A Floodplain Remapping Effort: Hydrologic Study of the Edgar's Ranch House

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1 Introduction

Tom and Donna Edgar are homeowners of a ranch house passed down to them from a line of four generations. This ranch house resides in central Texas' Burnet County near the county borders between Burnet and Lampasas. The ranch house is located near the Lampasas River and two of its smaller tributaries, the Moss Branch and Edgars Draw. In 2007, FEMA hired Halff Associates Inc. to undertake flood map modernizations for Burnet County, which took effect in March 2012. Half Associates performed a study in this region to revise the limits and elevations and created revised digital flood maps by leveraging terrain and GIS data.

Figure 1: The Edgar's ranch house.

The revised FEMA floodplain maps for Burnet County were released in March and showed that the Edgars' ranch house was positioned inside a floodplain rather than outside of it, as was described in the old FEMA floodplain maps. This alteration redefines their ranch house from Zone X, which indicates minimal flood hazard, to a Zone A, which is a Special Flood Hazard Area (SFHA). All residencies located inside a Zone A floodplain are susceptible to flooding every 100 years, in other words, having a 1% chance every year of flooding as calculated by FEMA calculation and projections.

Figure 2: The FEMA floodplain map a) before March 2012 and b) after March 2012.

The Edgars believe the proposed FEMA floodplain map inaccurately characterizes their property and dispute the quality of the FEMA mapping project in their county. The data used to create the FEMA remapping is 40-year old USGS contour data with questionable accuracy. There exists an "implied horizontal accuracy of 67 feet," according to Halff Consultants that causes the data to below FEMA's own data standard for accuracy. Unfortunately, the time to review and submit complaints for FEMA's map has passed, so the Edgars are currently in the process of applying to FEMA with an official Letter of Map Change (LOMC).

The objective of this project is to assess whether or not the Edgars' ranch house falls within the boundary of a 100-year floodplain by utilizing updated resources and data. In other words, the amount of flood flow occurring around their property and the water surface elevation need to be calculated and processed in a hydraulic model constructed using the best available elevation data. Currently, the most up-to-date data is LiDAR topographical elevation data provided by TNRIS. To accomplish this task, three students have been assembled from Dr. David Maidment's GIS Water Resources class to spearhead different aspects of the floodplain mapping: hydrologic, hydraulic and terrain analysis.

2 Edgars Ranch Visitation

On November 12, 2012, Donna Edgar invited Dr. Maidment and his flood remapping team to visit the ranch house in order to acquire a better idea of the scope of the project. The professional remapping team consists of Sean Sutton, a flood engineer at AECOM familiar with FEMA flood map revisions and amendments; Melinda Luna of TNRIS, who has provided the LiDAR data for the region; and Danny Quiroz, who is the expert in the HEC-GeoRAS program. The student team consists of Stephen Jackson, who is spearheading the hydraulic modeling of the project; Roxana Darvari, whose responsibility is creating a base map, and myself, working on the hydrologic model portion.

At the ranch house, Donna Edgar and Burnet County's Environmental Services Floodplain Director, Herb Darling, served as our local topographic guides as well as "historical evidence" for the lack of past flooding. We examined the historical watermarks of different locations on the tributaries and the bridge engineering over the Moss Branch and Edgars Draw. Additionally, we walked through the riverbed of both streams to gain a better understanding of the hydraulic terrain and network of these relevant tributaries.

Figure 3: A few images from our team's visitation, a) the Lampasas River and b) Stephen Jackson hand-measuring bridge lengths for the hydraulic model.

3 Objective

This remapping effort is broken down into roughly three pieces: the hydrologic, hydraulic, and base-mapping portions. The object of this hydrologic portion is to determine the design peak stream flow for a 100-year recurrence interval for the Lampasas River and two tributaries, Moss Branch and Edgars Draw using the 2009 USGS Scientific Investigations Regression Equations for Estimation of Annual Peak-Streamflow Frequency for Undeveloped Watersheds in Texas Using an L-moment-Based, PRESS-Minimized, Residual-Adjusted Approach.

The overall objective of this effort is to assess whether or not the Edgars' ranch house falls within the boundary of a 100-year floodplain map based on our analysis using up-to-date resources and LiDAR data.

4 Methodology

This project is a joint collaborative effort involving data collection, hydraulic analysis and a connection between GIS, HEC-GeoRAS and HEC-RAS for floodplain mapping. Roxana DarvariÕs analysis uses LiDAR topographical data and a land use map in HEC-GeoRAS to produce a base-map of our interested region. Stephen Jackson's analysis involves creating a hydraulic model using Roxanas results (including river center lines, cross sections, and basin characteristics) and the hydrologic results of this report to produce flow profiles in HEC-RAS for 100-year floods. My report focuses on the hydrological aspects, calculating the annual peak stream flow through using the 2009 Texas State-wide Regression Equations. This analysis is concerned with the peak flows at the 5 outlet points denoted in green in the image below.

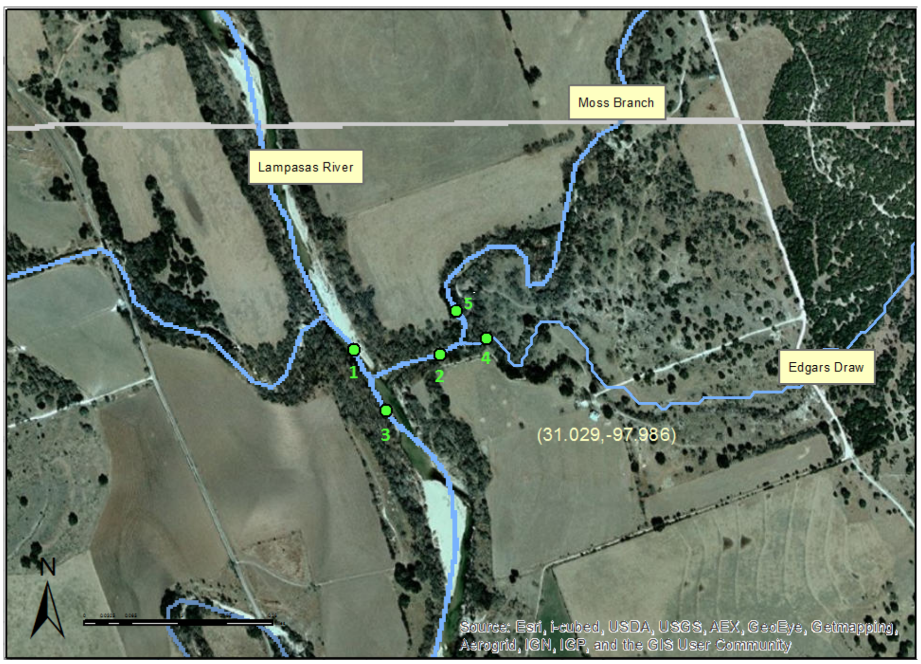

Figure 4: Geographic location of the Edgar's ranch house, its surrounding streams, and outlet points of interest.

4.1 Texas State-Wide Regression Equations

The methodology used in this report to obtain annual peak stream flow estimates are derived from the 2009 Texas State-wide Regression Equations. The basis of this method rests on analysis of annual peak stream flow data from USGS stream flow gaging stations. This regression assessment was constructed for floodplain management particularly in Texas, where objective assessment of flood risk is vital in the design and development of infrastructure in potentially flood-affected regions. These regression equations can characterize peak stream flow for nine recurrence intervals of 2, 5, 10, 25, 50, 100, 200, 250, and 500 years.

The method used to develop these regression equations is known as the "L-moment-based, PRESS-minimized, residual-adjusted approach." The approach is reasonably complex and theoretical. However, for the scope of this report, the methodology can be summarized into three main thematic components:

- L-moment-based statistics of the gaging stations were fit to seven probability distributions. Estimates of each station's peak stream flow frequency for each recurrence interval were extrapolated from these seven distributions.
- The development of the regression equations uses weighted-least-squares, multi-linear regression analysis of each station's peak stream flow frequency and watershed characteristics. This regression minimizes the Prediction Error Sum of Squares (PRESS) using power transformation of the drainage area.
- Regression residuals are additionally corrected for climate, terrain and variables not represented by selected watershed characteristics.

4.2 Primary Watershed Characteristics

The watershed characteristics essential for the regression analysis are summarized as follows:

- Drainage area is the horizontal projection of the area where surface water converges into a single outlet point and is measured in square miles.
- Dimensionless main-channel slope is defined as the change in elevation in feet between the end points of the main channel divided by the length of the main channel in feet.
- Mean annual precipitation is the mean of total annual precipitation in inches of a reasonably long period of time. This regression approach uses values from Asquith and Slade (1997) between the period 1951-1980.

4.3 ArcGIS Geoprocessing Analysis

The primary watershed characteristics needed for the peak stream flow regression analysis can be acquired using digital elevation models and hydrology tools in the ArcGIS Geoprocessing toolbox. Using the tools in ArcGIS, a hydrologic and terrain analysis can yield datasets with the information necessary for regression analysis.

4.3.1 Drainage Area

ArcGIS online's World Hydro Reference Overlay map is a useful tool designed by ESRI that provides a base-map of streams, water bodies and hydrologic units. Because the Lampasas River and the Moss Branch are mapped on this Hydro Map, ESRI's Automated Watershed Delineation Tool can be used to delineate watersheds for the Lampasas excluding Moss Branch, the Moss Branch only, and the Lampasas including Moss Branch (outlet points 1, 2, and 3 respectively).

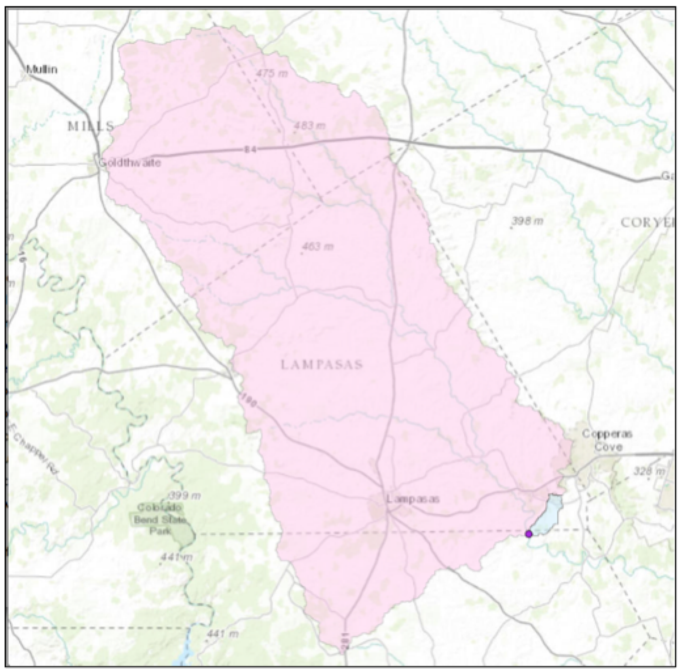

Figure 5: Delineations of the Lampasas and Moss Branch watersheds using ESRI's Automated Watershed Delineation Tool.

Unfortunately the Edgars Draw is too small of a tributary to be mapped out on the World Hydro Map. Thus, because ESRI's Automated Watershed Delineation tool is based on the World Hydro Map, this tool cannot be used for the Edgars Draw and its watershed must be delineated in another way.

For the Edgars Draw, a hydrologic terrain analysis method will be conducted instead. Using digital elevation model data, the hydrology of the watershed such as its drainage area, stream lengths, and flow direction can be evaluated and interpreted. First, the National Elevation Dataset files were downloaded using USGS's National Map Viewer platform. Because the Lampasas drainage area is so large, thirty-one separate 1/3 arc second DEM files in ArcGrid format had to be downloaded and mosaicked together. The elevation raster dataset can now be processed. First, the elevation values were modified using the fill function to eliminate potential grid sinks and then the flow direction was composed for each grid in the raster dataset, resulting in a grid designating steepest flow descent from each cell.

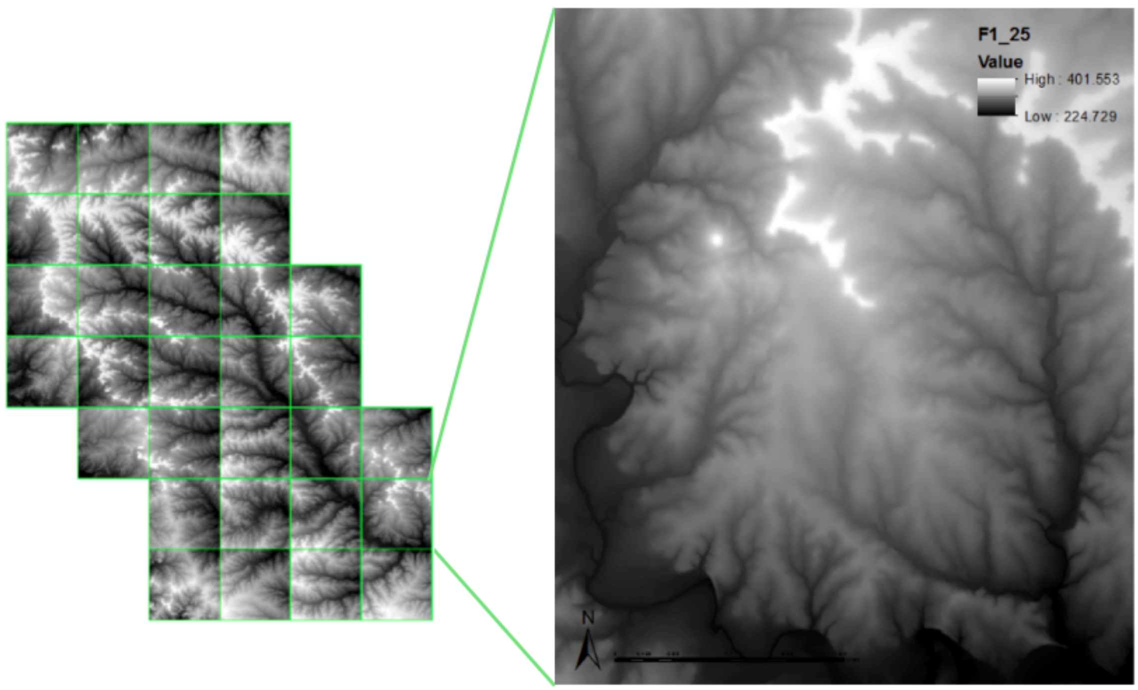

Figure 6: a) DEM raster datasets mosaicked together and b) the DEM segment containing the Edgars Draw ready for processing.

Finally, the flow accumulation for each cell in the input grid can be calculated using the Flow Accumulation tool to yield a raster of streams that were too small to for the World Hydro Map. The Edgars Draw has very low flow accumulation so for it to appear on the raster grid, the classification break values for flow amount were lowered to ensure the Edgars would appear.

Now, stream links and the drainage area for Edgars Draw can be calculated and converted to vector format to evaluation. We must use the Project tool to project the stream links and drainage area from GCS North American 1983, which presents values in angular units degrees into Contiguous USA Albers to find the drainage area in meters.

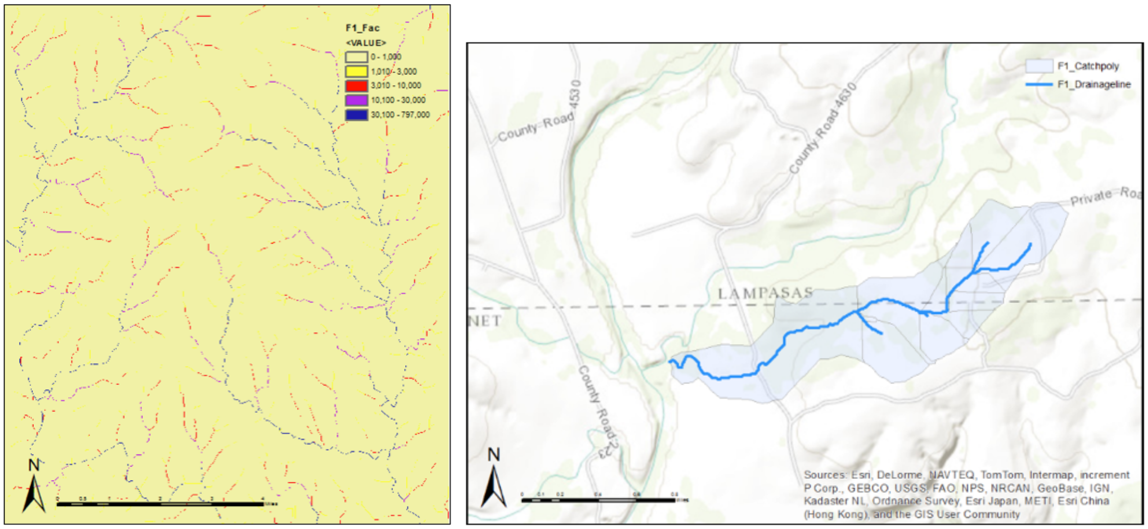

Figure 7: a) Flow accumulation derived from DEM and b) the final delineated watershed for Edgars.

4.3.2 Dimensionless Main-Channel Slope

As mentioned above, dimensionless main-channel slope is the change in elevation in feet between the endpoints of the main channel divided by the length of the main channel in feet. First, the main channel length can be found by using a base dataset comprising of flowlines and watershed boundaries from the National Hydrography Dataset Plus (NHDPlus) will be used (Water Resource Region 12 which covers most of Texas). the Clip Tool, the flowlines in the NHDPlus package can be clipped using the watersheds delineated above as boundaries. The result will be flowlines just for the relevant watersheds. To find the main channel length of the Lampasas, the relevant flowlines were selected by attribute when the "GNIS NAME = Lampasas River" and exported as a separate feature class. After projecting this feature class into NAD 1983 Contiguous USA Albers, the main channel length was found for each stream.

Now, the change in elevation between the endpoints of the main channel found above can be found by projecting the DEM raster extracted from the USGS website from its default GCS North American 1983 (decimal degrees) into NAD 1983 Contiguous USA Albers (meters) like in previous steps. Using the identify tool in the DEM projection, the elevation at each channel end point can be extracted easily.

Table 1: Summary of dimensionless main-channel slope for designated regions.

Region	Change in elevation (ft)	Channel length (ft)	Slope
Lampasas post confluence	837.4	335,095.6	0.0025
Lampasas prior confluence	837.8	334,798.2	0.0025
Moss post confluence	300.5	23,119.5	0.013
Moss prior confluence	282.7	22,514.9	0.126
Edgars Draw	208.3	11,469.6	0.018

4.3.3 Mean Annual Precipitation

The mean annual precipitation is the mean of the total annual precipitation over a suitably long period of time. These regression equations use precipitation values provided by Asquith and Slade (1997) during the period 1951-80 because they felt this source of mean annual precipitation over a course of 30 years is sufficient for the regression equation calculations. The mean annual precipitation value was estimated to be 28 inches for all outlet points based on data for the Lampasas River near Kempner, Texas gage station from the Asquith and Slade paper.

4.4 The Omega Parameter

The last step towards calculating the final peak flow estimates from the regression equations is computing the regression residuals using the Ω parameter. The Ω parameter is a special watershed characteristic that describes the generalized terrain and climate index and expresses the peak stream flow potential that is not represented in the selected watershed characteristics above. Below is a map from the USGS, 2003, that depicts, by 1-degree quadrangle, the Ω parameters superimposed on a base maps of Texas rivers, which are derived from analysis of spatial distributions of residuals from regression analysis.

There exists some discrepancy regarding the treatment of the Ω parameter in this analysis. The Ω parameter used in this analysis is 0.161 because all the relevant outlets are located in the quadrangle with an $\Omega = 0.161$ designation. However, the majority of the Lampasas Watershed is actually located in the quadrangle to the left where Ω is -0.106. An Ω of -0.106 yields a peak discharge that is 50% the discharge when Ω is 0.161. Furthermore, historical data shows that the peak flow value for the Lampasas is much closer to the higher flow estimate. Thus, for the sake of this floodplain mapping analysis, the higher flow rate and the more conservative Ω of 0.161 will be adopted to calculate the peak flow discharges.

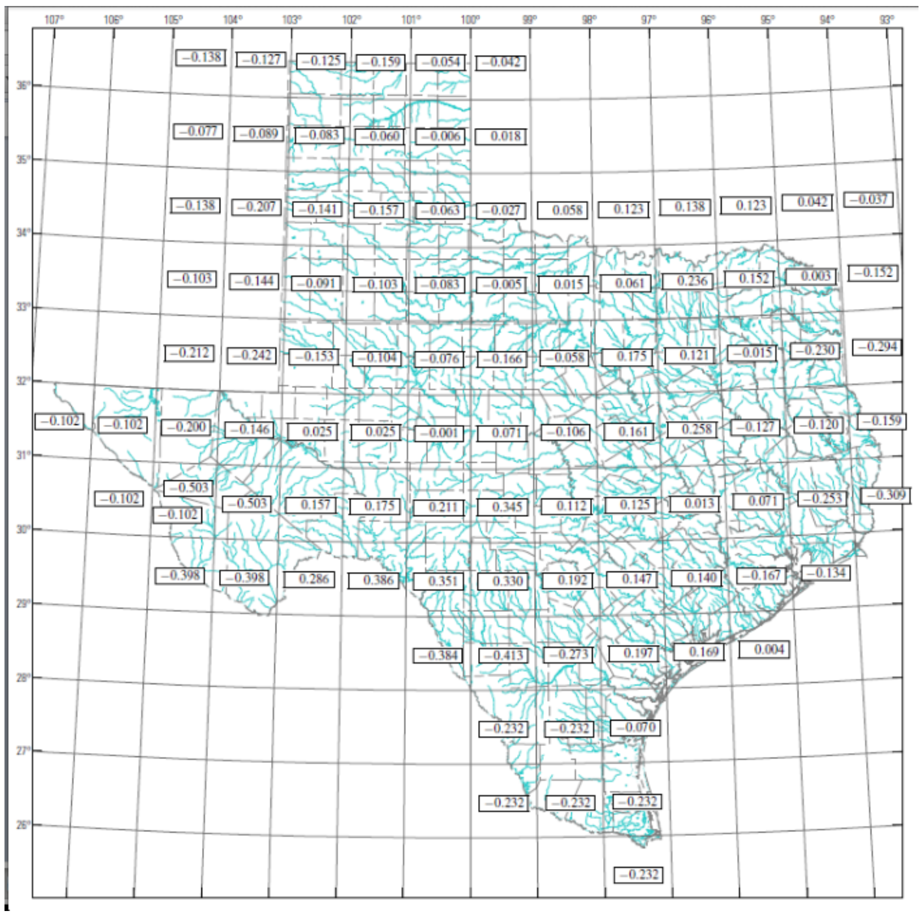

Figure 8: Omega parameters superimposed against a hydrologic base map in Texas. From Asquith and Slade (1997).

5 Regression Equation Results

Since the FEMA floodplain maps are delineated based on 100-year flood frequencies, this analysis is most concerned with the peak stream flows for this recurrence interval. The weighted-least squares, PRESS-minimized, regional regression equation for a 100-year recurrence interval from the USGS Texas Department of Transportation Report is

$$Q_{100} = P^{1.071} S^{0.507} \times \ 10^{[0.969\Omega + 10.82 - 8.448A^{-0.0467}]}$$

where Q is peak stream flow for 100-year recurrence interval in cubic feet per second; P is mean annual precipitation in inches; S is dimensionless main-channel slope; Omega is 0.161 as derived from Figure 9, and A is drainage area in square miles. The peak stream flow results along with its selected watershed characteristics for the 5 designated outlet points are shown below in Table w.

Table 2: Summary of regional regression equations for peak streamflow. [Q_{100}, peak discharge for a 100-year recurrence interval in cubic feet per second; P, mean annual precipitation in inches; S, dimensionless main-channel slope; A, drainage area in square miles; and the omega parameter.]

Region	A	S	P	Ω	Q_{100}
Lampasas post confluence	928.38	0.013	28	0.161	116,597.63
Lampasas prior confluence	924.10	0.0025	28	0.161	116,319.88
Moss post confluence	6.89	0.013	28	0.161	5,771.35
Moss prior confluence	6.87	0.013	28	0.161	4952.62
Edgars Draw	0.97	0.018	28	0.161	1,519.95

6 Revised Floodplain Map

As mentioned above, this effort has been a collaborative process. The final peak discharges from this hydrologic study were used as input values for the hydraulic model. Roxana Darvari processed the LiDAR elevation data in HEC-GeoRAS and prepared flow lines and cross-sections to be processed in HEC-RAS. Using HEC-RAS, Stephen Jackson calculated the speed and elevation of the flow in the study area based on the peak stream flow values computed in this report and LiDAR elevation dataset. Stephen incorporated a number of hydraulic parameters for each cross-section including bank location, Manning's coefficient, and bed elevation to calculate the final elevation information (refer to final report). Using these final elevation values, a flood map can be visualized in HEC-GeoRAS as shown in Figure 10.

Figure 9: Revised floodplain map with FEMA's 2012 floodplain map superimposed in red lines.

7 Conclusions

Based on the 2009 USGS Scientific Investigations Regression Equations, the design peak stream flow for the Lampasas River prior to confluence was calculated to be 116,319.88 cubic feet per second. This flow value was used to create our team's new floodplain map.

As the Edgars had expected and hoped, the new floodplain map does not include their ranch house. The floodplain derived from the LiDAR data shows that the flooding near their ranch house is controlled by the Edgars Draw, which has a much smaller peak flow and not by the Lampasas River. The floodplain of the Edgar's Draw does not reach their ranch house. These results await review by Dr. Maidment and Sean Sutton. When the collective report is finalized, Glenn Wright will create an estimate based on our results for AECOM to officially package and submit a letter of map amendment to FEMA.

8 References

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