REMOTE OBSERVATION OVER TIME (DRONE IN A BOX) - PHASE I

Task 1 Report – GIS Analysis of Natural Hazards to Roadways in MT

Prepared by

Ian Hellman, UAS Pilot, Technician, and GIS Analyst, and

Jeremy Crowley, Director, Autonomous Aerial Systems Office

University of Montana

Prepared for the
MONTANA DEPARTMENT OF TRANSPORTATION
in cooperation with the
U.S. DEPARTMENT OF TRANSPORTATION
FEDERAL HIGHWAY ADMINISTRATION

February 25, 2025

Table of Contents

List of Figures

I. Natural Hazards in Montana

This report is intended to be a GIS analysis and characterization of the natural hazard risk to transportation infrastructure in Montana by County. Globally the expected annual damages to road and railway infrastructure due to natural hazards is estimated to be from \$3.1 to \$22B (Koks et al., 2019). In 2015, MDT implemented a Rockfall Assessment Management Program (RAMP) (Landslide Technology, 2015) and the analysis determined that rock slope management costs would be approximately \$35M per year. In 2022 the US Department of Transportation (DOT) provided over \$513M in emergency relief to make repairs to roads and bridges damaged by natural disasters (Stone, 2022). The DOT also announced a \$7.9B program Promoting Resilient Operations for Transformative, Efficient, and Cost-saving Transportation (PROTECT) to help states and communities prepare and respond to extreme weather events from 2022-2026 (USDOT, 2022). In 2024 the Federal Transit Administration awarded \$110M to state DOTs to recover from recent natural disasters (Druga, 2024). In 2022, a single historic flood event on the Yellowstone River cost \$1B in federal recovery costs and infrastructure repairs (Tester, 2023).

Natural hazards that can affect transportation infrastructure in Montana include floods, rockfall, landslides, earthquakes and active faults. The Montana Bureau of Mines and Geology (MBMG) has a Geohazards group that has mapped active faults, earthquakes, and landslides throughout MT (MBMG, 2024a) and the USGS has a US landslide inventory that includes MT (USGS, 2024b). According to the National Ocean and Atmospheric Administration (NOAA) storm event database, from 2010 to 2024 there were 198 days of flooding and 490 flood events in MT and these events have affected all 56 counties in MT (NOAA, 2024). MDT implemented a Rockfall Assessment Management Program (RAMP) (Landslide Technology, 2015) to determine the slope stability in proximity to roads in MT. The areas of cell phone coverage and the cell phone "dead zones" in MT were also mapped to assist in DiaB testing (FCC, 2024). This geographical information system (GIS) data was compiled, categorized, and summarized to assist in targeting locations for DiaB deployment.

The GIS analysis resulted in a ESRI geodatabase, an ESRI ArcGIS Map Package, and an ESRI ArcGIS Online Web Map (Hellman, 2025) with which to access the level of susceptibility of transportation infrastructure to natural hazards (i.e. floods, rock falls, landslides, earthquakes, etc.) by county (ESRI, 2024). MDT was consulted to determine the preferred file formats, coordinate systems, and metadata requirements to provide data that is fully compatible with current MDT workflows, standard operating procedures, and reporting requirements.

II. GIS Analysis Methodology

To identify hazards that may impact roadways across the State of Montana, multiple datasets were used from three hazard categories: seismic activity, flooding, and landslides. Each dataset was filtered to only include hazards within Montana and when needed, restricted to a corridor buffer of 0.5mi on either side of the road (Figure 1). This narrows the focus of hazardous impact on the roadways rather than including events in remote areas that are unlikely to influence a state-maintained road. For example, a landslide 10 miles from the road is unlikely to have any impact but an earthquake epicenter at the same distance may still be damaging. To account for the varying size of counties and the length of state-maintained road within the counties, some data was normalized to the length of roads in the county (e.g. number of landslides near roads per mile of road in county). This allows for a more direct comparison between counties that may have greater or fewer hazards purely based on their size. Only state-maintained roads, as defined by the MDT (MDT, 2024a), were included in the analysis.

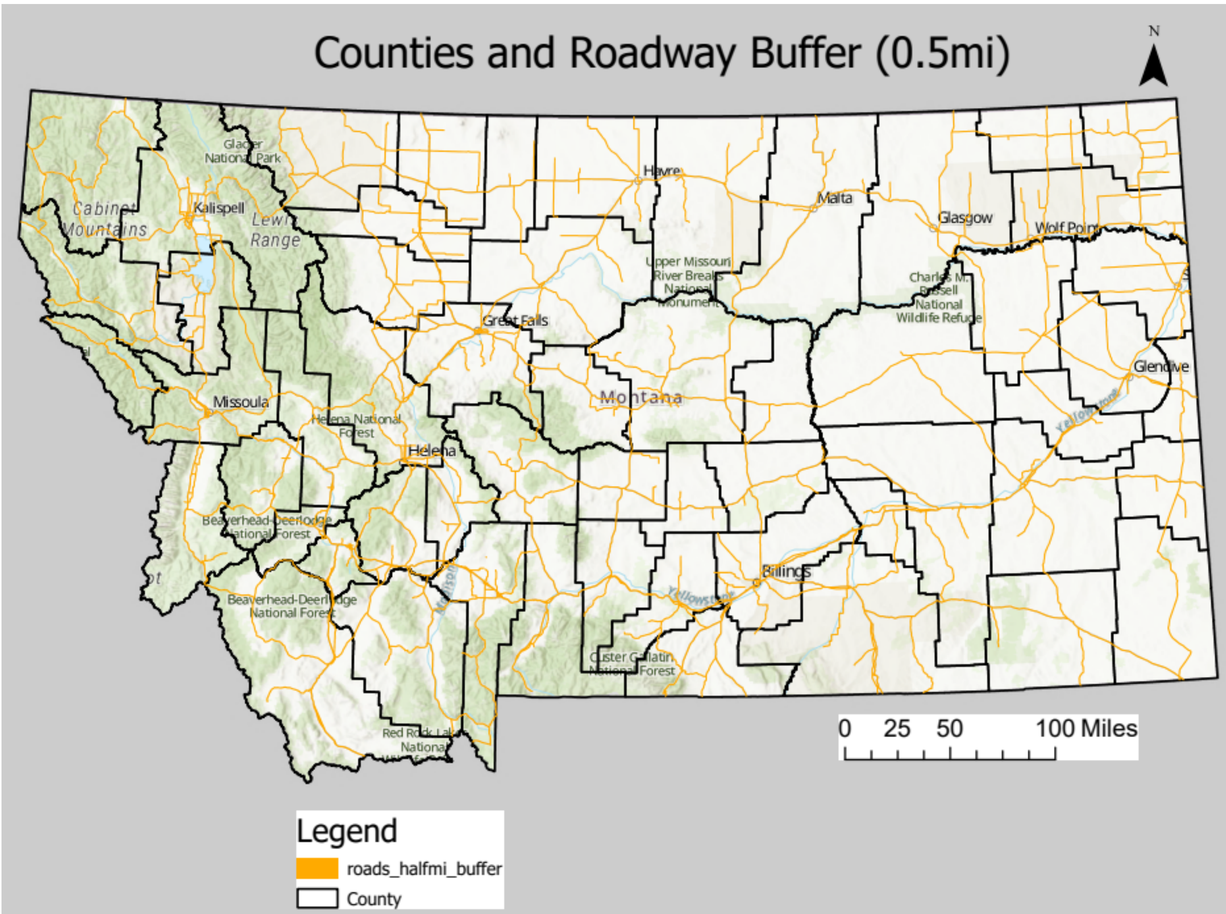

Figure 1. Counties and roadway buffer of 0.5 miles on each side of the road for hazards such as landslides.

Each hazard, the details of which are in the next section, was ultimately aggregated to the county level where a single value per dataset was assigned to each county (e.g. number of earthquakes or percentage of road in the 100-year floodplain). Each hazard was then normalized to a unitless 0-1 scale. All hazards within the county were then added together, therefore assuming equal weighting, and then normalized again to a final, unitless 0-1 hazard score where 0 = Low and 1 = High.

III. Data Sources

III.A. Seismic Activity

Two datasets were used to identify seismic hazards across the state:

1) National Seismic Hazard Model- chance of slight (or greater) damaging earthquake shaking in 100 years (USGS, 2024a)
2) Fault lines (MBMGa, 2024)

The National Seismic Hazard Model has multiple data products. Here, the gridded point shapefile with values for percent chance of a slight (or greater) damaging earthquake shaking in 100 years was used. Because effects may extend far away from the epicenter, all points were kept regardless of their proximity to roadways. The value used for each county is the average percent chance of a damaging earthquake within that county.

Faults are areas of distinct earth crust movement and therefore may damage roads that they intersect. All intersections of faults and roads are counted (Figure 2). The final data used has been scaled by the length of miles within the county. The value used for each county is the number of fault/road intersections per mile of road in county.

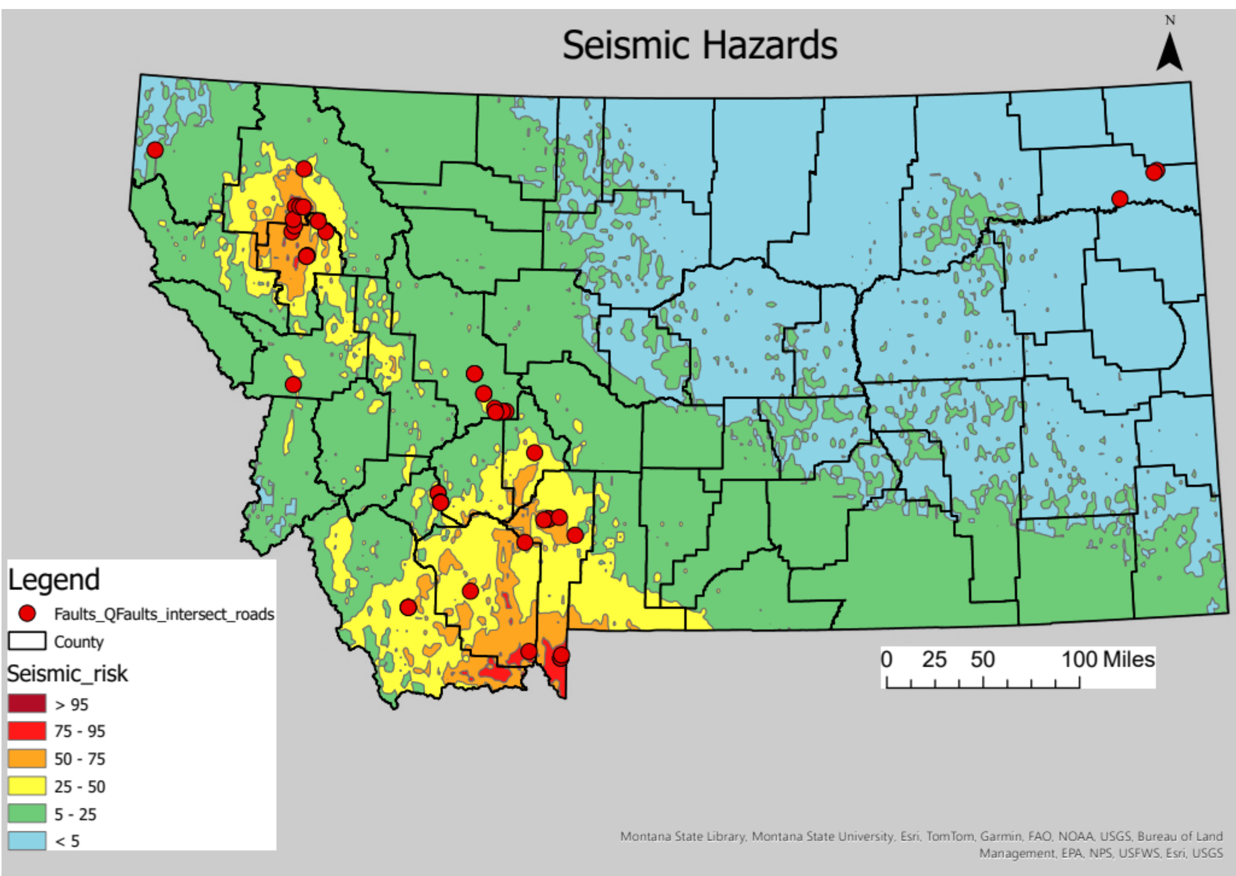

Figure 2. Seismic hazards including the intersection of fault lines and roadways and the chance of a damaging earthquake in the next 100 years.

III.B. Floods

Two datasets were used to identify flood hazards across the state:

1) Observed flood events from 2000-2024 (NOAA, 2024)
2) Length of road within the 100-year flood plain (FEMA, 2024)

The observed flood events come from a National Oceanic and Atmospheric Administration (NOAA) database of reports from law enforcement, NOAA observers, and other credible local sources. Each observation has a "begin" and "end" coordinate, so this was simplified to a single point at the midpoint. Because the coordinates are approximate, the final value used is the total of all events within the county.

The Federal Emergency Management Agency (FEMA) 100-year flood plain data was used to identify areas of overlap with Montana roads. The output of this included low lying roads likely to be inundated during high water events and bridges that could be damaged by scouring, debris, or other structural damage during a flood (Figure 3). The final value used was the percentage of roadway in the county within the 100-year flood plain.

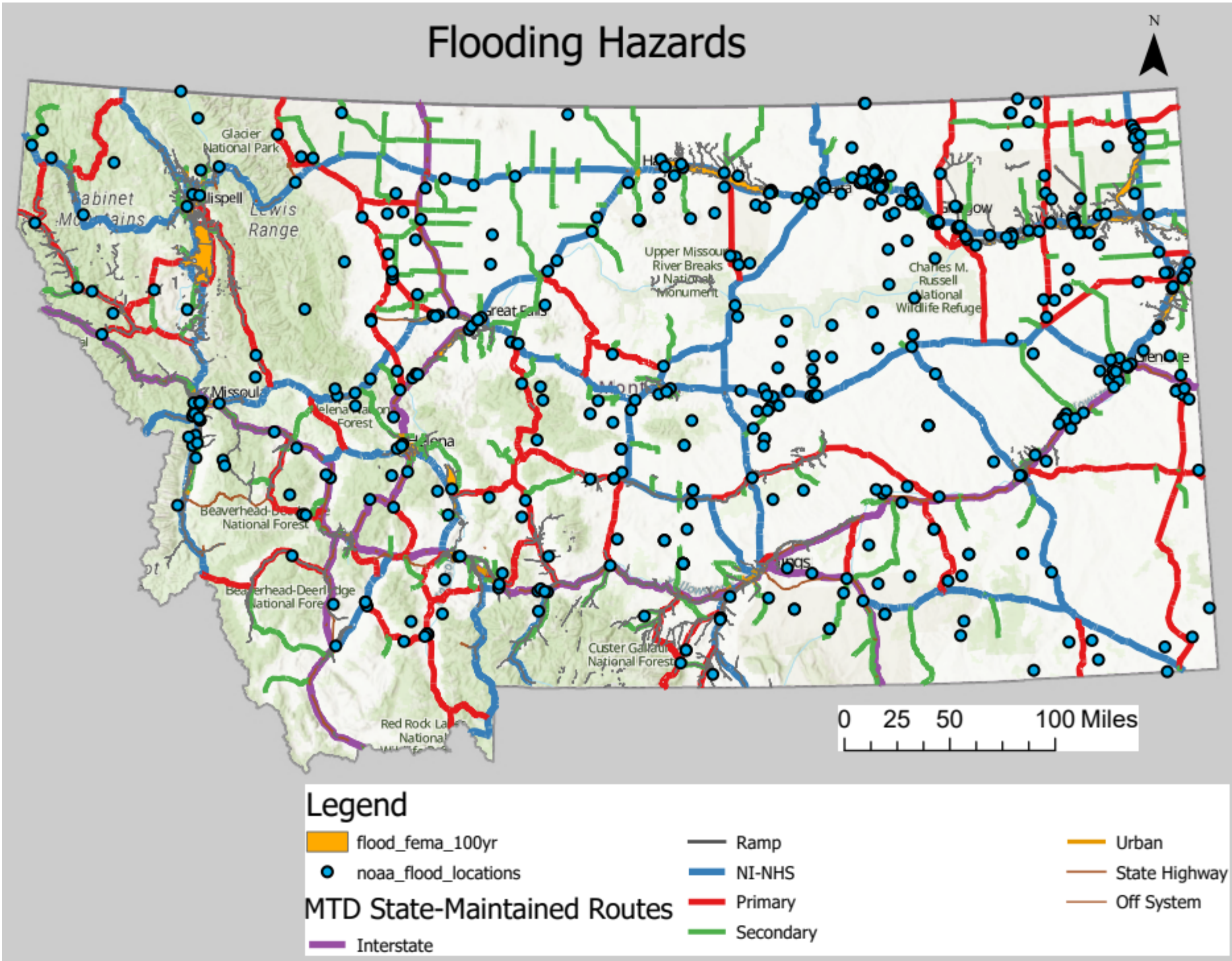

Figure 3. Flood hazards including the 100 year floodplain and number of NOAA flooding events.

III.C. Landslides

Three datasets were used to identify landslide hazards across the state:

1) USGS Landslide Susceptibility (USGS, 2024b)
2) USGS Landslide Inventory (USGS, 2024b)
3) Montana Bureau of Mines and Geology (MBMG) geologic maps (MBMG, 2024b)

The USGS Landslide Susceptibility data is a 90 m raster where the value of each pixel represents the number of 10m cells within it that are susceptible to landslides. To eliminate areas that are unlikely to pose a hazard to the roadway, only data within 0.5 mi buffer of a state-maintained road was used. The final value for each county is the percentage of area within 0.5 mi of a road that is susceptible to landslides.

The MBMG geologic map (1:100,00 scale) was filtered to only landslide polygon units. To eliminate areas that are unlikely to pose a hazard to the roadway, only polygons within 0.5 mi of a state-maintained road were used. This count was combined with the USGS Landslide Inventory point layer of landslides which was also limited to 0.5 mi from a road. The final value for each county is scaled by the length of road in the county and therefore is the number of landslides within 0.5 mi of a road, per mile of road in the county.

The geologic map data had some known gaps in geological mapping at the 1:100,000 scale in the northwest corner of the state, this includes Lincoln, Sanders, Flathead, and Lake Counties. This may result in those counties hazard scores being slightly lower than expected (Figure 4).

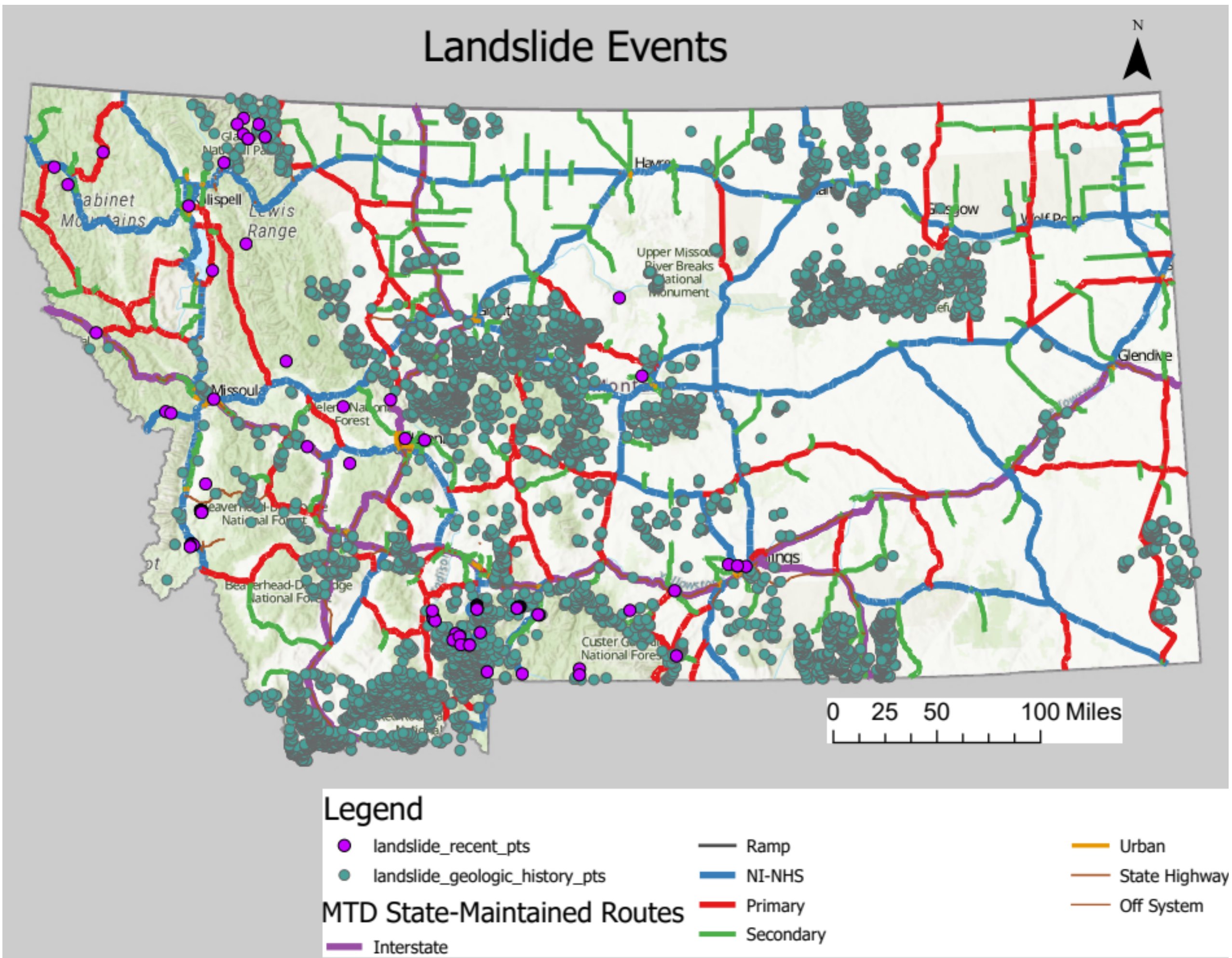

Figure 4. Landslide hazards including locations of reported landslides and geologic mapping of landslides.

III.D. Rock Slope Asset Management Program (RAMP)

The RAMP project dataset (Landslide Technologies, 2015) was collected to identify rock slope conditions along roadways. This MDT research project sought to update the rock slope asset database and increase compatibility within other internal management programs. Field crews visited sites throughout the state to assess and update conditions. Final scores of their assessment, based on several criteria, range from 1-5 where 1 is "Good", 2 and 3 are "Fair", and 4 and 5 are "Poor".

The RAMP point layer was filtered down to only include rock slopes with a "Poor" condition because these are the most likely to cause any hazard to the roadway. The final value for each county is the number of "Poor" condition points per mile of road in the county (Figure 5).

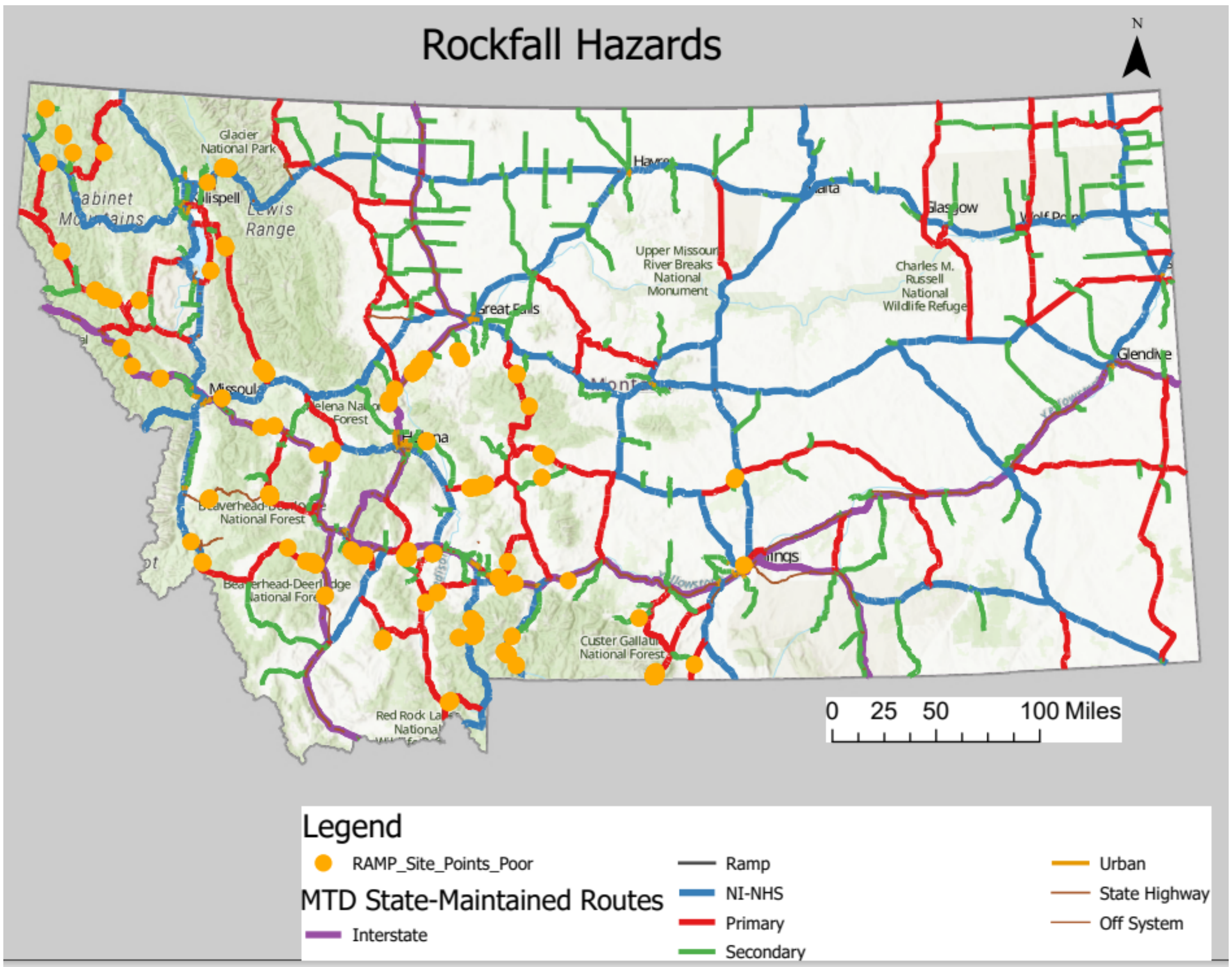

Figure 5. Rockfall hazards as represented by the rockfall assessment and management program (RAMP) locations of a "poor" condition.

III.E. 4G LTE Data Coverage

Cellular 4G LTE data coverage from the Federal Communications Commission (FCC) was used to identify communication dead zones across the state (FCC, 2024). Coverage for Verizon, T-Mobile, and AT&T have been included along with a layer combining all coverages. The data represents areas that have 5Mbps download and 1Mbps upload speed. The original polygons have been dissolved and slightly simplified to allow for quicker visualization. This dataset was not included in the hazard analysis and only used for reference (Figure 6).

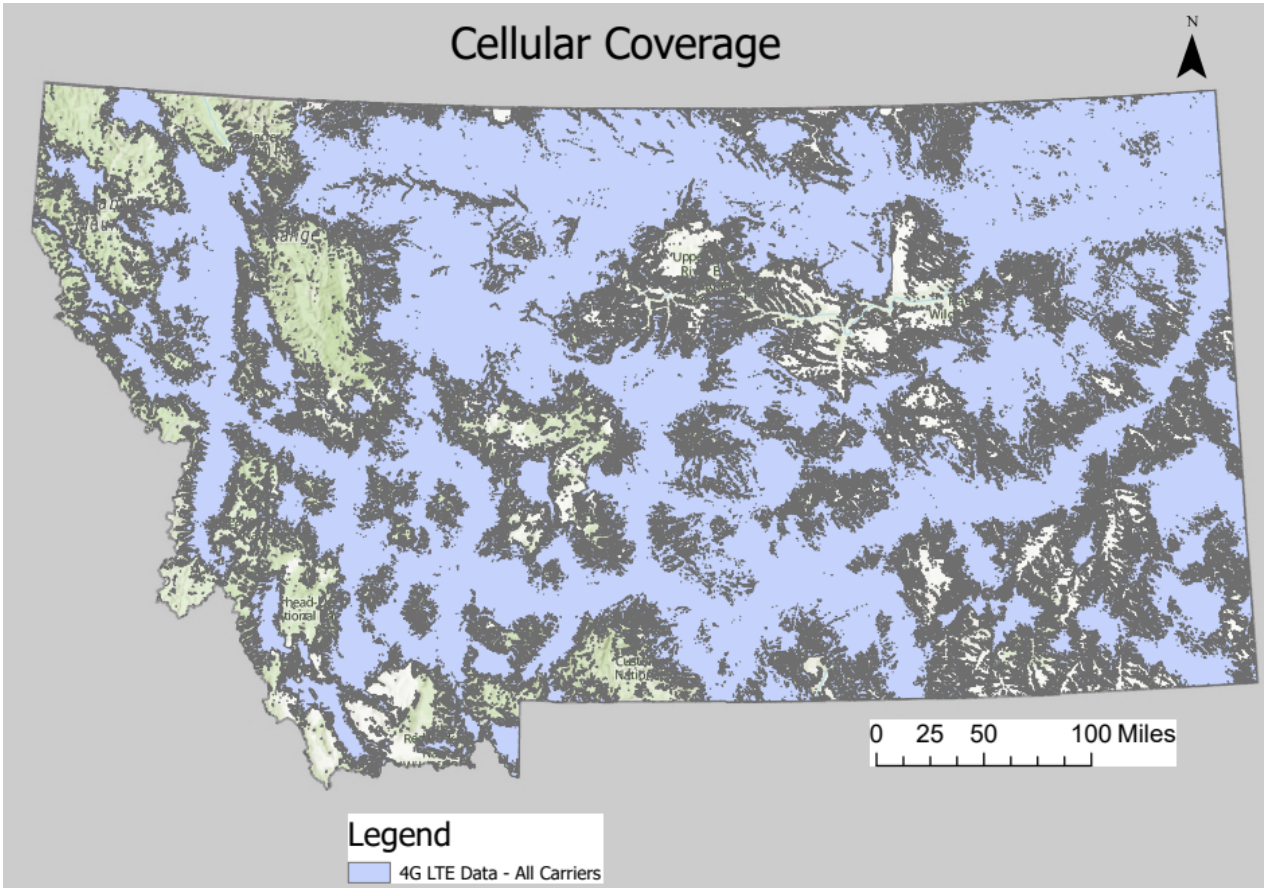

Figure 6. Area of cellular coverage shown in purple.

IV. Conclusions

In general, the moderate to high risk of hazards to transportation infrastructure is elevated in Western Montana, where the larger elevation changes in the Rocky Mountains have increased precipitation and folding and faulting that creates higher seismic risk and potential for landslides and floods. There are some areas in north central and south central Montana that have elevated risk, primarily due to flood and landslide hazards. The areas of lowest natural hazard risk occur in far eastern MT and some counties in north central MT. An interactive GIS web map was created to allow stakeholders to explore the data on natural hazards to roadways in MT https://umontana.maps.arcgis.com/apps/mapviewer/index.html?webmap=651bf3ec4dcf4238b3cb03615b9d495c. (Hellman, 2025).

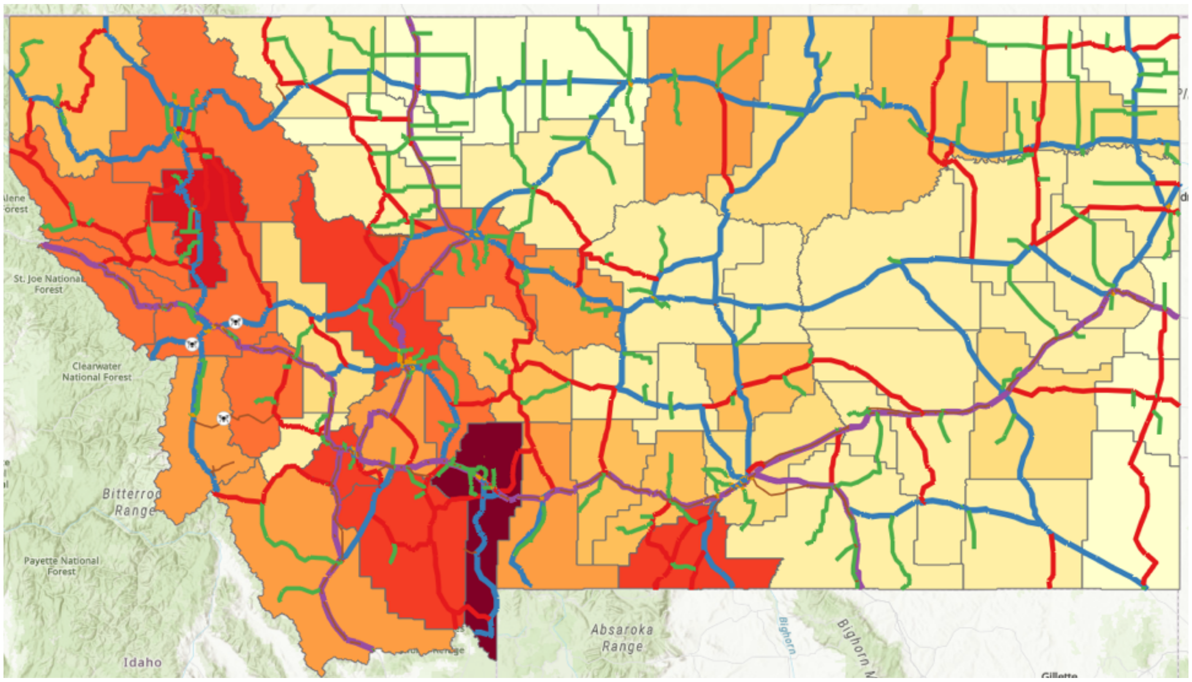

Figure 7. The interactive GIS online map of natural hazards to transportation infrastructure in MT. Counties with higher risk are shown in dark red and those with lower risk in light tan.

Acknowledgements

The authors would like to sincerely thank the Montana Department of Transportation and Technical Panel for their time and effort reviewing the work plan and timeline, providing guidance on the analysis and reports, providing logistical support, and steering the research. Without their help this research would not have been possible.

Technical Panel Members:

Vaneza Callejas, Research and Project Associate, MDT; Rebecca Ridenour, Research Program Manager, MDT; Mike Kuni, Project Chair, MDT; Paul Hilchen, Technical Panel Member, MDT; Curtis Buckley, Technical Panel Member, MDT; Lee Grosch, Technical Panel Member, MDT; Justun Juelfs, Technical Panel Member, MDT; Cameron Kloberdanz, Technical Panel Member, MDT; Patrick McCann, Technical Panel Member, MDT; Ethan Ritzen, Technical Panel Member, MDT; Patrick Dryer, Technical Panel Member, AKDOT; Stephanie Brandenberger, Technical Panel Member, FHWA; Raja Nagisetty, Technical Panel Member, Montana Tech

V. References

Druga, M., 2024. FTA awards nearly $110M to help agencies recover from natural disasters. https://transportationtodaynews.com/featured/32270-fta-awards-nearly-110m-to-help-agencies-recover-from-natural-disasters/. Accessed June 12, 2024.

ESRI, 2024. https://www.esri.com/en-us/home. Accessed October 12. 2024.

FCC, 2024. Federal Communications Commission. FCC National Broadband Map. https://broadbandmap.fcc.gov/data-download/nationwide-data?version-dec2023. Accessed October 15, 2024.

FEMA, 2024. Federal Emergency Management Agency, Flood Map Service Center. https://msc.fema.gov/portal/home. Accessed October 12, 2024.

Hellman, 2025. Autonomous Aerial Systems Office (AASO) MDT DiaB Hazard Map. https://umontana.maps.arcgis.com/apps/mapviewer/index.html?webmap=651bf3ec4dcf4238b3cb03615b9d495c. Accessed December 27, 2024.

Koks, E., Rozenberg, J., Zorn, C., Tariverdi, M., Vousdoukas, M., Fraser, S., Hall, J., and Hallegatte, S., 2019. A global multi-hazard risk analysis of road and railway infrastructure assets. Nature Communications. 10, 2677. https://doi.org/10.1038s41467-019-10442-3

Landslide Technology, 2015. Montana Rockfall Slope Asset Management Program (RAMP). Landslide Technology:: Projects : Montana RAMP - LANDSLIDE TECHNOLOGY. Accessed October 12, 2024.

MBMG, 2024a. Montana Bureau of Mines and Geology, Montana Geology, Geohazards. https://www.mbmg.mtech.edu/MontanaGeology/geohazards/main.asp#gsc.tab=0 . Accessed October 23, 2024.

MBMG, 2024b. Montana Bureau of Mines and Geology, Montana Geology, Geologic Mapping. https://www.mbmg.mtech.edu/MontanaGeology/GeologicMapping/main.asp#gsc.tab=0 . Accessed October 23, 2024.

MDT, 2024a. Montana Department of Transportation, GIS Data Portal, Montana State-Maintained Routes. https://gis-mdt.hub.arcgis.com/datasets/35aa8b0255b54a3ea03d4152acba49aa_0/. Accessed October 12, 2024.

MDT, 2024b. Montana Department of Transportation, Rockfall Hazard Process Assessment FHWA/MT-17-008/8239-001.

NOAA, 2024. National Oceanic and Atmospheric Administration, Storm events database. https://www.ncdc.noaa.gov/stormevents/ . Accessed October 17, 2024.

Stone, T., 2022. Traffic Technology Today. USDOT to provide over $513m to repair natural disaster damage. https://www.traffictechnologytoday.com/news/funding/usdot-to-provide-over-513m-to-repair-natural-disaster-damage.html Accessed June 6, 2024.

Tester, 2023. Tester reflects on Yellowstone flood anniversary, celebrates nearly $1B in targeted federal aid. https://www.tester.senate.gov/newsroom/press-releases/tester-reflects-on-yellowstone-flood-anniversary-celebrates-nearly-1-billion-in-targeted-federal-aid/ Accessed June 6, 2024.

UM, 2025.

USDOT, 2022. USDOT announces promoting resilient operations for transformative, efficient, and cost-saving transportation (PROTECT) program. https://content.govdelivery.com/accounts/USDOTFTA/bulletins/325c736 Accessed June 6, 2024.

USGS, 2024a. United States Geological Survey, National Seismic Hazard Model., https://www.usgs.gov/programs/earthquake-hazards/science/national-seismic-hazard-model. Accessed October 17, 2024.

USGS, 2024b. United Stages Geological Survey, U.S. Landslide Inventory and Susceptibility. https://usgs.maps.arcgis.com/apps/webappviewer/index.html?id=ae120962f459434b8c904b456c82669d. Accessed October 18, 2024.

VI. Appendix: GIS Data Dictionary for the mdt_diab_hazard_score layer

Attribute	**Description**
name	Name of county
area_sqmi	Area of county (square miles)
length_all_roads_miles	Sum length of all state-maintained roads (miles)
haz_combined	The final, combined hazard score
haz_quake	Hazard score for earthquakes greater than 2.5 magnitude
haz_faults	Hazard score for fault/road intersections
haz_noaaFlood	Hazard score for NOAA flood events
haz_100yrFlood	Hazard score for roadways within the 100 year floodplain
haz_landslideSusc	Hazard score for USGS landslide susceptibility
haz_landslides	Hazard score for landslides near roads
haz_poorRAMP	Hazard score for “Poor” condition RAMP points
haz_avg_chnc_dmg_quake	Hazard score for damaging earthquake shaking within 100 years
Avg_chnc_dmg_quake	Hazard score for damaging earthquake shaking within 100 years within a county
fault_road_intersections	Number of points where a fault intersects a road
flt_rd_inters_per_rd_mi	Fault/road intersection count per mile of state maintained road.
num_noaaFlood	Number of NOAA flooding events
mi_rd_in_100_yr_flood	Miles of state maintained roadway in 100 year floodplain
pct_rd_in_100yr_flood	Percentage of state maintained road in the 100 year floodplain
pct_susc_nr_rd	Percentages of area within 0.5 mi buffer of state maintained road susceptible to landslides
num_landslides_per_rd_mile	Number of landslides per mile of state maintained road
num_all_landslides	Number of all landslides within 0.5 mi buffer of state maintained roads
num_poorRAMP	Number of RAMP sites with condition rating of "Poor"
num_poorRAMP_per_rd_mi	Number of RAMP sites with condition rating of "Poor" per mile of state maintained road