ENHANCING THE RESILIENCE OF IDAHO'S TRANSPORTATION SYSTEM TO NATURAL HAZARDS AND CLIMATE CHANGE

FINAL PROJECT REPORT

by

Dr. Tim G. Frazier
University of Idaho

And

Lisa Nichols
University of Idaho

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16. Abstract

This research compiled information on past landslides, including date-referencing and geo-locating events; analyzed and mapped variables contributing to slide susceptibility; demonstrated the conditions of the future climate models that may increase landslide hazards; and designated the transportation routes most vulnerable to weather-triggered landslides. The study area was reduced to the northern and central counties, as primary and secondary transportation routes in the remainder of Idaho rarely cross areas of high topographic relief. The slide events located in this pilot study generally occur in areas of high susceptibility based on aspect, slope, and geology. The transportation routes most at risk given projections of climate change are in the northern-most counties of Idaho: Interstate 90 and northern sections of U.S. Highway 95. Luckily, these areas generally have dense canopy cover, an indicator of slope stability. However, land use changes, forestry management policy changes, and the threat of large-scale wildfires could each impact slope stability. With a larger, detailed record of landslide events, predictive models for homogenous "landslide" regions could be combined with historical and projected climate data to isolate specific sections of highways most vulnerable to extreme weather-triggered slope failures. LiDAR could greatly reduce the time and cost of compiling a landslide inventory for Idaho.

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Executive Summary

Natural hazards present a threat to human lives, towns, and transportation routes. In Idaho, large landslides seldom occur, but due to the state's topography and lack of alternate routes, landslides pose a special risk to the state. Earth and debris flows can engulf buildings, vehicles, and roads, or fall into rivers and create secondary flooding. Slope failures that undercut road beds can make travel unsafe. Rural towns can be isolated when routes are obstructed by debris or flood water, preventing emergency service access, evacuation, and deliveries of supplies. Most large landslides that have been documented in Idaho are related to extreme precipitation in winter and spring. Extreme precipitation event frequency is projected to increase with climate change, so understanding the causal conditions of slides specific to Idaho is critical in planning, managing, and maintaining infrastructure. Roads, bridges, and culverts designed for today's weather patterns or today's hydrologic regimes may result in considerable maintenance, extensive repairs, or even loss of life from record-breaking events in the climate of the future.

The State Of Idaho sought to create a permanent Landslide and Debris Flow Task Force in 1997 to analyze the impacts of extreme precipitation-triggered landslides and develop recommendations to reduce future losses. One of the main recommendations put forth by the short-lived task force was the creation of a landslide risk assessment to better understand triggering factors, recurrence cycles, and the links between wildfire and landslides. Having a long-term historical record of landslide occurrence would allow for predictive modeling, ultimately aiding in the monitoring and mitigation of unstable slopes. However, due to a lack of funding, no such state-wise assessment has been performed by any agency in the 18 years since the recommendation of the task force. Several counties have produced detailed landslide risk sections in their hazard mitigation plans, including Shoshone, Benewah, Latah, Clearwater, Nez

Perce, Lewis, Idaho, Adams, and Washington Counties. However, while these county plans identify areas of landslide risk, few specific landslides have been described and causal thresholds remain unknown.

A full assessment with the depth and breadth of data necessary to produce explanatory or predictive models across a landscape as heterogeneous as Idaho would be an expensive, interdisciplinary effort over multiple years. However, future climate models suggest increasing urgency to understand weather-related landslide triggering factors. This research compiled information on past landslides, including date-referencing and geo-locating events; analyzed and mapped variables contributing to slide susceptibility; demonstrated the conditions of the future climate models that may increase landslide hazards; and designated the transportation routes most vulnerable to weather-triggered landslides. The study area was reduced to the northern and central counties, as primary and secondary transportation routes in the remainder of Idaho rarely cross areas of high topographic relief.

A qualitative review of archives, official documents, and county plans was combined with an interview/survey of state professionals to uncover details of past landslide events. This information was cross-referenced to photographs, aerial imagery, and milepost records in the absence of precise location data, and a geographic information system (GIS) was created containing information on event approximate locations and dates, and geologic and topographic variables. Then, weather station records were referenced to understand the precipitation patterns that occurred leading up to each event. Transportation route volumes were added to the GIS to visualize critical routes. Downscaled climate projections for mid-century temperature and precipitation departures were reviewed to designate regions of the state that should plan for the greatest climatological change.

All but two of the 33 events occurred during patterns of higher-than-average precipitation, although the percent of departure from the average varied widely between events. The slide events located in this pilot study generally occur in areas of high susceptibility based on aspect, slope, and geology. The transportation routes most at risk given projections of climate change are in the northern-most counties of Idaho: Interstate 90 and northern sections of U.S. Highway 95. Luckily, these areas generally have dense canopy cover, an indicator of slope stability. However, land use changes, forestry management policy changes, and the threat of large-scale wildfires could each impact slope stability. With a larger, detailed record of landslide events, predictive models for homogenous “landslide” regions could be combined with historical and projected climate data to isolate specific sections of highways most vulnerable to extreme weather-triggered slope failures. LiDAR could greatly reduce the time and cost of compiling a landslide inventory for Idaho.

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Chapter 1 Introduction

1.1 Transportation and Natural Hazards

Transportation routes are vulnerable to delays and damage during extreme weather events. Heat waves may damage road surfaces, droughts can contribute to severe wildfire, rapid freeze-thaw cycles can produce cracks in roads and bridges, and intense rain and snow events can cause flooding and landslides. Human lives are directly at risk when natural hazards occur in the proximity of vehicles, and indirectly when road closures block emergency personnel access and evacuation routes. In rural towns, a single road may be relied upon for emergency services, evacuation, and deliveries of food and supplies. Extreme events are projected to increase with climate change and these projections have, so far, proven true (Diffenbaugh et al. 2005; Janssen et al. 2014). Planning, designing, constructing, operating, and maintaining surface transportation must take into account the local impacts of more frequent and more intense extremes (Transportation Research Board 2008). Roads, bridges, and culverts designed for today’s weather patterns or today’s hydrologic regimes may result in considerable maintenance, extensive repairs, or even loss of life from record-breaking events in the climate of the future.

As the evidence of climate change and the related extremes in weather escalates, more time and money is being allocated to mitigation and adaptation plans for local impacts. The 2008 Transportation Research Board’s report “*Potential Impacts of Climate Change on U.S. Transportation”* compiled and reviewed existing research and concluded with several recommendations for transportation professionals. The recommendations include weighing risks and costs, reviewing design standards, developing or expanding monitoring techniques, integrating evacuation and emergency plans, and including climate change into land use plans (Transportation Research Board 2008). Additional needs include improving communication between agencies, sharing best practices between jurisdictions, creating new multi-jurisdictional arrangements, and updating the national flood insurance rate maps (Transportation Research Board 2008). But the very first step in preparing networks for climate change is to create inventories of critical infrastructure and determine their vulnerabilities (Transportation Research Board 2008).

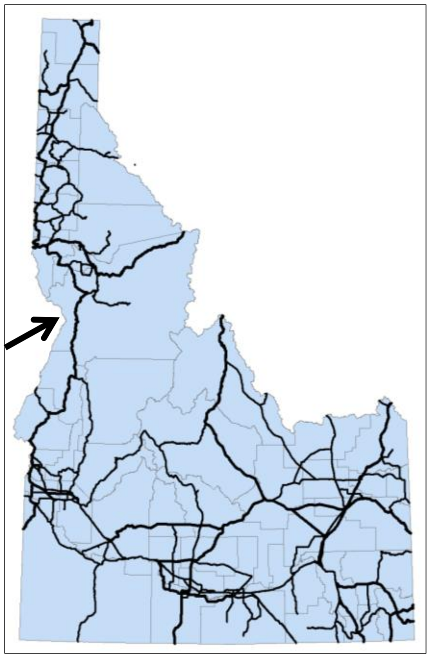


Figure 1.1 Map of Interstates and Highways in Idaho. (Note U.S. Highway 95 linking southern Idaho to the panhandle, indicated by arrow.)

1.2 <u>A Focus on Landslides in Idaho</u>

The state of Idaho has limited transportation routes between counties and to neighboring states due to vast areas of federal and agricultural land (Figure 1.1). Disruption of access and/or damage to one of Idaho's highways could mean a detour of hundreds of miles. The only highway linking northern and southern Idaho within Idaho is U.S. Highway 95. As extreme weather events become more frequent, transportation departments and local governments must anticipate exacerbated natural hazards and plan accordingly.

The first phase of our research included stakeholder engagement with the Idaho Transportation Department (ITD) at their headquarters in Boise, Idaho. ITD recommended our research focus shift exclusively to landslides, rather than examining all climate-related natural hazards. Understanding how climatological conditions contribute to slope failure today would allow for the prediction of landslides triggered in whole or in part by weather conditions ("weather-triggered") in the projected future climate. For example, if the extreme precipitation threshold for weather-triggered slides in today's climate is known, the threshold can be compared against future climate projections. However, a large inventory of historical events with details about contributing environmental and geologic variables is needed first. Then, the variables can be examined for patterns and trends, and regions of homogeneity can be delineated to begin predictive modeling.

After discovering that a comprehensive landslide inventory in the state does not exist, a qualitative investigation was conducted to compile as large a record of landslide dates and locations as possible, given time, resources, and agency involvement. The qualitative reconnaissance delved into historical records kept by the counties, and a survey/questionnaire distributed to relevant professionals in Idaho. This pilot study also demonstrates how weather station records can be useful in understanding precipitation triggering. This information was added to a Geographic Information System (GIS) of high slide potential, along with transportation route volumes. In addition, maps of downscaled future climate projections for changes in temperature and precipitation across Idaho indicate areas that ought to plan for climatological changes that may increase landslide frequency.

Chapter 2 Literature Review

2.1 Climate Change and Extreme Weather in the Northwest

In 2012, the inter-agency report “Climate Change Impact Assessment for Surface Transportation in the Pacific Northwest and Alaska” analyzed climate data and the potential future impacts to the Northwest’s transportation system, in large-scale terms. Based on the climate models from the Climate Impact Group at the University of Washington and the Oregon Climate Change Research Institute, the report concluded that the three-state region of Washington, Oregon, and Idaho may experience an increase of 2-3°C in average annual temperature by the end of the 21st century. More specifically, the climate models anticipate summertime average temperature increases of 1.5-2.5°C, and wintertime average increases of 3.5-7°C (Macarthur et al. 2012). The models also project summer precipitation decreases of 5-15%, winter precipitation increases of 30%, and earlier snow melt in spring (MacArthur et al. 2012). Therefore, more winter precipitation can be expected to fall as rain in greater quantities, and summers will likely be hotter and drier. These modeled changes are averages over a topographically-diverse region at a 50-kilometer resolution, based on two emission scenarios (MacArthur et al. 2012).

The impacts of climate change felt by society will be independent of slow changes in annual averages, but rather will be experienced as the increased frequency and intensity of singular, extreme events. Houghton et al. (1996) projected that extreme 20-year precipitation events in North America would decrease in return period to 10 years. Diffenbaugh et al. (2005) found that the Pacific Northwest region may have the highest increase in frequency of extreme events, resulting in a decrease in orographic rain shadows on the lee side of mountains in eastern

Idaho. Nevertheless, there’s no way to know when, if, how, or where extreme events will take place years into the future.

Current climate models are proving quite accurate for predicting temperatures, but projecting future precipitation is more difficult, and the difficulties grow at more refined spatial and temporal scales (Bernstein et al. 2007). The maritime climate of coastal Washington and Oregon is not going to experience the same climatological changes, or the same climate change *impacts*, as the continental climate of Idaho, as warming will be greater on land than over water (Bernstein et al. 2007). Even within Idaho, a state covering 83,642 square miles, the average changes in temperature and precipitation patterns will vary significantly as weather systems from the Pacific Ocean react with and to the landscape. For example, Diffenbaugh et al. (2005) used a high-resolution regional climate model to understand the impacts of land cover and local topography to extreme weather events. The spatial variability of soil-moisture anomalies in the western United States was related to spatial variability of land-cover boundaries, which are frequently aligned with topographical features in the region; furthermore, warm events in winter were subdued by the albedo of snow cover (Diffenbaugh et al. 2005).

The transportation report for the Pacific Northwest and Alaska (Macarthur et al. 2012) was a comprehensive assessment of a range of potential climate change impacts to all modes of transportation. Included in the report were explanations of sea level rise on the coastal states, melting permafrost and altered freeze/thaw cycles in Alaska, extreme heat effects to road surfaces and rail lines, increased precipitation intensity, increased potential of road closures and damage from wildfire, shifting wildlife corridors and their relevance to vehicle collisions, and the increased potential of transporting invasive species. The majority of the report focused on Washington, Oregon, and Alaska. The recommendations for future studies included integrating climate data with traffic volumes, maintenance records, updated FIRM's, and historic landslide information; coupling vegetation and hydrologic models with general circulation models (GCMs); furthering development of regional climate models; and compiling all this information into state-level assessments (MacArthur et al. 2012). Because of the limited study of impacts to Idaho, and Idaho's lack of redundant routes, further research was warranted.

2.2 Types and Triggers of Landslides in Idaho

"Landslide" can refer to soil and rock falls, slides of partially intact earth masses, or flows of heavily saturated material (State of Idaho 2013). The present study focuses on slides and flows, as most weather-related landslides in Idaho occur when heavy precipitation, rapid snowmelt, and/or rain-on-snow events contribute to slope failure (State of Idaho 2013). Therefore, the decision to focus this research exclusively on landslides is well-supported by the regional climate projections, which suggest such events are likely to increase in frequency, and perhaps intensity, in the future (Diffenbaugh et al. 2005; MacArthur et al. 2012).

When soil layers get saturated, pore pressures increase, and shear strength of materials decreases (Terzaghi 1943). Where vegetation is present, roots contribute to the slope's shear strength, while also removing water from the soil (State of Idaho 2013). Dixon (1998) found that 85% of slides in the Payette National Forest occurred in brush and grass, while only 15% occurred in timber stands. Slope aspect captures rain shadow, wind, and solar radiation factors. In the Payette watershed of central Idaho, west-facing aspects have a high slide occurrence and north aspects have the lowest occurrence (Dixon 1998). Similarly, McClelland et al. (1999) found in a study of the Clearwater National Forest that landslides most often occur on southeast-to-west aspects. In Idaho, slopes of 30-41degrees are particularly prone to slides (State of Idaho 2013). Depending on the level of soil saturation before a precipitation event, the initiation of a slide may be weeks or mere days of above normal precipitation (Wilson 1989; State of Idaho 2013). Each landslide has a unique set of conditions:

> "The geophysical processes that contribute to landslides during a particular year are statistically independent of past events. Unfortunately, the short period of recorded and observed landslides and associated conditions that contribute to the risk make it difficult to develop return periods for landslide-prone areas in Idaho." (State of Idaho 2013)

Many of Idaho's highway miles border rivers, so a heavy precipitation event could produce both flooding and landslides. If rock, soil, and debris choke a river, flooding on roadways may produce a subsequent hazard. The most dramatic example of such a combined-hazard event occurring in Idaho was during the winter of 1996-1997, when heavy rainfall rapidly melted an above-average snowpack across much of the state. Though many counties suffered from flooding and blocked culverts, U.S. Highways 55 and 95 and State Highways 17 and 21 experienced several massive slides, which blocked the flows of Payette and Little Salmon Rivers, washing out roads and isolating communities (State of Idaho 2013). At the base of a slope that had been burned by wildfire in 1992, a debris flow completely buried the unicorporated community of Lower Banks along the Payette River. Across the state, six people were killed and three sustained serious injuries (State of Idaho 2013).

Other impacts of climate change likely in Idaho, such as extreme heat impacts to infrastructure integrity, shifting wildlife corridors, increased invasive species, and increased wildfire, are outside the scope of this research. However, it must be noted that many of these impacts could be compounding threats. For example, certain invasive plant species can contribute to more intense wildland fires, which would contribute to increased soil instability on slopes, thereby increasing the threat of a landslide occurring. The number of factors leading to such a scenario are complex, and creating predictive models of these events would need to include social and economic variables along with all pertinent physical and biological variables—each of which would require an array of assumptions too numerous to make the endeavor sensible. Landslides in Idaho can also occur due to earthquakes, construction of structures and roads, and clearing vegetation—all potential compounding factors with extreme precipitation events.

2.3 Data Needs for Predicting Landslides

Predictive landslide models would help save lives and reduce financial losses. However, creating predictive models relies on data known about events in the past. Because landslides are "statistically independent of past events" (see above), isolated, and are small in comparison to the resolution of geologic and climatological variables that contribute to them, they must "be mapped and described one by one, and each one might have different characteristics" (van Westen, van Asch, and Soeters 2005). Date-location inventories are typically limited in both space and time; landslide maps often don't include an exact date, and therefore the triggering event cannot be determined (van Westen, van Asch, and Soeters 2005). GIS allows for the integration of whatever landslide inventory does exist for a study area with environmental factors. Unfortunately, landslide type, depth, and volume are not often included in studies (van Westen, van Asch, and Soeters 2005).

Parameters vary between models, but most require *in situ* measurements, large datasets, and are created for specific climatological and geomorphic regions. Process-based models are built on the physical variables associated with slides to estimate slope, cohesion, and moisture and therefore do well identifying specific causes of mass initiation (Miller 1995). However, the amount of fine-scale data that must be collected is often a limiting factor (Lineback Gritzner et al. 2001). GIS-based models can utilize DEM’s to capture slope and other topographic variables without costly and time-consuming field surveys.

Lineback Gritzner et al. (2001) created a GIS to determine if geomorphology variables and a wetness index could predict locations of 559 slides in one basin in Idaho. The data for the slides were collected in 1975 via aircraft and ground-based surveys (Lineback Gritzner et al. 2001). Geomorphology variables were determined with a DEM, but geology was assumed constant and therefore was not a tested variable. The wetness index utilized, DYNWET, combines a subsurface flow model, a DEM, soil parameters, and drainage times for a catchment (Lineback Gritzner et al. 2001), so some properties of the geomorphology variables could conceivably be included twice. Slope and elevation were found statistically significant predictors, while the wetness index and all other geomorphic variables tested (aspect, upslope contributing area, plan and profile curvature, and flow path length) were not found significant (Lineback Gritzner et al. 2001). The researchers cited coarse DEM and soil data resolution as one explanation for their surprising results.

The lack of comprehensive landslide inventories worldwide is being rectified by LiDAR surveys. High-resolution digital elevation models produced from LiDAR can detect, characterize, model, and monitor slides, and be used in hazard susceptibility mapping (Jaboyedoff et al. 2012). Because of the high resolution of LiDAR point clouds, a slide path can be seen by manual inspection or via feature detection such as curvature (Jaboyedoff et al. 2012). Therefore, LiDAR offers the best opportunity with current technology to advance landslide inventorying and prediction without surveying every mile of roadway on the ground.

Chapter 3 Methods

3.1 The Study Area

The state of Idaho has highly heterogeneous landscapes and regional climates (Figures 3.2 and 3.3). The northern Idaho panhandle is dominated by forested, mid- to high- elevation, warm summer climates with some high alpine taiga. Topographical complexity increases further south, with both dry steppe and temperate zones amidst low- to high- elevation, warm and hot summer continental climates. Small areas with maritime-temperate climates reflect windward sides of mountains, which receive high precipitation due to orographic lifting. The southernmost counties are made up of mid-to high-elevation, warm summer continental areas, continental alpine, and dry steppe. The regional response to climate change and the extreme precipitation threshold will not be uniform across these landscapes.

After contacting the Idaho Geological Survey (IGS), the Idaho Transportation Department (ITD), the Idaho Bureau of Homeland Security (IBHS), and the Idaho Department of Lands (IDL), we discovered that no landslide inventory with dated events exists for the state. Gritzner, Marcus, and Custer (2001) provide the only study of its kind undertaken in the state of Idaho. Researchers with the Idaho Geological Survey mapped over 3,000 landslides across the state; however, that dataset came with heavy caveats from IGS, no event dates, and limited descriptions or event references.

Due to the absence of a comprehensive date-location landslide inventory, the study area was reduced to those counties in Idaho known to have had one documented major landslide. That information was obtained from the 2013 State of Idaho Hazard Mitigation Plan, which listed landslide state and federal disaster declarations, a list sourced from the Spatial Hazards Events and Losses Database of the United States, a product of the University of South Carolina. The list was later found to include some counties which only had flooding, and not landslides, during certain disaster declarations. Some events could not be traced at all, and some could not be precisely dated or geocoded based on the information obtained. The inclusion of counties was therefore ultimately based on the location of known landslide events, survey responses, counties' hazard mitigation plans, the location of major highways, and general topography. This corresponded well to the counties with high topographical relief. Twelve counties were included

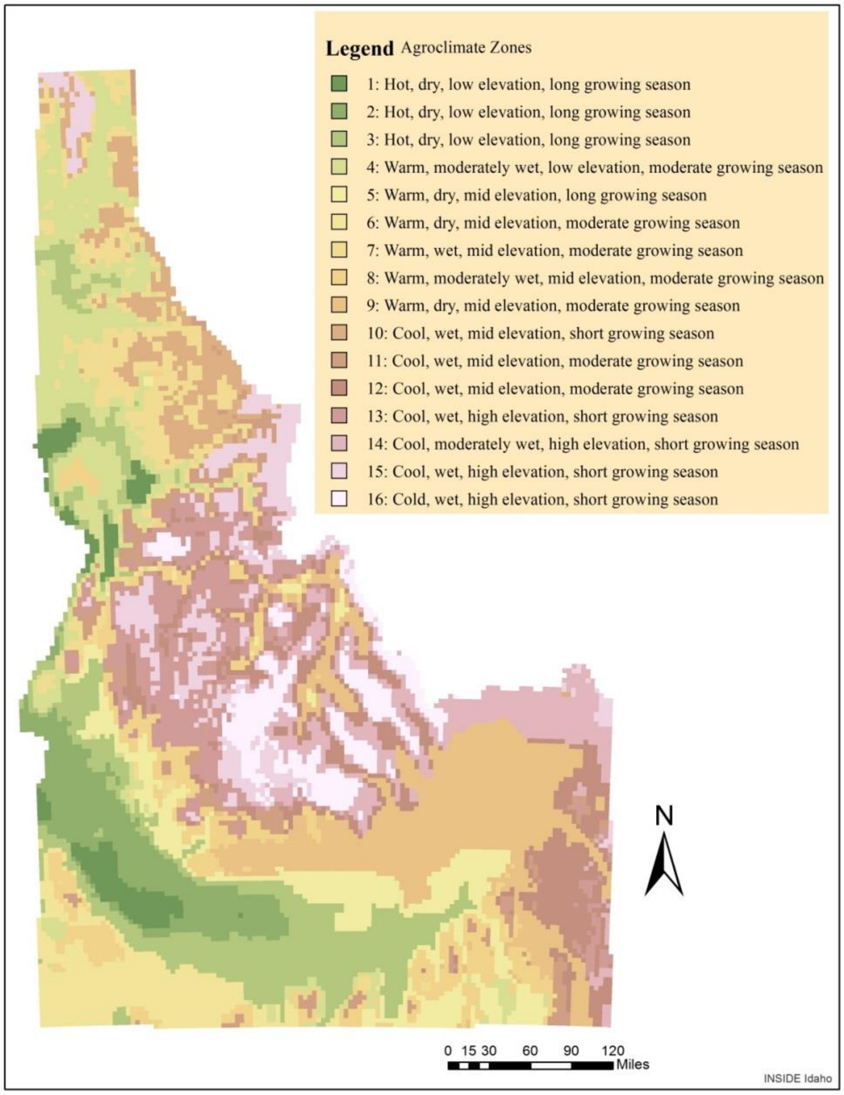


Figure 3.2 Agroclimate zones in Idaho, from INSIDE Idaho.

for further investigation: Boundary, Bonner, Kootenai, Shoshone, Benewah, Latah, Nez Perce, Lewis, Clearwater, Idaho, Adams, and Boise. By contacting managers in these 12 counties, information on several non-declared slides was also obtained. The study area was further reduced to a 24-kilometer (15-mile) buffer on U.S. and Idaho highways and Interstates going through those counties in order to reduce processing times and data storage space.

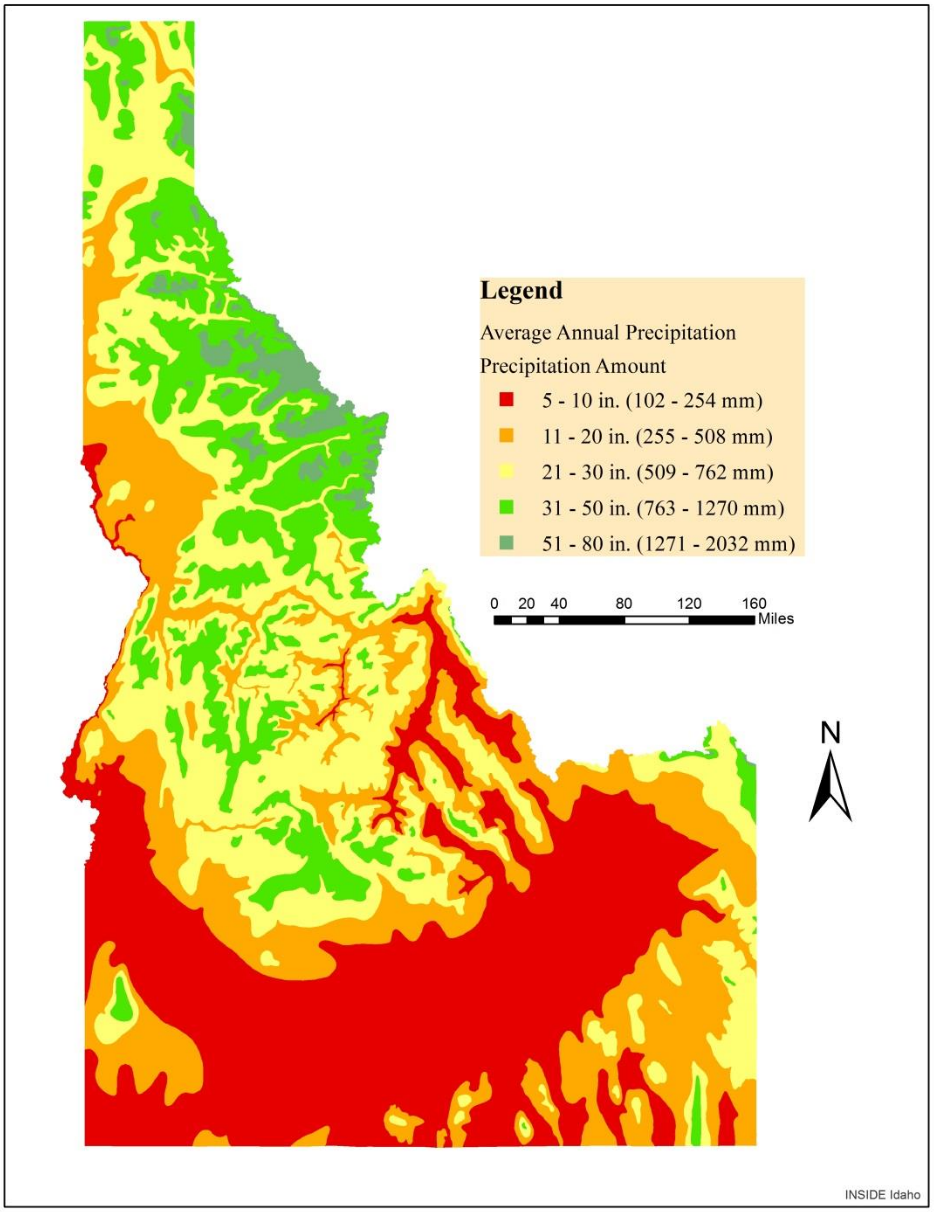


Figure 3.3 Average annual precipitation, from INSIDE Idaho.

3.2 Mixed Method Research Approach

Lacking an existing landslide inventory to pull data from, the first step in this study was to create a new “database” of landslide history from archives, GIS data obtained from county emergency departments, internet research, and a survey/questionnaire distributed to professionals at Idaho Department of Transportation, county governments, and Idaho Department of Lands. ITD does not keep records of landslide events that impact highways nor do they log mitigation or clean-up efforts. The geologists in each ITD district were then contacted for specific landslide event information; however, few responses were generated, and the few responses that were extracted noted the general areas within their districts which are prone to rockfall or slide activity, rather than specific dates, events, or locations.

Fifteen county hazard mitigation plans were reviewed for specific event details. Few distinct events are discussed in these plans, but most of the counties impacted by the severe landslides and flooding in 1996-1997 mention local impacts, and some counties have prepared highly-detailed plans noting areas of particular concern for infrastructure and emergency services. When these plans failed to provide dates and locations for the database, the planning and/or emergency management offices in each of the twelve selected counties were contacted.

In order to formalize responses as the search for event details continued, a survey/interview was drafted, approved by the University of Idaho Internal Review Board, and distributed to thirty-two state geology experts and county officials. Those invited to participate included county planners and planning office administrators, GIS managers/analysts, emergency managers, road and bridge superintendents, and ITD geologists. Invited participants had the choice to fill out the questions on their own time and return the responses via email, or to set up a call and answer questions over the phone. Two professionals had out-of-date contact information and/or no longer worked for their county, so a total of thirty professionals were invited to participate. Finally, historical reports and newspaper articles kept by county emergency management offices were reviewed. From this reconnaissance, a short list of landslide dates and coordinates was created. Several slides were not possible to pinpoint beyond being in proximity to a certain town, or beyond having occurred in a particular county, so those events were not included.

To be included in the dataset for this study, a landslide event description had to meet three criteria: 1) include information relating to a weather event/weather trigger, 2) include enough information to narrow down the event to a date (or a range of dates for multi-day precipitation events), and 3) contain enough information to approximate a location with reasonable certainty (see Appendix A for more information). The events that met all three criteria were geocoded, or transformed into spatial data, that could then be cross-referenced to weather station observations.

Only five slides were given exact coordinates in the information we obtained, and another three had mileposts specified which could be narrowed down to coordinates by cross-referencing Idaho Department of Transportation's milepost logs, available online. The locations of six additional slides were discovered by cross-referencing qualitative descriptions and/or photographs of the slides with aerial imagery on Google Earth. In each of the six cases, a clear image of the slide area before and after the event could be seen using Google Earth's timeline feature. Five slides were located thanks to aerial photographs in the reports obtained; the road cuts were clearly seen or marked, allowing the locations to be compared to Google Earth's imagery. Fourteen of the coordinates actually refer to the location of the road closures for multiple slides, based on closures at specific mileposts. In several of the historical multi-day events, individual slides were not recorded because there was debris and flooding along several miles, so that differentiating from one slide to the next would have been impossible. The full list of dated, located landslides, including event descriptions, information sources, and notes on certainty can be read in Appendix A. Finally, a GIS shapefile was created from the coordinates.

3.3 GIS Data and Methods

The locations of the slides were then investigated to understand the environmental and geomorphic variables that contribute to slope failure. To determine slope and aspect, ten-meter digital elevation models (DEM) and the "USGS National Hydrography Dataset (NHD) Best Resolution for Idaho" shapefile were downloaded from The National Map Viewer from the United States Geological Survey (http://viewer.nationalmap.gov/viewer/). The DEM's were mosaicked, then, to cut down on processing times and data storage, were first clipped to the counties being investigated, then clipped to a 24 kilometer buffer of Idaho's highways and interstates. Canopy cover, from the 2001 National Land Cover Database, was also examined against slide locations. For geology information, the geology shapefile was downloaded from the Idaho Geologic Survey's website (http://www.idahogeology.org), then turned into a binary classification: geologic classes which are known to contribute to instability and those that are not, based upon personal communication with Bill Phillips at the Idaho Geologic Survey. The identified susceptible groups were KPro, Kg, QTb, Qg, Qls, Qs, Tcr, Tcv, Tes (see Table 3.1 for descriptions). Soil variables were not included due to the coarse scale of this study.

To understand the most critical routes in Idaho, a transportation shapefile with Average Annual Daily Traffic (AADT) data, published by the Idaho Transportation Department, was downloaded from the INSIDE Idaho database. The most recent AADT data available was from

2013. In addition, shapefiles of county and city boundaries were downloaded from INSIDE Idaho.

Table 3.1 Geologic types in Idaho which contribute to slope instability. Descriptions provided by the Idaho Geologic Survey.

Type	Description
Kg	Granodiorite and two-mica granite (Cretaceous)—Granodiorite and granite containing biotite, commonly with muscovite.
Qs	Fluvial and lake sediment (Quaternary)—Largely fine-grained sediment, in part playa deposits of evaporative lakes.
Qg	Glacial deposits (Pleistocene)—Till and outwash consisting of gravel, sand, silt, and clay. Formed by valley glaciers at higher elevations and by the Cordilleran ice sheet in northern Idaho.
Tes	Sedimentary rocks (Eocene)—Fluvial, lacustrine, and air-fall deposits of conglomerate, volcanic sandstone, mudstone, and tuff near Challis, conglomerate north of Sandpoint, and conglomerate and sandstone of the Wasatch Formation in extreme southeastern Idaho.
Tcr	Columbia River Basalt Group (Miocene)—Large-volume lava flows of tholeiitic basalt, basaltic andesite, and subordinate andesite in western Idaho.
Qls	Landslide deposits (Quaternary)—Unsorted gravel, sand, and clay of landslide origin; includes rotational and translational blocks and earth flows.
Tcv	Challis Volcanic Group (Eocene)—Dacite, andesite, and rhyolite tuffs and flows and subordinate basalt and latite flows; covers large area in south-central Idaho.
Kpro	Riggins Group, Orofino series, and related rocks (Cretaceous to Permian)—Metasedimentary and metavolcanic schist, gneiss, amphibolite, and marble, all of uncertain age, along eastern margin of island-arc complex; typically hornblende-rich.
QTb	Basalt (Pleistocene and Pliocene)—Flows and cinder cones of olivine tholeiite basalt in and near Snake River Plain. Largely Pleistocene (<2.6 Ma) but includes flows as old as 3 Ma. Covered with 1-3 m (3-10 ft) of loess.

To examine weather conditions when each slide happened, National Weather Service Cooperative Observer weather station data were obtained through the Western Regional Climate Center's SCENIC platform. The "best station" for each slide was selected based on proximity, elevation, and topographic unity (e.g., when possible, a station in the same river valley as a slide occurrence was chosen over stations on the opposite side of a mountain ridge, even if the latter was closer to a slide in straight-line distance). The final defining requirement for stations was the length of the record and the completeness of the period of record. The chosen stations fell within

+/-0.27° of latitude (approximately 18.3 miles), within +/-0.40° of longitude (approximately 18.7 miles), and within +/- 320 meters (1,050 feet) of elevation of each slide event they are representing. Precipitation for the preceding month of each slide was then compared to that station's recorded average for that month. In this way, environmental conditions when the slide took place are compared to "normal" conditions in that area for a specific month, rather than attempting to look for "threshold" precipitation patterns across heterogeneous regional climates. A GIS shapefile was then created containing the location and weather record information.

The Multivariate Adaptive Constructed Analogs (MACA) obtained from the Northwest Knowledge Network (http://maca.northwestknowledge.net/index.php) and Regional Approaches to Climate Change (REACCH) have been downscaled from the Coupled Model Intercomparison Project 5 global climate model (CMIP5, see Taylor, Stouffer, and Meehl 2012 for overview) to four-by-four kilometer resolution, using the Multivariate Adaptive Constructed Analogs (MACA, Abatzoglou and Brown 2012) process with the METDATA (Abatzoglou 2011) training dataset. All climate projections used in this study are the multi-model means of 20 models.

Chapter 4—Results

4.1 Historical Slide Locations

The reconnaissance effort yielded a total of 33 landslide events in the state of Idaho for which exact or approximate coordinates and a date or date range could be established (Figure 4.4). Of these, only nine could be narrowed down to a specific date; the rest occurred during multi-day precipitation events. The elevations of the geocoded slides ranged from 1102 feet to 4857 feet. As noted previously, several slide locations actually refer to an indeterminate number of slides along several-mile-long sections of roadways, so the locations of the road blocks are referenced instead. Most of the slides in the dataset had unknown initiation points. Because of this, and because most of the information obtained referred to where a slide crossed a road, the average slope of where slides in this dataset occurred was 16°, well below the susceptible 30°-41° range. The steepest slope was 56°; the flattest slope was 0.79°.

Similarly, the majority of the slope failures occurred on geologic types **not** indicated as highly susceptible to slope failure. Again, many of the initiation points of the geocoded landslides were unknown or were roughly approximated, and several of the locations represent roadblocks, not the debris flows themselves. Surprisingly, none of the located slides occurred on past landslide deposits (Qls); however, this may reflect the small sampling scale required to identify past landslides and the approximation of event points. Many of the Qls deposits delineated in the IGS dataset are away from main roads. Eight of the located slides are near Qls deposits along U.S. Highway 12 between Lewiston and Kamiah. Qls deposits are also delineated in an area that was closed due to debris flows along Highway 95 during the winter of 1996-1997. The point locations and approximate point locations have the following geologic associations:

nine slides on eruptive basalt (Tcr), four on glacial deposits (Qg), and the remainder with igneous (Kg), metamorphic (Kpro), volcanic basalt (QTb), and fluvial and lake sediments (Qs).

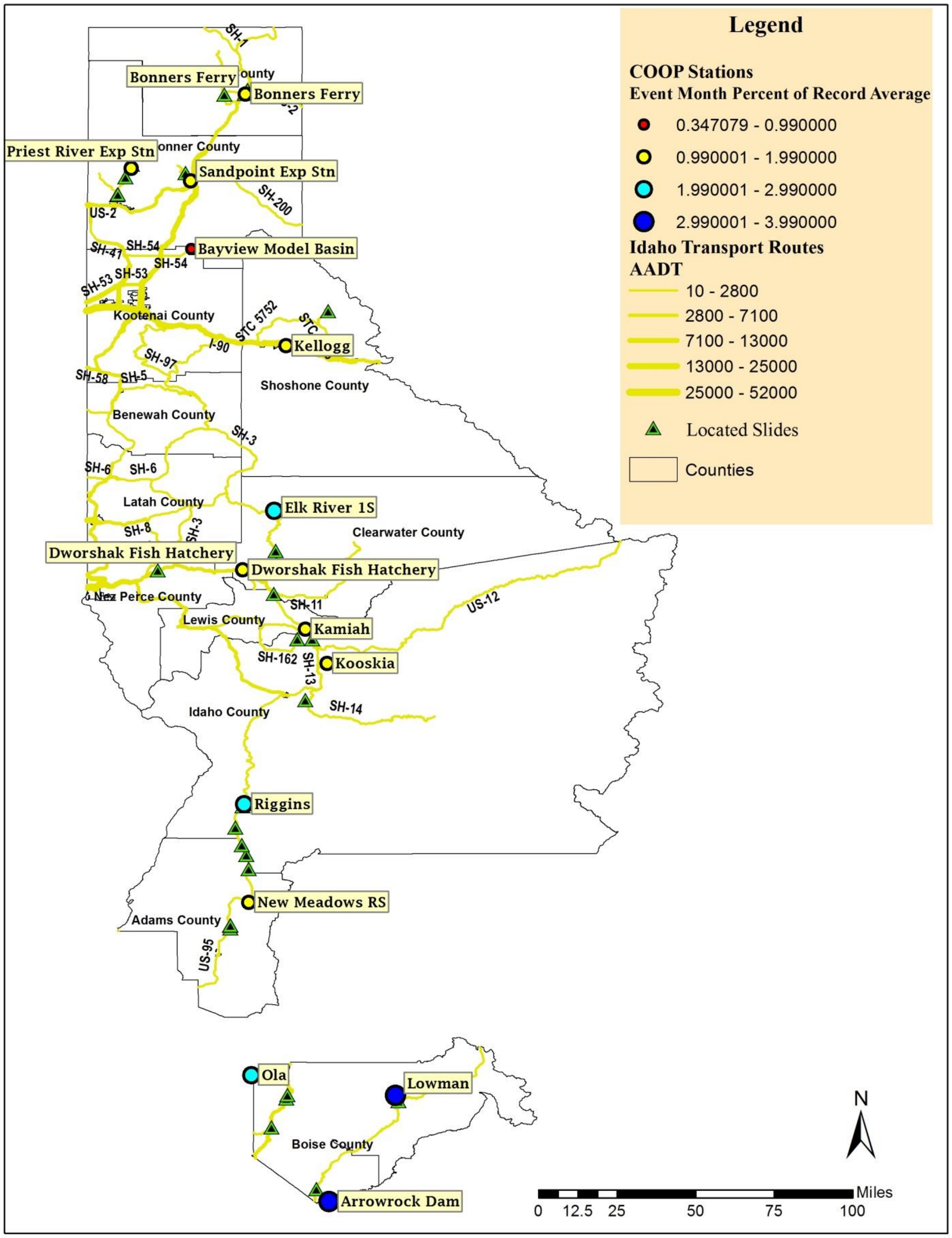


Figure 4.4 Map of the study area with 33 located slides, COOP stations used in this study, and transportation route relative volumes. (COOP stations labeled more than once were referenced during multiple event dates.)

Figures 4.5 through 4.10 display slide locations with event dates, susceptible geology, and susceptible slopes, as well as the relative traffic volumes on select roadways. In addition, the location of representative COOP stations are noted by the month of data that was used to describe the antecedent weather of the nearby slide(s). COOP stations are symbolized by the percent of normal for the antecedent month, *for each station*. That is, the precipitation leading to a nearby slide event is designated in relation to the mean weather observation only at the corresponding station, not against regional weather. The limited number of options among COOP stations in Idaho meant that the period of record at selected stations varied greatly, from 17 years to 117 years, with a mean period of record of 87 years. Therefore, some station records are capturing multiple cycles of interannual variability, while those with short records may have not yet captured all natural variability at their locations. The stations at Dworshak Fish Hatchery, Kamiah, and Kooskia have records less than 50 years. Two slide events took place during months that were lower than 100% of that month's average, with the lowest preceding month of precipitation equal to 34.7% of the station's average. Four slide events happened during precipitation that was 100-150% of average for the given month; six events between 150% and 200%; three events between 200% and 255%, and two events that occurred over 300% of average precipitation.

The aspects of hillsides of the located slides were similar to what was expected. The literature on Idaho slides stated that the majority of slides occur on southeast- to west-facing slopes due to the weather patterns in the inland Northwest and warmer slopes receiving warmer, heavier snowfall (McClellan et al. 1999). Nineteen of the 33 slides occurred on these warmer aspects, five on northeast-facing slopes, four on northwestern slopes, three on north-facing slopes, and two on eastern slopes. These results may be inaccurate for locations representing road closures; however, in examining these cases, areas of road closure were often parallel to rivers. Therefore, a consistent aspect was typically between each end of the road closure, perhaps with minor undulations of hillsides.

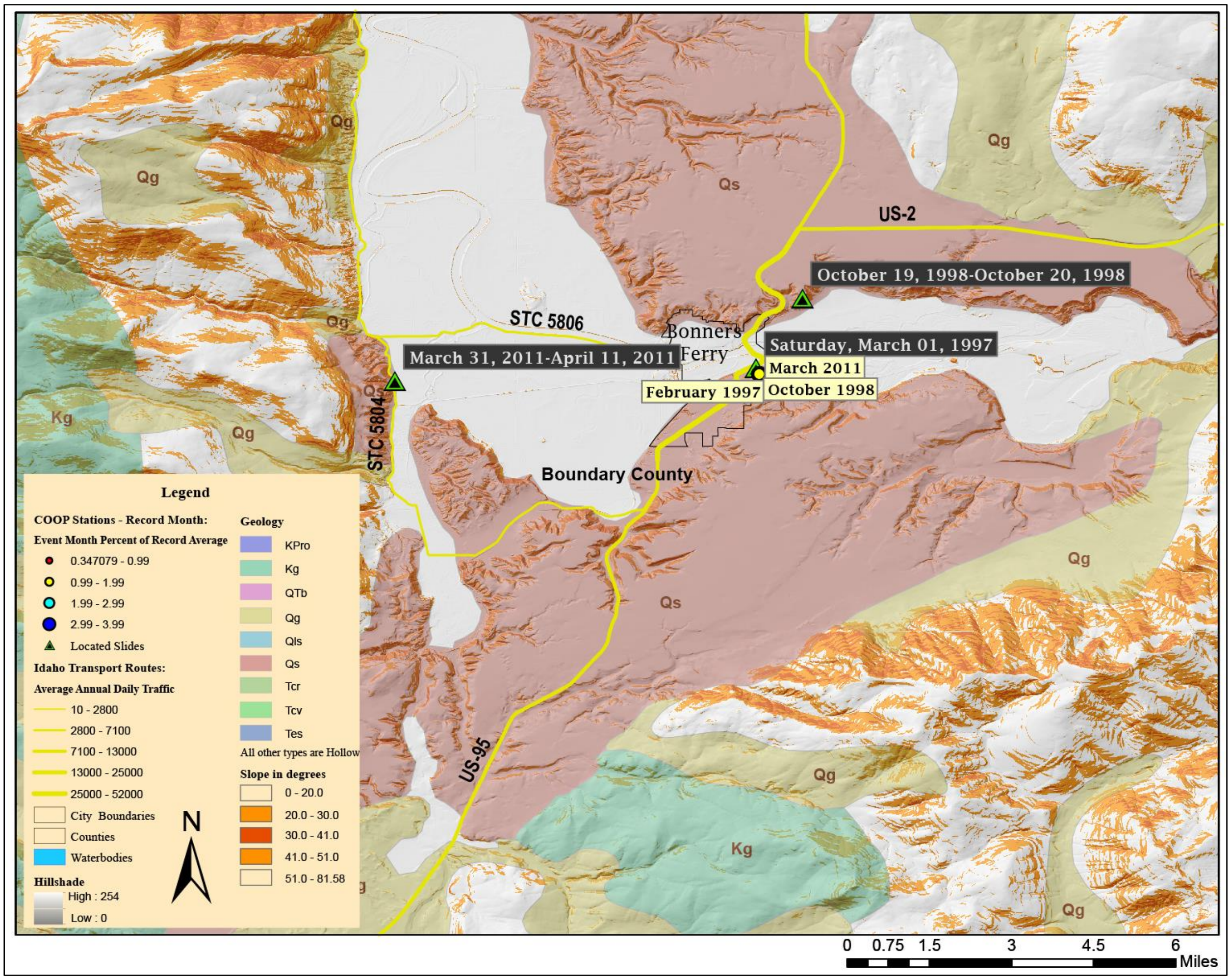


Figure 4.5 Located slides, relative AADT of select roadways, precipitation anomalies, and susceptible geology and slopes, near Bonners Ferry, Idaho.

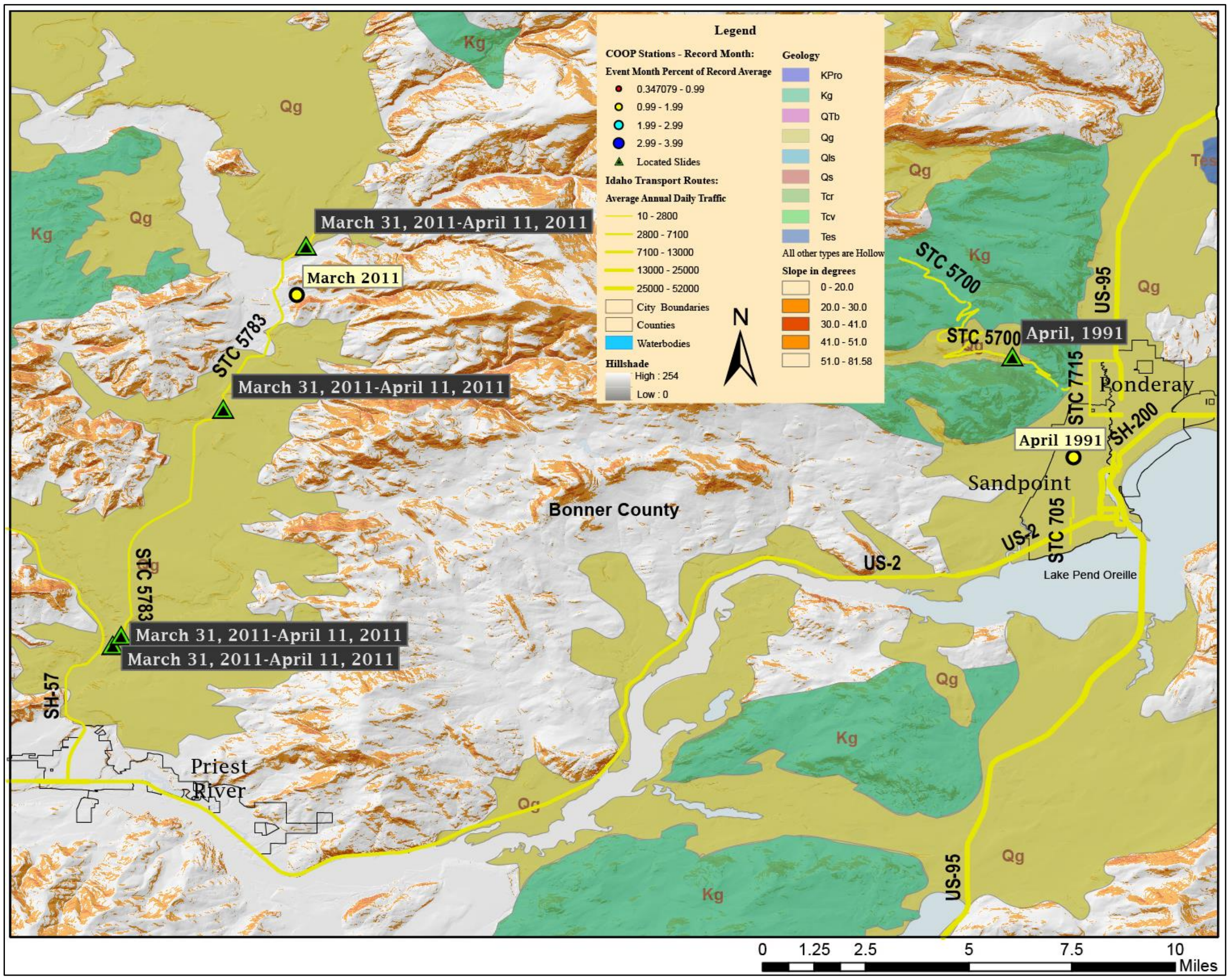


Figure 4.6 Located slides, relative AADT of select roadways, precipitation anomalies, and susceptible geology and slopes, in Bonner County, Idaho.

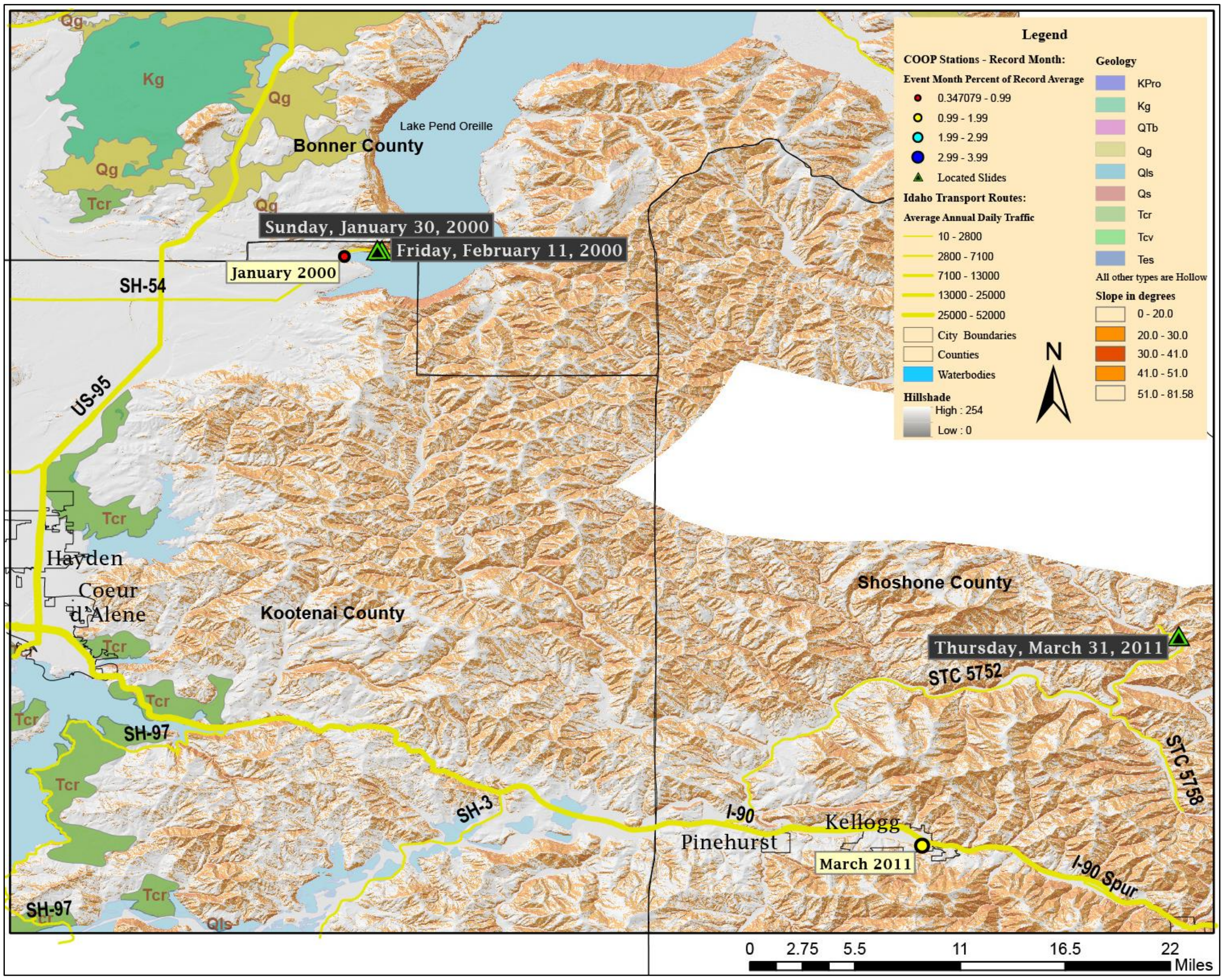


Figure 4.7 Located slides, relative AADT of select roadways, precipitation anomalies, and susceptible geology and slopes, in Shoshone and Kootenai Counties, Idaho.

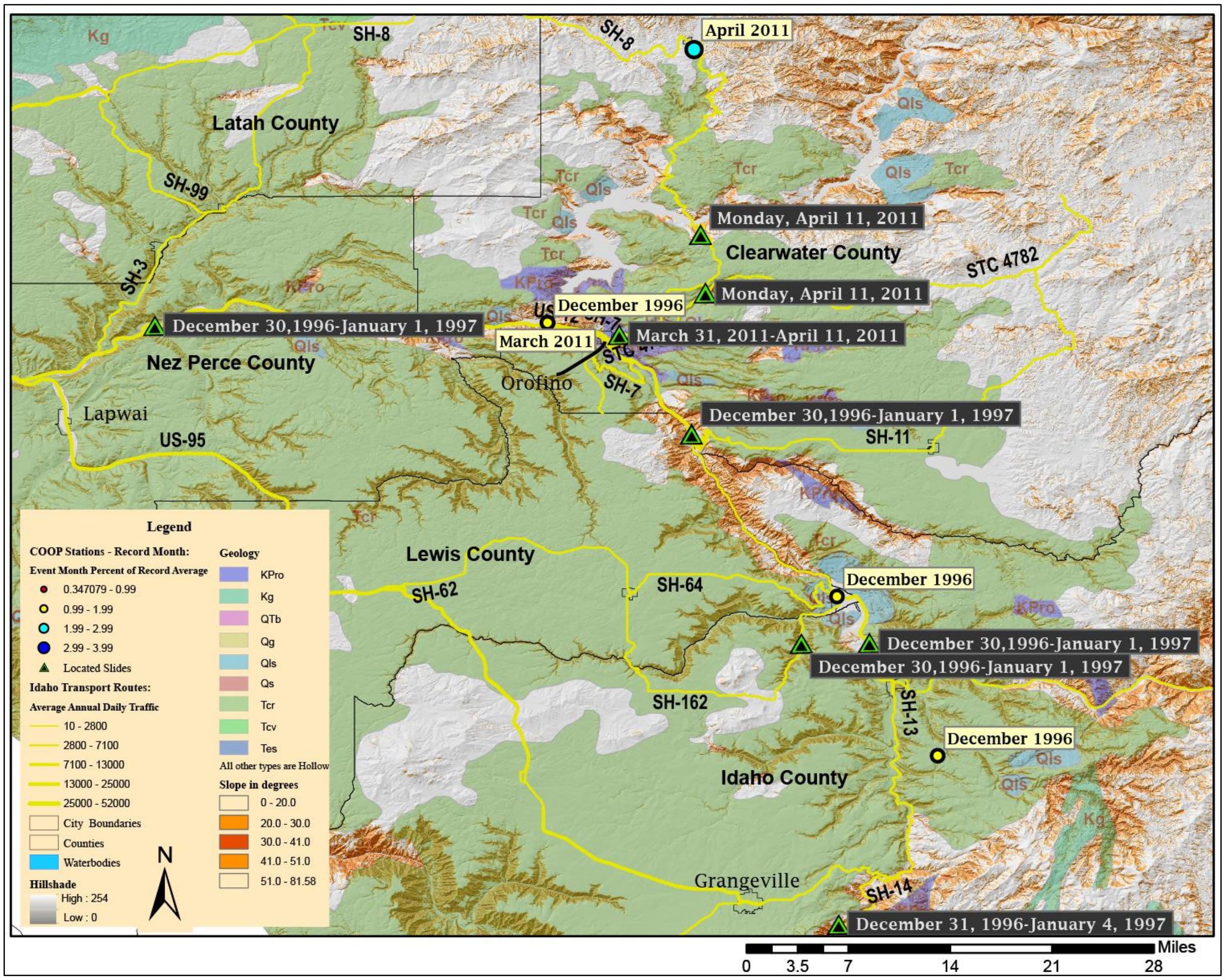


Figure 4.8 Located slides, relative AADT of select roadways, precipitation anomalies, and susceptible geology and slopes, near Orofino, Idaho.

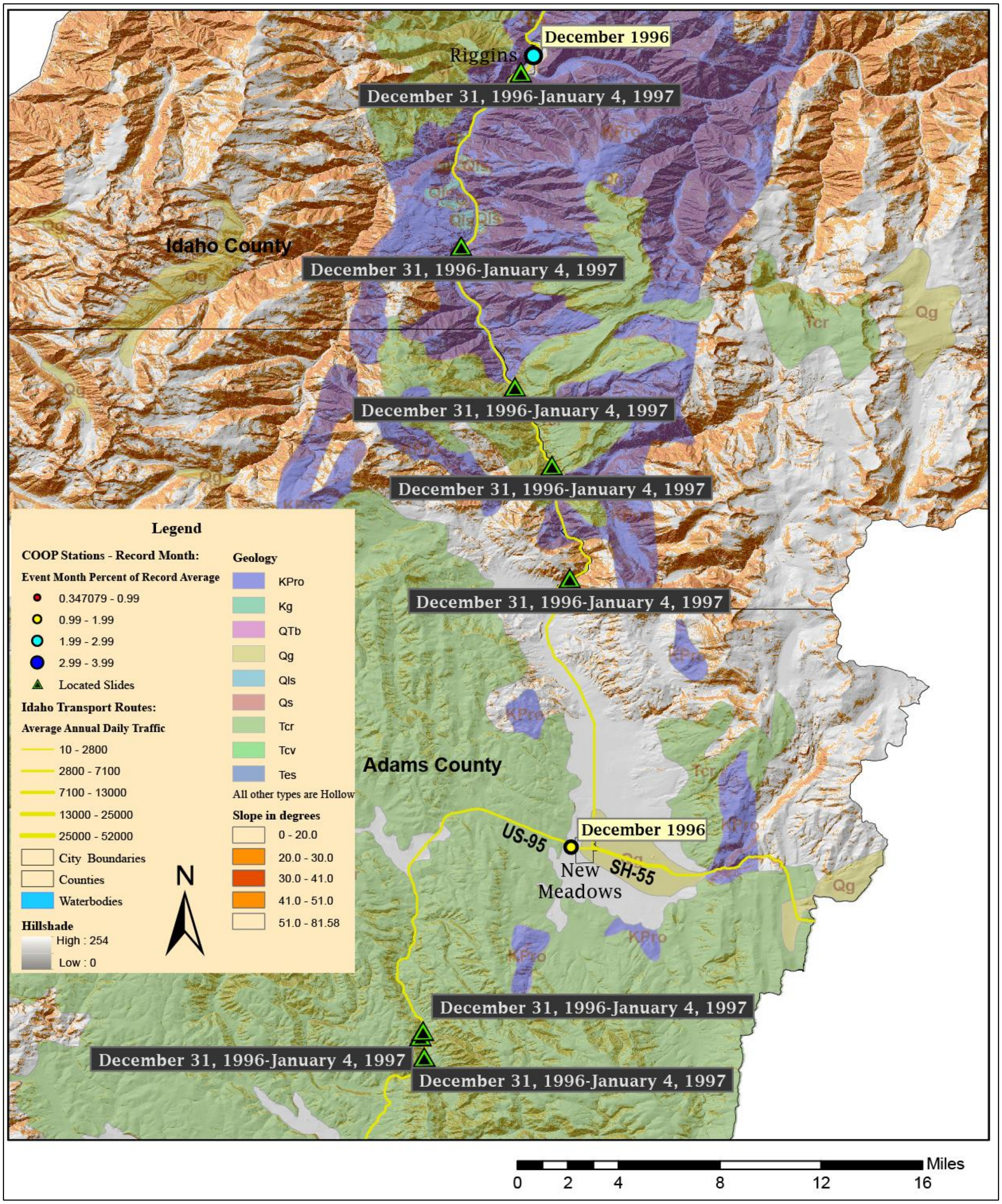


Figure 4.9 Located slides, relative AADT of select roadways, precipitation anomalies, and susceptible geology and slopes, near New Meadows, Idaho.

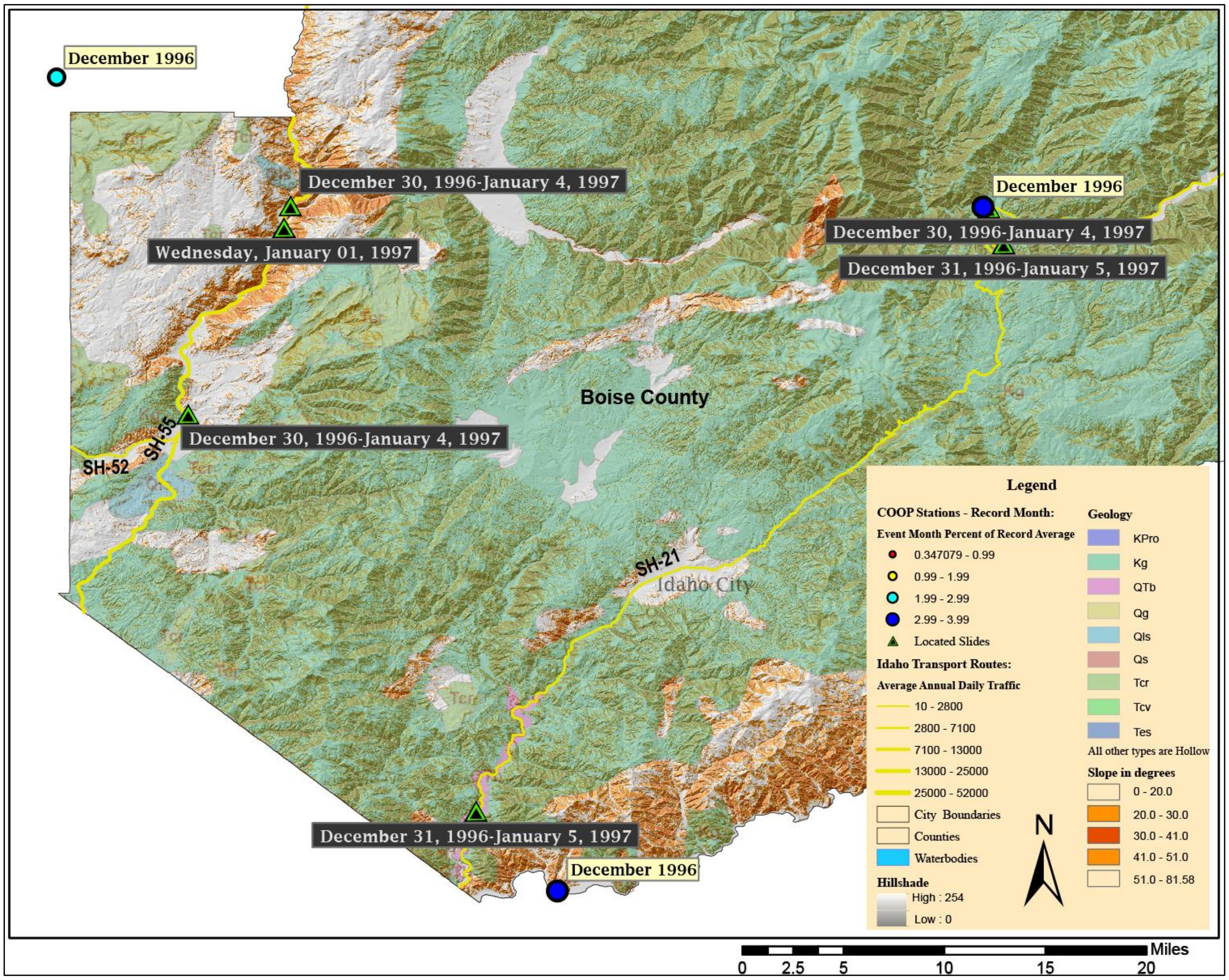


Figure 4.10 Located slides, AADT of select roadways, precipitation anomalies, and susceptible geology and slopes, in Boise County, Idaho.

Susceptible geologic types, slopes between 30 and 41 degrees, and aspects facing southeast through west were each transformed into binary rasters. Cells susceptible for each factor were given a 1 and all other areas were given a 0. Then, these three binary rasters were combined using Raster Math addition so that cells without susceptible geology, slope, nor aspect are still 0, and all other cells are given a 1, 2, or 3. Cells that are most susceptible to slope failure based upon the combined factors of geology, slope, and aspect are concentrated where landslides were found (Figures 4.11 to 4.13).

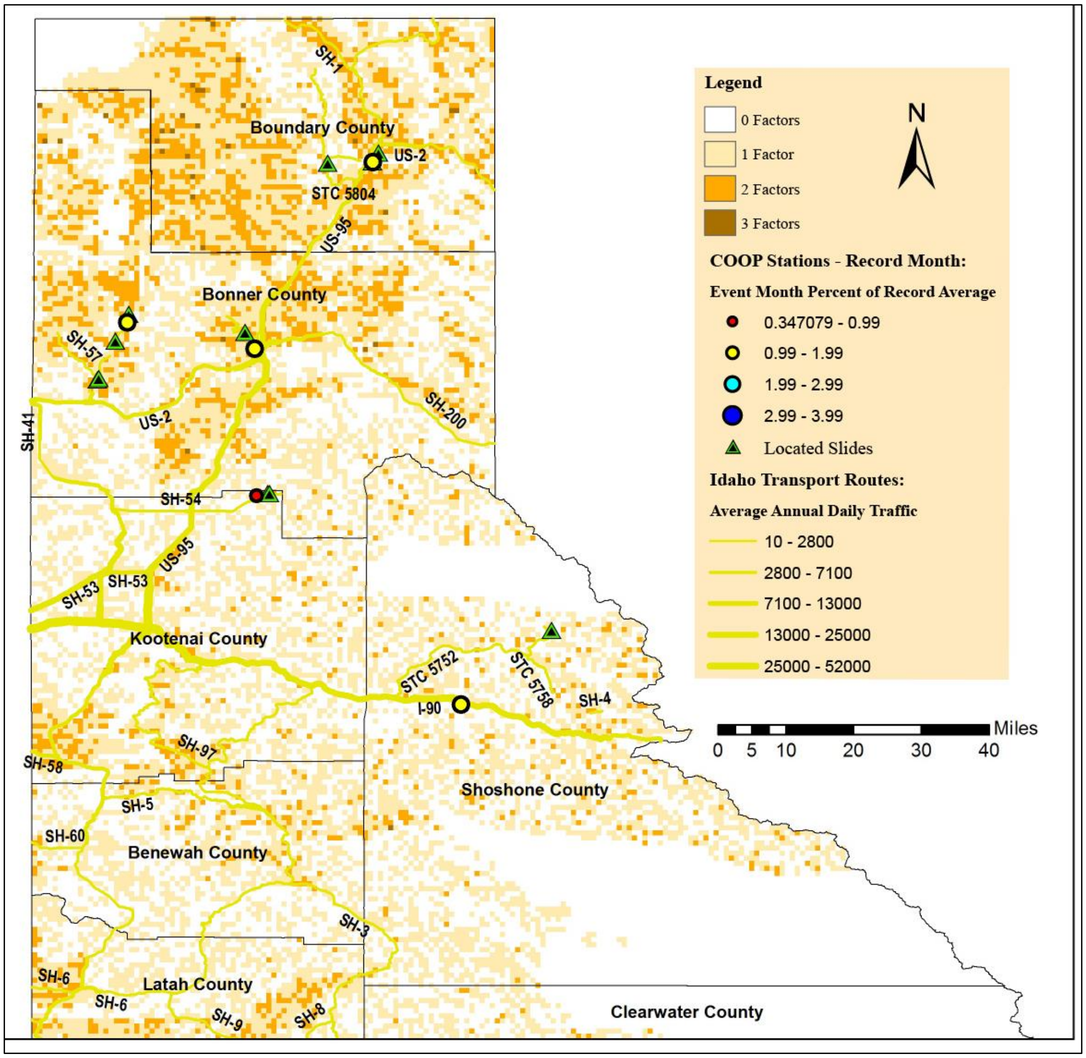


Figure 4.11 Combined analysis of geology, slope, and aspect for Northern Idaho. (Cells with 0 susceptible factors are hollow on the map, cells given a 1 or 2 are progressively darker, while cells with all 3 factors are darkest.)

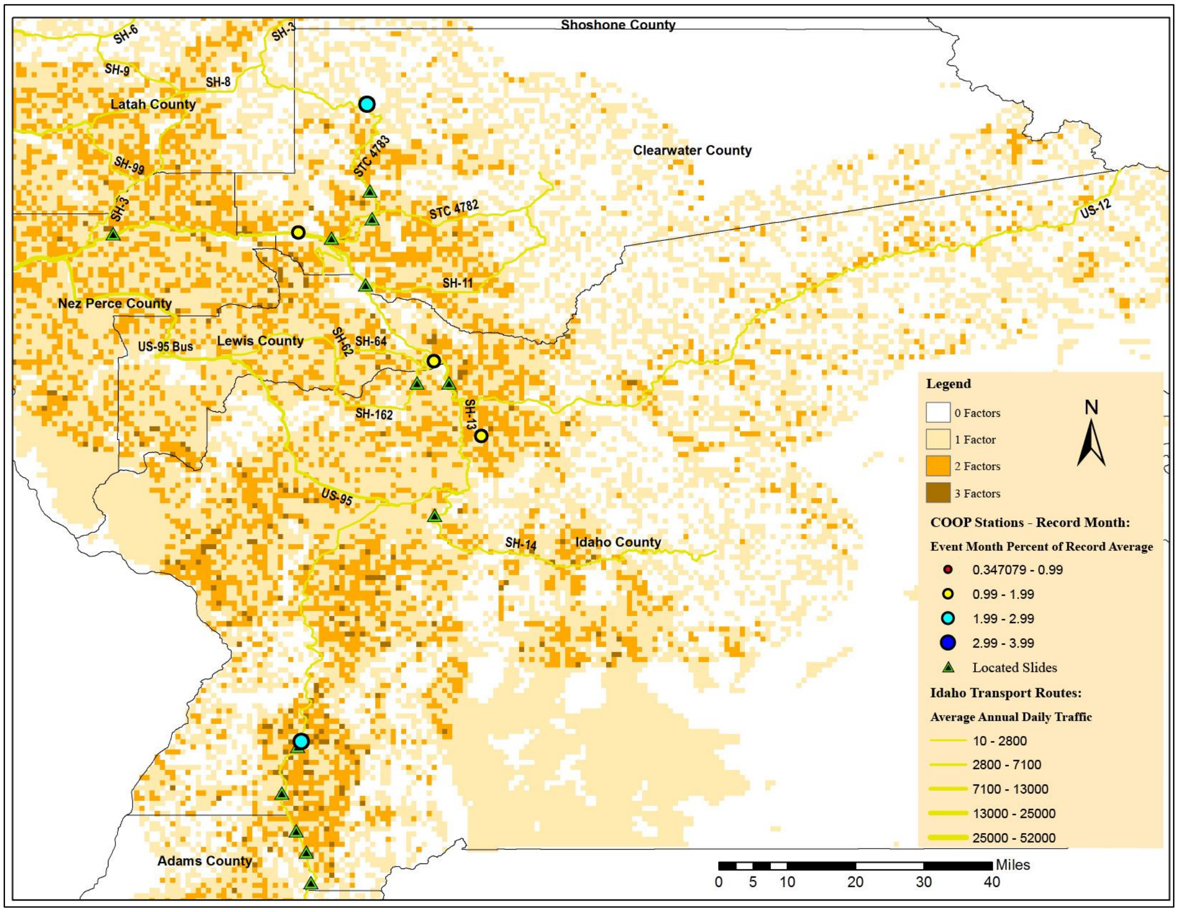


Figure 4.12 Combined analysis of geology, slope, and aspect for Central Idaho. (Cells with 0 susceptible factors are hollow on the map, cells given a 1 or 2 are progressively darker, while cells with all 3 factors are darkest.)

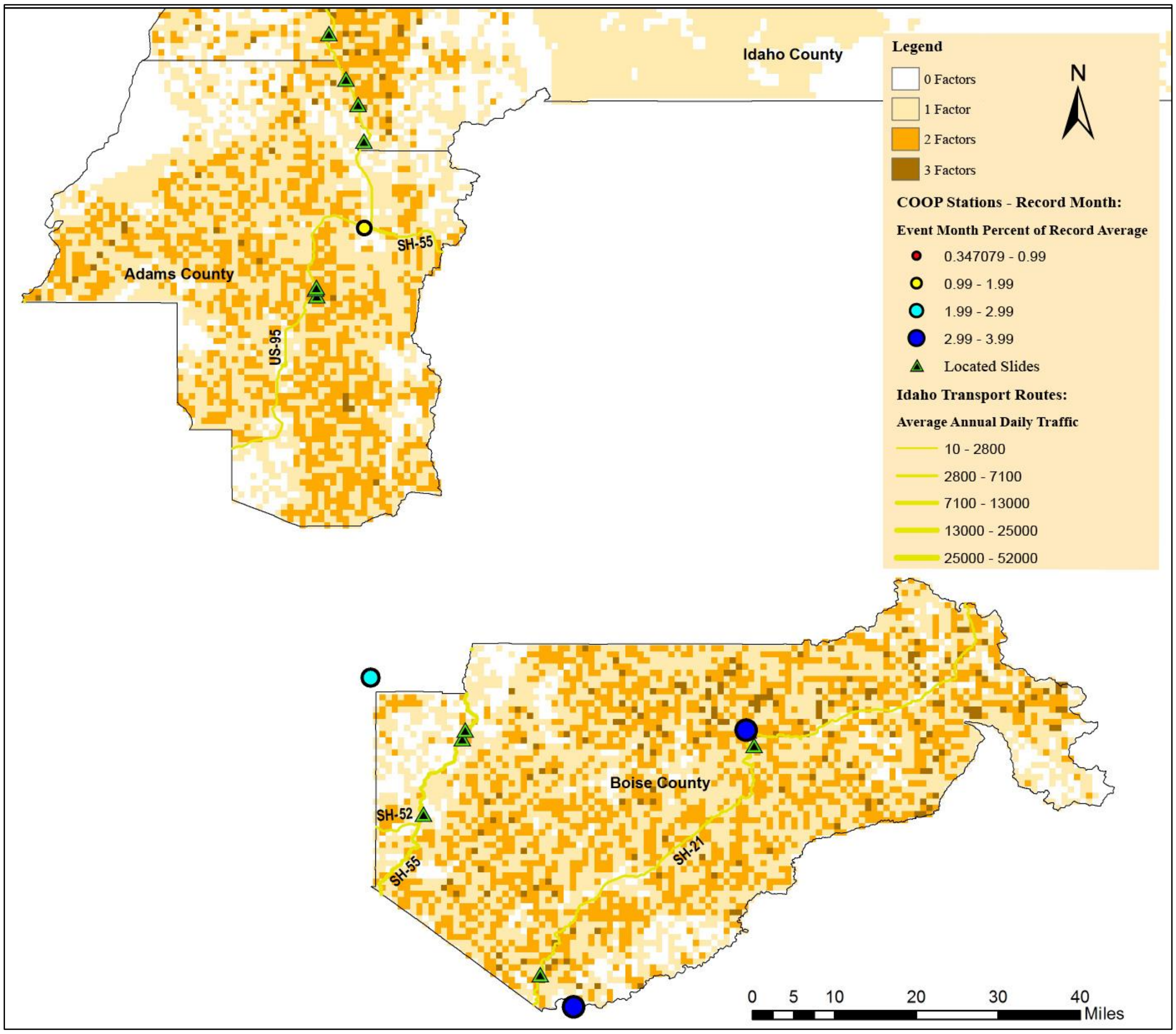


Figure 4.13. Combined analysis of geology, slope, and aspect for Adams and Boise Counties. (Cells with 0 susceptible factors are hollow on the map, cells given a 1 or 2 are progressively darker, while cells with all 3 factors are darkest.)

The literature for vegetation's impact on landslides was sparse. When *explaining* where landslides occur, the higher the canopy cover, the more roots are present to both stabilize the soil and reduce soil moisture. However, when *predicting* future slide locations, it is important to realize that dense canopy existing now could fuel a future, intense wildfire, leaving an area with little soil moisture retention capability. Because of this incongruity, canopy cover was left out of the combined analysis. The mean canopy cover for the located slides was 22%.

In terms of critical transportation routes, the highest traffic volumes are seen on Interstate 90 and U.S. Highway 95 through Kootenai and Nez Perce Counties. U.S. Highway 95 through Idaho and Adams Counties has significantly lower annual traffic, despite it being the only route within Idaho to connect Idaho's panhandle to the rest of the state.

4.2 Future Climate Projections of Idaho

In order to see the potential impacts of climate change on areas already prone to weather-related landslides, the 20-model mean was used for projections of minimum air temperature at the surface (the daily lows), maximum air temperature at the surface (the daily highs), the percent change in precipitation, and the amount of precipitation change. The following figures (Figures 4.14-4.17) depict the changes of these variables between the reference period 1970-2000 and mid-century (2040-2069) for two different emissions scenarios. RCP 4.5 assumes radiative forcing will be stabilized by 2100 through technology and policy choices, while RCP 8.5 assumes greenhouse gas emissions will continue to increase over time at roughly the current rate (IIASA 2009). The two diverge only slightly by the middle of the current century, then differ greatly thereafter. Figures 4.14 to 4.17 demonstrate the spatial patterns of change between the two emission scenarios are similar, with greater magnitudes of change in the RCP 8.5 future. RCP 8.5 multi-model mean projections for Idaho will be highlighted here, to provide "worst case" mid-century conditions for planning purposes.

Precipitation change can be considered in two ways: as a percent change, and as a measurement departure from the reference period. The seasons of greatest interest when anticipating landslides in Idaho are winter and spring. The areas projected to have the highest measurement increases (up to 84-92 mm) during December through May are the mountains of Boundary and Bonner Counties, and eastern Idaho, Clearwater, and Shoshone Counties.

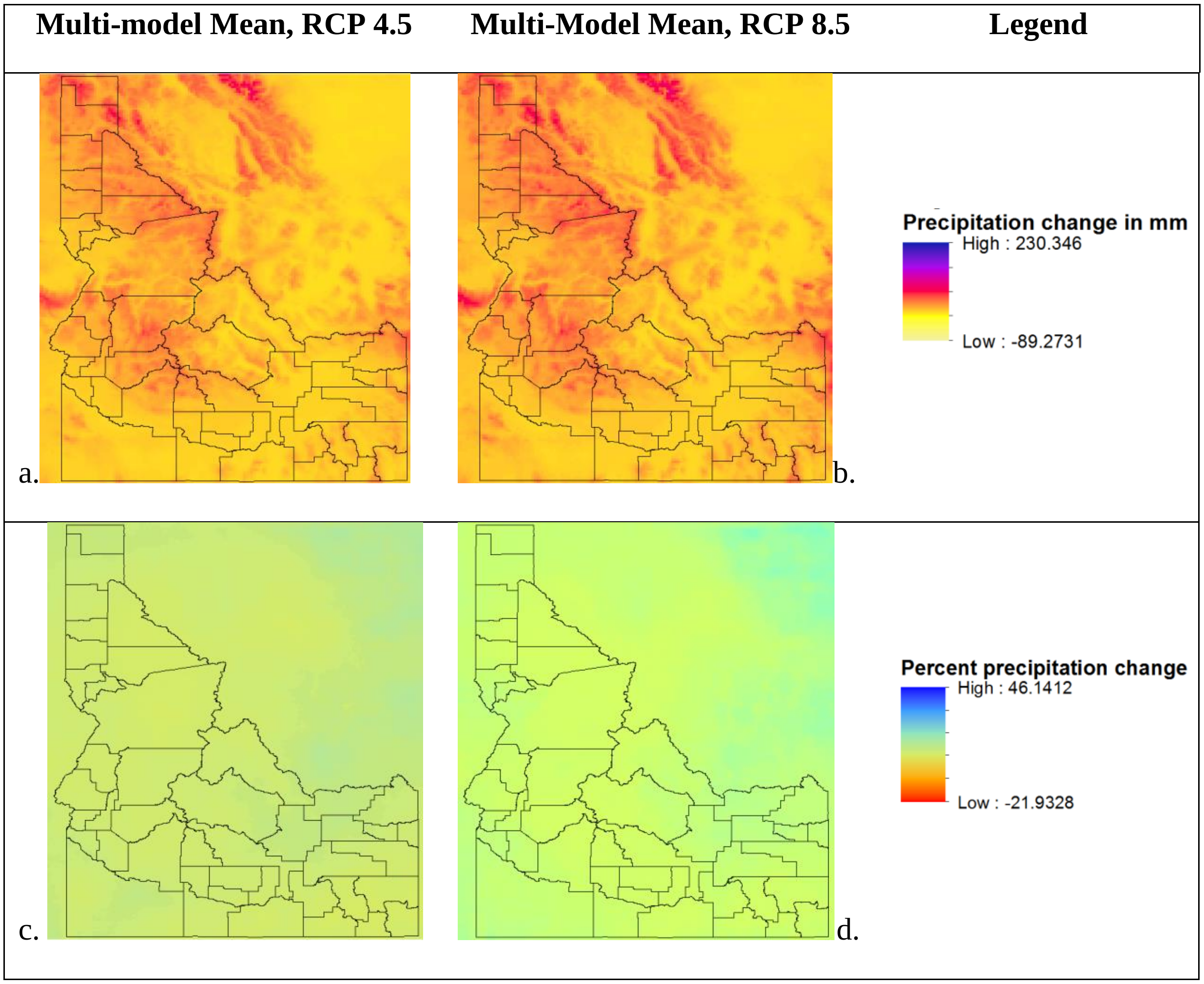
Increases will be more moderate in the valleys of the northern counties. Moderate increases (~10-50mm) are also projected for Boise, Lewis, and Nez Perce Counties during winter and spring, while southern Idaho's measurement increases will be negligible.

However, when future precipitation is considered in terms of percent-change from the reference period, the interpretation differs: the greatest changes (12-16%) will be in southwestern and southeastern counties, and the counties bordering southern Montana and western Wyoming. Within the study area of this research, precipitation is projected to increase by ~7-10% in winter and by 8-13% in spring. Fall precipitation follows a similar pattern of change as winter and spring. The highest increases in precipitation amount are predicted for the mountains of northern Idaho (up to +50 mm), and negligible to small increases (1-13 mm) across the remainder of the state, while percent-changes will be highest in eastern and southwestern Idaho, along with Boundary County in the north.

Summer precipitation patterns are opposite of the three other seasons. The highest negative departures are projected for Boundary County (up to -41 mm in the Selkirk Mountains), with lower negative departures in the valleys of northern and central Idaho, negligible change in Boise County, and even slight increases in southern Idaho. Across the study area for this research specifically, widespread moderate declines in summer precipitation are projected. When viewed in terms of percent-change from the reference decades, summertime precipitation will be between 8% lower (northern Idaho) and 8% higher (southeast and south-central Idaho).

Minimum daily (i.e., nighttime) temperatures in winter and spring are projected to increase by 2-4°C across Idaho by mid-century in the RCP 8.5 scenario, with the highest increases in Boundary and Bonner Counties and across south-central Idaho. Minimum daily temperatures are projected to increase by 3.2-3.8°C across Idaho in summer, and by 2.8-3.2°C in fall in this scenario, with the highest increases in south-central Idaho.

Maximum daily (i.e., daytime) temperatures in the RCP 8.5 scenario are projected to increase by 2.5-3.8°C in winter and spring with the highest changes in southwest and southeast Idaho. Summertime daily maximum temperatures are projected to increase by 3.8-4.2°C, with the highest departures in northwestern and southwestern Idaho. In fall, maximum temperatures are projected to increase by 3.0-3.6°C with the greatest change in southeastern Idaho.



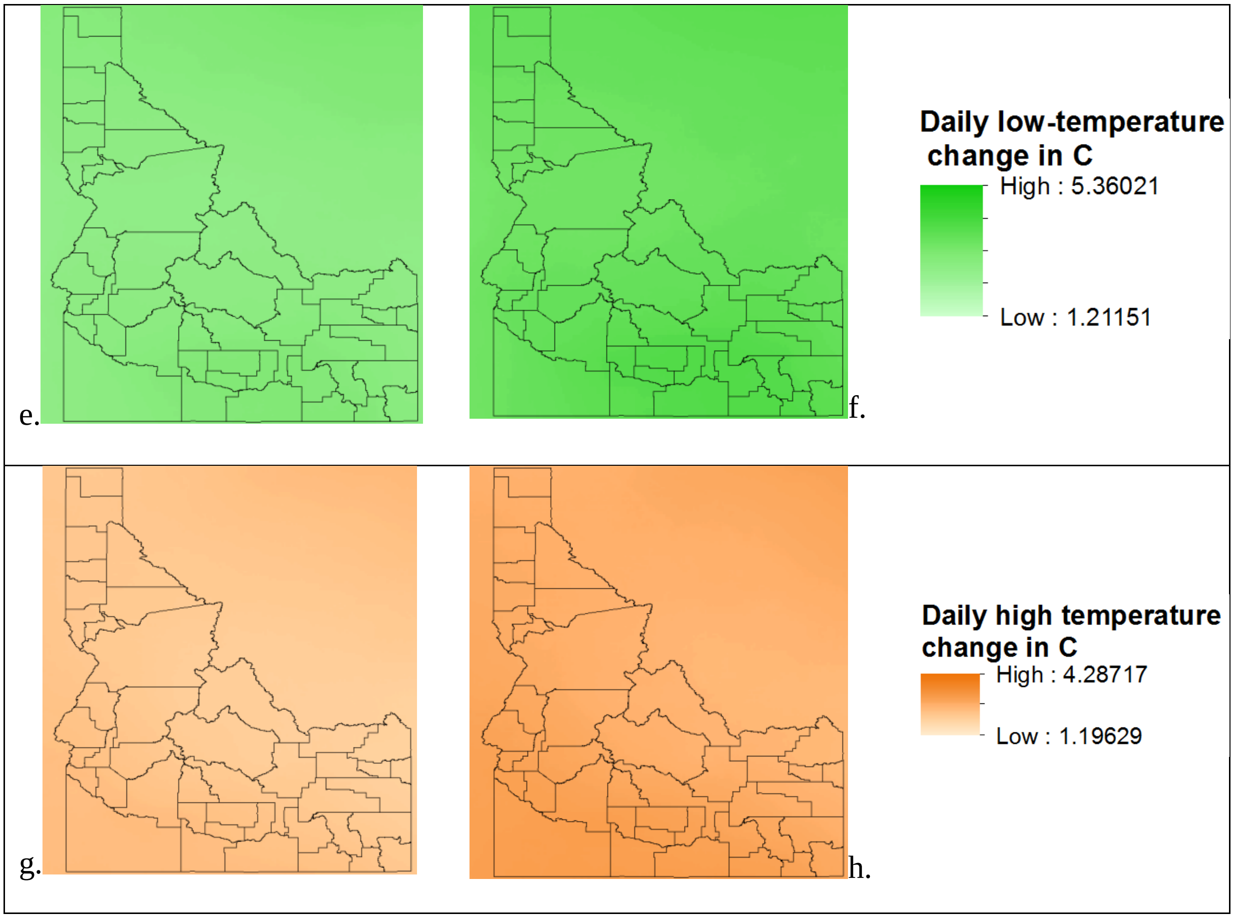
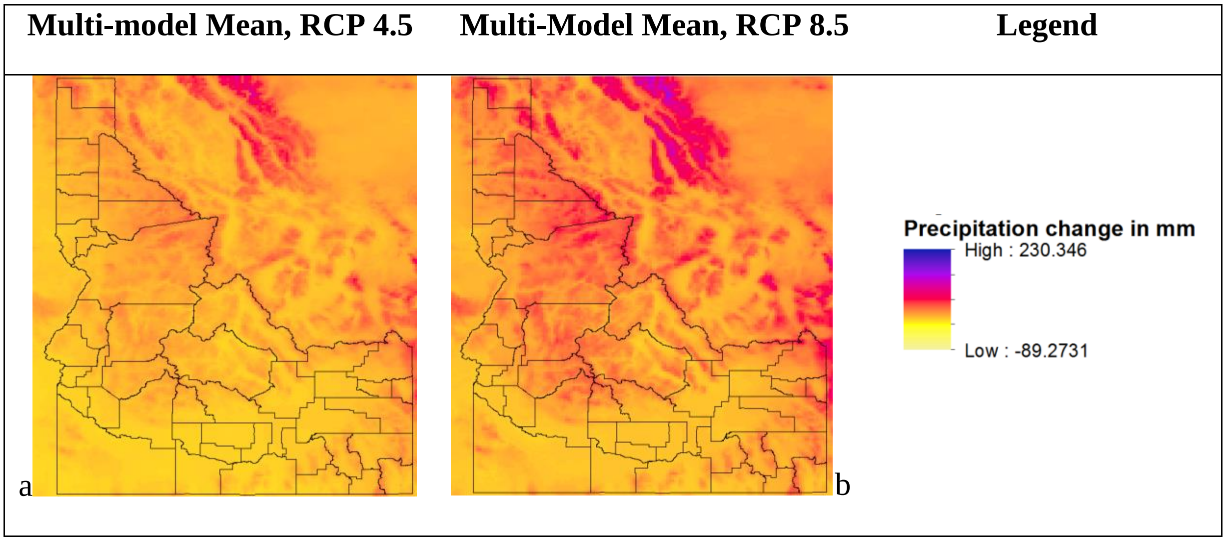


Figure 4.14 (a-h) December-January-February multi-model projected mean, compared to 1970-2000.



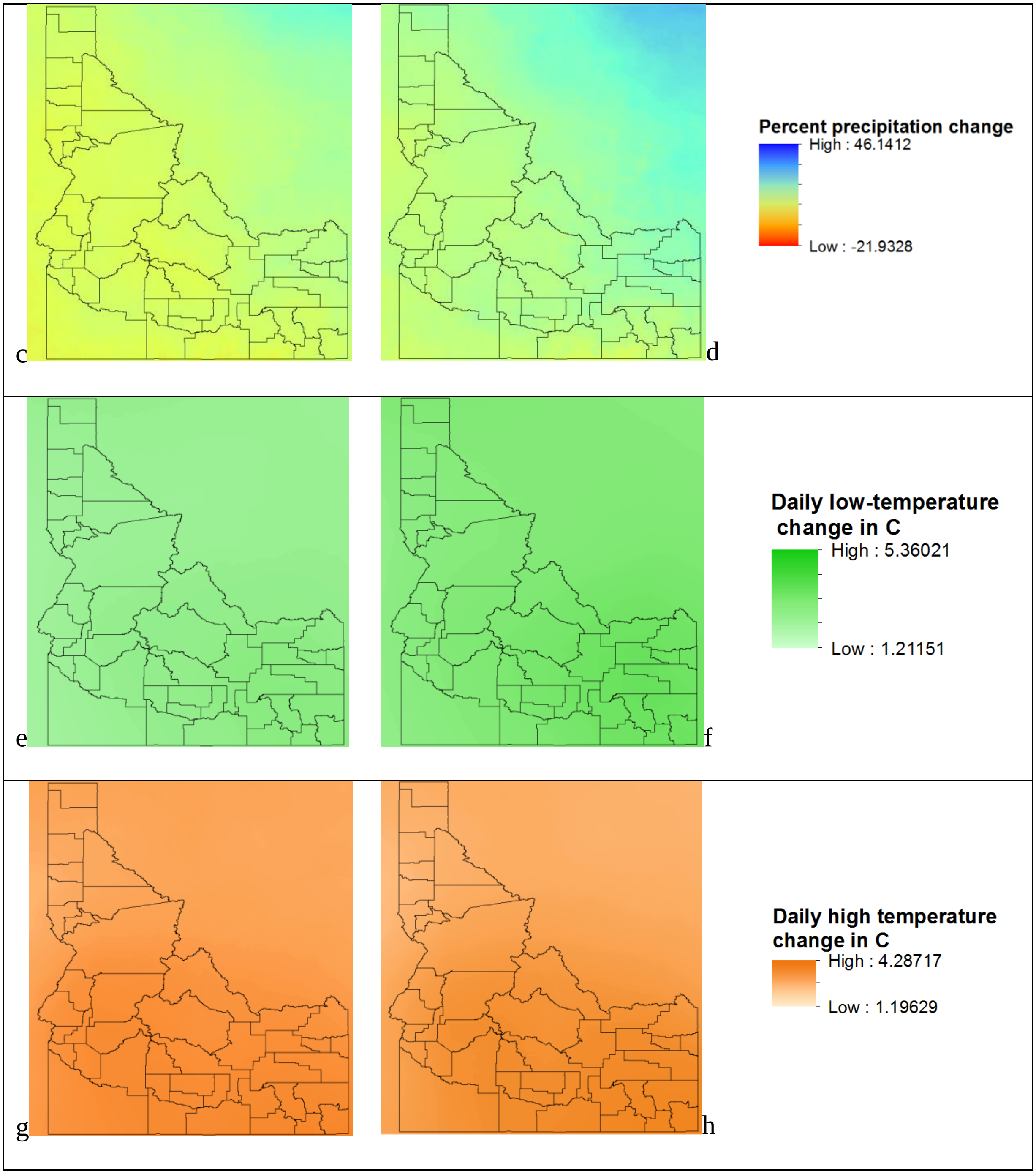
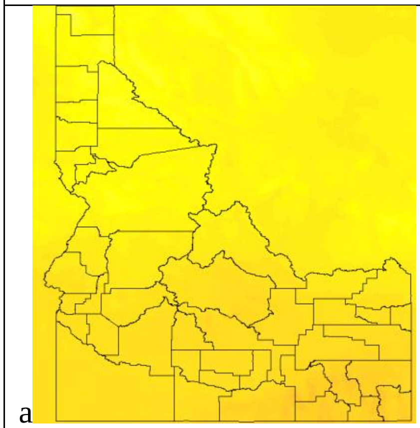
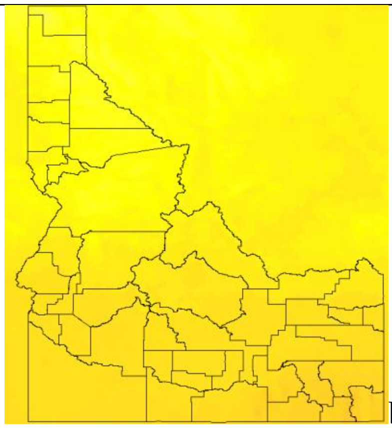
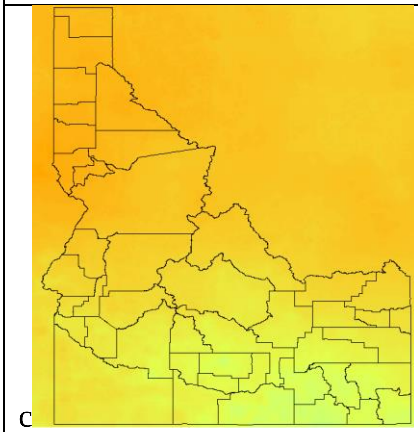
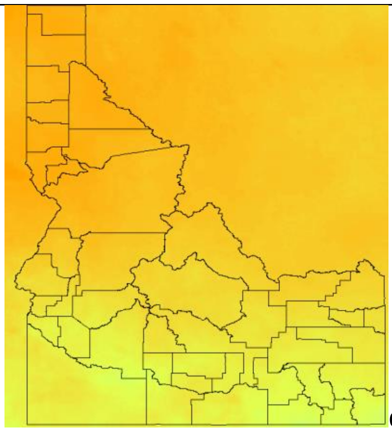
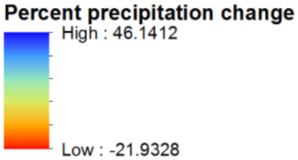
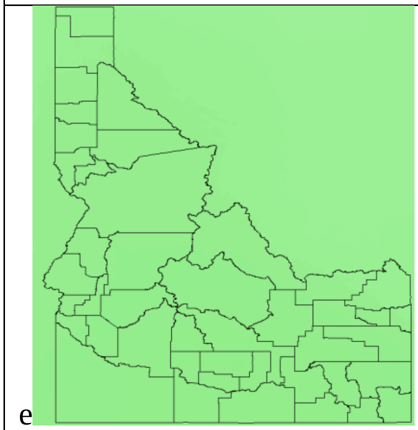
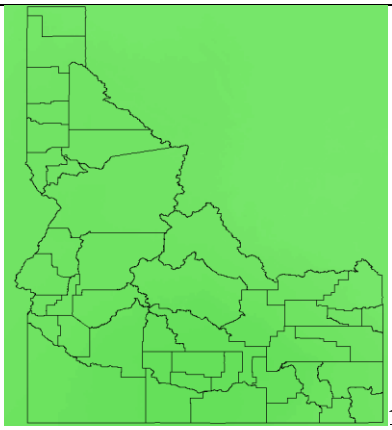
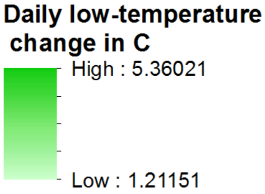


Figure 4.15 (a-h) March-April-May multi-model projected mean, compared to 1970-2000.

Multi-model Mean, RCP 4.5	Multi-Model Mean, RCP 8.5	Legend
 a	 b	
 c	 d	
 e	 f	

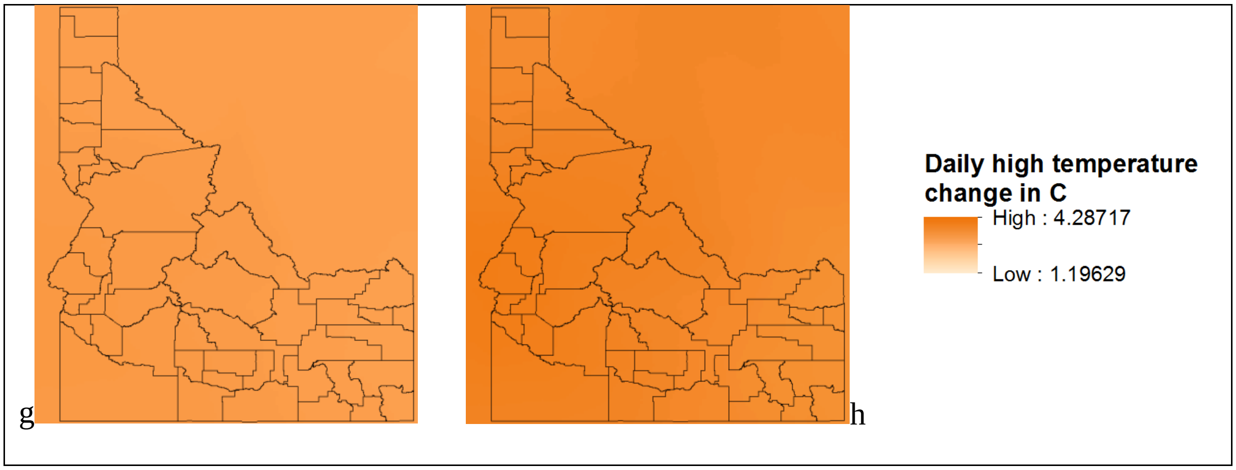
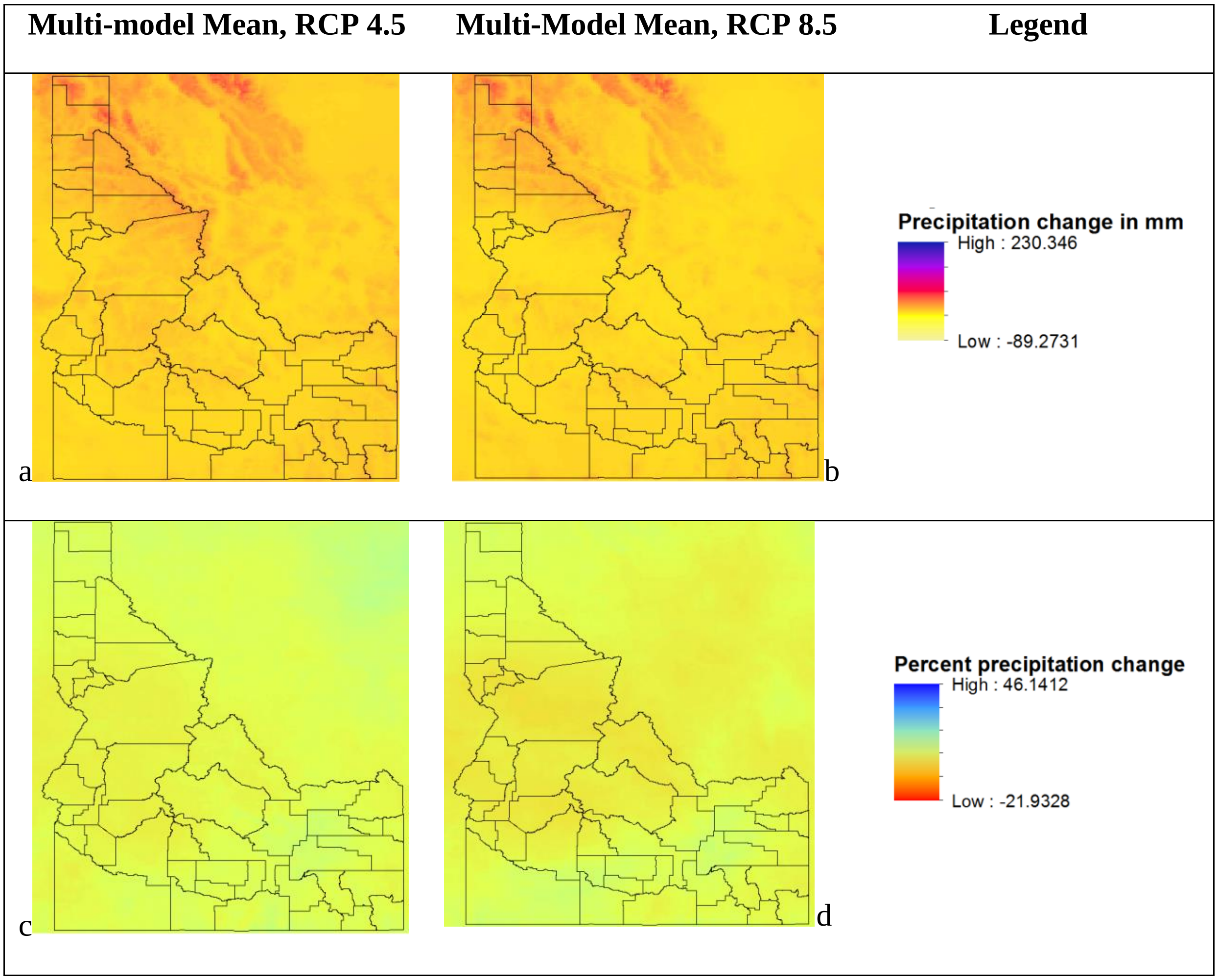


Figure 4.16 (a-h) June-July-August multi-model projected mean, compared to 1970-2000.



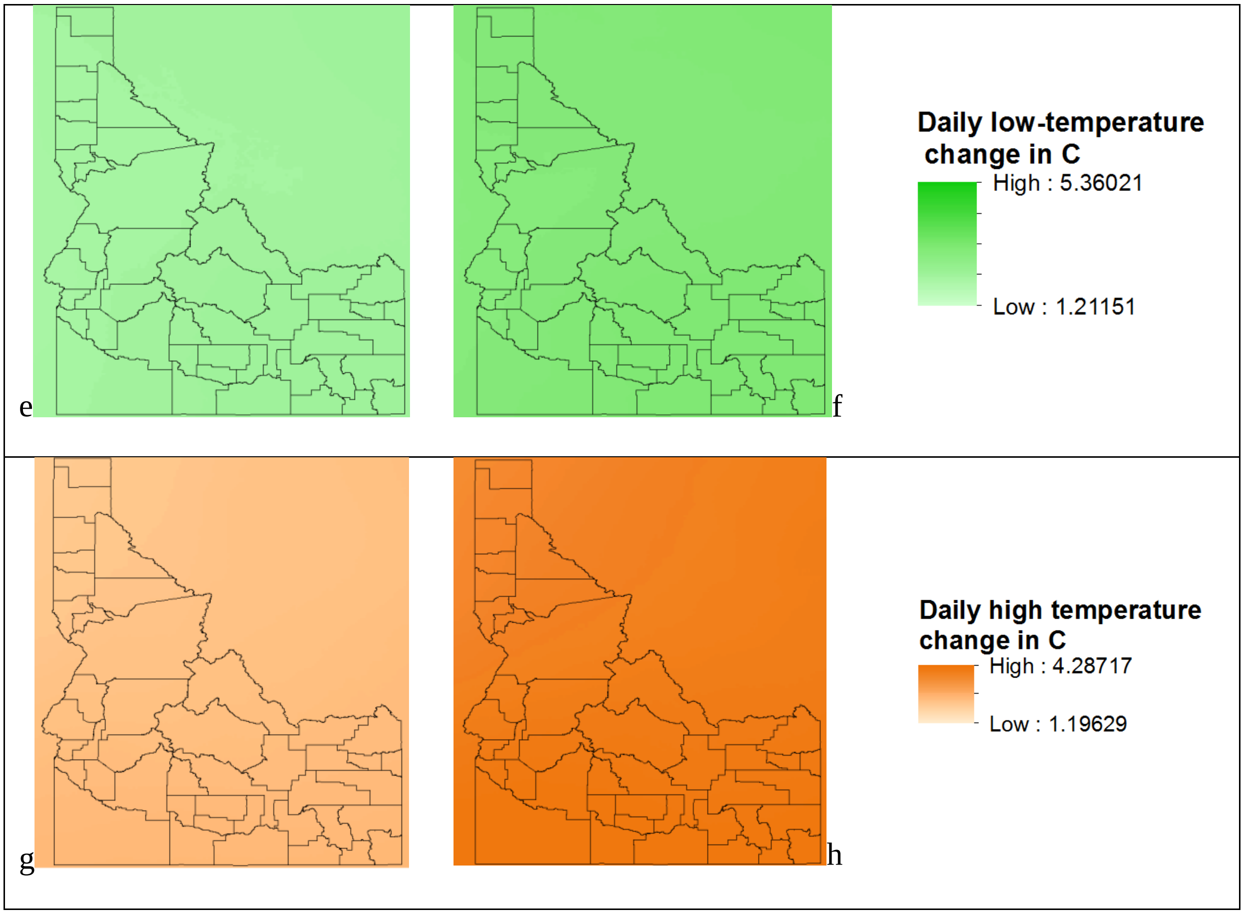


Figure 4.17 (a-h) September-October-November multi-model projected mean, compared to 1970-2000.

4.3 Interview/Survey of Experts

Thirty professionals were contacted and asked to participate in a phone interview or to complete a survey of the same questions and respond via e-mail, with the choice being left to each individual. After multiple rounds of e-mail notifications about the interview/survey, there were seven responses: five elected to type their answers on the provided form and two chose to schedule a phone call interview. Several more professionals had contributed to the early efforts of compiling archives and resources, but then later declined to participate or did not respond for the formal questions. Respondents were from county emergency planning offices, the Idaho Transportation Department, and the Idaho Department of Lands. Six of the seven respondents reported they had been in their current position from 1.5 months to 29.5 years, with a median of 13.5 years; the seventh did not provide that information.

Answers spanned the spectrum of opinions regarding the threat of landslides to transportation activities, climate change, and whether or not a landslide inventory would improve hazard mitigation efforts. Some respondents brought up climate change, others mentioned weather being unpredictable, some focused on the future of increased building in Idaho and slope stability, and one respondent called the idea of climate change “whacky.” Four respondents said the lack of a landslide inventory was a hindrance, two said it was not, and the final respondent did not specifically answer the question, but found the question “ambiguous.” County and ITD officials confirm that landslides near roads in Idaho are primarily associated with precipitation patterns in winter and spring, soil conditions, drainage design, and road location. Staff, resources, time, technology, and funding were cited as limiting factors to landslide documentation. When asked who is responsible for monitoring slopes for failure along roadways and who is responsible for mitigation and clean-up efforts, answers sometimes pointed to ITD personnel and sometimes pointed to county highway districts. Interview/survey answers can be read in Appendix B.

Chapter 5 Discussion

Since only 33 landslide events found through searching archives and available records could be dated and approximately geocoded across the entire heterogeneous state of Idaho, a predictive landslide model was not possible. However, this pilot study found that areas highly susceptible to landslides based upon geologic and geomorphic variables in northern Idaho will likely experience increasingly wet winters and springs, when landslides are most frequently triggered by heavy precipitation. Differences in spatial patterns between the projected changes in measured precipitation and precipitation percent-change were surprising; however, it reflects the current high quantity of precipitation observed in the northern counties and the mountains of the central counties, compared to the low precipitation in southern counties. For example, an 80 or 90 mm increase in measured precipitation may not be vastly different from current wet conditions in northern Idaho, but a 1-15 mm increase represents a large departure for the dry steppes of southern Idaho.

The heavily-traveled northern sections of U.S. Highway 95 and the critical east-west route of Interstate 90 traverse areas projected to have high magnitudes of precipitation change by mid-century, and are susceptible to landslides based on slope, aspect, and geology. The exclusion of soil variables due to the coarse scale of this study is an acknowledged limitation. Instead, canopy cover was examined, as roots help stabilize soil and remove excess water. Currently, most of the areas of steep, susceptible slopes are also heavily forested. However, summertime precipitation is expected to decline in most of Idaho by mid-century, increasing the potential for widespread wildfires and subsequent landslides on denuded slopes. Forest management policy changes or land use changes could also alter slope stability. Furthermore, temperatures are expected to rise in all seasons by mid-century, enhancing the potential for wintertime heavy, wet snow and rain, and faster snow melt. Luckily, the highest projected precipitation change over the reference period is in southern Idaho, in flat terrain or roadless areas.

The choice of “best” representative weather station for landslide events was often limited, and sometimes the only nearby station was several ridgelines away. Therefore, rather than examining the observations amongst stations to discern thresholds, the station data for the preceding month of a slide event was compared to that station’s ongoing record. Only two slide events occurred when the preceding month’s precipitation was less than 100% of normal. While the data set was small, this is a strong indication that above-average precipitation was an important trigger for the events that were geocoded. Unfortunately, three of the 14 weather stations referenced in this study had records going back less than 50 years. Those three stations were utilized as the best representative station for seven slide events. Historical normals at stations with short records may not accurately reflect long-term, natural cycles of interannual variability, so comparing one month of precipitation observations to the record for that month may under- or over-estimate the departure from the average.

Despite the low response rate on the interview/survey, most of the respondents indicated the utility a landslide inventory would provide. Limited budgets and personnel were cited as the barriers to creating a comprehensive landslide inventory. Only two of the seven respondents mentioned climate when considering the potential for landslide risk to increase in the future. However, all respondents supported the assertion that the majority of weather-related slide events in Idaho take place in winter and/or spring. In addition, all respondents also indicated at least one weather-related trigger of landslides in their county or district such as rain-on-snow, extreme precipitation events, and/or seasonally heavy precipitation. Some respondents also added sudden freeze-thaw cycles to the list of triggers, a phenomenon not addressed in this study, but worthy of future research into the influence of climate change on the frequency of extreme, landslide-triggering events.

Chapter 6 Conclusions and Recommendations

Each type of landslide has its own causal mechanisms and each should be analyzed individually, *in situ*, if statistical analysis is to be performed. The combination of mechanisms that contribute to landslides during a particular year are statistically independent of past events, requiring hundreds of data points to create a predictive model. Unfortunately, this research did not incorporate field measurements and did not have a budget for LiDAR. Assembling a database from existing, qualitative records was a time-consuming process that yielded little results. Many county agencies have not digitized all their pre-personal-computer-era records, and there seemed to be little knowledge transfer between hazard mitigation planners through time or across county lines. The Idaho Transportation Department and local highway departments clean up debris when it falls on roadways, and do not record location or other details for individual events, nor do they maintain a database of mitigation action. The one interviewee at the Idaho Department of Lands was knowledgeable about landslides in Idaho in general, but IDL rarely deals with major public roads. Due to these limitations, the dataset produced in this study was not large enough to perform statistical analysis for creating predictive models. But despite these limitations, the hope is that this pilot study will initiate a multi-agency effort at inventorying landslides, and that it demonstrates the types of data that can be compiled and analyzed for the creation of predictive models, in both current and future climatological conditions.

An extensive inventory of accurately-dated, precisely-located historical landslides would help plan for future weather-triggered landslides in Idaho. Though each landslide has a unique set of causal factors, a large inventory may elucidate thresholds. Predictive models could then be applied to geologically- and climatologically-homogenous regions. Data that should be contained in an inventory includes: date of the event, coordinates and elevations of the initiation point and the toe of the slide, flow path length, slope, cohesion, soil moisture, geology, soil type, plan and profile curvature, topographic wetness index, basin drainage times, land use, and canopy cover. This pilot study also demonstrated the utility of weather station records for examining landslide occurrence during above-normal precipitation patterns.

When *in situ* measurements are added to a landslide database, coupling with a hydrologic model such as CHASM becomes possible. This would be especially beneficial if further research added flood hazards to a landslide assessment. Many of the main transportation routes in Idaho are built in river canyons and flood plains and, as was seen to devastating effect on the Schweitzer Mountain Road in April 1991 and in the “New Year’s Day” flood event in 1997, floods and debris flows are often inseparable.

Past research that has used statistical models couldn’t account for variables that change over time, for example: the water table level, land use, land cover (especially in relation to unpredictable fire variables), and climate change. This study has attempted to provide ranges and “worst-case” mid-century climate projections for planning purposes, to reflect the lifespan of current infrastructure and promote conversations about the design of replacement infrastructure. Planners and engineers can use future climate projections to narrow down the most vulnerable roads, buildings, and infrastructure, then plan, design, and build for the worst case scenario in the future climate of extremes.

Soil moisture models based on field measurements are often used in the prediction of slope failures over small, homogenous areas. If climate models prove to adequately predict the changing frequency of extreme precipitation events, an alternative method may be to examine 3-day, 1-week, 30-day, 90-day, and 6-month antecedent rainfall for inventoried landslide events against long-term normals. Instead of assigning thresholds based on soil moisture capacity, this approach could reveal if a particular antecedent anomaly is more consequential in triggering slope failures than others. Then, precipitation events on the significant timescale(s) could be compared to future projections of extreme event frequency.

Another potential avenue for further research is to combine geologic and geomorphic landslide variables with a wildfire model. As climate change and the legacy of preventing wildfire contribute to increased intensity of conflagrations in the future, burned hillsides will become more prone to erosion and massive debris flows. Areas with the highest summer- and fall-temperature changes, highest winter precipitation increases, and highest density forest will likely be most at risk. In addition, more research on the significance of canopy cover on landslide events would allow for the canopy cover layer from the National Landcover Database to serve as a true proxy for slope stability.

Currently, the Idaho Geological Survey is in the process of expanding their outdated landslide database from 1991 that did not provide event dates, and will be publishing a new compilation soon. Expanding the coverage of LiDAR data along roads in conjunction with a knowledgeable field team will greatly support an inventory effort, and will provide better understanding of the causal mechanisms of landslides in Idaho for both emergency planners and road engineers.

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APPENDIX A. LIST OF GEOCODED HISTORICAL LANDSLIDE EVENTS FROM RECONNAISSANCE

Longitude	Latitude	Elevation (ft)	County	Date(s)	Information Source(s)	Certainty of location
-116.311207	48.694458	1958	Boundary	Saturday, March 01, 1997	Boundary Hazard Mitigation Plan (HMP)	Seen in Google Earth, map in AHMP
-116.298892	48.71291	2269	Boundary	October 19, 1998-October 20, 1998	Boundary HMP and State AHMP 2013	Map in county plan cross-referenced to Google Earth
-116.40667	48.691074	1811	Boundary	March 31, 2011-April 11, 2011	Damage Summary Report, Disaster Number ID11-01	Exact coordinates given in report
-116.584258	48.329641	2808	Bonner	April, 1991	Bonner HMP	**Approximate Only!** Cross-referenced to H_2O treatment location and Google Earth
-116.89997	48.22839	2231	Bonner	March 31, 2011-April 11, 2011	Damage Summary Report, Disaster Number ID11-01	**Approximate** coordinates obtained from cross-referencing aerial photographs in report
-116.897045	48.231764	2309	Bonner	March 31, 2011-April 11, 2011	Damage Summary Report, Disaster Number ID11-01	**Approximate** coordinates obtained from cross-referencing aerial photographs in report
-116.861148	48.31126	2275	Bonner	March 31, 2011-April 11, 2011	Damage Summary Report, Disaster Number ID11-01	**Approximate** coordinates obtained from cross-referencing aerial photographs in report
-116.832147	48.368522	2384	Bonner	March 31, 2011-April 11, 2011	Damage Summary Report, Disaster Number ID11-01	**Approximate** coordinates obtained from cross-referencing aerial photographs in report
-116.535002	47.985362	2609	Kootenai	January 30, 2000 and February 11, 2000	Kootenai HMP	Seen in Google Earth, referenced to online photographs. Unknown which slide occurred on which date.
-116.531592	47.985067	2530	Kootenai	January 30, 2000 and February 11, 2000	Kootenai HMP	Seen in Google Earth, referenced to online photographs
-115.928	47.69323	2480	Shoshone	Thursday, March 31, 2011	FEMA documents	Exact coordinates given in FEMA docs
-116.713297	46.499993	1199	Nez Perce	Wednesday, January 01, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!**, **representing road closure at Cottonwood Creek,** not the locations of multiple mud and rock slides beyond
-116.179053	46.391673	1102	Lewis	January 1, 1997-January 2, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!**, **representing road closure at Greer,** not the locations of multiple mud and rock slides

-116.001877	46.184463	1213	Lewis	January 1, 1997-January 2, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!**, **representing road closure at Kamiah,** not the locations of multiple mud and rock slides
-116.1655	46.5321	2284	Clearwater	Monday, April 11, 2011	Documentation provided by Don Gardner, Clearwater County	Exact coordinates given in Preliminary Damage Assessment from Don Gardner
-116.251113	46.491013	1525	Clearwater	March 31, 2011-April 11, 2011	Damage Summary Report, Disaster Number ID11-01	**Approximate** coordinates obtained from cross-referencing aerial photographs in report
-116.169952	46.5907	2566	Clearwater	Monday, April 11, 2011	Documentation provided by Don Gardner, Clearwater County. Damage Summary Report, Disaster Number ID11-01	Exact coordinates given in Preliminary Damage Assessment from Don Gardner (refer to start of slide and start of slide 100's feet long) and obtained from cross-referencing aerial photographs in report
-116.070184	46.183821	1673	Idaho	December 30,1996-January 1, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!** based on mileposts given for the road closure and cross-referenced to topography
-116.32247	45.414676	1785	Idaho	January 1, 1997-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate**, **representing road closure** not the locations of mudslides
-116.356369	45.315562	2310	Idaho	January 1, 1997-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate**, **representing road closure** not the locations of mudslides
-116.11536	44.084029	2805	Boise	December 30, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only**!, **representing road closure at Banks** not the locations of multiple mudslides
-116.188818	43.935172	2636	Boise	December 30, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!**, **representing road closure at Horseshoe Bend** not the locations of multiple mudslides
-116.120062	44.068445	2785	Boise	Wednesday, January 01, 1997	State AHMP 2013	Exact coordinates given by Keith Nottingham, ITD. Cross-referenced to Google Earth, coordinates give toe of slide, top of slide unknown.

-116.114603	44.084594	2820	Boise	Tuesday, December 31, 1996	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!, representing road closure at Banks** not the locations of multiple mudslides
-115.614711	44.08266	3835	Boise	Wednesday, January 01, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!, representing road closure at Lowman** not the locations of multiple mudslides
-114.939414	44.217398	6250	Boise	January 1, 1997-January 5, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!, representing road closure at Stanley** not the locations of multiple mudslides
-115.604564	44.05685	4857	Boise	January 1, 1997-January 5, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!, representing road closure 4 miles south of Lowman** not the locations of multiple mudslides
-115.982285	43.650976	3118	Boise	January 1, 1997-January 5, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (via Latah County records--hard copy document)	**Approximate Only!, representing road closure at Robie Creek intersection** not the locations of multiple mudslides
-116.29432	45.125501	3808	Adams	December 31, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	**Approximate** based on "eleven miles north of New Meadows" in report.
-116.30478	45.190218	3182	Adams	December 31, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	**Approximate** based on "seventeen miles north of New Meadows" in report. Multiple debris flows along 10-mi stretch of road during these dates
-116.325945	45.235169	2834	Adams	December 31, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	**Approximate** based on "twenty miles north of New Meadows" in report. Multiple debris flows along 10-mi stretch of road during these dates

-116.377683	44.851688	3618	Adams	December 31, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	Close to exact, cross-referenced to ITD's milepoint logs, http://itd.idaho.gov/highways/milepointlog/
-116.379892	44.863654	3688	Adams	December 31, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	Close to exact, cross-referenced to ITD's milepoint logs, http://itd.idaho.gov/highways/milepointlog/
-116.378512	44.866715	3683	Adams	December 31, 1996-January 4, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	Close to exact, cross-referenced to ITD's milepoint logs, http://itd.idaho.gov/highways/milepointlog/
-116.032956	45.904117	1912	Adams	Wednesday, January 01, 1997	Idaho Transportation Department/Disaster Declaration Task Force Committee Report (through Latah County records--hard copy document)	**Location of slide itself unknown**. Little detail found. **Coordinates refer to closure based on milepost given.**

APPENDIX B. INTERVIEW/SURVEY QUESTIONS AND RESPONSES

The following are the answers received via email (five) and over the phone (two). Respondents are employed across the state by the Idaho Transportation Department, Idaho Department of Lands, or work in their county's emergency management office. In order to help protect the anonymity of respondents, the answers to each question have been shuffled. When necessary, answers have been shortened (indicated by brackets) to maintain anonymity. Otherwise, answers via e-mail have been preserved, and answers over the phone reflect summarized, direct quotes, so all syntax, emphasis, and ambiguities below are part of the true answers.

1. Where are the known landslide "problem areas" in your county/district?
"Along the roads traversing up the river valleys."
"1. US26 Ririe to Wyoming State line. 2. SH31 Swan Valley to Victor. 3. US93 Montana Line to Challis 4. [ ] (Pocatello) has several areas scattered throughout [ ]. I know of some but not all."
"[ ]Our landside problems are adjacent to roads throughout the county both State HWY and County Rds. Hwy 64 from Nezperce to Kamiah is of greatest impact and concern."
"Hwy 99 going down the grade into Kendrick; McGary Grade in Juliaetta; Hwy 3 near Juliaetta; Cedar Ridge in Kendrick."
"I-90 East of CdA, US-95 south of CdA (N Mica), Bonners Ferry area, SH-57 north of Priest River, US-2 WSL to Priest River."
"East of Clarkia going back 100 miles around St. Maries, called "flood woods", mica schist very problematic—couple hundred square miles. No towns out there, just forest roads. Two types of landslides: deep and shallow (this area has both)."
"10-15 years ago, near Glen's Ferry that closed the road. State Hwy 55 milepost 82.2: rock- scaling project discovered landslide 300-400 feet up from road, moved road over 20 feet. Another in Banks area–a rain on snow event. Lower Banks condemned. Since then 2 or 3 events. In 1997, 8 out of 10 counties were affected along Highways 21, 55, and 95. Governor's landslide task force created. A 3-day rain pineapple express melted everything 4800 feet and lower. [ ] North of Weiser, just south of Manns creek. Route change, didn't affect the road but almost. Rearranged the road, overloaded material [ ]. Old Meadows, a huge ¾ mi slide not active but mapped, no roads nearby. Between Boise and Horseshoe bend, road rebuilt in 1993. [ ] North of Banks, by first railroad bridge."
2. Are roads and infrastructure at risk in these problem areas? If so, what specifically is at risk?
"The roads and creeks. Land-sliding into a creek with threatened and endangered fish."
"This depends on the size of the slide."
"No, moved the roads, not that we know of."

“Yes, could cause road failure disrupting transportation routes and access to and from location within the county.”

“Material in roads become a road hazard, Blocking roads”

“Yes, existing and potential for landslides.”

“1. US26 Ririe to Wyoming State line @ risk items 1 bridge and several sections of the highway. 2. SH31 Swan Valley to Victor @ risk are several sections of the highway. 3. US93 Montana Line to Challis @ risk are a couple sections of the highway.”

3A. What is the main cause of slope failure in these areas?

“Debris flow, rain on snow like 1997, little bit of everything. Post wildfire [ ] possibly a problem, still need a heavy rain…need both.”

“Poor soils and water and roadways traversing ancient landslides are the most common reasons in my district. The second most common is poor drainage design causing soils on embankment and natural slopes to become saturated and fail.”

“Erosion; snow melt.”

“Deep seated slope failures in both cut and fill and shallow failures in all slopes often caused by solifluciton. Natural, relatively undisturbed areas are also a threat, primarily along SH-57 and US-95 in the Bonners Ferry area.”

“Soils becoming saturated and freeze thaw events”

“Drainage, how we control water, need to get water off the road…surface or sub surface water.”

“Most generally due to too much water, we do have a dry slice that accelerates during dry times.”

3B. In your experience with slope failures in your county/district, are these events typically associated with:

Condition	***Number that answered “Yes”***	***Additional notes submitted:***
…rain-on-snow?	6	“rain on snow and are short timed except for the fixing part of the equation.” “springtime, dependent upon weather patterns. Happen in certain area at a certain elevation.”

…extreme events lasting less than a one week?	5	“concentrated rainstorms esp. near Banks (just had one last spring, was an area burned over)” “some events extreme for less than a day, definitely seeing more extreme events, mostly leading to shallow landslides.”
…a season-long pattern of higher than normal precipitation?	5	“one near Weiser” “when you have a long winter, snow hangs around until rain starts, long term pattern leading to rain on snow”
…post-wildfire conditions?	3	“locally, will be doing salvage logging, without triggering more landslides, what you end up triggering is shallow landslides.” “Not too much as we haven’t experienced the large wildfires.”
…more than one of these circumstances?	3	“most of these on the list”
…or something else entirely?	3	“Site disturbance, changes in natural drainage or vegetation, clear cutting, etc.” “Another contributing factor has been poor drainage design for the highway and placing roadways on unstable or marginally stable slopes.” “…freeze-thaw events and heavy rain storms lasting less than one week.”

4. At what time of year do most slope failures occur in your county/district?

“Spring”

“Early to mid-Spring”

“Spring, extreme thunderstorm events especially in southern Idaho. In fall sometimes.”

“Most generally January through March but occasionally due to rain storms of huge rain fall in June or July equaling more than an inch is less than one hour.”

“Late winter and spring”

“November to June.”

“Late winter (January rain-on-snow or rapid melt) to spring”

5. Who (agency or contact name) is responsible for monitoring potential slope failure in the “problem areas” along roads in your county/district?

“County road districts”

“Me.” [ITD District Geologist]

“Me.” [ITD District Geologist]

“Area folks find them, report them to [ ], then try to figure out the mechanism. [ ] has his roads, IDT has their roads. Most of [ ]’s roads are gravel”

“It is shared between Operations (Maintenance) and the geotech [ ]”

“County roads: N Latah County Hwy Dist; S Latah Hwy Dist. State roads: ITD”

“We have (5) road districts and [ ]EM Coord. [ ]”

6. Who (agency or contact name) is responsible for mitigation efforts and clean-up efforts in your county/district?

“Operations, each foreman area.”

“Whoever’s maintenance areas, whoever the local guys are, not ITD”

“County road districts”

“Idaho Transportation Department District [ ].”

“Same as above question, Road District and County Emergency Management”

“[ ] is for mostly gravel roads, just a case of rebuilding the road, design to fix it.”

“It depends on the incident for cleanup efforts. All Hazard Mitigation Plan is a county-wide effort to show vulnerable areas when improvement needs to be worked on.”

7. In your opinion, is the absence of a comprehensive landslide record in the State of Idaho a hindrance in mitigation efforts in your county/district? Why/why not?

“Yes, cataloging and mapping landslides and areas with a potential of landslides would be very beneficial for the ITD planning and maintenance but also for local agencies and developers.”

“This is an ambiguous question because you don’t define what you’re talking about and it’s not a term used in the industry. ITD has been a reactive agency when it comes to landslides. The department does not actively have a statewide database of known landslides but relies on institutional knowledge which is very inadequate because several have been mitigated but only a few individuals know about these. The four district geologists know of their existence but every district does not have a geologist and as for myself It has taken years of research in old plans and field work to put together what I know about in my district.”

“YES. It would be nice to have a way to track the landslides in the county (small/large) to better mitigate the situation, ie, minimize or eliminate.”

“Yes, We have potential landslide areas that we either are not aware of their existence or do not understand their potential for destruction. Many of the river bottoms are The USGS soils map shows many of the river bottoms Qal, alluvial deposits, we have Qls soils, landside deposits, and many of the river valley walls are Ywu or Ywml, a Wallace formation (middle proterozoic) We have fault lines in these areas. We probably do not have a good understanding of the potential problems these soil types could present.”

“NO Because of the Local knowledge base that exists and that remains for decades.”

“Don’t think it would make a difference or not. If it closes the road, it is cleaned up. Pollack area north of Riggins has had several road closing events, trying to get IGS to identify landslides there, possibilities with LiDAR. Mitigation efforts aimed at county and state highways and people.”

“Yes. We don’t have a landslide inventory. Part of it is grand scheme, landslides in Idaho are not like in western Washington. But more people are moving to Idaho, more building. Would be great to have a comprehensive inventory, especially with LiDAR. [ ]”

8. What is/are the barrier(s) to landslide documentation in your agency? …in the State?

“No clue”

“The county does not have the trained staff nor the funding.”

“Money and staff. LiDAR becoming more prevalent, building data consortiums. With LiDAR, algorithms can pick up the roughness [of a landslide]. The Oso, Washington slide brought this to light, which was preventable. But Idaho’s not a rich state.”

“In county it has to do with time, of personnel and availability of technology of the various road districts to document what they have done.”

“No Headquarters Geotechnical Section with staff and resources to archive these landslides and any information related to location, soils, mitigation or instrumentation."

"Budgets and personnel. We haven't near enough bodies, 4 geologists for the entire state, and we have very little to no budget for this work."

"Washington State had an unstable slopes program. If there is a problem, ITD Geologists work with managers. Along Snake River, the road was built out one lane because can't get a hold on the slope there)."

9. Do you anticipate landslide risk will increase in the future? Why or why not?

"I don't anticipate the risk to increase as the causes of instability are widely varied and can sometimes be controlled. The weather plays a large part in many of our problem areas so an increase in precipitation or long periods of precipitation increases the probability of landslides occurring."

"Hope we are gaining ground, depends on the weather, everything is weather related."

"Yes. Due to climate conditions."

"Yeah, two things: more extremes in weather from climate change, more high precipitation events and more people building, just like fire."

"That honestly depends on Mother Nature. We are trying to get proactive but with only four geologists in the districts and one geotechnical engineer in headquarters and no central program or budget to draw from for mitigation we will mostly be reactive. I believe as existing embankments and cut slopes age and marginal soils lose their shear strength due to increased soil moisture content then yes slides will eventually increase in frequency. Also remember that not all mitigation is permanent so some that have been stabilized may eventually fail again due to the design life of the mitigation and possibly lack of maintenance of mitigation features."

"No, most the county is flatter and those areas of prone sliding are documented and remain where they are."

"As development continues on the hillsides and as logging removes timber from the hill sides, the potential will increase."

10. Is there any other information about landslides or landslide documentation that you would like to add?

"There are many types and forms of landslides or slope instability. It would be beneficial to document and categorize each area according to the type and risks."

"LiDAR is really promising. Predictive tools, shallow stability analysis. Need to map existing landslides, then try to predict where they will happen. That would fit in for everybody, tell planners to check the inventory first."

"Now with each district having GIS personnel and a tool to capture geospatial information about landslides then it may be possible with extra resources to gather existing data into a central repository but the key work is resources."

"The more opportunities we have to become educated regarding landsides, the more we are apt to either mitigate, regulate and/or prepare."

"Said it all at the beginning: you have to think about geologic time scale versus climate change. There's 450 feet of gravel south of town from the Bonneville flood, came through Utah….In McCall area, they found 4 different ages of ice. Global cooling was a concern in 1970s, now it's global warming. Climate warming is whacky."

"Some kind of a layer system that could be available to counties through a GIS platform."

"No"