Duncan, Arizona

Floodplain Analysis and Levee Alignment along the Gila River (*50% Completion*)

Delivered By
Northern Arizona University Undergraduate Engineering Students

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Table of Contents

List of Figures

List of Tables

Acknowledgments

The Duncan, Arizona Floodplain Analysis and Levee Alignment along the Gila River project is part of Northern Arizona University's Senior Capstone Project for civil and environmental engineering. The project was made possible through the faculty of NAU and the project's client Philip Ronnerud, P.E.

Mr. Ronnerud serves as the Greenlee County Engineer, and is a former graduate of NAU. Mr. Ronnerud oversees engineering projects of Duncan, Arizona, and has provided NAU with this capstone project. NAU Crown Engineering has enjoyed working with Mr. Ronnerud and thanks him for his active involvement with the development of this project.

NAU Crown Engineering would also like to acknowledge the following people for their invaluable support in the production of this project.

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1 Project Description

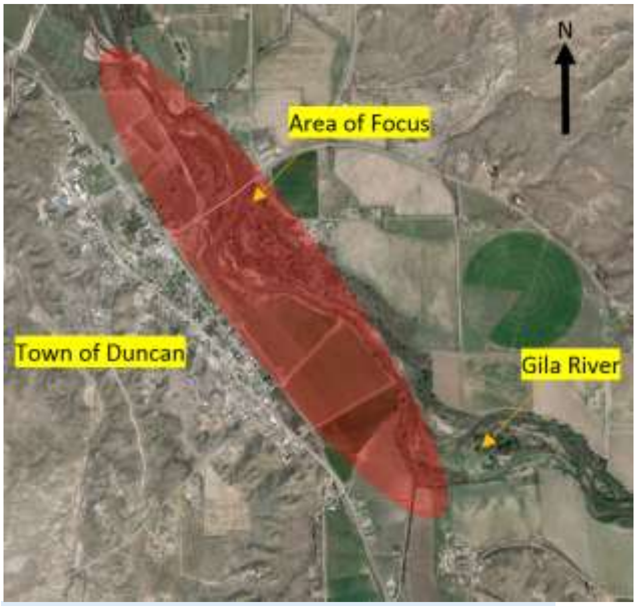

Figure 1-Gila River reach of focus

This floodplain analysis and levee alignment project is formed in partnership with Philip Ronnerud, P.E. who is the Greenlee County Engineer. Mr. Ronnerud provided NAU Crown Engineering with the project. Based on the request of Mr. Ronnerud, NAU Crown Engineering performed a floodplain analysis of a 1.5 mile reach of the Gila River in Duncan, Arizona. The area of focus is provided in Figure 1.1. The project's objective is to provide insight to Duncan's current risk of flooding based on updated topography and new 100 year flow conditions. This project will also focus on proposing a levee alignment and height specification capable of protecting the Town of Duncan from flood events. Using Autodesk Civil 3D and HEC-RAS engineering software, three models will be produced to achieve the aforementioned objectives:

- ***Effective Model-*** *Replication model of original floodplain evaluation that was performed in the area. In the case of Duncan, The Federal Emergency Management Agency (FEMA), produced a series of floodplain studies that began in 1974 and were completed in 2007* [1]. *The results of the test are provided in the Flood Insurance Rate Map (FIRM) in Appendix A. Ultimately, the production of the effective model is to ensure that the initial floodplain study was correct and reproducible. The goal is to move beyond this model and create a modern version that is more reflective of new hydraulic/topographical conditions.*
- ***Corrective Effective Model-*** *Using recent (2012) Lidar data of the area, an improved model of the study reach was developed. This model is to reflect how the Gila River currently behaves as opposed to the outdated effective model.*
- ***Proposed Conditions Model-*** *Based on information provided from the Corrective Effective Model, a new hydraulic model will be developed with the addition of a levee alignment. The goal of this model is to show the impact within the floodplain by assuming a levee placement with a specified height.*

The application of these models provide the Town of Duncan with new insight on the neighboring floodplain and exhibit how a levee placement could protect the town from damaging floodwaters. It is important to note that no other components of the proposed levee will be designed. Based on the information provided from this report, it is recommended that a future levee design that fits the prescribed alignment and height be completed. While various solutions are available to mediate the floodplain, this project will act as a vessel for potential implementation of a levee or perhaps create interest in the needed resolution of Duncan's flooding hazard.

1.1 Project Schedule

A proposal of the project was submitted in May of 2015. Upon acceptance, the project initiated on September 21st, 2015 and will last until December 16th, 2015, in accordance with Northern Arizona University's academic calendar. The tasks of the project and their respective deadlines are available in Figure 2 below. The amount of time delivered to each task is available in Appendix B.

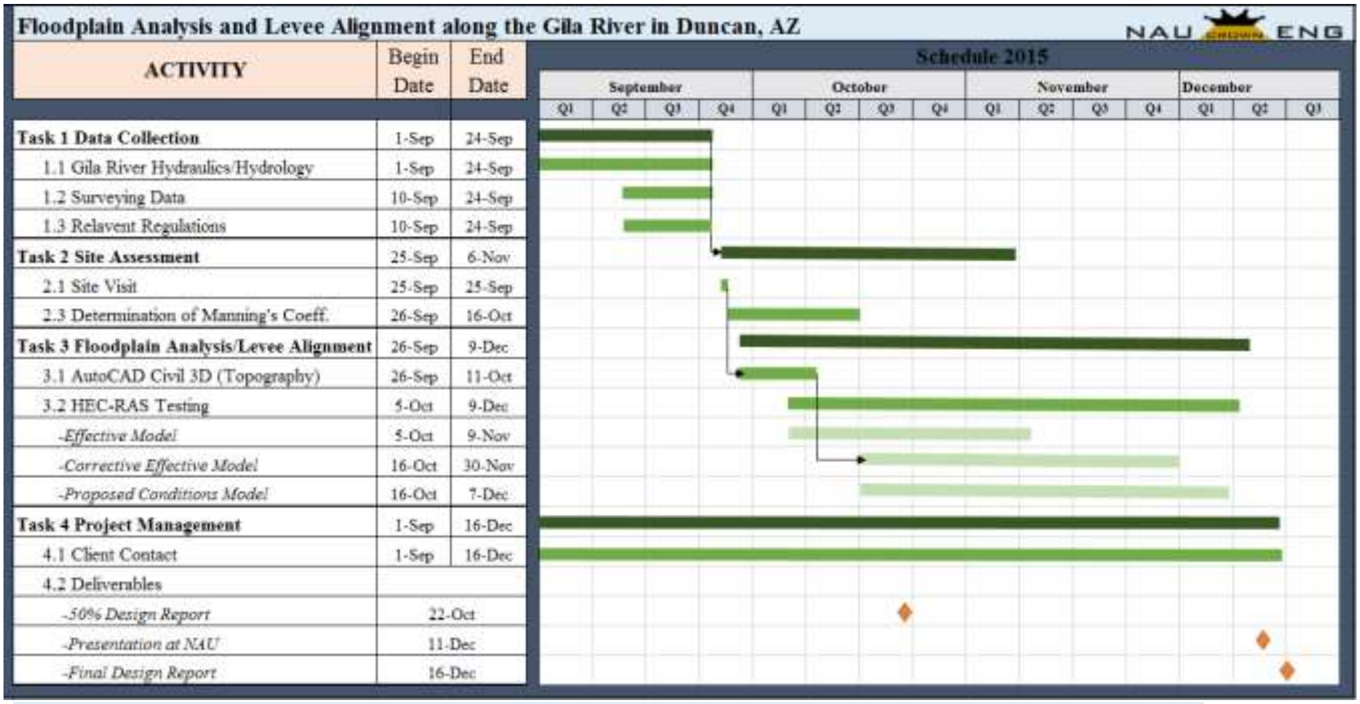

Figure 2-Project Gantt Chart

2 Project Background

Duncan, Arizona is an agricultural-based town of approximately 800 residents, most of whom live along the Gila River [2]. The town is situated in southeast Arizona, near the New Mexico border, and is part of Greenlee County (*refer to Figure 3 for location*). The community erected in the 1870's as a result of the mining industry in the nearby towns of Clifton and Morenci. Instantly, Duncan became noticed by farmers and ranchers for its naturally irrigated lands along the Gila River [2]. Unfortunately, early Duncan residents developed within the Gila River floodplain leading the town to experience numerous flooding disasters throughout its history.

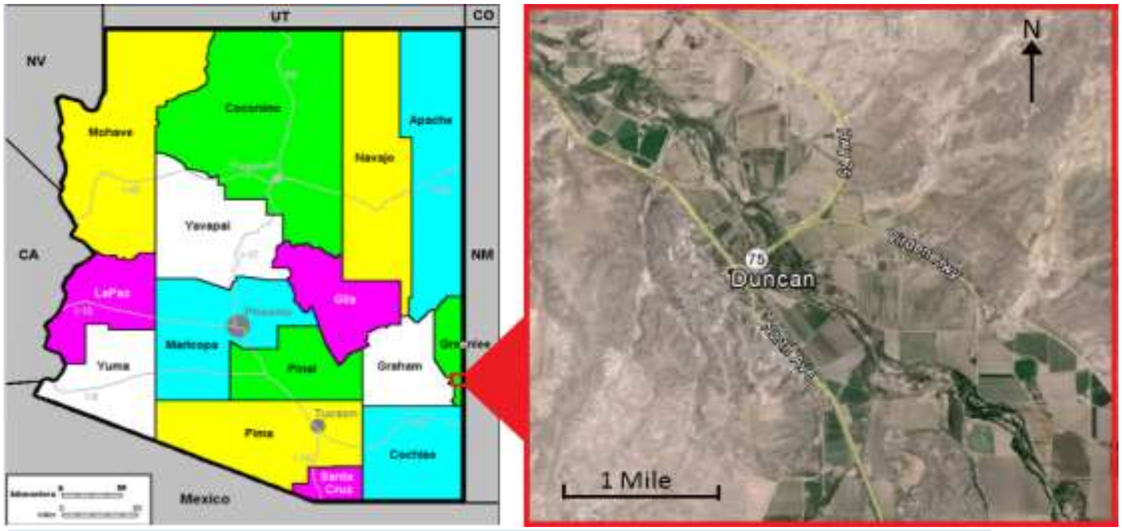

Figure 3-Project Location [11], [10]

With the Gila River flowing on average of 200-400 cfs [3], the river is nearly always contained. For small-scale flooding events, less than 10 years, an agricultural dike serves to protect Duncan along the focused river reach. Under larger flood events, the dike lacks sufficient engineering and has been breached multiple times. The worst flood on record occurred in December of 1978 when the Gila River reached a flow of nearly 60,000 cfs [4]. The flood severely damaged local infrastructure and brought siltation and erosion damage to the agricultural properties. Damage was estimated to a total of 9 million dollars (adjusted to the 2015 dollar) [5]. Figures 1.4 and 1.5 depict the conditions of Duncan during a flood.

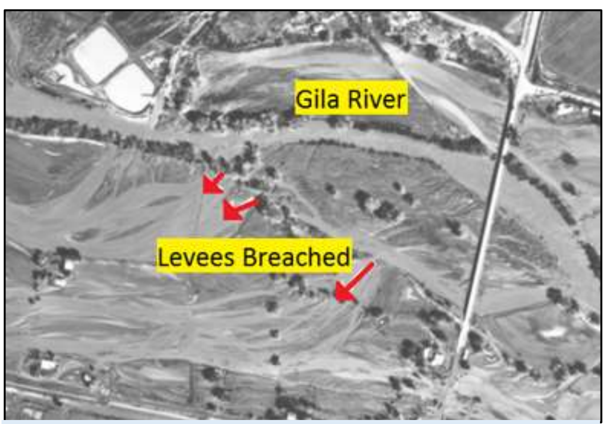

Figure 4-Aeiral photo of the 1978 Duncan flood [4]

Figure 5 –Duncan flood in 2005 [4]

To prevent flooding disasters, FEMA recommends levees be designed for at least 100 year flooding conditions. The 100 year flood for Duncan has recently been change from 28,500 cfs to 47,400 cfs based on a Letter of Map Revision for the upstream Town of Virden. This flood event poses a problem since Duncan's agricultural dike is estimated to receive considerable damage beyond 7,000 cfs and potential failure at 20,000 cfs [3]. As stated in FEMA's Flood Insurance Study of Duncan, "the levees have no effect on 100 and 500-year floods" [1] . Since the levee is considered inadequate for large 100 year floods, FEMA does not recognize it when developing Flood Insurance Rate Maps (FIRM). As a result, much of the town is considered in high risk of flooding under base flood (100 year) conditions *(refer to Appendix A for FIRM).* To protect Duncan from future flooding disasters, awareness of the hazard needs to be made, along with a with an upgraded levee system to conform to larger flooding conditions.

2.1 Stakeholders

While this specific project will consist of no physical design to be implemented, it involves multiple stakeholders who have influence or are impacted by the floodplain near Duncan. In the possible implementation of a levee design, these stakeholders will require considerable attention:

***Table 1**-Stakeholders of Project*

Stakeholder	Role
USACE	Since the Army Corps of Engineers is in charge of all navigable waterways in the United States, they will have the final decision in whether or not the construction of a new levee will be allowed.
Greenlee County Government	The Greenlee County government will need to find the resources to fund the design and construction of a new levee. The county's engineer will also need to be involved in the permitting process for constructing and certifying the levee.
Property Owners in the Floodplain	The property owners who live in the floodplain will benefit from the construction of a certified, accredited levee. These people will no longer need to pay for flood protection because FEMA will redraw the floodplain map with consideration of the levee's protection.
Agriculture	The people in Duncan who have an agriculture-based business will not need to worry about a flood wiping out their livelihood.
FEMA	After the levee has been certified by a qualified practicing engineer, FEMA will be in charge of the accreditation of the levee and reassessing the floodplain.
Environmentalists	The presence of threatened and endangered species in this area makes it necessary for certain acts, such as the Endangered Species Act, to be followed during the construction of the levee.

2.2 Site Assessment

On September 25th, 2015, NAU Crown Engineering traveled to Duncan, AZ for a field visit to accomplish a number of tasks. First, the group clarified the scope of services on this project. The previous scope had included flow analysis of the Gila River through Duncan, determination of all levee dimensions, and geo-structural design of a levee for this area. The client, Phil Ronnerud, along with the NAU Crown Engineering team members and advisors (Mark Lamer and Thomas Loomis) decided that the levee design project should be split into three capstone projects. The scope of NAU Crown Engineering's work was then narrowed to creating various well-detailed Gila River flow analysis models in HEC-RAS. These models will be used in future capstone projects as a base for the other aspects of levee design.

While in Duncan, the team was also able to view the agricultural dike that is currently in place, and see some of the damage caused by past floods. After seeing the town, it is very obvious how an overtopped dike would cause such extensive damage. While the dike is able to protect Duncan from the majority of the flood events, a new levee will greatly benefit the town.

The first section of the dike that NAU Crown Engineering visited is shown in Figure 6. The dike runs next to, and then ties in to the railroad tracks that go through town. The left side of the picture shows the railroad tracks, and the right side shows the dike that is currently protecting Duncan. At this particular location, the group was able to see how the neighborhood behind the railroad tracks still experiences flooding. This means that the dike is not long enough. The levee that will be designed will need to tie in farther upstream.

Figure 6*-Section of Agricultural Dike*

Figure 7-*Highway 75 Bridge*

Figure 8-*Gila River*

The second location that the group was able to view was the intersection of the dike and the bridge. As shown in Figure 7, this area of the floodplain is covered heavily in vegetation. The three main types of vegetation in this reach of the Gila River floodplain are: willow, cottonwood trees, and tamarisk. The client led the way to the Gila River bed, and the group was able to see the river flowing at approximately 400cfs. This flow looked like a trickle through the area of undisturbed floodplain. The client estimated that the floodplain for the Gila River along this stretch is about 1,300 feet wide. Figure 8 shows the Gila River as it was flowing on September 25th, 2015. This 400cfs flow can be compared to the 48,000cfs flow will be used as the 100 year flood. Imagining a flow rate 120 times greater than what is shown in Figure 8 flowing through the confines of the dike, it is easy to understand how the current dike fails after large storm events. It is also easy to see how these failures cause severe damage to the town.

After the bridge, the group visited the old wastewater treatment plant. Figure 9 shows the surrounding area. Although the river was barely visible at this location, Mr. Ronnerud explained that this area becomes completely submerged in large flood events. This submersion causes potential contamination issues in the Gila River. Putting an end to this contamination output will help towns downstream of this wastewater plant to have cleaner, safer water.

***Figure 9**-Wastewater Treatment Plant*

The last location that the team visited on this site assessment was the other end of the dike. This side of the dike also ties into the railroad tracks. Figure 10 illustrates this tie-in location. This area is flat, and flood water occasionally comes over the dike and floods the road near the town's high school.

At each of the four locations mentioned, and throughout the day, the group took a number of pictures. These pictures can be used to remember and explain details about the trip. These photos are currently being used to help determine Manning's n values. They are also being used to help check that lines drawn to highlight the railroad tracks and current dike, line up correctly with the topographic map in Civil3D.

Figure 10-Downstream Tie in Location

3.0 Technical Information

3.1 Data Collection

Prior to creating the effective, corrective effective, and proposed conditions models of the Gila River reach, technical information was required to assist in the methodology and generation of the models produced in Civil 3D and HEC-RAS. The following subsections present the obtained data that was implemented.

Hydraulics and Hydrology

The Gila River at Duncan is subject to a watershed area of approximately 3,800 square miles. According to a 2015 hydrology and geomorphology study, Apache Grove, which is 10 miles downstream of Duncan is estimated to receive a 100 year flow of 47,400 cfs [6]. Mr. Ronnerud, the client, requests that a 100 year flow of 48,000 cfs be applied to the hydrologic models to be produced [4].

Surveying Data

NAU Crown Engineering was not required to conduct any surveying work this project. Survey information of Duncan was provided by the client in the form of LiDAR data. The provided LiDAR points feature 164 sq. miles of the Gila River floodplain and were collected over the period of three days, through 137 flight lines by the Riegl LMS Q560. The Lidar study was conducted by Utah State University and further processed by Kimley-Horn and Associates, Incorporated. This information was essential in establishing elevation points to the study reach and its respective cross sections.

Regulations to Follow

It is important for government agencies, including FEMA, to ensure the safety of citizens and their area by making them aware of the risk that is associated with living behind a levee. To reduce this risk, it is necessary to have proper regulatory framework for designing and constructing levees. Before constructing a levee, the design must be certified by a professional engineer or a federal agency that designs levees. For the scope of this project, The *Code of Federal Regulations Section 65.10* and the *Study Guidelines and Specifications for Study Contractors* were used to provide guidance in the floodplain analysis and levee height and alignment of this project [7], [8].

3.2 Analysis of Gila River Reach

The analysis of the project relies on the use of Civil 3D and HEC-RAS. The methodology used and the results from each software are discussed in the following subsections.

3.2.1 Civil 3D

The application of Civil 3D for this project is to determine the topographical conditions along the investigated reach. This information is crucial for the effective corrective and proposed conditions models. The software was used as a means to define the river reach and its respective cross sections that feature elevation values. Contours of the LiDAR points were initially imported to ARC-GIS and exported to Civil 3D. From there, a surface was created over the existing contours. Furthermore, an alignment and a sample line were created for the river to determine the polyline for

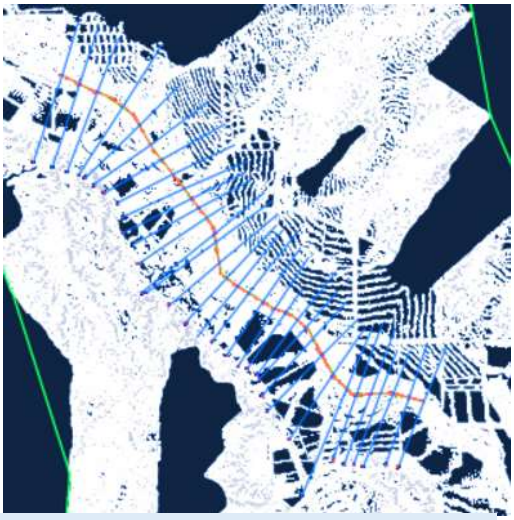

Figure 11-Civil 3D Model

each cross section. Figure 11 represents the model at this point, from which the data was finally exported to HEC-RAS for analysis.

3.2.2 HEC-RAS Modeling

The HEC-RAS software serves as a tool to simulate flooding conditions and measure the hydraulic impact that a flow has at each assigned cross section. It is ultimately from HEC-RAS software that NAU Crown Engineering will perform the floodplain analysis and the suitable levee alignment.

Effective Model

The purpose of the effective model is to replicate the existing model that FEMA created for its 2007 Flood Insurance Study of Duncan [1]. In order to perform this model, the original HEC-RAS model or HEC-2 input files are required, along with the exact cross sections that were initially tested (Refer to Appendix C).

Content in progress

- ***Determining whether a FEMA model is readily available. Currently, the HEC-2 output files are in custody, as well as a BLR geomorphic HEC-RAS file from 2002.***

Corrective Effective Model

This model is an updated version from the Effective Model that features updated LIDAR data from 2012. This model is more representative of current conditions of the Gila River. Furthermore, this model will be tested using a recently calculated 100 year flow rate of 48,000 cfs. To maintain continuity, the same cross sections of the effective model are featured in this model, as well as new ones to create a more accurate simulation. The results of this model will serve to educate the citizens of Duncan on where the 100 year floodplain is and whether their property is in danger.

All the geometry data and cross sections for this model were imported to HEC-RAS from Civil 3D. In total 33 cross sections were drawn over a reach extending 3 miles. A plan view of the model is available in Figure 12. An example of a cross section is provided in Figure 13.

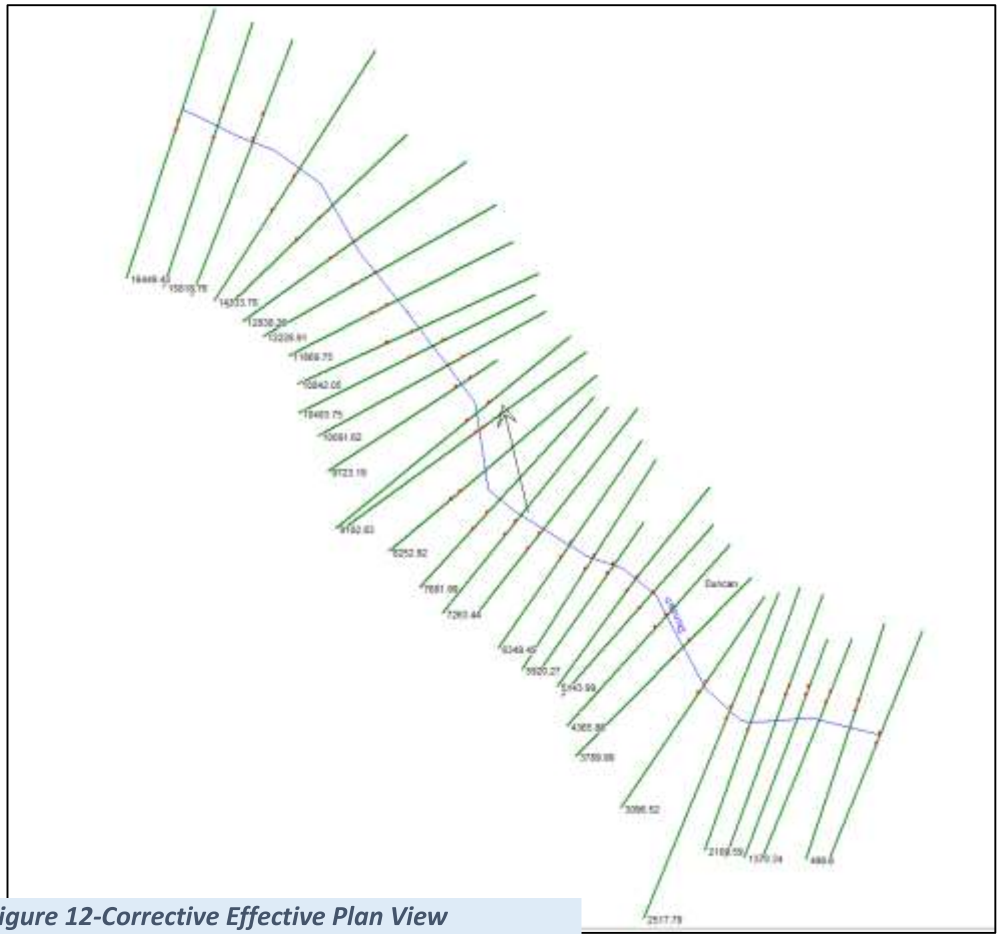

Figure 12-Corrective Effective Plan View

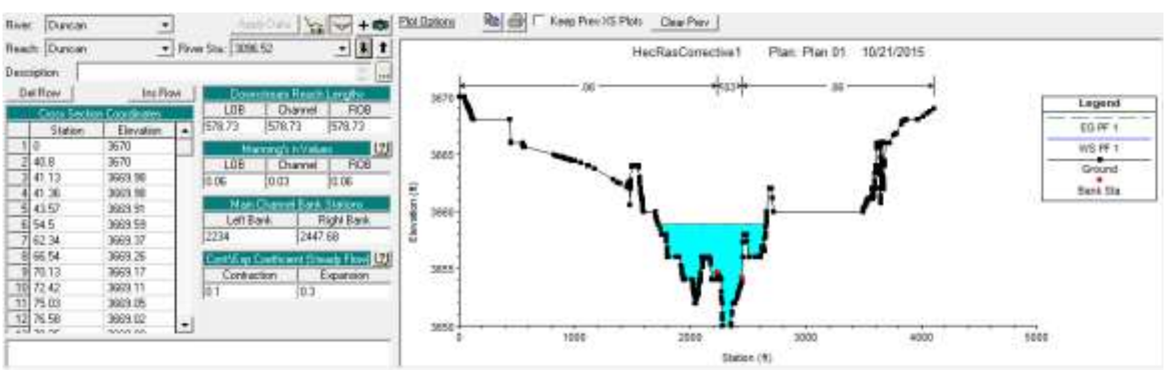

Figure 13-HEC-RAS Cross Section

Due to the complexity of data points in each cross section, the data filter tool was used to reduce all data points of each cross section to no more than 500 points. Manning's values were assigned to the channel and overbank conditions of the reach. Based on the dense vegetation observations a Manning's value of 0.06, 0.03 and 0.06 were assigned to the left overbank, channel, and right overbank areas respectively. Upon determining the characteristics of each cross section, a boundary was defined and a steady flow analysis was performed with the flows provided in Table 2. The information provided from this model offers insight to the residents of Duncan on the impact of a levee alignment and why this flood protection is important for the community's preservation from damaging waters.

***Table 2**-Corrective Effective Model*

Flow Recurrence Interval	Flow (cfs)	Observations
Typical	400	
$Q_{1.25}$	2,650	
$Q_{1.5}$	3,790	
Q_{2}	5,520	
Q_{5}	12,400	
Q_{10}	18,300	
Q_{25}	28,100	
Q_{50}	37,000	
Q_{100}	48,000	

Content in progress

- ***Determining accurate Manning's values for each cross section***
- ***Currently the simulation is not registering proper flow conditions so the model needs to be further investigated and modified***

Proposed Conditions Model

Using the Corrective Effective Model's cross sections, defined reach, and topography, the Proposed Conditions model depicts the impact of a levee and any modified conditions to the floodplain. Other design alternatives may lead to modifying the floodplain's Manning coefficient, removing unnecessary obstructions in the floodplain, and/or changing the alignment and height of the assigned levee. The flows tested in this model are to be identical to those of the Effective Corrective Model. A plan view of the proposed 1.5 mile alignment is provided in Figure 14. Additionally, a description of each flow's impact is provided in Table 3 (In progress).

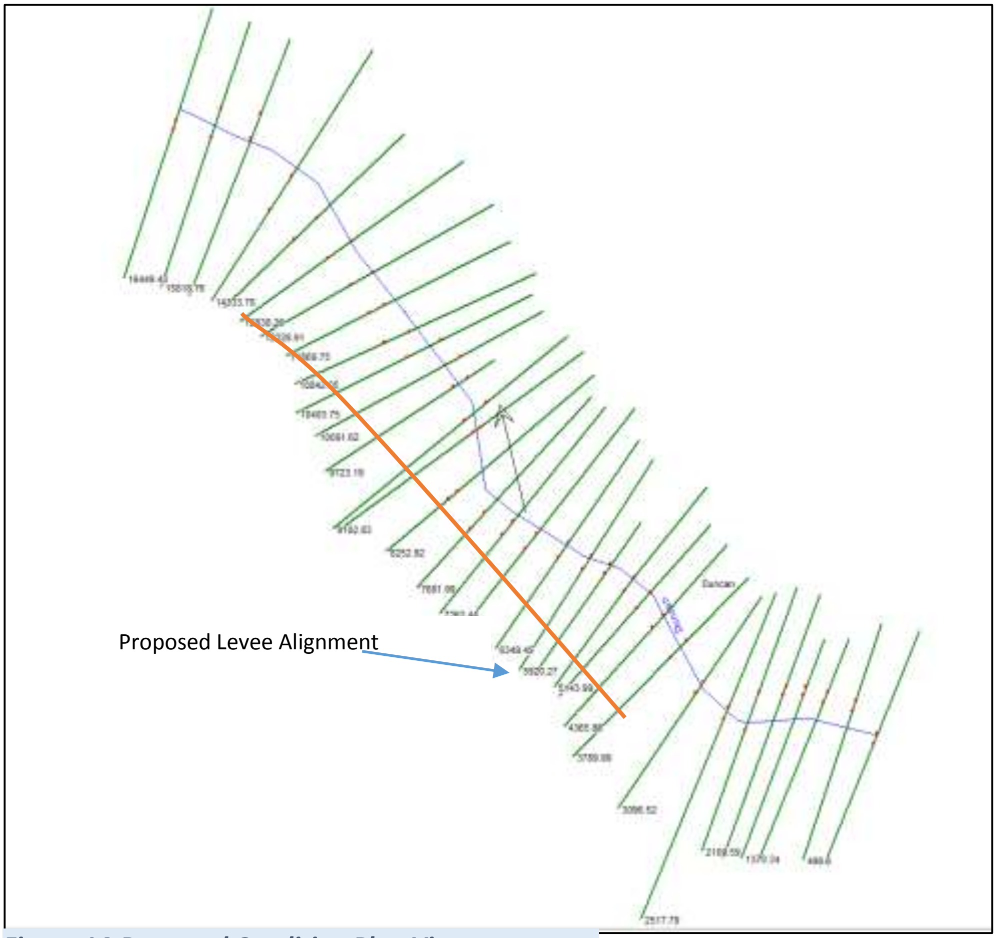

Figure 14-Proposed Condition Plan View

***Table 3**-Proposed Conditions Model*

Flow Recurrence Interval	Flow (cfs)	Observations
Typical	400	
$Q_{1.25}$	2,650	
$Q_{1.5}$	3,790	
Q_{2}	5,520	
Q_{5}	12,400	
Q_{10}	18,300	
Q_{25}	28,100	
Q_{50}	37,000	
Q_{100}	48,000	

Content in progress

- ***Since a proper Corrective Effective Model is not in place, a proposed conditions model has not yet been produced.***

- ***Alternative designs are being considered in addition to a levee. The client has mentioned that perhaps natural floodplain conditions may mediate floodwaters more efficiently.***
- ***Ideally, tabular outputs an cross sectional views of this model will be provided in the appendix as well as a scaled Civil 3D plan view of the levee alignment***

4.0 Cost of Implementing the Design

In Progress

5.0 Summary of Project Costs

In Progress

References

[1] FEMA, "Flood Insurance Study: Greenlee County, Arizona," 28 September 2007. [Online]. Available: http://www.co.greenlee.az.us/engineering/Flood%20Insurance%20Study.pdf. [Accessed 15 February 2015].

[2] "Greenlee County History: Duncan," 2015. [Online]. Available: http://www.co.greenlee.az.us/historyduncan.aspx. [Accessed 24 February 2015].

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[5] Arizona Department of Water Resources, Reconnaissance Report of the Gila River Flood COntrol Project, 1981.

[6] Natural Channel Design, Inc., "Apache Grove Hydrology Design," 2015.

[7] Code of Federal Regulations 44, Office of the Federal Register National Archives and Records Administration, 2002.

[8] Flood Insurance Study Guidelines and Specifications for Study Contractors, 2007.

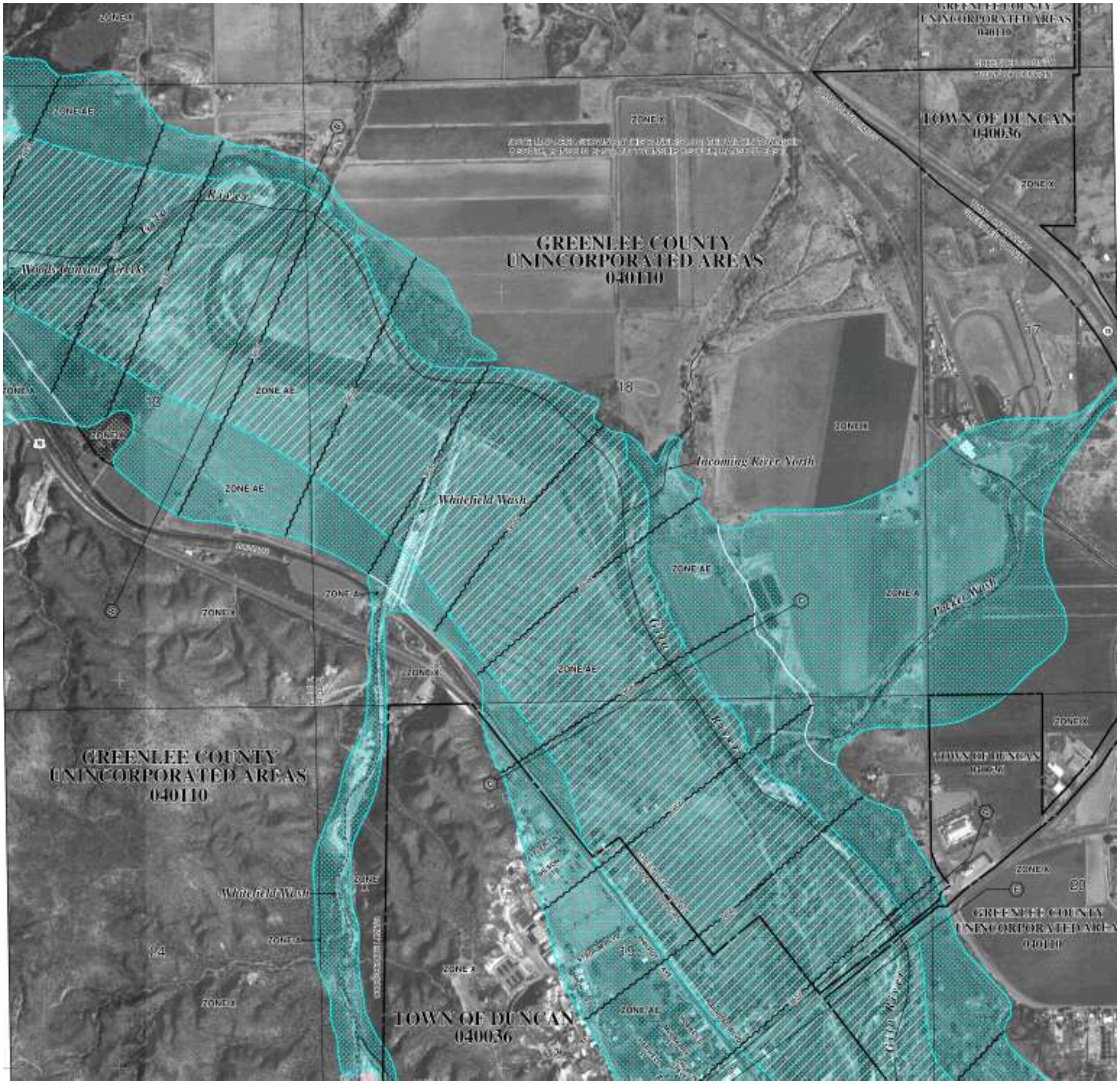
[9] FEMA, "Flood Map Service Center," 28 September 2007. [Online]. Available: https://msc.fema.gov/portal/search?AddressQuery=Duncan%2C%20Arizona. [Accessed 1 February 2007]. [Accessed 1 February 2015].

[10] Google, "Maps," 2015. [Online].

[11] "Arizona County Map," Dirtopia, January 2012. [Online]. [Accessed 26 February 2015].

Appendices

Appendix A-FIRM of Duncan Area



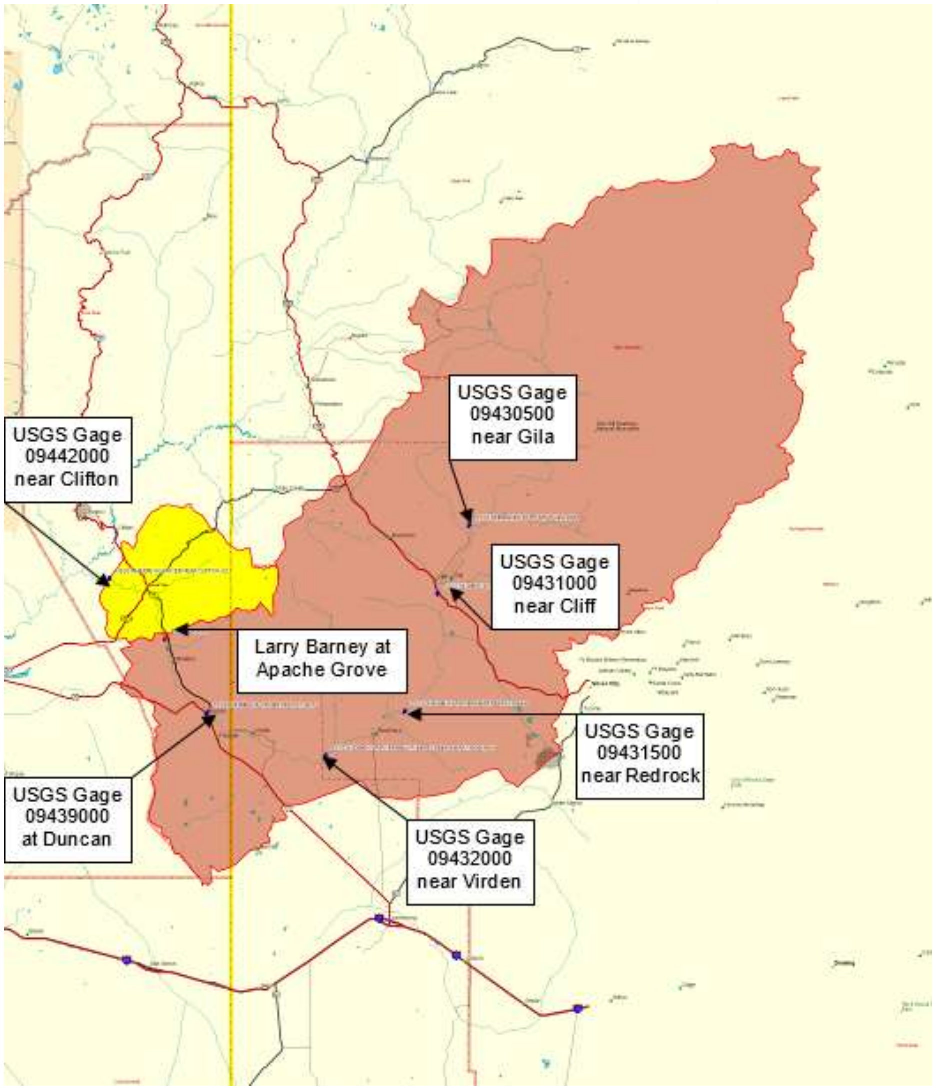
Areas in blue, surrounding the Gila River, show projections of how far the 100 year flood will spread. This information is used by FEMA's National Flood Insurance Program to assess flood risk for insurance companies. If a certified levee were in place, the flood risk of Duncan would decrease and insurance rates would lower.

Appendix B-Hours Allotted Towards Project

Team Member	Meetings	Research	Civil 3D	HEC-RAS	Report Preparation	Total (hrs)
Ahmad Alfalaji	32.5	4	14.25	4	2.5	57.3
Abdulaziz Ebrahim	29	3	6.5	4.5	2	45
Jennalise Rapinchuk	33.9	2	7.75	1	1	45.7
Charlie Wilson	26.5	9.5	12	11	8	67
Total Hours	121.9	18.5	40.5	19.5	12.5	212.9

**Effective as of October 22nd, 2015*

Appendix C-Watershed Area of the Gila River near Duncan



The area in red indicates the ~3800 square mile watershed that drains into the Gila River at Duncan [6]**.**

Appendix D-FEMA Cross Sections Tested

FLOODING SOURCE		FLOODWAY			1-PERCENT-ANNUAL-CHANCE FLOOD WATER-SURFACE ELEVATION (FEET NAVD)			
CROSS SECTION	DISTANCE[1]	WIDTH (FEET)	SECTION AREA (SQUARE FEET)	MEAN VELOCITY (FEET PER SECOND)	REGULATORY	WITHOUT FLOODWAY	WITH FLOODWAY	INCREASE
Gila River								
A	0	1,308	5,784	4.9	3622.6	3,622.6	3,623.5	0.9
B	5,700	2,083	9,353	3.0	3633.9	3,633.9	3,634.8	0.9
C	11,520	1,411	6,951	4.1	3644.3	3,644.3	3,645.2	0.9
D	14,485	1,830/ 840 [2]	8,183	3.5	3650.3	3,650.3	3,651.2	0.9
E	14,595	1,770/ 820 [2]	7,813	3.6	3650.4	3,650.4	3,651.3	0.9
F	18,040	905	4,673	6.1	3654.5	3,654.5	3,655.4	0.9
G	22,515	2,071	12,812	2.2	3665.2	3,665.2	3,666.2	1.0
H	25,465	1,302	5,737	5.0	3668.2	3,668.2	3,669.1	0.9
I	30,600	847	3,204	8.9	3676.6	3,676.6	3,677.1	0.5

[1] Feet above Limit of Detailed Study
[2] Width/Width Within City of Duncan

TABLE 8

FEDERAL EMERGENCY MANAGEMENT AGENCY
GREENLEE COUNTY, ARIZONA
AND INCORPORATED AREAS

FLOODWAY DATA

GILA RIVER