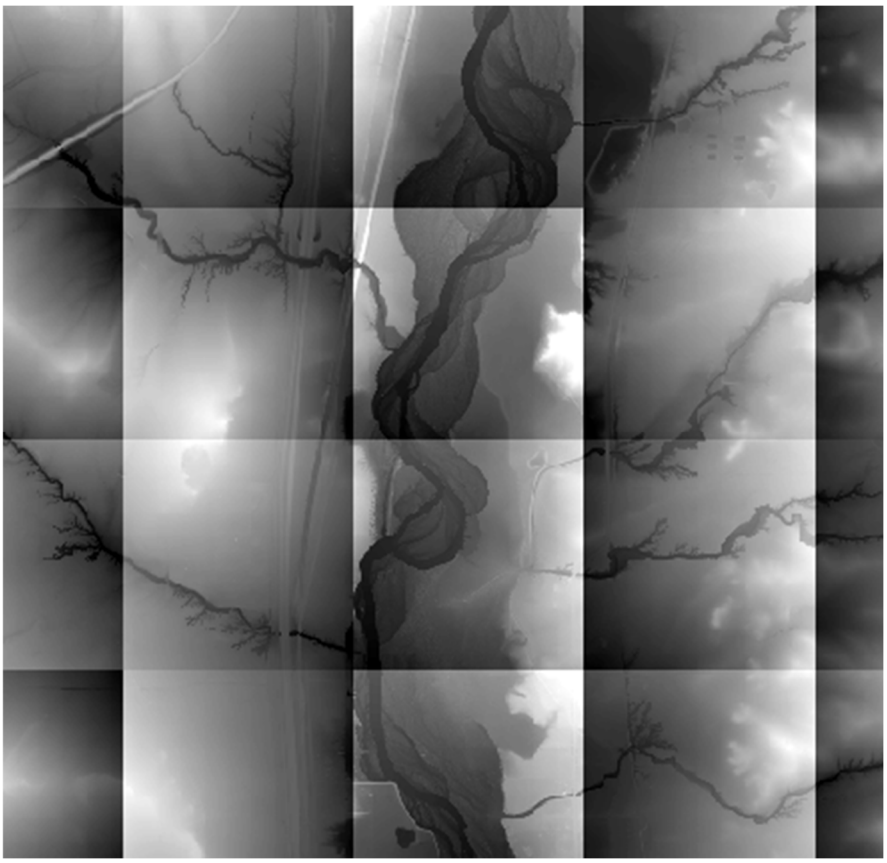
A Primer on the Utility of Fluvial Hazard Zone Mapping
Case Study - Fountain Creek, Colorado



Kevin Pilgrim, PE

Hydrology, Hydraulics, Fluvial Geomorphology

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Disclaimer

The purpose of this document is to provide the reader with an introduction to the Colorado Fluvial Hazard Zone Delineation Protocol (Blazewicz, et. al., 2020) that was developed after the floods along the Colorado Front Range in 2013. The author is volunteering this time outside of working hours and the work does not represent work or views of any employer.

The disclaimer from the Fluvial Hazard Zone (FHZ) protocol is the maps are not a prediction tool and intentionally do not use magnitude, frequency or rate of fluvial geomorphic hazards. Most flood hazard analysis involves assessment of recurrence interval and, therefore, annual exceedance estimation. This is used to make decisions by planners on how much money to spend to avoid the risk. At the end of the day, we do not know how much snow we will get in the winter nor when the next massive rain event will happen. That is life. It is a risky business.

1. Introduction

In September 2013, 16 inches of rain fell on the Colorado Front Range in a week and 9 inches in a day, at some locations (not accounting for spatial variability of rainfall). The magnitudes of the peak flows were estimated using stream flow gages (that did not break) and high-water mark estimations called Paleoflood estimation (Jarret and Tomlinson, 2000). Paleoflood estimation involves back calculating the peak flow of a flood event using physical, geomorphic indications of a past flood in the stream channel or valley. The use of the word Paleo does not indicate a time period, only that a flood event occurred in the past. After the 2013 floods, 100s of millions of dollars were spent restoring watersheds, fixing infrastructure and building resilience into the watersheds of the Colorado Front Range. Much of the impacts to infrastructure and homes occurred outside of floodplains mapped by the Federal Emergency Management Agency (FEMA). The Fluvial Hazard Mapping Protocol was born out of this recognition that pure hydrologic and hydraulic analysis is flawed and sometimes negatively influenced by political pressure. The purpose of the FHZ map is to inform about fluvial hazards that are not conveyed by FEMA floodplain maps nor do FEMA floodplain maps cover all the fluvial hazard zones throughout the country. Numerical hydraulic models are approximations of reality, but they are useful approximations when the limitations are understood and acknowledged. We will never have perfect computer models that describe the world. That is called virtual reality. It is best if we stay grounded in this reality and observe the natural world the best we can.

2. Data Collection

The Colorado Water Conservation Board (CWCB) has collected terrestrial Light Detection And Ranging (LiDAR) data throughout Colorado (https://coloradohazardmapping.com/lidarDownload). Data for this effort was downloaded through the website and was collected by Merrick and Company from April 21, 2016 to May 22, 2016. The date the LiDAR data was obtained is always important as river environments change quickly whether through human activities or river process.

The terrestrial LiDAR uses light to determine elevations of objects on the ground (Meng et al, 2010; see also Meng et al, 2009, Shan 2005, Sihole, 2001). The LiDAR is filtered to determine what the object is that the light has detected such as vegetation, road surface, buildings, ground surface or water. Terrestrial LiDAR does not detect water surface elevations as well as ground surface. The light reflects off of water differently and has a larger error in the estimation of the elevation. The data is prost processed, hopefully, to remove the areas identified as water bodies in through the filtering techniques (Yan et al, 2019).

Shown below in **Figure 1** is a screen capture from the Federal Highways Administration (FHWA) Two-Dimensional (2D) Hydraulic modeling reference document Robison et al, 2019). The hydro breaklines are a term for lines that represent breaks in elevation along linear features. A real world example of a

breakline would be the edge of a curb or the corner of a house where the foundation wall meets the footer. It is a line that is used when building triangulated irregular networks (TIN) from survey data. The LiDAR data collects points. Those points are then filtered to represent bare-earth. When the water surface elevation is removed due to error in elevation measurement the remaining surface has a “hole” across which elevation is interpolated on the TIN. The interpolated surface elevation over water bodies in illustrated in the bottom of figure 1 by the red dashed line. LiDAR data obtained from the CWCB may or may not have filtering techniques applied and may or may not use hydro breaklines.

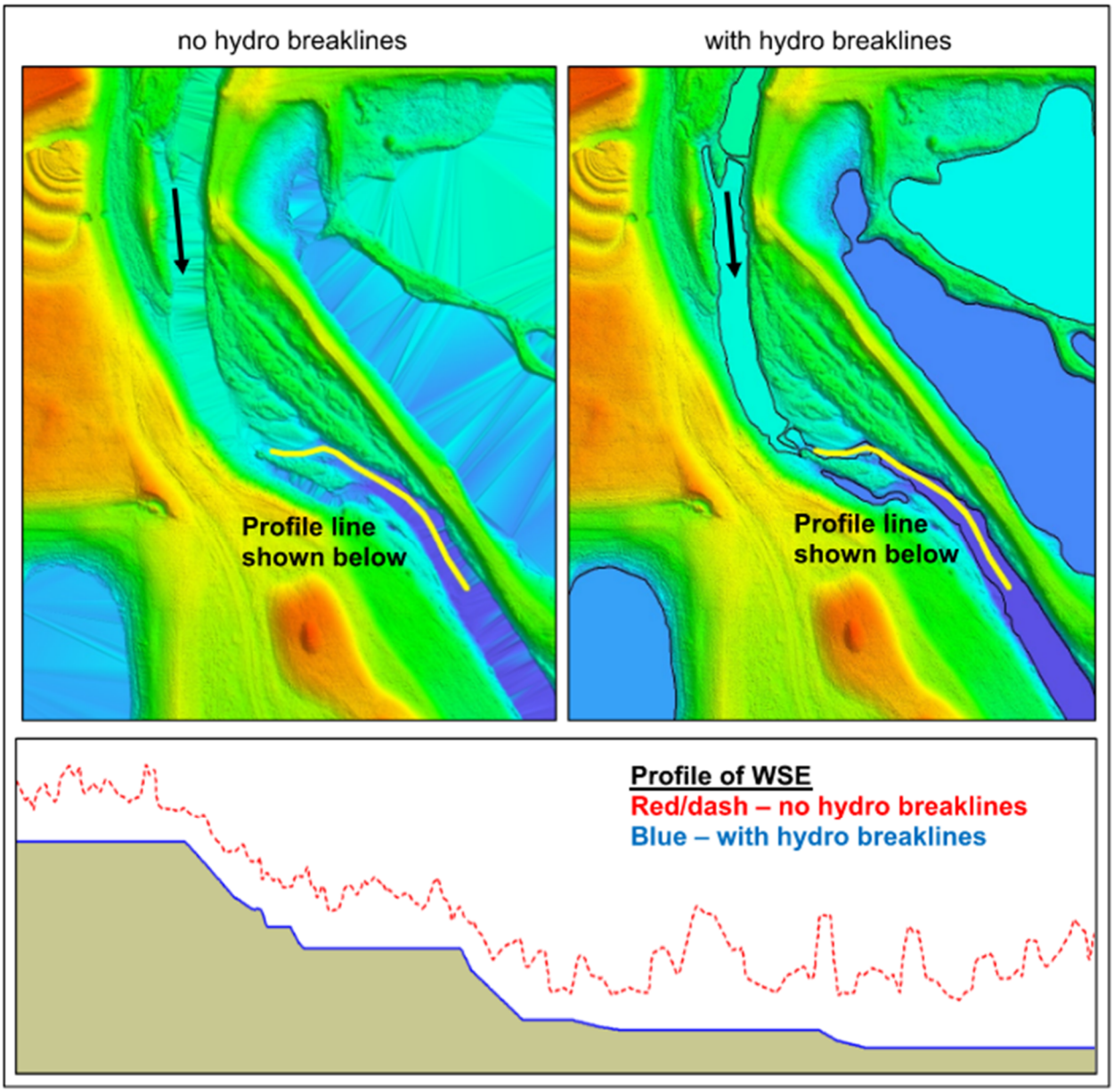


Figure 1. Screen capture from FHWA Two-Dimensional Hydraulic Modeling Reference Document (Robinson et al, 2019)

Once the Tin is created the final step in creating the Digital Elevation Model (DEM) is to use software such as ESRI ARC-MAP to process the TIN. The average elevation for each square based on the resolution of the original data. Typically, 3 ft by 3 ft data is warranted. Resolutions of 2 ft by 2 ft are better for use in hydraulic modeling. It all depends on the data collection methods, whether additional

bathymetric data was collected to supplement the LiDAR and the use of the LiDAR such as floodplain mapping or FHZ mapping.

3. Analysis

Due to limitations of time and acknowledging the focus of this document is a primer on FHZ mapping the analysis presented here is a qualitative effort. The full FHZ mapping protocol is comprehensive. One of the primary techniques of the FHZ protocol is use of a Relative Elevation Model (REM). To quote directly from the FHZ mapping protocol version 1.0, section 3.1.1 "Whereas a DEM represents the absolute elevation, a REM represents the elevation relative to the lowest point along the channel centerline (typically water surface elevation at the time of the LiDAR survey)." The author of this paper has some reservations about the utility of a Relative Elevation Model when the post-processing or filtering techniques as described above are unknown. As noted above, and it numerous peer reviewed scientific publications, terrestrial LiDAR does not accurately estimate elevation. It is important that the professional using the FHZ mapping protocol understand the origin of the LiDAR data as well as the resolution of the LiDAR data. The resolution refers to the cell size of the data as it was processed from the data points collected. The LiDAR data obtained from the CWCB website for this exercise has a resolution of 3 ft by 3 ft. This means the LiDAR data is representing bare earth with average elevations of 3 ft by 3 ft.

Figure 2 is a screen shot of the DEM as it was downloaded from the CWCB and using the default color in ARC-MAP 10.8.1. The LiDAR looks like squares due to how the data is organized. Each tile in this case is 3,000 ft by 3,000 ft. The numbers marked on figure 2 are used to call out points of interest. Below is a description of each number location.

1. Location # 1 is pointing to a tributary to Fountain Creek. The linear feature running north and south is likely Interstate 25 and can be verified by overlaying the data on a map. The bridge or culvert across the creek has been removed but not have been hydro flattened.
2. Location #2 is pointing to a tributary that has not been filtered to remove the bridge or culvert crossing the tributary.
3. Location #3 is likely a man-made side channel. The author is making an assumption based on knowledge of fluvial geomorphology and braided sand bed river systems.
4. Location #4 is likely a man-made area. Possibly a building or development area.

The point of the locations and observations is to illustrate that not all data is filtered and treated equally. Each of these data sets are collected over large areas. The metadata available from the CWCB website may or may not contain enough information to understand the post processing of the LiDAR to create the DEM. Each individual professional using the data must take care that the quality of the data meets the users' needs. In this case, the resolution of the data is likely meets the FHZ mapping protocol. The use of the DEM to create a REM would necessitate some form of hydro flattening in order to create an REM that is actually relative to a given water surface flow.

The next step in the process is to create one surface to work with. The tools in ESRI ARC-MAP were utilized to create a continuous surface (DEM) with the same resolution as the original tiles to preserve the data quality. A tool called a hillshade was used to create a visual three-dimensional (3D) effect on 2D paper and images. The hillshade is a separate data set that is not used for FHZ or hydraulic modeling. It is just for display. The colors representing the elevation range of the LiDAR data was changed for visual effect (**Figure 3**).

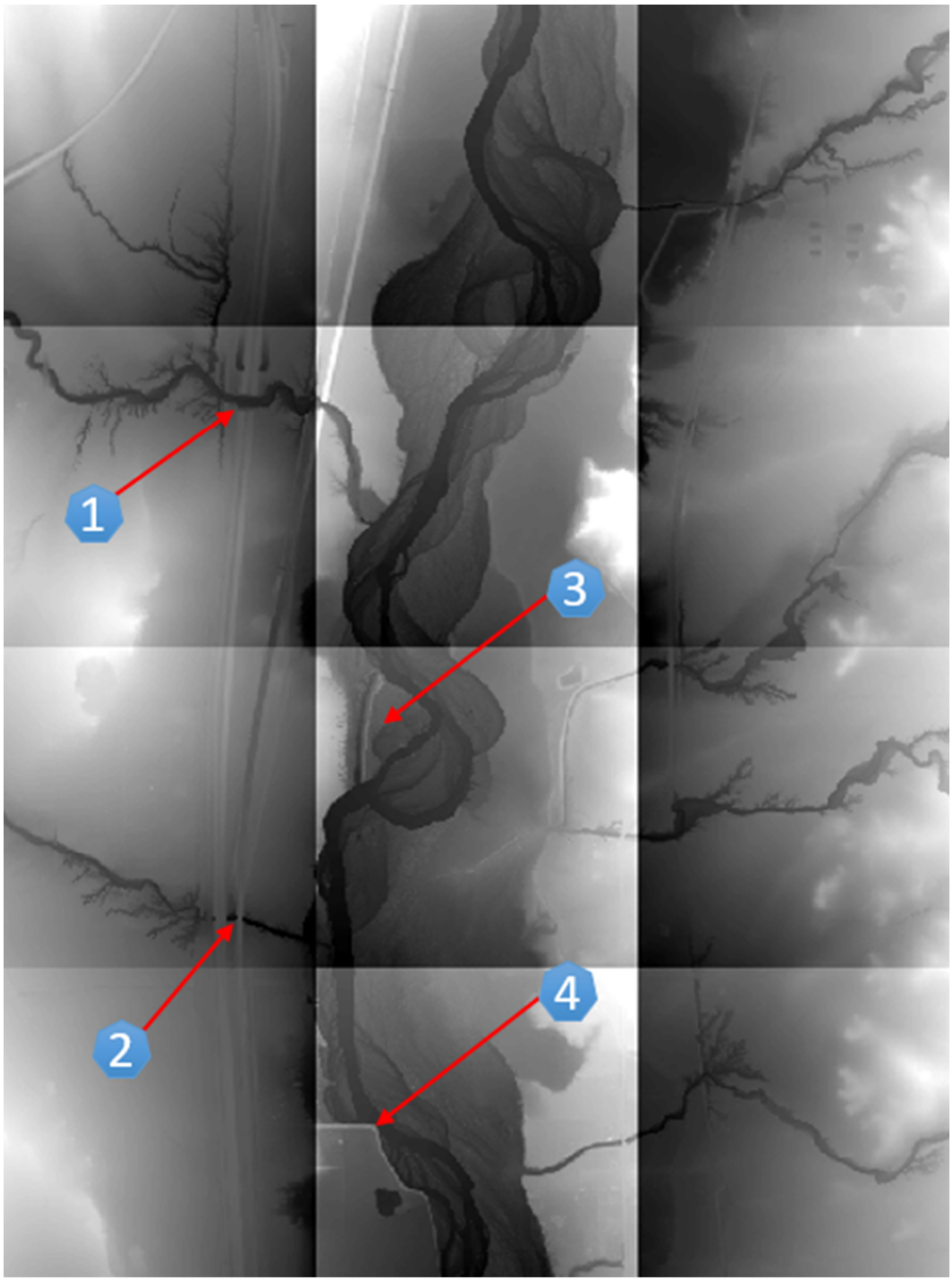


Figure 2. A screen shot of the LiDAR DEM. The grid pattern are the tiles that the LiDAR format comes in. Tiles are squares the LiDAR DEM is delivered in representing 3,000 ft by 3,000 ft areas.

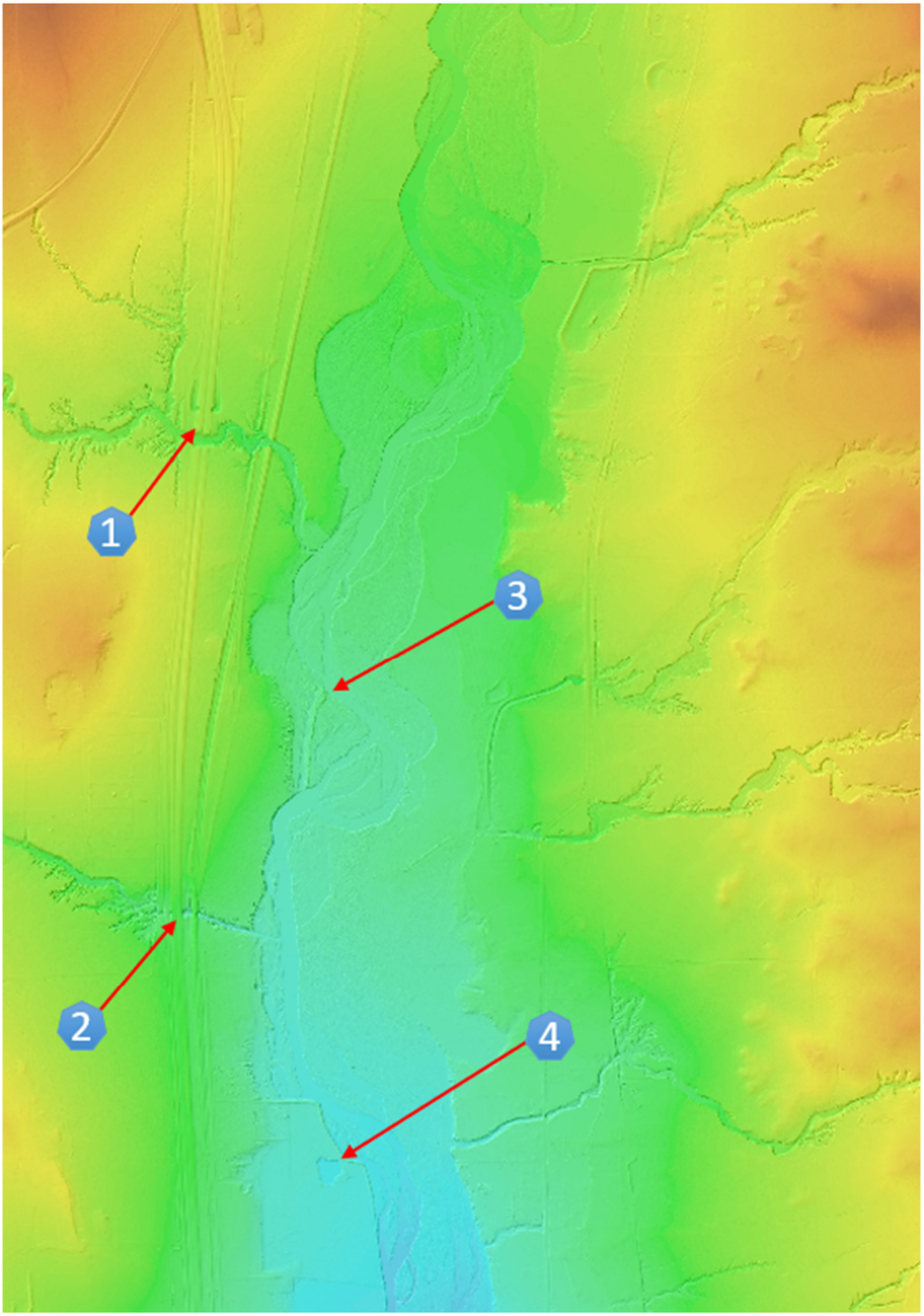


Figure 3. A DEM combined from the underlying tiles to create one continuous surface. The common points are left to illustrate common locations.

The next step for this primer was to change the color again and zoom in on one location in the river to illustrate the effect shown in figure 1. Figure 4 is a screen shot of the DEM. This time the color was changed and the hillshade effect was turned on for the DEM specifically. Using this technique accomplishes two things. First, the squares of the resolution of the data, the 3 ft by 3 ft cells can be seen. Second, the triangulation of the original TIN surface can be seen across what would be the bed of the Fountain Creek. This is the important part of the evaluation of the data. In this case, no hydro breaklines were created for the underlying data and, therefore, a REM will contain error based on where the triangulation occurs (see the red line in figure 1).

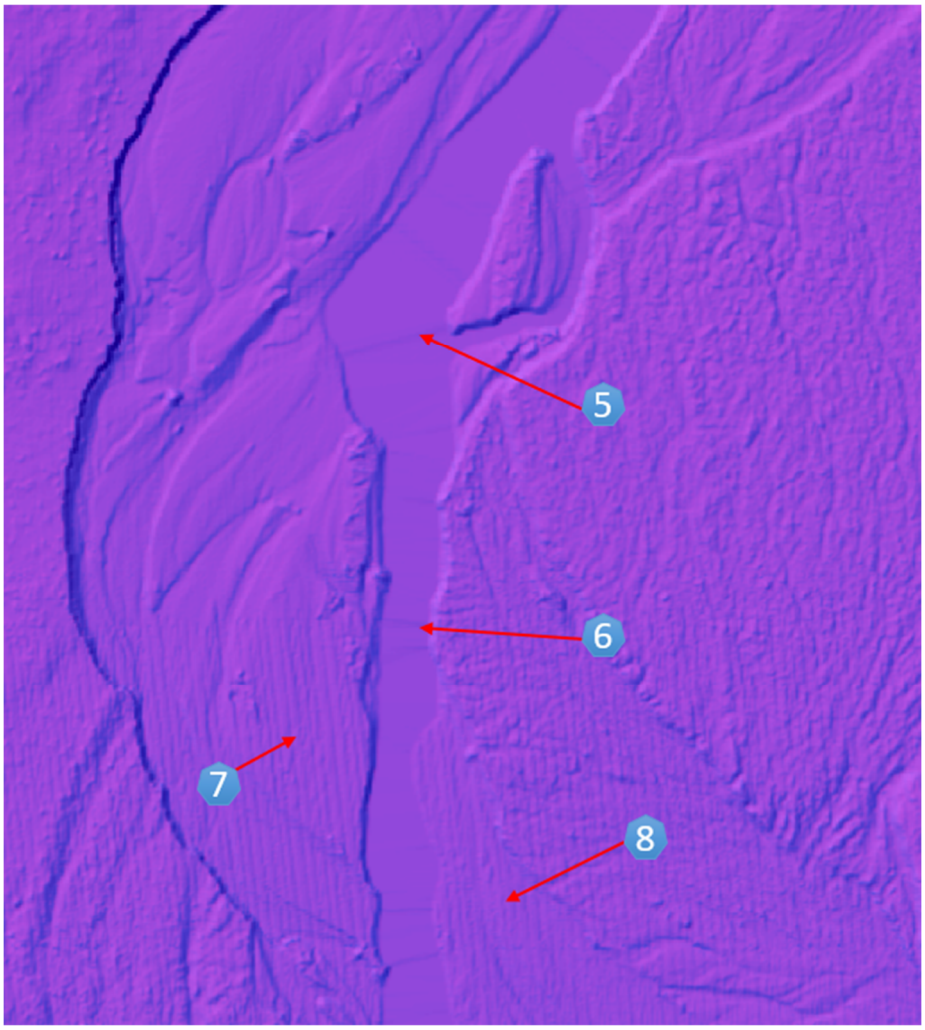


Figure 4. A screen capture from ESRI ARC-MAP with the color of the DEM changed. The hillshade effect was turned on for the DEM to illustrate the 3 ft by 3 ft resolution and the triangulation across the channel of the river bed indicating this DEM was not hydro-flattened.

In figure 4 points 5 and 6 are pointing to the triangulation across the bed of the channel. This means there is no elevation data representing the bed of the Fountain Creek. The elevation is only representative of the channel banks and it is unknow where the triangulated elevation is tied ot on the bank. It could be top of bank or bottom of bank depending on the technique used to process the LiDAR data. To fix this problem, the practitioner would need to obtain the original data from the CWCB website and post process the data points based on available data. This is a time-consuming process, but it is possible to accomplish. Points 7 and 8 are pointing to the squares that illustrate the resolution of the data.

The final step in this primer is to zoom back out to the original scale and just take a look at the potential fluvial hazard zone. Again, this effort is just to give the reader an understanding of the FHZ mapping potential. The full FHZ mapping protocol has not been followed at this point. The author is simply calling out preliminary features that may indicate the historic channel of the Fountain Creek and where the fluvial hazards may be. The basic premise of the FHZ map is rivers tend to find their way back to where they flowed previously regardless of the river engineering efforts that occur. “The FHZ is defined as the area a stream has occupied in recent history, may occupy, or may physically influence as the stream stores and transports water, sediment and debris.” (Blazewicz et al, 2020). Streams tend to follow preferential flow paths. If development occurs on an alluvial fan, chances are there is groundwater movement through the deposited alluvium and low area water will find its way to. **Figure 5** is a simple identification of the potential Fluvial Hazard Zone based on a cursory examination of the LiDAR data.

In figure 5 the arrows are intended to illustrate the potential meander zone of the Fountain Creek. The area show is north of downtown Pueblo, so it is more illustrative of an area not urbanized. There is a specific protocol for urban areas since the it becomes more and more difficult to identify past fluvial geomorphic signatures in heavily urbanized areas. Additionally, upstream flow regulation and flood control structures reduces the frequency of large flood events but does not eliminate them. The arrows in figure 5 simply represent the authors first impression of the historic stream flow. Braided, sand bed channels are very dynamic and can change with frequent flood events. The key point for sand bed channels is sand is always moving at any flow.

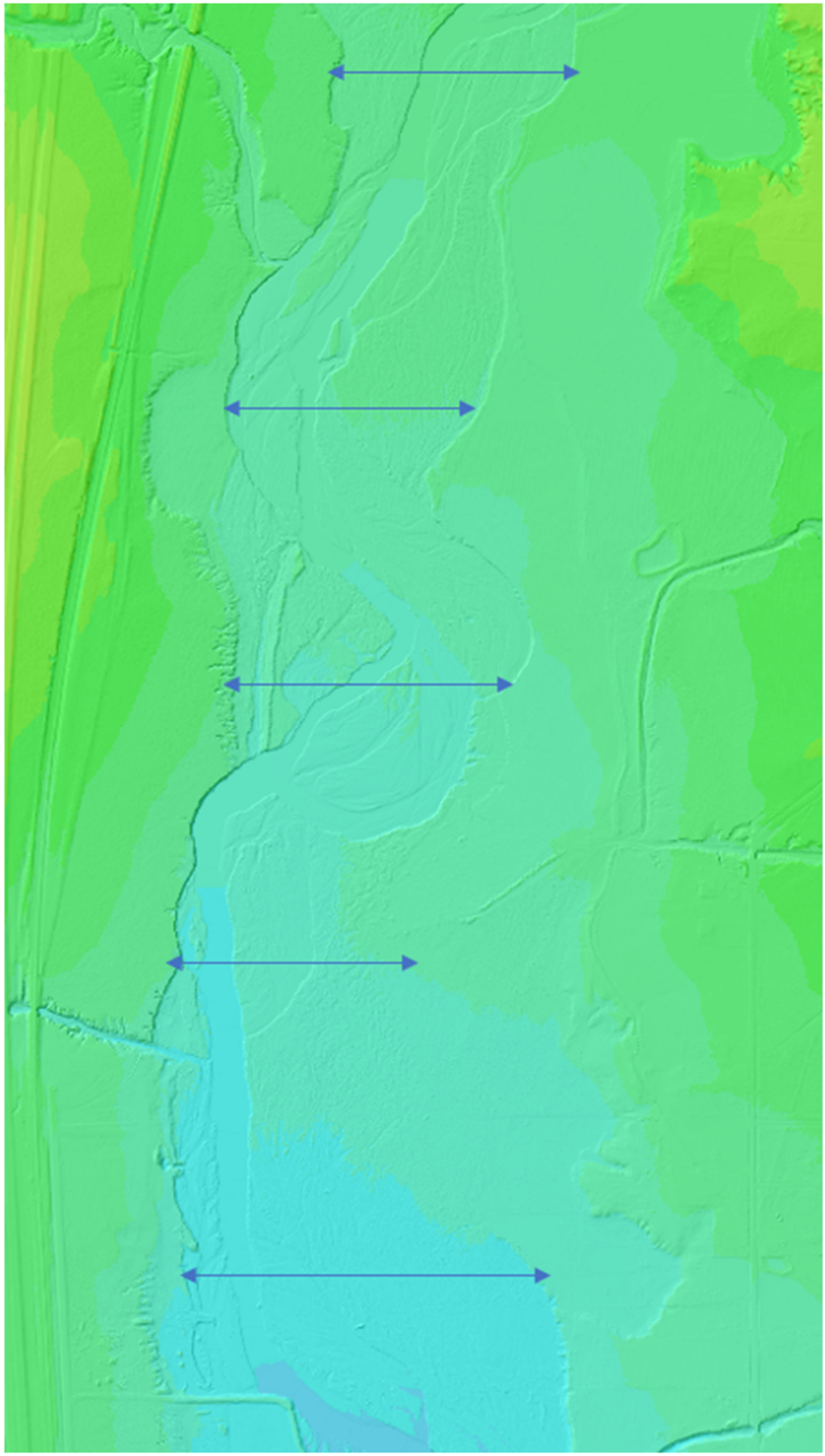


Figure 5. The potential FHZ zone based only a cursory examination of the LiDAR data for this primer.

4. Conclusions

The 2103 Colorado Floods had a deep impact on communities along the Colorado Front Range. Steep mountain terrain can and does generate a lot of stream power that can move a lot of sediment. Dynamic, episodic flood events can result in loss of life and destruction of public and private infrastructure. According to the FHZ protocol, 52% of flood insurance claims occurred outside of regulatory FEMA mapped floodplains. The FHZ mapping protocol, when used correctly and peer reviewed by independent third party professionals, can create a better illustration of the hazards from flood events we all live with whether we recognize them or not. I will leave the reader with one final quote from the FHZ protocol that I firmly support. “While the process of identifying fluvial geomorphic hazards on a map may be a new endeavor in many places, the act of mapping does not introduce a new hazard to a community or landowner. The hazard has always existed;” (Blazewicz, et. al., 2020).

5. References

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