitude through each transfer, see Figure 13.

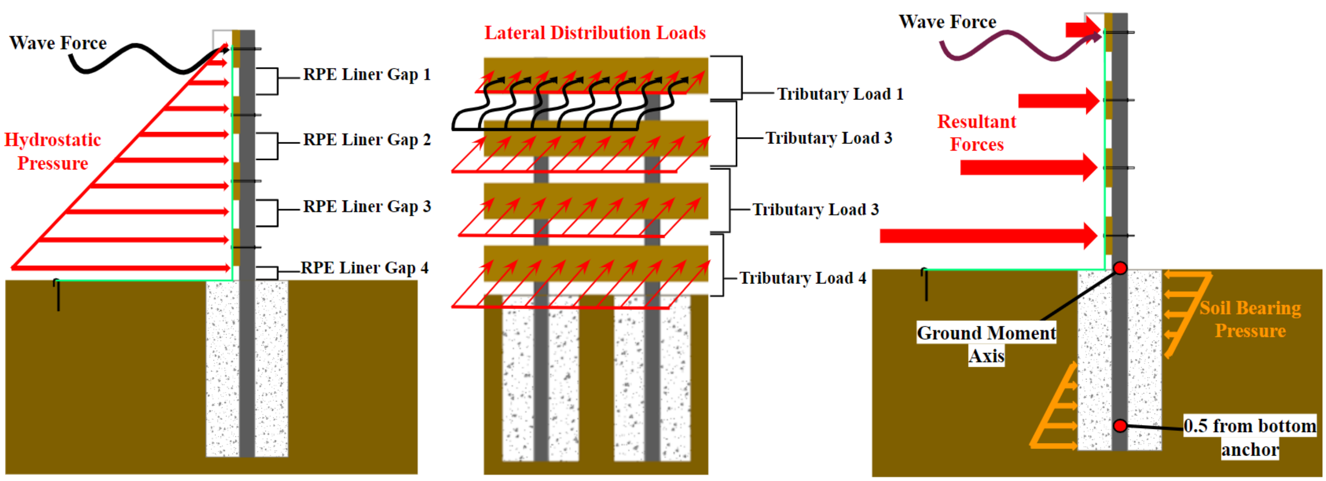

Figure 12: Force Diagrams

Figure 13 displays all considered applied forces. A critical load path was determined and the summary of stress load for each subset of components is in Table 7. The critical load path is defined as the path where the force load is the highest for each component and where the designed components would fail if the stress load stress exceeded the capacity. This critical path is at the bottom of the fence where hydrostatic forces are large, and at the top of the fence where the live wave load is applied. The load distribution of the wave was 136 lbs/ft for a 2.2-foot wave height, which was determined with Equation 7 in Appendix B.

Table 5: Structural Analysis

40mil RPE Liner	Section	Liner Stress Pressure (psi)	Liner Bursting Capacity (psi)
	Gap 1 (Top)	0.3	685
	Gap 4 (Bottom)	1.7	685
Douglas Fir Sideboard	Section	Bending Stress Load (psi)	Douglas Fir Bending Capacity (psi)
	Tributary 1 (Top)	316	900
	Tributary 4 (Bottom)	241	900
	Section	Shear Stress (psi)	Douglas Fir Shear Capacity (psi)
	Tributary 1 (Top)	19.7	170
	Tributary 4 (Bottom)	32.2	170
HSS Steel Post	Section	Bending Stress (ksi)	HSS Steel Bending Capacity (ksi)
	Ground Connection	24.9	50
	Section	Soil Bearing Stress (psf)	Soil Bearing Capacity (psf)
	0.5 ft from bottom of Anchor	1492	1500

Table 7 indicates the design will withstand maximum stress conditions, defined by the 4-feet flooding and wave live load. The bearing load indicates that the structure will not compress into the soil -providing enough resistance for the liner and fence. All equations used for the structural analysis and Table 7 are in Appendix B.

Hydraulic Analysis.

This design was hydraulically modeled using HEC-RAS to ensure that the final design mitigates flooding in residential areas. The existing HEC-RAS storage area was manipulated to represent where the liner would be located, see Figure 9 for the final design implementation. The liner reduces the storage area which increases the maximum water surface elevation. This produces a water depth that the final design needs to withstand. The maximum water surface elevation was compared to the average elevation that residences are located on, which was 4988 feet. Table 8 demonstrates the existing flood depth conditions and flood depth at the liner, where anything less than 4 ft would be fully mitigated be the final design.

Table 6: Stage Depths

Storm Event	Peak Flow (cfs)	Existing Flood Depth (ft)	Implemented Final design Flood Depth (ft)
10-year	527.9	No Flooding	No Flooding
25-year	839	No Flooding	2.36
50-year	1114.3	2.42	3.61
100-year	1429.5	4.26	6.03

As seen above, the liner design will work for the 25 and 50-year storms. The model for implemented final design depicts a 25-year storm flood depth unlike the existing conditions due to the decrease in storage area. During a storm, residents are encouraged to follow Navajo County guidance, as the liner only has the capacity to manage storms under 4 feet in water depth. Figure 14 shows the modeled flooding and storage areas during the 50-year storm, before and after the design is implemented.

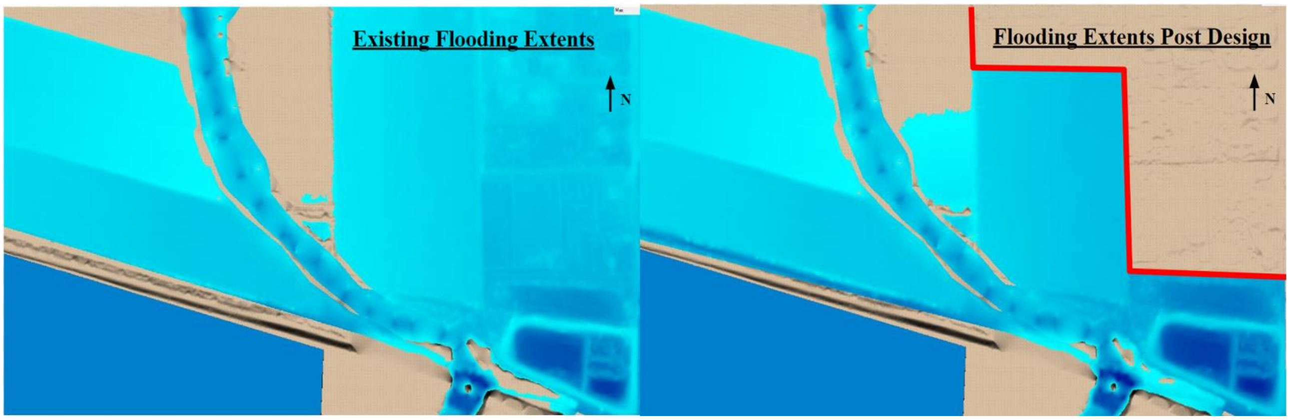

Figure 13: HEC-RAS Flooding Extents Before (left) & After (right)

BUSINESS PLAN

Funding for this project is to be acquired through Joseph City; they can request funding through the State of Arizona or Navajo County. The funding proposal will highlight the money that will be saved through flood mitigation rather than allowing flooding to continue damaging property.

Capital Expenses Economic Analysis.

The capital expenses (CAPEX) of the project were estimated to determine the total cost for the full-scale liner design. All materials and construction costs were estimated to be $259,000 in 2024. Engineering is estimated to cost 7.5% of the materials cost and construction services, including fence installation, are estimated to be 6.5% of the materials cost. Table 9 below displays the cost analysis.

Table 7: Capital Expenses Economic Analysis

Item	Quantity	Units	Cost	Total Cost
40mil RPE Liner (7' x 36') [12]	87	S.F.	$ 197	$ 17,139
87" Long Steel Posts (3 x 3 x 1/8 in.) [16]	1300	EA	$ 92	$ 119,464
Douglas Fir Boards (2" x 8" x 8') [17]	5200	EA	$ 10	$ 52,416
Concrete (0.12 cy/ fence post) [18]	156	C.Y.	$ 160	$ 24,960
NRS (1" x 1' - 2 pack) [19]	217	EA	$ 12	$ 2,604
Roof Flashing (4" x 5" x 10') [20]	260	EA	$ 22	$ 5,590
Carriage Bolt and Nut (1/4" x 7" - 100 count) [21,22]	13	EA	$ 60	$ 778
Grommets (5/8" - 50 pack) [23]	87	EA	$ 10	$ 870
Steel Rebar Stakes (8 pack) [24]	55	EA	$ 22	$ 1,210
Rainfall Gauge [25]	1	EA	$ 947	$ 947
Rainfall Transmitter [25]	1	EA	$ 1,027	$ 1,027
			MATERIALS SUBTOTAL	**$ 227,005**
Construction Services	1	L.S.	6.5% of Const. Cost	$ 14,755
Engineering Design	1	L.S.	7.5% of Const. Cost	$ 17,025
			PERSONNEL SUBTOTAL	**$ 31,781**
			PROJECT TOTAL	**$ 258,785**

The RPE liner, steel posts, and wood boards are all assumed to be limiting materials for their life span.

Operation and Maintenance Economic Analysis.

The operation expenses (OPEX) include material maintenance and structural repairs for the final design. The estimated annual operation costs are $6,455 as of 2024. The community garden shall be tended by community members. Structural maintenance repairs may also be done by Joseph City Fire District and will be the full replacement cost over the material life span. The materials included in this are the RPE liner, steel fence, and wooden fence side boards. The fire district is volunteer based, meaning there will be no labor costs associated with the maintenance costs. The green space will not be subject to taxes because Navajo County will own it after completion. The replacement expenses were calculated by determining the lifespan of the limiting materials and determining the average cost per year over the life span, see Table 8

Table 8: Operational Expenses Economic Analysis

Item	Lifespan (yrs)	Unit	Value
RPE Liner Replacement[12]	30	$/S.F./year	$ 571
Steel Post Replacement[26]	50	$ average/year	$ 2,389
Fence Sideboard Replacement[27]	15	$ average/year	$ 3,494
		Annual Total	$ 6,455

A complete life cycle economic analysis was completed for a 50-year project life cycle. During the 50-year period, only the liner and sideboards will require replacing. Figure 14 displays the total life cycle cost for the implemented final design.

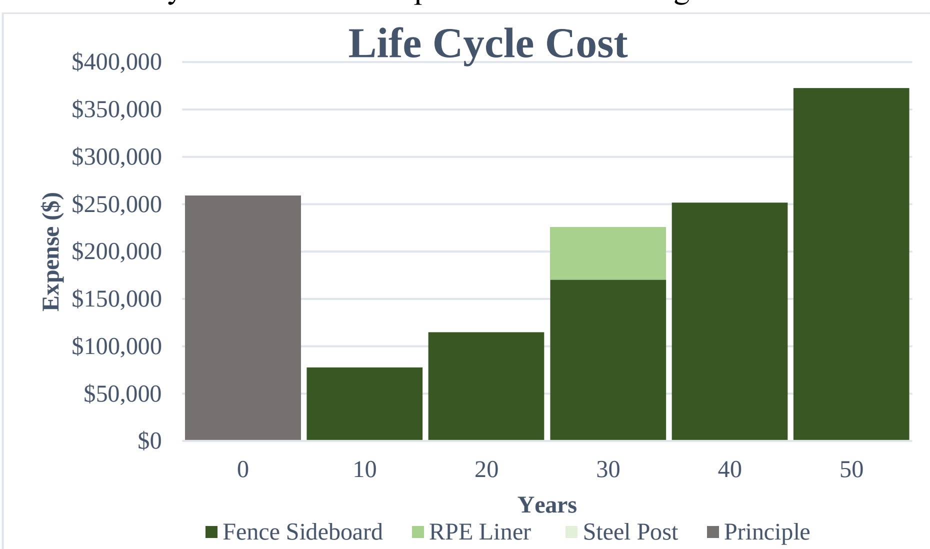

Figure 14: Life Cycle Analysis

The complete life cycle cost includes the capital expense of the project in year 0, and the expense for replacing any materials with an assumed 4% interest rate using simple interest. The 4% interest rate was assumed because costs would be paid off by Navajo County, which is a government entity and dependable customer.

Flood Damage Economic Analysis.

To determine how much flood damage without the design implementation would cost Joseph City, FEMA values were used for the average 2,500 ft^2 one-story home[28]. The total damage costs were evaluated for different water depths associated with the differing storm events. Table 12 displays the costs, with the 25-year design storm costing approximately $2.1 million in damages.

Table 9: Flood Damage Cost Estimates

Water Depth (in)	Damage Cost ($/2,500 ft^2 homes)	Total Cost
1	$ 26,807	$ 620,000
6	$ 52,037	$ 1,200,000
9	$ 62,100	$ 1,500,000
24	$ 87,326	$ 2,100,000
36	$ 94,538	$ 2,300,000
48 (Design Capacity)	$ 103,355	$ 2,500,000

This economic analysis demonstrates the cost-saving potential for the implementation of the liner. The estimated capital expenses of this design are $259,000, which is nearly 10x less than the damage that would arise from a 4-foot flood. This demonstrates a high return on investment, even for 1-in of flooding that reaches residents.

Implementation Schedule.

The implementation of this design shall begin on the first of the fiscal year. It's assumed that from community outreach to post-construction activities, the full implementation course will take one year. This means that the design will be fully operable for the monsoon season a year after initial plans. The full implementation schedule is depicted in Figure 12.

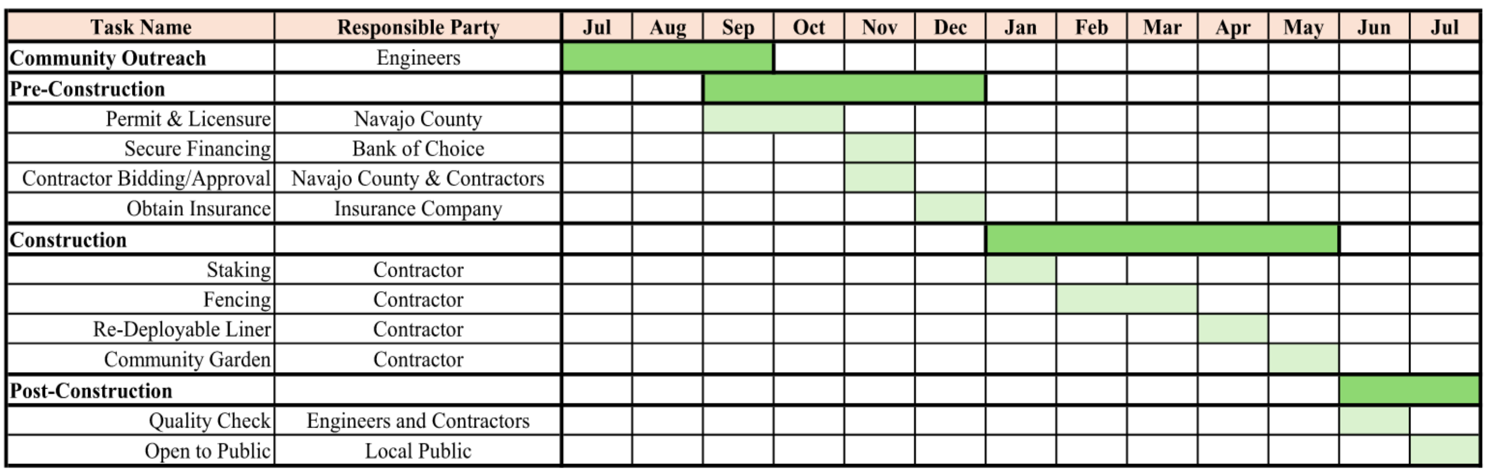

Figure 15: Implementation Schedule

WASTE REPORT & MANAGEMENT

All excess usable materials post construction will be collected by Joseph City and stored for future repairs. The remaining generated construction material waste will be non-hazardous and disposed of properly according to Navajo County waste management. Sediment clean-up after storm events is considered waste material and will be moved back to the channel banks by the proper personnel.

ENVIRONMENTAL HEALTH AND SAFETY

Health Regulations.

Since no hazardous waste is generated from the implementation of the liner, the only realistic health hazards occur during construction and flooding dangers. During construction, any hazards from materials will be made known to any potential users and will be avoided as best as possible while following guidelines set forth by Occupational Safety and Health Administration (OSHA[29]) guidelines and Arizona Division of Occupational Safety and Health (ADOSH[30]). Hazardous materials are kept to a minimum though careful material selection. Any waste generated from construction material will be disposed of properly according to Navajo County waste management.

Safety Regulations.

The safety risks associated with this project involve construction hazards, user flood risks in the community space, and unwanted unraveling of the liner. To address the community space user flood risk, proper warring signs following OSHA guidelines will alert users. These warning signs will be set up at all community space entrances and written to communicate the severity of potential flooding. To prevent the liner from unraveling, one chain and lock will be used at the start and end liner segments to prevent tampering. Operators of the liner should also follow OSHA guidelines by wearing personal protective equipment (PPE) and completing any necessary training for use of the device. Construction safety risks will be mitigated using PPE, safety-vests, and equipment training following OSHA and ADOSH. Additionally, signage will be posted during construction to ensure residents are safe and aware of the construction process. All health emergencies will comply with the Navajo County Public Health Services and all serious or fatal injuries will be treated at the Petrified Forest Medical Center.

Environmental Regulations.

The environmental risks associated with this project are determined to be minimal; considerations were assessed to ensure that there was no water quality degradation or habitat destruction. The integrity of water quality was upheld following guidelines set by the Clean Water Act (CWA), the Environmental Protection Agency (EPA[31]) and Arizona Department of Environmental Quality (ADEQ). Through the CWA, a stormwater discharge permit will be obtained, because the constructed design will require more than one acre of land. Sediment transport through the wash is the primary identified pollutant. The design does not contribute to an increase in sediment transport, complying with water quality regulations in accordance with ADEQ. The project will be reviewed by ADEQ to see if it qualifies for Phase II MS4 permits. This specific permit revolves around municipal separate storm sewer systems for semi-small communities. Habitat protection was considered in design by preserving natural riparian zones and constructing the design on previously developed land, following EPA and ADEQ guidelines.

Legal Regulations.

The legal regulations necessary for this project are proper land acquisition in both residential and commercial land areas. The land needed for the project will be acquired properly, fairly, and equitably to ensure guidelines set by the Uniform Relocation Assistance and Real Property Acquisition Policies Act are followed. Permits for stormwater discharge will be obtained as an Arizona Pollutant Discharge Elimination System permit (AZPDES)[31]. Additionally, the final design will be developed following the Arizona State Land Department guidelines to assure compatibility with the surrounding land and resources. As this design will not use any surface water for other projects, no surface water rights will be impeded on[32]. Any increase or diversion of flow to other properties would be illegal in the state of Arizona and an agreement must be met with the surrounding landowners before the construction begins. Because the liner will extend to the BNSF right-of-way, additional permits, approvals, and railroad protective insurance will be acquired. Final property contracts between all necessary parties will be notarized to ensure proper legal binding. All necessary construction permits will be obtained from Navajo County prior to construction. Navajo County[33] zoning and land use regulations will be followed to ensure that the intended land uses are allowed. Navajo County and the Navajo Nation will be contacted to ensure the archeological preservation of the land is upheld and to permit adding a rainfall gauge in the watershed -which is largely located in Navajo Nation- causing tribal members to grant the necessary permissions.

COMMUNITY RELATIONS AND INVOLVEMENT PLAN

A community relations plan is included in this project, as this project is focused on providing flood protection and a usable community green space. The goal is to heavily involve the Joseph City community in determining what function of the community green space would best fit their needs. The current options that are open to expansion and input from the community include a community garden, community park with swings, a public dog park, or general communal gathering area.

Initial Project Education & Acceptance Plan: The community engagement plan involves an initial briefing during the project start date to explain the project to residents, connect with stakeholders and others impacted by the project. The following 6 months will include understanding community concerns during weekly meetings, interviews, surveys, and social media posts. The social media portion of this plan will focus on addressing community questions and concerns regarding the liner. Also, public announcements will be made via social media to keep community members informed and updated on the project's status.

Action & Decision Plan: In the final three months, a community vote will take place to decide on the function for the community green space. An announcement that a vote will occur will be made public via social media, local newspaper, and mail to make sure the public is aware. The voting will take place during November and December -the last two months designated for community engagement. Any resident of Joseph City is eligible to vote one time, with no restriction on age. Information project pamphlets will be available on social media and mailed to all residents. The results will be announced via social media, local newspaper, and mail at the end of the community engagement period of the project in January.

Public Operation Plan: The community will be informed on how to properly operate the device. This ensures that those interested in operating the design understand how the device functions and governmental agencies have input on potential safety and practicality concerns. Information regarding such meetings will be relayed via newsletters to locals, emails to governmental organizations, public information meetings, and uploads on social media. The local Joseph City Fire District will be sought out as a key candidate to manage and operate the deployment of the liner.

Public Construction, Operation, & Maintenance Announcements*:* All involved parties will be kept up to date on the construction timeline of the project to minimally disrupt residents and keep governmental organizations aware of any progress made. Additionally, operation and maintenance announcements will be delivered to the public. This information will be distributed via newsletters to locals, emails to government organizations, public information meetings, and via social media.

CONCLUSIONS

The design process for a cost-effective and innovative stormwater management solution highlighted the issues that underserved communities face in mitigating climate change's future effects. Joseph City, Arizona is a community that is seeing those effects first-hand when it comes to lacking infrastructure to protect from intense storm events. Adding a flood solution, along with community green space, improves the overall quality of life. The chosen design is cost-effective, environmentally conscious, aesthetically pleasing, and easily implementable to other areas within the community. While the capital cost is initially expensive, it is shown to pay off when intense storms become more commonplace. The community is heavily involved through the community action plan and the implementation schedule, ensuring all design aspects are considering the needs and wants of Joseph City.

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APPENDICES

Appendix A: Existing Site Topographic Map

Appendix B: Structural Analysis Equations

Equation 1 Hydrostatic Pressure

$$P = \rho g h$$

Where:

P is pressure, lbs/ft^2
ρ is density of water, 1.940 slugs/ft^3
g is gravity, 32.174 lbs/ft^2
h is depth, ft

Equation 2 Distributed Load

$$LD = P * h$$

Where:

LD is lateral distributed load, lbs/ft
P is pressure, lbs/ft^2
h is tributary height, ft

Equation 3 Max Shear

$$V_{max} = \frac{LD * L}{2}$$

Where:

V_{max} is max shear force, lbs/ft
LD is lateral distributed load, lbs/ft^2
L is length, ft

Equation 4 Max Shear Stress (on a board)

$$T_{max} = 1.5 \frac{V_{max}}{A}$$

Where:

T_{max} is shear stress load, psi
V_{max} is max shear force, lbs/in
A is distributed load area, in^2

Equation 5 Max Movement

$$M_{max} = \frac{(LD) * \; w^2}{8}$$

Where:

M_{max} is max moment distributed load, lbs*ft
LD is lateral distributed load, lbs/ft
w is board width, ft

Equation 6 Bending Stress Load (on a board)

$$\sigma_b = \frac{M_{max}}{\frac{bd^2}{6}}$$

Where:

σ_b is bending stress load, psi
M_{max} is max moment distributed load, lbs*ft
b is nominal breadth of board, 7.5 in
d is nominal depth of board, 1.5 in

Equation 7 Reaction Force

$$F = LD * w$$

Where:

F is reaction force, lbs
LD is lateral distributed load, lbs/ft
w is board width, ft

Equation 8 Bending Stress Load (on steel beam)

$$\sigma_b = \frac{M_{max} * C}{I}$$

Where:

σ_b is bending stress load, ksi
M_{max} is max moment distributed load, lbs*in
c is distance to extreme fiber, 1.5in
I is moment of inertia, 1.78in

Equation 9 Wave Pressure

$$P_w = 0.5(2.4\gamma_w h_w)\frac{3}{8}h_w$$

Where:

P_w is wave pressure load, lbs/ft
γ is specific gravity of water, 62.43 lbs/ft^3
h_w is wave height, ft

Equation 10

$$\frac{H_w}{D} = 0.55$$

Where:

H_w is wave height, ft
D is depth of water, ft

Business Plan Audit: Stormwater Management Solution Design

Audited by Walter Cuculic, Vice President of Renewable Energy at Sunwest Bank

Introduction: The following audit assesses the business plan for a stormwater management solution designed for the 34th WERC competition capstone project for the Northern Arizona University Team. The project targets Joseph City, AZ, addressing historical stormwater flooding exacerbated by climate change. The audit evaluates the proposed hydrologic and hydraulic modeling solution, aiming to provide constructive feedback and commendation.

Overall Assessment: The business plan demonstrated a deep understanding of the challenges posed by historical stormwater flooding in Joseph City, AZ, especially considering the increasing impacts of climate change. The emphasis on designing a cost-effective solution tailored to an underserved community is commendable, reflecting a strong commitment to social responsibility and real-world applications. Involving the local community (Volunteer Fire Department) showed creativity and common sense.

The incorporation of hydrologic and hydraulic modeling techniques showcases a rigorous analytical approach to problem-solving. By simulating the multiple flood event including the 100-year flood event, the project demonstrates a comprehensive understanding of the magnitude of the challenge and the necessity for resilient and cost-effective infrastructure solutions.

The alignment of the proposed solution with the competition's objective of addressing environmental concerns within underserved communities is noteworthy. The emphasis on sustainability, cost effective solution, and community empowerment reflects a strategic vision that transcends mere technical feasibility. This is further enhanced by the community garden benefit as an additional resource for the people of Joseph City.

Recommendations: While the business plan exhibits commendable strengths, there is potential for some improvement:

Financial Viability Analysis: The team did a great job of conducting a detailed financial viability analysis to assess the long-term cost effectiveness of several proposed solution. The team could have looked at additional wall building materials in addition to the one proposed.

Stakeholder Engagement: Additional details on the involvement of the Volunteer fire department could have been included in the original write up. After discussing the solution with the team, I understand and valued the involvement of the local community in the proposed solution.

Conclusion: The business plan for the stormwater management solution design represents a commendable effort, reflecting a strategic blend of technical expertise and social responsibility. With further refinement and implementation of the recommended enhancements, the project is poised to make a meaningful and lasting impact in addressing stormwater flooding issues in Joseph City, AZ, while serving as a model for sustainable community development initiatives.

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NORTHERN ARIZONA UNIVERSITY

Environmental Health and Safety

Memorandum

TO: **Caroline Reed, Matthew Helms, Tiana Deloney, Zachary William Lyon**
From: **James Biddle, Assistant Director NAU Environmental Programs**
RE: **CENE 486C Capstone Project, Joseph City, AZ.**
Date: **April 1, 2024**

Thank you for giving me the opportunity to review and comment on your Spring 2024 Environmental Capstone project involving the 100-year flood mitigation measures to be incorporated in the Joseph City, Arizona wash bed.

With any environmental regulatory process, it's critical to determine regulatory applicability which will dictate jurisdictional discretion and subsequent controls. This will ensure the regulatory process goes smoothly during the project. Since the project site is in Joseph City which lies in Navajo County, we need to determine if this will trigger Federal EPA applicability involving the Phase II Municipal Separate Storm Sewer System (MS4) rules. The Arizona Department of Environmental Quality (ADEQ) currently exempts small MS4's that are physically located on any Indian Country lands as stipulated in the General Permit (expires September 2026).

If not in ADEQ jurisdiction, the EPA Region IX office would determine if any Small MS4 rules apply. Although this may not be likely as the stormwater rules involving Small and Large MS4 municipalities are based on the most recent decennial census for an urbanized area. If the population of Joseph City exceeds 50,000 based on the decennial census, it would trigger the Small MS4 rules for Federal sites.

It might also be prudent to determine if the project would trigger the need for a Dredge and Fill permit (Section 404) with the U.S. Army Corps of Engineers.

As you already astutely surmised in the project, the safety aspect of worker safety during the project is extremely important. The Bureau of Labor statistics on injuries at construction sites is staggering which is a shame as most injuries can be avoided with proper training, personal protective equipment, and a good Site Health Safety Plan.

But again, the need to determine jurisdictional applicability is warranted if on Federal land (Tribal) or not. If the site is on Tribal land, the Federal OSHA office would be helpful for any support in construction safety. If on State land, the ADOSH office in Phoenix can assist in any consultative manner.

Finally, perform careful consideration if the wash site lies in a pit, pond, or lagoon area as this may trigger OSHA's Confined Space entry work procedures.

This seems like a great project for a worthy cause, good luck!

Jim Biddle

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March 30, 2024

Mses. Deloney and Reed, and Messrs. Helms and Lyon
Northern Arizona University
Stormwater Management for EJ/CJ Community Resilience

RE: Legal/Regulatory Audit

Dear Sir/Madam:

I appreciate the opportunity to provide your team with a legal and regulatory audit of your paper. I understand that the goal of the contest you are entering is to design a low-cost solution to mitigate historical stormwater flooding issues for an underserved community. The design should be both innovative and include community co-benefits. I reviewed your report from a legal and regulatory viewpoint.

The team did a good job reviewing the health, safety, environmental, and legal regulations that would cover a project of this nature. The team is correct to point out that that under the Clean Water Act a stormwater discharge permit will be required because the construction site will disturb an area larger than one acre. The team may want to note that the Arizona Department of Environmental Quality ("ADEQ") received authorization to administer the NPDES program in Arizona on December 5, 2002 (Final 2013 CGP Fact Sheet (azdeq.gov)). The project will be required to obtain an Arizona Pollutant Discharge Elimination System ("AZPDES") permit coverage for stormwater discharges.

It was unclear to my why the team noted that the "…Navajo Nation will be contacted to ensure the archeological preservation of the land for the Tribe." In reviewing Google maps, it does not appear that the site is located within the Navajo Nation. If the site is located within the Navajo Nation, the laws and regulations of the Navajo Nation should be reviewed, as they could differ from federal, state, and county regulations and laws.

It is difficult to determine if the intermittent deployment of the liner will impact surface water rights, which are regulated pursuant to A.R.S. 45-141 through 167. A surface water right is associated with a specific parcel of land. Changes can be made through administrative proceedings before the Arizona Department of Water Resource. The amount of water available under a surface water right is subject to prior right appropriations. I do not believe that your project would impact any groundwater rights due to the intermittent placement of the liner. If the liner will be deployed for extended periods of time it could change my conclusion. The potential impact of the project on any water rights should be reviewed prior to implementation of the project.

I could not determine from the draft report if fencing would be on only one side of the liner or completely surround the area to be lined. In reading your paper I picture water running down the liner and downslope, resulting in a potential attractive nuisance (e.g., a giant slip and slide). An attractive nuisance is a dangerous condition on a landowner's property that may particularly attract children onto the land and pose a risk to their safety. A landowner may be held liable for injuries to children trespassing on the land if the injury is caused by an object on the land that is likely to attract children. You may want to consider appropriate fencing and signage on the dangers associated with entering the area during wet conditions. Signage warning children of the dangers might be different than the OSHA signage noted in your paper.

It appears from the drawings that construction will take place within 50 feet of the centerline of the BNSF railroad. You should be aware that working within the BNSF right-of-way might require additional permits and approvals from the railroad, as well as a Railroad Protective insurance policy. The Railroad Protective insurance policy provides coverage only for the railroad and is purchased by the contractor to cover all the work (prime and all subcontractors) within 50 feet of the centerline of the tracks.

In summary, the Northern Arizona University Stormwater Management for EJ/CJ Community Resilience Team's identification of legal and regulatory concerns (e.g., OSHA, Clean Water Act, zoning and land use regulations) are appropriate and adequate. I have identified a few areas that Team may want to consider in the finalization of their report.

Good luck in the competition!

Very truly yours,

Steven F. Blarr, P.E., Esq
SVP, General Counsel & Director of Enterprise Risk Management
Steve.Blarr@westonsolutions.com