A GIS DATABASE FOR AVALANCHE FORECASTING IN COLORADO

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ABSTRACT: The Colorado Avalanche Information Center (CAIC) is a statewide avalanche forecasting and education group. The CAIC produces avalanche safety products for both transportation and recreation applications. The Center's operational responsibility covers a large geographic area including 30 road sections and over 120,000 km^2 of backcountry. Forecasters require access to vast amounts of data while composing avalanche safety products and have limited time to find and retrieve it. Over the past 5 years the staff of the CAIC worked with Avalanche Mapping to create a GIS database of information applicable to their forecasting operation. This is an ongoing project as data and data categories are added each day and each year.

KEYWORDS: avalanches, avalanche forecasting, geographic information systems, GIS.

1.INTRODUCTION

Since 1950 avalanches have killed more people in the state of Colorado than any other natural hazard. Accidents in Colorado account for one-third of all avalanche deaths in the United States since 1950. The Colorado Avalanche Information Center (CAIC) is a state government agency tasked with reducing the impact of avalanches on visitors, residents, and the economy of Colorado. Forecasters use a variety of data with a geospatial component in daily operations. We built a single platform that includes as much of these data as possible. The system allows forecasters to access large amounts of data with a single query and without changing computers or software.

The CAIC provides education and forecasting for winter recreation and maintenance operations along state and federal highways. The CAIC's forecast area includes over 15 mountain ranges, 30 stretches of highway through 17 mountain passes, and a total area over 120,000 km^2 (Figure 1). This area includes a myriad of operations, installations, and topographic features that are affected by avalanches. In 2005 the CAIC teamed with Avalanche Mapping to create a geospatial database of these elements and information typically recorded for avalanche forecasting operations (Greene et al., 2010).

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2. DATA AND METHODS

Our approach is 1) collect all of the data we use on a daily basis or that we need during weather and avalanche cycles and 2) put it into a single platform (Figure 2). When possible, we collected geo-referenced data from existing sources. Otherwise we digitized old publications or maps provided by other groups.

The base data elements included in the database are listed in Table 1. Some of the elements include nothing more than a location and a name (e.g. natural and political features). Others include supporting information (avalanche occurrence, accident reports, etc…)

We have divided avalanche paths into application specific layers (Table 2). Paths are separated into those that affect state and federal highways, county roads, ski areas, backcountry areas, and where an accident occurred. Whenever possible we included specifics about the avalanche path (similar to an avalanche atlas), images of the path, and avalanche occurrence. We also record specifics of hazard mitigation missions such as explosive type and number.

2.1 Software

We used graphical information system (GIS) software from ESRI ArcGIS for this project. ArcMap and Catalog are used for data development and management. ArcReader/ Explorer is used for the delivery and dissemination of the project. ArcPad is used for field data collection with GPS.

3. DISCUSSION

The result of this effort is a single catalog that includes all (or much) of the data we use on a daily basis. Forecasters can look up measured values of aspect or slope angle in a specific avalanche path. They can search for a mountain or drainage name associated with an observation. They can locate a backcountry hut and examine the vegetation in aerial photographs to locate an avalanche area or advise search and rescue efforts. They can examine a groomed track to follow the route of a group of snowmobilers. In each case, they use existing data collected for a variety of applications to address an avalanche forecasting question.

This project is designed to collect and display information of historically occurring avalanches and accidents. In addition we use the platform to analyze resource use along roads. We use the

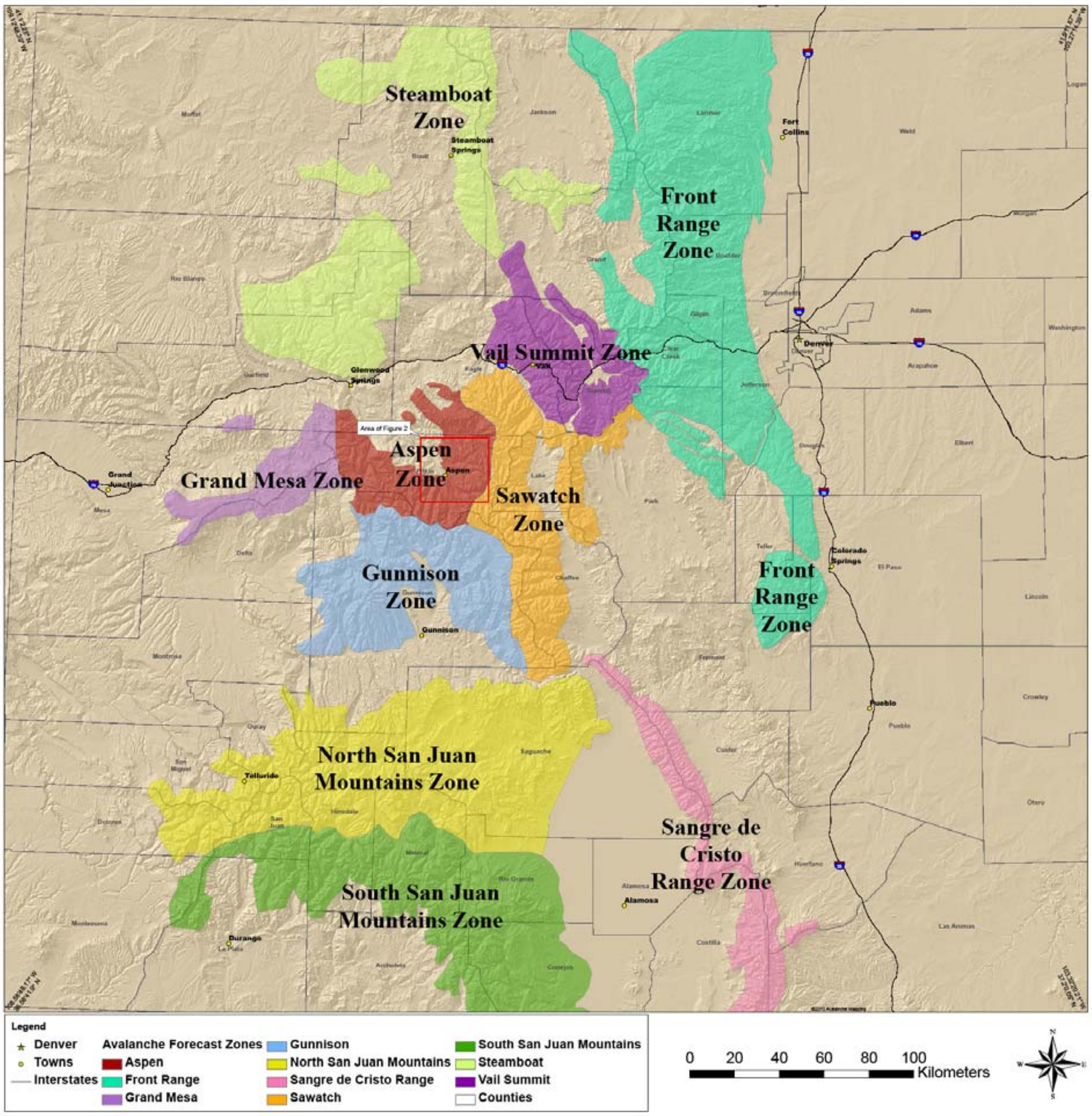

Figure 1: An overview of the area covered by the Colorado Avalanche Information Center including county boundaries, major highways, and the backcountry forecast zones. The red square is the location of Figure 2.

Table 1: Base Data Layers in the Colorado Avalanche Information Center's GIS Database.

Base Data Layer Name	Layer Description and Type
Above_7000ft	Area over 2134 m (7000 ft) asl
CDOT_Eng_Regions	Department of Transportation regions
CO_Cities	Cities
CO_Counties	County boundaries
CO_Mtn_Ranges	Mountain ranges
CO_Mtn_Summits	Mountain summits
CO_Rds	State highways
COBndry	State boundary
COWXStations	Weather stations
ESRIStreams	State wide detailed streams USGS/NHD sourced
ForecastOfficeZones	Forecast area extent of each CAIC office
ForestService_Rds	Roads on U.S. Forest Service land
Highways2010	State and federal highways
Interstates	Interstate highways
Milepost	Mileposts on state and federal highways
MjRivers	Major rivers
NHDWaterBodies	Major lakes
Quad24K	24K Topographic map sheet grid (quadrangle names)
Ski_Area_Bndry	Ski area boundaries
SnowMachineTrails	Snow machine trails
TenAvZones	CAIC backcountry zones
MtnHuts	Location of mountain huts
MtnTrails	Common routes to mountain trails

Table 2: Avalanche Data Layers in the Colorado Avalanche Information Center's GIS Database.

Avalanche Data Layer Name	Layer Description and Type
AvpathAccidents	Point layer of avalanche accident locations
BackCountryAvpaths	Avalanche paths observed in the backcountry
CDOTRds	Avalanche paths that affect state and federal roads
CntyRdAvpaths	Avalanche paths that affect county roads
LandUseAvPaths	Avalanche paths surveyed for land-use applications
MapbookExtents	Map page extent for highway corridor map books
Obs1	General weather observations based on SWAG
Obs2	General avalanche observations based on SWAG
SkiareaAvpaths	Avalanche paths within ski area boundaries

1:24K vector data (USGS topo sheet) for all applications. We do not try to interpolate or model weather, snow, or avalanche fields on USGS DEM (Digital Elevation Model) data. The DEM data was originally developed at 30 meter resolution and the 10 meter data currently available is a resample version of the original data. The error in elevation of the DEM over Colorado is as high as 23 m (75 ft) (Dial, 1999). DEMs of this scale can contain large errors in other parameters that are critical for avalanche applications (McCollister and Birkeland, 2006).

4. SUMMARY

We have created a database using a geographic information system (GIS) that contains as much of the data we use for avalanche forecasting into one platform. The system is a catalog of information and is not used to estimate or derive additional parameters. It provides quick and easy

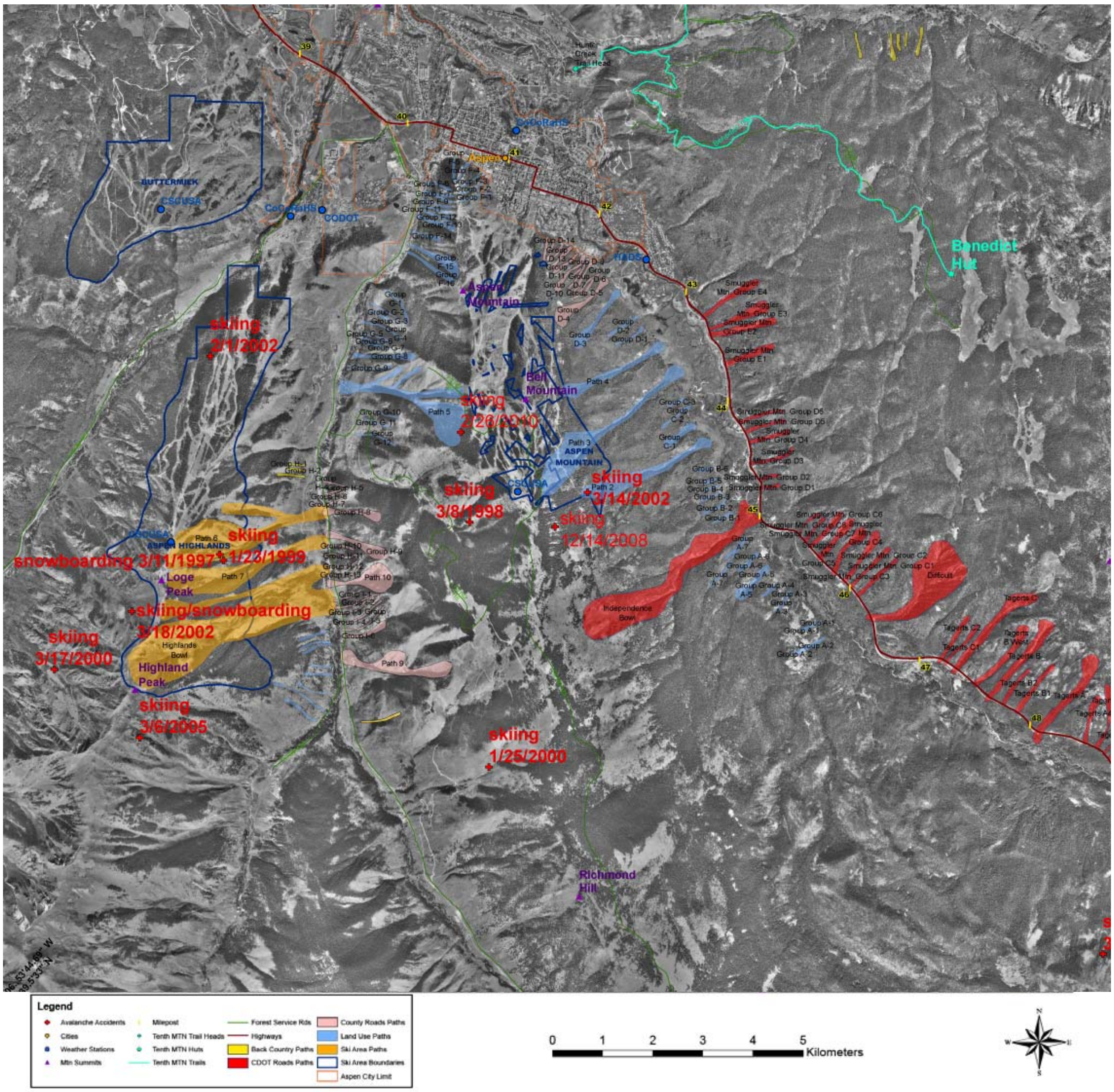

Figure 2: The area surrounding the town of Aspen, Colorado. This region includes many of the components included in the Colorado Avalanche Information Center's GIS database.

access to a variety of different types of information. It also allows us to create figures for different types of education programs using the same data we use for forecasting operations.

5. ACKNOWLEDGEMENTS
We would like to acknowledge the contributions of previous avalanche practitioners and researchers that compiled the data used in this project. They include (but are limited to) Betsy Armstrong, Richard Armstrong, Lee Dexter, Art Judson, Art Mears, and former and current staff of the Berthoud, Loveland, and Arapahoe Basin ski areas. The CAIC staff (past and present) helped quality control the digitized data. They include: Dale Atkins, Mark Gober, Susan Hale, Rob Hunker, Nick Logan, Spencer Logan, Brian McCall, Ann Mellick, Lee Metzger, Mark Mueller, Mark Rikkers, Jerry Roberts, Brad Sawtell, Stuart Schaefer, John Snook, Scott Toepfer, Simon Trautman, and Knox Williams. We would also like to thank the numerous college interns that digitized and entered data for the project. Lastly we would like to thank Vince Matthews (Director of the Colorado Geological Survey) for his contribution to and support of this work.

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AN AVALANCHE TERRAIN ASSESSMENT OF PROPOSED MANITOBA MOUNTAIN AND WHISTLE STOP HUT-TO-HUT SYSTEMS USING A GEOGRAPHICAL INFORMATION SYSTEM

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ABSTRACT: Alaska Mountain and Wilderness Hut Association has proposed a hut-to-hut system on the Kenai Peninsula of Southcentral Alaska. A terrain assessment is first of several steps necessary before construction of huts begins. Locating huts in this remote area may increase the use of the area, with potential for an increase in less skilled users. It is important to provide all recreational users with safe routes and safes resting locations. A model was created to determine the amount of terrain in potential release areas. An equation was applied to the ridgelines above proposed hut sites to estimate potential run-out distances of slides. Results were compared to actual historical run-out in the area observed by the Alaska Railroad. All of this was calculated and displayed using both a GIS and knowledge of avalanche terrain. Raster data available for this area, and most of Alaska, has a fairly large cell size so many micro-terrain features are missed in the assessment. As a result of the cell size limitations there is a need for further study of these areas including field observations. Outlined in the following article is a preliminary assessment of the avalanche terrain along the proposed hut-to-hut systems at Manitoba Mountain and along the Whistle Stop route.

1. INTRODUCTION

On February 13th of 2010 two snowmachiners died in an avalanche in Southcentral Alaska. Though they were not in a major avalanche path they were in terrain capable of producing a slide big enough to burry both of them. Not far from where the two were killed a wilderness hut site has been proposed. With the construction of this hut will come an increase in recreationists like the two men caught in that slide. Providing information about the terrain of this area will hopefully prevent an increase in similar accidents.

The intent of this project is to produce a preliminary assessment of the avalanche terrain along a hut-to-hut system proposed by the Alaska Huts. This assessment is necessary to the Alaska Hut Association so that they might plan their routes and hut locations with the least amount of exposure to avalanche terrain. Proposed hut sites were selected with certain terrain features in mind, protection from avalanche being a major part of the selection process. This study aims to confirm that the sites selected are in suitable locations.

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2. LOCATION

The location of this study (Figure 1) is on the Kenai Peninsula in Southcentral Alaska (an area considered to be a maritime climate). Two specific areas are evaluated: Manitoba Mountain and a Whistle Stop route.

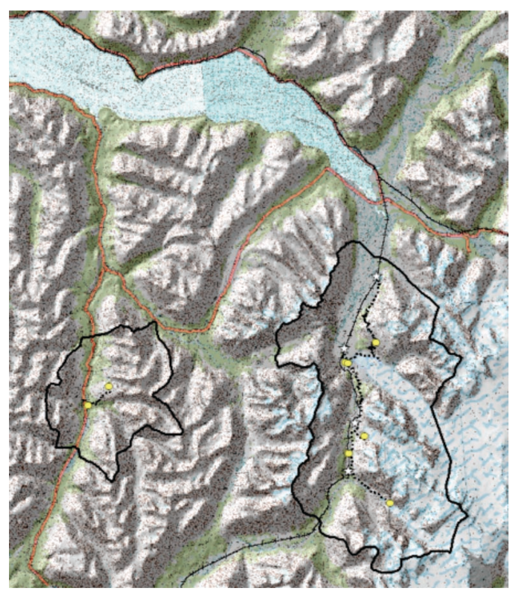

Figure 1. Study sites are located south of Turnagain Arm on the Kenai Peninsula in Southcentral Alaska.

A small portion of the assessment surrounds a peak locally known as Manitoba Mountain. This peak is located along the Seward Highway and the winter trail-head is most commonly accessed via a pull-out about one mile north of Lower Summit Lake at mile 48. The area of the study covers 39 square miles (100 square kilometers) surrounding the proposed hut sites and trails.

The second portion of the study follows a Whistle Stop route along the Alaska Railroad south of Portage. The area taken into consideration surrounds a proposed trail from the Leubner Lake Whistle Stop 32 miles south to the terminus of the Trail Glacier. The area of this study covers 117 square miles (303 square kilometers) surrounding the proposed hut sites and trails.

3. IMPLICATIONS

Construction of huts in this area will increase the number of users and the number of less skilled users. Winter travel in the area covered by this assessment will unavoidably involve navigation of avalanche terrain. Weather and snowpack may be variable but terrain is constant. Terrain must be taken into account by all involved be it planners or users.

4. METHODOLOGY

Using field observations and raster modeling within a GIS specific data layers including a digital elevation model (DEM)(USGS Seward 1:63,360 quadrangle) with a resolution of 50 meters, a second DEM with a resolution of 25 meters, topographic maps (Seward C6, Seward C7, Seward D6) from USGS, point and polyline shapefiles from Ian Moore of Alaska Map Science (AMS), and hut coordinates from John Wolfe of Alaska Huts Association. Field observations include analysis of alpha angles and micro-terrain features not visible using GIS techniques.

5. TECHNIQUES

5.1 Hut Sites and Routes

An ArcMap project was built using a Hillshade image created from the Seward_63 DEM and topographic maps sewardc6, sewardc7, and sewardd6. The hut and route databases were edited to eliminate portions not of interest to this study.

5.2 Establishing Assessment Area

A buffer of three miles and a buffer of four miles were applied to all proposed hut sites and a buffer of one mile was applied to all proposed trails. The assessment area was digitized based on the buffers and local terrain. The resulting assessment area includes all areas hut users are likely to travel to on day trips from the hut sites. (Figure 2)

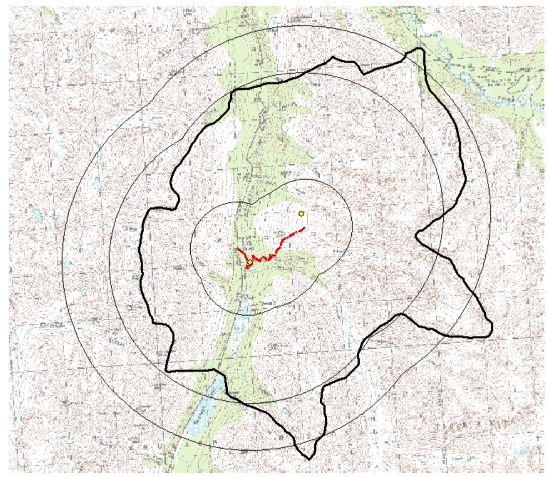

Figure 2. Trail, huts sites, buffers and final assessment area of Manitoba Mountain.

5.3 Terrain Model for Assessment Area

To produce a general assessment of the study area a model was created using ArcGIS (ESRI, 2010)(Figure 3). Slope and aspect, were calculated from the DEM. Slope was then reclassified into three values (Table 1) based on avalanche risk levels outlined in avalanche terrain literature (Gruber, 2001; McClung, 2006; Tremper, 2001). Aspect was reclassified into three values (Table 2) based on the predominant wind direction of the area (Scott, 2006). A weighted overlay was applied to these two new layers in which reclassified slope angles were given a weight of 75% and reclassified aspects 25%. The output of this model contains three categories; 1 indicates low potential for slide release, 2 indicates moderate potential for slide release and 3 indicates high potential for slide release. The resulting raster was compared to the topographic map to verify findings (Figure 4).

The same process was repeated with another DEM. This layer has a cell size of 25 meters and would be expected to produce more accurate results.

Slope Angle	Value
0 - 15	1
15 – 25	2
25 - 70	3

Table 1. Breakdown of slope angle and values assigned to each. 70 – 90 is not included since such steep slopes are not represented by the DEM used. 1 is lowest concern, 3 is highest concern.

Slope Aspect	Value
0 – 20	1
20 – 125	2
125 – 155	3
155 – 250	2
250 - 360	1

Table 2. Breakdown of slope aspect and values assigned to each. 1 is lowest concern, 3 is highest concern.

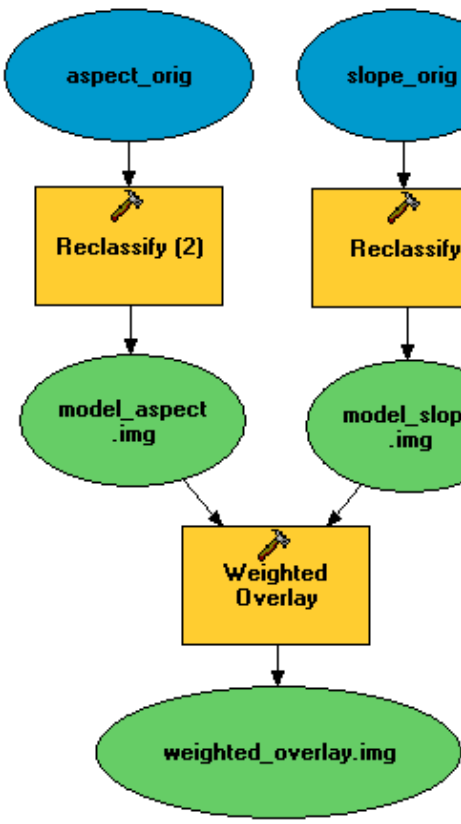

Figure 3. Model used to create overlay raster.

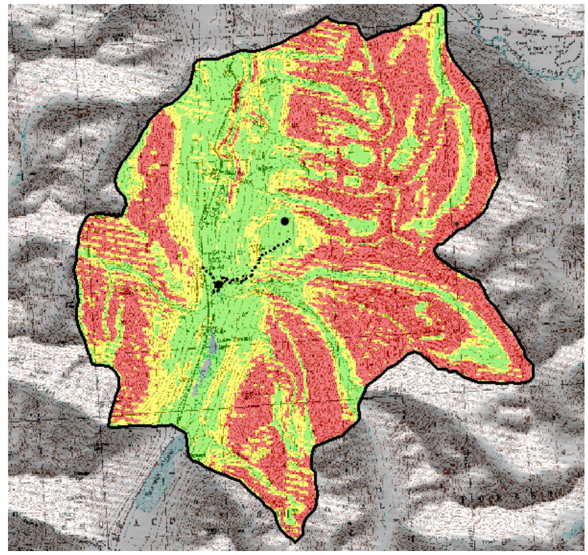

Figure 4. A portion of the resulting raster from the overlay model. Red is high, yellow is moderate and green is low.

5.4 Calculating Run-out Distances Near Huts

A multi-step process was used to determine the length of potential slide paths above hut sites. Ridgelines above hut sites were digitized into polylines using the Seward_63 Hillshade layer with the topographic maps overlain (topographic maps were set to 50% transparency) (Figure 5). The polyline was then converted into a raster with a cell size to match the Sewrard_63 DEM (Figure 6). The raster was used to extract corresponding cells from the DEM only where the original polyline existed (Figure 6). Finally the raster was converted into elevation points (Figure 7). The process of extracting elevation points from the Seward_63 DEM was also used to find the elevation of hut sites.

After the elevation was found for ridgelines and hut sites a formula was applied to determine if the maximum distance of run-out from each ridge point could reach the hut site (Figure 11). The elevation of a hut site was subtracted from the elevation of each ridge-point above it. The difference was multiplied by 2.75 equaling the distance needed for a 20° angle from the ridge (Tremper, 2001).

Point distance was used to find the distance from each point on the ridgeline to the corresponding hut below. The resulting table was joined to the attribute table of the ridgeline elevation points. The run-out distance was subtracted from the hut distance to find if the run-out exceeded the distance to the hut and if so by how much.

A buffer was applied to each individual ridge point based on the distance multiplied earlier; the resulting buffers were then dissolved to create one polygon (Figure 9). A new area was hand digitized using the original polyline of the ridge and the buffer created from elevation points (Figure 10).

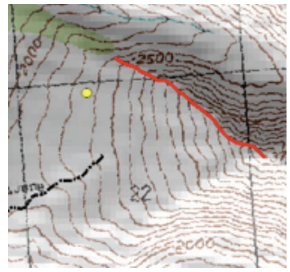

Figure 5. Ridgeline polyline digitized by hand.

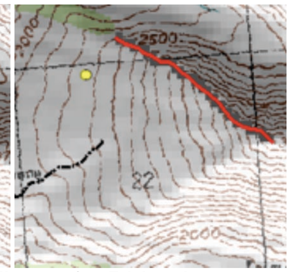

Figure 6. Ridgeline raster extracted using polyline.

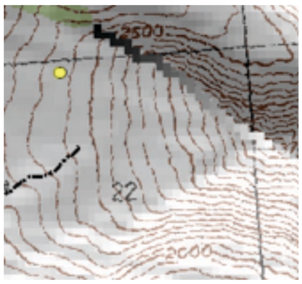

Figure 7. Elevation raster of Manitoba ridgeline.

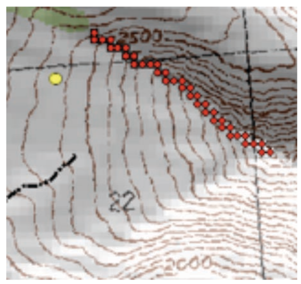

Figure 8. Elevation points of Manitoba ridgeline.

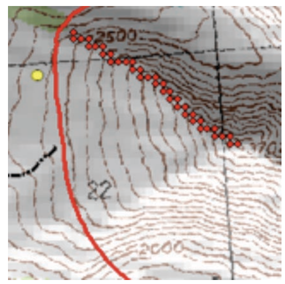

Figure 9. Elevation points of ridgeline and buffer of run-out distance for Manitoba.

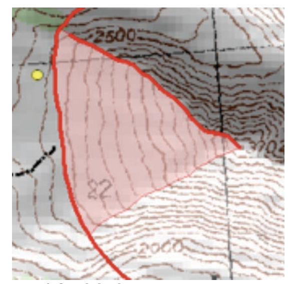

Figure 10. Using ridgeline polyline and buffer to digitize polygon of final run-out distance

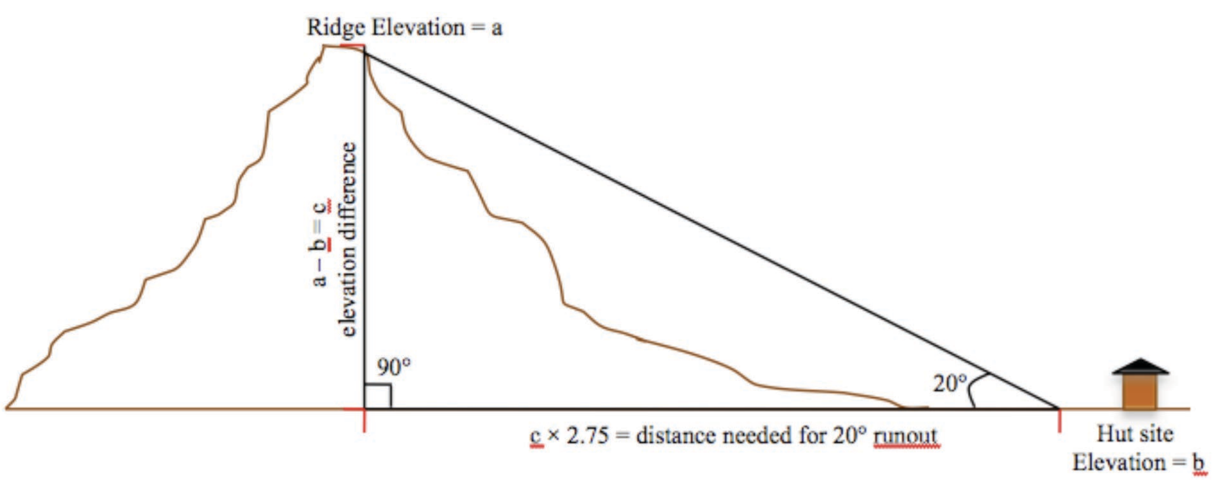

Figure 11. Side view showing the equation used to determine possible distance of slide run-out.

6. RESULTS

6.1 Terrain Model

The three categories resulting from the models represent the level of potential for slide release based on the weighted combination of slope and aspect. For example an area with a high slope value and a high aspect value would come out as having high potential for slide release. An area with a low slope value and a high aspect value might come out as having moderate potential for slide release.

After running the DEMs through the terrain model and extracting values falling within the assessment area percentages were calculated in the attribute tables for each area of the study (Table 3 & 5). The tables give an idea of how much of the terrain is capable of releasing a slide while the raster shows the physical location of potential release areas (Figure 12 & 13).

Trails were used to extract the level of exposure each was subject to (Table 4 & 6). Trails may have to intersect areas with moderate to high release potential but only for a limited distance.

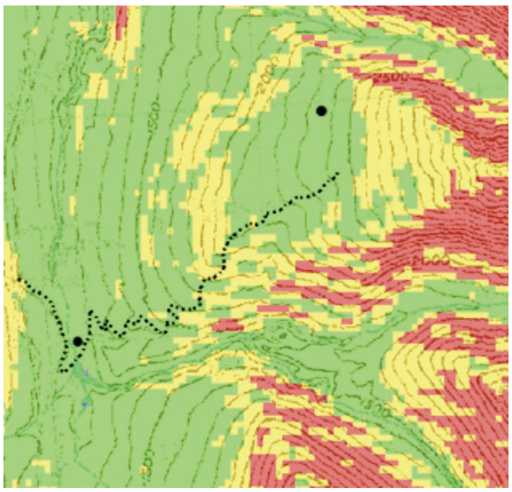

Figure 12. 50 meter DEM model result of Manitoba.

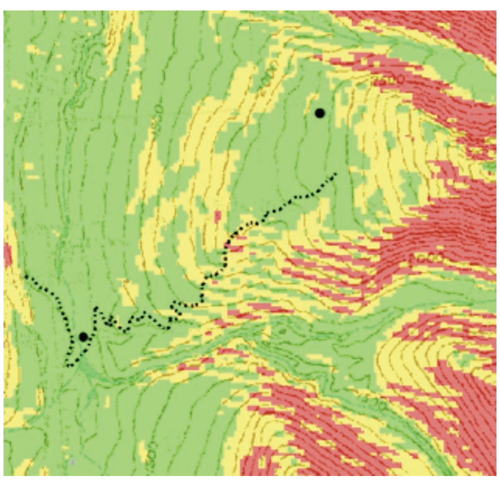

Figure 13. 25 meter DEM model result of Manitoba.

Slide Release Potential	Manitoba Assessment Area	Whistle Stop Assessment Area
Low	27.5%	34%
Moderate	27.5%	24%
High	45%	42%

Table 3. Percentages of potential release areas for each study area derived from the DEM with cell size of 50 meters.

Slide Release Potential	Manitoba Assessment Area	Whistle Stop Assessment Area
Low	91%	68%
Moderate	9%	25%
High	0%	7%

Table 4. Percentages of potential release area trails intersect with in each study area derived from the DEM with cell size of 50 meters.

Slide Release Potential	Manitoba Assessment Area	Whistle Stop Assessment Area
Low	27%	32%
Moderate	29%	25%
High	44%	43%

Table 5. Percentages of potential release areas for each study area derived from the DEM with cell size of 25 meters.

Slide Release Potential	Manitoba Assessment Area	Whistle Stop Assessment Area
Low	82%	66%
Moderate	17%	26%
High	1%	8%

Table 6. Percentages of potential release areas trails intersect with in each study area derived from the DEM with a cell size of 25 meters.

6.2 Estimated Run-out Distances Near Huts

The upper Manitoba hut site was found to be outside of the estimated run-out distance of any avalanches released from the northern ridgeline of Manitoba Mountain. The closest any run-out distances from the ridgeline came to the upper hut site was 108 meters away. (Figure 13)

Run-out distance near the lower Manitoba hut site was not calculated. This is because it is located in a densely forested area (Gruber & Bartlet, 2007). The trees in the area are old growth and in field observations did not appear to be affected by avalanches. There is

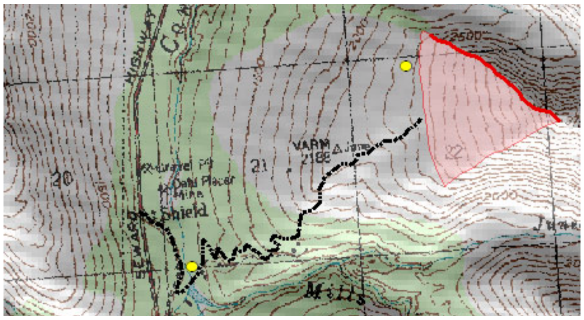

Figure 14. Potential Manitoba runout distance.

also no historical evidence of avalanches reaching this area. (Figure 14)

The Grandview hut site was found to be within the estimated run-out distance of potential slides released from the Eastern and Western ridgelines above the site. The run-out distance of 84% of the eastern ridgeline (42 out of 50 points) exceeded the distance deemed acceptable. The maximum distance the hut site was exceeded by was 463 meters. The run-out distance of only 2.3% of the Western ridgeline (2 out of 85 points) exceeded the distance deemed acceptable. The maximum distance the hut site was exceeded by was 36 meters. (Figure 15)

The Spencer Flats hut sites were also found to be within the estimated run-out distance of potential slides released from the ridgeline of Spencer Mountain. The run-out distance of 59% of the ridgeline (105 points out of 178) exceeded the distance deemed acceptable. The maximum distance the hut sites were exceeded by was 110 meters. (Figure 16)

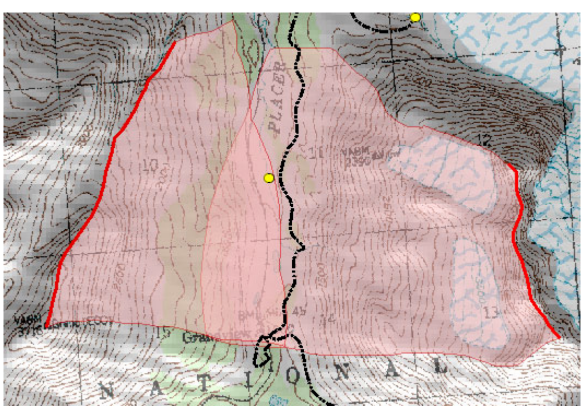

Figure 15. Potential Grandview runout distances.

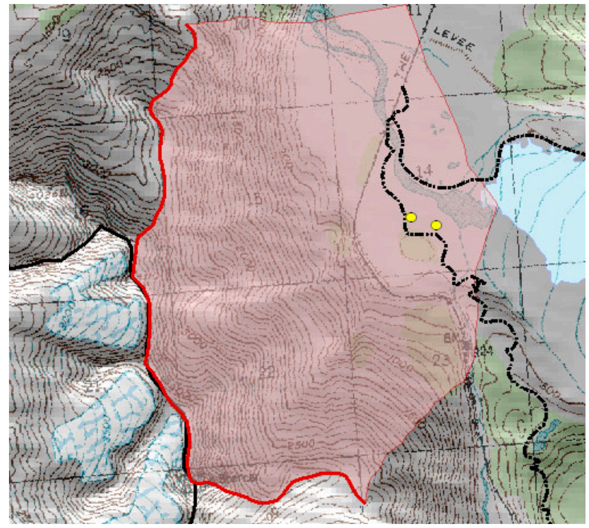

Figure 16. Potential Spencer Flats runout distance.

6.3 <u>Actual Historical Run-out Distances</u>

A final measure was taken to determine if the proposed huts sites were indeed within reach of slide run-outs. Personal correspondence with Dave Hamre of the Alaska Railroad confirmed that hut sites along the railroad tracks are not in actual historical run-out areas. A portion of the trail below Deadman Glacier (between Spencer and Grandview sites) it well within the run-out distance of a historical slide area.

The Grandview site is protected by tree and micro-terrain features from the western ridgeline above it. On the eastern side it is also protected by trees and any slides coming down are funneled to the north by a large terrain feature. (Figure 17)

The slide above the Spencer hut sites runs into a large terrain trap on the south side of the railroad tracks. The huts are also protected by a forested area to the south. (Figure 18)

The portion of trail below Deadman glacier crosses through terrain with moderate potential for slide release and is in an area that slides do run across. (Figure 19)

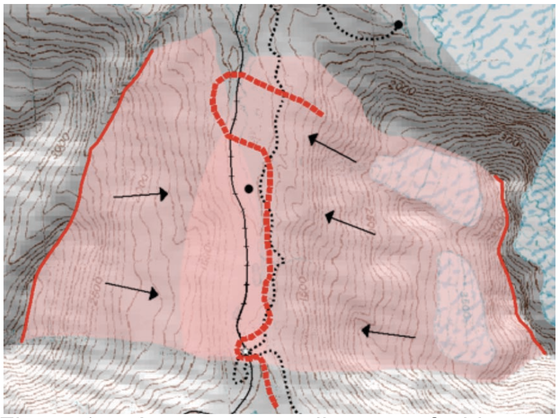
Figure 17. Actual run-out distance of slides released from the eastern ridge above Grandview hut site.

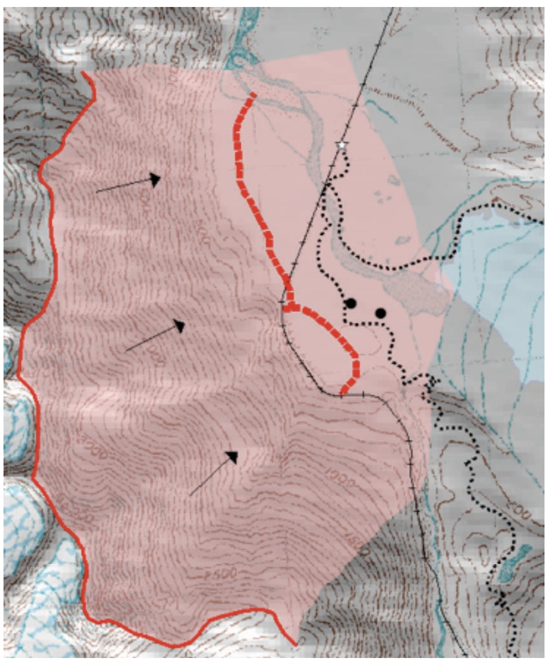
Figure 18. Actual historical run-out of slopes above Spencer hut sites.

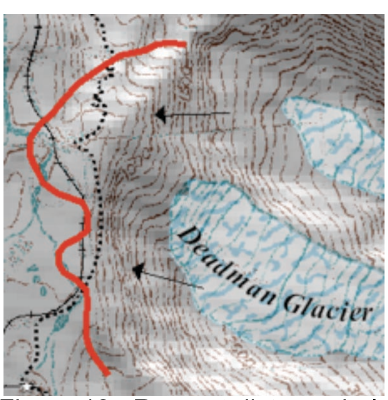

Figure 19. Run-out distance below Deadman Glacier intersecting trail.

7. DISCUSSION

The results of this study give a good idea of what to look for when assessing the avalanche terrain in this area. There are, however, several drawbacks to the DEMs used in this assessment. The rasters have such large cell sizes (each cell represents nearly 2,500 square meters in the 50 meter DEM and 625 square meters in the 25 meter DEM) that two things happen. The first is that slope angle and aspect are not completely accurate. Comparing results to a topographic map helps to verify whether or not the data is correct. The second drawback is that small terrain features are easily missed in the assessment. Possible terrain traps are looked over and “safe areas” may not appear. This issue is not as easily solved using topographic maps. Field observations must be done to find such terrain features or better data obtained such as DEMs with a much smaller cell size. (Gruber, 2001; McCollister & Comey, 2009).

As a result of the data used and the methods performed some of this assessment may overestimate the reach of potential avalanches in the area. This is not necessarily bad. One large avalanche may not slide as far as predicted but in a major storm cycle the same path may slide multiple times over a short period. Such an event can cause debris to be deflected in different directions and distances than previously seen (Gruber & Bartlet, 2007; Gruber & Margareth, 2001).

Not calculated into any of this study (excluding the lower Manitoba hut site) is vegetation cover. Overlaying run-out distance layers with aerial photographs or LiDAR data would allow the extraction of specific slide paths based off of vegetation quality. Huts such as the Grandview site, which appear to be in a high risk area may in-fact be protected by dense forest (Gruber & Bartlet, 2007).

The last item not taken into consideration in this assessment is the fact that the Spencer Flats and Grandview huts are located along the Alaska Railroad. The AKRR mitigates avalanche risk in these areas. Backcountry travelers are no less likely to trigger an avalanche but hut sites may be less likely to be reached by a slide.

8. RECOMENDATIONS

The intent of this study is to provide a preliminary assessment of the area. Further analysis is needed. The Manitoba hut sites appear to be in acceptable locations based off of GIS analysis and field observations. The Spencer Flats sites and Grandview sites appear to be in acceptable locations as well. Results for the Whistle Stop hut sites should be further confirmed by field observations.

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