NORTHERN ARIZONA UNIVERSITY
College of Engineering, Forestry & Natural Sciences

Hydro Engineering

CENE 476 Capstone Prep
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Duncan Floodplain Analysis

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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.

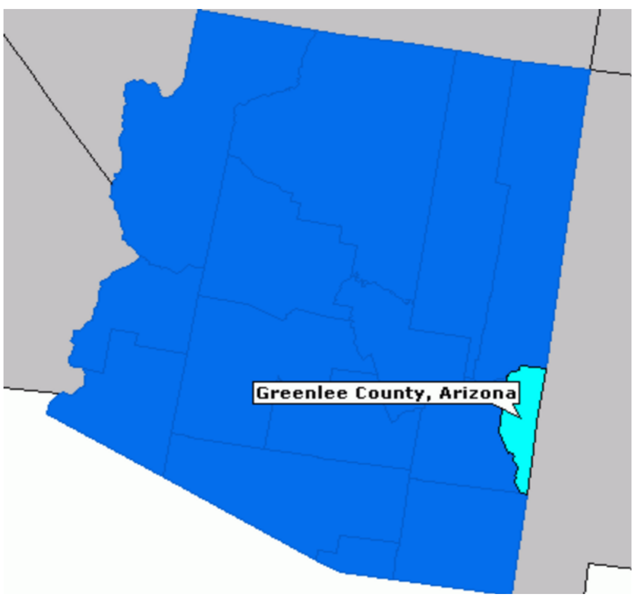

FIGURE 1. LOCATION OF GREENLEE COUNTY IN ARIZONA [14]

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.

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.

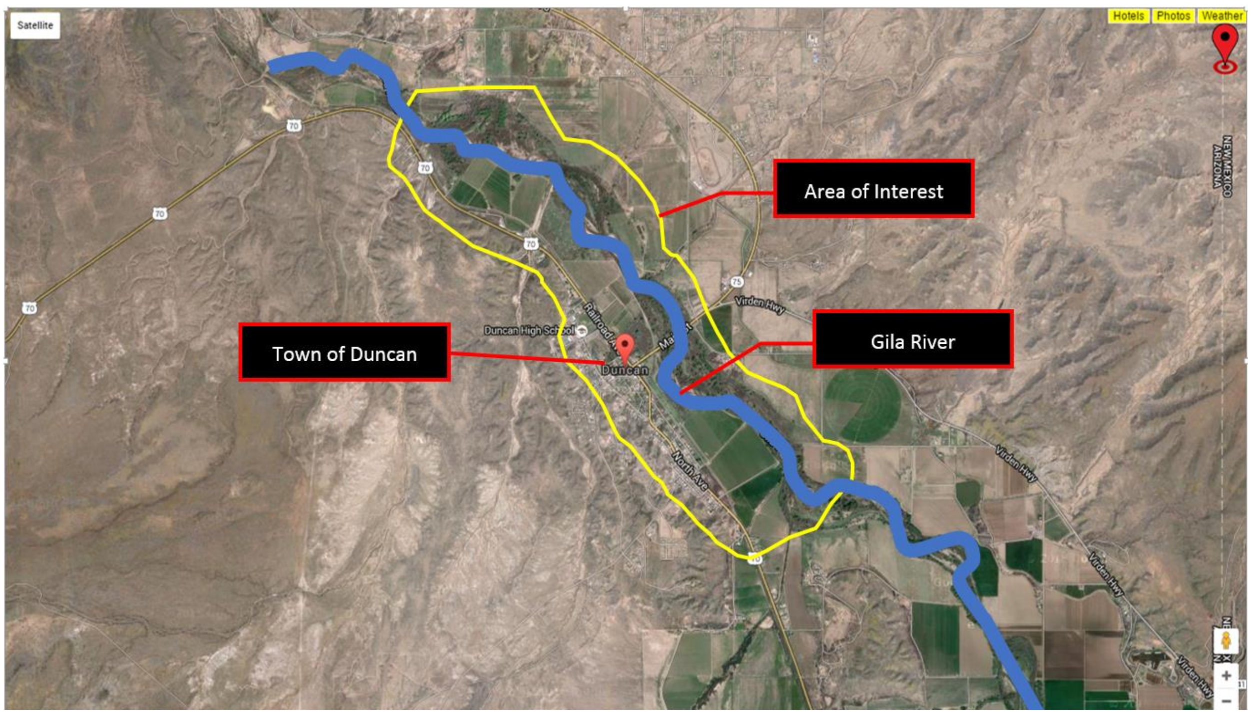

FIGURE 1-2. ARIEL VIEW OF TOWN OF DUNCAN, WITH AREA OF INTEREST [15].

1.3. Technical Considerations

Duncan, Arizona is susceptible to flooding of businesses, residences, and highway 70 from overflow in the Gila River. Flo-2D 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

The Flo-2D software is approved for FEMA studies. A main aspect that Flo-2D 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 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 though.

1.3.2.1. Flow Impacts

In order to provide an area for Flo-2D 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 model. The hydrologic data consists of rainfall and discharge hydrographs. The infrastructure that needs to be considered in a Flo-2D 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 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 model to analyze the floodplain and Gila River under various conditions.

1.4. Potential Challenges

This section discusses the challenges Hydro Engineering will face throughout this project. Hydro Engineering will also provide solutions to overcome listed problems to ensure a quality project is created. These challenges are pertinent and will influence steps taken in the process of this project.

1.4.1. Distance

The distance between Northern Arizona University and the site of interest is about a 5 hour drive in a vehicle. This distance poses a problem with communication, as there is no way to meet face to face on a regular basis. The technical advisor is located in Phoenix, Arizona. This challenge will be addressed by conducting constant communication through phone calls and email with everyone involved. This would ensure Hydro Engineering understands what the client is wanting, as well as the correct direction of the project. The site visits will need to be efficient due to cost and time constraints. Hydro Engineering will ensure all information is gathered during site visits by pre-task analyses, in-depth site research, and discussion with client and advisor prior to site visits.

1.4.2. Unfamiliarity

This potential challenge arises because Hydro Engineering has not used Flo-2D in any previous course, therefore will be completely new to the company. Although we have done background research on the program, as well as receiving input from our technical advisor, Hydro Engineering will need to become familiar with the program before we proceed. Hydro Engineering will become familiar with Flo-2D by obtaining further input from industry leaders, completing any necessary tutorials, and conducting further research.

1.4.3. Communication

As mentioned in previous sections, communication will be imperative with the client and the technical advisor. Due to the busy schedules of the client and technical advisor, Hydro Engineering will make every effort to contact the client and advisor in advance and set up appointments for conference calls, video-chat, and face-to-face meetings

1.5. 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. Scope of Services

Hydro Engineering will provide the following services for Duncan, Arizona after approval from Phillip Ronnerud.

Task 1.0 Data Collection

The study completed by NAU Crown Engineering using Civil 3D and HEC-RAS provides various data that will be used by Hydro Engineering, which consists of hydraulics and hydrology, surveying, and geotechnical analysis. Hydrologic data such as, largest precipitation event and river flow, is a main component of two dimensional modeling because it is necessary for determining the model parameters stated below. Hydrologic models provide the understanding of various catchment processes for rainfall, runoff, evaporation, and flow in rivers [1]. Hydro Engineering will also conduct further research to determine any necessary data needed not obtained from the previous study.

Task 1.1 County

The county of Greenlee provides the hydrologic data to run both the HEC-RAS and FLO 2D models. This includes the largest precipitation event provided by the client, the river flow at this precipitation event, and the process of rainfall, runoff, evaporation, and flow in the rivers, will not be determined, but will be provided by the county of Greenlee. Greenlee County will provide sufficient dimensions for the bridge that spans the Gila River in Duncan, AZ so Hydro Engineering can simulate this condition in FLO 2D and HEC-RAS 2D.

Task 1.2 NAU Crown Engineering

A working one-dimensional HEC-RAS model was completed by NAU crown engineering in a previous project. All parameter information that can be extracted from this model will be extracted and used as a starting point for both the FLO 2D and HEC-RAS 2D models. The survey data used to create the AutoCAD civil 3D model will be used to create any surfaces needed for this project. Geotechnical information was also collected by NAU Crown Engineering, and will be used as needed by Hydro Engineering.

Task 1.3 FEMA

Since this project will deal with comparing different environmental simulations, Hydro Engineering will use the FEMA data such as floodplain limits, cross sections, township, section, range, zones, etc. This will allow Hydro Engineering to re-create environmental models of client's wanted simulations.

Task 2.0 Hydraulics: 2D Modeling

Hydraulics studies movement of liquids in relation to disciplines such as fluid mechanics and fluid dynamics [2]. The hydraulic data of Gila River will be put into Flo-2D and RAS-2D in order to create a simulation run. The watershed being analyzed is approximately 3,800 square miles, which a 100-year storm will cover with 47,400 cfs [8].

Task 2.1 Model Parameters

Hydro Engineering will produce four models in Flo-2D and RAS-2D. These four models are existing conditions, existing without agricultural dike, proposed levee, and proposed Gila River restoration. All models consists of the same parameters: hydrology, hydraulics, grid system, manning's number, and courant and DEPTOL values.

Task 2.1.1 Grid System

A necessary component of the Flo-2D model is the grid system. Hydro Engineering will create the grids in Flo-2D using the grid developer system (GDS) [9]. Hydro Engineering will also determine infrastructure that can influence the grid elements. For example, bridges and culverts will need rating curves or tables and streets will need curb height and width. Levees are placed on boundaries of grid elements [9].

The grid sizes will be obtained based on the project area. Grid sizes will be at least twice the size of the largest depth of flow determined from the previous HEC-RAS model. If the ratio of peak discharge to area of grid elements is greater than 10 cfs, then the model will perform slower simulations than if the ratio was less than 10 cfs [9].

Hydro Engineering will determine the number of grid elements based on the project area and grid sizes. The number of grids will be kept under 100,000 to decrease the run time. If the run times are too long it can become impractical. With a maximum of 100,000 grid elements, the model will have a run time of no longer than an hour [9].

Hydro Engineering will use LiDAR data to determine the area details. With the LiDAR data Flo-2D can visualize the project area and topography. The model domain will also be determined with this data. Hydro Engineering will obtain average grid elevation for each grid element. This will allow the model to visualize the project area as various contours for the grid elements and change in slope along the river. Elevations can influence the velocity of flow by slowing it down or speeding it up. This can also help determine where the main flooding will occur.

Task 2.1.2 Manning's Number

The n-value can be influenced by vegetation, infrastructure, and variations in channel geometry. It is important not to underestimate the n-value because this will cause the resulting data to be too large [9]. For changes throughout the river, an n-value will be re-determined when necessary. This ultimately means different cross sections in the channel can have several different n-values. In order to find the correct n-value for given areas, a Manning's n for channels table will be used [10]. However, a default n-value of 0.06 and a shallow n-value of 0.20 will be used for the initial runs in Flo-2D and RAS-2D [11].

Task 2.1.3 Courant and DEPTOL Values

The determination of both the depth tolerance (DEPTOL) and courant number are significant to this project, due to the fact both control the magnitude of the time step of simulations Hydro Engineering will be running. The recommended and initial value for the courant number is 0.6, and can be modified to be from 0.0 to 1.0 with 1.0 being the largest time step FLO-2D can run in a simulation [9]. The DEPTOL will be set initially at 0.1 feet for this project, as recommended by the project technical advisor [11]. Any requests to decrease or increase the DEPTOL are excluded and will not be considered unless processed through a formal work order form.

Task 2.2 Two Dimensional Modeling

Hydro Engineering will provide engineering services for Greenlee country in the form for two different hydraulic engineering programs. The first program will be the Flo-2D software and the second will be the HEC-RAS 2D hydraulic modeling. Running both models will provide more data to the client and Hydro Engineering will be able to develop recommended solutions to flooding issues of Duncan, Arizona. The program will end at the railroad and the models will be run at the 10, 25, and 100 year flood events. For both Flo-2D and RAS-2D a two dimensional bridge will be created, since this will affect the simulations in each modeling software.

Task 2.2.1 Flo-2D

Since FLO-2D is a volume conservation flood routing program, Hydro Engineering will control the variables listed in this scope of services under model parameters. This will allow Hydro Engineering to develop an accurate cost benefit ratio to all proposed changes to the channel of interest and provide Greenlee County with a suggested direction to mitigate the flooding issues. Arc-GIS will be used to establish a surface for Flo-2D to analyze. The established grid system will be imported into Flo-2D.

Task 2.2.2 RAS-2D

Hydro Engineering will also provide 100 year flooding events simulations for the area of interest in the HEC-RAS 2D software. As with the Flo-2D software Hydro Engineering will control all variables listed in this scope of services. Arc-GIS will also be used to develop a surface in order to create polygons in RAS-2D. Polygons will contain varied n-values and courant and DEPTOL values in each polygon. In addition to this, Hydro Engineering will develop an integrated one and two dimensional model using the data from a previous project. Running all these simulations will ultimately provide Greenlee County with the data to provide direction to combat the flooding situation at Duncan, Arizona.

Task 2.2.3 Model Conditions

Hydro Engineering will produce four models in Flo-2D and RAS-2D. The four models consist of: existing conditions, existing without agricultural dike, proposed levee, and proposed Gila River restoration. The models will be created in Flo-2D and RAS-2D to compare results from each model in each software. This will also allow Hydro Engineering to compare the methods from each software and determine which software is more suitable for Duncan’s flooding scenario. The models will be analyzed due to a 10, 25, and 100-year storm event.

Task 2.2.3.1 Existing Conditions

As of now, the Gila River has an agricultural dike that protects Duncan, AZ from small flooding. The agricultural dike is a mound of soil that was put in place to mitigate flooding. However, during the flood of 1978 and 2005, the dike could not contain the demand from each storm event. Although an existing design will not change Duncan’s flooding issues, Hydro Engineering will create a 2D model that will help develop a better understanding for Duncan’s current situation and when comparing other simulations ran.

Task 2.2.3.2 Existing Without Agricultural Dike

FEMA does not recognize the agricultural dike when running model simulations. Therefore, Hydro Engineering will create a model without the agricultural dike to match a FEMA analysis for the floodplain in Duncan. This design is not an alternative, but used as a comparison model.

Task 2.2.3.3 Proposed Levee

One alternative is to replace the agricultural dike with a levee system remove Duncan from a 100-year storm. The FEMA flood zone identification number for the area of interest is 04011C0901D [12]. Hydro engineering will determine the height and location of a levee based on the flows from a 100 year storm event and area of interest. After the levee height and length are determined, break-lines will be input into Flo-2D and RAS-2D in order to establish where the proposed levee will exist. A two dimensional model of the proposed levee alternative will be created to analyze the outcome against the price to implement a levee and compare with the other conditions.

Task 2.2.3.4 Proposed Gila River Restoration

Another alternative for Duncan is to establish thriving vegetation along the river and improve channel morphology. The existing vegetation is overgrown and is not allowing infiltration, which allows flooding to occur more often. The existing vegetation in surrounding farm fields will be replaced with vegetation. The vegetation will assist with infiltration and in return assist with flood prevention. Along with vegetation replacement, Hydro Engineering will also restore the Gila River by returning it to more natural conditions. Returning the river to more natural conditions will allow the river to have a greater capacity. Areas of the Gila River that have not been impacted will be analyzed in order to determine the river's response to storm events and to determine if the original form of the river would assist with flood prevention.

Task 3.0 Model Analysis

Hydro Engineering will evaluate information of generated computer model to fulfill client's request. Hydro Engineering will apply knowledge gained through NAU coursework, as well as the professional input to determine significance of retrieved data and simulations. After running simulations with existing conditions, existing without a levee, proposed levee, and proposed vegetation, Hydro Engineering will analyze each model in order to determine where the flooding is or is not occurring. During the analysis Hydro Engineering will also determine why the flooding is occurring. The findings and data will be reported to all necessary sources for input and feedback.

Task 4.0 Flo-2D and RAS-2D Model Comparison

The four different models stated above produced in Flo-2D and RAS-2D will be compared. Hydro Engineering will recommend the most appropriate solution considering environmental impacts and cost analysis.

Task 4.1 Cost Analysis

The suggested recommended solutions will be analyzed with the cost associated with the implementation of each solution. The estimated cost of each solution will be determined and analyzed. For the proposed levee alternative the cost for soil per cubic foot and construction will be determined. For the proposed Gila River restoration alternative Hydro Engineering will determine the cost for channel reconfiguration, vegetation removal, and planting native vegetation.

Task 4.2 Recommended Solutions

After getting approval from the client, Hydro Engineering will develop possible solutions to mitigate the impact of river flooding in the area of interest. Hydro Engineering will determine the best proposed solution based upon the client's criteria, impacts, and cost analysis. Client's criteria has yet to be determined, and will commence once a face to face meeting has taken place.

Task 4.3 Impacts

As a responsibility of a practicing engineer, the Hydro Engineering design team will determine appropriate regulatory, environmental, and economic impacts of each computer model. The findings will then be presented in the final report and final presentation as to comprehensively analyze each solution. This will convey a broader impact this project will possibly have if a chosen solution is implemented.

Task 5.0 Project Management

Project Management will be required to ensure clients requests are made at the times set by the client. Hydro Engineering has estimated the milestones' due sate on Table 1. These are taken from the NAU academic calendar for the semester of Fall 2016.

Task 5.1 Coordination

Hydro Engineering will remain in constant contact with both the client and technical advisor. Due to the distance between the parties involved, meeting alternatives will be considered, such as, but not limited to: video conferencing, teleconferencing, and emailing regularly. Communication is a priority of Hydro engineering, and all messages will be replied to promptly. Hydro Engineering will abide by the Schedule in Appendix A. This will ensure the project is completed in a timely manner. The budget for staffing and engineering services will also be followed throughout completion of this project.

Task 5.2 50% Design Report

Hydro Engineering will develop a 50% design report at midterms of the Fall 2016 semester. This Report is to ensure the client Hydro engineering is meeting all requests of the client and that Hydro Engineering will complete all scoped work in a timely fashion.

Task 5.3 Impacts Report

Hydro engineering will provide a report of the impacts from the recommended solution in order to compare each recommended solution.

Task 5.4 Final Presentation

Hydro Engineering will provide a presentation for all pertinent parties on reading week of the Fall 2016 semester. The presentation will provide highlights of the project, including but not limited to: methodology, simulations, comparisons, conclusions, and recommendations.

Task 5.5 Final Report

Hydro Engineering will complete a Final Report detailing all findings about the projects. These findings will include the working models of all scenarios proposed in this scope of services. The final report is the culmination of all work completed by Hydro Engineering and will be of a professional standard.

Task 5.6 Website

The website will be running by September 1, 2016 and will be updated frequently throughout the duration of the project until completion on December 16, 2016.

Deliverables	Deliverable Date
50% Design Report	November 1, 2016
Formal Presentation	December 8, 2016
Project Website	December 16, 2016
Final Report	December 16, 2016

TABLE 1 DELIVERABLES AND DUE DATES

2.1. Exclusions

The following is being excluded from the scope of work:

- Surveying
- Geotechnical Analysis
- Levee width, slope, and soil type
- New One Dimensional Model
- Hydrological Data Collection
- Future Development Analysis
- Invasive Species Management

3. Schedule

3.1. Gantt Chart

The following Gantt chart provides estimated dates of completion for all major and minor parts of Hydro Engineering's Duncan Floodplain project. Within the chart, there are many task that overlap and occur during the same time frame. This overlapping has to do with the several minor parts for a single major aspect. For example, the two dimensional model will undergo work while hydrology and hydraulics will be inputted into the software. Another component of the chart shown is the ending of a section before starting of the next. This occurs when a section cannot be starting till the completion of the prior component. For example, the analysis of all possible solutions cannot be compared until each are ran in the 2D software. The arrows connecting tasks is the critical path; the most efficient and fastest way to complete the project.

4. Staffing and Cost of Engineering Services

4.1. Staff Titles/Positions

The staffing required and duties for the completion of engineering services is located in Table 2 below.

TABLE 2: TYPICAL DUTIES FOR EACH POSITION

Position	Duties
Senior Engineer (SENG)	The senior engineer is resposible for overseeing each task. The senior engineer will also schedule meetings and be the main point of contact to the client. Assistance with two dimensional modeling will also be performed.
Engineer (ENG)	The engineer will be responsible for establishing the grid system along with determing the manning's number and courant and DEPTOL values as they vary throughout the floodplain.
Intern (INT)	The intern will be responsible for collecting the necessary data, under the direction of the senior engineer, to begin two dimensional modeling. The intern will also be learning basic components for two dimensional modeling and report writing.

4.2. Task Matrix

TABLE 3: STAFFING TASKS AND HOURS

Task	SENG	ENG	INT	Total
1.0 Data Collection				
1.1 County	0.5		1	1.5
1.2 NAU Crown Engineering	0.5		1	1.5
1.3 FEMA	0.5		1	1.5
2.0 Hydraulics				
2.1 Model Parameters	0.5		1	1.5
2.1.1 Grid System	5	23	12	40
2.1.2 Manning's Number	3	10	10	23
2.1.3 Courant and DEPTOL	0.5	3	2	5.5
2.2 Two Dimensional Modeling				
2.2.1 Flo-2D	25	62	50	137
2.2.2 RAS-2D	25	62	50	137
2.2.3 Model Conditions	0.5	0	2	2.5
3.0 Model Analysis	8	4	4	16
4.0 Model Comparisons				
4.1 Cost Analysis	2	10	10	22
4.2 Recommended Solutions	5	10	5	20
4.3 Impacts	3	8	6	17
5.0 Project Management				
5.1 Coordinations	32	32	32	96
5.2 50% Design Report	5	10	15	30
5.3 Impacts Report	3	10	15	28
5.4 Final Presentation	1	1	3	5
5.5 Final Report	5	10	15	30
5.6 Website	1	2	5	8
Total	126	257	240	**623**

TABLE 4: TOTAL STAFFING COST [13]

Classification	Billing Rate ($/hr)	Hours	Total Cost
SENG	131.03	126	16,509.78
ENG	80.46	257	20,678.22
INT	36.62	240	57,600.00
Total Staffing			**$94,788.00**
Travel (2 Meetings)			
700 miles/meeting	$0.54/mile	1400 miles	756.00
Rental Car	$40/day	4 days	160.00
Hotel	$50/night/room	4 rooms	200.00
Per Diem	$10/meal/person	16 meals	160.00
Total Travel			1,276.00
Project Total			**$96,064.00**

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Appendix A: Schedule