NORTHERN ARIZONA UNIVERSITY

CENE 486C

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Duncan Floodplain Analysis

Design Report

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Abbreviations

Waste Water Treatment Facility - WWTF

Acknowledgements

The Duncan Flood Mitigation Analysis project is part of Northern Arizona University's Senior Capstone Project for civil and environmental engineering. The client for this project is Mr. Ronnerud, P.E. and Greenlee County Engineer. Hydro Engineering would like to thank Mr. Ronnerud for making this project possible. Mr. Ronnerud is an NAU alumni and provided this project for Hydro Engineering. Mr. Loomis also provided excellent training throughout the completion of the project.

Hydro Engineering would also like to send a special thank you to

Thomas R. Loomis, P.E., RLS, FCDMC

Tech Advisor

Mark Lamer, P.E.

Grading Instructor, NAU Lecturer

1. Project Understanding

Hydro Engineering is continuing a flood study completed by NAU Crown Engineering in the fall of 2015. The previous study used a flood simulation with HEC-RAS. From these models, the current flood prevention method and model containing a levee was analyzed. The HEC-RAS simulation provided one dimensional analysis of the flow of the river was only done in one-dimension. The client has asked for the study to be continued with a two dimensional simulation. The two dimensional study analyzes flow in the lateral and horizontal directions, which will provide more realistic results.

1.1. Project Purpose

There is currently an issue with flooding in Duncan, Arizona. This flooding causes damage to communities in the floodplain of the Gila River, destroys crops, and also damages homes and infrastructure in the area. In order to solve or-mitigate this issue, further study on a levee needs to be completed. Previously a flow study was done using HEC-RAS and AutoCAD Civil 3D analysis. The result from this study was then used to determine if a levee was the most appropriate solution for the Duncan, Arizona flooding. By creating a two dimensional model using Flo-2D and RAS-2D, a more enhanced levee analysis can be completed to better serve the town of Duncan, Arizona. A two dimensional model is more accurate and realistic than a HEC-RAS model because flow is traveling in two dimensions.

1.2. Project Background

Duncan, Arizona is located within Greenlee County, in southeastern Arizona, as shown in Figure 1-1. Greenlee County lies on the New Mexico border. The town of Duncan is located in the southern portion of the county. The Gila River is a major river of the southwest, and it runs directly through Duncan. This provides the community with rich farmland because silt and clay soils are located in floodplains, which create fertile soil [1]. The fertile soil creates agricultural opportunities in Duncan, Arizona. According to Arizona Demographics, 783 residents comprise the town's population [2]. With the town being reliant on the Gila River as a main force driving the agricultural industry, it is also its biggest threat, due to the potential flooding of the area.

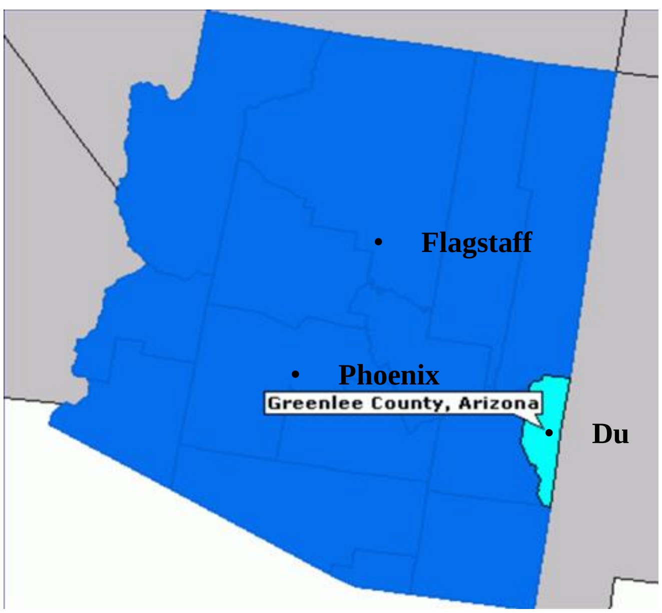

FIGURE 1. LOCATION OF GREENLEE COUNTY IN ARIZONA [9].

The climate of Duncan area is the climate, which occurs primarily on outer limits of a low altitude, true desert, with semiarid steppe regions. [3]. The result is cooler, wetter winter resulting from the higher latitude frontal cyclone activity. The annual precipitation amounts vary fairly, but are not as much as true desert regions. The average amount of yearly precipitation Duncan receives is 10.9” with August (2.1”) as the wettest month and April (0.2”) as the driest month [3]. Although for this project, the team needs to analyze the climate of the entire watershed for this area, and not just the town of Duncan.

The flood of December 1978 caused major damage to homes, businesses, and most public buildings and facilities [4]. A study showed large holes developed in structure that was currently in place at the time and allowed a wall of silt and water to rush through the community. The normal level of the river is 2.5 feet (average), and during the flood event of 1978, the water level was 7 feet (maximum) in some locations. The estimated maximum discharge for this event was 60,000 cfs [4]. The flood of 1978 was greater than a 100-year flood event and the earth dike, which was in place to mitigate the floods, was overwhelmed and provided little to no protection [5].

For this project, the engineering is going to be focusing on an approximately one mile section along the banks of the Gila River in the middle of the town in the Figure 1-2. The area of interest is shown by the yellow area, the area with the greatest risk of flooding. The blue line is an outline of the Gila River, which dissects the town. The place marker in the Figure 1-2 shows the western side of town, which is the location prone to flooding.

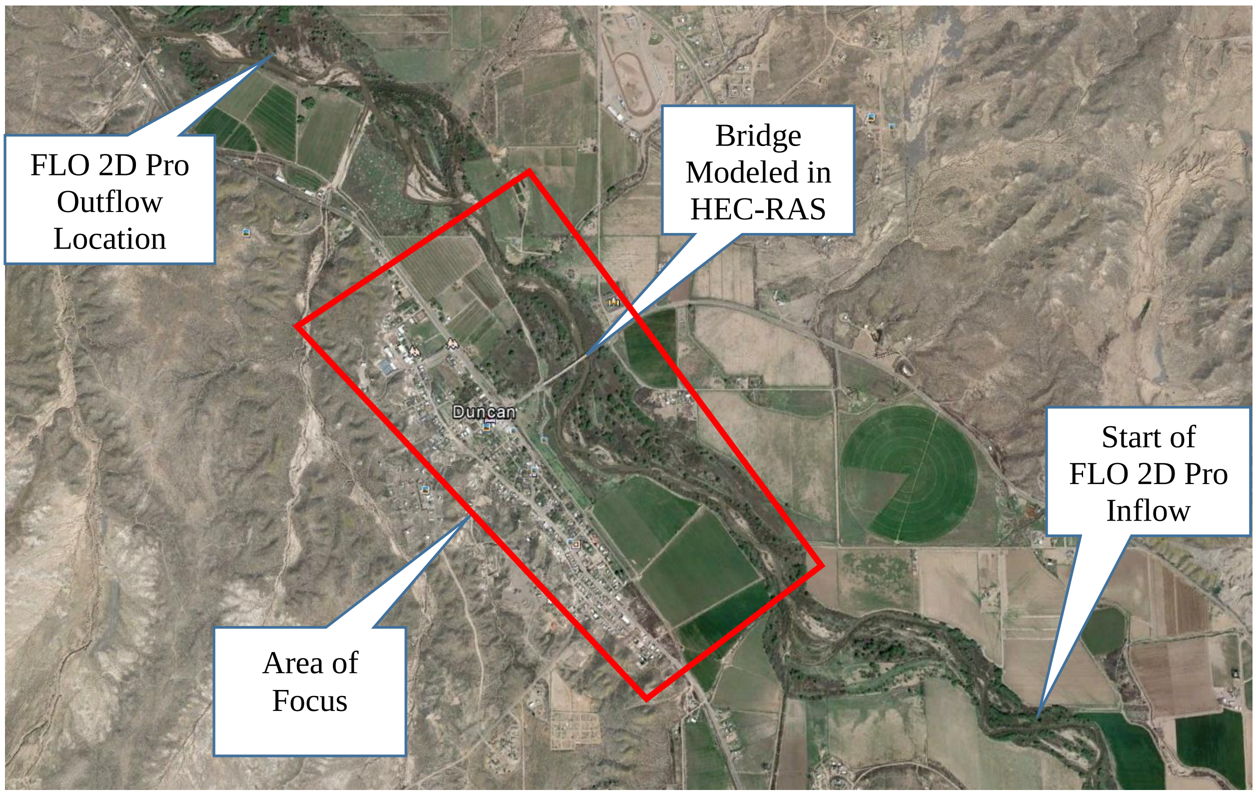

FIGURE 2. ARIEL VIEW OF TOWN OF DUNCAN, WITH AREA OF INTEREST.

1.3. Technical Considerations

Duncan, Arizona is susceptible to flooding of businesses, residences, and highway 70 from overflow in the Gila River. Flo-2D Pro will be used to analyze the floodplain and Gila River under various conditions. The model will provide a greater understanding of the option of a levee to protect Duncan, Arizona. The various conditions that could impact the flow are vegetation, infrastructure, and Gila River dimensions. The current capacity of the Gila River is causing an issue with flooding. The river has a smaller capacity in the past due to vegetation. The smaller capacity is allowing the river to flood quicker and easier than before.

1.3.1. Flo-2D Pro

The Flo-2D Pro software is approved for FEMA studies. A main aspect that Flo-2D Pro can analyze is river overbank flooding. Rainfall/Runoff and flood routing can be modelled in the two dimensional software because it is a hydrologic and hydraulic model [6]. Flo-2D Pro provides analysis in the lateral and horizontal directions of flow. The previous study analyzed the Gila River using HEC-RAS, which only takes the lateral direction of flow into account. Considering the flow in each direction creates a different impact on the floodplain than the previous one-dimension study.

1.3.2. RAS-2D

HEC-RAS is a modeling system that allows for a deeper analysis of waterways or extensive storms. NAU Crown Engineering created two models, effective and corrected effective, before finalizing their proposed conditions model. The effective model consists of a mirrored model created by FEMA in 2007, with information collected from 1975-1976. This had little impact due to the old data; yet gave insight to the flooding trends in Duncan [7].

The corrected effected model used more recent data from 2012, allowing the proposed 100-year storm of 48,000 cfs to bring light to a real issue in Duncan. Over a total of 3.4 miles of Gila River, 24 cross sectional widths of allowable flow were analyzed. The total points were no more than 500, to allow for a close, but not too intense, analysis of the projected flooding [7].

The proposed model for Duncan, AZ, according to NAU Crown Engineering, was surprisingly to find a different solution. The group claims Duncan, AZ does not have the funds or support to create a levee system [7]. However, with the small amount of data and analysis, a conclusion such as this can be faulty. Provided with more effective two- and three-dimensional analysis, a levee system can be more productive and effective than originally thought.

1.3.2.1. Flow Impacts

In order to provide an area for Flo-2D Pro to analyze, an aerial image and a digital topographic map must be imported into the model. The hydrologic data is also essential when running a Flo-2D Pro model. The hydrologic data consists of rainfall and discharge hydrographs. The infrastructure that needs to be considered in a Flo-2D Pro model is bridges, culverts, buildings, and roads. Cross sections of the floodplain and channel are to be used in the analysis [7]. Levees can be simulated in the model along with floodplain storage loss due to vegetation and infrastructure. Flo-2D Pro can provide a flood animation and assess the amount of damage that can be done from the flood [6]. Hydro Engineering will use a Flo-2D Pro model to analyze the floodplain and Gila River under various conditions.

1.4. Stakeholders

Stakeholders of a new levee in Duncan, AZ range from the local population to governmental bodies. The US Army Corps of Engineers is a major stakeholder; USACE has a say in the construction of a levee due to the connection to a navigable waterway, Gila River. Another stakeholder is the general public and homeowners of Duncan, AZ. The people of Duncan can reject or support the project; it is important the city agree with the team's proposal. Greenlee County has a say in the project, as well. The County, given the project is affordable and provides necessary protection will help guide to implementation of a levee. FEMA has the ability to completely reject and end the project; FEMA carries a large stake in a new levee. Ultimately, they are in charge of the final accreditation of the project. Environmentalists are the last stakeholders to mention. Environmentalists have shut down projects in the past if they do not support the local animals, especially those in danger. Given the levee supports animal life, environmentalist will be on board with a new levee.

2. Technical Sections

2.1. Model Preparation

Hydro Engineering has completed two site visits consisting of analyzing various sections of the Gila River and surveying. The Gila River contains a variety of vegetation throughout Duncan, AZ. In order to establish an accurate model, pictures were taken along the river where the team noticed a wide variety of vegetation. Locations were predetermined using ArcGIS and aerial images from google maps, as shown in Figure 2-1 below. Pin drops were placed in google maps to determine the occupied location during the site visit and pictures were taken.

FIGURE 3. SURFACE FEATURE CHARACTERIZATION OF DUNCAN AND GILA RIVER.

The surveying completed consists of obtaining elevations of low water, high water, and peak flow marks on the County Building and Simpson Hotel from the 1978 flood Duncan experienced. The County Building and Simpson Hotel were chosen because they were present during the 1978 flood and the water marks were recognizable. The marks compare the depths of flow obtained in Flo-2D Pro at the completion of existing conditions model to the depths measured in order to check the models for accuracy. The low water, high water, and peak flow marks were measured using an auto-level, tripod, and a measuring rod. LIDAR data was used to identify elevations at two distinct locations outside of the two buildings. From the elevations on the LIDAR data the instrument height was determined and therefore, the water mark elevations could be measured.

2.1.1 ArcGIS Surface Feature Characterization

Aerial images and LiDAR data were input into ArcGIS in to establish various surfaces. Each surface was created by drawing polygons around the characteristics of that layer. The surfaces consisted of buildings, paved surfaces, low vegetation, medium vegetation, heavy vegetation, cottonwood, bare ground, and agricultural fields. While creating these surfaces gaps and overlaps were noticed, which are not desired since errors will occur in the model. These gaps and overlaps were eliminated by assigning a priority to each surface, clipping the higher priority surface out of the lower priority surface(s) and pasting the higher priority surface back into the existing surface. Pasting the surface back into the existing surface allowed for all the voids to be filled. After completion surface establishment, n-values were determined.

Various n-values were determined for each surface using input from Tom Loomis and the *Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains* [8]. N-values varied based on the ability of obstructing flow for each surface. The surface containing the highest n-value was for paved land and the lowest n-value was assigned to heavy vegetation. Figure 2 below shows n-values for each surface.

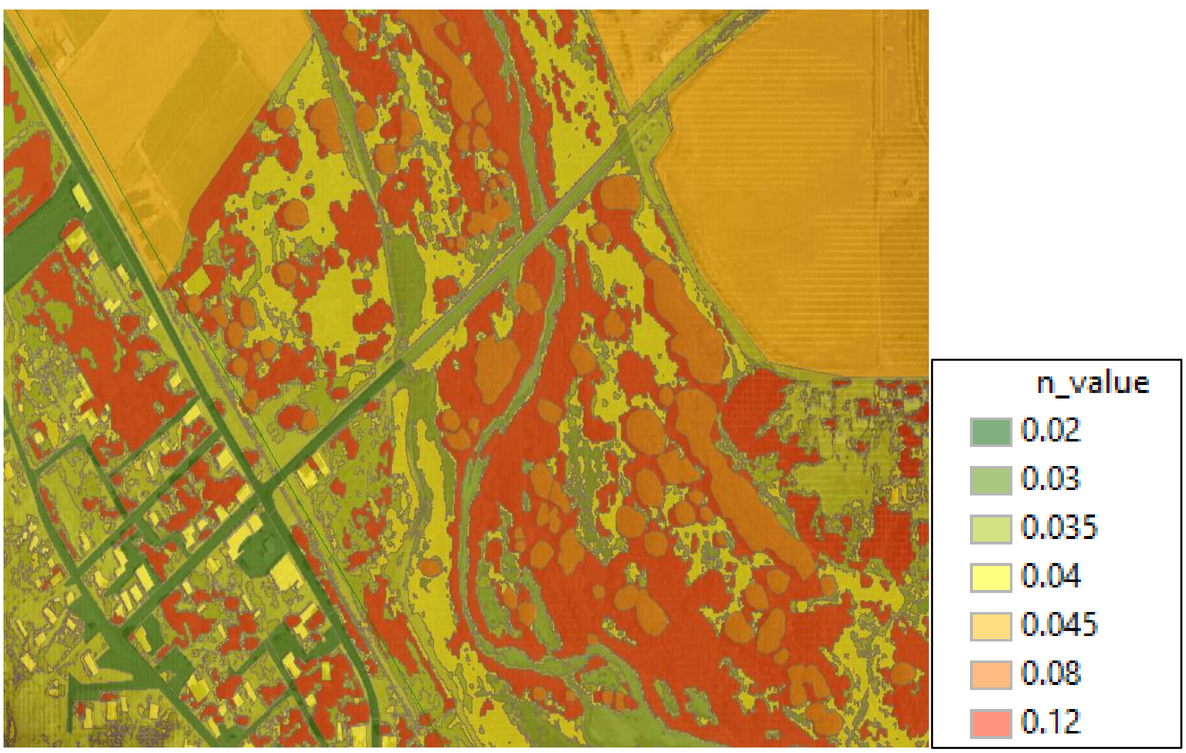

FIGURE 4: SPATIALLY VARIED ROUGHNESS VALUES.

The upstream and downstream cross sections closest to the bridge needed to be adjusted in order to model the bridge more effectively. The previous cross sections were greater than 5 feet away from the bridge and did not follow the bridge alignment. Vertices were created along each cross section and the cross section was pulled to within 5 feet of the bridge. Applying the cross sections within 5 feet of the bridge allowed for the HEC-RAS model to model the hydraulic structure more accurately, which was desired since Flo-2D Pro does not have the capabilities of modeling this hydraulic structure.

2.1.2 Hydrographs

Figure 2 below shows the combined hydrographs obtained based on the flow data recorded for both Virden, and Clifton Arizona., which was interpolated to obtain the flow data for Duncan, Arizona. This hydrograph shows a different flow rates for different storm events, the highest flood event is the 1978 flood which is about 57000 cfs. Whereas, the 100, 25, and 10-year flow rates are based on an estimated flow rates that will have a similar flow pattern as shown in the 1978 flow. These three flow rates are computed based on the highest flow that will be presented in that event.

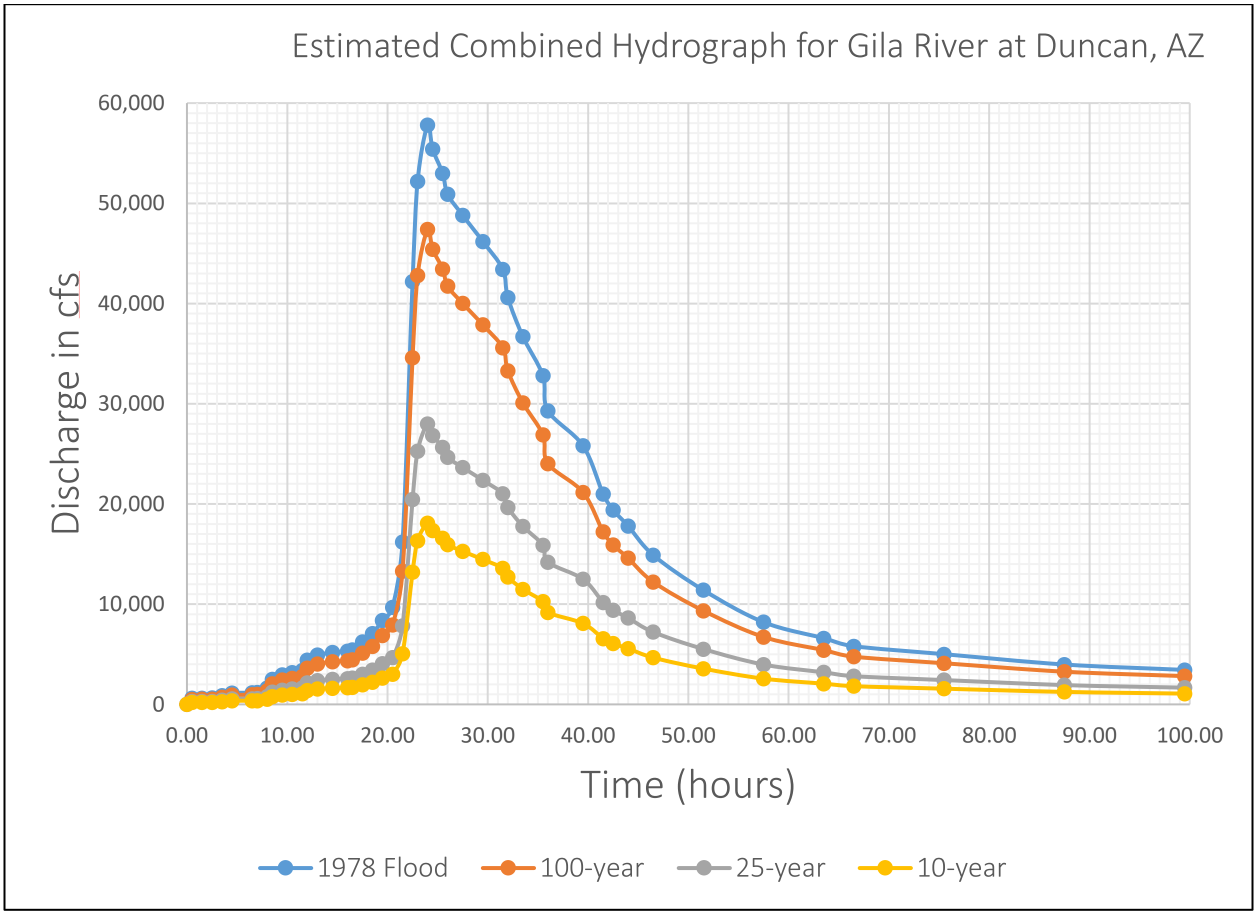

FIGURE 5: HYDROGRAPH

2.1.3 Bridge and Pier Modeling

The Hydro Engineering team needed to model the bridge at Duncan, Arizona. Since FLO-2D PRO currently has no efficient way to complete this task, it was decided upon to model the bridge in the HEC-RAS, then manually enter the results into FLO 2D-PRO. This would be completed by creating an accurate HYSTRUC.DAT file to import into FLO-2D PRO.

This section will discuss the methods used to model the hydraulic structures at the location of interest. The hydraulic structures considered in this project were the Highway 75 bridge crossing the Gila River at Duncan, Arizona. The components of the bridge considered were all 12 piers, the bridge deck, the bridge girders and the fence along the south face of the bridge (shown in Figure XX), from the east abutment to the west abutment. These dimensions and measurements were taken from the "as-builts" of the bridge that was present during the flood of 1978.

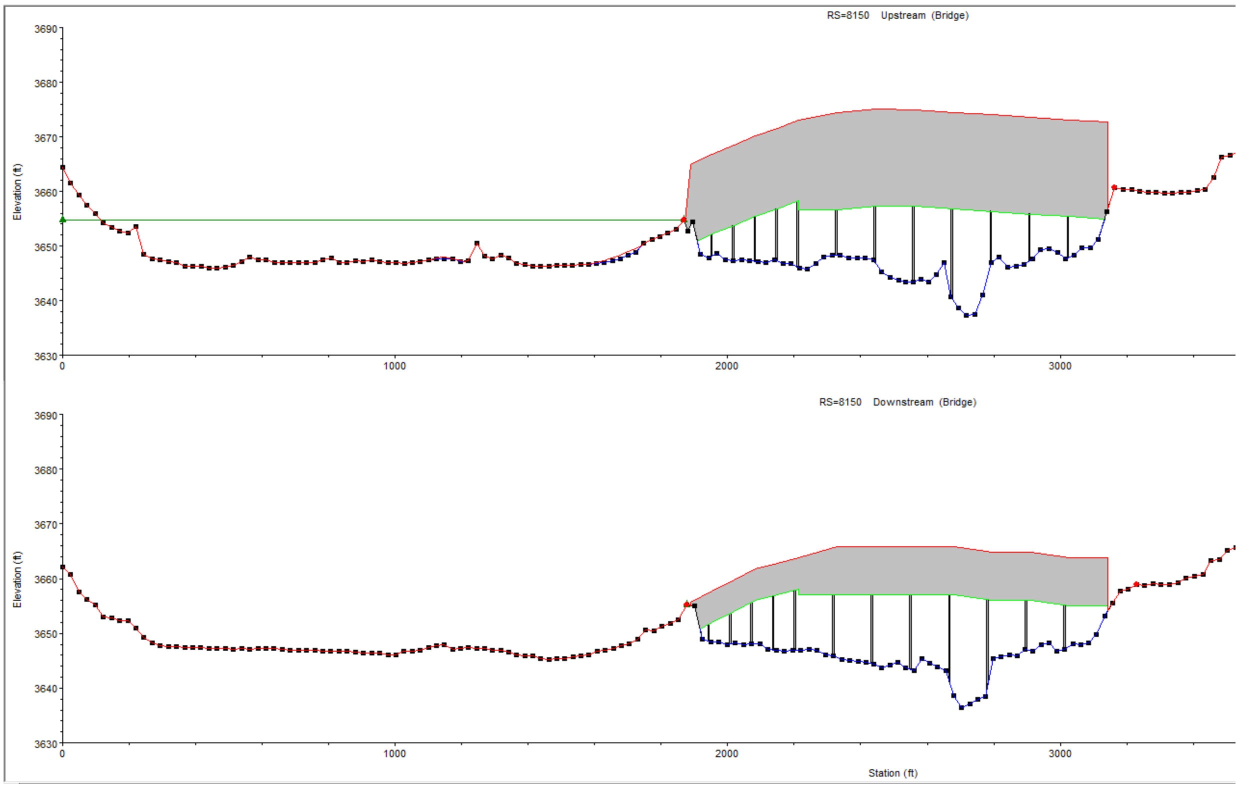

FIGURE 6: UPSTREAM AND DOWNSTREAM CROSS SECTIONS FOR THE BRIDGE.

Figure 4 shows the upstream and downstream cross sections created in HEC-RAS that is used to run the HEC-RAS model. A majority of the HEC-RAS information received in this project came from the Crown Engineering Fall 2015 capstone project [7]. Figure 5 below shows the cross section upstream from the modeled bring used by NAU Crown Engineering.

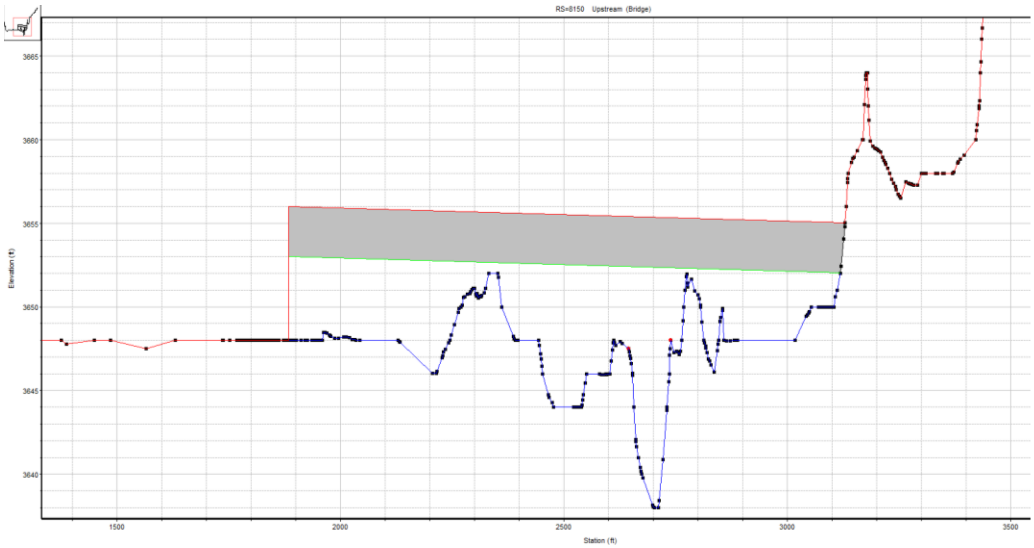

FIGURE 7: BRIDGE MODELED BY PREVIOUS TEAM [7].

The Hydro Engineering team consulted with our technical advisor, and it was concluded that NAU Crown Engineering's bridge model was not sufficient to accurately calculate the hydraulic phenomenon's at this location.

The changes to the US Highway 75 Bridge done by Hydro Engineering includes the following:

- While reviewing the as-builds, the team noticed the arc in the bridge, and therefore accounted for that in the structure Hydro Engineering's HEC-RAS design.
- The addition of piers was needed due to the piers being absent in NAU Crown Engineering's model.
- The addition of connections from the ground to the abutment was added to Hydro Engineering's HEC-RAS model.
- The addition of the screen to the was added to the upstream cross section of the bridge. A picture of the screen can be seen in Figure 4.
- Changes to the overbanks at the cross sections was made as recommended by the technical advisor.

Figure 8 shown below are an aerial view of the cross sections created by NAU Crown Engineering and the cross sections used by Hydro Engineering. Modifications were necessary in order to model the bridge more effectively in Flo-2D Pro. Figure 9 below shows the adjusted overbanks and ineffective flow areas.

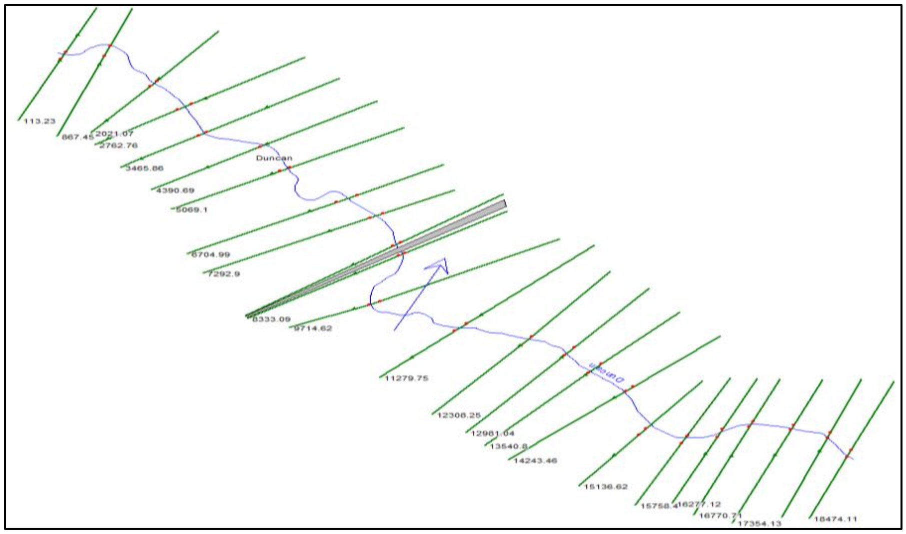

FIGURE 8: NAU CROWN ENGINEERING HEC-RAS CROSS SECTIONS [7].

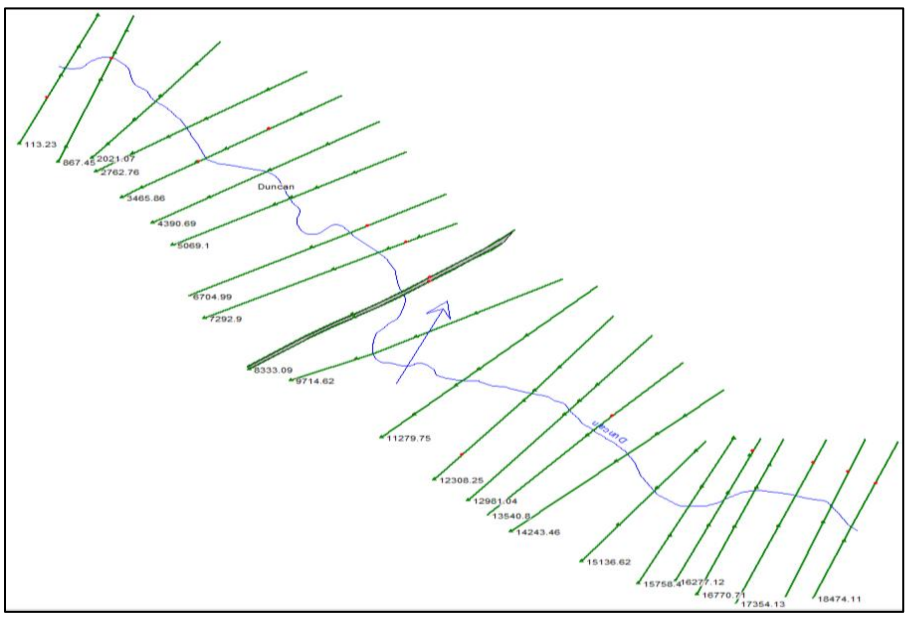

FIGURE 9: ADJUSTED OVERBANKS AND INEFFECTIVE FLOW AREAS.

NAU Crown Engineering had cross section skewed to the bridge as shown in Figure 10. The cross sections Hydro Engineering created were parallel with the downstream and upstream cross section, moving them 5 feet upstream and downstream from the bridge, which will provide more accurate results and is shown in Figure 11 below. The addition of vertices at the cross section allowed for the cross section to be curved to fit the actual dimensions of the bridge

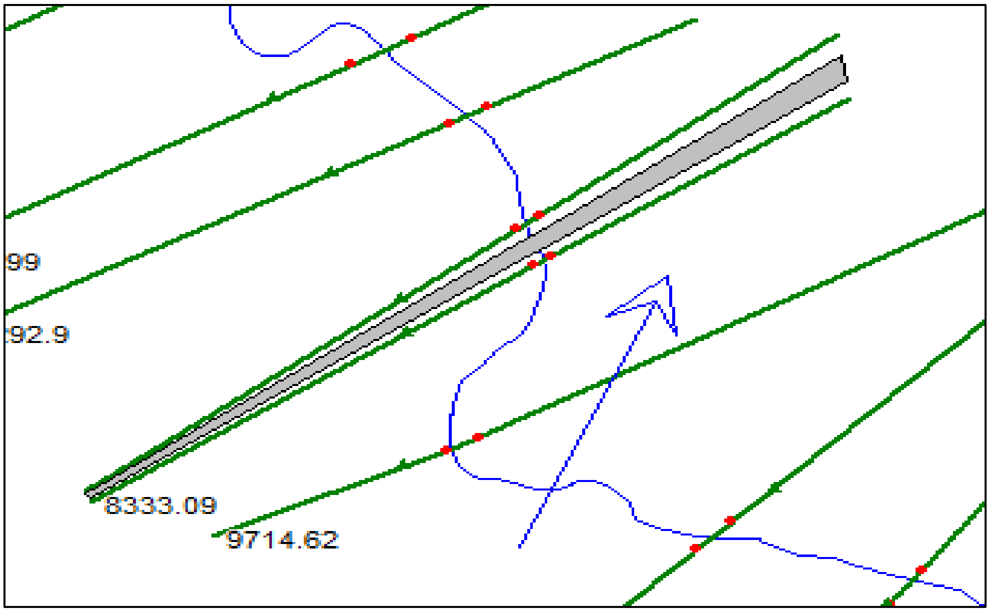

FIGURE 10: NAU CROWN ENGINEERING UPSTREAM AND DOWNSTREAM BRIDGE CROSS SECTIONS [7].

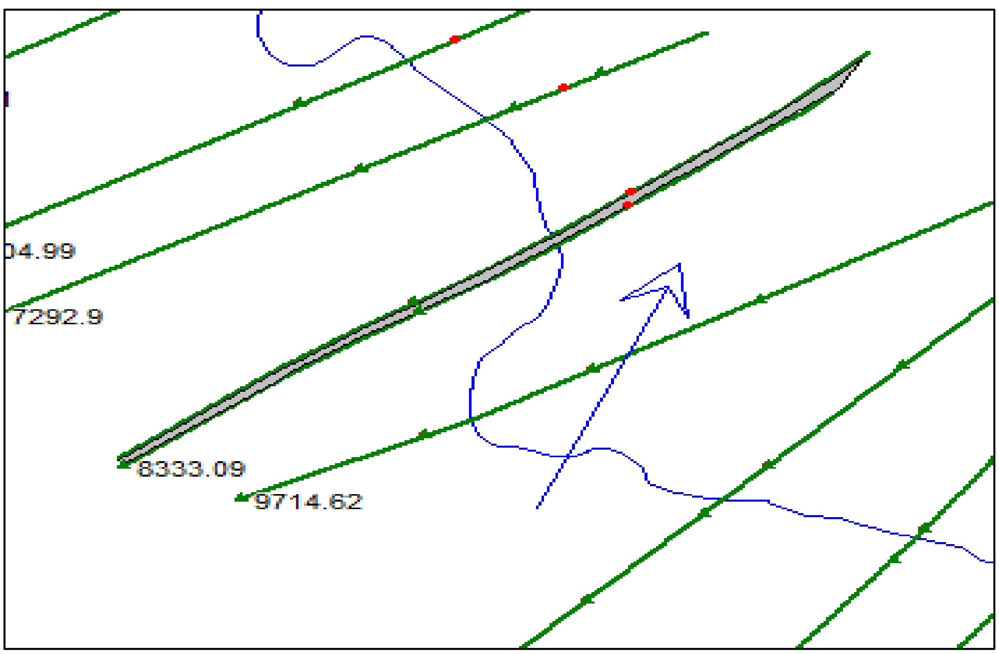

FIGURE 11: ADJUSTED UPSTREAM AND DOWNSTREAM BRIDGE CROSS SECTIONS.

2.1.4 HEC-RAS to Flo-2D Pro Transition

Moving information over to Flo-2D is a huge step in this project. The team is unable to directly put flow data into Flo-2D Pro without first using HEC-RAS because Flo-2D does not model hydraulic structures; and there is a major bridge in the town of Duncan. Therefore, the team must first model the bridge in HEC-RAS, then move the output data into a .DAT file to finally explore Flo-2D. However, it is not as simple as "copy and paste;" when the information is moved from software to software, the team must ensure the information is properly formatted.

2.2. Designs

Hydro Engineering alternatives were simulated with FlO-2D Pro; this allowed the analyzed study to conduct the work along with these 2 dimensional models. The FlO-2D Pro model is effective when modeling the simulation of the floodplain in 2 dimensional. For FlO-2D Pro grid 25 is the selected grid showing the most accurate results of the flow modeling. Hydro Engineering used Flo-2D Pro with the corrected flow for the proposed 100-year storm in Duncan.

Hydro Engineering will also work on the following alternative models:

2.2.1 Existing Conditions

Existing conditions model was created to establish a baseline for all the models created by Hydro Engineering. Using the established surfaces and HEC-RAS data, this model was ran using the flow from the 1978 flood, which was 57,800 cfs. Upon completion of the first existing conditions model expected results from the teams' surveying data were not obtained. This unexpected result was due to the construction of a new bridge after the 1978 flood. The new bridge was determined to have about 40% greater capacity than the bridge present during the 1978 flood. Once the capacity for the new bridge was lowered, the existing conditions model was simulated and maximum depth conditions were analyzed. As seen in Table 1, the maximum depth seen in the existing conditions model around the Simpson Hotel and County Building was 7.5 feet for both buildings, while the maximum depth surveyed was 9.3 feet for the Simpson Hotel and 6.5 feet for the County Building. Results for the existing conditions model can be seen in Appendix A. Comparing the model results with actual conditions experienced illustrates accuracy of the existing conditions model and allowed for creation of accurate models that can provide possible flood mitigation solutions for Duncan. The Gila River Restoration, Proposed Levee and Gila River Restoration with the Proposed Levee models were created by modifying the existing conditions model.

TABLE 1: SURVEY DATA FROM SITE VISIT

Location	Max Survey Depth (ft)	Model Depth (ft)
Simpson Hotel	9.3	7.5
County Building	6.5	7.5

2.2.2 Proposed Levee

The second model the team has considered is inputting a levee; replacing the town's agricultural dike. This levee will be just to the East of the town's railroad, ensuring any trains are safe from flooding events. After the levee has been modeled in Flo-2D, the team re-designed it with three feet of freeboard above the flooding height giving a proposed levee height of 23-feet, which can also be seen in Appendix A. This is to ensure there is sufficient height to protect against flooding in downtown Duncan. The team will also assume there will be temporary flooding measure taken at the ends of the levee and when crossing Highway-75 to ensure backflow does not damage the town. This will consist of sandbags or other temporary placements.

2.2.3 Gila River Restoration

Gila river restoration; this alternative focused on removing the overgrown vegetation obstructing flow along the river and removing the existing WWTF. The existing WWTF is abandoned and is a possible source of contamination when flooding occurs. The Gila river restoration model consideration consist of removing and trimming an approximate of 60 percent of the salt cedar trees, and cotton-wood trees respectively. In addition, this model also consisted of removing the waste water treatment facilities present near the river way in Duncan. In order to adjust this model, a set of new n-values was implemented, these n-values are based on the team's site visit, and aerial photos. The new n-values show less obstructed areas along the river's flow path. However, the max depth range presented in this model is in between 4 ft. to 10 ft. These maximum depth results are shown in Appendix A.

2.2.4 Gila River Restoration and Proposed Levee

Gila river restoration and proposed levee is a combination of the previous two models. This model also has the WWTF removed. Compared to the proposed levee model, the combined model brought the height of the levee down 3-feet, giving a levee height of 20-feet, which can be seen in Appendix A.

2.3. Cost of Implementing Designs

The cost of Implementing the design can be shown in the table below. The total cost of the levee is approximately $6.4 million, with a base cost of $3.75 million per mile. The Gila River Restoration, which included tree removal and trimming of 150 and 85 trees respectively, is $57.75 thousand. The combined cost of the two came out to $6.5 million. The team also took into account the possibility it may be cheaper to buy out Duncan. So the property acquisition came out to be $600,000, for all land. This price does not include any businesses or houses.

TABLE 2: COST ANALYSIS FOR POSSIBLE SOLUTIONS.

<table>
<tr><td rowspan="2">Levee</td><td>Length (mi)</td><td>Cost ($/mi)</td><td colspan="4" rowspan="2"></td><td rowspan="2">Levee Cost $6,487,500</td><td rowspan="4">Combined Cost $6,545,250</td></tr>
<tr><td>1.73</td><td>3.75M</td></tr>
<tr><td rowspan="2">River Restoration</td><td>Tree Removal</td><td>Tree Trimming</td><td>Total Trees Removed</td><td>Total Trees Trimmed</td><td>Total Cost for Tree Removal</td><td>Total Cost for Tree Trimming</td><td rowspan="2">Restoration Cost $57,750</td></tr>
<tr><td>$300 per tree [3]</td><td>$150 per tree [3]</td><td>150</td><td>85</td><td>$45,000</td><td>$12,750</td></tr>
<tr><td rowspan="2">Property Acquisition</td><td>Cost Per Acre</td><td>Acres in Duncan</td><td colspan="4" rowspan="2"></td><td rowspan="2">Land Cost $600,000</td><td rowspan="2"></td></tr>
<tr><td>$2,000</td><td>300</td></tr>
</table>

2.4. Impacts

Hydro Engineering considered potential impacts on stakeholders if either the construction of a levee or modeled Gila River Restoration was implemented.

The construction of a levee at the modeled location will impact the stakeholders in a multitude of ways, both positive and negative. The first and most prominent impact is the downtown portion of Duncan will be out of the 100-year floodplain. This will provide a feeling of comfort knowing their town will be saved from flooding by a 100-year storm event, the result is the investment of time and money into the community and improving the overall quality of life. There will be minimal disturbance to the animals and vegetation because the floodplain east of the levee will still receive annual surges to recycle nutrients. The construction of levees will obvious bring a short term economic boost to a town that has an unemployment rate higher than that of the state average. This is a positive impact to the stakeholders regarding the economic impacts, but Hydro Engineering also identified the need for continuous up keep and monitoring for the levee to remain safe and functional. That source of revenue has to be taken into consideration and will put a monetary burden on the Greenlee county. There have been studies done on introducing invasive species of plants through the use of heavy equipment. There is a possibility that the introduction of Noxious Weeds could upset the balanced ecosystem in the area of Duncan.

3. Project Costs

For this project, the team assumed there will be three type of people, a Senior Engineer, an Engineer, and an Intern working together. The rate of pays are approximately $118, $70, and $30, respectively. The total proposed hours were 752 and an actual total time of 706 hours for the team. Finally, the proposed cost was decreased by about $3, 000, to get the total cost of $45,000. Exact hours and pay can be located in the table below.

TABLE 3: STAFFING COST

Classification	Billing Rate ($/hr)	Proposed Hours	Actual Hours	Proposed Cost	Actual Total Cost
SENG	117.51	169	156	$19,859	$18,332
ENG	70.11	300	278	$21,033	$19,491
INT	29.64	283	272	$8,388	$8,062
		752	**706**	**$49,280**	**$45,884**

4. Project Schedule

Task Name	Start	Finish
1.0 Data Collection	Thu 9/1/16	Fri 9/2/16
1.1 County Data	Thu 9/1/16	Thu 9/1/16
1.2 NAU Crown Engineering Data	Thu 9/1/16	Thu 9/1/16
1.3 FEMA Data	Fri 9/2/16	Fri 9/2/16
2.0 Hydraulics: 2D Modeling	Mon 9/5/16	Fri 11/18/16
2.1 Model Parameters	Mon 9/5/16	Tue 9/20/16
2.1.1 Grid System	Mon 9/5/16	Tue 9/13/16
2.1.2 Manning's Number	Wed 9/14/16	Thu 9/15/16
2.1.3 Courant & DEPTOL Values	Fri 9/16/16	Mon 9/19/16
2.2 Two Dimensional	Wed 9/21/16	Wed 11/16/16
2.2.1 FLO-2D	Wed 9/21/16	/ed 11/16/16
2.2.2 HEC-RAS 2D	Wed 9/21/16	/ed 11/16/16
2.2.3.1 Existing Conditions	Wed 9/21/16	Wed 11/16/16
2.2.3.2 Existing w/o Dike	Wed 9/21/16	Wed 11/16/16
2.2.3.3 Proposed Levee	Wed 9/21/16	Wed 11/16/16
2.2.3.4 Gila River Restoration	Wed 9/21/16	Wed 11/16/16
3.0 Model Analysis	Thu 11/17/16	Fri 11/18/16
4.0 FLO 2D & HEC-RAS 2D Model Comparison	Mon 11/21/16	Wed 11/30/16
4.1 Cost Analysis	Mon 11/21/16	Tue 11/22/16
4.2 Recommended Solutions	Wed 11/23/16	Mon 11/28/16
4.3 Impacts	Tue 11/29/16	Fri 12/2/16
5.0 Project Management	Thu 9/1/16	Fri 12/16/16
5.1 Coordination	Thu 9/1/16	Fri 12/16/16
5.2 50 % Design Report	Tue 11/1/16	Tue 11/1/16
5.3 Final Presentation	Fri 12/16/16	Fri 12/16/16
5.4 Impacts Report	Fri 12/9/16	Fri 12/9/16
5.5 Final Report	Fri 12/16/16	Fri 12/16/16
5.6 Website	Fri 12/16/16	Fri 12/16/16

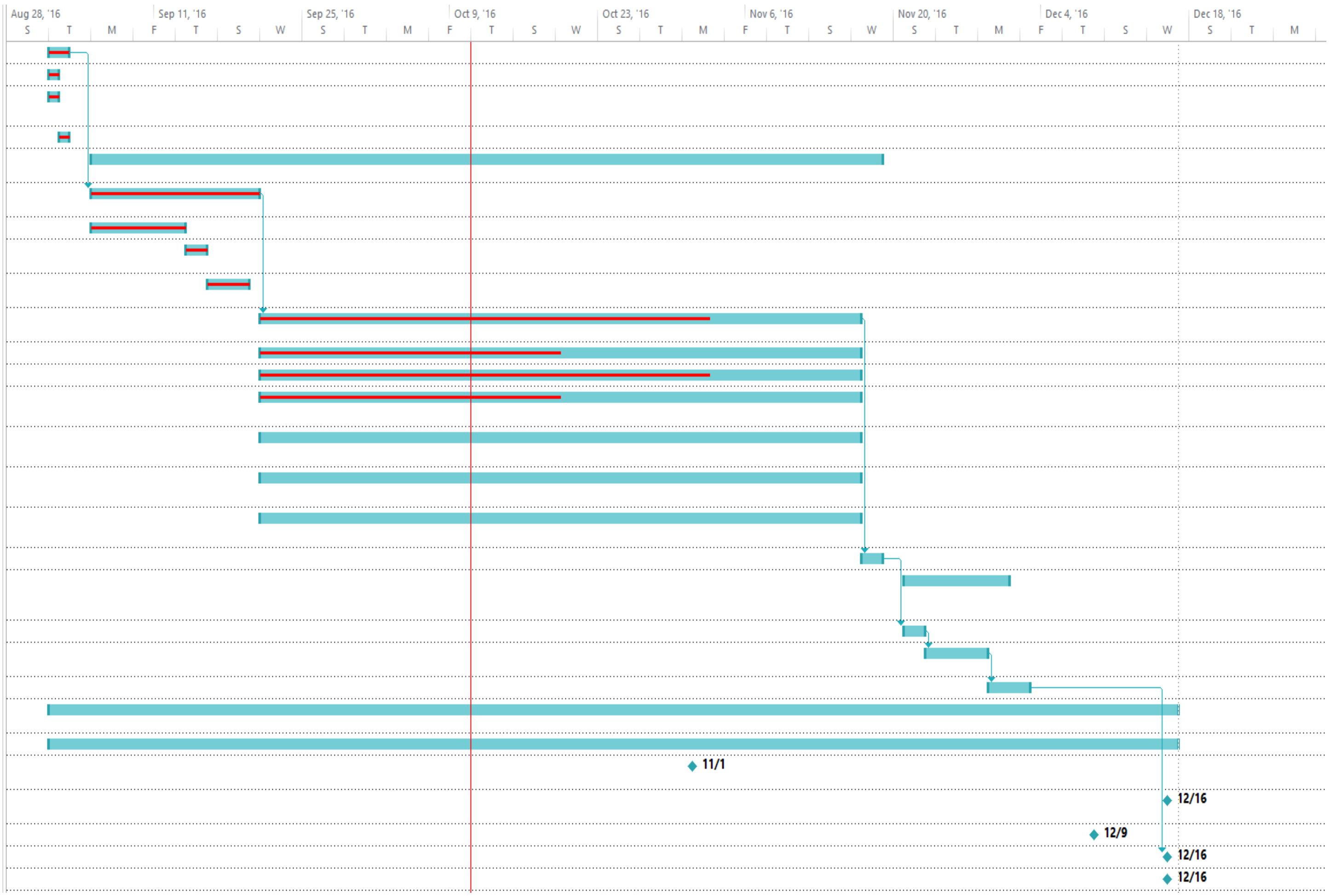

FIGURE 12: PROPOSED SCHEDULE.

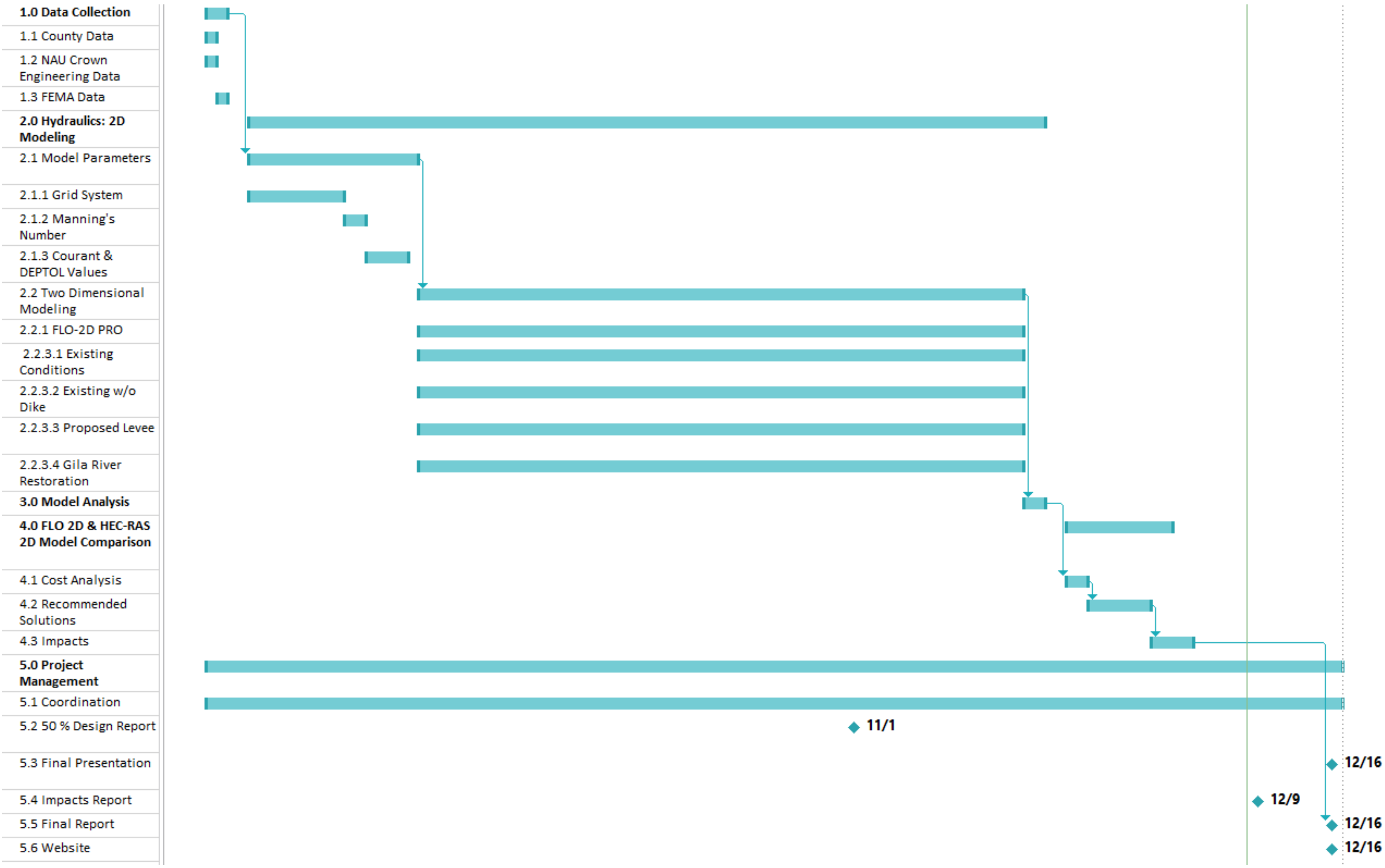

FIGURE 23: ACTUAL SCHEDULE.

References

[1] "Floodplain," Science Clarified, 2016. [Online]. Available: http://www.scienceclarified.com/landforms/Faults-to-Mountains/Floodplain.html. [Accessed 7 March 2016].

[2] Cubit, "Duncan Demographics," Arizona Demographics, 2016. [Online]. Available: http://www.arizona-demographics.com/duncan-demographics. [Accessed 2 March 2016].

[3] Canty Media, "Weatherbase," Canty Media, 2016. [Online]. Available: http://www.weatherbase.com/weather/weather-summary.php3?s=457220&cityname=Duncan%2C+Arizona%2C+United+States+of+America&units. [Accessed 12 Feburary 2016].

[4] T. A. H. B. N. Aldridge, "Floods of November 1978 to March 1979 in Arizona nad West-Central New Mexico," 1948. [Online]. Available: http://pubs.usgs.gov/wsp/2241/report.pdf. [Accessed 12 Feburary 2016].

[5] E. Polasko, "Water Lecture Series," 2007. [Online]. Available: http://aces.nmsu.edu/wls/documents/ed-polasko-part-b.pdf. [Accessed 12 Feburary 2016].

[6] Flo-2D Software, Inc., "Flo-2D Software," 2009. [Online]. Available: http://www.flo-2d.com/flo-2d-basic/. [Accessed 25 February 2016].

[7] NAU Crown Engineering, Floodplain Analysis and Conceptual Levee, Flagstaff, 2015.

[8] J. G. Arcement and V. Schneider, "Guide for Selecting Manning's Roughness Coefficients for Natural Channels and Flood Plains," USGS.

[9] National Weather Service, "Flood Related Hazards," National Oceanic and Atmospheric Administration, 2016. [Online]. Available: http://www.floodsafety.noaa.gov/hazards.shtml. [Accessed 12 Feburary 2016].

Appendix A – Model Results

Existing Conditions Results

Max Depth Range (ft)	
0 - 1	
0.5 - 1	
1 - 2.5	
2.5 - 5	
5 – 7.5	
7.5 - 10	
10 - 24	

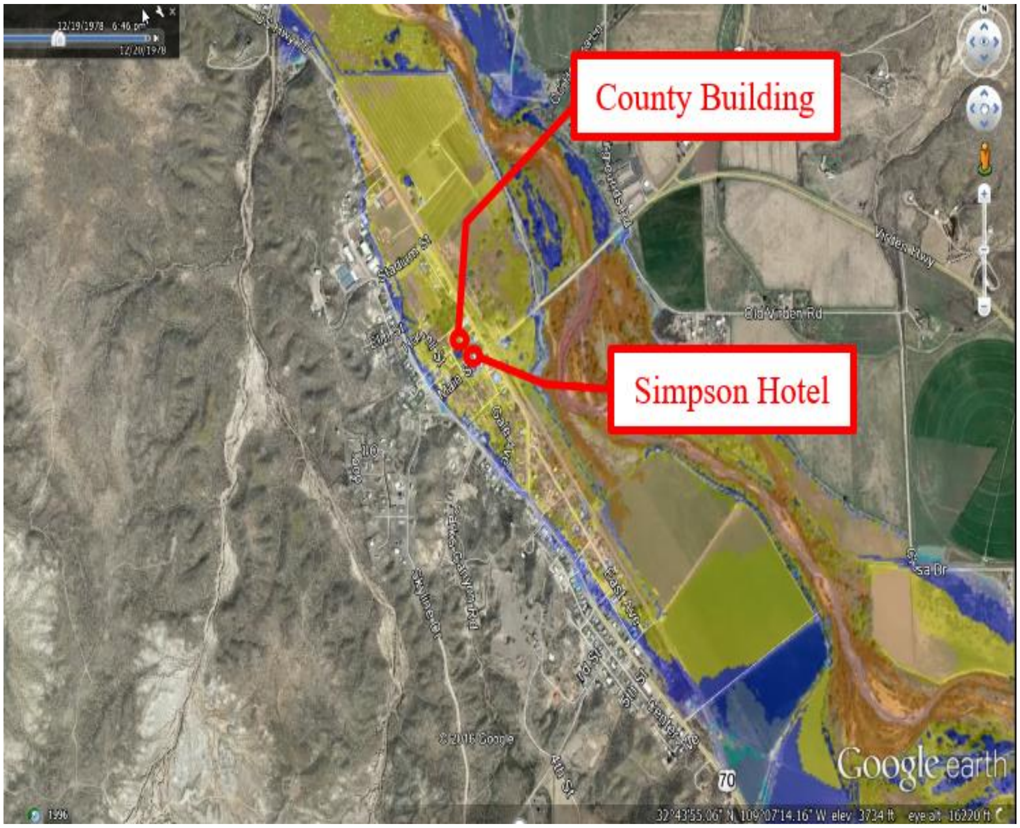

FIGURE 34: EXISTING CONDITIONS MAXIMUM DEPTH RESULTS.

Gila River Restoration

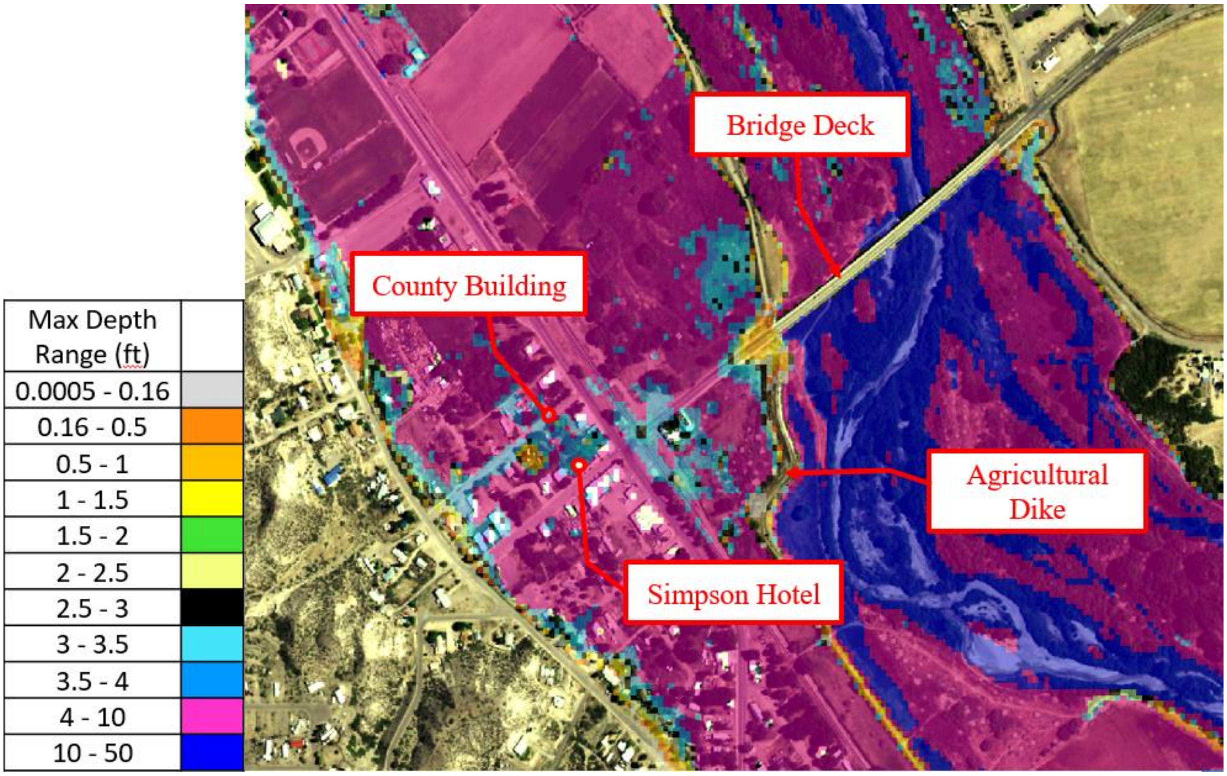

FIGURE 45: GILA RIVER RESTORATION MAXIMUM DEPTH RESULTS.

Proposed Levee

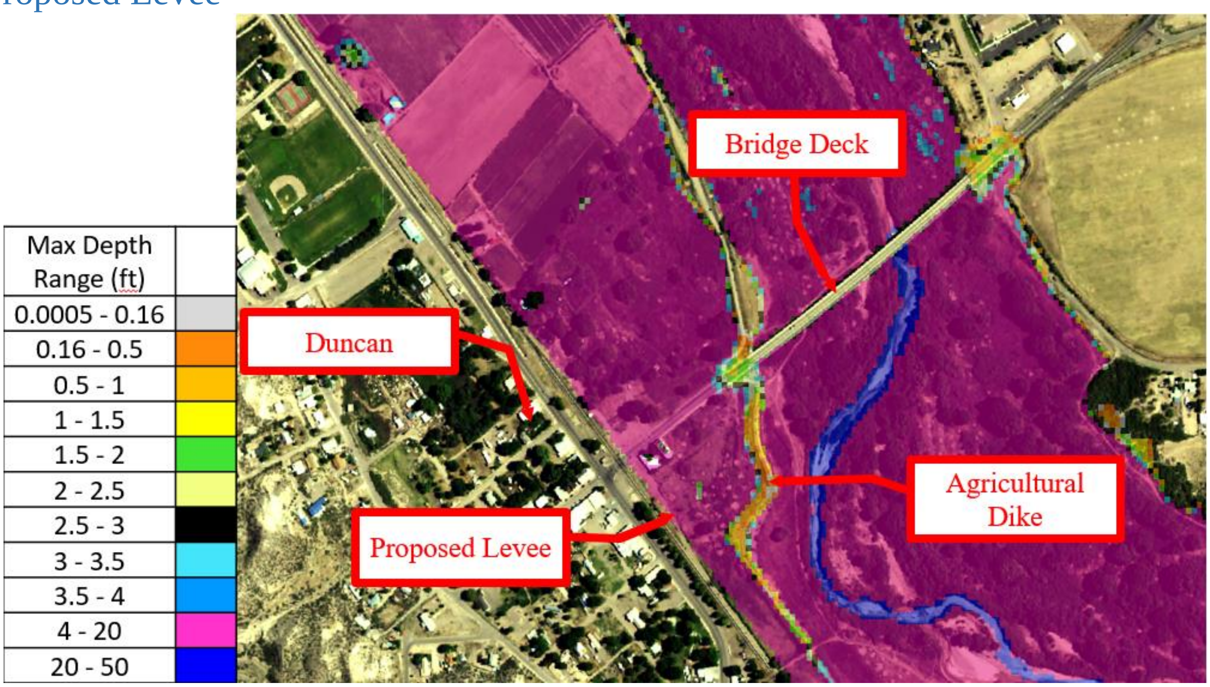

FIGURE 56: PROPOSED LEVEE MAXIMUM DEPTH RESULTS.

Gila River Restoration and Proposed Levee

FIGURE 67: GILA RIVER RESTORATION AND PROPOSED LEVEE MAXIMUM DEPTH RESULTS.

Appendix B – Site Visit

Survey Data

Table 4: Survey data from September 2016 site visit.

Station	+	HI	-	Elevation	Description
BM_Hotel	4.8	3651.7		3646.9	
	3.5			3655.2	Tom Highwater mark
	4.42			3656.12	Tyler Highwater mark
	4.5			3656.2	Phil Highwater mark
	2.42			3654.12	Nail Highwater mark
			2.33	3649.37	Lower water mark front door
			1.75	3649.95	Backdoor Low watermark
BM_County	3.85	3651.15		3647.3	County Bldg front door
			2.58	3648.57	SW Low
	2.42			3653.57	SW High
	5.67			3656.82	Sw peak
			2	3649.15	Mid Low
	2.83			3653.98	Mid High
	5.75			3656.9	Mid Peak
			2.33	3648.82	NW Low
	2.75			3653.9	NW High
	5.67			3656.82	NW Peak
			1.92	3649.23	SE Low
	2.75			3653.9	SE High
	5.67			3656.82	SE Peak