Hydraulic and Breach Analysis of a Dam in North Texas

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Background

Dams are important to provide water supply, recreation, flood protection, and/or to generate electricity. The Texas Commission on Environmental Quality (TCEQ) regulates dam construction, inspections, and emergency action planning through Texas Administrative Code Chapter 299. The hydrology and hydraulics of a dam and its watershed are evaluated to ensure the safety of people living downstream of a dam. The hydrology evaluation ensures that a dam is capable of safely passing a required percentage of the probable maximum precipitation (PMP). The hydraulics evaluation includes a breach analysis to determine the area that would be affected if the dam were to breach. This project focuses on a dam in north Texas and follows TCEQ Hydrologic and Hydraulic Guidelines.

FIGURE 1 - UPPER AND LOWER DAM

Dam Characteristics

The dam evaluated for this project includes an upper dam and lower dam. The upper dam was built in 1955 with a height of 67 feet and a length of 2,500 feet. The crest of the upper dam is at 934.8 feet-mean sea level (ft-msl) and the principal spillway is at 920 ft-msl. In 1980, the lower dam was built with a height of 80 feet and a length of 1,750 feet. The crest of the lower dam is at 944.8 ft-msl and the principal spillway is at 920 ft-msl. Figure 1 shows the configuration of the two dams. When the water level reaches the crest of the lower dam (944.8 ft-msl), the total storage volume is 102,300 acre-feet. At this capacity, the upper dam is submerged. The hydrology and hydraulics of the lower dam is the focus of this project. Additionally, the dam owner's consulting engineer provided elevation, storage, and discharge data for each dam, principal spillway and emergency spillway.

Hydrology

The first step of this study was to determine if the lower dam could pass the PMP without overtopping the structure. This involves delineating the watershed, obtaining the PMPs, calculating a time of concentration, determining a curve number for each reservoir, and preparing a model of each PMP in HEC-HMS.

Watershed Delineation

The first step in determining the hydrologic capability of the dam is to define the drainage area of the dam area. ArcGIS and GeoHEC-HMS software was used to delineate the watershed using a 30-meter national elevation dataset (NED) of the area. The NED was converted to a raster digital elevation model (DEM). The DEM was reconditioned with the national hydrology dataset (NHDplus) as the stream. Then the slope, fill sinks, flow direction, and flow accumulation tools were run. Next, using GeoHEC-HMS, the catchments and drainage lines were defined. This analysis resulted in the delineation of multiple catchment basins within the drainage area of the two dams. These basins were combined into one upper reservoir and one lower reservoir. The longest flow path and river slope was determined for each reservoir. Figure 2 shows the drainage areas, drainage lines, and the longest flow path for each reservoir.

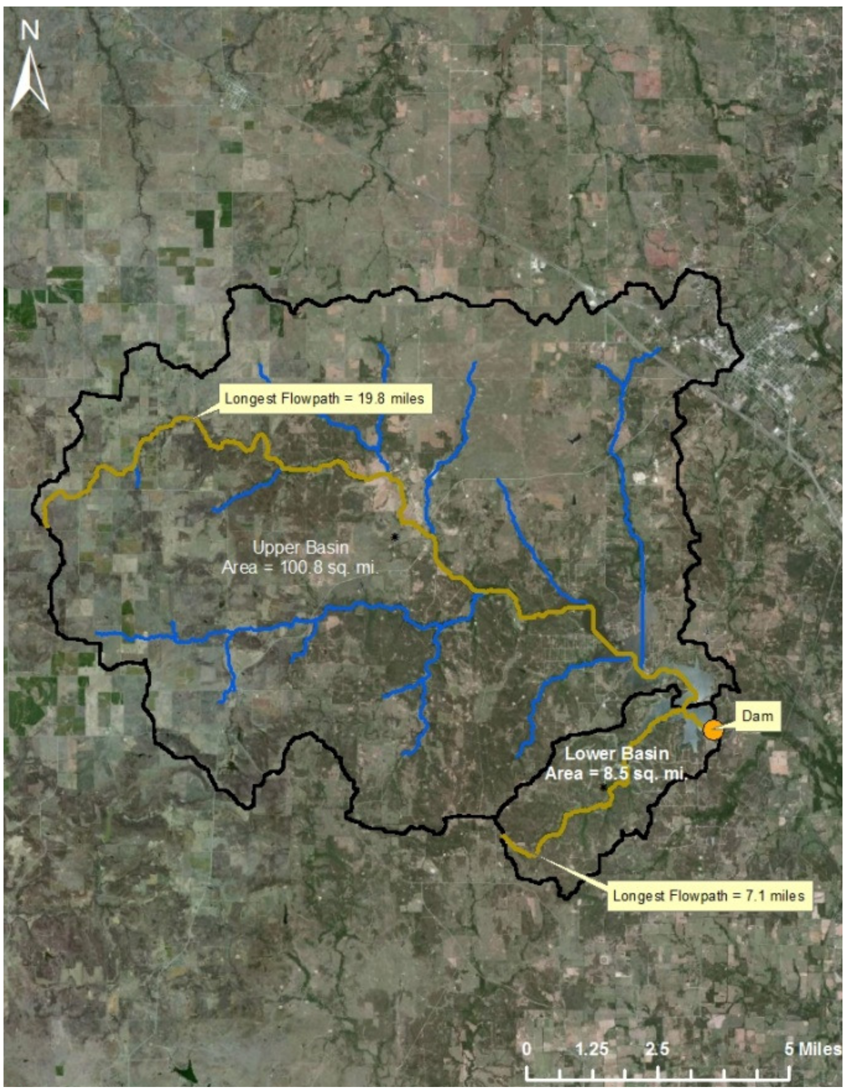

FIGURE 2 - DRAINAGE AREA

Probable Maximum Precipitation

After finding the acreage of the total drainage area (109 acres), the PMP for the 6-hour, 12-hour, 24-hour, 48-hour, and 72-hour storms were obtained from the hydrometerological report 51 (HMR-51) for drainage areas less than 200 square miles. Additionally, the 1-hour, 2-hour, and 3-hour storms were estimated with a logarithmic regression of storm duration versus rainfall. Figure 3 shows the PMPs for the study area. Figures 4 and 5 show the distribution of the storms over time for the drainage area that was used in the model per TCEQ guidelines. Each of these storms was modeled in HEC-HMS to determine the design storm for the dam. The design storm is the one that causes the highest water level elevation for the dam.

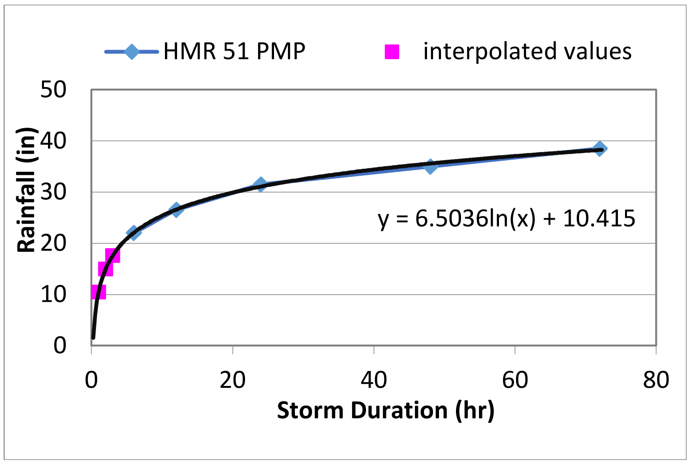

FIGURE 3 - DRAINAGE AREA PMPs

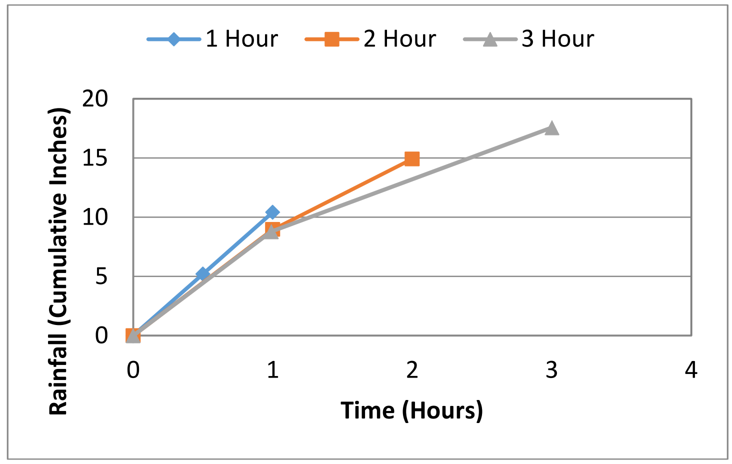

FIGURE 4 – 1-, 2-, AND 3- HOUR PMP DISTRIBUTION

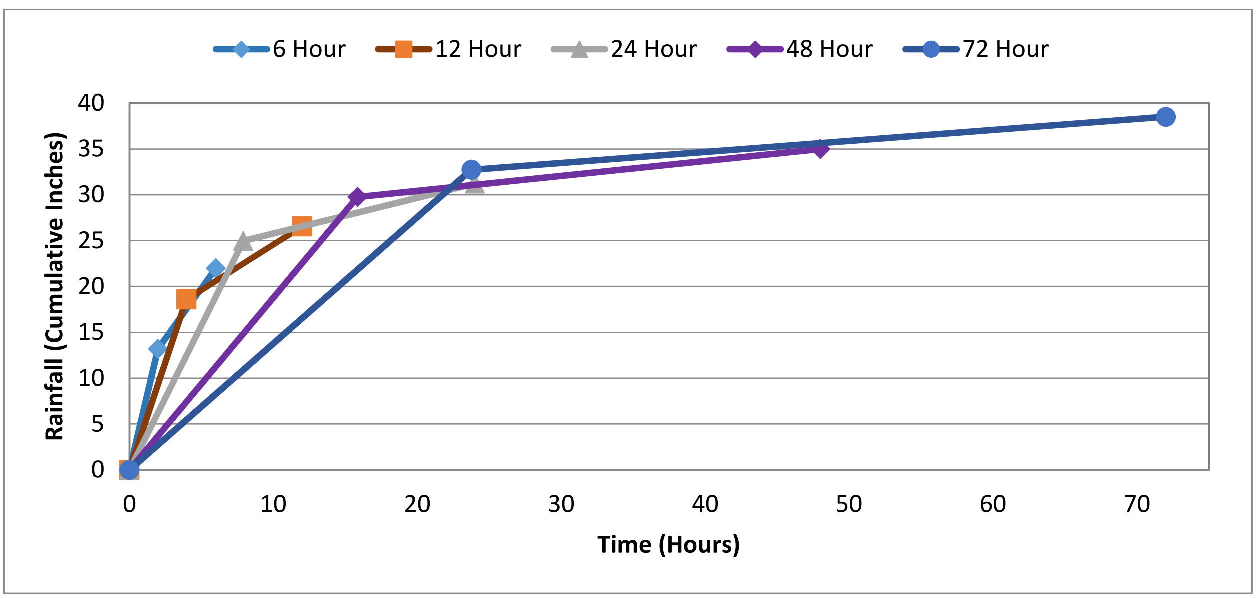

FIGURE 5 – 6-, 12-, 24-, 48- AND 72- HOUR PMP DISTRIBUTION

Time of Concentration

The time of concentration, T_c, is the time it takes for water to flow down the longest flow path. The T_c was calculated following the Natural Resources Conservation Service (NRCS) Technical Release 55 (TR-55) equations for overland sheet flow, shallow concentrated flow, and open channel flow. The data needed for these calculations (flow lengths and slopes) was from ArcGIS using the GeoHEC-HMS "TR-55 Export to Excel" tool. Additional data included the two year, 24-hour rainfall for the area which was obtained from the National Weather Service Technical Paper 40. For the HEC-HMS model the T_c was converted to a lag time, T_L, by multiplying the 0.6 times the T_c. Since this drainage area is large, the Snyder method for calculating the lag time was also considered. The Snyder T_L was obtained from the dam owner's consultant. Table 1 summarizes the T_c and T_L that were used in this study.

TABLE 1 - TIME OF CONCENTRATION

Reservoir	TR-55 T_c (hrs)	TR-55 T_L (hrs)	Snyder T_L (hrs)
Upper	12.1	7.3	5.1
Lower	4.8	2.9	2.5

Curve Number

In order to model the design storm, it is necessary to estimate the runoff that makes it to the dam. This requires knowledge of the soils and land use in the drainage area to determine the infiltration rate. The NRCS curve number loss method was used to estimate the runoff in the HEC-HMS model. The soils data was obtained from the NRCS web soil survey website. The web soil survey provides information on the soils present in the area of interest. The soils are divided into hydrologic groups of A (most pervious soil), B, C, and D (most impervious soil). Figure 6 shows the hydrologic groups for the drainage area. The study area is dominated with soils from the hydrologic group C classification resulting in mostly impervious soils and high precipitation runoff for this area. Visual observation of the aerial image was used to further divide the drainage area into land use parameters (i.e. – residential, pasture, industrial, woods, etc.). The acreage for each land use parameter/hydrologic group combination was estimated. Curve numbers for these combinations were obtained from tables in TR-55. The

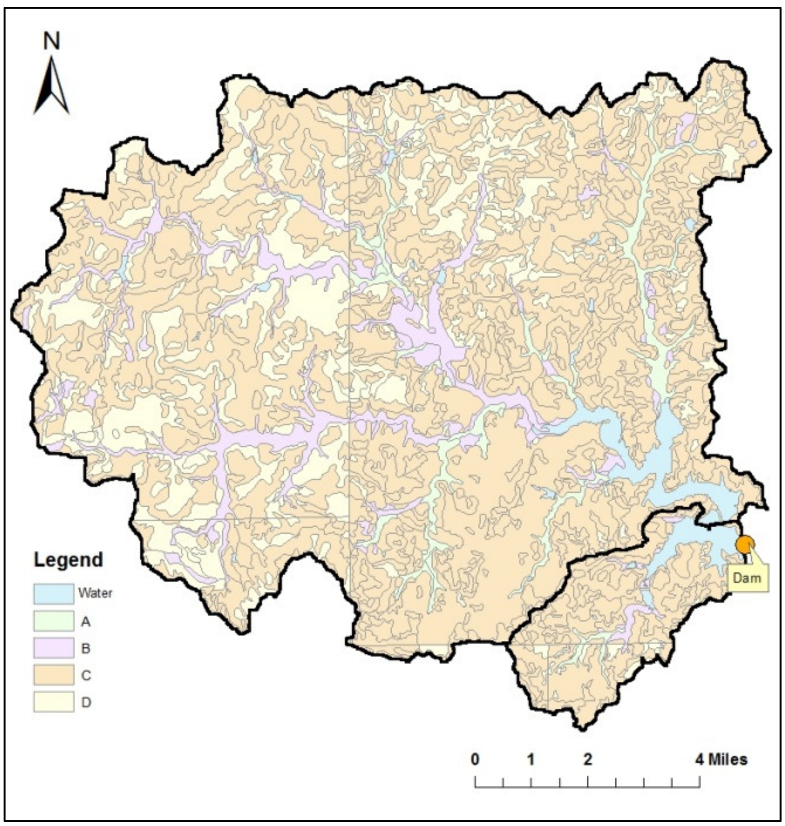

FIGURE 6 - SOIL HYDROLOGIC GROUPS

overall curve number was calculated by averaging the individual curve numbers weighted by area. The resulting overall curve numbers for the upper and lower reservoirs was 87 and 86, respectively.

HEC-HMS

The Army Corps of Engineers HEC-HMS software was used to predict the water level elevations during the PMP storms. The drainage area information generated in ArcGIS was exported to HEC-HMS. Additionally, the dam characteristics including T_L, elevation, discharge and storage data for the two dams, their service spillways, and their emergency spillways was entered into HEC-HMS. The hourly accumulation of the PMP distribution was an additional input into the model. Finally, the calculated curve numbers were entered so the model could calculate the expected runoff to the dam. Simulations were run for each of the storms (1-hour through 72-hour) to determine the design storm. Two models were prepared in HEC-HMS due to the configuration of the two dams. The first model was set up for when the water levels were below the upper dam. This model included both dams and their respective spillways. The second model was set up for instances when the water levels rise above the upper dam. For this model, the upper dam characteristics (crest and principal spillway) were removed and the focus was on the lower dam. The storage volume of the lower dam was modified at elevations above the upper dam's crest to include the total storage volume. The emergency spillway of the upper dam was included in this model. The second model was run for both lag times (TR-55 and Snyder).

Results

The HEC-HMS model showed that the lower dam is capable of safely passing the PMP for all of the storms without overtopping the dam. Figure 5 shows a graph of the water elevations expected for the storms for each of the lag times. There is little difference between the two lag times; however, the elevations for the Snyder lag time are a better estimate for this drainage area due to its large size. The design storm for this dam was determined to be 48 hours since it produced the highest water elevations. These results are similar to the consultant's results of a design storm of 24 hours and a maximum water elevation of 944.6 ft-msl. The variance from the consultant's values is most likely due to a difference in configuration of the HEC-HMS model.

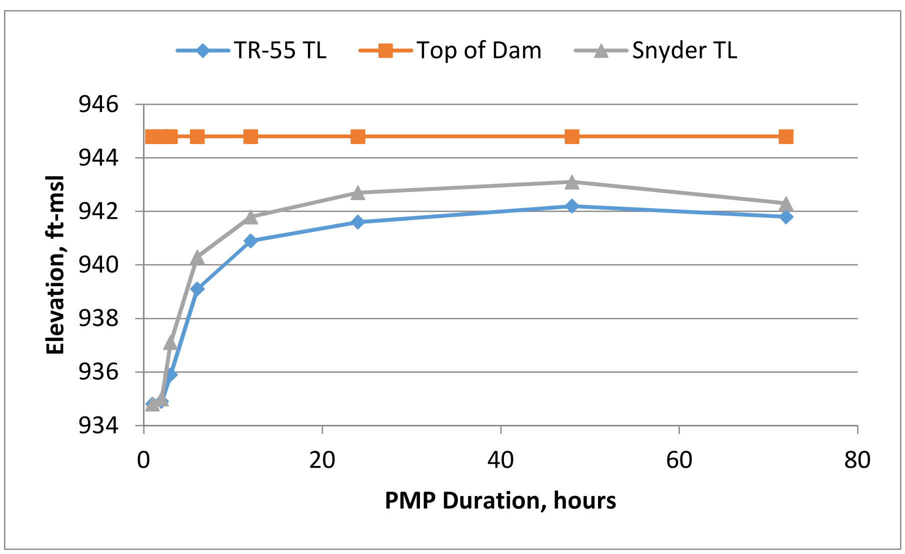

FIGURE 7 - HEC-HMS MODEL WATER ELEVATIONS

Hydraulics

The second portion of this project was to perform a breach analysis for the dam to determine the inundation area that would result from a breach. This involved determining the inundation length and flow rate of the water after a breach, configuring GeoHEC-RAS, and finally modeling the breach in HEC-RAS.

Inundation Length and Flow Rate

The inundation length is the length downstream that is expected to be affected by a breach of the dam. This length, L_u, is estimated with the equation 1. The variable K_s is a correction factor for the spillway size and is a ratio of the breach flow rate (Q_b) to the spillway flow rate (Q_s). Values of K_s can only range from 0.5 to 2. If K_s is determined to be greater than 2, the value of 2 is used in equation 1. The variable C is the total capacity of the reservoir (acre-feet) and H is the maximum height of the dam (feet).

$$L_u = 0.012K_s\sqrt{2CH} \qquad \text{(Eqn. 1)}$$

The spillway flow rate was provided by the dam's consultant and the breach flow rate was calculated using equation 2 where B is the bottom width of the dam breach and H is the height of the dam in feet. The variable B is estimated as three times the dam height for earthen embankments.

$$Q_b = 3.1BH^{3/2} \qquad \text{(Eqn. 2)}$$

For the lower dam, the L_u was estimated to be 97 miles. The Q_s and Q_b were 1,565 cubic feet per second (cfs) and 532,363 cfs, respectively. The inundation length actually used in this project was 78 miles which ended at a subsequent dam downstream. The

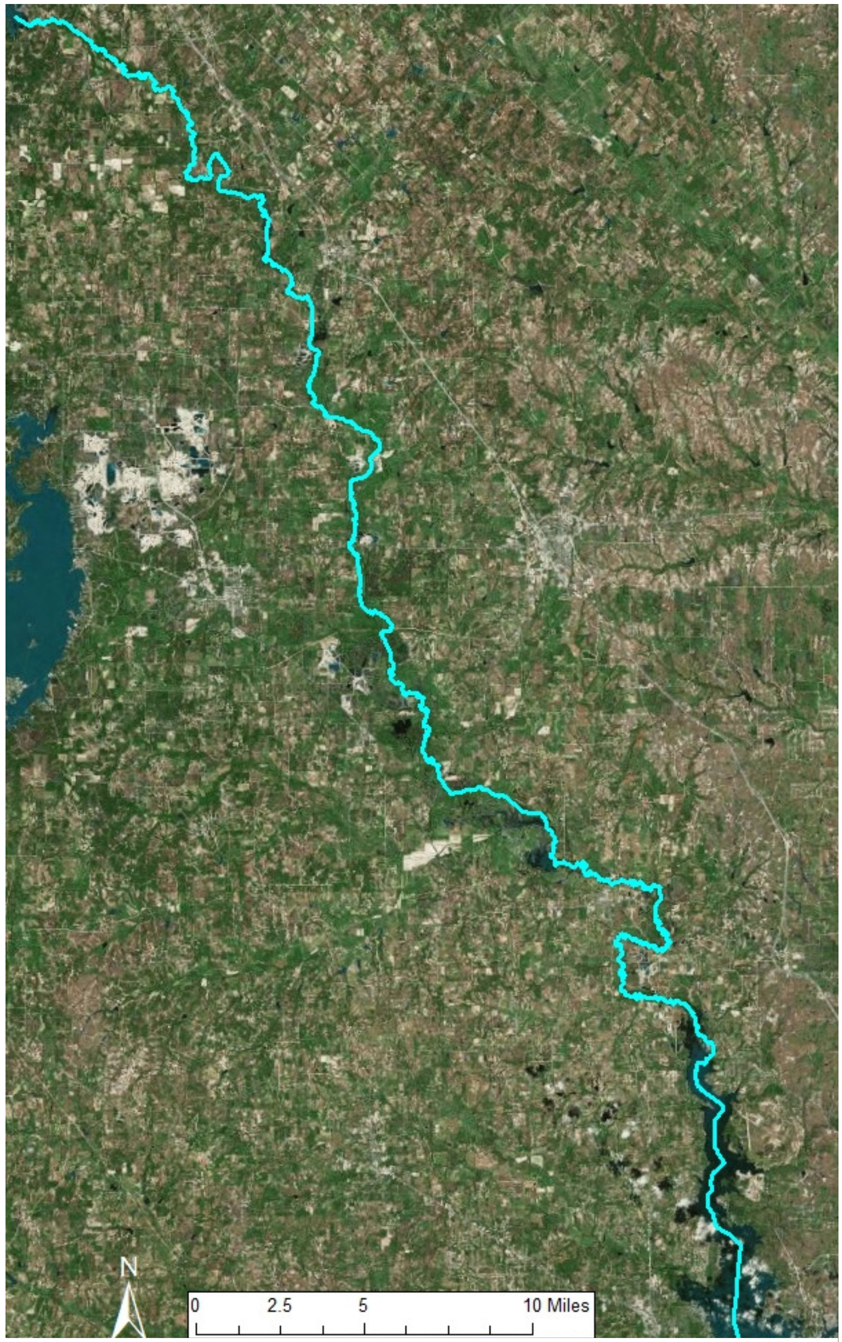

FIGURE 8 - INUNDATION LENGTH

dam's consultant stated that this subsequent dam has sufficient capacity to not overtop with a breach of the lower dam. Figure 8 shows the inundation length along the downstream river.

GeoHEC-RAS Configuration

A 10-meter NED was used in ArcGIS to configure the GeoHEC-RAS model. The NED was converted to a triangulated irregular network (TIN) file with a z factor of 3.281 to convert the elevation units from meters to feet. A shapefile of the river downstream of the lower dam was created by tracing the NHDplus along the inundation length. Next, cross-sections of the river were configured for the entire inundation length. Cross-sections were added upstream and downstream for each bridge or major road that crossed the river. Finally, flowpaths and bank lines were added on each side of the river. Each of these layers was defined in ArcGIS and then the data was exported for use in the HEC-RAS software.

HEC-RAS

The data was processed in HEC-RAS under steady-state conditions assuming a breach of the dam occurs when the dam is at full capacity. Each cross-section was reviewed and Manning's n-values were entered for the channel and the left and right banks. The Manning's n-values were obtained from the dam's consultants. Additionally, it was noted that some of the bank lines that were developed in ArcGIS did not align with the actual channel banks. These bank lines were adjusted in the cross-section view. Finally, the Q_b that was previously calculated was prorated for each cross-section along the inundation length and these values were entered into the model.

Results

Figure 9 shows the inundation length, flowpaths, bank lines, and cross-sections that were analyzed with the HEC-RAS. This figure also includes the water inundation area developed by the model.

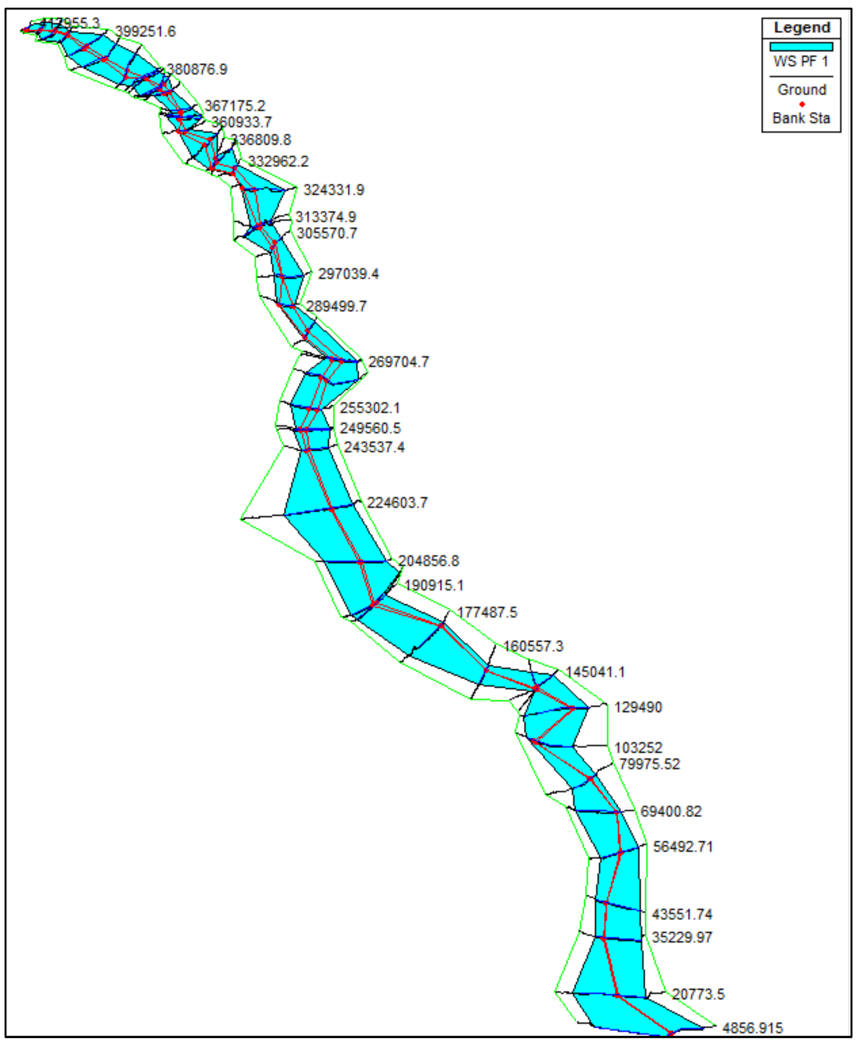

Figure 9 - HEC-RAS Model

Another feature of the HEC-RAS software is the ability to view the profile of the river. Figure 10 shows the river profile. The lower dam would be located at the upper right of this diagram. The final step in this analysis was to export the data back into ArcGIS and study the inundation zone to determine the areas where people and structures could be affected by a breach of the dam. Figure 11 shows a small portion of the inundation zone located near a highway and a neighborhood. This view shows that both the road and the houses would be inundated with water should the lower dam breach. The highway in this figure is approximately 15 feet above the stream bed. The water level is about 30 feet, so the highway is under 15 feet of water. The house is submerged under 18 feet of water. This type of information is extremely useful for emergency management personnel in the event of extreme flooding and/or during a possible breach of the dam.

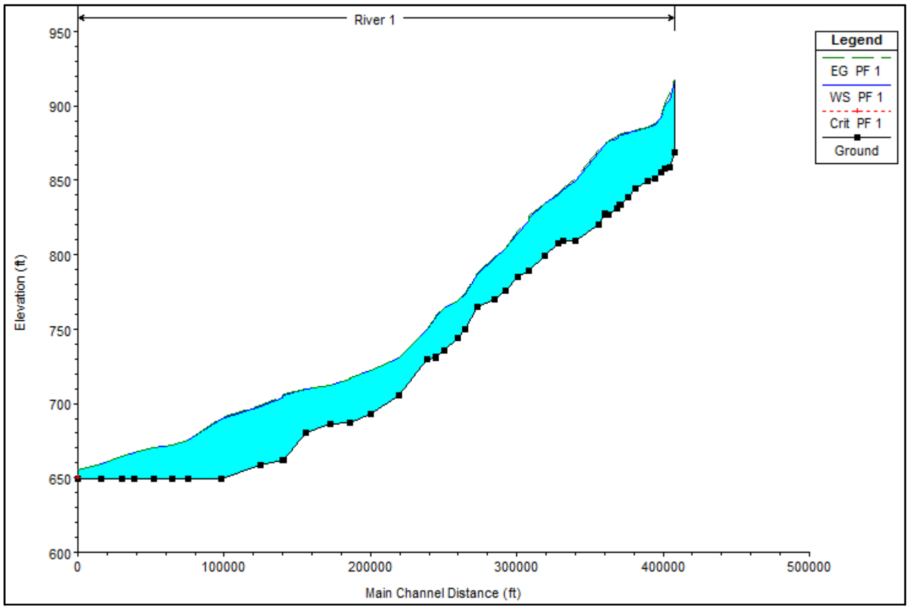

FIGURE 10 - HEC-RAS PROFILE VIEW

Inundation maps are included in a dam's emergency action plan to assist with evacuations and road closures if a breach is imminent or during flooding events. Since the inundation length is so long, a flyover animation (Figure 12) was prepared to show the results of the breach analysis. The line in the middle of the inundation zone is the original river shapefile. The blue shaded area is the boundaries of the inundation zone with the darker blue area representing deeper water levels and the lighter blue areas representing shallower water levels.

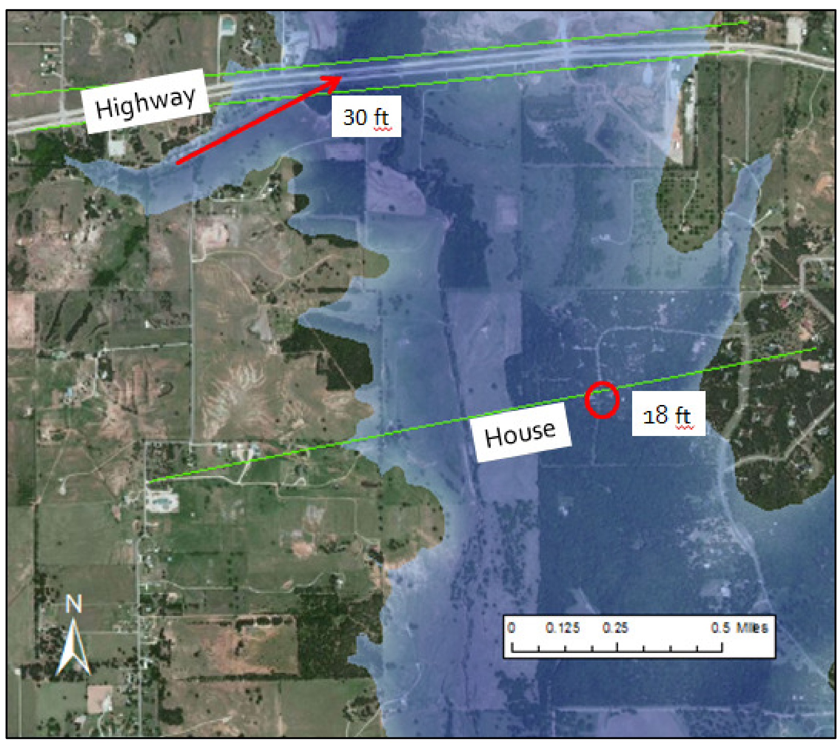

FIGURE 11 – INUNDATION ZONE EXAMPLE

FIGURE 12 – FLYOVER ANIMATION

Conclusions

Hydrologic and hydraulic studies are becoming increasingly important as neighborhoods are encroaching into the areas downstream of large dams. While the dam in this study will not be overtopped by the PMP storms, it could affect many roads and neighborhoods downstream if a breach occurred.

Sources

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