Flood Analysis of Cedar Rapids Using LiDAR

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Lidar: Principals and Applications

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Contents

Introduction:

This project evaluates the flood hazard concerning Cedar Rapids, Iowa, specifically the downtown section bordering the Cedar River. By utilizing LiDAR-derived elevation data alongside relevant geospatial datasets, I executed the flow modeling of surface water to locate low-lying regions susceptible to flooding. This analysis aimed to evaluate how topography, especially its slope and impervious areas, and how it facilitated concentration and accumulation of runoff.

Subsequently, I analyzed the estimated flood risk zones against FEMA floodplain maps to determine where terrain evaluation using LiDAR might complement existing models and floodplain maps by revealing additional risk areas not included in the FEMA maps. As a result, this project aims to improve my understanding of the flood processes in Cedar Rapids and show how important LiDAR data is when analyzing flood risk and planning urban developments.

Data:

The project used a variety of datasets to assist with hydrology modeling, stream network creation, and flood risk evaluation for Cedar Rapids downtown. Geotree supplied the primary elevation data as it had high-resolution LiDAR point cloud data. I performed ground point classification from this dataset and derived a Digital Terrain Model (DTM), which became the basis for all the later terrain and hydrology analyses. The precision modeling possible for surface runoff within Cedar Rapids is due to the high spatial accuracy of the LiDAR dataset, together with subtle topographic depressions that control local flooding dynamics.

The National Hydrography Dataset (NHDPlus High Resolution) provided a vector dataset containing features such as rivers, retreats, and waterbodies, which helped me assess LiDAR stream networks. With the comparison of modeled flow paths and NHDPlus vectors, it was possible to refine flow accumulation thresholds and verify the accuracy of stream alignments (refer to Map 2).

The NOAA Atlas 14 contains an estimated statistical rainfall dataset, which served for modeling inputs, and for this specific project, allowed me to access the rainfall estimate for Cedar Rapids. Incorporating the return period of 100 years, 24-hour duration, provided a 7.49-inch storm depth, which was useful for runoff estimation and an analysis of flood potential (see Map 4).

I obtained USGS Streamflow data to assist in the corroboration of calculated runoff and accumulation patterns. Each day's streamflow data provided context for interpreting modeled flow paths, estimating flood volume and stage, and assessing high-flow metrics during Cedar River inflow and tributary inflow floods.

The 2021 National Land Cover Database (NLCD) obtained urban land cover and impervious surfaces. This raster classification at a 30-meter resolution includes impervious surface classes, which were reclassified for purposes of runoff estimation. With the slope and flow accumulation datasets clipped to impervious surfaces, I determined how urban growth contributes to increased runoff and surface flooding (see Map 3).

Lastly, I referred to the Iowa Flood Information System (IFIS) which is an interactive website with historical flooding data and depth grids of flood hazard zones. This data set helped validate existing recorded events with modeled flood areas. IFIS data helped verify the model’s accuracy in high-risk zones in Cedar Rapids downtown.

Methodology

The project began by creating surface elevation models based on LiDAR data. I started with the USGS 2019 dataset, from which I previously processed raw point cloud data, classifying it to extract the ground points and removing vegetation, buildings, and other features above the ground. Using these ground classified points, I produced a Digital Elevation Model (DEM) of the bare-earth terrain surface. I generated a Digital Surface Model (DSM) which included the elevation of tree tops, roofs, and other structures using the first return points.

Compared to the bare terrain DEM, the surface DSM has a noticeable elevation relative to the terrain features. Comparing both models allowed for estimating the vertical differences between ground and surface features, which is vital to determining obstruction to overland flow. This analysis enhanced understanding of areas within infrastructure that might suspend natural water runoff in urban settings and, as a result, disrupt irrigation flow patterns.

Once I finished developing the terrain model, I proceeded with surface hydrology. I employed a sink removal algorithm using the DEM to fix lower resolution data artifacts and noise. This created a surface capable of realistic flow modeling. Then I used algorithms and determined the flow direction calculating water's hypothetical movement over the region's elevation descending steep slopes. After that, I conducted flow accumulation calculations identifying topographic high points where overland flow converges.

These calculations along with the flow data helped define straight features which had a high probability of developing into linear drainage networks or flood-sensitive basins (See Map 1).

I conducted a stream alignment accuracy assessment for the modeled hydrology. I validated the defined stream network with the NHDPlus HR hydrography dataset to check against the accumulation thresholds and adjusted channel density and spatial distribution to fit real channels. This demonstrated the modeled network relied on topographic signals instead of urbanized boundaries and abrupt elevation changes urban barriers on elevation-dependent flow interruptions (See Map 2).

In slope and elevation analysis, combined with flow accumulation analysis, hydrologic depressions and flat places with low relief where water collection is highly probable were recognized. These areas were marked as vulnerable to flooding, especially during heavy rainfall. To define the water input, historical precipitation returns periods data were used, particularly a storm of 100-year recurrence on a 7.49-inch rainfall that was returned for 24 24-hour duration (NOAA Atlas 14). This information aided in estimating the value for surface water volume and the potential stress runoff that would be exerted on the land. I also evaluated if essential features such as steep banked proportional basins would allow accumulation or massively divert large amounts of runoff (see Map 4).

To convey the high spatial extent of flood risk, modeled flow paths, and concentrations of runoff, I created a set of illustrated maps (Maps 1-4). These graphics were meant to illustrate not just the flood zones, but also the newly identified areas of concern which were particularly due to urban sprawl, inadequate draining systems, and slight descending ground depressions. The maps are very beneficial in city planning, response to emergencies, and in studying the region's hydrology and the associated dynamics.

Results

This project aimed to analyze surface water movement and flood vulnerability in the downtown Cedar Rapids region, using LiDAR-derived elevation data alongside hydrological models. Accumulation of flow was calculated from the Digital Elevation Model (DEM), which enabled visualization of the revealed drainage driven by the slope of the terrain. Surface flow runoff emerged as linear and depicted channels within various topographies, with an increase in increment, as shown in Map 1.

Although circular depressions in the contours do not directly signal flooding, they create bottlenecks where a collection of water can potentially submerge and then exacerbate the impact of floods on the site and expand the radius about the center of the inundation.

Flow accumulation paths were fully corroborated with constructed features such as alleys, road cuts, and stormwater known corridors. These patterns support the argument of how man-made infrastructures are incorporated with the natural landscape, accommodating surface water in a directed manner. Map 1 highlights dominant surface water runoff along predictable gradients about the elevation, demonstrating accuracy.

To show where concentrated surface runoff is likely to develop into streams, a threshold was placed on the accumulation raster. This value was set with respect to stream density and the local slope of the area. As shown in Map 2, the modeled stream network was in good agreement with other datasets of hydrology The Cedar River watershed dataset had, which was primary channel-driven. Besides confirming known drainage pathways, the model exposed numerous unmapped drainage lines in flat, impervious zones, especially within urbanized parts of the basin. While smaller tributaries and headwater channels may not be included in federal datasets such as NHDPlus HR, they are important for surface flooding during high precipitation events.

Runoff risk was analyzed further using slope rasters and land cover classification. Areas likely to produce rapid runoff due to steep slopes were reclassified. When combined with urbanization data, patches of impervious surface were identified as obstructions to water infiltration. Map 3 features soil polygons derived from the NRCS Web Soil Survey which adds context for potential runoff. Special attention was paid to Group D soils in the region because they have low infiltration rates. These poorly drained soils within Cedar Rapids tend to be adjacent to some highly developed, steeply sloped areas. These regions, particularly around the downtown areas, cause substantial surface runoff as well as heightened flooding due to strong convective storms.

An 100-year, 24-hour storm event was simulated during rainfall, where a 7.49 inch precipitation (NOAA Atlas 14) measurement was used. The resulting flow accumulation and runoff areas were analyzed alongside historical flood extent data and FEMA flood maps. As displayed in Map 4, considerable spatial alignment was noted between documented floods near the model's high-risk zones. This relationship confirms that topographic and land cover features such as slope, elevation, and infiltration capacity have practical roles in predicting flood behavior. The integration of LiDAR data of high precision along with hydrological modeling helps us identify water-related challenges in urbanized watersheds.

Regulatory floodplain maps aid in the risk assessment process, however, detailed topographical studies prove to be useful for zoning, emergency response, and infrastructure development in flood prone cities such as Cedar Rapids.

Discussion

To determine potential locations of channelized concentrated runoff, a flow accumulation cutoff was applied to the DEM created from LiDAR. Observed stream density and topographic changes across the city center of Cedar Rapids were used to refine this threshold. Model stream networks have been integrated with other stream and river datasets, and their confluence with major stream corridors within the Cedar River watershed was important. Still, the model indicated additional urban draining located within low-slope, impervious areas that were absent from national datasets. These streams, together with small headwater streams, provide a more precise representation of anticipated runoff during severe precipitation events (Map 2).

The combination of elevation, slope, and flow accumulation intensity was utilized to identify flood-prone regions. Affected target zones flagged were comprised of low and shallow relief with high contributing flow. **While low elevation does not directly equate to flooding, it adds to the risk of water pooling at certain sites, damaging infrastructure and property.** This flood hazard analysis corroborated known floodway corridors but also depicted unmapped high-risk regions within dense urban central blocks.

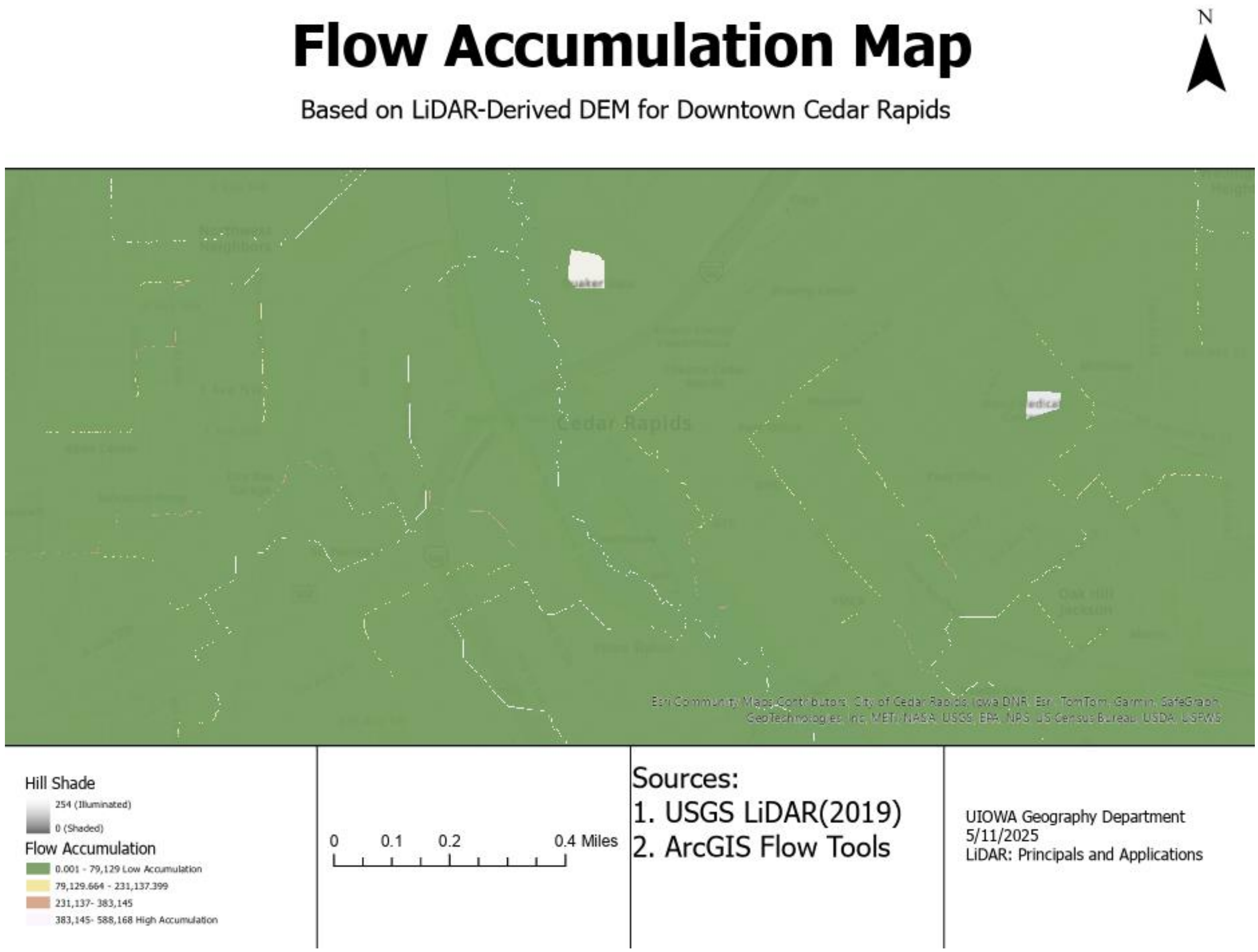
Map 1 illustrates areas characterized by increased flood risk and susceptibility linked to underlying 215 meters in elevation, demonstrating how terrain-based models identify hidden flood risks.

Zones of steep slope with the potential to give rise to surface runoff were extracted through the reclassification of slope rasters. These zones were integrated with land use data to capture urbanized areas as well as regions which, due to their soil type, have very little possibility of absorption. The soils were categorized using NRCS hydrologic groups. Group D soils, known to have low infiltration, steep urban soils, and even urban soils matched significantly in distribution. These overlaps, particularly within Cedar Rapids region, suggest areas where rainwater is likely to be collected due to inadequate drainage systems and heightened rainfall. The combined increase of urban land cover and poor soil types significantly contribute to flooding exacerbated by storms. (Map 3).

Simulated high-intensity storm events utilized a 100-year, 24-hour rainfall estimate of 7.49 inches from NOAA Atlas 14. Areas with high runoff were modeled from flood prone regions mapped using LiDAR-derived DEM and showed rigorous correlation with known areas flooded previously. Risk zones identified were taken and combined with FEMA mapped hazard zones to evaluate how floodplains depict observable behavior in surface extreme precipitation.

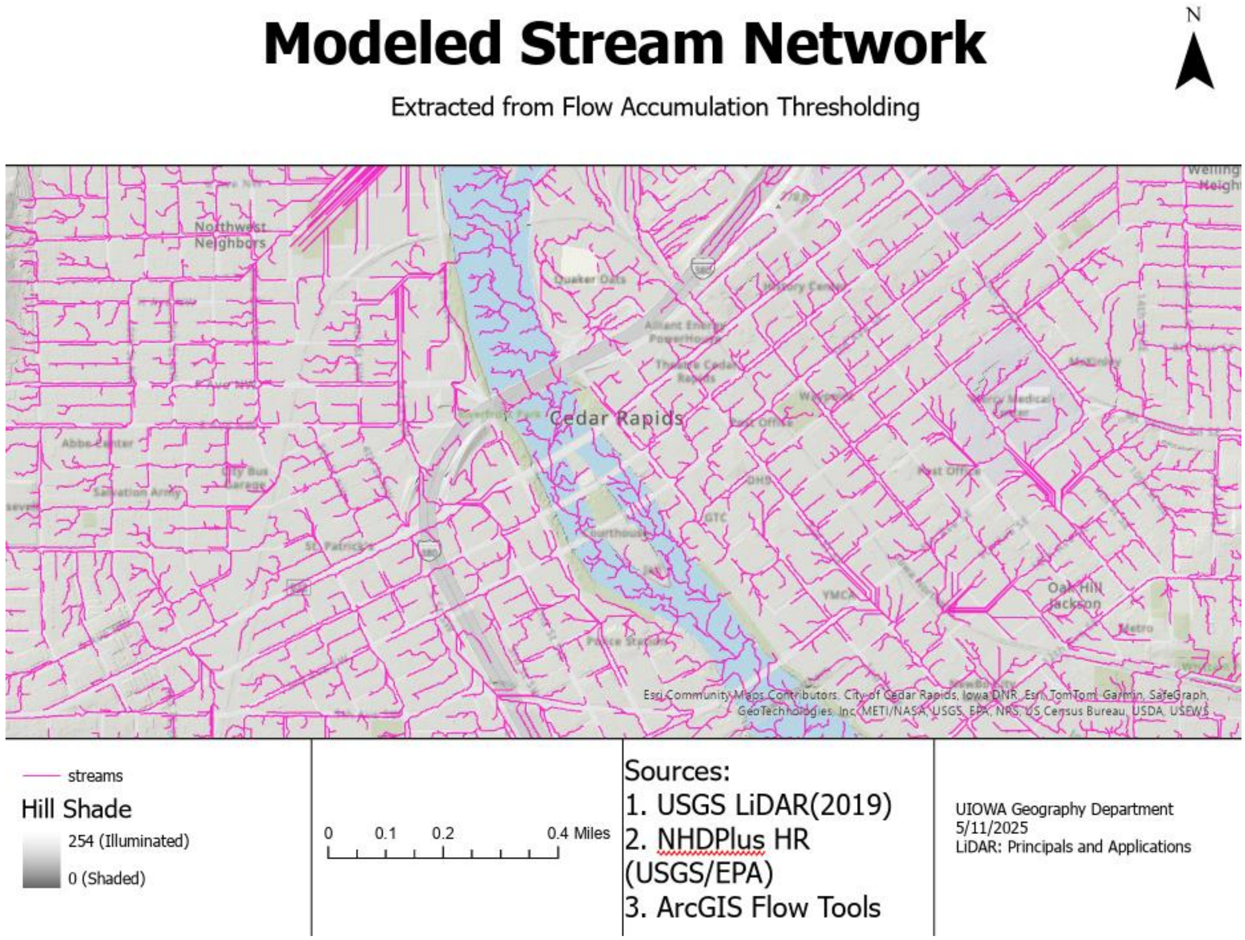
The findings validated that the elevation, slope, impervious surfaces, and poorly draining soils all strongly predict flood behavior in the downtown area of Cedar Rapids. Topographic depressions, while not responsible for causing floods, do serve as accumulation zones which increase impact severity (Map 4).

Appendix



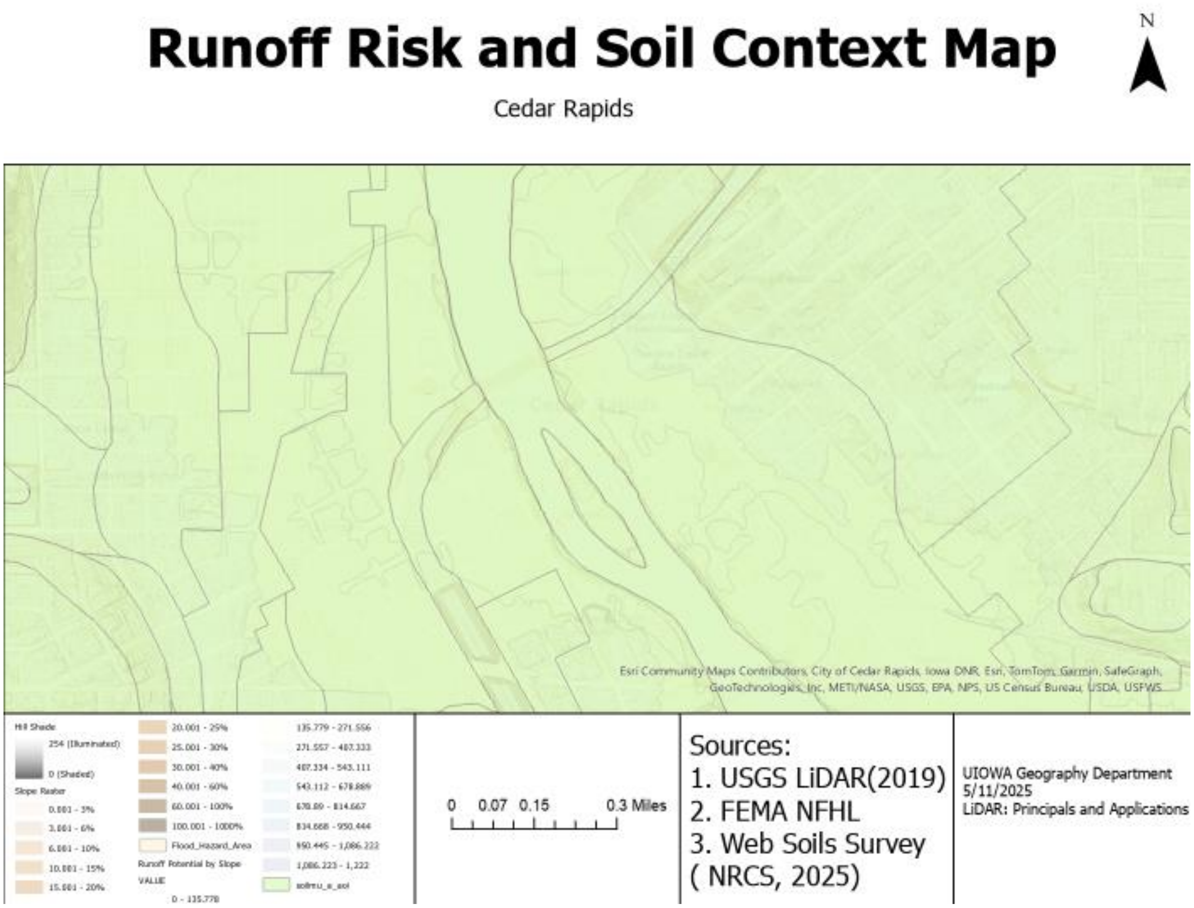
(Source 1: My flow accumulation map. This map represents the amount of accumulation, red being the highest and green being the least.)

Appendix



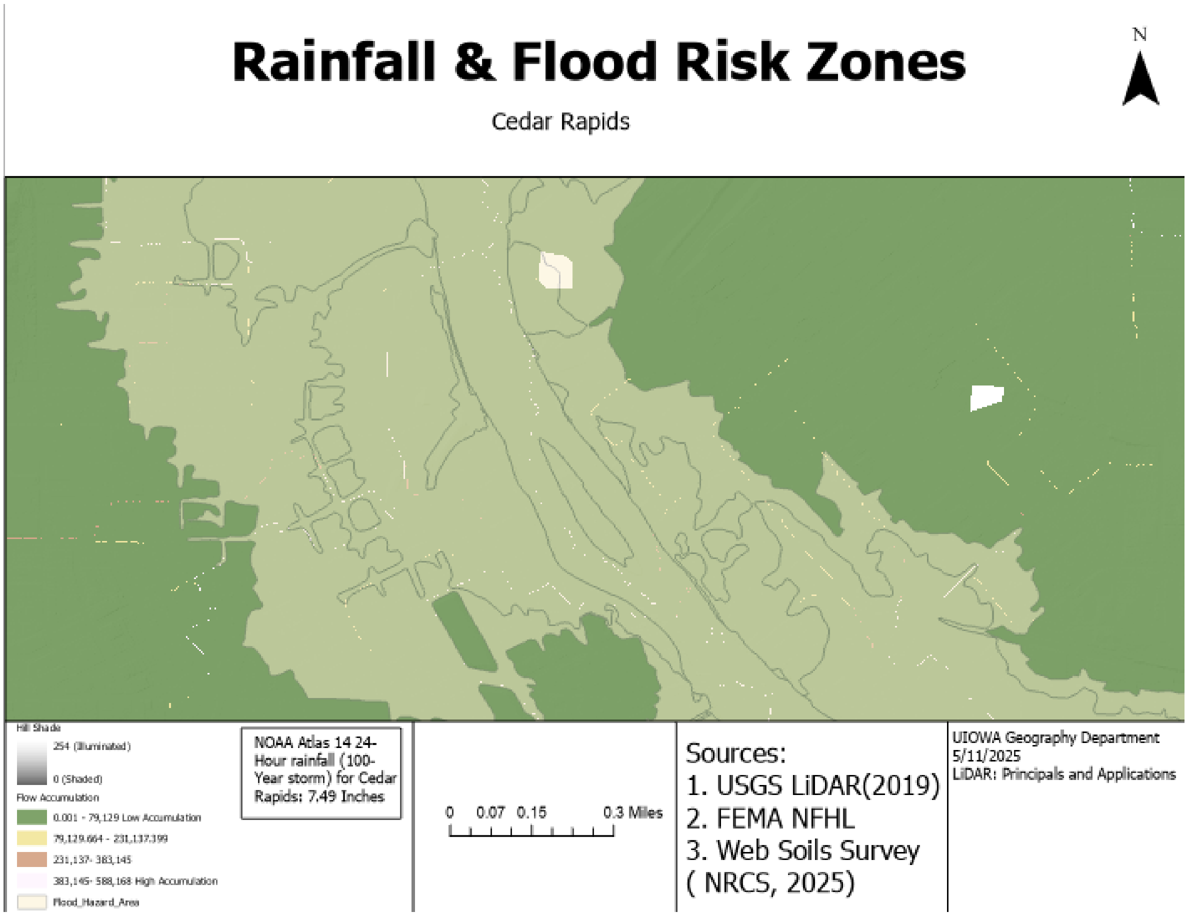
(Source 2: My modeled stream network. This map represents both major and minor flow paths, magenta lines are the flow paths.)

Appendix:



(Source 3: My Runoff Risk and soil context map.)

Appendix



(Source 4: My Rainfall and flood risk zones. This map represents the amount of accumulation, red being the highest and green being the least.)

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