Designing a Dam for Blockhouse Ranch

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Introduction

Blockhouse Ranch is located in the Northwest corner of Mason County close to Brady, Texas. Typically Calf Creek runs through the ranch, feeding into the San Saba River. However, due to the low flows in Calf Creek this tributary does not contain enough water to sustain the livestock on the ranch. I will be investigating the feasibility of using a dam to turn Calf Creek into a reservoir in order to increase the ranch's water supply.

My first task in this project was to define the study area. After I created an ArcMap document and added a topographic base map layer, I began by obtaining a shapefile of the state of Texas as well as a shapefile of the counties of Texas. I will primarily be concerned with Mason County, but since the Calf Creek watershed also covers portions of the two adjacent counties I will also be concerned with small portions of McCulloch and Menard counties. These counties border Mason County on the North and West sides respectively.

Since the area I will be concerned with is only the area that drains to Calf Creek, I also obtained the Watershed Boundary Dataset Hydrologic Unit Code 12 (HUC 12) watersheds shapefile. Two HUC 12 watersheds will make up the area of this study: Upper Calf Creek and Lower Calf Creek. The HUC 12 identifying numbers and total areas of these watersheds are summarized in Table 1. The total study area is 43,604 acres.

Table 1: Calf Creek Watersheds

HUC 12 Name	HUC 12 Number	Area (acres)
Upper Calf Creek	120901090603	33,656
Lower Calf Creek	120901090604	9,948

Data Sources

The following section will outline the datasets used I used to analyze the Calf Creek Watershed. The sources of all datasets will be discussed in addition to the data format. I will also note the organization responsible for publishing each dataset and any known quality assurance measures. Any measures taken to prepare the data for analysis in Arc GIS are outlined in this section.

Precipitation Data

Due to the rural location and sparse population surrounding the area of this study, no stream gauge data was available from the United States Geological Survey (USGS) or other organizations. Therefore, in order to analyze the quantity of flow in Calf Creek, precipitation data for the Calf Creek Watershed was obtained. Parameter-elevation Regressions on Independent Slopes Model (PRISM), a climate mapping system run by Oregon State University, publishes monthly and annual average precipitation data for the nation.

Figure 1: 30 Year Annual Average Precipitation Raster

The precipitation data produced by PRISM is interpolated from numerous point sources. Point estimates of precipitation are obtained from various organization including the National Weather Service (NWS), Natural Resources Conservation Service (NRCS), United States Forest Service (USFS) and Bureau of Land Management (BLM) stations. Additional quality control procedures were applied to data by PRISM prior to their use in national average computations.

Gridded precipitation data utilized the North American Datum 1983 (NAD 1983) as a horizontal reference frame and had a resolution of 30 arc seconds. This corresponds to grid cell sizes of 900m X 900m. The units of precipitation are given in millimeters (mm) times 100. Since the purpose of a installing a dam is to provide a long term water source for native wildlife and livestock, the 30 year annual average precipitation data was used. Since the study area is significantly smaller than the entire nation, the precipitation data covering the watershed was extracted using a raster of the watershed as a mask.

Elevation Data

My first attempt to download elevation data for the Calf Creek Watershed was unsuccessful because the United States Geological Survey (USGS) Seamless Data Warehouse download website was unavailable. Next, I tried ordering data from the US Department of Agriculture (USDA) National Resources Conservation Service (NRCS) Geospatial Data Gateway. Unfortunately the files I received were incomplete and did not load correctly into ArcGIS. I was finally able to obtain appropriate elevation data for the Calf Creek watershed by selecting a rectangular area in the National Map Seamless Server on the USGS website (USGS).

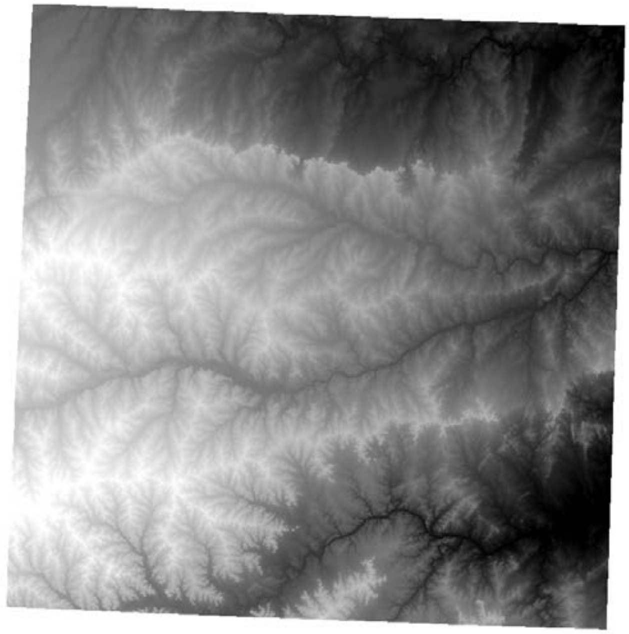

Figure 2: Raw Digital Elevation Model

The raw elevation file used the NAD 1983 horizontal datum as a spatial reference and the size of the raster grid cells was 1/3 arc second or 10 m. Although the USGS Seamless server does have 1/9 arc second (3m resolution) data for some of the country, the Calf Creek watershed area is not yet available. Elevation data was also cropped to the watershed using the tool extract by mask.

Geographic Boundary Shapefiles

Shapefiles for the state of Texas as well as all of its counties were obtained from the zip file provided with Exercise 1 of this course (Maidment). All of these files were also in the geographic coordinate system (GCS) NAD 1983 and had to be projected into the USA Contiguous Albers Equal Area Conic projected coordinates. The three counties surrounding the watershed were selected and exported as a layer in order to maintain some perspective around the watershed.

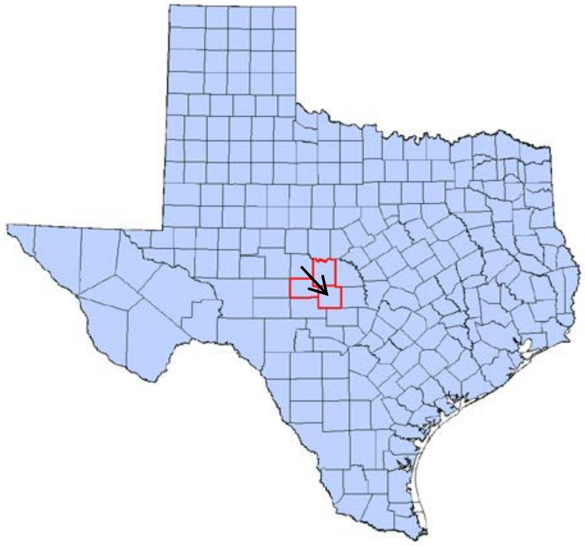

Figure 3: Location of Calf Creek in Texas

NHD Flowlines

The National Hydrography Dataset Plus (NHDPlus) provides hydrologic data for the nation, divided up into 21 regions. The Texas Gulf is classified as Region 12. Catchment flowline shapefiles were downloaded and added to the map. Since this data used the NAD 1983 GCS, it was immediately projected into the Albers Equal Area projected coordinates.

The select by location tool was then used to select features from Target layer, nhdflowlines, using the watershed boundaries as the Source layer. The spatial selection method used was "Target layer features are within the Source layer feature". However, upon inspection of the selected features I realized that two small sections of the stream within the watershed were not selected. First I tried to add these sections to the selected features by holding the shift key and using the select by rectangle tool. The section would be added to the selection, but the boundary line between the upper and lower Calf Creek watersheds would also be selected.

Next I decided to try the select by attributes tool. Using the identify tool, I found the FID values of both stream links. I then added the two stream sections to the previously selected flow lines within Calf Creek using the "add to current selection" method within the select by attributes tool. The unique FID value of the missing sections allowed me to isolate these sections for addition to the Calf Creek flowlines.

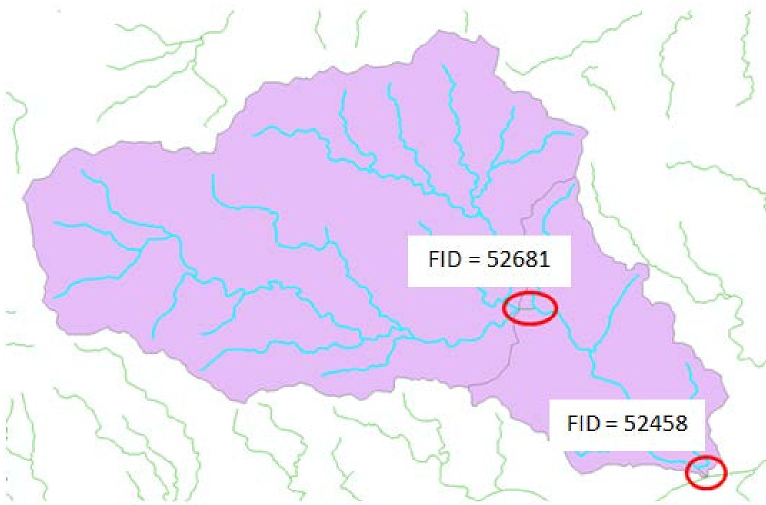

Figure 4: Selection of Calf Creek Flowlines

Once all the stream sections within the watershed were selected, I was able to export the selected data as a layer called CalfCreekFlowlines. After adding this layer I was able to focus in on the Calf Creek Watershed by removing all other flow lines from the map.

Watershed Boundaries

Boundaries for the HUC 12 watersheds were obtained from the United States Department of Agriculture (USDA) Geospatial Data Gateway. Relevant watersheds were determined by examination of the flowlines within the watersheds adjacent to the potential dam construction site. Both Upper and Lower Calf Creek watersheds were determined to be pertinent by visual inspection. I verified this conclusion by using Hydro Desktop, an open source hydrologic data tool made available by the Consortium of Universities for the Advancement of Hydrologic Science, Inc. (CUAHSI). By indicating the potential location of the dam as an outlet, Hydro Desktop automatically delineated the upstream basin which was composed of the same two HUC 12 watersheds determined in the previous analysis. These two watersheds were selected and exported as a layer so that all other watershed boundaries could be deleted. This overall Calf Creek Watershed (composed of the two HUC 12 watersheds) was converted to a raster using the feature to raster tool and used as a mask to extract relevant data from the larger rasters of elevation and precipitation data.

Legal Considerations

Another important part of this feasibility study was researching the legal restrictions related to the construction of a dam or reservoir. Chapter 297 of Title 30 of the Texas Administrative Code is concerned with Substantive Water Rights. Part (b) of Rule 297.21, Domestic Livestock and Wildlife Permit Exemptions, of Subchapter C, Use Exempt from Permitting, states that "a person may construct on the person's own property a dam or reservoir with a normal storage of not more than 200 acre-feet of state water for domestic and livestock purposes without obtaining a permit." The goal of this project will be to ensure that any potential reservoir created by a dam on Calf Creek does not exceed this limit.

Data Analysis

I began by adding the DEM obtained from the USGS Seamless Map, National Hydrography Dataset Flowlines, and HUC 12 Watersheds. The extent of all of this data was the same as the boundaries of the Calf Creek watershed.

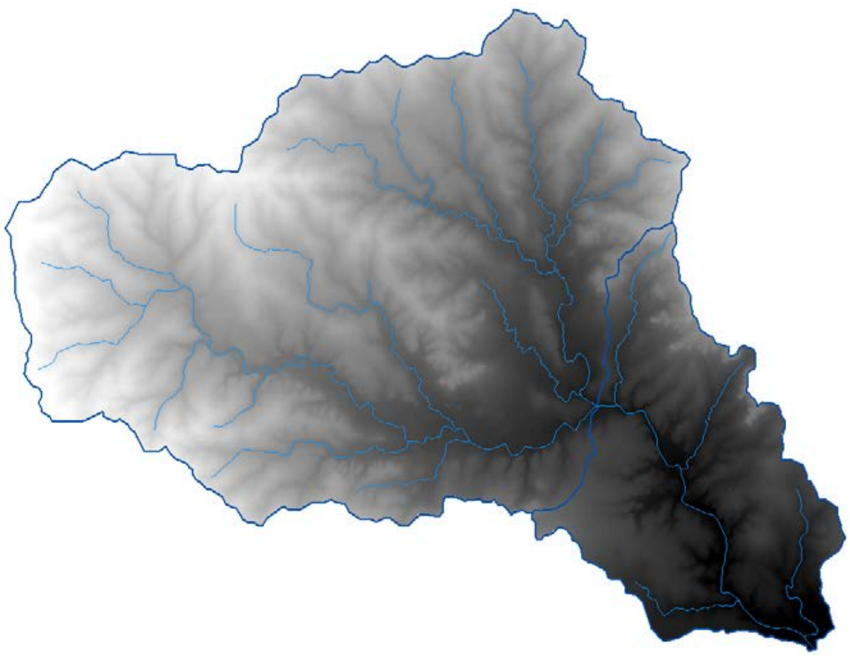

Figure 5: Elevation, Watershed Boundaries, and Flowlines of Calf Creek

After the digital elevation model (DEM) was added to the map, it had to be projected into the Albers Equal Area conic projection in order to ensure an accurate estimation of the earth surface area. By using the Project Raster tool in the Data Management toolbox, I was able to project the DEM from the NAD 1983 GCS to the projected coordinate system, Albers Equal Area projection. The cell size was set to 30m and a cubic method of interpolation was used.

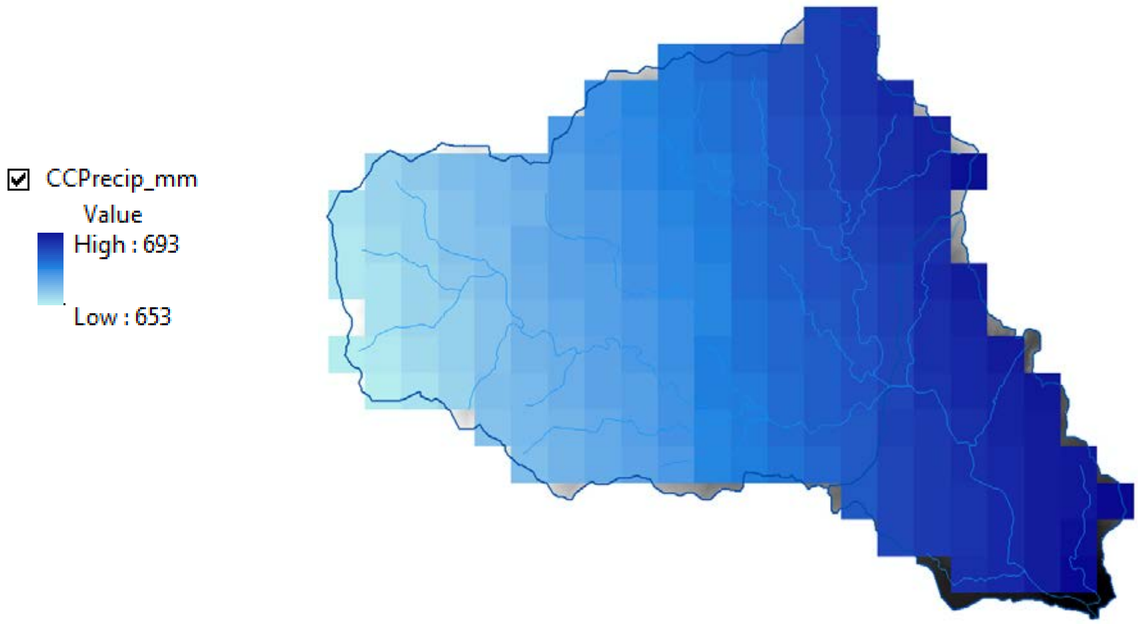

Figure 6: Extracted Precipitation Data

Prism precipitation values are given in millimeters (mm) times 100, so I used the raster calculator to divide the entire raster by 100 to obtain precipitation values in mm. Next, I used a rainfall runoff function to calculate the runoff since stream gauge data was not available for my study area. Although the resolution of the precipitation data from Prism was not ideal, there were no USGS or other gauges within the watershed to interpolate from. The rainfall runoff function used was developed by researchers at the Center for Research in Water Resources (CRWR) at the University of Texas's Pickle Research Campus (Reed, Maidment, & Patoux, 1997).

> "To estimate the runoff in ungaged locations, a curve of "expected" annual runoff as a function of rainfall was developed. The term "expected" refers to runoff that occurs under normal or natural conditions In other words, watersheds with unique hydrogeology that exhibit unusually large recharge or springflows were removed from consideration, as well as watersheds with a *large* amount of urban development, and

watersheds with *significant* reservoir evaporation. The terms *large* and *significant* are described by a set of criteria developed using GIS data layers."

For areas with a lower annual rainfall, an exponential function was fit to the data. Drier areas like this were defined as areas with mean annual rainfall less than P_o (801 mm year^{-1}). It turned out that a linear function yields a better fit to the wetter watersheds with rainfall above P_o, but it was evident upon examination of the Calf Creek Watershed that nowhere in the area received more than 801 mm annually. The exponential function generated by researchers at CRWR used to calculate runoff for the Calf Creek watershed is shown below. Q is runoff (mm year^{-1}) and P is precipitation (mm year^{-1}).

$$Q = 0.00064Pe^{0.0061P}$$

This function was applied to the map using the Raster Calculator, producing a raster with runoff values for the entire watershed.

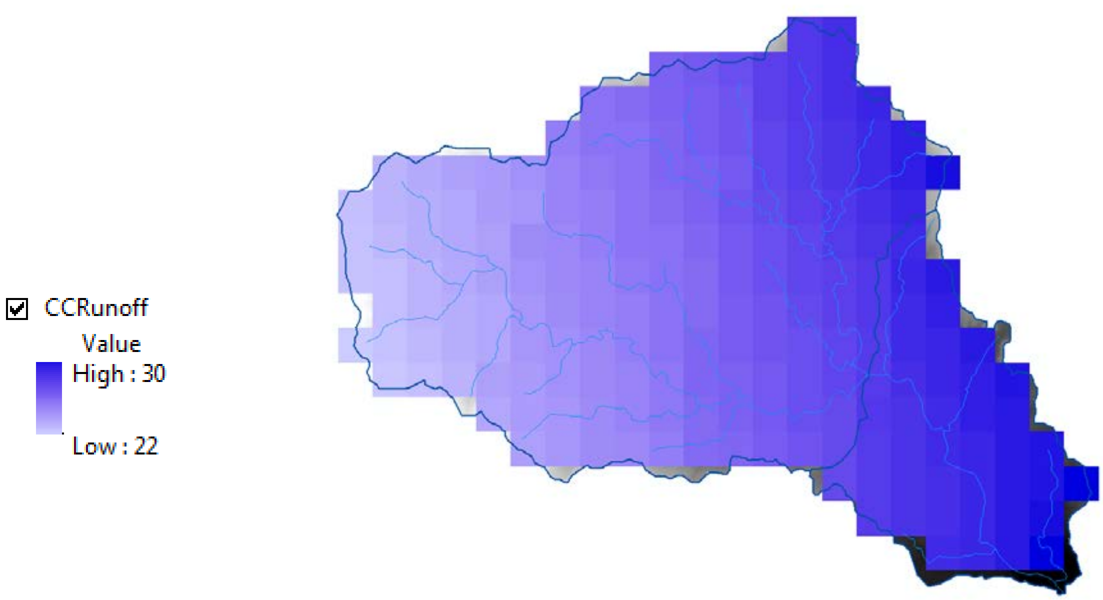

Figure 7: Calculated Runoff Data

The first step in creating a dam was to create a new feature class to store line features. I then used the Editor toolbar to draw a new line in this feature class across Calf Creek where a dam could potentially be constructed. Using the feature to raster conversion tool, I then turned the polyline representing the dam into a raster. In order to give the dam an appropriate height relative to the elevation of the terrain I used the raster calculator to add the Calf Creek digital elevation model to the dam raster. In order to synthesize this data, I created a new mosaic dataset to hold both the DEM and dam rasters.

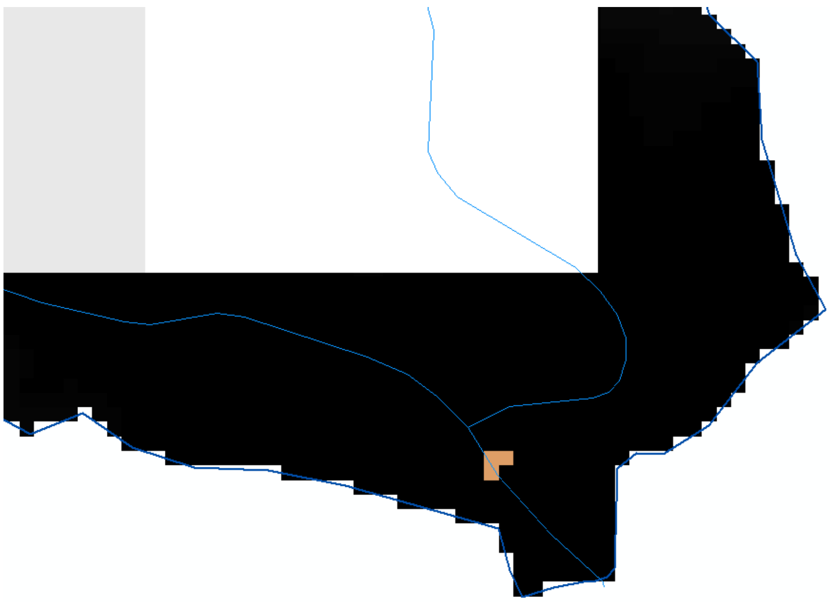

Figure 8: Dam and Elevation Mosaic

Using this mosaic dataset I used the Flow Direction Spatial Analyst tool to compute the flow direction for the dam and elevation mosaic. The values in the cells of the flow direction grid indicate the direction of the steepest descent from that cell.

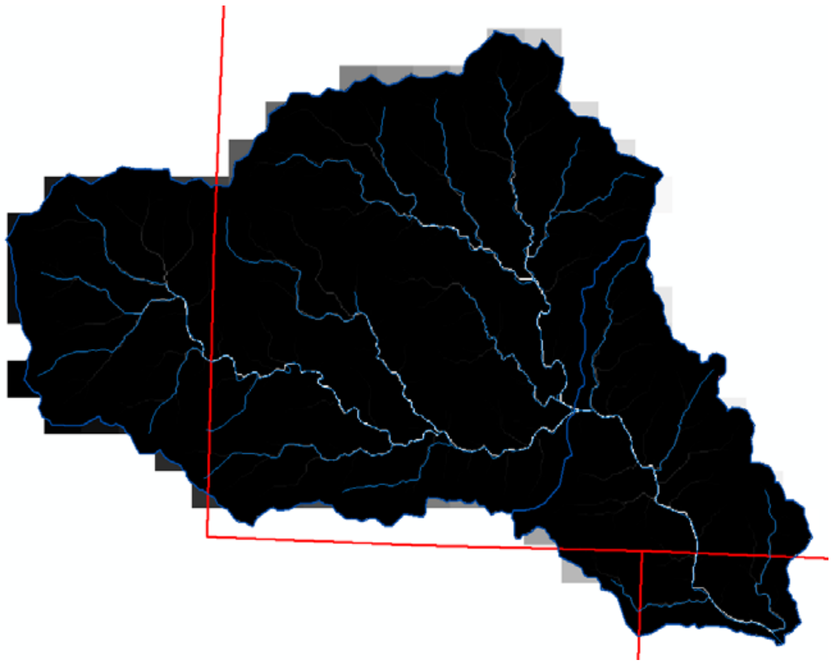

Figure 9: Flow Accumulation Grid

In order to determine the volume of water that could potentially collect upstream of the dam I used GIS to computes a flow accumulation grid. A typical flow accumulation grid contains the accumulated number of cells upstream of a cell, for each cell in the input grid. However, since I was interested in the accumulation of water instead of cells I used a weight raster in the Flow Accumulation function in order to determine how much runoff exists within the watershed. In this case, the weight raster was the runoff raster calculated by applying the rainfall runoff function to the continuous raster representing average runoff for a thirty year period. Before applying the flow accumulation tool, I resampled the runoff raster to change its grid cell size to 30m, matching the elevation data used to create the flow direction grid. The result was a weighted flow accumulation value just upstream of the dam of 4,991,483.5 mm/year.

Conclusions

By manipulating the precipitation and elevation data obtained for Calf Creek Watershed, I estimated that 4,991,483.5 mm/year could be collected. This corresponds to 3,641,995 acre-feet of storage for the watershed as a result of the dam. This is much larger than the maximum storage allowed by the state of Texas without a permit. Therefore the dam would have to be constructed in order to allow overflow when the storage in the reservoir exceeds 200 acre-feet. However, the simulation of a dam in ArcGIS may not yield the most reliable results. The presence of a dam on Calf Creek was simulated in ArcGIS by altering the DEM, but a more accurate prediction of the hydraulic behavior of a dam across Calf Creek may be obtained using Hydrologic Engineering Center's River Analysis System (HEC-RAS). HEC-RAS would allow for various designs of a dam to be investigated and would also provide a better estimate of the effects on the floodplain as well.

Future Work

For a more accurate analysis of the potential storage that may be achieved if a dam is installed, Geometric data should be imported into the Hydrologic Engineering Center's River Analysis System (HEC-RAS). By creating a series of line themes in HEC-GeoRAS, such as stream centerline, main channel banks, and cross section cut lines, the geometric data can be prepared for import into HEC-RAS for analysis. In HEC-RAS, various designs for a dam may be considered such that the best alternative is selected for implementation. Some analysis in HEC Hydrologic Modeling System (HMS) may also provide a more accurate prediction of the rainfall and runoff processes.

References

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