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Enhancing Culvert Capacity Assessment Through Regression Analysis

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Introduction

Floods are widespread and destructive, requiring effective disaster preparedness. New Mexico's diverse terrain adds complexity to flood resilience efforts. Accurate culvert capacity assessment is vital for effective flood forecasting and emergency planning. This study aims to bridge the gap in culvert capacity assessment for more than 40,000 culverts in New Mexico.

Objective

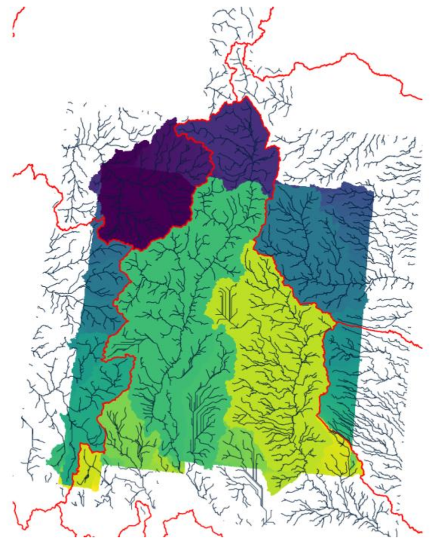
The study aims to identify culverts peak discharge through regression analysis for different recurrence intervals and compare that with the actual capacity.

Materials and Methods

Experimental methods

1. Hydrologic Unit Code (HUC) watershed dataset integration

This method integrates the Hydrologic Unit Code (HUC) watershed dataset with the Digital Elevation Model (DEM) to analyze watershed characteristics and enhance the representation of natural boundaries. While the DEM effectively captures topographical features, challenges persist in accurately modeling flow direction through culverts.

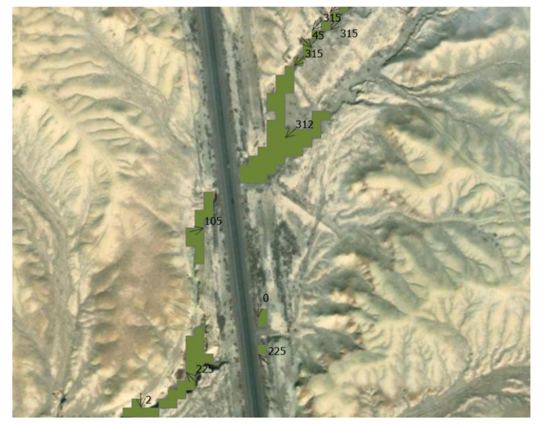


2. Integration of bridge and culvert data

Flow accumulation lines were developed by integrating culvert and road network data into a modified DEM, raising road elevations where no culvert lines existed. The analysis revealed inaccuracies, such as flow lines bypassing culverts, forming sinks in areas lacking hydraulic structure data, and ongoing challenges with flow direction and line terminations.

3. Determination of flow direction angle for each digital dam

Digital dams, identified by subtracting the raw DEM from the filled DEM, commonly formed near bridges and culverts. While flow direction angles were calculated using sine and cosine conversions, determining the final outlets of these digital dams remained a persistent challenge.



Hydrograph Generation

Fenton's (1992) equation for the inflow hydrograph $Q(t)$ in volume per time is defined as

$$Q(t) = Q_0 + P \cdot t^s \cdot e^{-ft}$$

where

- t is time,
- Q_0 is a base flow in the same unit as $Q(t)$,
- P and f are constants in the same unit as $Q(t)$and the inverse unit of t,
- s is a dimensionless constant

Peak Discharge and Culvert Capacity Analysis

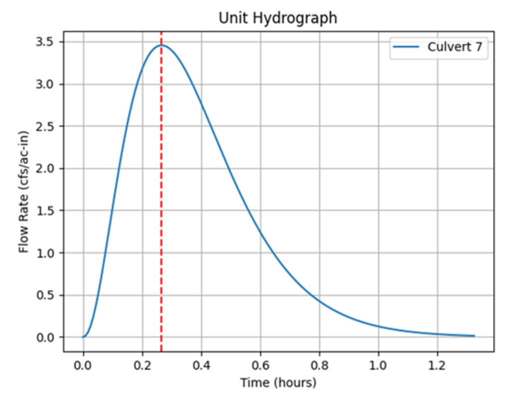
United States Geological Survey (USGS) Scientific Investigations Report 2008-5119 was used to calculate peak discharges for different recurrence intervals based on regional regression equations. GIS analyses were conducted using GRASS GIS, and the actual culvert capacity was evaluated using Manning's equation and inlet control equations. These methods enabled a comprehensive assessment of culvert performance under varying hydrological scenarios

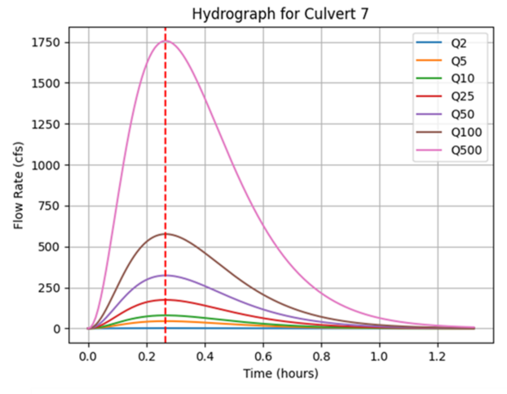
GRASS GIS

r.flowaccumulation (Cho, 2023)

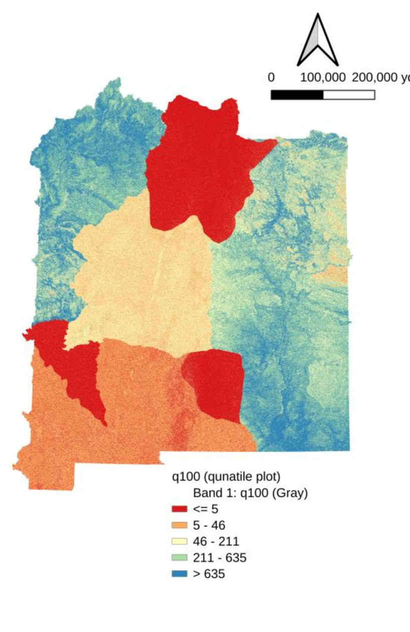
Results

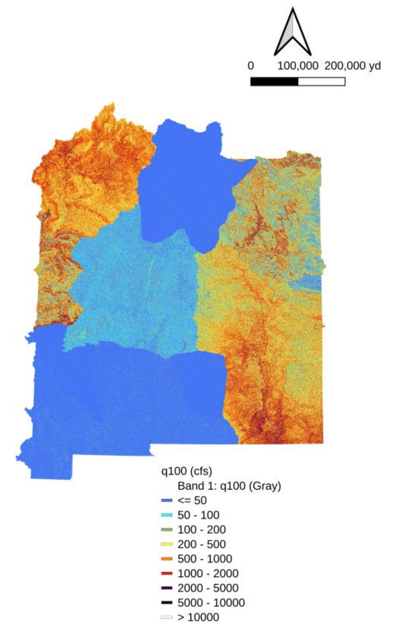
Unit hydrographs were generated for each culvert using the report 'USGS Relations for Estimating Unit-Hydrograph Parameters in New Mexico' and Fenton's equations.

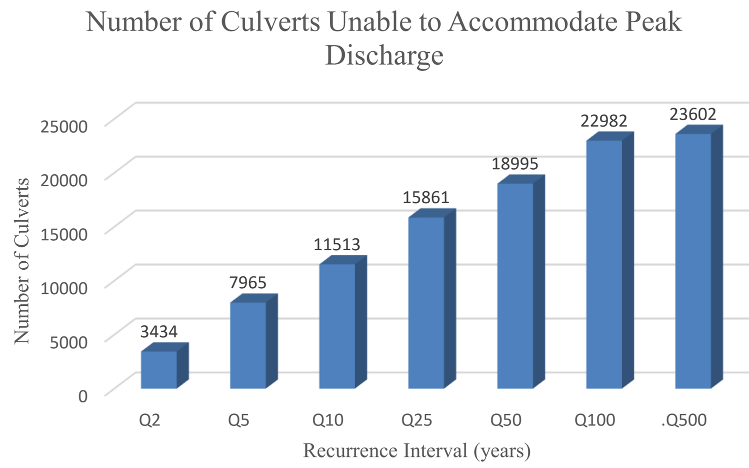




The discharge and quantile plot are presented for a return period of 100 years.







Flow Accumulation Comparison

The flow accumulation values (numbers) are overlaid with the National Hydrography Dataset (lines) and United States Geological Survey (USGS) StreamStats (yellow cells), illustrating variations for different raster resolutions.

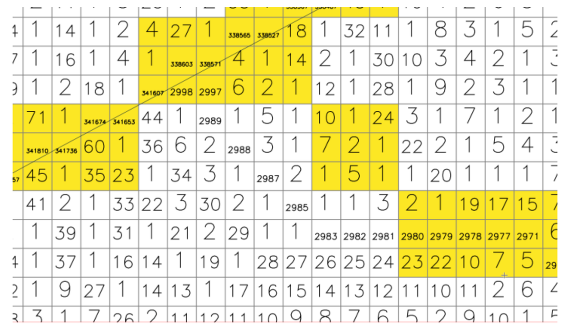


Fig. : Flow Accumulation Derived from 10 m Resolution DEM

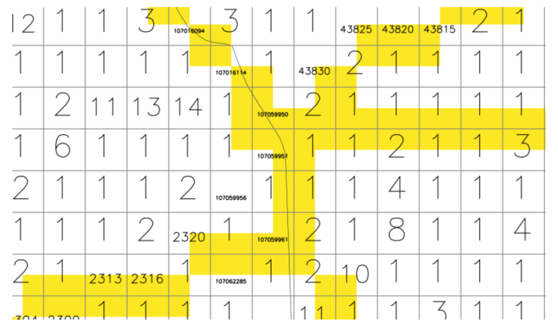
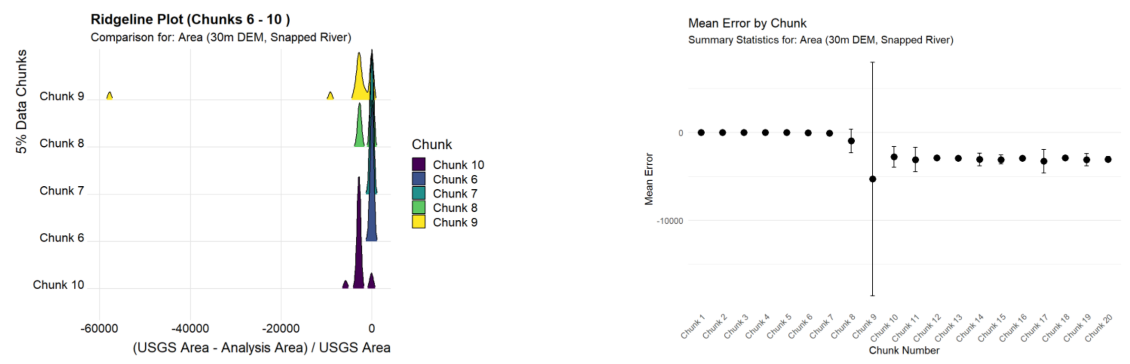


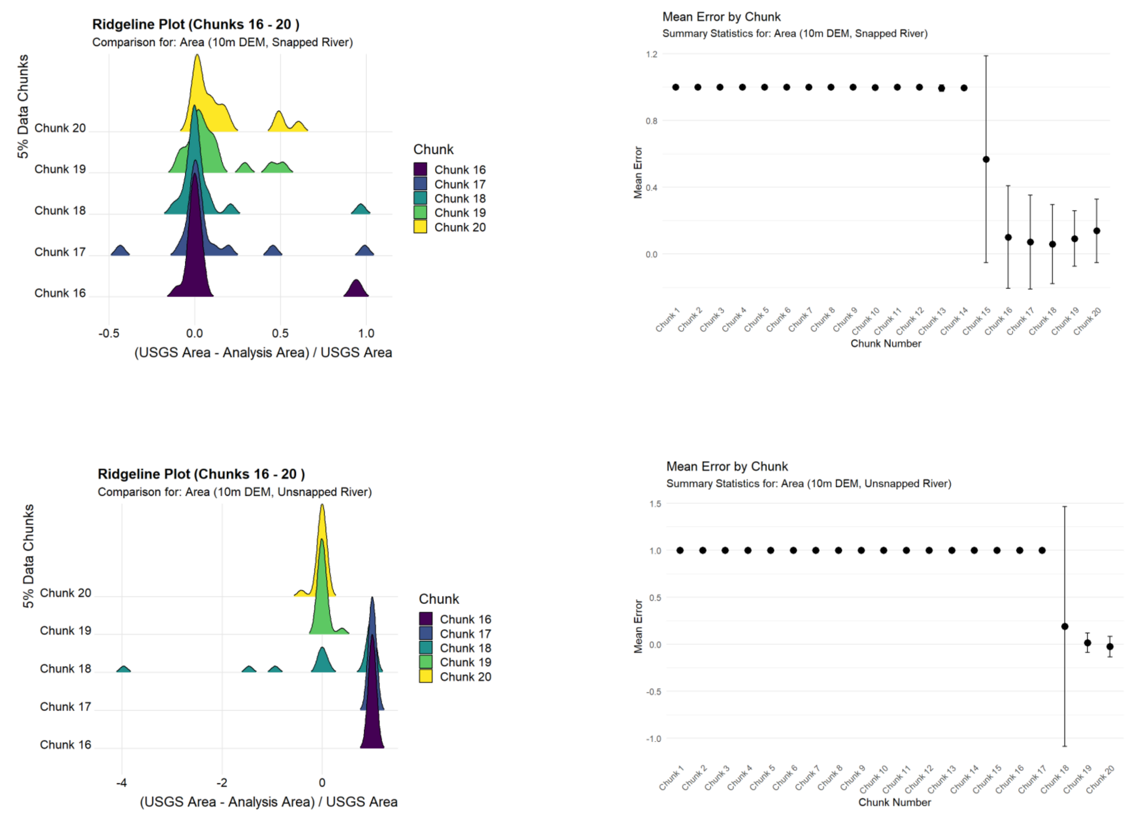
Fig. : Flow Accumulation Derived from 30 m Resolution DEM

Fig. : Showing the StreamStats and NHD lines only

Area Uncertainty

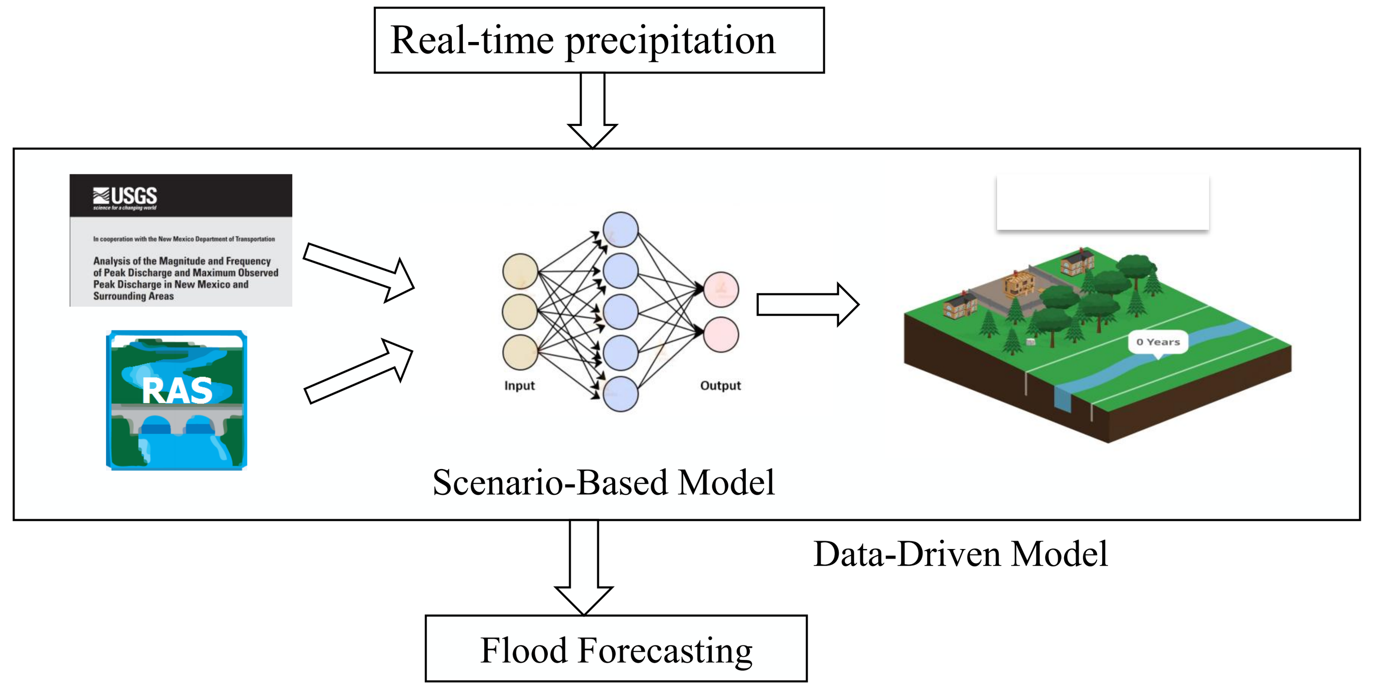
Area uncertainty analysis was conducted by comparing the USGS drainage area with three flow accumulation datasets: 30m DEM (snapped to the nearest high-flow accumulation cell) and 10m DEM (snapped and unsnapped). Relative errors were calculated, and the data was organized into 5% chunks sorted by minimum to maximum drainage area. The results were visualized using summary statistics plots and ridgeline plots to illustrate error distributions across selected chunks..





Future Work

The HEC-RAS simulation results, combined with USGS analysis data, will be utilized to enhance flood forecasting capabilities in the future. By integrating these results with real-time precipitation data and scenario-based models, a data-driven framework will be developed to predict flood extents and impacts more accurately.



Acknowledgment

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Reference

Cho, H., 2023. Memory-Efficient Flow Accumulation Using a Look-Around Approach and Its OpenMP Parallelization. Environmental Modelling & Software 167, 105771. doi:10.1016/j.envsoft.2023.105771.