Preliminary Investigation

Caltrans Division of Research,
Innovation, and System Information

Produced by AHMCT Research Center

Avalanche Mapping Study

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The Caltrans Division of Research, Innovation and System Information (DRISI) receives and evaluates numerous research problem statements for funding every year. DRISI conducts Preliminary Investigations on these problem statements to better scope and prioritize the proposed research in light of existing credible work on the topics nationally and internationally. Online and print sources for Preliminary Investigations include the National Cooperative Highway Research Program (NCHRP) and other Transportation Research Board (TRB) programs, the American Association of State Highway and Transportation Officials (AASHTO), the research and practices of other transportation agencies, and related academic and industry research. The views and conclusions in cited works, while generally peer reviewed or published by authoritative sources, may not be accepted without qualification by all experts in the field.

Executive Summary

Background

As discussed in the Caltrans 'Snow and Ice Control Operations Guide,' avalanches pose a substantial threat to the safety of the traveling public and Caltrans maintenance workers. Caltrans Division of Maintenance deals with avalanches in both proactive and reactive modes. Proactive maintenance includes installation of structures to mitigate avalanches, and avalanche control using guns, propane and oxygen gas explosion chambers (Gazex) and other means to initiate "controlled avalanches." When avalanches occur, obstructing the roadway, Caltrans reacts by clearing the road with front-end loaders, graders, plow trucks, blowers, and other heavy equipment.

Caltrans has identified the need to conduct a statewide inventory of all avalanche paths effecting state highways. The work would require locating avalanche paths and mapping in an Avalanche Atlas. By following industry standards in the mapping of avalanche paths, Caltrans would be more equipped to provide avalanche mitigation to protect the traveling public and employees.

This preliminary investigation presents the results of a review of completed research and a survey of consultants in avalanche mapping. To gather information for this investigation, we:

- Conducted a literature search on avalanche mapping as performed worldwide, including methods of avalanche modeling, use of sensing systems for avalanche mapping, avalanche forecasting, case studies, and general overviews. Various guidelines were also found.
- Performed a detailed interview of consultant contacts regarding previous mapping experience and approaches, and map generation methods and technologies.

Summary of Findings

Our literature review found extensive information for Europe, and some information for North America. The references can be classified into guidelines, overviews, avalanche modeling, forecasting, case studies and mapping applications, and sensing. The individual papers have been classified and grouped as follows:

- *Guidelines*: (Canadian Avalanche Association 2002; Canadian Avalanche Association 2002; Stoffel and Schweizer 2008)
- *Overviews*: (Jamieson and Stethem 2002; Stethem *et al.* 2003; Greene *et al.* 2004; Sauermoser 2006; Marienthal *et al*. 2010)
- *Avalanche Modeling*:
    - *Dynamic / Physical models*: (Salm 2004; Jamieson *et al.* 2008)
    - *Statistical models*: (Barbolini and Keylock 1999; McCollister *et al.* 2002; McCollister *et al.* 2003; McCollister 2004; Barbolini *et al.* 2011)
    - *Other modeling*: (Mears 1988; McClung and Mears 1991; Barbolini *et al.* 2002; Maggioni *et al.* 2002; Maggioni and Gruber 2003; Gruber and Bartelt 2007)
- *Forecasting*: (Hägeli and McClung 2000)
- *Case studies and mapping applications*: (Freer and Schaerer 1980; Hackett and Santeford 1980; Ives and Plam 1980; Mears 1980; Dow *et al.* 1981; Heywood 1988; Frutiger 1990; Borrel 1992; Stoffel *et al*. 1998; McLaren 2000; Hägeli and McClung 2003; Arnalds *et al.* 2004; Oller *et al.* 2006)
- *Sensing*: (Gruber and Haefner 1995; Vallet *et al.* 2000; Wiesmann *et al.* 2001; Walsh *et al.* 2004; Huggel *et al.* 2005; Scott 2006; Bühler *et al.* 2009; Frauenfelder *et al.* 2010; Marienthal *et al.* 2010)

DOT Questionnaire

We surveyed six DOTs with the following questionnaire. Staff at the six DOTs responded. See **DOT Questionnaire Results** beginning on page 9 of this report for the full text of these survey responses.

1. Do you have an avalanche map (avalanche-hazard map), atlas, or cadastre? (all herein referred to as "map") [Yes / No]
2. Is a copy of your map or a sample available? [Yes / No] Are map specifications or requirements available? [Yes / No]
3. What does your map include?
    a. Start zones? [Yes / No]
    b. Trigger points? [Yes / No]
    c. Runout zones? [Yes / No]
    d. Safety zones? [Yes / No]
    e. Frequency / Return period? [Yes / No]
    f. Other? [Please comment:____]
4. How did you create your avalanche map? What technologies were used? In-house or contracted?
    a. If in-house what training and qualifications were needed?
    b. If contracted, who did the work?
5. How do you quantify a hazard for a particular chute or area? [Such as an Avalanche Hazard Index or other method. Please list method]
6. What were your sources (if any) for snow pack information?
7. How do you update your avalanche map?
8. Who at your agency may we contact for further information about this issue (email and phone)?

The DOT contacts exhibited a high degree of knowledge and expertise in the area of avalanche forecasting and mapping. Each of the DOTs has an existing map, or maps. All were willing to provide samples (see Appendices B - G). The map format and content varies between states. It is common practice to quantify avalanche hazards using the Avalanche Hazard Index (see (Shaerer 1989), provided by Rob Bickor, Caples Lake Maintenance Yard, Caltrans District 10, for information on the AHI). Map creation was performed by a mix of in-house staff (typically forecasters and GIS personnel) and consultants. All DOT personnel were receptive to further contact from Caltrans.

Consultant Interviews

We attempted to contact five consultants who provide avalanche-related services, particularly zoning and mapping (see contact list). The consultants were asked the following set of questions, at a minimum:

1. Have you developed avalanche map(s), atlas, or cadaster (all herein referred to as "map")? If so, for what agencies / cities?
2. Do you have any example reports from previous avalanche mapping work? Can you provide a PDF copy? Would it be acceptable to include it as an appendix in our report?
3. Have you published any of your work in conferences or journals? Please provide reference information.
4. What do your maps include? Start zones? Runout zone? Frequency / Return period? Other?
5. What techniques do you use in your mapping work? Interviews? Historical records?
6. Do you use any public sources of information? E.g. USGS Digital Elevation Models, topographic maps, etc.?
7. What technologies do you use to create your avalanche map? Satellite? Aerial photogrammetry? GIS? Synthetic aperture radar? Computational models?
8. Did you use digital terrain models or digital elevation models in your map generation? How were the DEMs obtained / created?
9. Do you use aerial photography (what types), and to determine what features?
10. Do you use aerial LiDAR? If so, for what purposes?
11. Do you use satellite, what sensing approach(es)? Black and white, multispectral, infrared, other?
12. What software tools do you use to generate, store, view, and maintain avalanche maps?
13. Did you develop the software for your avalanche mapping in-house?
14. Did you use any commercial or open-source software for dynamic modeling of avalanches? If so, what?
15. Can Caltrans contact you for follow-up information?

Three consultants were contacted and responded to this questionnaire. (See **Consultant Interview Results** beginning on page 17 of this report for the full text of these interview responses.) We were unable to reach Chris Stethem, due to expired contact information. We left a message for Art Mears, but did not hear back from him at the time this document was completed. We were also unable to reach Chris Wilbur at the time this document was completed.

In general, the consultants exhibited a high degree of knowledge and expertise in the area of avalanche mapping and atlas generation. There were a range of approaches, and a range of technologies used. Some of the consultants were well-versed with GIS tools, while others were more likely to use more manual methods to generate maps. However, all were experienced in updating GIS systems to overlay the map information. They indicated that publicly available Digital Elevation Models were not accurate enough for mapping needs, but were useful for identifying avalanche risk areas that could then be targeted for more detailed field investigation and mapping. The maps generated typically include start zone, track, and runout zone. In some cases, the maps distinguished different return periods (e.g. 30-year return, 100-year return, etc. All used interviews and historical records, publicly available maps and imagery, any more detailed available maps and imagery. All were receptive to further contact from Caltrans.

Related Research

Search of Google Scholar (http://scholar.google.com) for "avalanche," "avalanche mapping," and "avalanche zoning" yielded numerous results found in section "Related Research."

A search of Cold Regions Research and Engineering Laboratory (CRREL, http://www.crrel.usace.army.mil/) yielded no relevant results.

On the Federal Highway Administration site (http://www.fhwa.dot.gov/), search for "avalanche" retrieved ~231 hits. Went through these manually, as avalanche mapping still had ~123. Note that in quotes, "avalanche mapping" and "avalanche zoning" had no results. Search for "avalanche zoning" also had no results. Did find substantial information on topics including avalanche control, avalanche-resistant structures, avalanche warning systems, avalanche sheds, avalanche prediction. However, no relevant results on avalanche mapping or zoning.

On National Transportation Library (http://ntl.bts.gov/), "avalanche mapping" yields 53 results. Deferred sorting through these, went with "avalanche" instead. See below.

Search of "avalanche zoning" yielded 4 results. Only one of minor interest:

"**IVHS Study – Traffic Operations Center, IVHS Denver Metro Area**", by CENTENNIAL ENGINEERING, INC, 1993 (also 1994)

http://ntl.bts.gov/lib/jpodocs/repts_te/2547.pdf (for 1993)

http://ntl.bts.gov/lib/jpodocs/repts_te/2550.pdf (for 1994)

Refers to an "Avalanche Database" for the Denver metro area on page 1-5.

"avalanche" yielded 131 results. Going through these manually, found no relevant results on avalanche mapping or zoning.

A search of Caltrans DRISI, going back 20 years to 1994, yielded no relevant results.

Searching TRIS RiP at: https://rip.trb.org/

A search of TRIS RiP yielded no relevant results.

Straight Google search for "avalanche map" and "avalanche zone" and "avalanche zoning" yielded numerous results presented in sections "Related Research" and "Resources."

Search of Transportation Research Board, http://pubsindex.trb.org/index.aspx

A search of Transportation Research Board yielded no relevant results.

Gaps in Findings

- Unable to locate avalanche mapping consultant Chris Stethem, due to old contact information.
- Unable to contact Art Mears or Chris Wilbur of Mears and Wilbur (avalanche mapping consultants) as of submission of this report.

Next Steps

Moving forward, we recommend that Caltrans:

- Strongly consider integrating any avalanche maps into its existing enterprise GIS system, as part of the up-front avalanche map development.
- Investigate Colorado DOTs avalanche control program, which includes an avalanche atlas.
- Look into international practices for avalanche mapping. Candidate countries include Switzerland and Canada (provinces of Alberta, British Columbia, and Yukon Territory).
- Contact the Colorado Avalanche Information Center (CAIC), http://avalanche.state.co.us/ for further information.
- Find out information on existing avalanche hazard maps in four communities:
  - Juneau, Alaska
  - Ophir, Colorado
  - Vail, Colorado
  - Ketchum, Idaho
- Contact Alpine Meadows Ski Corporation, Tahoe City to see if they have any information on the Galena Basin avalanche hazard map.
- Obtain reference: Mears, A. I. (1993). "Snow-Avalanche Hazard Analysis and Mitigation Methods on Highways." Transportation Facilities through Difficult Terrain. Proceedings of a Conference Held August 8-12, Aspen-Snowmass, Colorado. Available for purchase from: http://trid.trb.org/view.aspx?id=451250
- Find updated contact information for avalanche mapping consultant Chris Stethem, and follow up with questionnaire.
- Follow up with questionnaire to Art Mears or Chris Wilbur of Mears and Wilbur (avalanche mapping consultants).
- Develop a scope of work for a project to meet Caltrans' needs for avalanche mapping or an avalanche atlas.

Contacts

During the course of this Preliminary Investigation, we spoke to or corresponded with the following individuals (unable to contact consultants Mears, Wilbur, and Stethem):

State Agencies

Alaska
Matt Murphy
Alaska Department of Transportation and Public Facilities
Safety and Emergency Support Specialist
Seward Highway Avalanche Program

Colorado
Ethan Greene, Ph.D.
Director, Colorado Avalanche Information Center

Idaho
Bill Nicholson
ITD Avalanche Safety

Utah
Bill Nalli
UDOT Avalanche Safety Program Manager

Washington
John Stimberis
Avalanche Forecast Supervisor
WSDOT- Snoqualmie Pass

Wyoming
Jamie Yount
Maintenance Avalanche Control, WYDOT

Consultants

Larry Heywood
Ski and Snow Consultant
530-525-1077
larryheywood "at" sbcglobal.net

Dynamic Avalanche Consulting, Ltd.
Alan Jones M.Sc, P.Eng., Principal and Senior Engineer
(also spoke with Chris Argue, Avalanche and GIS Technician)
250-837-4466
Alan.Jones "at" dynamicavalanche.com
http://www.dynamicavalanche.com/

Douglas Scott
Director, Avalanche Mapping
303-910-5247 (cell)
ddscott "at" avalanchemapping.org
http://avalanchemapping.org/

Arthur I. Mears, P.E., Inc.
970-641-3236
info "at" mearsandwilbur.com
http://mearsandwilbur.com/

Wilbur Engineering, Inc. (Chris Wilbur)
970-247-1488
info "at" mearsandwilbur.com
http://mearsandwilbur.com/

Chris Stethem & Associates Ltd
Snow Safety Services

DOT Questionnaire Results

The responses for the questionnaire are provided below. Any sample maps and related material are provided in Appendices B - G. For reference, we have included an abbreviated version of each question before the response; for the full question text, please see the Summary of Findings on page 3 of this report.

Matt Murphy, Alaska DOT

1. **Do you have an avalanche map?** Yes. We have a couple of different maps and GIS layers that we use for locator maps.

2. **Copy of map or sample available? Map specifications or requirements available?** I have attached some examples (see Appendix B).

3. **What does your map include?** Our maps show starting zones and general location of each path. The runout zones are only estimated. The GIS layers have the runout stop at the roadway and do not reflect the maximum runout distance. The main purpose of these maps is to show locations of paths. Some of the atlas have some historic occurrence data, but we keep much more detailed records in a separate database.

4. **How did you create your avalanche map? What technologies used? In-house or contracted?** One of our atlas was done by a State agency, the other was done by a private contractor for a private power line company. They have been generous enough to share with us.

   a. It is critical to have a professional avalanche specialist involved in the mapping project.

   b. The Chugach Electric Atlas was created by a private contractor called Alaska Mountain Safety Center. There are numerous contractors in the U.S. and Canada who would be qualified to help your project.

5. **How quantify hazard for particular chute or area?** The Avalanche Hazard Index (AHI) is the industry standard for calculating hazard and mapping design magnitudes. However, in addition to the AHI, it is also critical to have a professional avalanche specialist conduct daily hazard assessments during the avalanche season to complement the AHI.

6. **Sources for snow pack information?** ADOT&PF (Alaska Department of Transportation & Public Facilities) does its own field work to gather snowpack information, but we also rely heavily on shared information with the Alaska Railroad, Alyeska Ski Resort, Chugach National Forest Avalanche Information Center, and Chugach Electric, and Chugach Powder Guides. It is truly a team effort in this area.

7. **How do you update your avalanche map?** We don't make too many changes to our avalanche maps because they are mostly just "Locater Maps." However, I have made some changes in GIS.

8. **Agency contact?** Please feel free to contact me with any questions you have about this project for Caltrans. I'm very interested in this and I'm happy to provide info.

   Matt Murphy
   Alaska Department of Transportation and Public Facilities
   Safety and Emergency Support Specialist
   Seward Highway Avalanche Program

Ethan Greene, Colorado DOT

1. **Do you have an avalanche map?** Yes

2. **Copy of map or sample available? Map specifications or requirements available?** Yes (see Appendix C)

3. **What does your map include?**

    a) **Start zones?** Yes

    b) **Trigger points?** We have shot placements for some areas

    c) **Runout zones?** Yes

    d) **Safety zones?** In some areas

    e) **Frequency / Return period?** In some areas

    f) **Other?** Bunch of other stuff

4. **How did you create your avalanche map? What technologies used? In-house or contracted?**

    a) **If in-house, what training and qualifications were needed?** Yes **-** people experienced with the specific paths; snow, weather, and avalanche data; historical research.

    b) **If contracted, who did the work?** Yes- PE with experience in avalanche zoning, mapping, runout, return rate, engineering applications.

5. **How quantify hazard for particular chute or area?** Currently AHI. We have been looking at ways of determining risk for specific areas.

6. **Sources for snow pack information?** We use a variety. We have relatively long study plot records and automated weather station records. We also use data from other groups like ski areas and SNOTEL (Snow Telemetry). We have developed 30 year cold season precipitation maps based on the PRISM dataset, then augmented with our own records.

7. **How do you update your avalanche map?** We don't have a structured process, but have been discussing one. We have done annual updates and distributed the information in October. We haven't updated the AHI values, but are looking to create a tool that we could update as new traffic values are available. Also as terrain or vegetation changes. We will probably institute a procedure for changes or reviews on 3, 5, and 10 year intervals.

8. **Agency contact?** Jim Walker is a good contact. You could also contact me.

Bill Nicholson, Idaho Transportation Department

1. **Do you have an avalanche map?** Yes

2. **Copy of map or sample available?** Yes (see Appendix D). **Map specifications or requirements available?** No.

3. **What does your map include?**

   a) **Start zones?** Start zones are defined, but not targets in the start zones.

   b) **Trigger points?** No

   c) **Runout zones?** Yes

   d) **Safety zones?** Yes. These are marked as small circles on the map, and referred to as "rescue staging areas." They do not advertise them as safety zones.

   e) **Frequency / Return period?** Yes (return period)

   f) **Other?** Yes. For each avalanche area (two of them, Highway 21 and U.S. 12), they have three maps. The overview map includes methods for avalanche control, and shows return interval, weather stations, closure gates, gun mounts, and related. The second map shows the aspect of the paths using shading. The third map shows slope angle of the paths, shaded into 35 – 40 degrees, and 40 – 45 degrees.

4. **How did you create your avalanche map? What technologies used? In-house or contracted?** Created them internally, three maps for each highway (see item 3f). ITD forecasters developed outlines of slide paths in Google Earth. Then, ITD GIS staff converted this information into their GIS system, and calculated vertical fall of path, start zone elevation, elevation of centerline, and rain lines. The process included meetings between forecasters and GIS personnel to make sure the information was properly transferred and represented.

   a) **If in-house, what training and qualifications were needed?** Avalanche forecasting capability, and GIS training.

   b) **If contracted, who did the work?** In 1988, a contractor (Duane Bolles) produced an atlas for Idaho. This provided a starting point. Such atlases are very common in DOTs. The work involved the maintenance and district engineers. The atlas was pretty accurate. They also developed an Avalanche Hazard Index, which factored in runout, return interval, and traffic count. This information is separate from the maps. It was never recalculated since the 1980s, as at that time, the AHI was already ranked "very high." It has only gotten higher as traffic increased, and there is no higher rating.

5. **How quantify hazard for particular chute or area?** Avalanche Hazard Index

6. **Sources for snow pack information?** Maintenance workers have been gathering data for about 17 years. They also use SNOTEL (Snow Telemetry).

7. **How do you update your avalanche map?** They haven't. They know of a couple of additional slide paths, and will need to add these to their maps. The process will consist of forecasters updating their information, then GIS doing the update in the system. He doesn't think they'll need to use Google Earth as an intermediary.

8. **Agency contact?** Bill Nicholson.

   Other comments / notes: Mr. Nicholson has been at ITD for about 7 years. Before that, he was a forecaster at UDOT. He started ITD's avalanche mapping work from scratch. ITD's GIS person had worked at Alta, UT.

   ITD is planning to install small, self-contained Gazex system(s). These do not have a separate shed for gas storage and control.

Bill Nalli, Utah DOT

1. **Do you have an avalanche map?** Yes
2. **Copy of map or sample available?** Yes, can send a copy of the American Fork Atlas. See Appendix E for related material. **Map specifications or requirements available?** No.
3. **What does your map include?**
   a) **Start zones?** Yes
   b) **Trigger points?** No
   c) **Runout zones?** Yes
   d) **Safety zones?** No
   e) **Frequency / Return period?** Yes
   f) **Other?** Size classification, road mile, vertical fall, distance to highway, history, control method, topo maps shaded, photos shaded, average daily traffic.
4. **How did you create your avalanche map? What technologies used? In-house or contracted?** I created our last two atlases, Provo Canyon and American Fork, using the template from our other atlases in Big and Little Cottonwood.

   ArcGIS, Microsoft Publisher, Photoshop, and iPhone Topo Maps app v. 1.12.1 were the main tools used.

   a) **If in-house, what training and qualifications were needed?**
   b) **If contracted, who did the work?**
5. **How quantify hazard for particular chute or area?** The Avalanche Hazard Index for these areas was calculated using the formula originally produced by Peter Shaerer in 1989 then updated by Mears in 1995.
6. **Sources for snow pack information?** We have data in Little Cottonwood dating back to the 1950s. Conversely, the latest atlas project I am working on for Logan Canyon is in a location with no snow data, so I am relying on vegetation clues and minimal historical references.
7. **How do you update your avalanche map?** Periodically, new history and/or adjusted path boundaries are updated.
8. **Agency contact?** Bill Nalli
   UDOT Avalanche Safety Program Manager

John Stimberis, Washington DOT

1. **Do you have an avalanche map?** Yes

2. **Copy of map or sample available?** Yes, see Appendix F. **Map specifications or requirements available?** Yes

3. **What does your map include?**

   a) **Start zones?** No, start zones aren't specifically called out. Future update to include that info.

   b) **Trigger points?** No, trigger points aren't specifically called out. Future update to include that info.

   c) **Runout zones?** Yes, runout is shown but not specifically called out nor drawn to include return periods.

   d) **Safety zones?** Not in the context of safety zones within an avalanche path.

   e) **Frequency / Return period?** Some information exists in the original report. Updated information for the East Shed paths was completed during the planning and design phase of our current Snoqualmie Pass East construction project. The project includes avalanche mitigation for the East Shed and Slide Curve avalanche paths: http://www.wsdot.wa.gov/Projects/I90/SnoqualmiePassEast.

   f) **Other?** Path outlines.

4. **How did you create your avalanche map? What technologies used? In-house or contracted?** ArcGIS, based on original atlas created by Ed LaChapelle.

   a) **If in-house, what training and qualifications were needed?** I have attended the Canadian Avalanche Association's Avalanche Mapping Course.

   b) **If contracted, who did the work?**

5. **How quantify hazard for particular chute or area?** Currently developing a standard framework for Avalanche Hazard ratings w/ other DOTs.

6. **Sources for snow pack information?** Occurrence records, weather stations, direct observations.

7. **How do you update your avalanche map?** Have not updated but plan to update with more detailed field data.

8. **Agency contact?** John Stimberis, Avalanche Forecast Supervisor, WSDOT South Central Region.

Jamie Yount, Wyoming DOT

1. **Do you have an avalanche map?** Yes

2. **Copy of map or sample available?** Yes, see Appendix G. **Map specifications or requirements available?** No

3. **What does your map include?**

   a) **Start zones?** Yes

   b) **Trigger points?** No

   c) **Runout zones?** Yes

   d) **Safety zones?** No

   e) **Frequency / Return period?** Yes

   f) **Other?** Terrain, slope angles, history, comments

4. **How did you create your avalanche map? What technologies used? In-house or contracted?** Helicopter for aerial photos, Photoshop, Adobe. Done in-house.

   a) **If in-house, what training and qualifications were needed?** None. 20 years' experience.

   b) **If contracted, who did the work?**

5. **How quantify hazard for particular chute or area?** Return interval

6. **Sources for snow pack information?** Historical documents. Anecdotal records from plow drivers.

7. **How do you update your avalanche map?** As I see more avalanche events, I update the atlas.

8. **Agency contact?** Best to contact me directly: Jamie Yount

Consultant Interview Results

The notes from each phone interview are provided below. For reference, we have included an abbreviated version of each question before the response; for the full question text, please see the Summary of Findings on page 4 of this report.

Douglas Scott, Director, Avalanche Mapping

1. **Developed maps? What agencies?** Yes. Developed atlas for Colorado DOT. Also did various avalanche maps in California, including at Lee Vining, Tioga Pass, Mammoth, and Donner. For a wide range of maps developed, see: http://www.avalanchemapping.org/Avatlas.htm

2. **Example reports?** The most recent work was for Alaska DOT. Report not currently available.

3. **Published work?** Yes. Works published typically in International Snow Science Workshop (ISSW) and ESRI User Conference. Most relevant work is:

   - Scott, D. (2006). "Using GIS and remote sensing to assess avalanche hazards for new road corridors in Alaska." In International Snow Science Workshop (ISSW), Telluride, Colorado, United States (pp. 465-467).

   - Douglas Scott ESRI 2007 User Conference: Paper "GIS Techniques for Avalanche Mapping and Snow Science Observations"

4. **What do your maps include?** Document anywhere anyone knows an avalanche has happened. Modeling for 100 year return avalanche. Estimation of biggest avalanche seen – digitize that. To get start zones, field investigation is needed.

5. **Techniques used in mapping?** Interviews, records, any information available.

6. **Public sources of information?** NAIP imagery, ESRI imagery. Digital Elevation Models (DEM) and topo maps for rough assessment of avalanche risk.

7. **Technologies used?** ESRI ArcGIS, Global Mapper (GIS). Also mentioned Erdas, and ENVI, which are both remote sensing software. He uses ENVI for feature extraction in passes, as it has advanced feature extraction, and is best for hyperspectral analysis. Technologies enhance user expertise.

8. **Use DTM or DEM? How obtained/created?** Yes, for rough assessment of avalanche risk. Generally, publically available. Too inaccurate (100 ft. x,y,z or worse) for any detailed work.

9. **Use aerial photography? For what?** Yes. Black and white Digital Orthophoto Quarter Quads (DOQQs) from every county (digitized). NAIP imagery, other online imagery. Use to locate scars of avalanches, where trees downed. Also, the shape of the ridgeline.

10. **Use aerial LiDAR? For what?** Yes, if can get it. Build slope and aspect data. Like to have 6" LiDAR. Otherwise, use to get rough estimate.

11. **Use satellite, what sensing approach(es)?** Yes. DigitalGlobe imagery used in Aleutians work for Alaska. Generally, color images, also 4-band, but did not use extra bands.

12. **Software used?** ESRI ArcGIS, Global Mapper (GIS). Erdos and NB (a little).

13. **Developed software in-house?** Not really. Used ArcPad for field collection.

14. **Use commercial or open-source software?** See above for commercial. Open-source included QGIS. His friends have used GRASS (Geographic Resources Analysis Support System) GIS. Some use of PostgreSQL (database), and Google Maps API.

15. **Can Caltrans contact you?** Yes. Douglas has been in contact with Caltrans on and off for about 7 years.

    Other comments / notes: Mr. Scott has done numerous avalanche mapping projects in California, some of which are unpublished. These include mapping at or near Lee Vining, Tioga Pass, Mammoth, Donner, and Angel's Crest Highway (La Canada to Angeles Forest).

    Mr. Scott recommended a Mr. Denny Hogan, a forecaster and snow ranger with the USFS in Tahoe. He noted that Mr. Hogan is likely not the right person to do the mapping, but would be an excellent local resource or partner for any needed field work to develop detailed maps.

    Mr. Scott noted that the biggest part of the job, in terms of requiring Caltrans input and effort, is in developing the needed static data for the avalanche map. This includes information on slope, aspect, and avalanche size. Also, how often avalanches hit a given area of highway, and what is the average height of the pile of snow on the highway. It can be hard to get any historical information, especially if people have retired. It is also important to have input from maintenance supervisor to determine what assets are at risk, and to get any other local data.

    In his work, he sometimes relies on existing hard copy atlases, which he then scans and turns into a relational GIS.

    He noted that one should not use USGS DEM (or similar) data for mapping as there is too much error (at least 100 ft. x,y,z). He does use DEM for preliminary risk assessment. If a risk is found, *then* need to do detailed field measures to develop mapping.

    The most important data is weather leading to occurrence. Also, continuous weather data, very localized, in order to forecast. Important information includes wind loading and snowfall.

    In Boulder, Colorado, they have developed a side-fire imaging LiDAR system. They use it to scan hillsides for rock and landslide hazards.

Alan Jones, Principal and Senior Engineer, Dynamic Avalanche Consulting, Ltd.

1. **Developed maps? What agencies?** Yes. This is common work for them. Industrial projects. Also, currently reviewing Colorado avalanche control program. Work for mining, hydroelectric, pipelines, etc. Some work in Washington State.

2. **Example reports?** Provided sample maps from a report. See Appendix H.

3. **Published work?** Yes.

   Jamieson, B., S. Margreth and A. Jones (2008). "Application and limitations of dynamic models for snow avalanche hazard mapping." Proceedings of the 2008 International Snow Science Workshop.

4. **What do your maps include?** Locator mapping, center of flow of avalanche path, terminus of runout zone. Start, track, runout zone, at least to highway. Sometimes extreme runout zone.

5. **Techniques used in mapping?** Desktop review, available imagery (satellite, Google, ArcGIS), elevation data, LiDAR, contour lines. Then field verification / mapping. Interviews and historical data.

6. **Public sources of information?** British Columbia has good available data called E-Access. Imagery. Trim data set at 20 m intervals.

7. **Technologies used?** Satellite / aerial imagery. Orthorectified and georeferenced. ArcGIS. LiDAR if available. They often convert ArcGIS to Google Earth for more accessible interface for clients. They use statistical models. Also dynamic avalanche models (velocity, impact pressure). Spreadsheet models. Often use AVAL-1D software. Also have used RAMS for 3D modeling. Also used a model from University of British Columbia for flow depth, speed, and runout distance.

8. **Use DTM or DEM? How obtained/created?** Yes. Publicly available through Canada. If client has higher resolution DEM, use that.

9. **Use aerial photography? For what?** Yes. Vegetative clues for magnitude and frequency of avalanches, also runout distances. Trim lines, scarring. Identify path, boundaries, and runout distances.

10. **Use aerial LiDAR? For what?** Yes. Provided by client. Contour data with better vertical and spatial resolution.

11. **Use satellite, what sensing approach(es)?** Yes, most commonly used. Free images. If have higher resolution images, will use them. Usually, color images. Also have used Landsat for vegetation. We also use Landsat imagery for determining seasonal snow cover and wind distribution in areas with limited or no historical information (e.g. often for our work in Chile and Argentina).

12. **Software used?** ArcGIS. Google Earth.

13. **Developed software in-house?** Not specifically. Have developed spreadsheets for dynamic modeling.

14. **Use commercial or open-source software?** QGIS a little bit for some of its tools.

15. **Can Caltrans contact you?** Yes.

    Other comments / notes: Mr. Jones recommended two Canadian publications as useful guides for any future Caltrans work in avalanche mapping. The first is geared towards land mangers (e.g. Caltrans) and can help in defining the problem and seeking expert assistance, and the second is meant to provide guidance and standards for such experts.

    - **Land Managers Guide to Snow Avalanche Hazards in Canada**. Canadian Avalanche Association, 2002. Should be available for purchase at http://www.avalancheassociation.ca/?page=Standards
    - **Guidelines for snow avalanche risk determination and mapping in Canada**. Canadian Avalanche Association, 2002. Should be available for purchase at http://www.avalancheassociation.ca/?page=Standards

Mr. Jones followed up with an email, including sample sections from some of his avalanche mapping reports, sample atlases (some developed previously by others). These items are included in appendices. One of the items (not in appendix) is:

British Columbia Ministry of Transportation and Infrastructure (2011). "**Avalanche Safety Plan**". British Columbia, Canada.

This document, in pages 33 – 36, discusses the British Columbia avalanche atlases. Information includes: avalanche path summaries, avalanche path inventory, potential avalanche paths, removal of avalanche paths from the avalanche path inventory, avalanche strip maps, and example maps.

Mr. Jones also provided an extensive report on the south-central avalanche atlas for Alaska from 1982. This report is too extensive (174 pages) to include herein, but is available to Caltrans on request.

March, G. and L. Robertson (1982). "**Snow Avalanche Atlas, Seward Highway, South-Central Alaska**", Division of Geological and Geophysical Surveys.

Mr. Jones also provided a Washington State DOT report:

LaChapelle, E. R., C. B. Brown and R. J. Evans (1974). "**Methods of Avalanche Control in Washington Mountain Highways**", Washington State Highway Commission.

This report includes identification of avalanche paths, and development of a summary sheet for each path, including: path name, map location, avalanche dimensions (starting zone elevation, vertical fall, and length), description of any special features of the avalanche, expected effects on the highway, and history of avalanching. Accompanying the summary sheet are photographs and a map showing definable avalanche boundaries, contours, road and other characteristics. Where possible, a vertical profile of the avalanche path is also included.

Mr. Jones is currently working on a California project at Alpine Meadows.

Mr. Jones has quite a few published papers (about 20), which are summarized and provided at their company website:

http://www.dynamicavalanche.com/media/publications/

Mr. Jones also provided a list of typical deliverables and a methodology that would apply for Caltrans:

Typical Deliverables:

- Locator map(s), identifying the location of avalanche paths, normally with an arrow pointing down the middle of each major path; or
- Avalanche atlas, showing individual avalanche paths, runouts and path characteristics;

Methodology:

- Review any historical avalanche occurrence records and previous mapping;
- Interviews with avalanche technicians;
- Assemble relevant base maps, orthophotos, air photos;
- Preliminary identification of avalanche locations from air photos and maps;
- Site inspection to field truth map/air photo work;
- Preparation of locator map or atlas with avalanche path locations. This would be presented as print originals and as a digital mapping layer;
- Avalanche risk assessment in terms of avalanche path frequency and magnitude, and classification (e.g. high, moderate and low risk);
- Preparation of avalanche path descriptions; and
- Reporting.

Larry Heywood, Ski and Snow Consultant

1. **Developed maps? What agencies?** Yes. For numerous mountain developments. Squaw Valley Village. Alpine Meadows Ski Area, Martis Creek development. Individual homeowners and property owners. Peripherally related, Caples Lake assessment for Caltrans of current avalanche program operations, controls, and rescue preparedness.

2. **Example reports?** Yes. Provided sample map (Appendix I), Evaluation of the California State Highway 88 Avalanche Control Program Carson Pass and Carson Spur (Appendix J), and Preliminary Avalanche Hazard Report, Martis Valley West Parcel Project, Placer County, CA (Appendix K).

3. **Published work?** Yes. Below, and others in ISSW.

   Heywood, L. (1988). "Rain on snow avalanche events - Some observations." Proceedings of the 1988 International Snow Science Workshop.

4. **What do your maps include?** Avalanche path, start zone, track, runout zone. May also differentiate return period.

5. **Techniques used in mapping?** Interviews, historical records. Caltrans workers, residents, for stories. Newspaper searches (if someone killed). Review of records that Caltrans programs have (highways 50, 88, 395) to know return periods, and sizes. Field surveys (topography). Maps, often USGS topo, better if available, Google Earth. Both Summer and Winter surveys. Summer survey includes vegetation analysis, trees bent over, tree ring dating. Statistical analysis (beta and alpha points of avalanches), working from known events.

6. **Public sources of information?** Yes. Topo maps, DEMs. USGS maps. Detailed maps if available. Google Earth.

7. **Technologies used?** Input boundaries of avalanche path into whatever other maps or programs are available.

8. **Use DTM or DEM? How obtained/created?** Yes. Often obtained from project developer when available. May only be USGS mapping, DEM.

9. **Use aerial photography? For what?** Yes, if available. In and around Forest Service Land, use USFS and USGS aerials from different years, different flights. Start zone, track, and runout. Series of years, then maybe can see forest vegetation changes. Flights from ~ 1939, 1970's, 1980's, 1990's, and some newer.

10. **Use aerial LiDAR? For what?** Not for avalanche mapping. Yes, in other projects.

11. **Use satellite, what sensing approach(es)?** No.

12. **Software used?** Indirectly uses whatever program is used in the project's digital mapping. Sometimes will use PowerPoint, pull in USGS map, and overlay polygons for avalanche map.

13. **Developed software in-house?** No.

14. **Use commercial or open-source software?** No open-source. Commercial: Depends on the project. If working with new detailed digital maps, avalanche maps are an overlay, e.g. in ArcGIS.

15. **Can Caltrans contact you?** Yes.

Chris Stethem, Chris Stethem & Associates Ltd
Unable to contact. Phone number not working. Sent a follow-up email for updated contact information, but the email bounced.

Arthur I. Mears, P.E., Mears and Wilbur
Called several times. Left message. Unable to contact as of submission of this report.

Chris Wilbur, Mears and Wilbur
Called several times. Unable to contact as of submission of this report.

Related Research

Guidelines

Land Managers Guide to Snow Avalanche Hazards in Canada. Canadian Avalanche Association, 2002. Should be available for purchase at http://www.avalancheassociation.ca/?page=Standards

This is a very useful publication for land managers, including transportation corridor managers. It discusses, as noted in a presentation by McClung, recognition of potential avalanche problems, methods used for avalanche hazard mapping, elements of a hazard / risk map and report, selecting avalanche mapping expertise, typical mitigation and mapping for land uses, and methods for avalanche protection. This would be of great use in developing an RFP or in selecting and hiring an expert for Caltrans' avalanche mapping needs. To my knowledge, no similar publication exists in the U.S. This publication has been used to guide projects in the U.S., according to a Canadian avalanche expert.

Chapter 4 of this guide presents typical methods for avalanche hazard mapping. These include:

- Terrain analysis from maps and air photos
- Field studies of terrain
- Study of vegetation for signs of past avalanches
- Oral and written records of avalanches
- Weather and snow records
- Surficial materials (transported tree debris, rocks, and soil)
- Application of statistical models
- Application of dynamic models
- Combined estimates from various methods

Guidelines for snow avalanche risk determination and mapping in Canada. Canadian Avalanche Association, 2002. Should be available for purchase at http://www.avalancheassociation.ca/?page=Standards

A companion publication to the above land manager's guide, this publication is meant as a guide for the avalanche expert or consultant when performing avalanche mapping or risk determination. Provides, according to a presentation by McClung, limitations of mapping, types of snow avalanche mapping, definition of risk and avalanche terms, risk guidelines for various applications (risk matrices), and typical methods used for risk determination.

Stoffel, L. and Schweizer, J. (2008). **Guidelines for Avalanche Control Services: Organization, Hazard Assessment and Documentation – An Example from Switzerland**, International Snow Science Workshop, Whistler, B.C., Canada, pp. 483-489.

Page 485: Provides a reasonable definition of an avalanche map (or atlas): map with avalanche paths (starting zones and avalanche flow directions), avalanche protection measures (e.g. supporting structures); possibly complemented with a table describing terrain characteristics (e.g. starting zones: altitude, inclination, aspect, topography, area), photographs; if available terrain inclination map. Also, avalanche history: date of large events (incl. run-out, damage); possibly map with area affected by large events.

Note that this avalanche map is distinct from an avalanche hazard map.

Overviews

Jamieson, B., & Stethem, C. (2002). **Snow avalanche hazards and management in Canada: challenges and progress**. Natural Hazards, 26(1), 35-53.

For Canada: "The annual direct cost of avalanche-related highway closures exceeds CAD$5M per year (Jamieson, 2001). Indirect costs due to business losses have not been estimated, but would substantially increase the economic impact of transportation delays."

Stethem, C., Jamieson, B., Schaerer, P., Liverman, D., Germain, D., & Walker, S. (2003). **Snow avalanche hazard in Canada–a review**. Natural Hazards, 28(2-3), 487-515.

From the abstract: Snow avalanches affect recreation, transportation, resource industries and property. During the 1990s, an average of 12.5 persons per year were killed in avalanches in Canada. The snow avalanche hazard has affected people and facilities in B.C, Alberta, Yukon, NWT, Nunavut, Ontario, Quebec and Newfoundland. Avalanche risk may be voluntary, for example skiing and snowmobiling, or involuntary, for example public transportation corridors. A worst-case avalanche scenario is most likely to occur in the Western Cordillera, resulting from a single large-scale weather pattern, where a cold period resulting in the development of a weak layer in the snowpack is followed by a series of major mid-winter storms. Emergency preparedness for avalanches is most advanced in western Canada. New education and information initiatives in Quebec and Newfoundland are aimed at improving preparedness there. Current research is focused on avalanche forecasting, weather forecasting for avalanche prediction, avalanche failure characteristics, forestry and avalanches and geomorphology and avalanches. An important area of future research is the impact of climate change on avalanches, particularly in northern Canada.

From page 502:

"The factors in preparing an avalanche hazard zoning plan (Freer and Schaerer, 1980) include evaluation of terrain and vegetation, study of climate, collection of historical data, calculation of runout distance, comparison of avalanche paths and application of experience. Experts use statistical analyses of topography (Lied and Bakkehoi, 1980; McClung and Mears, 1991), dynamic models of avalanche motion (Salm et al., 1990; Perla et al., 1980) and risk-based models (Jónasson et al., 1999; Keylock et al., 1999) to help determine the runout distance of avalanches. McClung et al. (1989) have compiled regional databases to identify the different coefficients for statistical runout estimations in different mountain ranges. A model has also been produced by McClung (2000) to estimate the effective return period as a function of the position of the avalanche deposit in the runout zone.

Greene, E. M., Birkeland, K. W., Elder, K., Johnson, G., Landry, C., McCammon, I., Moore, M., Sharaf, D., Sterbenz, C., Tremper, B., and Williams, K. (2004). **Snow, weather, and avalanches: Observational guidelines for avalanche programs in the United States**. American Avalanche Association, Pagosa Springs, Colorado, vol. 150, 2004.

(Latest version 2010, likely a useful resource for standardizing terms, and as a template for database design)

Sauermoser, S. (2006, October). **Avalanche hazard mapping—30 years' experience in Austria**. In Proceedings of the 2006 International Snow Science Workshop, Telluride, Colorado, ISSW USA, Colorado, USA (pp. 314-321).

"Summarizing it can be stated from the Austrian point of view, that the delimitation of avalanche hazard zones should be the result of the experience of experts, historical records, statistical investigations and the use of different run out models. This comprehensive method takes into account that the avalanches as natural phenomenon can change their character and spreading in a way that cannot be forecasted and calculated only by formulas and theoretical approaches."

Marienthal, A., Mancey, J., Guy, Z., Rains, F., and Schwab, D. (2010, April) **Geospatial Science and Snow-Avalanche Research**, The Avalanche Review, Vol. 28, No. 4, pp. 26-28.

http://www.avalanche.org/moonstone/Terrain/GIS%20articles.2.28.4.pdf

Provides a general overview of the use of GIS for snow and avalanche research, including example figures of avalanche-hazard maps, and software to generate them.

Avalanche Modeling

Dynamic / Physical Models

Salm, B. (2004). **A short and personal history of snow avalanche dynamics**. Cold Regions Science and Technology, 39(2), 83-92.

“We needed a better concept of 'risk' since the ultimate goal of mapping is to determine 'risk'. Risk is defined as the product of the probabilities of danger, damage and presence. In the case of snow, danger is the fracture probability of a snow mass on a slope and the subsequent movement until standstill. The probability of damage is the possibility that a structure is damaged or destroyed. Here obviously fatalities and injured persons or animals are an important factor too. For buildings the probability of presence is always one, whereas for persons staying in the open or for motor vehicles this can vary considerably. The final-intricate-problem is to fix a 'tolerated risk'.”

“The Swiss 'three-zone' system for avalanche hazard mapping is now applied in many alpine countries as Austria, France, Norway, Canada and the United States, sometimes with certain modifications.”

“I think that this success is based on the fact that only three quantities must be known to delineate the different zones. The first is the approximate avalanche speed at the end of the avalanche track before it begins to decelerate in the runout zone. Next, the runout distance must be estimated. Finally, these quantities must be determined as a function of the return period.”

“Generally, it seems that so-called 'hydraulic models'—although not much is left from hydraulics—are best fit for a use in practice. The maximum of parameters involved for practicable models are Coulomb friction, Chezy resistance and angle of internal friction. Indispensable, however, is to calibrate them on the basis of numerous field observations (different topography and climate, involved mass etc.). Without this, a model can never be a credible one.”

“To conclude with an important saying of the late Malcolm Mellor—certainly, one of the best qualified snow and ice researcher in recent time—shall be cited: It seems unrealistic and presumptuous to immediately seek complete generality when much simpler materials (than snow) are presenting formidable problems in other branches of solid mechanics. Elegant simplification of complicated behaviour is very much needed!”

Jamieson, B., Margreth, S., & Jones, A. (2008, September). **Application and limitations of dynamic models for snow avalanche hazard mapping**. In Proceedings of the ISSW (pp. 730-739).

From the abstract: Dynamic models, initially based on fluid flow, have been used since the 1950s for modelling the motion and runout of extreme snow avalanches. The friction coefficients cannot be directly measured. They can, however, be calibrated to reproduce an extreme runout that was observed or statistically estimated in a particular path, and the resulting modelled velocity can be used to calculate impact pressures in the runout zone. Alternatively, the friction coefficients can be obtained from extreme avalanches in similar nearby paths and used, often with estimates of available snow mass, to estimate extreme runout in a path that threatens proposed development. This method is controversial because with average values of the friction coefficients, runout estimates from dynamic models are more variable than estimates from statistical runout models. However, uncertainty in the release mass and friction coefficients can be simulated with dynamic models, improving confidence in the runout, impact pressures and return intervals, all of which are required for risk-based zoning. Also, various scenarios can be modelled to see which yields reliable impact pressures for a given position in the runout zone. We argue that dynamic runout estimates can complement estimates from statistical models, historical records and vegetation damage, and be especially useful where some of these estimates are not available or are of low confidence. Limitations of dynamic models involving friction coefficients, snow mass estimates, number of variables and dimensions, entrainment and deposition as well as flow laws are reviewed from a practical perspective.

From invited talk by Deiter Issler at "L'ingegneria e la neve" of the Associazione Georisorse e Ambiente, Politecnico di Torino, Torino (Italy), 21 February 2006:

Among avalanche researchers, there are two opposite attitudes towards [the] problem:

One group considers that our knowledge of avalanche dynamics will always be insufficient and therefore advocates the use of the simplest models with three or fewer adjustable parameters that are to be calibrated extensively. The price to pay is a very wide range of these parameters that are moreover nearly devoid of precise physical meaning. Prime examples are the Voellmy-Salm and PCM models.

The opposite attitude is to try to construct models that correctly capture the main physical processes in avalanche flow and contain parameters with a clear physical meaning. Advocates of this approach argue that the parameters can in principle be measured in experiments and their probable range of values can be guessed in advance.

"There are two basic ways to apply dynamic models in hazard mapping (e.g. Barbolini et al., 2000):

Direct calibration: For the path to be mapped, the friction coefficients and release mass or depth are adjusted so the dynamic model stops at an extreme runout taken from historical (human) records, vegetation damage and/or statistical models. This is sometimes called back-calculation of friction coefficients. With some expertise in the fitting of parameters and flow density, useful estimates of velocity and hence impact pressure along the path and, in particular, in the runout zone are possible.

Indirect calibration: Use resistance and flow parameters taken from extreme runouts in other paths and/or published values, sometimes supplemented with estimates of release area and mass or depth of released snow, and often adjusted with expertise or simulations to estimate extreme runouts in the path to be mapped."

Side note: AVAL-1D dynamic modeling software is commercially available. 4000 Swiss Franc, or $4580 (5/6/14). "In Switzerland, AVAL-1D is currently the standard model for hazard mapping."

http://www.slf.ch/dienstleistungen/software/aval1d/index_DE

Statistical Models

Barbolini, M., & Keylock, C. J. (1999). **A new method for avalanche hazard mapping using a combination of statistical and deterministic models**. Natural Hazards and Earth System Science, 2(3/4), 239-245.

From the abstract: The purpose of the present paper is to propose a new method for avalanche hazard mapping using a combination of statistical and deterministic modelling tools. The methodology is based on frequency-weighted impact pressure, and uses an avalanche dynamics model embedded within a statistical framework. The outlined procedure provides a useful way for avalanche experts to produce hazard maps for the typical case of avalanche sites where historical records are either poorly documented or even completely lacking, as well as to derive confidence limits on the proposed zoning. The methodology is implemented using avalanche information from Iceland and the Swiss mapping criteria, and applied to an Icelandic real world avalanche mapping problem.

McCollister, C., K. Birkeland, K. Hansen, R. Aspinall, R. Comey. 2002. **A probabilistic technique for exploring multi-scale spatial patterns in historical avalanche data by combining GIS and meteorological nearest neighbors with an example from the Jackson Hole Ski Area, Wyoming**. Proceedings of the 2002 International Snow Science Workshop, Penticton, BC, Canada, 109-116.

(abstract and paper very similar to below 2003 paper)

Page 3: “Each avalanche event is a record in a table with the date, slide path name, time, type, trigger, depth, U.S. Size, and sliding surface as attributes.”

McCollister, C., K. Birkeland, K. Hansen, R. Aspinall, R. Comey. 2003. **Exploring multi-scale spatial patterns in historical avalanche data, Jackson Hole Mountain Resort, Wyoming**. Cold Reg. Sci. Tech. 37(3), 299-313.

From the abstract: Many ski areas, backcountry avalanche centers, highway departments, and helicopter ski operations record and archive daily weather and avalanche data. This paper presents a probabilistic method that allows avalanche forecasters to better utilize historical data by incorporating a Geographic Information System (GIS) with a modified meteorological nearest neighbors approach. This nearest neighbor approach utilizes evolving concepts related to visualizing geographic information stored in large databases. The resulting interactive database tool, Geographic Weather and Avalanche Explorer, allows the investigation of the relationships between specific weather parameters and the spatial pattern of avalanche activity. We present an example of this method using over 10,000 individual avalanche events from the past 23 years to analyze the effect of new snowfall, wind speed, and wind direction on the spatial patterns of avalanche activity. Patterns exist at the slide path scale, and for groups of adjacent slide paths, but not for either the entire region as a whole or when slide paths are grouped by aspect. Since wind instrumentation is typically located to measure an approximation of the free air winds, specific topography around a given path, and not simply aspect, is more important when relating wind direction to avalanche activity.

Page 305: Includes discussion of GeoWAX software for data visualization and hypothesis generation. Geographic Weather and Avalanche Explorer.

McCollister, C.M. 2004. **Geographic knowledge discovery techniques for exploring historical weather and avalanche data**. M.S. Thesis, Department of Earth Sciences, Montana State University. 106 pp.

From the abstract: Many ski areas, backcountry avalanche centers, highway departments, and helicopter ski operations record and archive daily weather and avalanche data. The objective of this thesis is to present probabilistic techniques that allow avalanche forecasters to better utilize weather and avalanche data by incorporating a Geographic Information System with a modified meteorological nearest neighbors approach. This nearest neighbor approach utilizes evolving concepts related to visualizing geographic information stored in large databases. The resulting interactive database tool, Geographic Weather and Avalanche Explorer, allows the investigation of the relationships between specific weather parameters and the spatial pattern of avalanche activity. In order to validate these new techniques, two case studies are presented using over 10,000 individual avalanche events from the past 23 years that occurred at the Jackson Hole Mountain Resort.

The first case study explores the effect of new snowfall, wind speed, and wind direction on the spatial patterns of avalanche activity. Patterns exist at the slide path scale, and for groups of adjacent slide paths, but not for either the entire region as a whole or when slide paths are grouped by aspect. Since wind instrumentation is typically located to measure an approximation of the free air winds, specific topography around a given path, and not aspect, is more important when relating wind direction to avalanche activity.

The second case study explores the spatial variability of hard slab and dry loose avalanches, and characterizes these avalanche types with respect to their geographic location and associated weather conditions. I analyzed these data with and without the incorporation of three weather parameters (wind speed, 24-hour maximum temperature, and new snow density). Slide paths near each other often had similar proportions of hard slabs and a higher proportion of hard slabs occurred on exposed ridges. The proportion of loose avalanches also was similar for adjacent slide paths, and these paths were typically sheltered from strong winds. When I incorporated the three weather parameters I found significant increases in the average proportion of hard slabs with increases in new snow density, but not for changes in the 24-hour maximum temperature or wind speed. When I analyzed the proportion of loose avalanches associated with the three weather parameters I found a more direct relationship than with hard slabs. Changes in both wind speed and density significantly changed the average proportion of loose avalanches, with low wind and low density resulting in higher proportions of loose avalanches. My results quantify what operational avalanche forecasters have long known: Geographic location and weather are both related to the proportion of hard slab and dry loose avalanches.

Barbolini, M., Pagliardi, M., Ferro, F., & Corradeghini, P. (2011). **Avalanche hazard mapping over large undocumented areas**. Natural hazards, 56(2), 451-464.

From the abstract: An innovative methodology to perform avalanche hazard mapping over large undocumented areas is herewith presented and discussed. The method combines GIS tools, computational routines, and statistical analysis in order to provide a ‘‘semi-automatic’’ definition of areas potentially affected by avalanche release and motion. The method includes two main modules. The first module is used to define zones of potential avalanche release, based on the consolidated relations on slope, morphology, and vegetation. For each of the identified zones of potential release, a second module, named Avalanche Flow and Run-out Algorithm (AFRA), provides an automatic definition of the areas potentially affected by avalanche motion and run-out. The definition is generated by a specifically implemented ‘‘flow-routing algorithm’’ which allows for the determination of flow behaviour in the track and in the run-out zone. In order to estimate the avalanche outline in the run-out zone, AFRA uses a ‘‘run-out cone’’, which is a 3D projection of the angle of reach a. The a-value is evaluated by statistical analysis of historical data regarding extreme avalanches. Pre- and post-processing of the AFRA input/output data is done in an open source GIS environment (GRASS GIS). The method requires only a digital terrain model and an indication of the areas covered by forest as input parameters. The procedure, which allows rapid mapping of large areas, does not in principle require any site-specific historical information. Furthermore, it has proven to be effective in all cases where a preliminary cost-efficient analysis of the territories potentially affected by snow avalanche was needed.

“Our study addresses these situations and develops a procedure that fulfill the following requisites: (1) map avalanche-prone zones for large areas where historical information is lacunose or lacking; (2) be as objective as possible; (3) require a limited amount of data; and (4) be simple to implement and cost effective.”

“The method allows rapid, cost-effective, mapping of large areas. It requires as input parameters only a digital terrain model and an indication of the areas covered by (protective) forest.”

“The proposed method does not intend to contrast current mapping methods based on avalanche dynamic models. Conversely, it is complementary to them. In fact, physical models are appropriate for detailed mapping at the scale of a single path, when dynamic parameters of the avalanche (flow velocity, pressure, deposition depth, etc.) are also needed; nevertheless, their use requires collection of a relevant amount of data (snowfalls, history, field surveys, etc.), and it is expensive in terms of time and costs. For these reasons, in practical situations where a preliminary and swift mapping of large areas is needed, sophisticated calculation of the avalanches is not always convenient, and the procedure illustrated in this study could represent a valid alternative. This is especially true for those cases where the avalanche’s history is poorly known or even completely missing, given that our procedure does not require any site-specific historical information.”

Other Modeling

Mears, A.I., 1988, **Comparisons of Colorado, Eastern Sierra, Coastal Alaska, and Western Norway Avalanche Runout Data**, International Snow Science Workshop, Whistler, B.C.

Important paper in that European models are often used in avalanche runout prediction, and this paper shows these models will underpredict runout distance.

From the abstract: Avalanche runout-distance data from 130 Colorado paths, 90 E. Sierra paths and 52 Coastal Alaska paths are compared with data obtained from III paths in Western Norway. Positive correlations between alpha and beta were obtained from all 4 mountain areas, however considerably more scatter is observed in data from the 3 U.S. areas than in W. Norway. A regression equation derived from W. Norway systematically over-predicts alpha (underpredicts runout distance) in the 3 U.S. mountain areas studied.

McClung, D. M., & Mears, A. I. (1991). **Extreme value prediction of snow avalanche runout**. Cold Regions Science and Technology, 19(2), 163-175.

From the abstract: Avalanche runout distances have traditionally been calculated by selecting friction coefficients and then using them in an avalanche dynamics model. Uncertainties about the mechanical properties of flowing snow and its interaction with terrain make this method speculative. Here, an alternative simple method of predicting runout based on terrain variables is documented. By fitting runout data from five mountain ranges to extreme value distributions, we are able to show how (and why) extreme value parameters vary with terrain properties of different ranges. The method is shown to be applicable to small and truncated data sets which makes it attractive for use in situations where detailed information on avalanche runout is limited.

Barbolini, M., Natale, L., & Savi, F. (2002). **Effects of release conditions uncertainty on avalanche hazard mapping**. Natural hazards, 25(3), 225-244.

"The release of a certain avalanche mass is indeed a complex combination of many different factors: snow precipitation, snowdrift, release zone topography and vegetation, snow cover evolution and stability."

"In view of the large financial resources required for effective protection structures, risk management approaches to avalanche problems are becoming increasingly important. Reliable and reasonably precise avalanche hazard mapping is a key tool in such considerations. Even though in countries with a long history of avalanche protection a very valuable body of experience in the judgment of avalanche hazard has been collected, and consequently experienced practitioners can make use of their "good feeling" in assessing hazardous situations, a more scientific base is needed to establish sound technical procedures. In this respect, computational models for calculating snow avalanche motion and/or runout distance appear to be irreplaceable tools."

Maggioni, M., Gruber, U. and Stoffel, A. 2002. **Definition and characterisation of potential avalanche release areas**, Proceedings of the 2002 ESRI International User Conference, San Diego, CA, pp. 204-221.

Includes a flowchart for an approach to automatically identify Potential Release Areas.

Maggioni, M., & Gruber, U. (2003). **The influence of topographic parameters on avalanche release dimension and frequency**. Cold Regions Science and Technology, 37(3), 407-419.

"For single terrain parameters, for example, slope angle, avalanche frequency distributions exist (Munter, 1999), yet, there is no detailed study of the combined influence of various geomorphologic parameters available."

"Based on Salm (1982) and Munter (1999) and an analysis of the terrain of the starting zone of past events, the first selection is made in that it is considered to be a potential avalanche release area only terrain with a slope angle of between 30 and 60 degrees (Fig. 1). The reason for this choice is that on slopes with an angle greater than 60 degrees, avalanches are very frequent and of small dimension, since big lasting deposition is not possible, while on slopes with angles smaller than 30 degrees, the component of the gravity force along the slope is not strong enough to initiate an avalanche."

“In GIS, the curvature of a terrain is computed in such a way that it is separated into two orthogonal components, where the effects of the gravitational process are either maximized, profile curvature, or minimized, plan curvature”

“In summary, this preliminary analysis indicates that mean slope, curvature and distance to the ridge are the most important parameters influencing the avalanche release area frequency. Convex potential release areas usually have a low avalanche activity, and often only a small share of the whole PRA (potential avalanche release area) is released. Within flat or slightly concave PRAs, the avalanches release areas are more equally distributed over the whole range of PRA percentages when compared with convex and concave PRAs. Higher average slope angles lead to the frequent release of small avalanches.”

Gruber, U., & Bartelt, P. (2007). **Snow avalanche hazard modelling of large areas using shallow water numerical methods and GIS**. Environmental Modelling & Software, 22(10), 1472-1481.

“Potential avalanche release areas are strongly related to the slope inclination of the terrain. Below a slope angle of 28 degrees almost no large avalanches have been observed and above 60 degrees, the terrain is so steep that the snow is continuously avalanching without being able to form large avalanches”

Forecasting

Hägeli, P., & McClung, D. M. (2000). **A new perspective on computer-aided avalanche forecasting: scale and scale issues**. Montana, 1, 8.

“This paper discusses the problems related to scale in avalanche forecasting models. The term ‘scale’ refers to a characteristic length or time of a process, observation or model.”

“The contributing factors, which lead to the formation of avalanches, are manifold and span several orders of magnitude in time and space. They can basically be divided into two main classes. The first class are made up of external factors like terrain and climate. These have very long time scales with respect to avalanches and hence influence their formation only in a static way. While climate has a large spatial scale as well, terrain varies on all scales and does not have dominant length scales. The second group contains internal factors, which have shorter time scales than one season and affect avalanche formation dynamically. Weather as well as snowpack variables belong to this class.”

“The characteristics of the avalanching process itself are very similar to the characteristics of the contributing factors. The complex interaction of all the contributing factors at different scales makes it a multi-scale phenomenon in space and time. This makes it impossible to focus on individual processes and scales for the forecasting task, unlike in weather forecasting. This characteristic of avalanches makes the forecasting task very challenging.”

“larger scale studies about avalanche activity seem to be more useful from the forecasting perspective. The only study of this kind has been done by Stoffel et al. (1998), who looked at the distribution of avalanche activity in the surroundings of the village of Zuoz (Switzerland). They were able to show the development of specific patterns, but could not explain them.”

“Numerical models like the Swiss SNOWPACK (Lehning et al., 1999) are a possible solution for this scale problem. The high cost for the installation of the necessary weather station make this method too expensive for many operations.”

“Type B forecasts use actual weather observations and sometimes snow profile and stability test results are included as well. It is therefore more an evaluation than an actual forecast. Almost all early morning forecasts in ski resorts or highway operations are of this type. The vast majority of avalanche forecasting models is designed for this task, especially tailored towards the needs and resources of an operation.”

“Type C forecasts are typically made in helicopter skiing or backcountry traveling after avalanche occurrences have been scanned for and stability tests have been performed (class I data). Here, the focus lies on the stability evaluation of individual terrain features, such as rolls or gullies. The forecasting tool NX-LOG (Bolognesi and Buser, 1995) calculates avalanching probabilities for individual gullies. The model combines the nearest neighbor method with an expert system. Input parameters are similar to the systems mentioned above and therefore it is expected that the resulting forecasts have the same shortcomings.”

“A completely different approach is pursued with the SNOWPACK model of Lehning et al. (1999). This model uses high quality meteorological input data to calculate the snowpack characteristics at specific locations. Each location is equipped with an automatic weather station which consists of a wind station on a mountain crest and a snow study plot nearby. The ultimate goal of this system is to predict avalanches with the help of a rupture criterion calculated on the basis of the snow properties modeled. Although correct from the scale perspective, we suspect that the output of this model is just one point sample with only insufficient support to give adequate evidence about the stability situation in its larger surroundings."

Case Studies and Mapping Applications

Freer, G. L., & Schaerer, P. A. (1980). **Snow-avalanche hazard zoning in British Columbia, Canada**. Journal of Glaciology, 26(94), 345-354.

From the abstract: Many developed areas in British Columbia are exposed to snow-avalanche hazards. Avalanche-hazard zoning has been undertaken by the British Columbia Ministry of Transportation, Communications, and Highways during the past five years. Recommendations from these zoning studies are forwarded to those agencies responsible for land-use zoning and development approval. Existing and possible legislation are described, as well as problems associated with implementation of the legislation. Technical considerations are outlined; interpretation of vegetation is a very important factor in evaluating each avalanche site. Calculation of run-out distances and consideration of other factors serve as a check on the vegetation interpretation. A special safety factor has been developed.

Socio-political considerations with respect to British Columbia are described. Existing developments have the most wide-ranging implications.

Hackett, S. W., & Santeford, H. S. (1980). **Avalanche zoning in Alaska, USA**. Journal of Glaciology, 26(94), 377-392.

From the abstract: Over 30% of Alaska's 586,400 squares miles is subject to snow-avalanche activity. For a state-wide avalanche hazard evaluation, Alaska has been divided into six major snow avalanche regions on the basis of topography, climatological data, dominant snow-pack conditions, and typical avalanche activity. They are: Arctic Slope, Brooks Range, Western, Interior, South-central, and South-east.

Mountainous terrain was studied at scales of 1 : 250,000 and 1 : 1,584,000; final compilation was at a scale of 1 : 2,500,000. Regional snow-pack and climatic conditions were cross-correlated with relief zonation of each avalanche region to produce a map of Alaska's provisional snow-avalanche potential.

Most of the mountainous areas in the South-central and South-east regions, because of their northern latitude, closeness to large masses of water, and large orographic and cyclonic weather processes, are susceptible to major avalanche activity. For areas near population centers, the potential avalanche terrain has been identified from data on known and suspected avalanche activity through air photographs, terrain analysis, and documented snow-avalanche occurrences compiled at scales of 1 : 250,000 and 1 : 63,360.

The state-wide regional data compilation and study are initial steps toward avalanche zoning in Alaska. Local land-use planning and detailed investigations are needed to establish effective natural-hazard zoning in municipal areas as related to snow avalanche activity.

Ives, J. D., & Plam, M. (1980). **Avalanche-hazard mapping and zoning problems in the Rocky Mountains, with examples from Colorado, USA**. Journal of Glaciology, 26(94), 363-375.

From the abstract: Avalanche-hazard mapping as a basis for land-use decision-making was not undertaken systematically in Colorado until 1974. Passage of Colorado House Bill 1041 required counties to map areas subject to snow avalanche, landslide, debris flow, and mountain flood at 1:24,000, and funds were provided. This legislation induced several approaches: work undertaken directly by the Colorado

Geological Survey; private contract work; mapping by the Institute of Arctic and Alpine Research (INSTAAR) funded by a NASA research grant. This latter effort produced 37 individual 1:24,000 map sheets of Hinsdale, Ouray, San Juan, and San Miguel counties, San Juan Mountains. This emphasized problems of scale and degree of cartographic accuracy. Swiss, Austrian, and French experience, together with the actual Colorado mapping experience, facilitated further definition of problems facing the Rocky Mountains states, both in terms of resolution of actual mapping problems, and of using such developing experience to influence the decision-making process.

Two mapping attempts are described: (i) development of a combined hazard map for a mountain type area, indicating the difficulties of, and need for, combining hazard assessment of avalanche and other physical processes that frequently overlap; (ii) consideration of avalanche-zoning problems in a wilderness area.

Finally, scale limitations and the need to define rigorously "hazard" are discussed. Definition of hazard must include consideration of recurrence interval, impact pressures in the run-out zone, and limitations of displaying this type of data on available topographic maps, all in relation to types of impact, i.e. to moving or stationary objects in relatively sparsely populated terrane. Additional critical needs facing Rocky Mountains states are itemized: (i) standardized mapping legends for different scales; (ii) establishment of an avalanche cadastre; (iii) systematic reporting of climax events; (iv) development of an historical archive; (v) public awareness; (vi) attention to legal aspects of the avalanche equivalent of the hundred-year flood, and its legal testing.

Mears, A. I. (1980). **Municipal avalanche zoning: contrasting policies of four western United States communities**. Journal of Glaciology, 26(94), 355-362.

From the abstract: Four communities in the western United States (Vail, Colorado; Ketchum, Idaho; Ophir, Colorado; and Juneau, Alaska) have detailed avalanche-hazard mapping available. In response to this detailed information, Vail restricts building in a red (high hazard) zone but permits specially designed buildings in the blue (moderate hazard) zone. Ketchum allows single-family dwellings in red or blue zones regardless of design but will not permit such structures to be rented from the period 15 November through 15 April of each year. Multi-family dwellings in Ketchum hazard zones must be designed for avalanche forces. Ophir will restrict buildings from the red zone and permit specially designed structures in the blue zone. Juneau does not restrict development in any avalanche-hazard zone.

Dow, V., Kienholz, H., Plam, M., & Ives, J. D. (1981). **Mountain hazards mapping: the development of a prototype combined hazards map, Monarch Lake Quadrangle, Colorado, USA**. Mountain Research and Development, 55-64.

Documents development of a hazard map (more than avalanches) for an area in Colorado. Interesting view of map generation process before availability of GIS. Also interesting in that a foldout version of the map was included with this journal publication.

Another interesting aspect was the breakdown of map costs. For example, 330 hours of drafting cost $2,046 (note the year of publication).

Heywood, L. (1988). **Rain on snow avalanche events - Some observations**. In Proceedings of the 1988 International Snow Science Workshop (pp. 135-136).

This is a useful study for Caltrans, in that it was performed at the Alpine Meadows Ski Area in the California Sierras. A particularly interesting portion of the paper notes that “Artificial release with explosives on wet snow avalanches has been found to be ineffective. Wet snow does not respond to explosive control as does dry snow. The physical properties of wet snow suppress the propagation of explosive shock waves through the snowpack. Wet snow tends to be less brittle and more fluid than dry snow. This property appears to lessen the effectiveness of explosive control.”

From the abstract: Methods of prediction of rain-induced avalanches are examined. Historical avalanche events are evaluated with respect to rainfall amounts, rainfall intensity, and days since last snowfall. A simple experiment was performed to monitor movement of water through an inclined snowpack. The mechanical effects of water movement and its relationship to avalanche activity is discussed. Observations and suggestions of explosive control for rain on snow avalanches are examined.

Frutiger, H. (1990). **Maximum avalanche runout mapping: a case study from the central Sierra Nevada**. In Proc. 1990 Int. Snow Sci. Workshop (pp. 245-251).

This paper is of particular interest to Caltrans, as it is a study from the central Sierras.

This paper compares the Avalanche Hazard Map produced in 1983 to the avalanche occurrences of February 1986. The area of interest was the Galena Basin, a proposed future ski resort on Mt. Rose Pass, 37 km (23 mi.) northeast of Tahoe and 35 km (22 mi.) southwest of Reno, Nevada. Of particular interest was how the maximum runout distances determined basically by the Swiss Calculation Method compare to those experienced in February 1986 (Frutiger 1987).

“The AHM of November 1983 indicated the outer limits of a 20-years avalanche and a 100-years avalanche. Of the 16 avalanches which became active in 1986 three stopped within the limit of a 20-years avalanche, 7 stopped in between the 20-years and the 100-years limits, and 6 avalanches overran the 100-years limit, 5 of them by 30 to 40 meters, and one (No. 27) by 108 meters. Note that path No. 27 is the only one with a NE-aspect.”

“The assumption that only the newly fallen snow is involved in most of the far reaching avalanches applies especially to maritime climate regions. This assumption is supported by a publication by Armstrong and Armstrong (1987), where they state: "the majority of failures in the maritime zone occur at the old snow - new snow interface".”

“For the remainder of the paths the observed runout distances are close to those modeled with the Voellmy equation (with parameters defined in the paper)”

“Although 10 of the 16 avalanches stopped within the limits of the 100-years avalanche, as indicated on the 1983 AHM, it was not acceptable that six of them had overrun those limits. On the basis of the measured runout distances and the storm data of February 1986 a revision of the AHM was undertaken (Frutiger, 1987).”

Borrel, Gilles, **The new French avalanche map**, (1992). Proceedings of the 1992 International Snow Science Workshop, Breckenridge, Colorado, USA, http://arc.lib.montana.edu/snow-science/item/1255

"Since 1970, the French Government has been supporting a large program of avalanche mapping, which takes two different forms: hazard "registration" maps (Cartes de Localization Probable des Avalanches or CLPA) and hazard zoning maps (Plans des Zones Exposees aux Avalanches or PZEA)."

(Note: Not sure of the difference between these two types of maps, have not seen this terminology elsewhere, i.e. registration vs. zoning)

McLaren, S. (2000). **Suitability mapping of avalanche trigger sites on the north shore mountains, Vancouver using a digital elevation model and GIS**. UniGIS, Simon Fraser University.

http://www.avalanchemapping.org/Repapers/Avalanche%20Hazard%20Mapping.zip

Presents an approach for avalanche hazard mapping used in Canada.

Hägeli, P., & McClung, D. M. (2003). **Avalanche characteristics of a transitional snow climate—Columbia Mountains, British Columbia, Canada**. Cold Regions Science and Technology, 37(3), 255-276.

"The focus of this study lies on the analysis of avalanche characteristics in the Columbia Mountains in relation to the local snow climate."

"The study implies that, even though the 'avalanche climate' and 'snow climate' of an area are closely related, there should be a clear differentiation between these two terms, which are currently used synonymously. We suggest the use of the term 'avalanche climate' as a distinct adjunct to the description of the snow climate of an area. The more encompassing term should also include information, such as typically important snowpack weaknesses and avalanche activity statistics, which are directly relevant to avalanche forecasting."

"LaChapelle (1966) was the first to describe dominant weather and avalanche characteristics for the different zones. He describes the coastal snow climate to be characterized by relatively heavy snowfall and mild temperatures."

"We propose the term 'avalanche climate' as a distinct adjunct to the hydrological/meteorological term 'snow climate'. In addition to snow climate information, the more encompassing term also contains information about avalanche characteristics, such as dominant snowpack features and avalanche activity statistics."

Arnalds, Þ., Jónasson, K., & Sigurðsson, S. (2004). **Avalanche hazard zoning in Iceland based on individual risk**. Annals of Glaciology, 38(1), 285-290.

From the abstract: Avalanche hazard is a threat to many residential areas in Iceland. In 1995 two avalanche accidents, causing a total of 34 fatalities in areas thought to be safe, prompted research on avalanche hazard assessment. A new method was developed, and in 2000 a new regulation on avalanche hazard zoning was issued. The method and regulation are based on individual risk, or annual probability of death due to avalanches. The major components of the method are the estimation of avalanche frequency, run-out distribution and vulnerability. The frequency is estimated locally for each path under consideration, but the run-out distribution is based on data from many locations, employing the concept of transferring avalanches between slopes. Finally the vulnerability is estimated using data from the 1995 avalanches. Under the new regulation, new hazard maps have been prepared for six of the most vulnerable villages in Iceland. Hazard zones are delineated using risk levels of 0.2×10^{-4}, 0.7×10^{-4} and $2 \times 10^{-4} a^{-1}$, with risk less than $0.2 \times 10^{-4} a^{-1}$ considered acceptable. When explaining the new zoning to the public, a measure of annual individual risk that allows comparison with other risks in society has proven advantageous.

Stoffel, A., Meister, R., & Schweizer, J. (1998). **Spatial characteristics of avalanche activity in an alpine valley-a GIS approach**. Annals of Glaciology, 26, 329-336.

"The potential starting zone within the study area is approximately 14.6 km^2 and was, as a first guess, calculated considering all slopes not wooded between 30° and 50°"

"Schneebeli and others (1997) proposed threshold values of 50 cm of snow depth for both the 3 day sum of new-snow depth and the total snow depth for large avalanches causing damage in the Inn valley."

Oller, P., Muntán, E., Marturià, J., García, C., García, A., & Martínez, P. (2006, October). **The avalanche data in the Catalan Pyrenees. 20 years of avalanche mapping**. In Proceedings of the international snow science workshop, Colorado, USA (pp. 305-313).

"The Avalanche Paths Map is a susceptibility map that shows areas potentially affected by avalanches. It is based on the French 'Carte de Localisation Probable des Avalanches' (CLPA; Pietri, 1,993). It is suitable for land planning at a regional scale. This information was compiled through terrain analysis, inquiries to the population and winter avalanche activity surveillance."

Sensing

Clendon, P. C., **Avalanche path mapping with GIS and the effect of DEM resolution**

http://www.avalanchemapping.org/Repapers/ClendonPenelope.zip

"The identification of an avalanche path requires more topographic detail than for zones and thus requires a higher-resolution digital elevation model (DEM) as input.... A 10 m resolution DEM, created specifically for this study, was used as the high-resolution input whilst a pre-existing 25 m resolution DEM was used as the low-resolution input."

Gruber, U., & Haefner, H. (1995). **Avalanche hazard mapping with satellite data and a digital elevation model**. Applied Geography, 15(2), 99-113.

"The aim of avalanche hazard mapping is to prevent catastrophic damage to people, animals, settlements and transportation facilities."

"An avalanche hazard map informs on the size, frequency and areal extent of the danger zone of potential avalanches."

"Indispensable prerequisites include precise information on the topography (altitude, slope angle and aspect, for example), which is only traceable from a digital elevation model (DEM). Hence, the availability of high-resolution DEMs of about the same spatial resolution as the satellite imagery is essential. In addition, the DEM is also needed for geocoding the satellite scenes and for feature extraction."

"The track begins within the starting zone, a treeless area with a slope of 28-50 degrees"

"For avalanche hazard mapping, the exact geometric position of each image element is of utmost importance. Avalanche tracks are always situated in very steep terrain, where the geometry is severely distorted in a satellite image. The geocoding was achieved using reference points and by utilizing the DEM"

"The necessary software packages for the preprocessing and processing of the satellite data are available in the IBIS library (Meier, 1992)."

(Their hazard maps show three degrees of hazard, which correlates 85% with manually produced avalanche-cadastre maps.)

Vallet, J., Skaloud, J., Koelbl, O., & Merminod, B. (2000). **Development of a helicopter-based integrated system for avalanche mapping and hazard management**. International Archives of Photogrammetry and Remote Sensing, 33(B2; PART 2), 565-572.

Develops a helicopter-based avalanche mapping system using aerial photogrammetry and GPS/INS. The system attains approximately 20 cm position accuracy, and 0.01 degree in attitude.

Wiesmann, A., Wegmuller, U., Honikel, M., Strozzi, T., & Werner, C. L. (2001). **Potential and methodology of satellite based SAR for hazard mapping**. In Geoscience and Remote Sensing Symposium, 2001. IGARSS'01. IEEE 2001 International (Vol. 7, pp. 3262-3264). IEEE.

Synthetic Aperture Radar: “The applicability of SAR interferometry for the detection of snow avalanches, however, is a promising new approach, especially when two satellites monitor the earth in tandem in about one day intervals.”

Walsh, S. J., Weiss, D. J., Butler, D. R., & Malanson, G. P. (2004). **An assessment of snow avalanche paths and forest dynamics using Ikonos satellite data**. Geocarto International, 19(2), 85-93.

From the abstract: Ikonos panchromatic and multispectral satellite data were acquired in October 2000 and August 2002 for a test area along US Highway 2, the southern border of Glacier National Park (GNP), Montana, USA. The research goals were to map snow avalanche paths and to characterize vegetation patterns in selected paths for longitudinal (i.e., source, track, and runout) and transverse (i.e., inner, flanking, outer) zones as part of a study of forest dynamics and nutrient flux from paths into terrestrial and aquatic systems. In some valleys, as much as 50 percent of the area may be covered by snow avalanche paths, and as such, serve as an important carbon source servicing terrestrial and aquatic ecosystems. Snow avalanches move woody debris down-slope by snapping, tipping, trimming, and excavating branches, limbs, and trees, and by injuring and scaring trees that remain in-place. Further, snow avalanches alter the vegetation structure on paths through secondary plant succession of disturbed areas. Contrast and edge enhancements, Normalized Difference Vegetation Index (NDVI), and the Tasseled Cap greenness and wetness transformations were used to examine vegetation patterns in selected paths that were affected by high magnitude snow avalanches during the winter of 2001-2002. Using image transects organized in longitudinal patterns in paths and in forests, and transects arranged in transverse patterns across the sampled paths, the Tasseled Cap transforms (and NDVI values) were plotted and assessed. Preliminary results suggest that NDVI patterns are different for paths and forests, and Tasseled Cap greenness and wetness patterns are different for longitudinal and transverse zones that describe the morphology of snow avalanche paths. The differentiation of paths from the background forest and the characterization of paths by morphometric zones through remote sensing has implications for mapping forest disturbances and dynamics over time and for large geographic areas and for modeling nutrient flux in terrestrial and aquatic systems

“In 1979, a widespread cycle of snow avalanches deemed “500-year events” by the National Park Service occurred throughout the area, uprooting and snapping trees, and extending the boundaries of many avalanche paths on both their transverse and longitudinal margins. Several avalanches blocked US Highway 2 and an adjacent transcontinental railroad line, and one enormous avalanche removed a bridge on US 2, necessitating a 300-km detour to the south during the height of hazardous winter travel, effectively isolating the eastern portion of Glacier Park and the adjacent Blackfeet Indian Reservation.”

Huggel, C., Zgraggen-Oswald, S., Haeberli, W., Kääb, A., Polkvoj, A., Galushkin, I., Evans, G. B. Crosta, J.-L. Schneider & Strom, A. (2005). **The 2002 rock/ice avalanche at Kolka/Karmadon, Russian Caucasus: assessment of extraordinary avalanche formation and mobility, and application of QuickBird satellite imagery**. Natural Hazards & Earth System Sciences, 5(2).

“QuickBird is currently the best available satellite sensor in terms of ground resolution (0.6 m) and opens new perspectives for assessment of natural hazards. Evaluation of the potential of QuickBird images for assessment of high-mountain hazards shows the feasibility for detailed avalanche mapping and analysis of flow dynamics, far beyond the capabilities of conventional satellite remote sensing.”

“The recent emergence of commercial satellite sensors with very-high ground resolution, comparable to aerial photography, such as IKONOS, QuickBird or Orbview-3 (Birk et al., 2003) opens new perspectives for applications in the area of natural hazards. These may range from detailed mapping and assessment to disaster management and response”

“Together with IKONOS (1 m) and Orbview-3 (1 m), QuickBird represents a new generation of satellite sensors which open new perspectives in earth surface mapping and analyses. QuickBird has a black and white (panchromatic) band with 0.6 m ground resolution and four multispectral bands (3 bands in the visible and 1 band in the near-infrared spectrum) with 2.5 m resolution.”

“Beyond the process analysis, it was an objective of this paper to evaluate the potential of QuickBird satellite images for assessment of glacial and high-mountain hazards. QuickBird is thereby representative for new satellite systems such as IKONOS or Orbview-3. The use of QuickBird imagery has been demonstrated for estimates of avalanche dimension, analysis of flow formation and dynamics, and for topographic measurements in combination with digital terrain data. Though not specifically described here, QuickBird satellite images can furthermore be applied for disaster management and response. A limiting factor with QuickBird (and generally very-high resolution satellite data) is the high cost of image acquisition. Even though this data has virtually not yet been applied for assessment of high-mountain hazards so far, this study suggests that the large potential of such images will trigger an increasing number of applications in the future.”

Scott, D. (2006). **Using GIS and remote sensing to assess avalanche hazards for new road corridors in Alaska**. In International Snow Science Workshop (ISSW), Telluride, Colorado, United States (pp. 465-467).

“Analysis of USGS digital elevation models to ascertain approximate slope angle and aspect. Analysis of USGS topographic maps of the area to analyze the contour intervals of the areas of concern. Analysis of aerial photography (summer) to observe vegetation damage along the study area. Analysis of Ikonos satellite imagery (winter) to observe the snow pack characteristics such as; cornice build up, avalanche debris, terrain traps, and possible run out zones. Analysis of wind data from the FAA’s Cold Bay weather station to find the average winter wind direction. Analysis of mountain snowpack averages from the NRCS National Water and Climate Center.”

Data was gathered from these sources:

1. The NRCS Data Gateway:
http://datagateway.nrcs.usda.gov/

2. National Geographic Alaska Topo Series.

3. The USGS NED Dataset:
http://gisdata.usgs.net/

4. The Alaska State Geospatial Clearing House:
http://www.asgdc.state.ak.us/

5. National Resource Conservation Service’s, Alaska Snow, Water and Climates Services Website:

http://www.ambcs.org/aksnow/snow_map.htm

6. National Weather Service, Alaska-Pacific River Forecast Center:
http://aprfc.arh.noaa.gov/data/stations/climate.php?site=pacd

7. Space Imaging Satellite Imagery.
http://www.geoeye.com/

Bühler, Y., Hüni, A., Christen, M., Meister, R., & Kellenberger, T. (2009). **Automated detection and mapping of avalanche deposits using airborne optical remote sensing data**. Cold Regions Science and Technology, 57(2), 99-106.

"This paper presents a novel, automated approach to detect and map avalanche deposits over large areas using remote sensing data."

"Rapidly available and accurate information about the location and extent of avalanche events is important for avalanche forecasting, safety assessments for roads and ski resorts, verification of warning products, as well as for hazard mapping and avalanche model calibration/validation."

Frauenfelder, R., Kronholm, K., Solberg, R., Larsen, S. Ø., Salberg, A. B., Larsen, J. O., & Bjordal, H. (2010). **DUE avalRS: Remote-Sensing Derived Avalanche Inventory Data for Decision Support and Hind-Cast after Avalanche Events**. In Proceedings of ESA Living Planet Symposium.

This paper discusses the Norwegian National Public Roads Administration form for avalanches and other gravitational processes:

"In this form, the type of observed gravitational process (in the context of this project only 'avalanches' are relevant) is reported, the approximate height between the road and the release area, the depositional volume and the length of the blocked road segment. Additional information such as reporting of damage (no/yes; if any: what type), current weather situation, and imposed road closure measures is also required. Weather information from weather stations may also be reported but is not required. Maps and photographs are linked to the reports where such material is available."

"For the inventory, information on the size of the avalanche, the run-out length, the avalanche type (slab, loose snow, point release, etc.) are of interest."

Marienthal, A., Jordan Mancey, Z. G., Rains, F., & Schwab, D. 2010, **Snow avalanche research and forecasting with GIS and geospatial sciences**, 2010 International Snow Science Workshop, Squaw Valley, CA, pp. 687-692.

From the abstract: Geographic information systems (GIS) and geospatial sciences have been used effectively in data collection and snow avalanche related research for over 50 years. Improved processors and programs have provided more user-friendly data collection and management applications, and the modern digitization of avalanche atlases allows for consistent recording and easy identification of avalanche events and their locations. Historic weather records and observations of snow pack properties (depth, SWE, stratigraphy) can be efficiently correlated with observations of avalanche activity when records of both weather and avalanche activity are managed digitally. Weather data is stored with a spatial attribute to help account for spatial variability, and allow for correlation with topography derived from a digital elevation model (DEM). A majority of avalanche and weather data is collected in areas of high use, such as highways, towns, or ski areas. Therefore, there are few complete and thorough temporal records of avalanche activity and weather data, and spatially complete records are non-existent as remote locations between areas of concentrated use are rarely observed. Remote sensing instruments have been used to record avalanche activity data in backcountry areas, and satellites are used to collect a variety of snowpack properties. Avalanche forecasting applications using statistical correlation of avalanche activity and weather data have been explored in many regions, but these analyses are only exploratory and used as an expert aid in forecasting. Further exploration of creating more temporally and spatially complete datasets may lead to more thorough and meaningful analyses in snow-avalanche research.

Other

Art Mears and Chris Wilbur, **Avalanche Zoning**

http://mearsandwilbur.com/avalanche_zoning.html

Provides a succinct and excellent overview of avalanche zoning and hazard mapping.

Gruber, Urs,

http://proceedings.esri.com/library/userconf/proc01/professional/papers/pap964/p964.htm

Discusses the Swiss avalanche mapping approach using GIS.

Larry Heywood, "Wet Snow Forecasting and Control," a talk given at the National Avalanche School, 2011.

This talk and any associated written material are not available. However, some notes regarding the talk are available at:

http://utahavalanchecenter.org/blog-wet-snow-avalanches

These notes include the Wet Snow Triangle diagram and the Wet Avalanche Balance Sheet.

Larry Heywood, Alpine Meadows: March 31, 1982: The Story

http://www.avalanche.org/moonstone/TAR/avi%20review%20articles/Alpine%20Meadows%20-%20The%20Story.htm

Provides insight into the 1982 avalanche at Alpine Meadows.

Further discussions by other authors can be found on the following page:

http://www.avalanche.org/moonstone/TAR/tar.htm

Resources

Avalanche Glossary, http://www.fsavalanche.org/encyclopedia/ includes definitions and pictures of key terms, including starting zone, track, and runout zone.

Avalanche Centers in North America

Forest Service National Avalanche Center	http://www.fsavalanche.org/	
Sierra Avalanche Center	http://sierraavalanchecenter.org	
Eastern Sierra Avalanche Center	http://www.esavalanche.org/	Includes minimally interactive map
Mount Shasta Avalanche Center	http://shastaavalanche.org	
Avalanche.org	http://www.avalanche.org/	Includes a list of avalanche centers by state
Avalanche.ca	http://www.avalanche.ca/	Canada
Northwest Avalanche Center	http://www.nwac.us/	Includes an interactive avalanche warning map for Washington
Utah Avalanche Center	http://utahavalanchecenter.org/	Includes interactive warning map for Utah
Sawtooth Avalanche Center	http://www.sawtoothavalanche.com/	Includes an interactive danger rating zone map with forecasts
Gallatin National Forest Avalanche Center	http://www.mtavalanche.com/	Includes an interactive danger rating zone map with forecasts
Bridger-Teton National Forest Avalanche Center	http://www.jhavalanche.org/index.php	Includes an interactive danger rating zone map with forecasts
Payette Avalanche Center	http://payetteavalanche.org/	Includes a non-interactive map
Chugach National Forest Avalanche Information Center	http://www.cnfaic.org/	Includes an interactive danger rating zone map with forecasts
Flathead Avalanche Center	http://www.flatheadavalanche.org/	Includes an interactive map
Idaho Panhandle	http://www.idahopanhandleavalanche.org/	Includes an interactive

Avalanche Center		map with forecasts
Mount Washington Avalanche Center	http://www.mountwashingtonavalanchecenter.org/	Includes maps under “Current Advisories”
Crested Butte Avalanche Center	http://www.cbavalanchecenter.org/	
Wallowa Avalanche Center	http://wallowaavalanchecenter.org/	Includes interactive map
National Snow and Ice Data Center	http://nsidc.org/cryosphere/snow/science/avalanches.html	
Anchorage Avalanche Center	http://www.anchorageavalanchecenter.org/	
Kachina Peaks Avalanche Center	http://www.kachinapeaks.org/	Includes maps
Big list of avalanche centers	http://www.avalanchemapping.org/linkstoavcnt.htm	

Avalanche Centers in Europe

EAWS – European Avalanche Warning Services	http://www.avalanches.org/eaws/en/main.php	Includes map highlighting countries subject to avalanches, with links to individual country sites
Swiss Federal Institute for Snow and Avalanche Research	http://www.slf.ch/	Includes interactive map

Other Avalanche Centers

New Zealand Avalanche Centre	http://www.avalanche.net.nz/	Includes maps of avalanche areas, with forecasts
Argentina	http://www.clubandino.org/	Includes a map of Nahuel Huapi National Park

List of research papers related to GIS/GPS and snow science and avalanche studies: http://www.avalanchemapping.org/linksresearch.htm

National Elevation Dataset (NED) – USGS: The National Elevation Dataset (NED) is the primary elevation data product of the USGS

http://ned.usgs.gov

USGS DEM, From Wikipedia, the free encyclopedia:

"The USGS DEM standard is a geospatial file format developed by the United States Geological Survey for storing a raster-based digital elevation model. It is an open standard, and is used throughout the world. It has been superseded by the USGS's own SDTS format but the format remains popular due to large numbers of legacy files, self-containment, relatively simple field structure and broad, mature software support."

http://en.wikipedia.org/wiki/USGS_DEM

The National Map, Land Cover: The USGS collects and maintains data that show both natural and manmade land cover of the United States. These data are collected from orbiting Landsat satellites and produced for access through the National Land Cover Database (NLCD)… Further information and data download available at: http://www.mrlc.gov/"

http://nationalmap.gov/landcover.html

The National Agriculture Imagery Program (NAIP) "acquires aerial imagery during the agricultural growing seasons in the continental U.S. A primary goal of the NAIP program is to make digital ortho photography available to governmental agencies and the public within a year of acquisition." Some avalanche experts state that this is one source of publicly available imagery used in their work.

http://www.fsa.usda.gov/FSA/apfoapp?area=home&subject=prog&topic=nai

AVAL-1D dynamic modeling software is commercially available. 4000 Swiss Franc, or $4580 (5/6/14). "In Switzerland, AVAL-1D is currently the standard model for hazard mapping."

http://www.slf.ch/dienstleistungen/software/aval1d/index_DE

Avalanche Map - Scottish Avalanche Information Service, http://www.sais.gov.uk/avalanche_map.asp (Seems to be a map of latest avalanche occurrences, not a hazard map).

Colorado Avalanche Information Center, http://avalanche.state.co.us/ (Don't see hazard mapping on the site, but I believe they were involved in developing Colorado hazard map).

American Avalanche Association, The Organization of US Avalanche Professionals: http://www.americanavalancheassociation.org/

There is an "American Association of Avalanche Professionals," which is a scientific society. Have not found their website, and this may be the same as the American Avalanche Association. The official web site is:

http://www.avalanche.org/

WSDOT Avalanche Control, http://www.wsdot.wa.gov/maintenance/avalanche includes avalanche area map for Stevens Pass.

Juneau Avalanche Path maps, http://www.juneau.org/avalanche/mapsinfo.php

Avalanche Atlas Maps, http://www.avalanchemapping.org/avatlas.htm , developed by Douglas Scott. Includes below avalanche maps (links available at Avalanche Atlas Maps):

Teton Pass, Wyoming
John F. Stevens Canyon, Glacier National Park, Montana
Cameron Pass, Colorado
San Francisco Peaks, Arizona
Chinook/Cayuse Pass, Washington
Stevens Pass, Washington
Washington Pass, Washington
Lizard Head Pass, Colorado
Big Cottonwood Canyon, Utah
Wolf Creek Pass, Colorado
Turnagain Pass, Alaska
Hatcher Pass, Alaska
Red Mountain Pass, Colorado
Arapahoe Basin Ski Area, Colorado
Independence Pass, Colorado
Berthoud Pass, Colorado
Loveland Pass, Colorado
Little Cottonwood Canyon, Utah
Arapahoe Basin Ski Area, Colorado

Map of Washington Pass Eastside Avalanche Areas: https://www.flickr.com/photos/wsdot/5242152485/ wherein they note:

"We cannot physically keep the North Cascades Highway open all winter. The North Cascades Highway has avalanche chutes that are more than 2,000 feet long. Even if a couple inches of snow slides, the chutes can dump a 20-foot-deep avalanche on the highway in a matter of minutes. (The avalanche chutes on Stevens and Snoqualmie are all well under 1,000 feet long.) Couple that with the fact that the highway has among the most avalanche chutes of any mountain pass highway in the country and there's no way anyone could provide a safe highway, short of putting the route in a tunnel (which would eliminate all of its appeal, even if someone had that much money)."

Forest Service National Avalanche Center has a page on "Spatially Analyzing and Displaying Historical Avalanche Data Using GIS" at http://fsavalanche.com/Default.aspx?ContentId=41&LinkId=52&ParentLinkId=38

This page highlights the work of Chris McCollister, who was then a graduate student in the Department of Earth Sciences at Montana State University, to investigate techniques for searching historical databases and displaying avalanche data.

QuickBird satellite imagery pricing:

http://apollomapping.com/imagery/high-resolution-imagery/quickbird?gclid=CNqJ6YSAorwCFYhbfgodYS0AZQ

North American Public Avalanche Danger Scale:

http://upload.wikimedia.org/wikipedia/commons/b/b6/Danger_Scale_-_English.jpg

http://www.avalanche.org/pdfs/DangerScaleFront.pdf

http://www.avalanche.org/pdfs/DangerScaleBack.pdf

North American Public Avalanche Danger Scale

Avalanche danger is determined by the likelihood, size and distribution of avalanches.

Danger Level		Travel Advice	Likelihood of Avalanches	Avalanche Size and Distribution
5 Extreme	4 5	Avoid all avalanche terrain.	Natural and human-triggered avalanches certain.	Large to very large avalanches in many areas.
4 High	4 5	Very dangerous avalanche conditions. Travel in avalanche terrain not recommended.	Natural avalanches likely; human-triggered avalanches very likely.	Large avalanches in many areas; or very large avalanches in specific areas.
3 Considerable	3	Dangerous avalanche conditions. Careful snowpack evaluation, cautious route-finding and conservative decision-making essential.	Natural avalanches possible; human-triggered avalanches likely.	Small avalanches in many areas; or large avalanches in specific areas; or very large avalanches in isolated areas.
2 Moderate	2	Heightened avalanche conditions on specific terrain features. Evaluate snow and terrain carefully; identify features of concern.	Natural avalanches unlikely; human-triggered avalanches possible.	Small avalanches in specific areas; or large avalanches in isolated areas.
1 Low	1	Generally safe avalanche conditions. Watch for unstable snow on isolated terrain features.	Natural and human-triggered avalanches unlikely.	Small avalanches in isolated areas or extreme terrain.

Safe backcountry travel requires training and experience. You control your own risk by choosing where, when and how you travel.

Appendix A

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Appendix B

Material from:

“Snow Avalanche Atlas, Seward Highway, South-Central Alaska,” State of Alaska Department of Natural Resources, Professional Report 81, by G.D. March and L.G. Robertson, 1982

Courtesy of Alaska DOT

and

“**Chugach Electric Atlas,” created by Alaska Mountain Safety Center, March 2003**

Courtesy of Chugach Electric

STATE OF ALASKA
DEPARTMENT OF NATURAL RESOURCES

PROFESSIONAL REPORT 81

SNOW AVALANCHE ATLAS, SEWARD HIGHWAY, SOUTH-CENTRAL ALASKA

By
G.D. March and L.G. Robertson

Published by
DIVISION OF GEOLOGICAL AND GEOPHYSICAL SURVEYS

ROSS G. SCHAFF
STATE GEOLOGIST

SNOW AVALANCHE ATLAS, SEWARD HIGHWAY, ALASKA

By
G.D. March and L.G. Robertson[1]

This atlas is intended as an operational guide to snow avalanche paths that affect the Seward Highway and its spur roads.

The atlas will be updated as new information becomes available; please forward any comments to the authors, c/o Alaska Division of Geological and Geophysical Surveys, P.O. Box 80007, College, AK 99708.

INTRODUCTION

The Seward Highway traverses the Kenai Peninsula from Seward on the south to Anchorage on the north. It is designated Alaska Route 9 from Seward to Tern Lake, a distance of 37 miles; from there it is a segment of Alaska Route 1.

Elevations of the terrain along the Seward Highway range from sea level to 6,000 ft (1,800 m). The highway winds through the Kenai Mountains to Turnagain Arm, where it traverses the base of the Chugach Mountains. The lower mountain slopes are covered with extensive coniferous (evergreen) and deciduous (leafy) vegetation, except in avalanche zones. The upper slopes are either tundra covered or bare rock.

PREVIOUS WORK

Atlases of avalanche paths have previously been compiled in Colorado by Miller and others (1976) and Armstrong and Armstrong (1977); in Washington by LaChapelle (1974); and in British Columbia by the Snow Avalanche Section, Maintenance Services, Ministry of Transportation and Highways. Earlier reports on the Seward Highway include State of Alaska (1963) and Alcan Avalanche Services (1979).

HOW THE DATA WERE COMPILED

Base maps of the Seward Highway area were compiled from U.S. Geological Survey topographic maps at a scale of 1:63,360. Avalanche paths were mapped on 1979 NASA AMES infrared air photos at a scale of 1:65,000 by examining stereopairs. Black-and-white USGS airphotos at a scale of 1:60,000 were also used to map the area between Portage and Bird Creek. Photos taken by the authors from light aircraft were valuable in resolving questions. Extensive field checking and an examination of path histories completed the compilation. General methods of data compilation followed those of Mears (1976).

CLIMATE

Major storm systems originating in the Gulf of Alaska produce a precipitation gradient across the Kenai Peninsula. Rates of snowfall increase from west to east and from low to high elevations. Wet snow and rain are common at low elevations throughout the winter, but temperatures decrease with altitude.

AVALANCHES

The Seward Highway is affected by about 60 known avalanche paths. Five additional paths impact the Hope Road. One avalanche path reaches the Sterling Highway and one the Portage Road.

AVALANCHE CONTROL

In the early 1960's, earth mounds were constructed at the base of a few avalanche paths along Turnagain Arm in an attempt to stop moving snow before it reached the highway. Avalanching in the areas of Turnagain Arm, mile 37-38 (the Y), and Kenai Lake have been controlled by recoilless rifle since 1969 (Alcan Avalanche Services, 1979).

DEFINITIONS OF TERMS USED IN AVALANCHE-PATH SUMMARIES

The following terms are used in describing avalanche paths throughout the atlas.

NUMBER: The Seward Highway corridor and spur roads have been divided into regions based on geography. The regions are subdivided into zones based on similarity of characteristics of adjacent avalanche slopes, and these zones are further divided into individual paths where information is available. All avalanche slopes visible from the road have been given an identification number. The avalanche-path summaries address snow slides that affect the road; their identification numbers include region, zone, and sometimes path, for example

[1]DGGS, College, Alaska 99708.

3.2-1. Because numbers have been used to identify all avalanche slopes visible from the highway, each number on the maps does not have a corresponding path description (table 1).

MAP: Standard USGS topographic maps were used as a base; their contour interval is 100 ft.

AERIAL PHOTOGRAPHS: Aerial photographs were produced by both NASA AMES and the USGS. The former photos, taken in August 1978, are false-color infrared (CIR). Mission and frame numbers are denoted by M and F; the scale is 1:65,000.

The black-and-white USGS photos, taken in 1957, have the mission, role, and frame numbers denoted as BMO, R, and F, respectively. The scale is 1:60,000.

Oblique photos used in this report were taken from light aircraft by Jim Hackett of the U.S. Forest Service, the Alaska Department of Transportation and Public Facilities, and the authors.

ELEVATION: Taken from USGS topographic maps at a scale of 1:63,360. The starting zone elevations give the probable range in which an avalanche will start; the runout zone elevations give the probable range in which an avalanche will stop.

VERTICAL FALL: The vertical distance from the highest to the lowest elevation of an avalanche path.

STARTING ZONE ASPECT: The direction in which the avalanche starting zone faces. Aspects were measured with a compass from USGS 1:63,360-scale topographic maps and are expressed as compass directions.

INCLINE: The slope angle of the starting zone, track, and runout zone of the avalanche path. Slope angles in degrees were calculated from published 1:63,360-scale maps.

STARTING ZONE: The area where unstable snow usually breaks away from the slope and begins to move downhill. Occasionally, changes in the elevation of the freezing line caused by above-freezing temperatures or rain, can cause avalanches to start at a lower elevation.

TRACK: That area between the starting zone and the runout zone where the avalanche reaches its maximum velocity.

RUNOUT ZONE: The area at the bottom of the avalanche path where the moving snow and entrained debris decelerate and stop.

Terrain and vegetation are described for the starting zone, track, and runout zone. Descriptions are based on field observations.

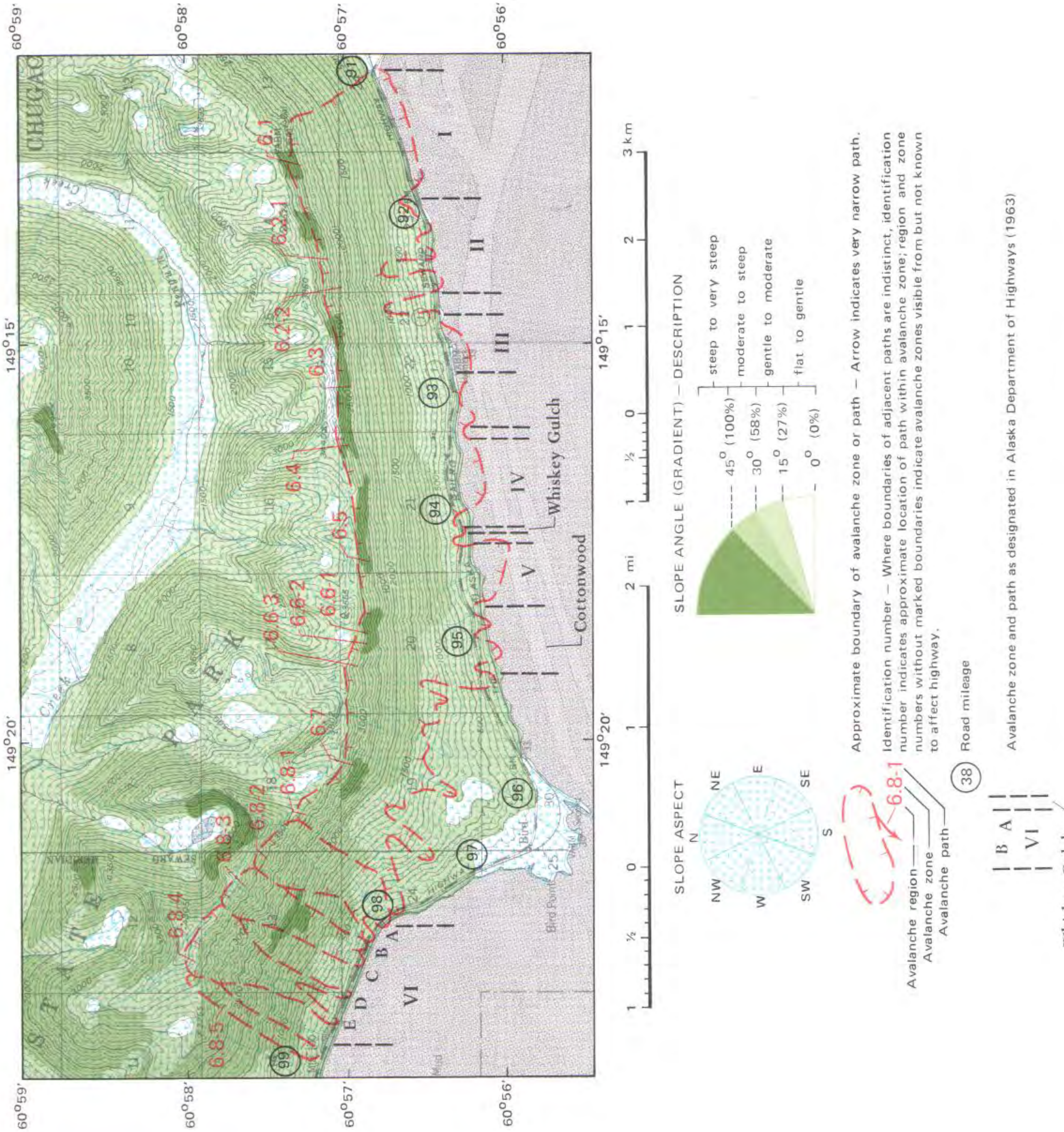
HISTORY: In the early 1900's Bird Hill trail was the route between Anchorage and Girdwood. In 1951 the Seward Highway was completed, joining Seward with Anchorage. The highway between Potter and Girdwood was built on the abandoned bed of the Alaska Railroad, which was moved closer to Turnagain Arm.

Avalanche path histories were compiled by Douglas Fesler, Alaska Division of Parks.

NOTES: Primarily data from fallen trees in the runout zones of avalanche paths. Ages of these trees can be used for a rough determination of the frequency of avalanching (Potter, 1969; Burrows and Burrows, 1976; Mears, 1976). Ages of downed trees were determined by counting annual rings at a height of 4.5 ft above the base; 10 years was added to each as an estimate of the time required for the tree to grow to 4.5 ft. Because of the scarcity of data, avalanche frequencies were not calculated.

ACKNOWLEDGMENTS

The authors thank Doug Fesler, Alaska Division of Parks, for supplying histories of avalanche paths and for many helpful suggestions and continued support. Jim Hackett, USDA Forest Service, made helpful suggestions and supplied many photographs. Devril Peterson, Alaska Department of Transportation and Public Facilities, reviewed and corrected mileages on the maps. Les Viereck, Institute of Northern Forestry, assisted with the tree-ring dating. Larry Mayo, USGS Water Resources Division, and Jerome B. Johnson, University of Alaska Geophysical Institute, reviewed the manuscript and offered helpful suggestions. Illustrations were prepared by Karen Pearson, DGGS cartographer.


SLOPE ANGLE (GRADIENT) – DESCRIPTION
45° (100%)
30° (58%)
15° (27%)
0° (0%)
steep to very steep
moderate to steep
gentle to moderate
flat to gentle
SLOPE ASPECT
Approximate boundary of avalanche zone or path – Arrow indicates very narrow path.
Identification number – Where boundaries of adjacent paths are indistinct, identification number indicates approximate location of path within avalanche zone; region and zone numbers without marked boundaries indicate avalanche zones visible from but not known to affect highway.
Avalanche region
Avalanche zone
Avalanche path
Road mileage
Avalanche zone and path as designated in Alaska Department of Highways (1963)
Whiskey Gulch
Cottonwood
3 km
2 mi

6.1

SEWARD HIGHWAY
AVALANCHE-PATH SUMMARY

NUMBER: 6.1 MILE: 91 - 92 NAME:

LOCATION: 1 mi (1.6 km) north of Girdwood junction

MAP: Seward D-6 Quadrangle, Alaska (1951)

AERIAL PHOTOGRAPHS: NASA AMES Aug. 78 M02662 F6946, CIR, 1:65,000
USGS 1957 BMO221 R40 F5158, 5159, B+W, 1:60,000

DESCRIPTION:

ELEVATION (above sea level):
Starting zone: 2,900-2,000 ft (885-600 m)
Runout zone: 0 ft (0 m)

VERTICAL FALL: 2,900 ft (885 m)

STARTING-ZONE ASPECT: Southwest, south

INCLINE: Starting zone: 40°
Track: 29°
Runout zone: Level

STARTING ZONE: Rock cliffs and gullies

TRACK: Broad, open slope covered by low vegetation; lower track has immature coniferous and scattered deciduous vegetation

RUNOUT ZONE: Highway, railroad track, and Turnagain Arm

HISTORY
Mar. 23, 1979: Highway and railroad track blocked
Jan. 22, 1978: Highway blocked
Feb. 20, 1962: Highway blocked
Apr. 18, 1960: Highway blocked by two slides
Feb. 28, 1960: Highway blocked
Dec. 27, 1959: Highway blocked
Dec. 22, 1959: Highway and railroad tracks blocked
Dec. 21, 1959: Highway blocked
Dec. 17, 1959: Highway blocked by three slides
Apr. 9, 1959: Highway blocked by two slides
Apr. 8, 1959: Railroad blocked
Jan. 6, 1958: One vehicle hit
Feb. 26, 1956: Highway blocked
Jan. 6, 1952: One pedestrian killed, one car destroyed
Winter 1920: Two rotaries derailed, two persons injured (present highway alignment)
Apr. 20, 1920: Six railroad workers killed, 19 trapped or injured (present highway alignment)
Feb. 1913: Bird Hill trail (400 ft above present road) blocked
Feb. 11, 1911: Bird Hill trail blocked

NOTES: Zone I in Alaska Dept. of Highways (1963)

CHUGACH
POWERING ALASKA'S FUTURE

AVALANCHE ATLAS

UNIVERSITY-QUARTZ CREEK 115 kV TRANSMISSION LINE, INDIAN-GIRDWOOD 24.9 kV DISTRIBUTION LINE, DAVES CREEK-LAWING 69 kV TRANSMISSION LINE, HOPE 24.9 kV DISTRIBUTION LINE, AND PORTAGE-WHITTIER 24.9 kV & 12.5 kV DISTRIBUTION LINE

MARCH 2003

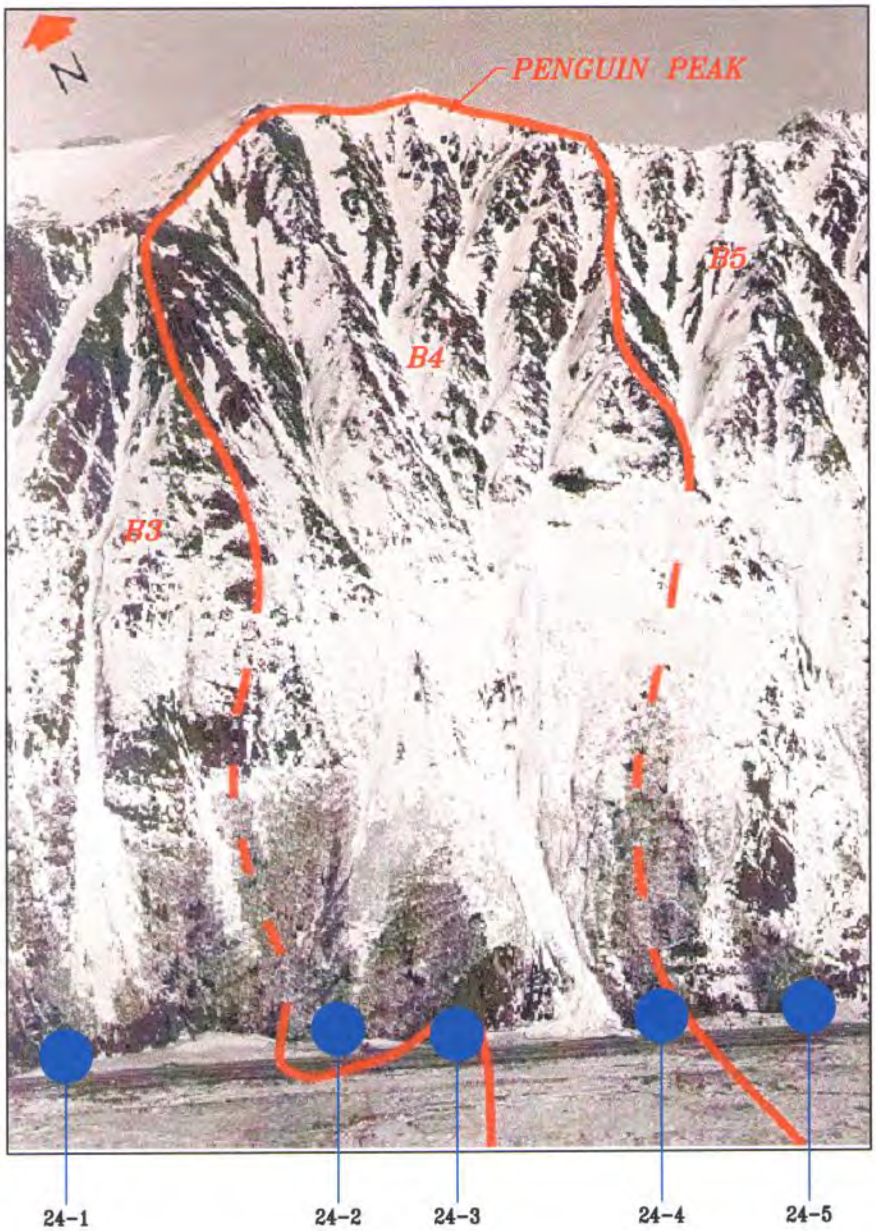
WORK ORDER NUMBER: E00 63750

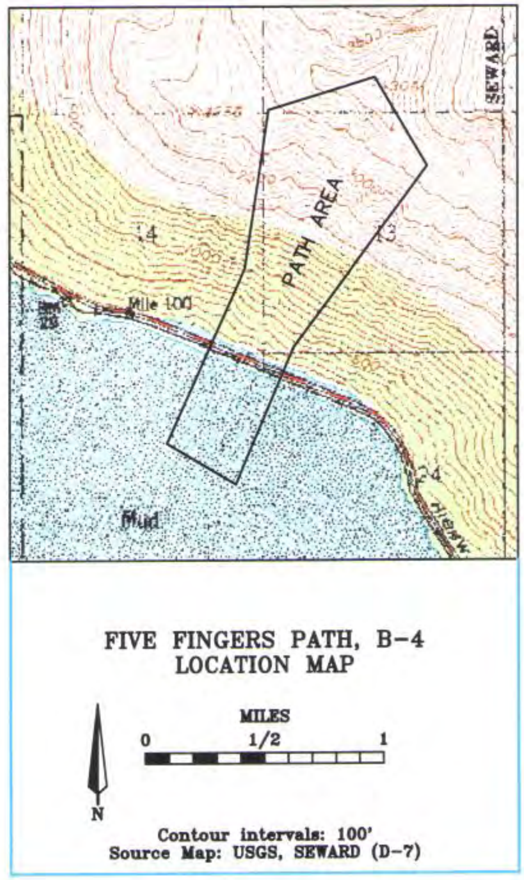
TEXT PREPARED BY:

ALASKA MOUNTAIN SAFETY CENTER, INC.
9140 BREWSTERS DRIVE
ANCHORAGE, ALASKA 99516-6928

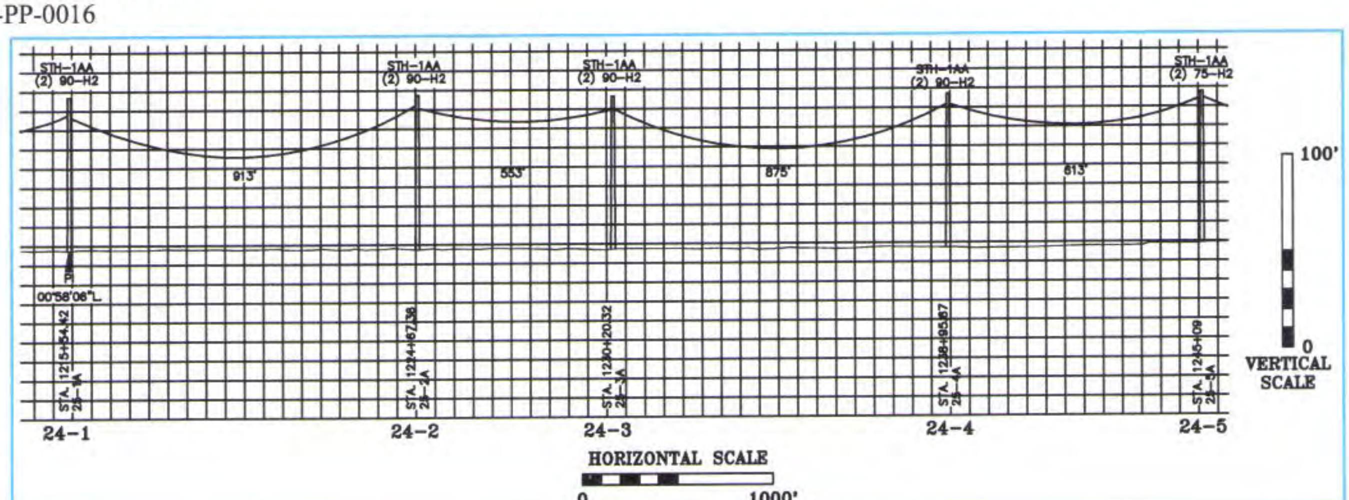
AND GRAPHICS BY:

CHUGACH ELECTRIC ASSOCIATION, INC.
P.O. BOX 196300
ANCHORAGE, ALASKA 99519-6300





REF: IDGW-PP-0003 &
KEN1-PP-0016



PATH NAME/AREA: Five Fingers (aka: Bird Flats No. 2 and No. 3) / Bird Flats Area

LOCATION: South face of Penguin Peak (Peak 4305) in the vicinity of MP 98.3 - 98.5 Seward Highway along Bird Flats (approximately 2 miles SE of the gas station in Bird Creek).

NEAREST SAFETY ZONE: The nearest safety zone is 200' west of Structure No. 23-6 at the eastern end of Bird Flats.

PATH SYNOPSIS: Five Fingers is a very large and complicated path that has the capability of producing large destructive avalanches on a regular basis (every 3-5 years). Small to moderate sized avalanches with the capability of reaching the powerline can occur several times each winter. Avalanche activity typically consists of soft and/or wet slab releases that are usually related to storm or warming events. Additionally, glide crack development is common in the mid-elevation range. Large, destructive avalanches have occurred from November to May. Because of the predominantly southerly aspect, avalanches triggered by solar warming are common during late March and April. Debris depths from major slides have been estimated in excess of 40' at the powerline though typical depths are less than 10'. Powderblast heights from large slides can exceed 200' and avalanche velocities within the 80-120 mph range are not uncommon. Contamination of debris with trees, rocks, and mud is common and the entrainment potential for loose, unconsolidated snow at the lower elevations is considerable.

PATH CONFIGURATION/CHARACTERISTICS: The upper half of the mountain consists of five major gullies that funnel into one track mid-slope. These high alpine starting zones are composed of steep scree slopes divided by prominent rocky ribs. This combination of multiple release zones funneling into one runout zone is subject to cross-loading by wind and is particularly dangerous. The track remains steep and smooth (mostly grass-covered) all the way to the bottom, where the gradient abruptly changes, causing debris to pile up deeply in the area of the powerline.

Starting Elev.: 4300' **Ending Elev.:** 0 **Vertical Drop:** 4300' **Starting Zone Aspect:** SE-S-SW

SPECIAL OPERATIONAL CONSIDERATIONS: *CAUTION:* This path poses a serious potential risk to personnel working in the runout zone along the powerline or highway right-of-ways. Personnel should avoid the area during or immediately after storms or warming events, when conditions are the most unstable. As a standard procedure, a specialist prior to commencing field operations should evaluate the potential avalanche hazard.

PATH HISTORY: This is one of the most active paths affecting the powerline with numerous events resulting in damage and expense to the powerline, highway, and the railroad. A sampling of the more significant events includes the following: In November 1977, a fast moving soft slab avalanche that also blocked the road damaged two or more structures. In 1978 the powderblast from one large avalanche in this path split the cross-arms and pulled the insulators from 13 consecutive structures and threw the conductors several hundred feet out into Turnagain Arm. Additionally, a vehicle was hit and several others were nearly hit. Debris was 20' deep by 650 long. A March 1979 avalanche piled debris over 50 deep between the base of the mountain and the powerline. In 1988, three spans were destroyed and debris was piled higher than the height of the conductors (±40') along the powerline right-of-way and the road. Structures along Bird Flats were relocated shortly afterwards to better locations. In January 1980, a soft slab avalanche hit a pickup truck and four other vehicles nearly hit the debris while driving in whiteout conditions. In 1992, a lobe of wet debris turned 90° (parallel to the road) and just missed hitting Structure 24-4, which was relocated along with others in 1988. In February 2000, the powderblast from a large avalanche hit a crew clearing the highway and railroad of debris from a previous slide. One piece of road maintenance equipment was blown over 300' from the road and destroyed and the equipment operator was killed. Two other pieces of road maintenance equipment were partly buried and the operators caught and shaken. A television film crew was also dusted, but escaped unharmed.

ADDITIONAL INFORMATION: Chugach State Park rangers named Five Fingers during the mid-1970s in reference to the fact that the upper starting zones consist of five major fingers (gullies).

CROSS-REFERENCE DATA:

Maps: USGS, Seward (D-7) NE, 1:25,000; Seward (D-7), 1:63,360

Aerial Photos: CEA/AE photo No. 4-6 (5-16-88)

Other Facilities Affected: Seward Highway, Alaska Railroad, pipeline (buried)

Artillery Control Capability Limited DOT&PF or ARR blind fire capability exists.

NOTES:

Appendix C

Cover from:

"Colorado Department of Transportation Region Three Avalanche Atlas: SH 65 Grand Mesa, SH 139 Douglas Pass, SH 133 McClure Pass"

(Full report available in PDF format)

and maps for SH 17, US 50, US 160, and US 550

Courtesy of Colorado DOT

COLORADO DEPARTMENT OF TRANSPORTATION

REGION THREE

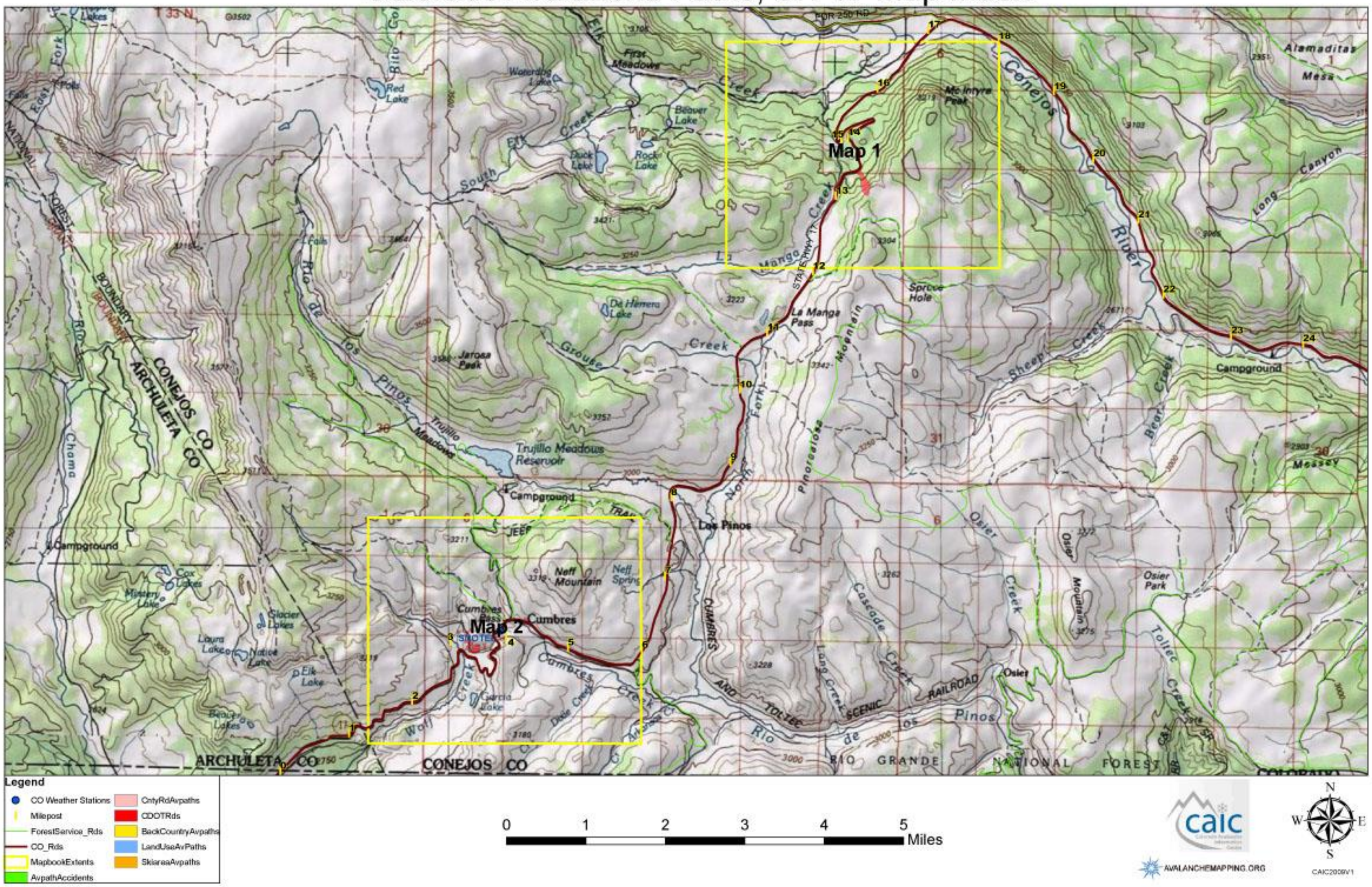
AVALANCHE ATLAS

SH 65 GRAND MESA

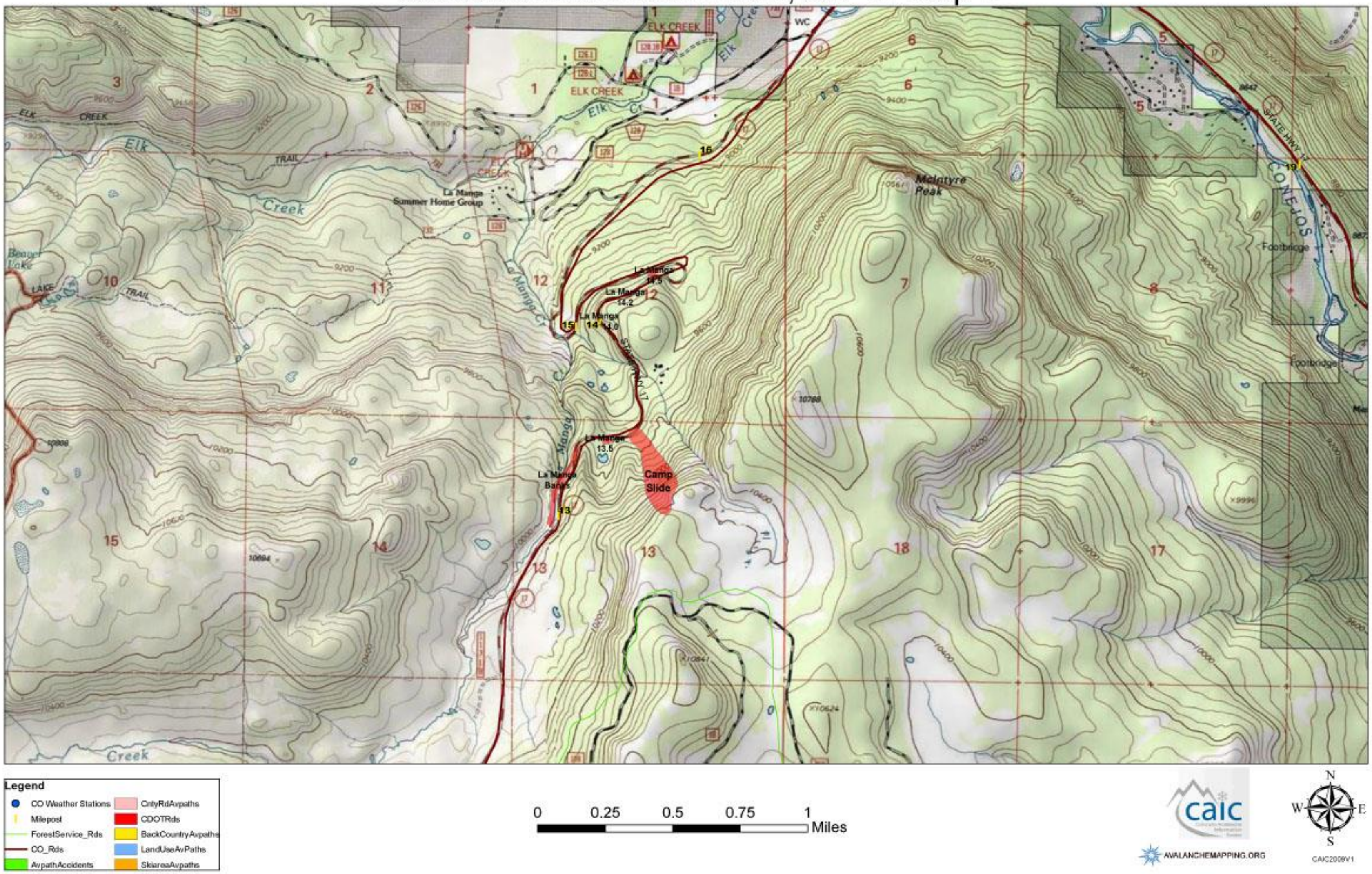
SH 139 DOUGLAS PASS

SH 133 McCLURE PASS

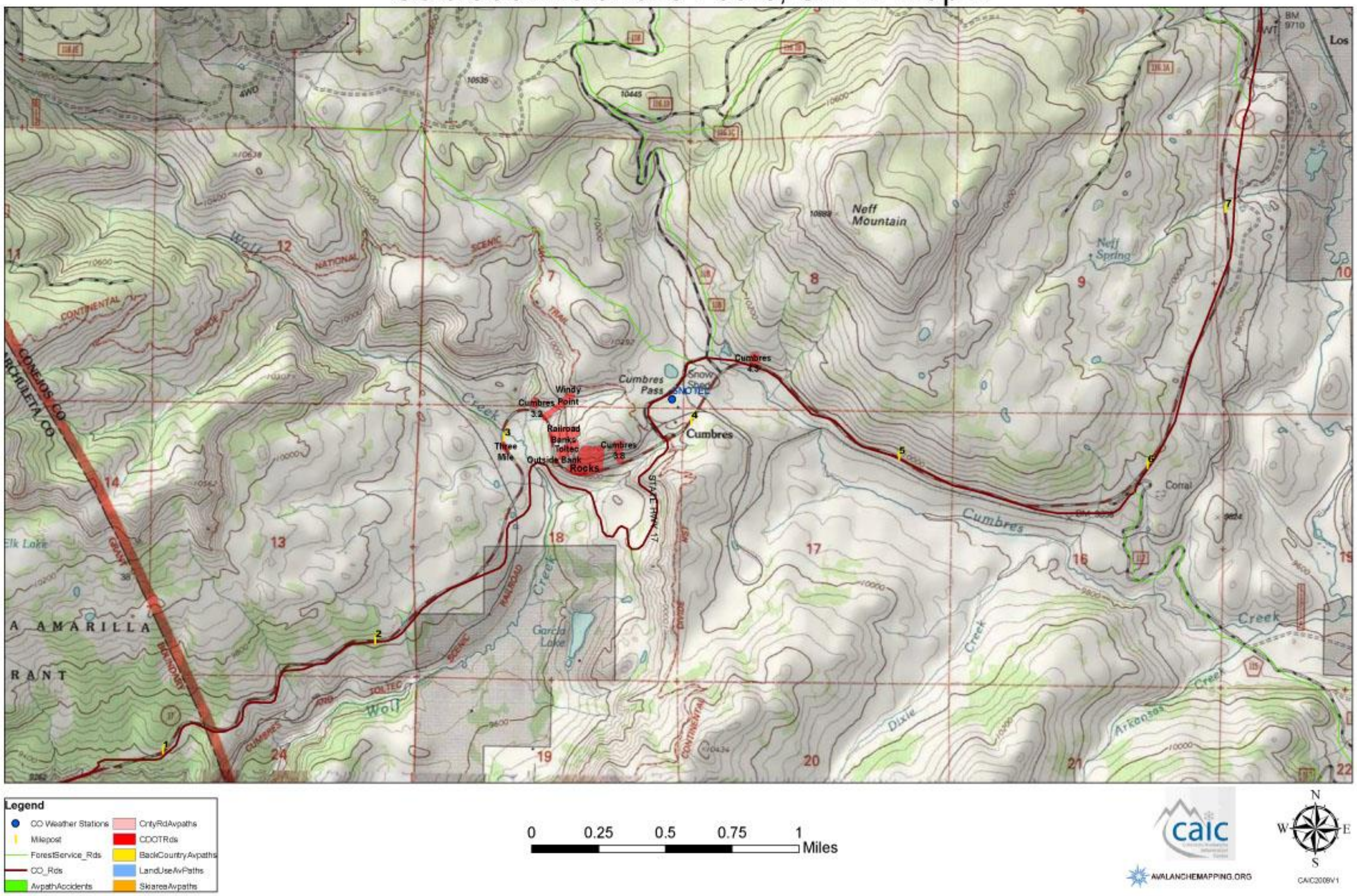
Colorado Avalanche Paths, SH 17 Map Index



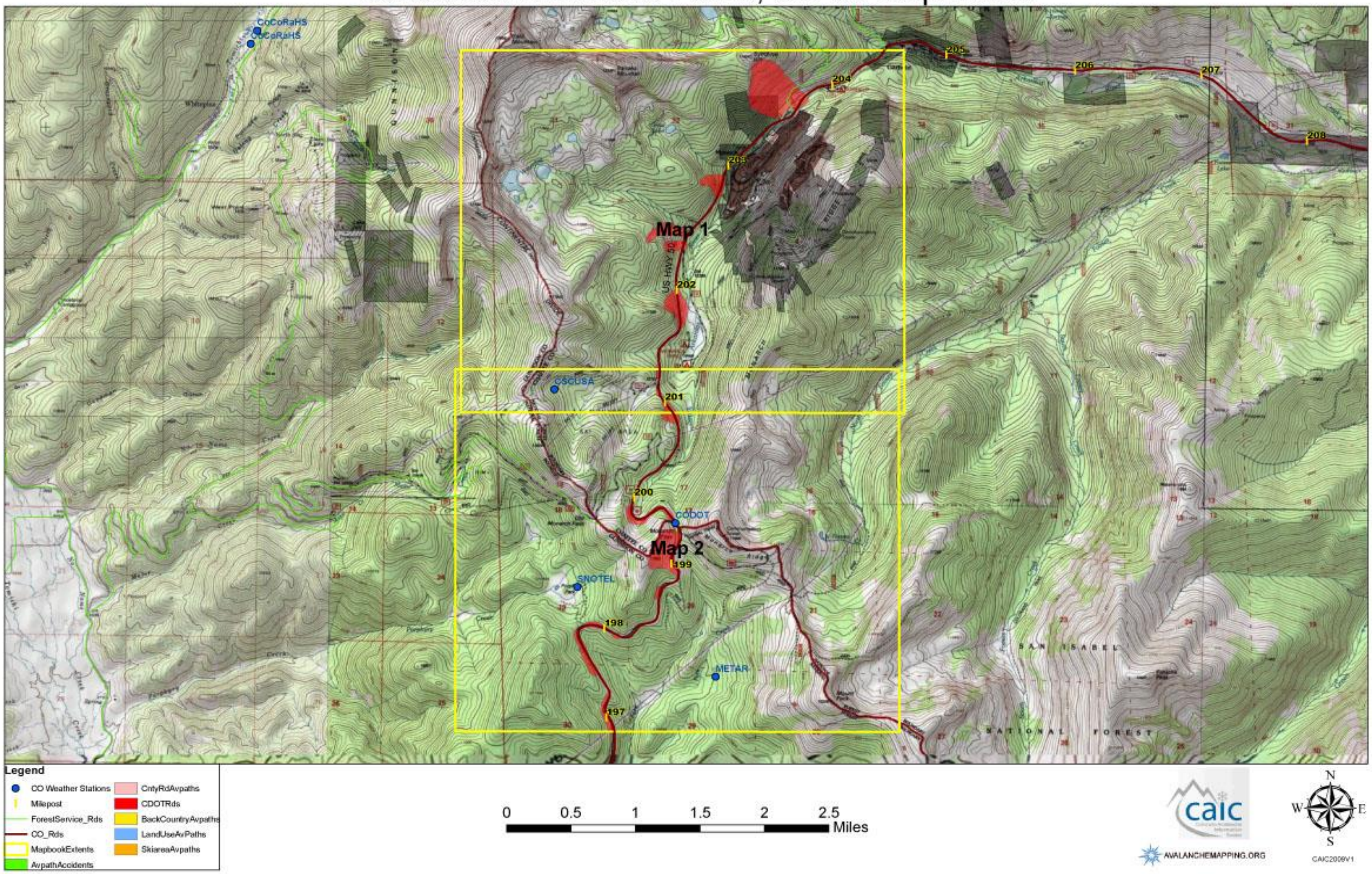
Colorado Avalanche Paths, SH 17 Map 1



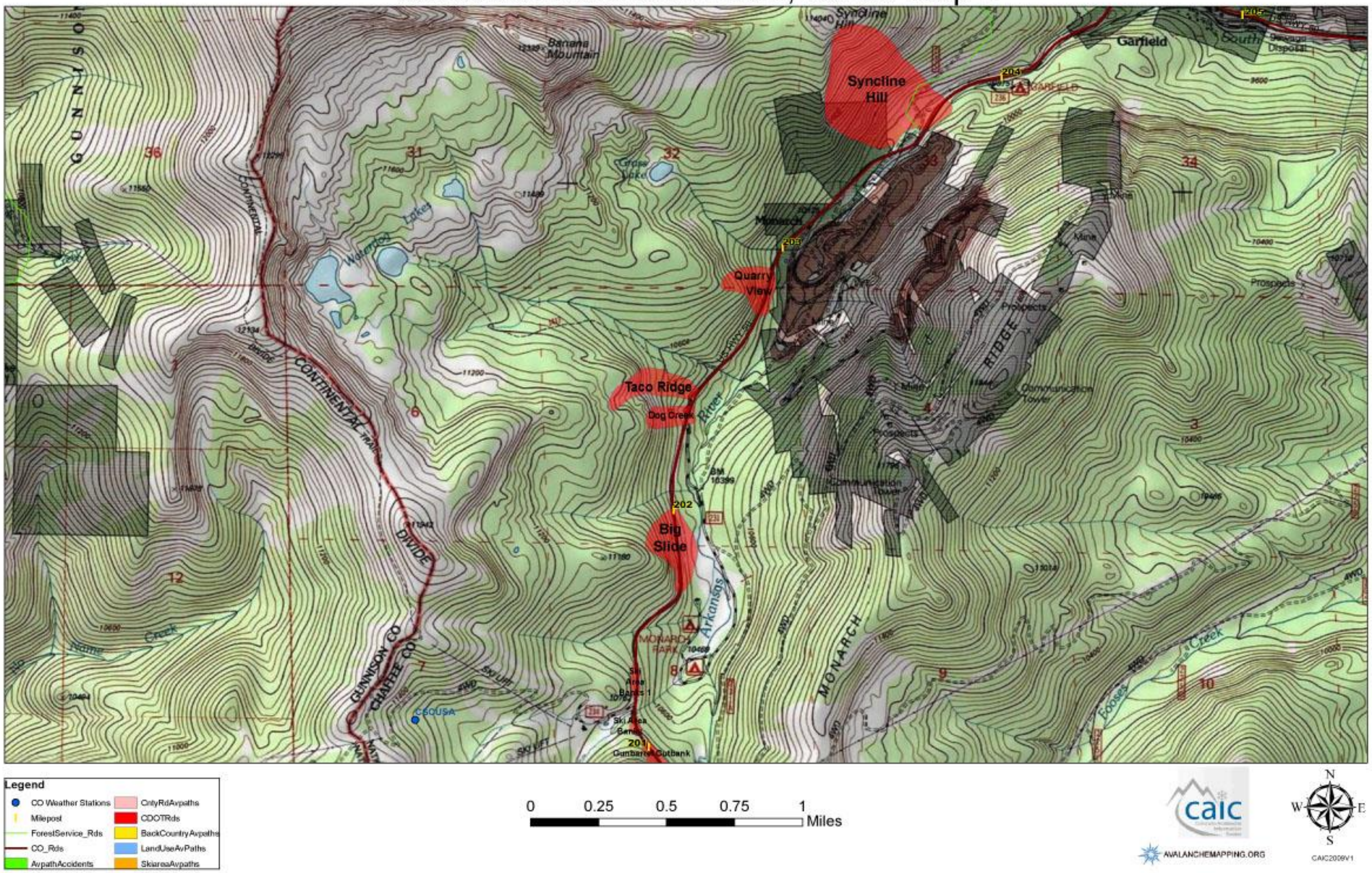
Colorado Avalanche Paths, SH 17 Map 2



Colorado Avalanche Paths, US 50 Map Index



Colorado Avalanche Paths, US 50 Map 1



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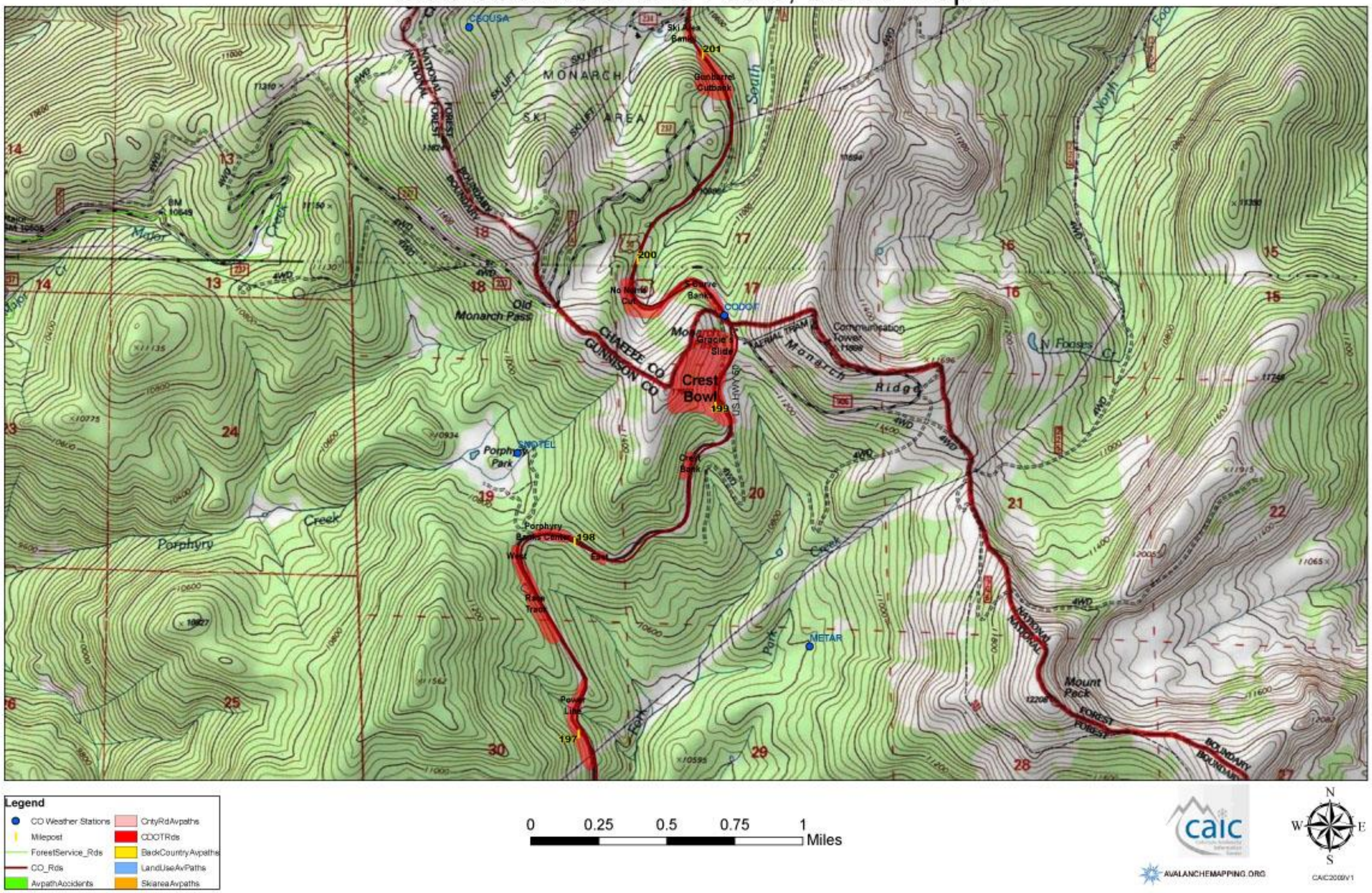
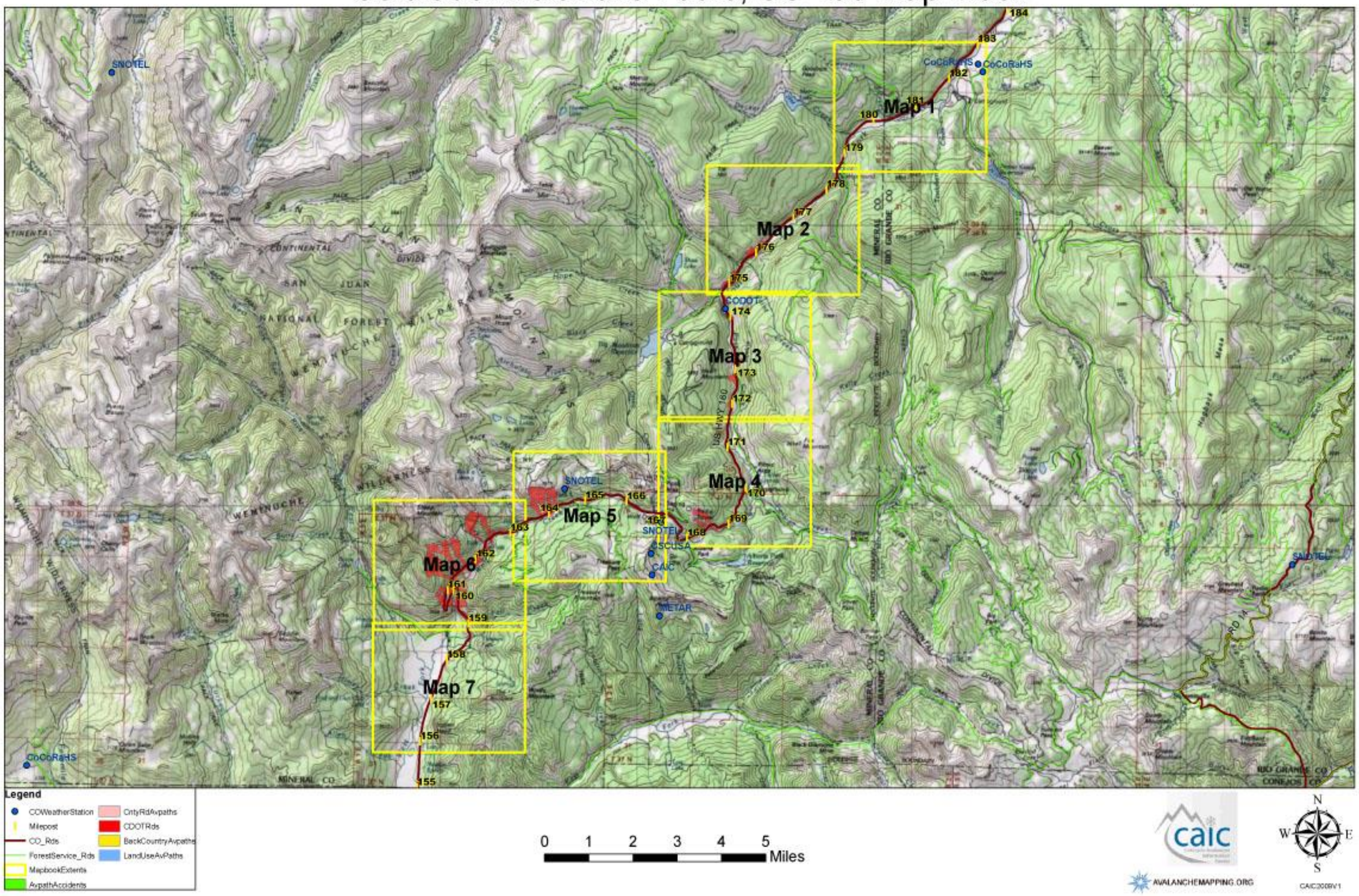
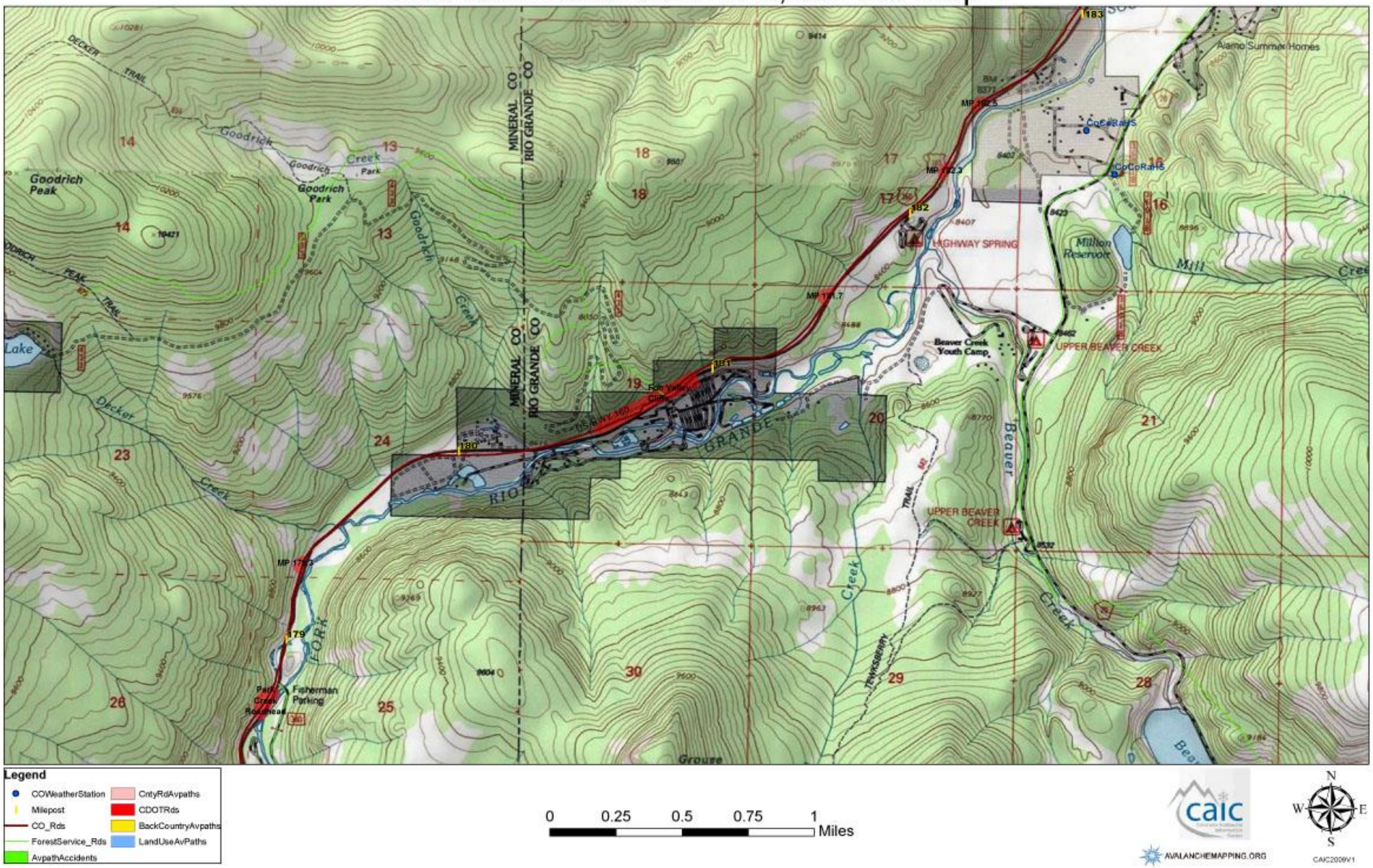


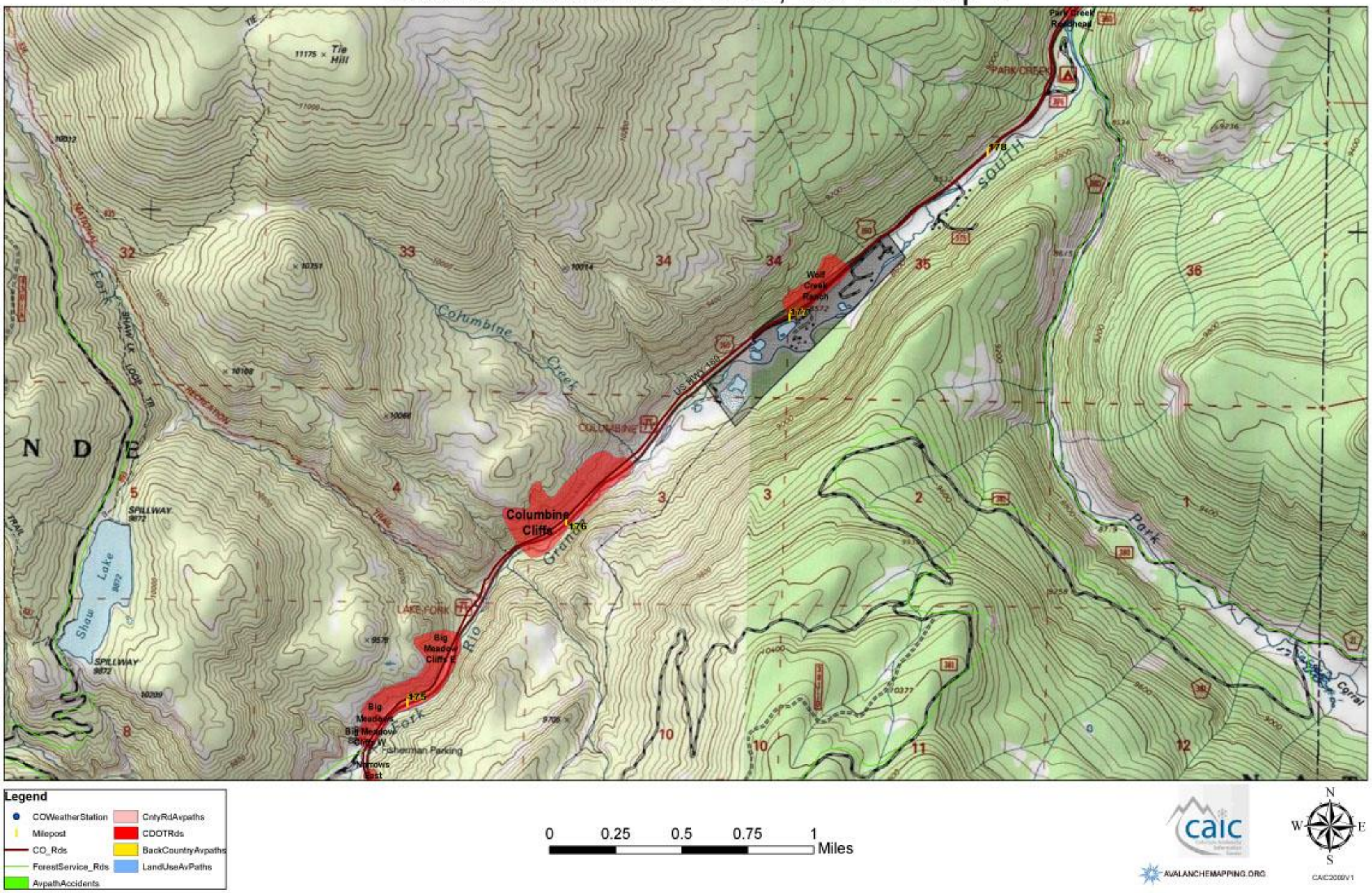
Colorado Avalanche Paths, US 160 Map Index



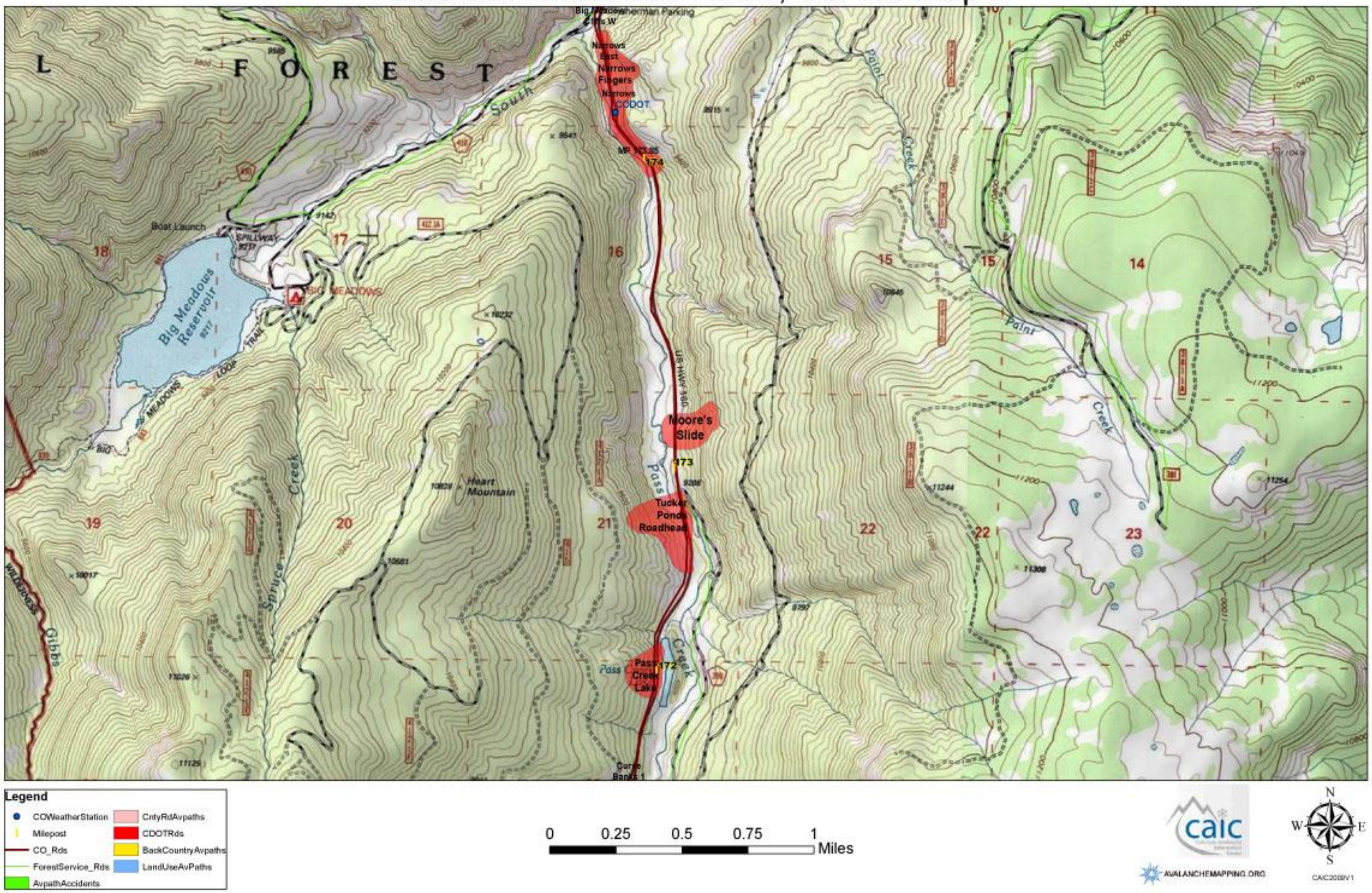
Colorado Avalanche Paths, US 160 Map 1



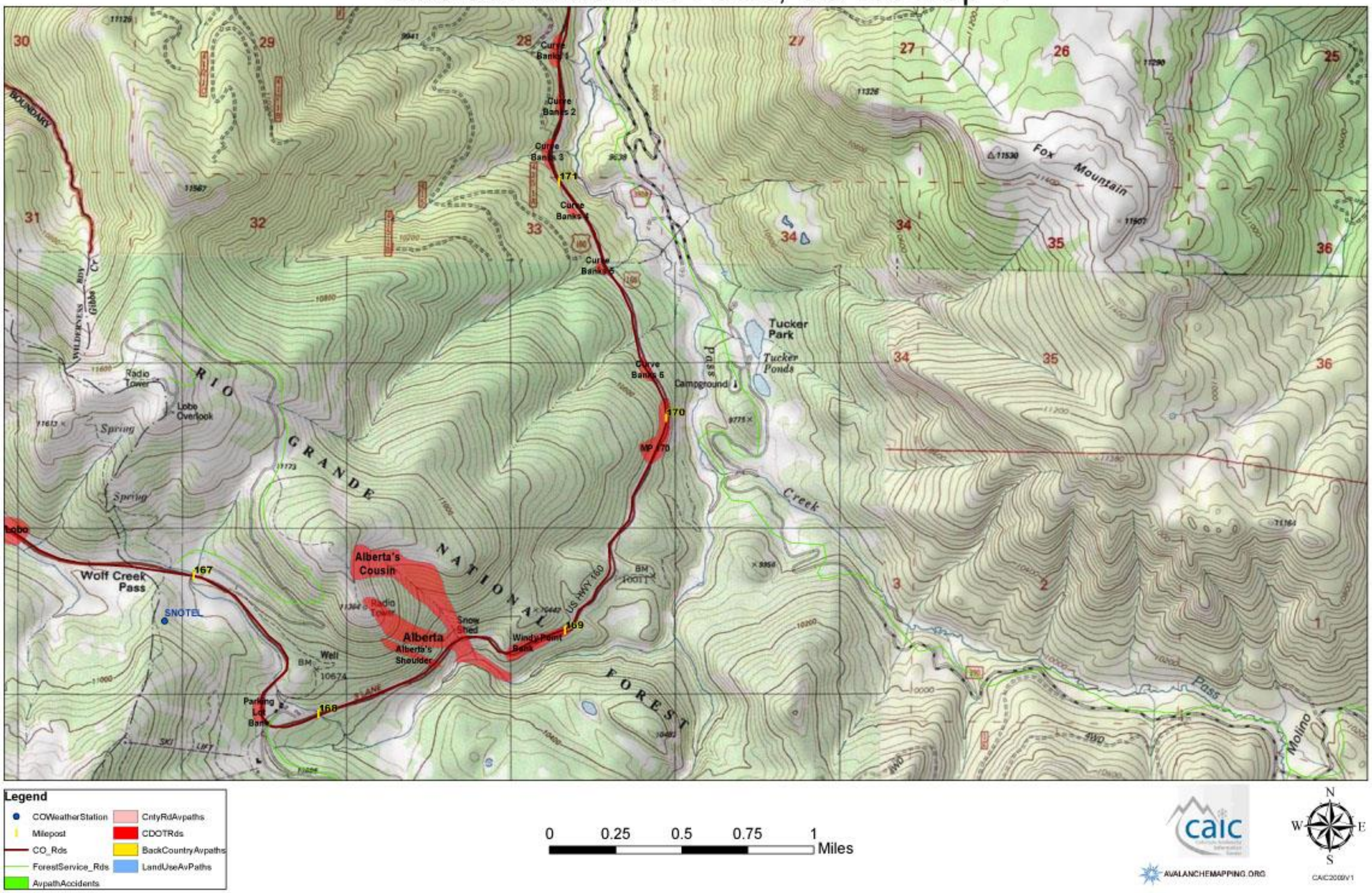
Colorado Avalanche Paths, US 160 Map 2



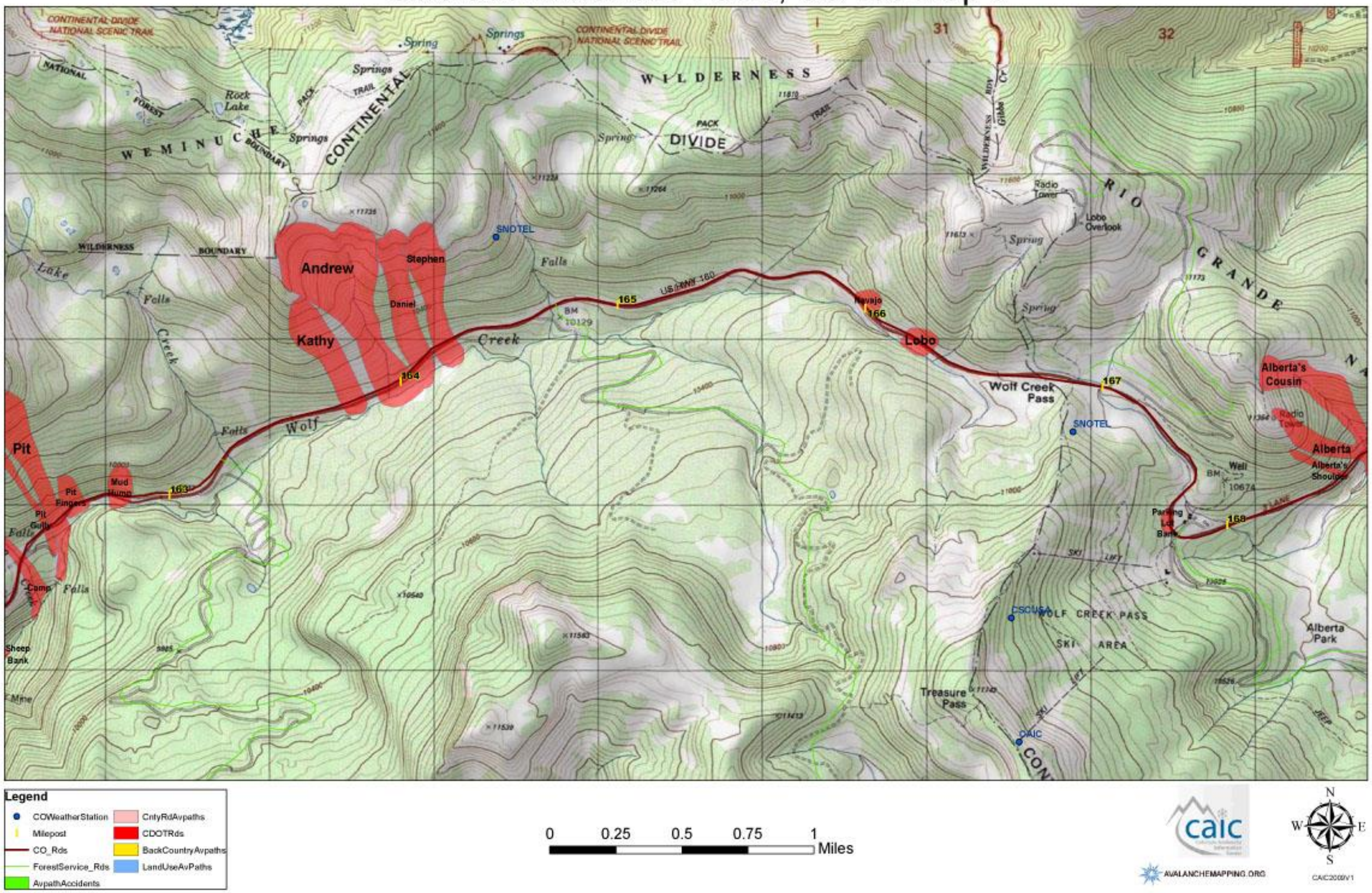
Colorado Avalanche Paths, US 160 Map 3



Colorado Avalanche Paths, US 160 Map 4



Colorado Avalanche Paths, US 160 Map 5



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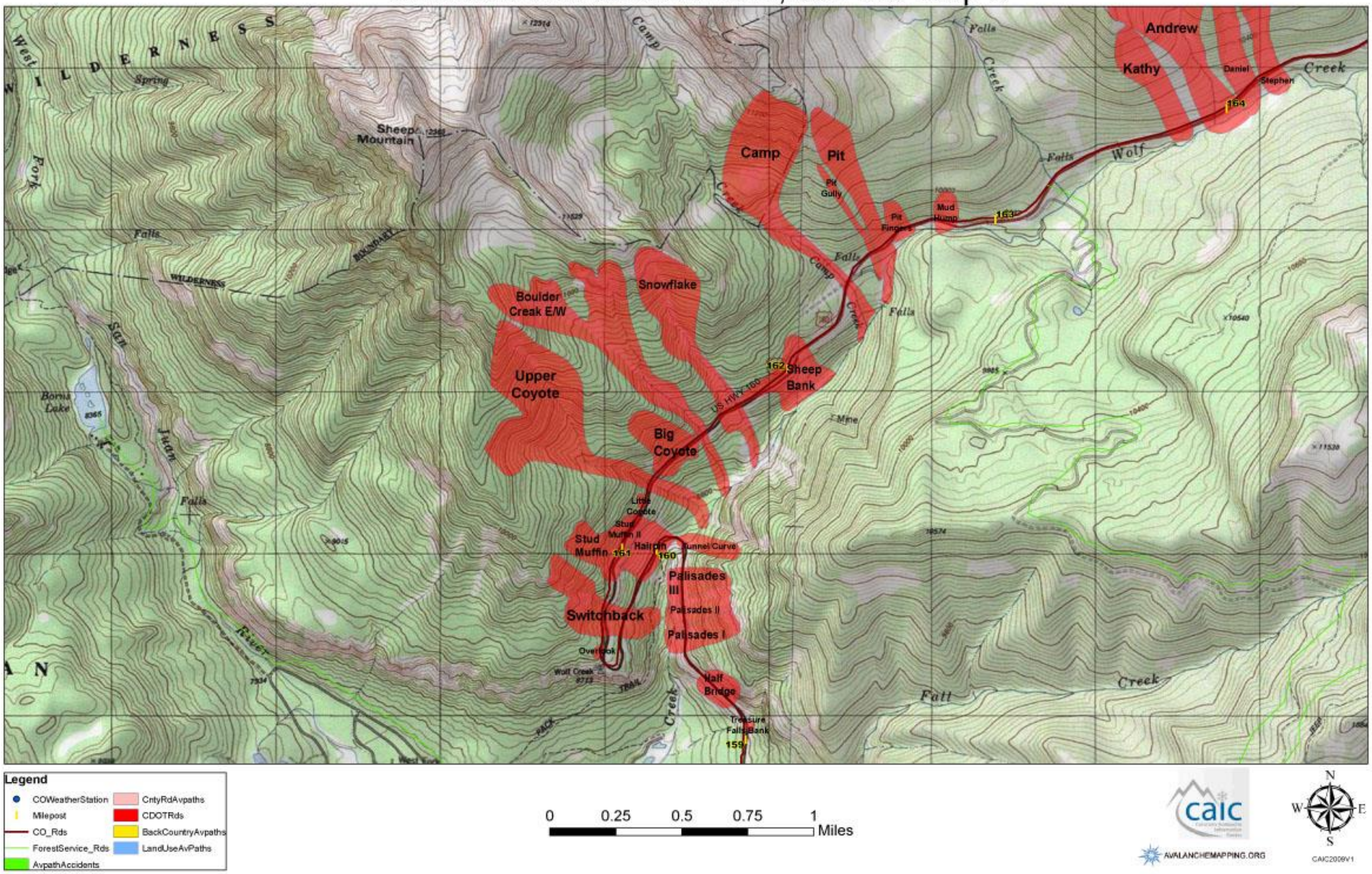
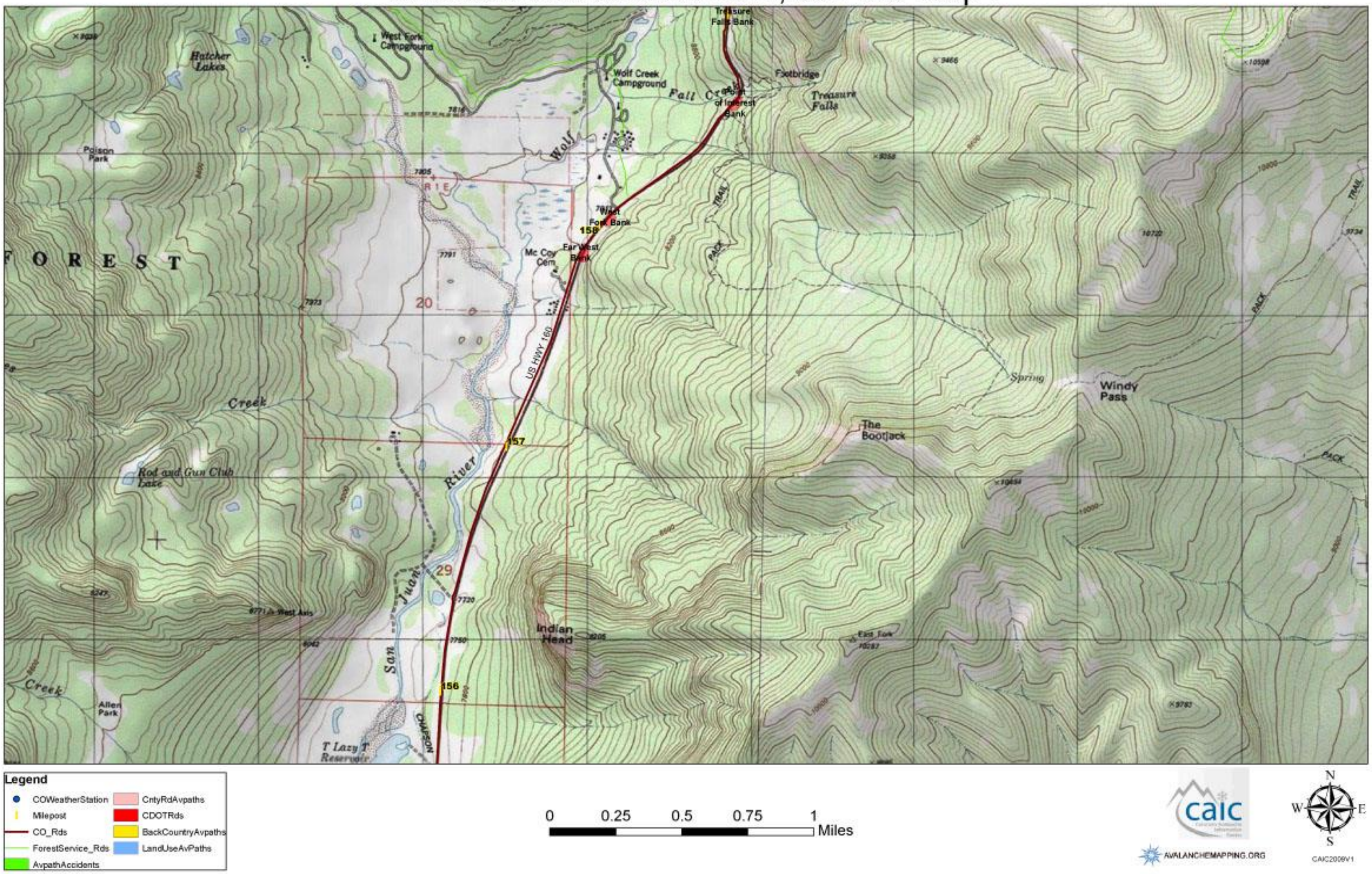
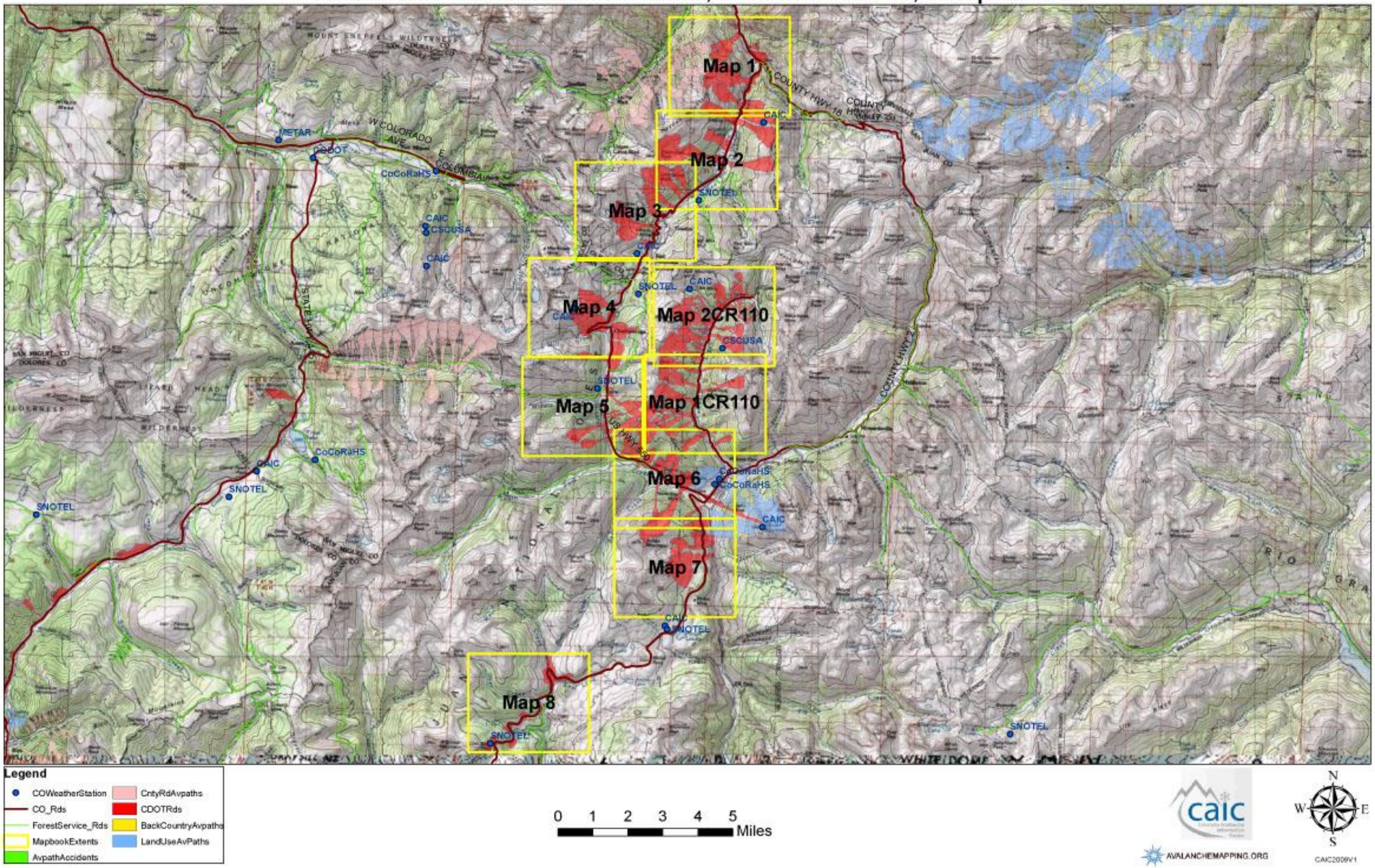


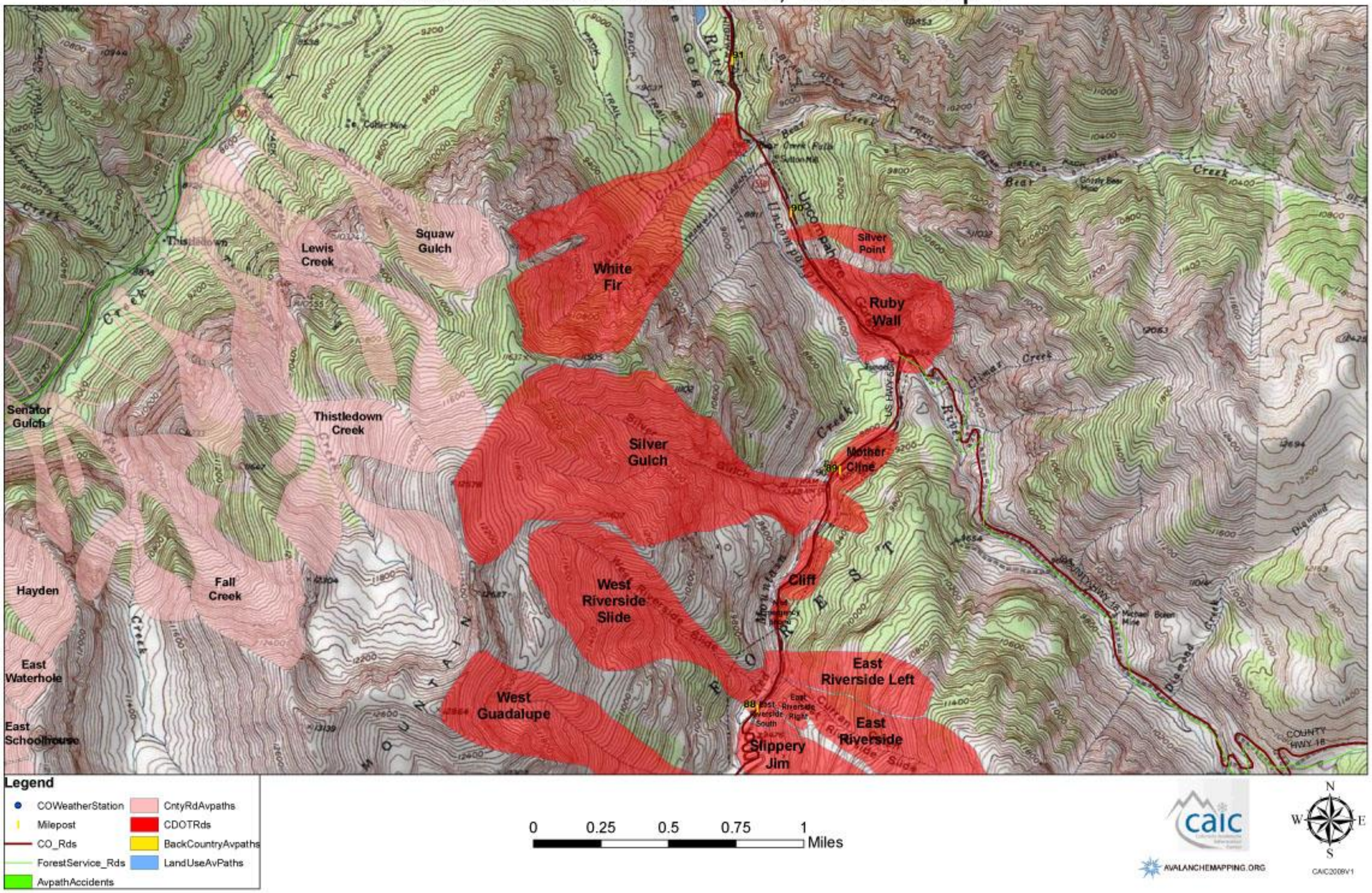
Colorado Avalanche Paths, US 160 Map 7



Colorado Avalanche Paths, US 550 Area, Map Index



Colorado Avalanche Paths, US 550 Map 1



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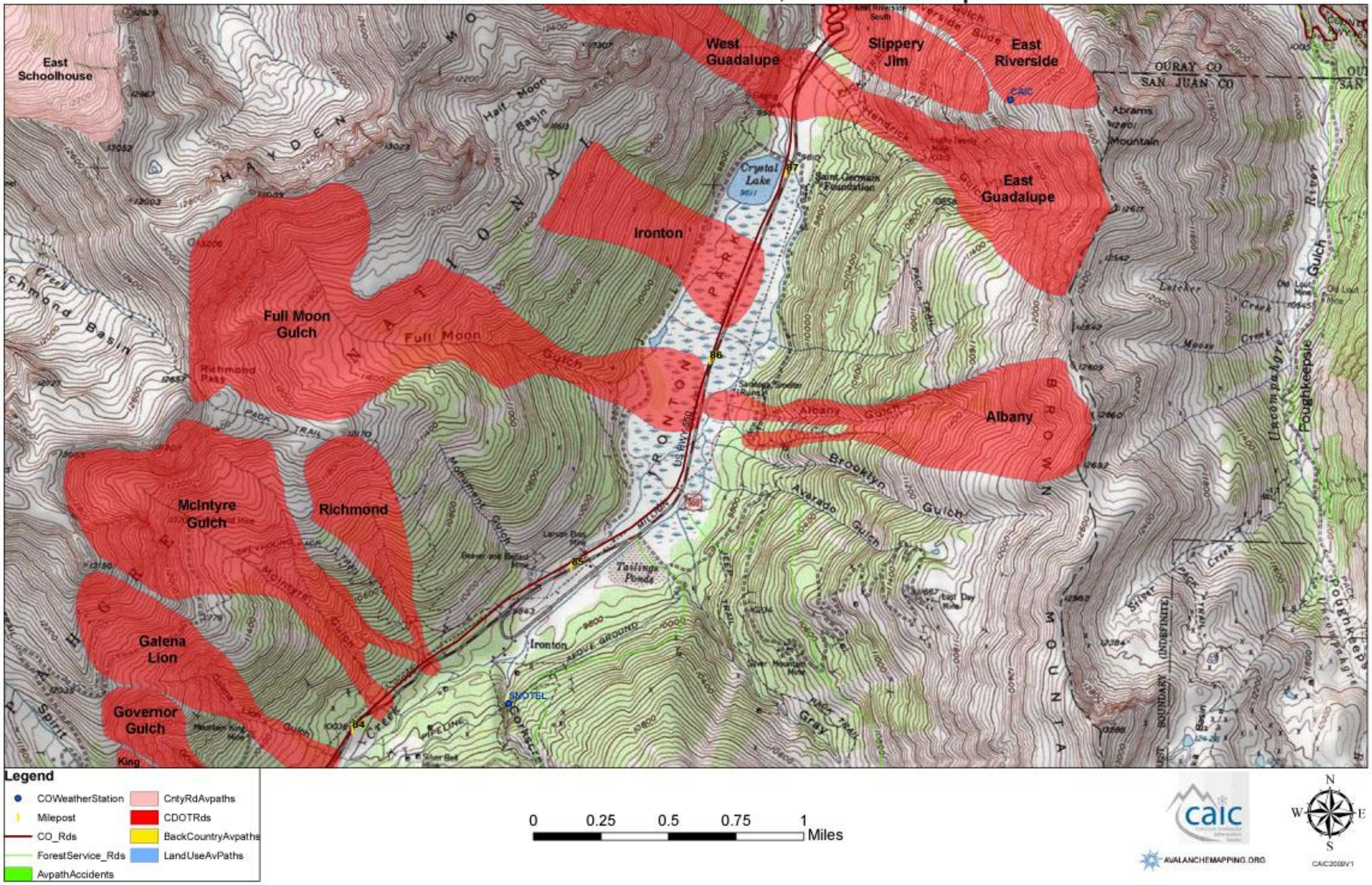

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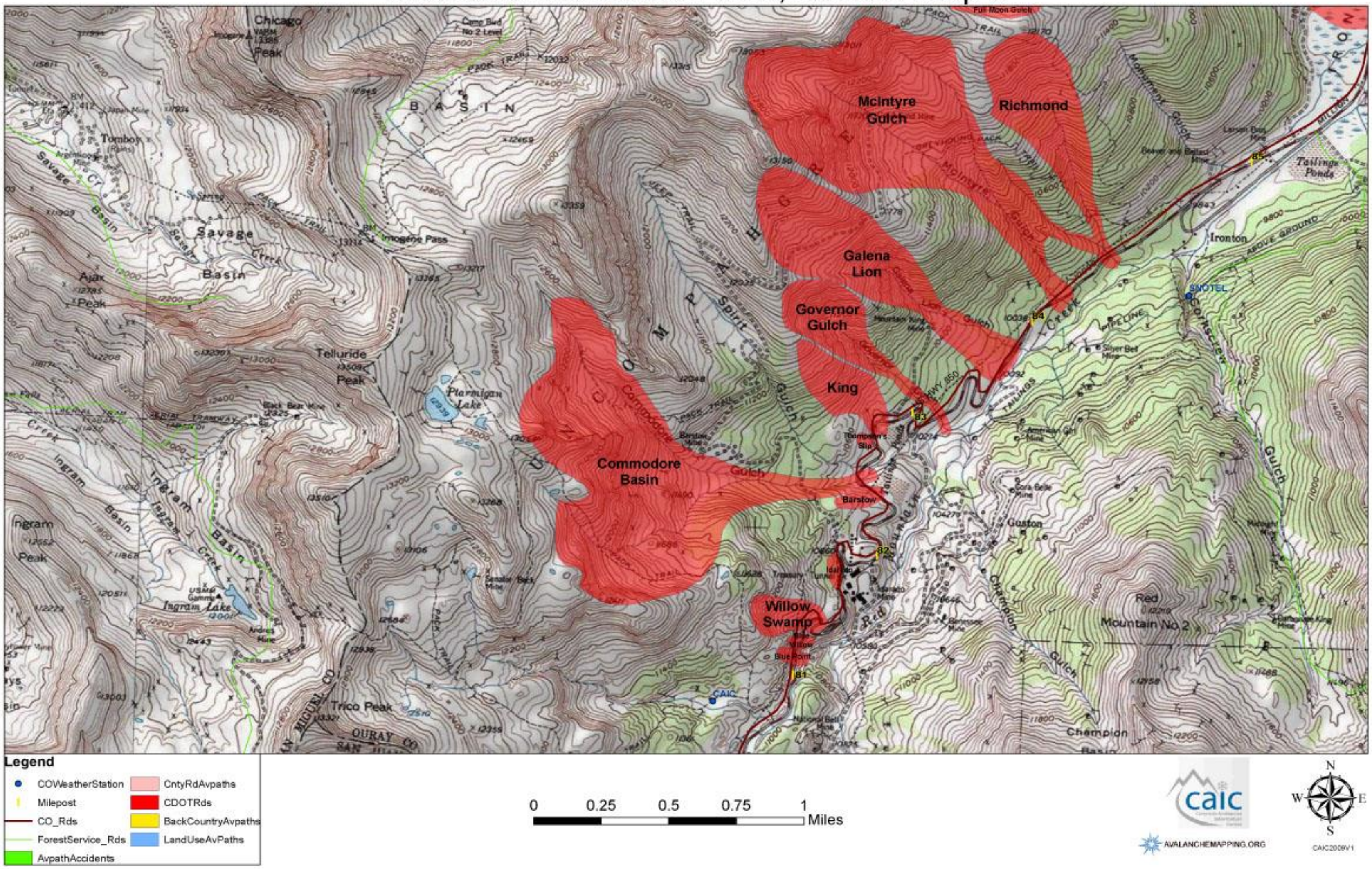
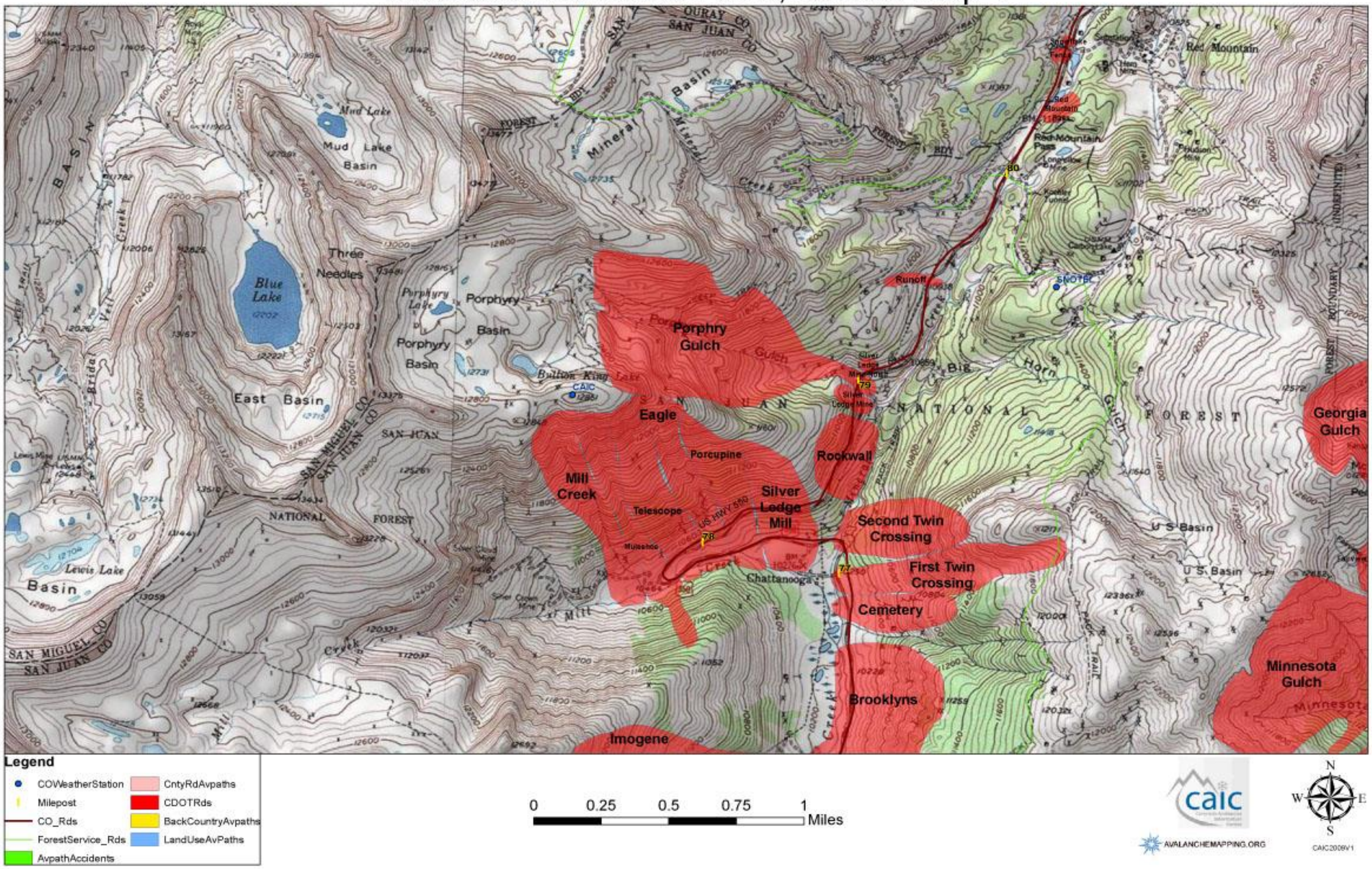
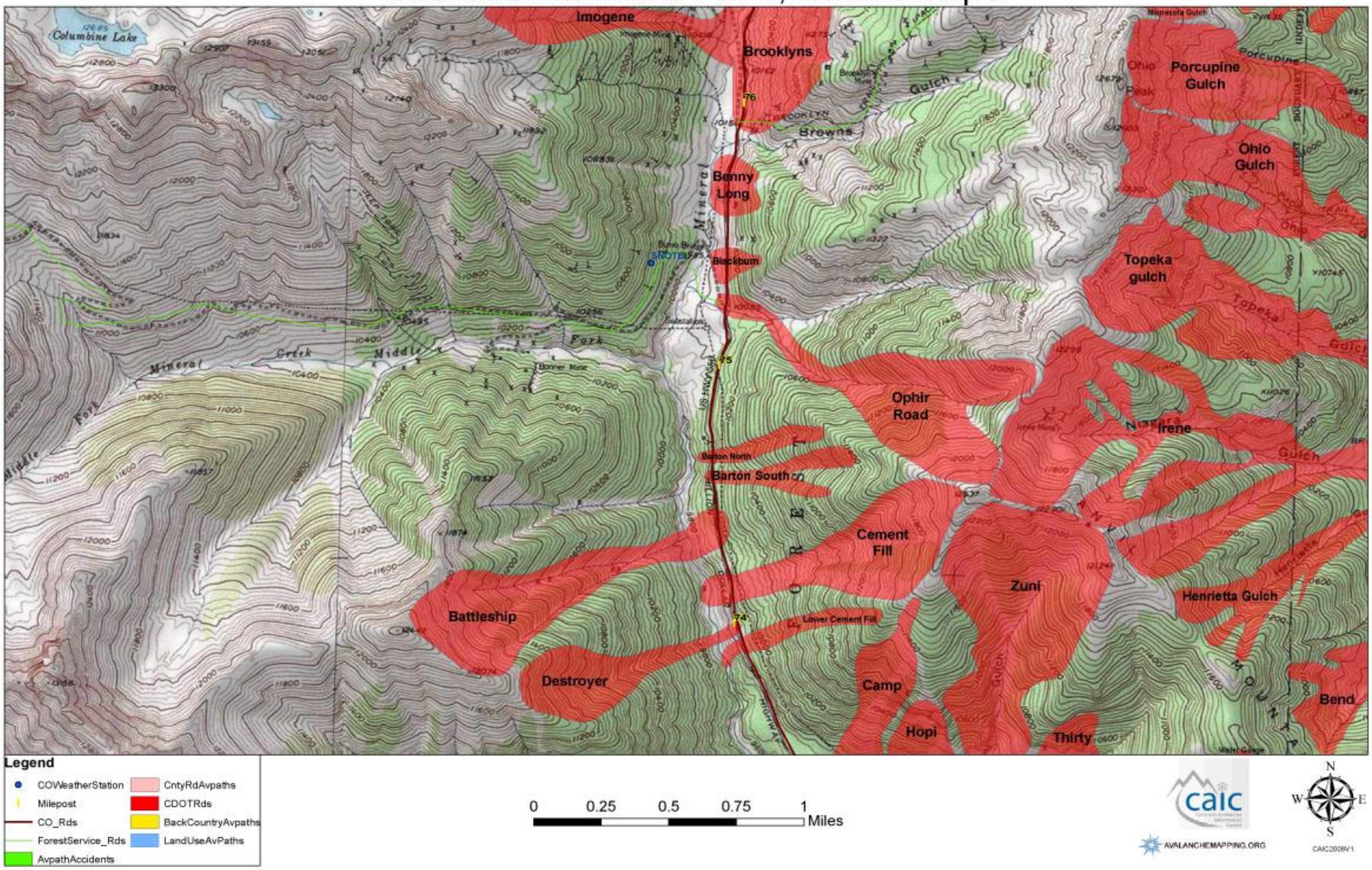


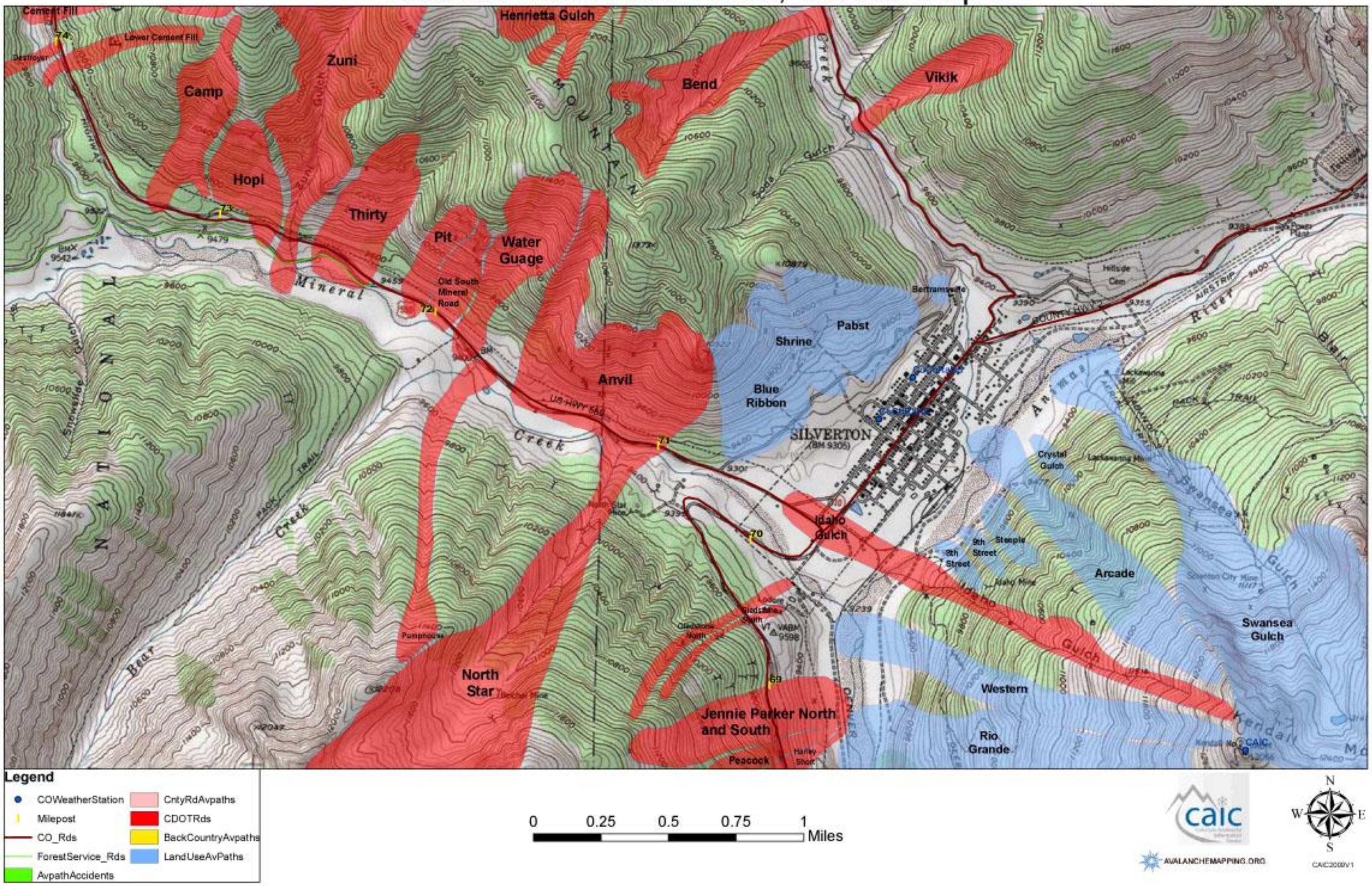
Colorado Avalanche Paths, US 550 Map 4



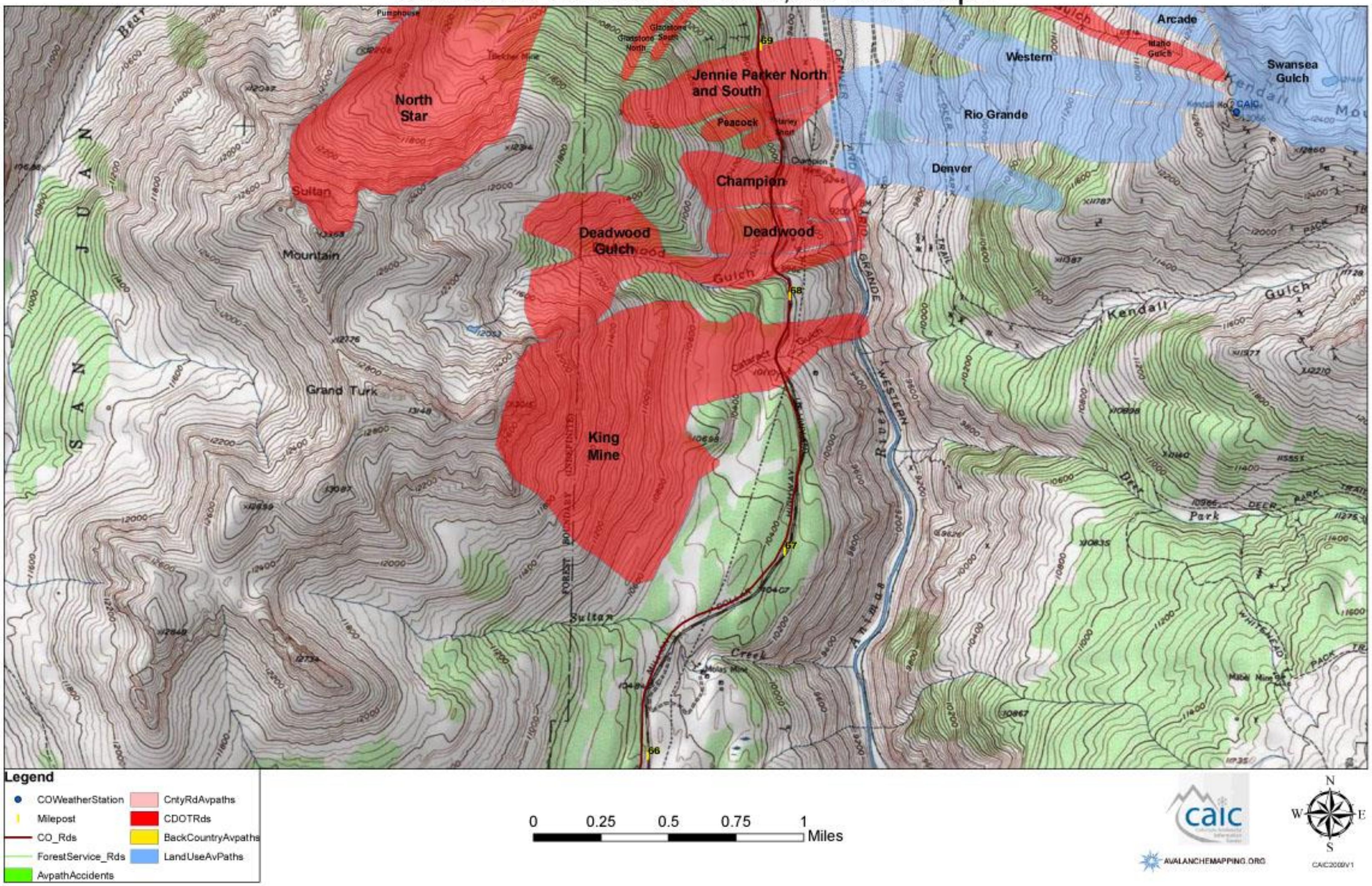
Colorado Avalanche Paths, US 550 Map 5



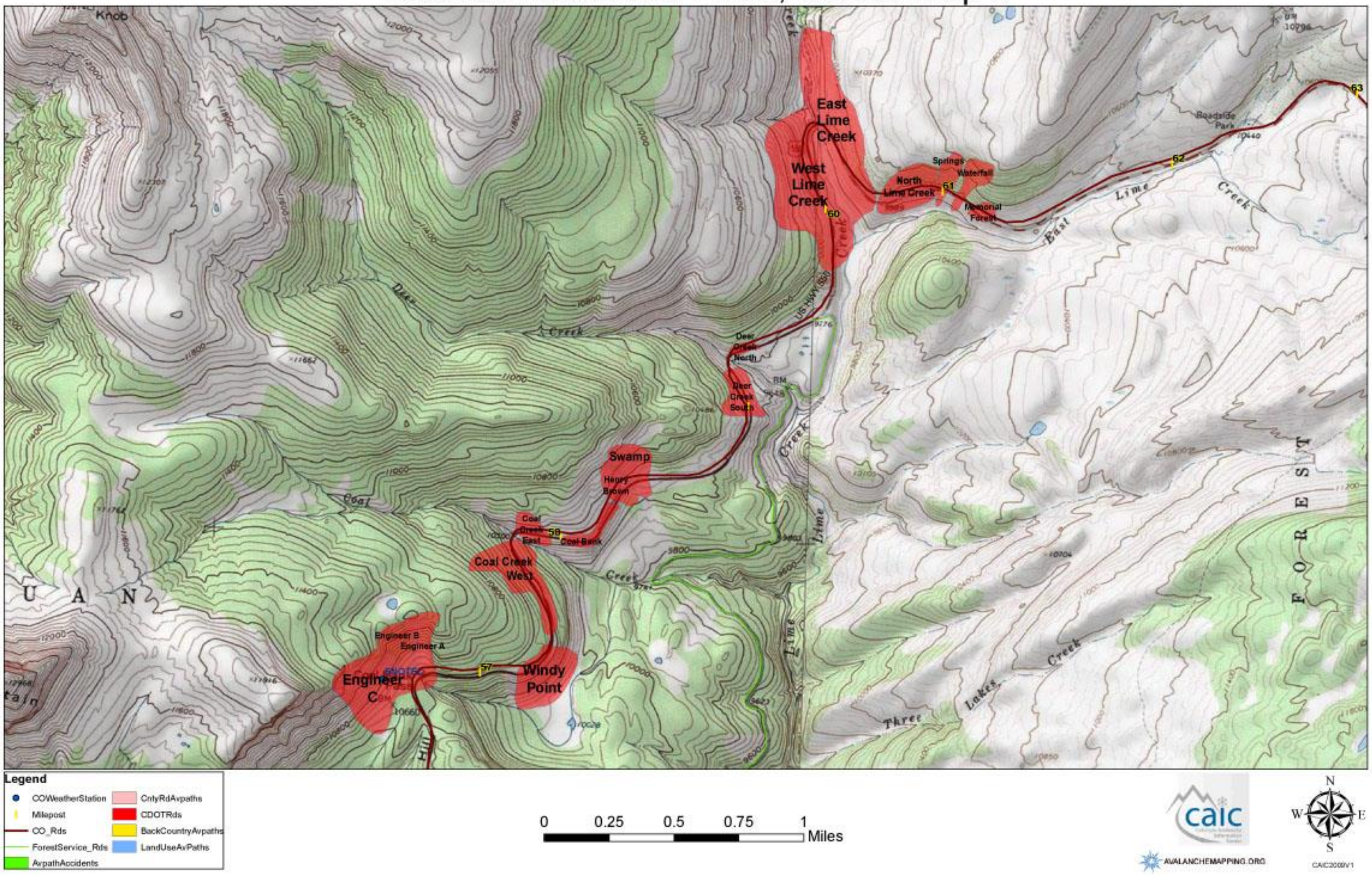
Colorado Avalanche Paths, US 550 Map 6



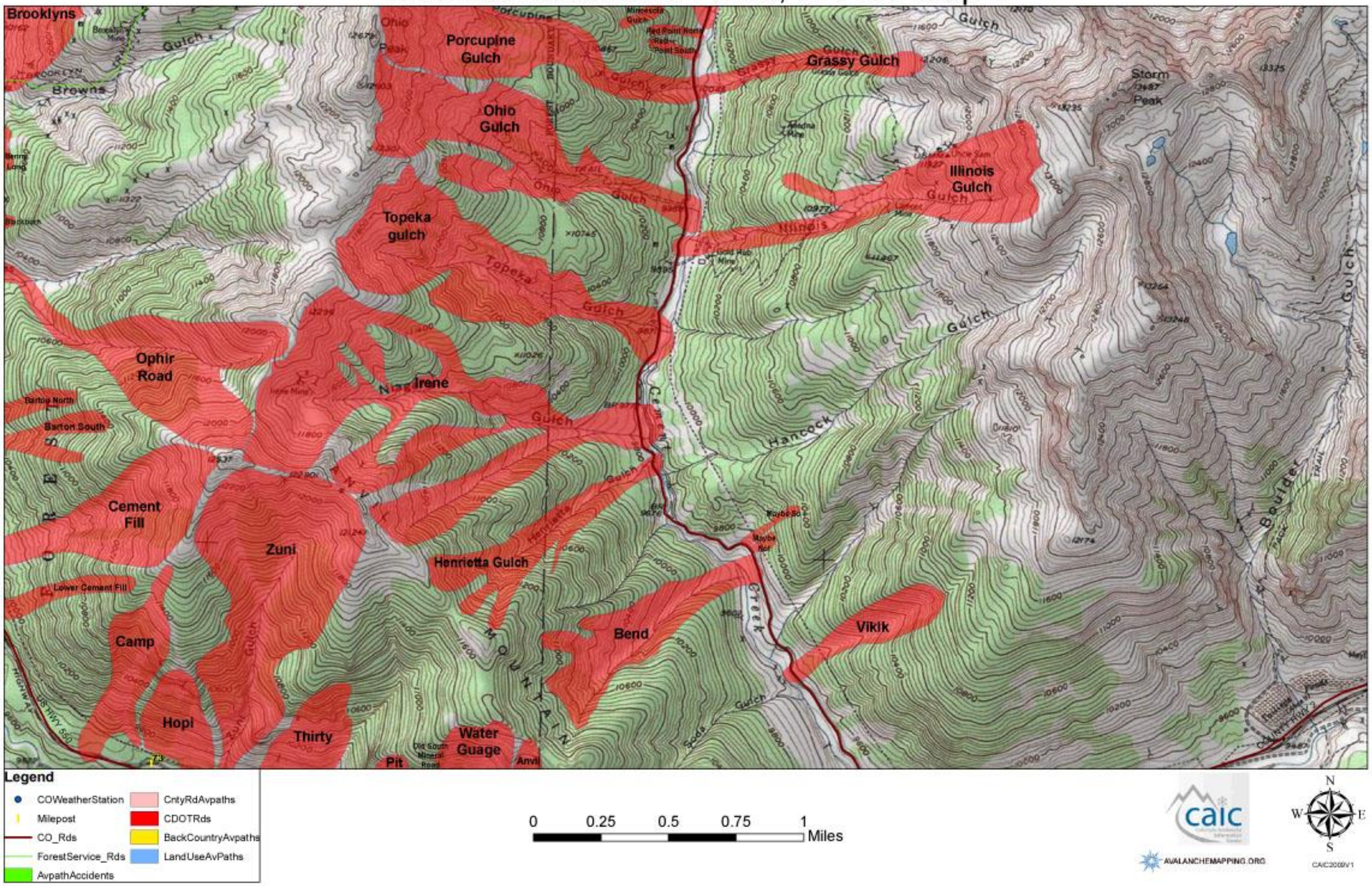
Colorado Avalanche Paths,US 550 Map 7



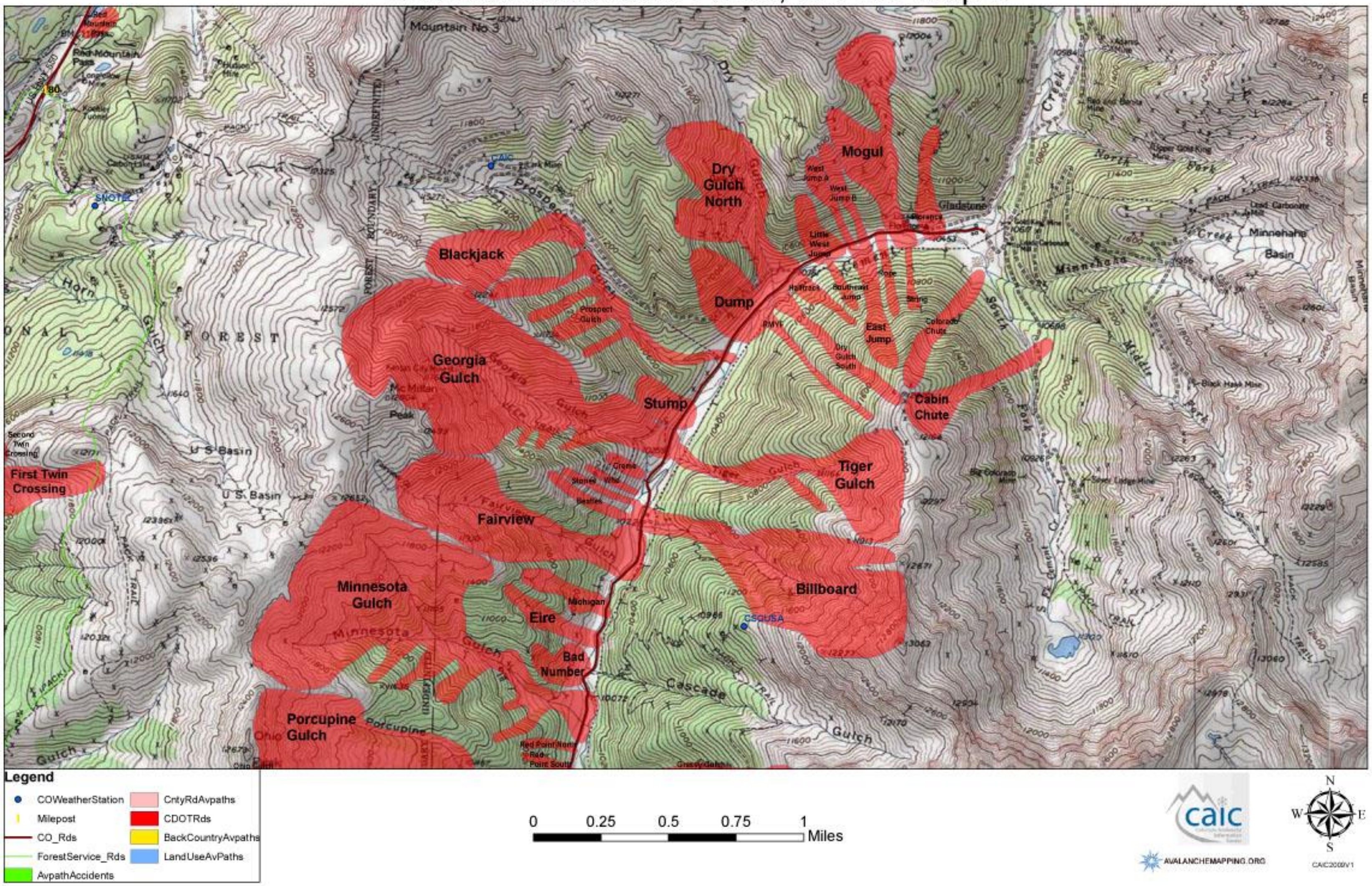
Colorado Avalanche Paths, US 550 Map 8



Colorado Avalanche Paths, CR 110 Map 1



Colorado Avalanche Paths, CR 110 Map 2



<u>Appendix D</u>

Sample avalanche maps for Idaho Highway 21

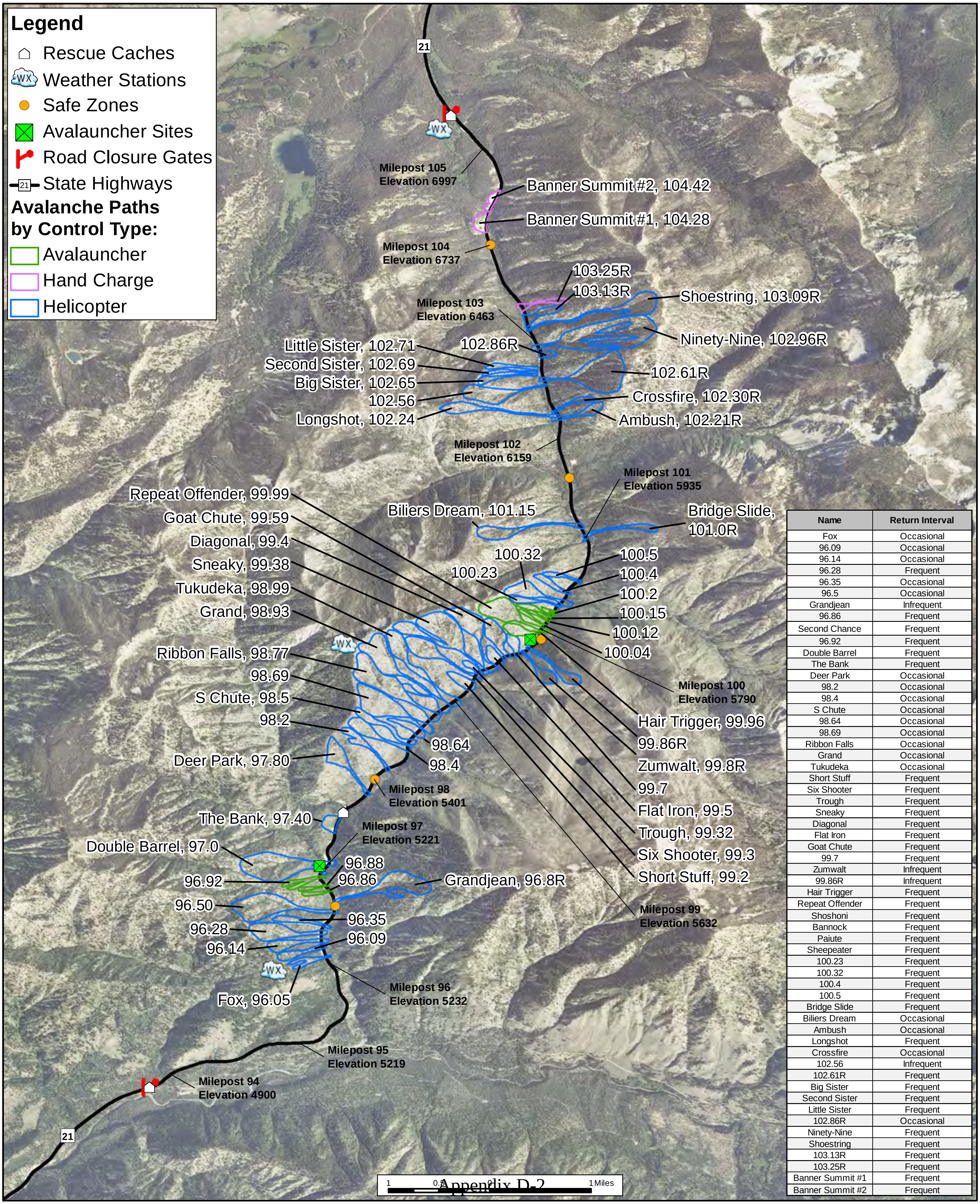
Overview map

Degree aspect

Degree slope

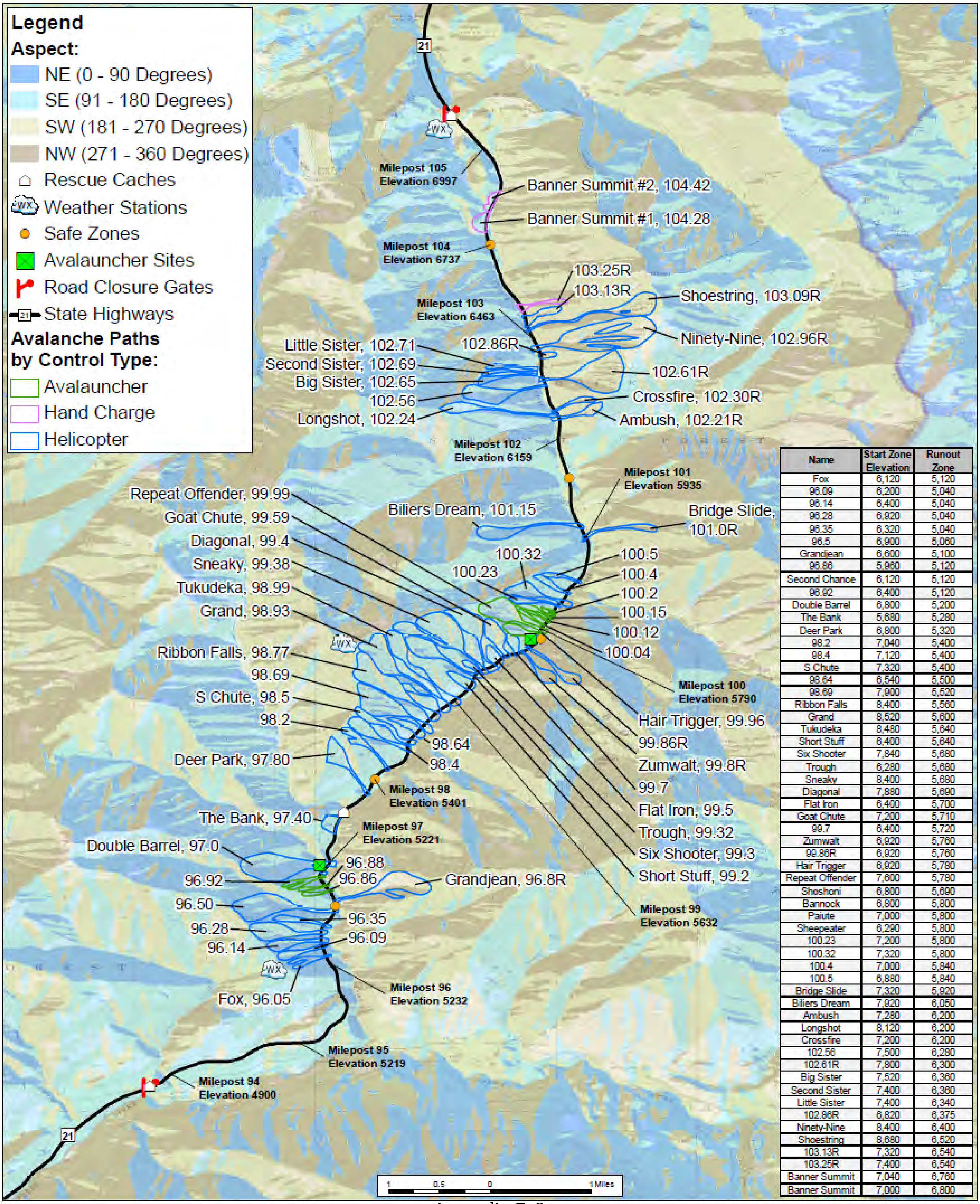
Courtesy of Idaho Transportation Department

Avalanche Paths
Idaho Highway 21

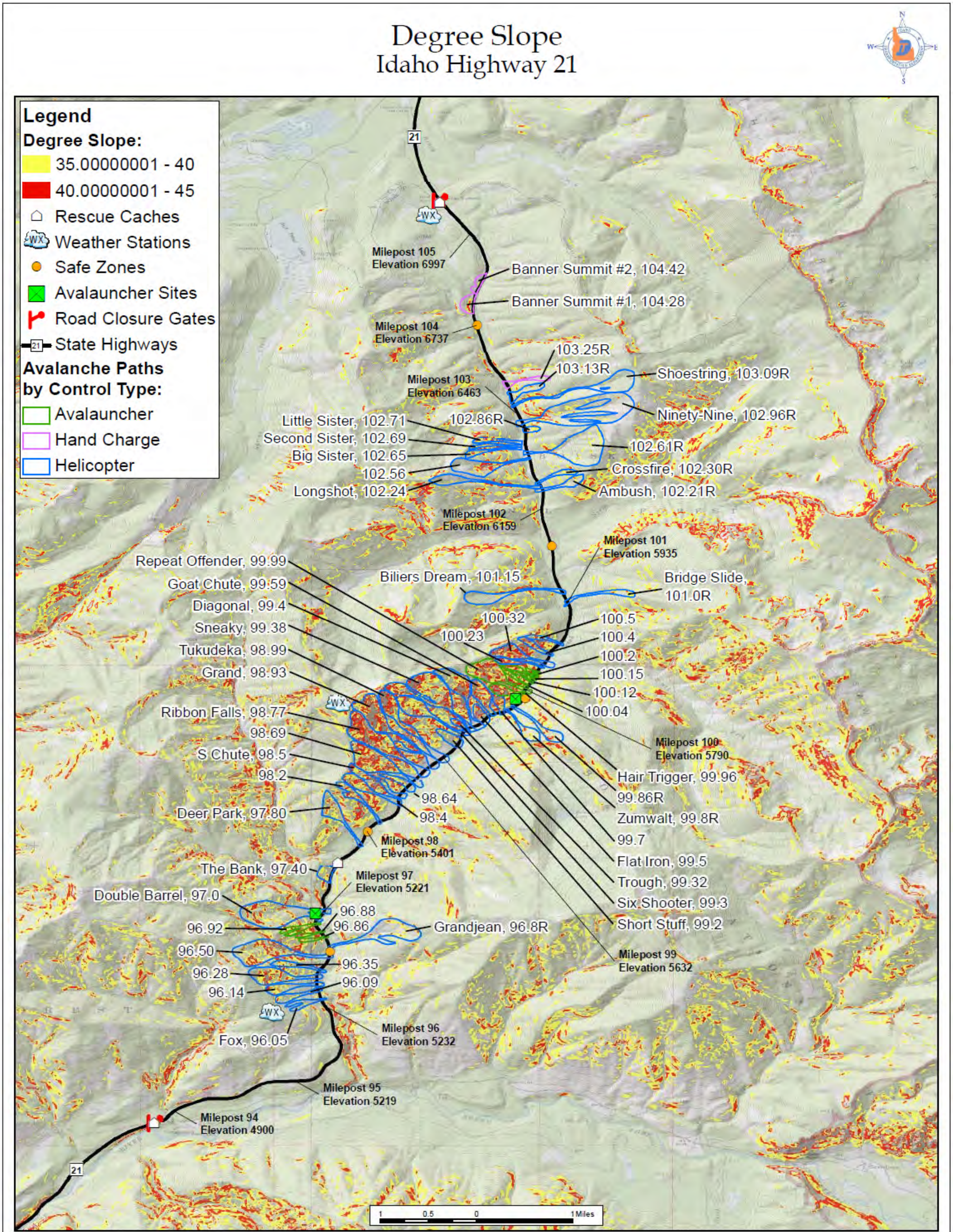


Name	Return Interval
Fox	Occasional
96.09	Occasional
96.14	Occasional
96.28	Frequent
96.35	Occasional
96.5	Occasional
Grandjean	Infrequent
96.86	Frequent
Second Chance	Frequent
96.92	Frequent
Double Barrel	Frequent
The Bank	Frequent
Deer Park	Occasional
98.2	Occasional
98.4	Occasional
S Chute	Occasional
98.64	Occasional
98.69	Occasional
Ribbon Falls	Occasional
Grand	Occasional
Tukudeka	Occasional
Short Stuff	Frequent
Six Shooter	Frequent
Trough	Frequent
Sneaky	Frequent
Diagonal	Frequent
Flat Iron	Frequent
Goat Chute	Frequent
99.7	Frequent
Zumwalt	Infrequent
99.86R	Infrequent
Hair Trigger	Frequent
Repeat Offender	Frequent
Shoshoni	Frequent
Bannock	Frequent
Paiute	Frequent
Sheepeater	Frequent
100.23	Frequent
100.32	Frequent
100.4	Frequent
100.5	Frequent
Bridge Slide	Frequent
Biliers Dream	Occasional
Ambush	Occasional
Longshot	Frequent
Crossfire	Occasional
102.56	Infrequent
102.61R	Frequent
Big Sister	Frequent
Second Sister	Frequent
Little Sister	Frequent
102.86R	Occasional
Ninety-Nine	Frequent
Shoestring	Frequent
103.13R	Frequent
103.25R	Frequent
Banner Summit #1	Frequent
Banner Summit #2	Frequent

Aspect
Idaho Highway 21



Name	Start Zone Elevation	Runout Zone
Fox	6,120	5,120
96.09	6,200	5,040
96.14	6,400	5,040
96.28	6,920	5,040
96.35	6,320	5,040
96.5	6,900	5,060
Grandjean	6,600	5,100
96.86	5,960	5,120
Second Chance	6,120	5,120
96.92	6,400	5,120
Double Barrel	6,800	5,200
The Bank	5,680	5,280
Deer Park	6,800	5,320
98.2	7,040	5,400
98.4	7,120	5,400
S Chute	7,320	5,400
98.64	6,540	5,500
98.69	7,900	5,520
Ribbon Falls	8,400	5,560
Grand	8,520	5,600
Tukudeka	8,480	5,640
Short Stuff	6,400	5,640
Six Shooter	7,840	5,680
Trough	6,280	5,680
Sneaky	8,400	5,680
Diagonal	7,880	5,690
Flat Iron	6,400	5,700
Goat Chute	7,200	5,710
99.7	6,400	5,720
Zumwalt	6,920	5,760
99.86R	6,920	5,760
Hair Trigger	6,920	5,780
Repeat Offender	7,600	5,780
Shoshoni	6,800	5,690
Bannock	6,800	5,800
Paiute	7,000	5,800
Sheepeater	6,290	5,800
100.23	7,200	5,800
100.32	7,320	5,800
100.4	7,000	5,840
100.5	6,880	5,840
Bridge Slide	7,320	5,920
Biliers Dream	7,920	6,050
Ambush	7,280	6,200
Longshot	8,120	6,200
Crossfire	7,200	6,200
102.56	7,500	6,280
102.61R	7,800	6,300
Big Sister	7,520	6,360
Second Sister	7,400	6,360
Little Sister	7,400	6,340
102.86R	6,820	6,375
Ninety-Nine	8,400	6,400
Shoestring	8,680	6,520
103.13R	7,320	6,540
103.25R	7,400	6,540
Banner Summit	7,040	6,760
Banner Summit	7,000	6,800



Degree Slope
Idaho Highway 21
Legend
Degree Slope:
35.00000001 - 40
40.00000001 - 45
Rescue Caches
Weather Stations
Safe Zones
Avalauncher Sites
Road Closure Gates
State Highways
Avalanche Paths by Control Type:
Avalauncher
Hand Charge
Helicopter
Milepost 105 Elevation 6997
Banner Summit #2, 104.42
Banner Summit #1, 104.28
Milepost 104 Elevation 6737
103.25R
103.13R
Shoestring, 103.09R
Milepost 103 Elevation 6463
Ninety-Nine, 102.96R
Little Sister, 102.71
102.86R
Second Sister, 102.69
102.61R
Big Sister, 102.65
102.56
Crossfire, 102.30R
Longshot, 102.24
Ambush, 102.21R
Milepost 102 Elevation 6159
Milepost 101 Elevation 5935
Repeat Offender, 99.99
Goat Chute, 99.59
Biliers Dream, 101.15
Bridge Slide, 101.0R
Diagonal, 99.4
100.32
100.5
Sneaky, 99.38
100.23
100.4
Tukudeka, 98.99
100.2
Grand, 98.93
100.15
100.12
Ribbon Falls, 98.77
100.04
98.69
Milepost 100 Elevation 5790
S Chute, 98.5
Hair Trigger, 99.96
98.2
99.86R
98.64
Deer Park, 97.80
98.4
Zumwalt, 99.8R
Milepost 98 Elevation 5401
99.7
Flat Iron, 99.5
The Bank, 97.40
Milepost 97 Elevation 5221
Trough, 99.32
Double Barrel, 97.0
Six Shooter, 99.3
96.88
Short Stuff, 99.2
96.92
96.86
Grandjean, 96.8R
96.50
Milepost 99 Elevation 5632
96.35
96.28
96.09
96.14
Fox, 96.05
Milepost 96 Elevation 5232
Milepost 95 Elevation 5219
Milepost 94 Elevation 4900
21
1 0.5 0 1 Miles

Appendix E

Definition of Terms Used in Avalanche Path

Template for Logan Canyon, Utah SR 89 Avalanche Path Summary

American Fork, Utah SR 92 Avalanche Path Summary

and

photos, sketches, and overlays of avalanche paths

Courtesy of Utah DOT

DEFINITION OF TERMS USED IN AVALANCHE PATH

SUMMARIES AND MAPS

CLASSIFICATION OF SLIDE PATH (three classes)

Class	Avalanche Destructive Potential	Typical Mass	Typical Path Length
-			
Major	Could destroy a railway car, large truck, several buildings, or a forest area up to 4 hectares (10 acres)	10^3t-10^4t	1000-2000 m
Significant	Could bury and destroy a car, damage a truck, destroy a wood frame house, or break a few trees.	10^2t-10^3t	100-1000m
Minor	Could bury, injure or kill a person	up to 10^2t	10-100m

RETURN INTERVAL

Frequent - Avalanche to highway at least once in five years.

Occasional - Avalanche to highway at least once in 14 years.

Infrequent - Avalanche to highway not known to be more frequent than once in 14 years based on historical record and re-growth of vegetation.

DESCRIPTION

Starting zone elevation: Elevations taken from 7.5 minute series maps. The elevation of the highest point of where the avalanches start.

Vertical fall: The vertical distance from the highest to the lowest elevation of an avalanche path.

LOGAN CANYON **UTAH SR 89 AVALANCHE PATH SUMMARY**

NAME: **ROAD MILE:**

SIZE CLASSIFICATION:

RETURN INTERVAL:

VERTICAL FALL:

DISTANCE TO HIGHWAY:

STARTING ZONE:

ELEVATION:

ASPECT:

INCLINE:

ACREAGE:

TOPOGRAPHY:

TRACK:

INCLINE:

TOPOGRAPHY:

RUNOUT ZONE:

INCLINE:

TOPOGRAPHY:

ACREAGE:

LENGTH OF HIGHWAY AFFECTED:

HISTORY:

METHOD OF CONTROL:

PRIMARY: SECONDARY:

AMERICAN FORK CANYON **UTAH SR 92 AVALANCHE PATH SUMMARY**

NAME: Powerline Gully East **ROAD MILE:** 8.7 (0.8)

SIZE CLASSIFICATION: Minor

RETURN INTERVAL: infrequent

VERTICAL FALL: 3400'

DISTANCE TO HIGHWAY: 5400'

STARTING ZONE:

ELEVATION: 8650'

ASPECT: NNW

INCLINE: 41°

ACREAGE: 4

TOPOGRAPHY: Narrow scree gully with sparse conifers.

TRACK:

INCLINE: 35°

TOPOGRAPHY: Complex scree face.

RUNOUT ZONE:

INCLINE: 10°

TOPOGRAPHY: Confined scree gully.

ACREAGE: 2

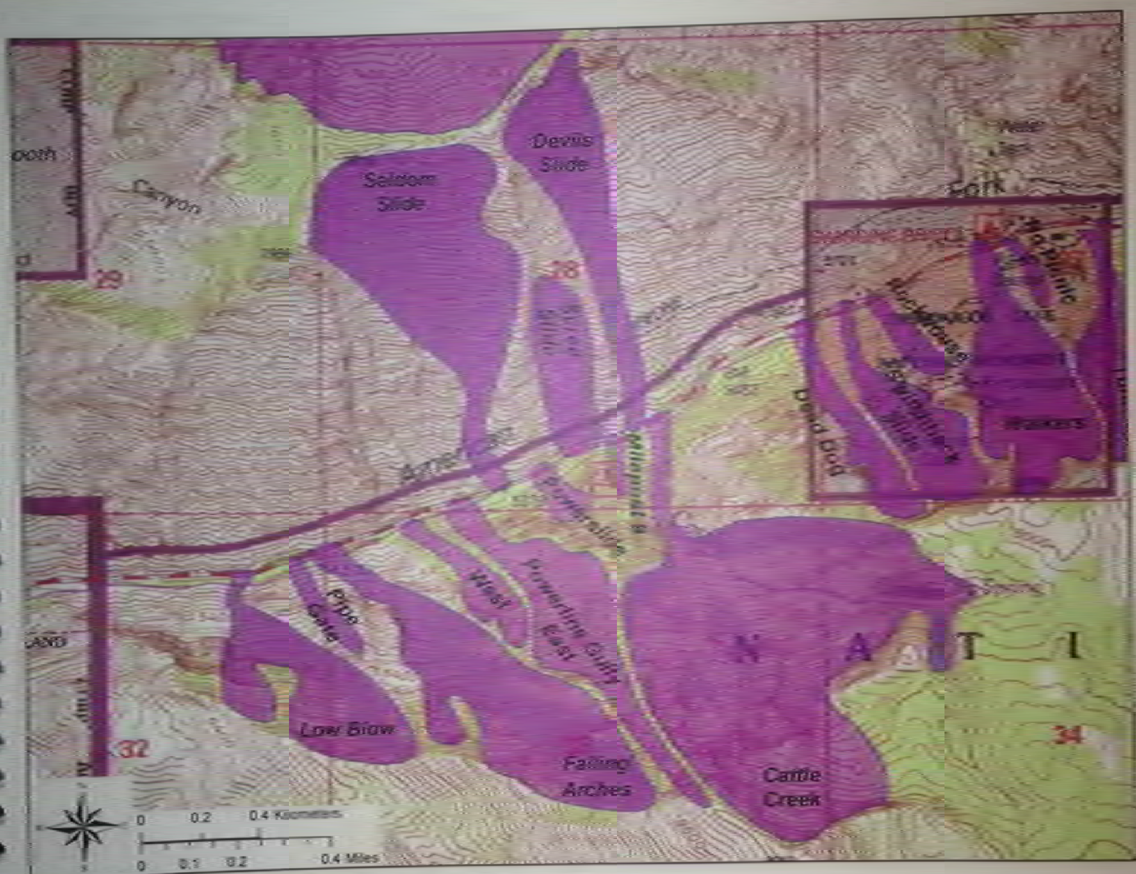
LENGTH OF HIGHWAY AFFECTED: 100'

HISTORY: No recorded history of reaching highway

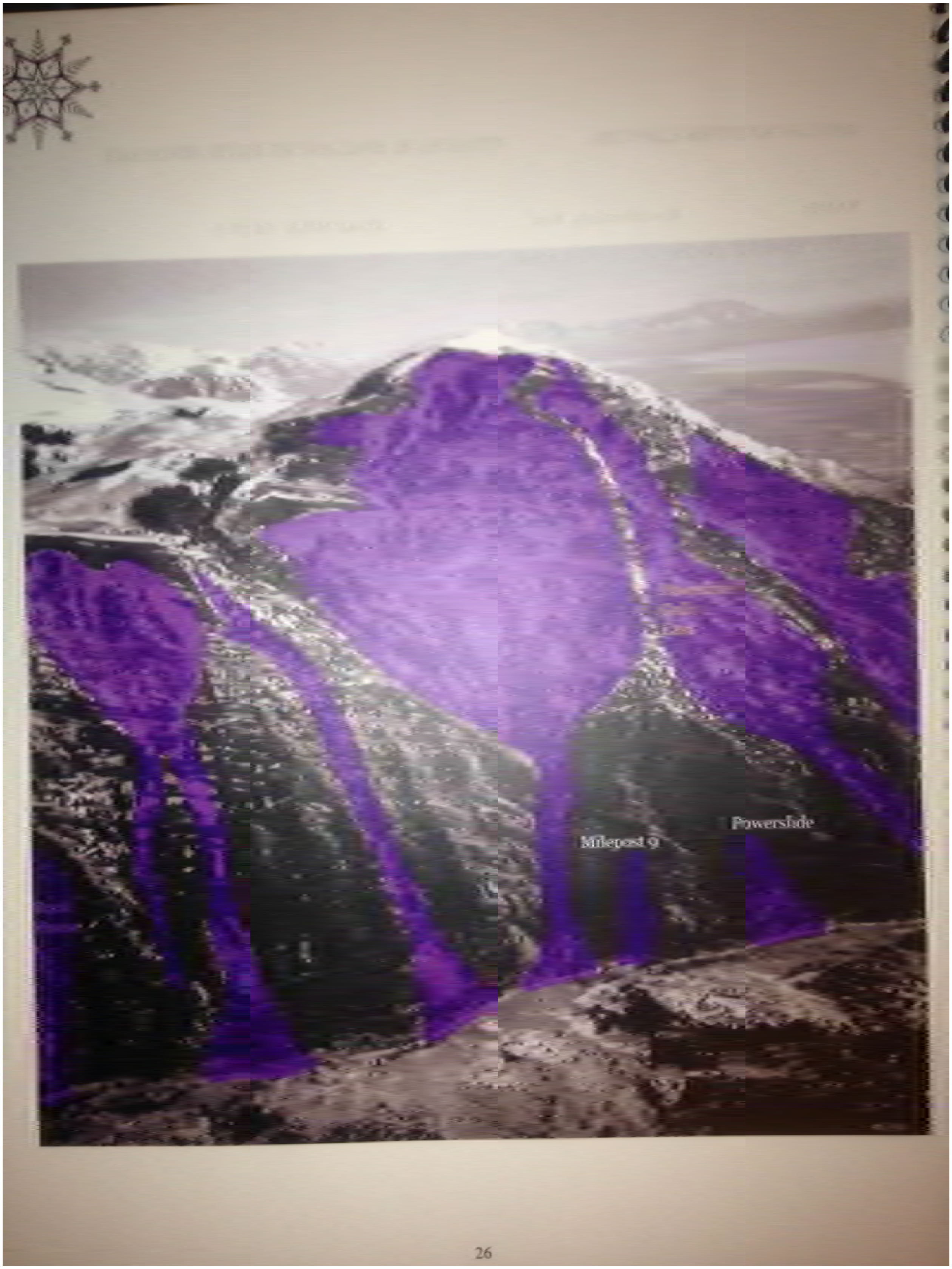
METHOD OF CONTROL:

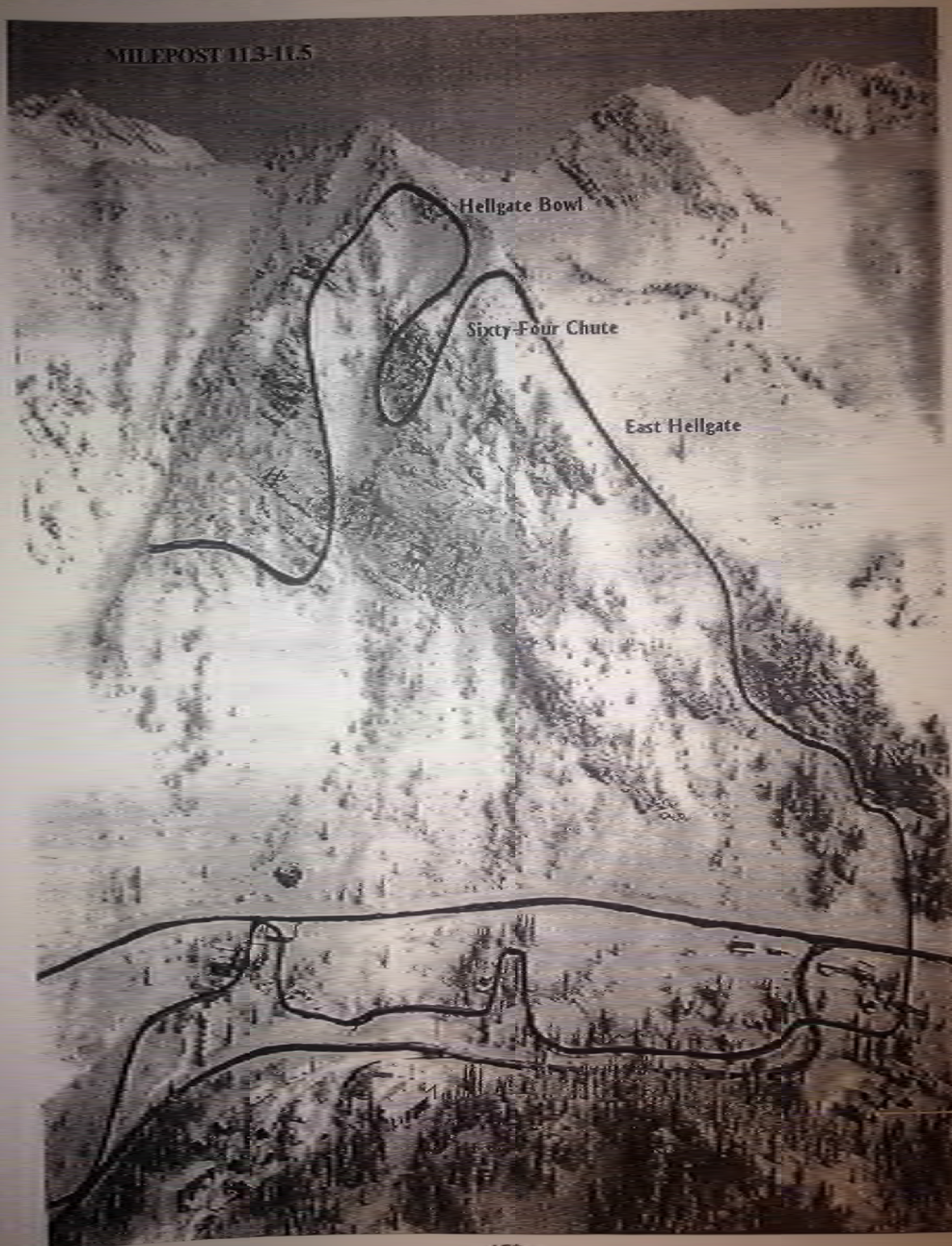
PRIMARY: Helicopter SECONDARY: Avalauncher

Canyon Mouth Topographic Map



17


Milepost 9
Powerslide
26


MILEPOST 11.3-11.5
Hellgate Bowl
Sixty-Four Chute
East Hellgate

-172-

Appendix F

Covers from:

“Cascade Passes Avalanche Atlas, Part I: Chinook, Cayuse, White, and Snoqualmie Passes,” August, 1974

“Cascade Passes Avalanche Atlas, Part 2: Stevens Pass and Tumwater Canyon,” May, 1975

“Methods of Avalanche Control in Washington Mountain Highways,” E.R. LaChapelle, C.B. Brown, and R.J. Evans, July, 1974

(Full reports available in PDF format)

and

sample maps for U.S. 12 White Pass area, and west and east portions of Snoqualmie Pass

(PDF of maps available. Maps do not appear in this appendix.)

Courtesy of Washington State DOT

 8.7

CASCADE PASSES

AVALANCHE ATLAS

Part 1

Chinook, Cayuse, White and Snoqualmie Passes

Prepared for
Washington State Highway Commission
Department of Highways
and in cooperation with
U. S. Department of Transportation
Federal Highway Administration

by

Geophysics Program and Department
of Civil Engineering
University of Washington
Seattle, Washington

August 1974

CASCADE PASSES

AVALANCHE ATLAS

Part 2

Stevens Pass and Tumwater Canyon

Prepared for
Washington State Highway Commission
Department of Highways
and in cooperation with
U. S. Department of Transportation
Federal Highway Administration

by

Geophysics Program and Department
of Civil Engineering
University of Washington
Seattle, Washington

MAY 1975

TECHNICAL REPORT STANDARD TITLE PAGE

1. Report No.	2. Government Accession No.	3. Recipient's Catalog No.
4. Title and Subtitle Methods of Avalanche Control on Washington Mountain Highways - Summary Report		5. Report Date July 1974 6. Performing Organization Code
7. Author(s) E.R. LaChapelle, C.B.Brown and R.J. Evans		8. Performing Organization Report No.
9. Performing Organization Name and Address Geophysics Program and Department of Civil Engineering University of Washington Seattle, Washington 98195		10. Work Unit No. 11. Contract or Grant No. Y-1301
12. Sponsoring Agency Name and Address Washington State Highway Commission Department of Highways, Highway Administration Bldg. Olympia, Washington 98504		13. Type of Report and Period Covered SUMMARY REPORT 1970-74 14. Sponsoring Agency Code

15. Supplementary Notes

Cooperation with U.S. Department of Transportation, Federal Highway Administration

16. Abstract

This Summary Report synthesizes the work on avalanche control carried out at the University of Washington from 1970 through 1974. Five problem areas are addressed:

1. Identification of avalanche paths.
2. Description of historical frequency and size of avalanches.
3. Prediction of avalanching.
4. Identification of control methods.
5. Inclusion of control and prediction schemes in highway design and operation.

17. Key Words Avalanche, Snow, Weather, Creep, Glide, Avalanche Forecasting	18. Distribution Statement

19. Security Classif. (of this report)	20. Security Classif. (of this page)	21. No. of Pages	22. Price
Unclassified	Unclassified	21	

Appendix F-4

Form DOT F 1700.7 (8 69)
HWY FORM 341-004

Appendix G

Cover from:

“Snow Avalanche Atlas: Lincoln, Sublette, and Teton Counties,” Wyoming Department of Transportation, District 3, 2004

(Full report available in PDF format)

Courtesy of Wyoming DOT

SNOW AVALANCHE ATLAS

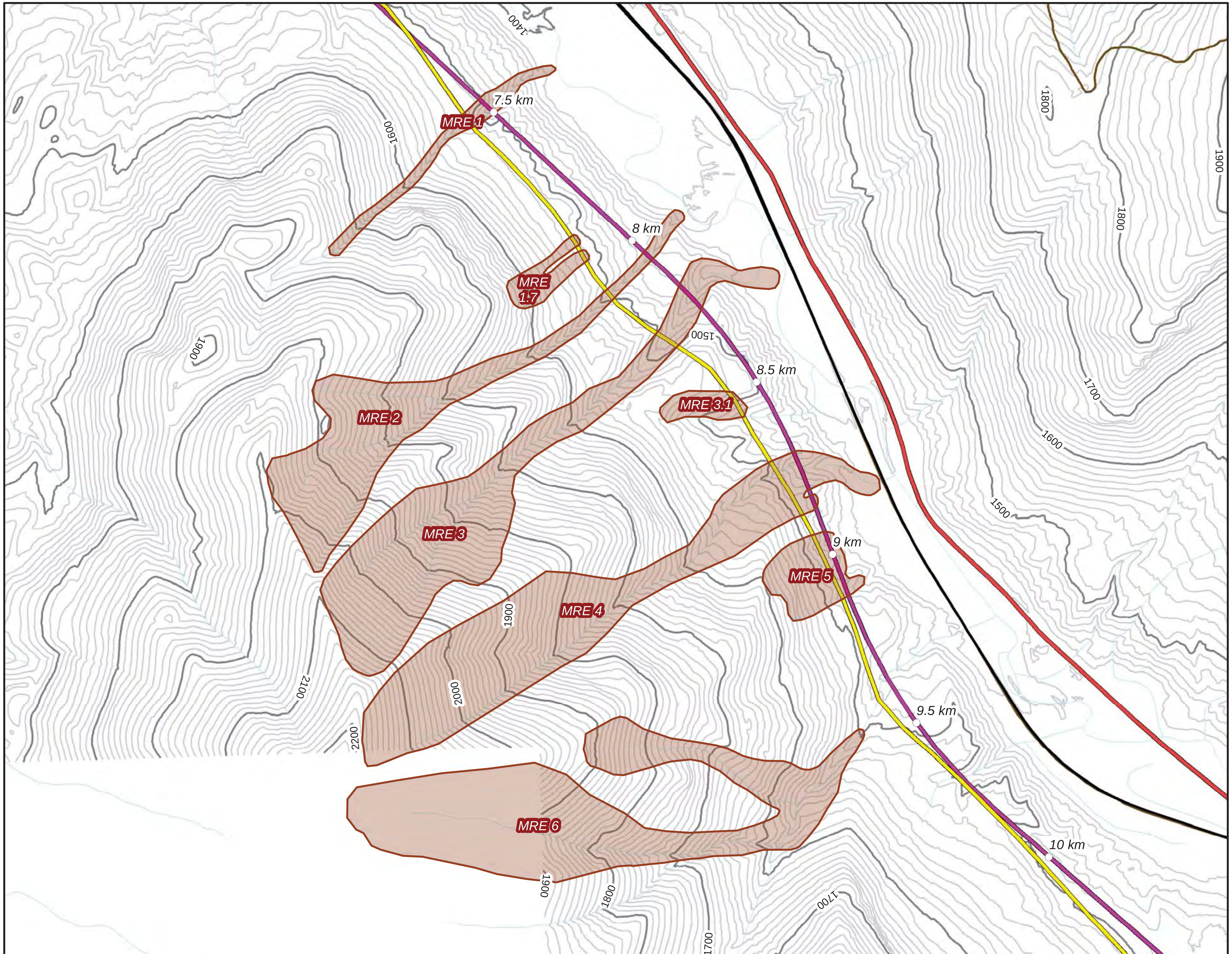
Lincoln, Sublette, and Teton Counties

WYOMING DEPARTMENT OF TRANSPORTATION
DISTRICT THREE

Appendix H

Sample Avalanche Path Map

Courtesy of Dynamic Avalanche Consulting



Avalanche Path Map

Map Sheet 3 of 4

Legend

- Avalanche Path
- Stream or River
- Gravel Road
- Paved Road
- Haul Road
- Rail
- Conveyor Alignment
- Haul Road Alignment
- Conveyor or Haul Road Alignment

Contours - 10 m

- Index Contour
- Intermediate Contour

NOTES:
Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.

N

Meters

0 125 250 375 500

Scale: 1:10,000
Contour Interval 10 m
Coordinate System: NAD 1983 UTM Zone 11N
Unit: Meter

DYNAMIC
AVALANCHE CONSULTING LTD
Box 2845 Revelstoke, BC, Canada V0E 2S0
Ph: (250) 837-4466 dynamicavalanche.com

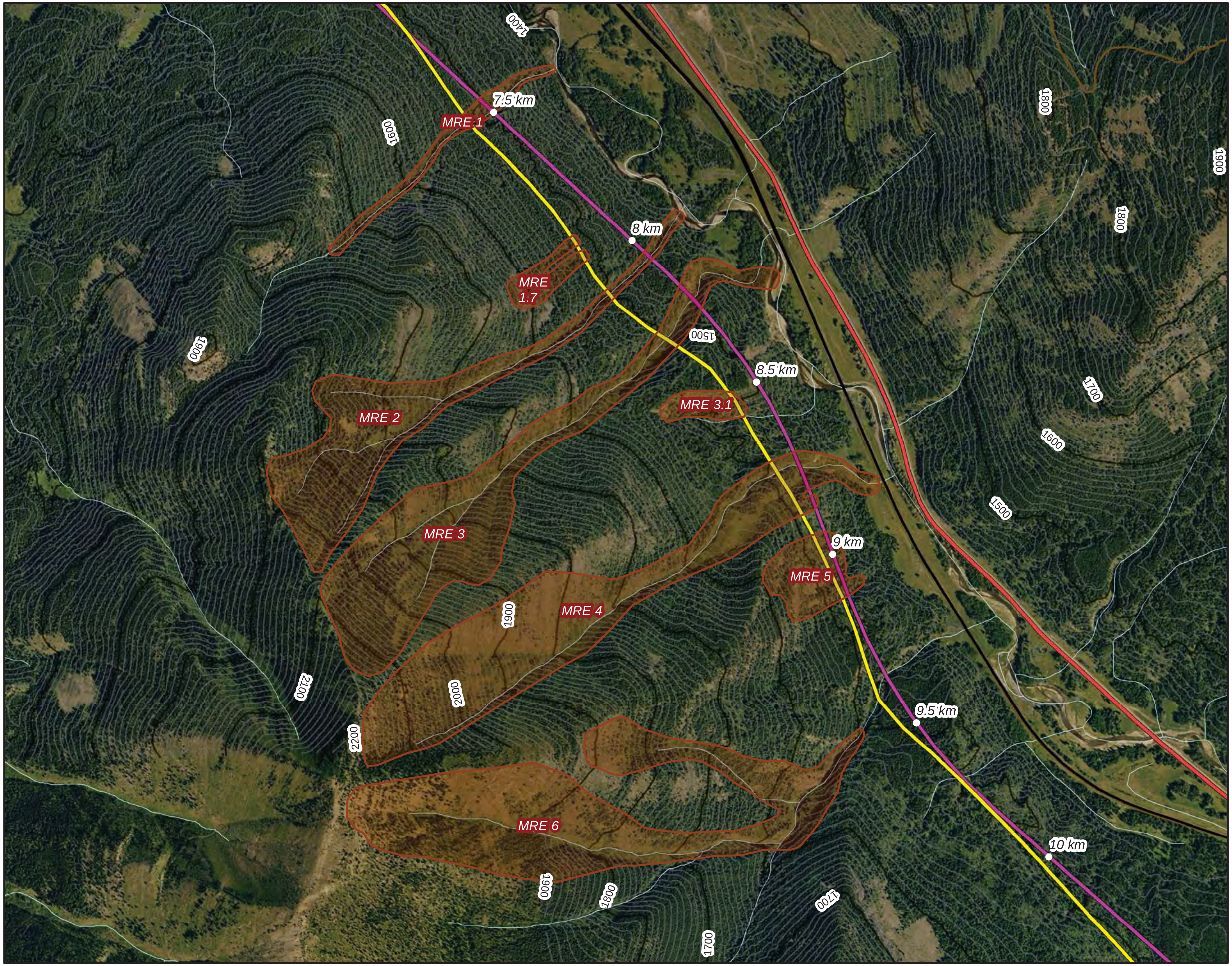
Drawing Number:

Date:

Designed by:

Reviewed by: Alan Jones, P. Eng

Drawn by: Chris Argue, Dipl. T



Avalanche Path Map

Map Sheet 3 of 4

Legend

- Avalanche Path
- Stream or River
- Gravel Road
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- Conveyor Alignment
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NOTES:
Map scale is intended for 11" x 17" paper size. Actual scale may vary depending on printed paper size and printer settings.

Data Sources:
1. Base imagery from Bing Maps

N

Meters

0 125 250 375 500

Scale: 1:10,000
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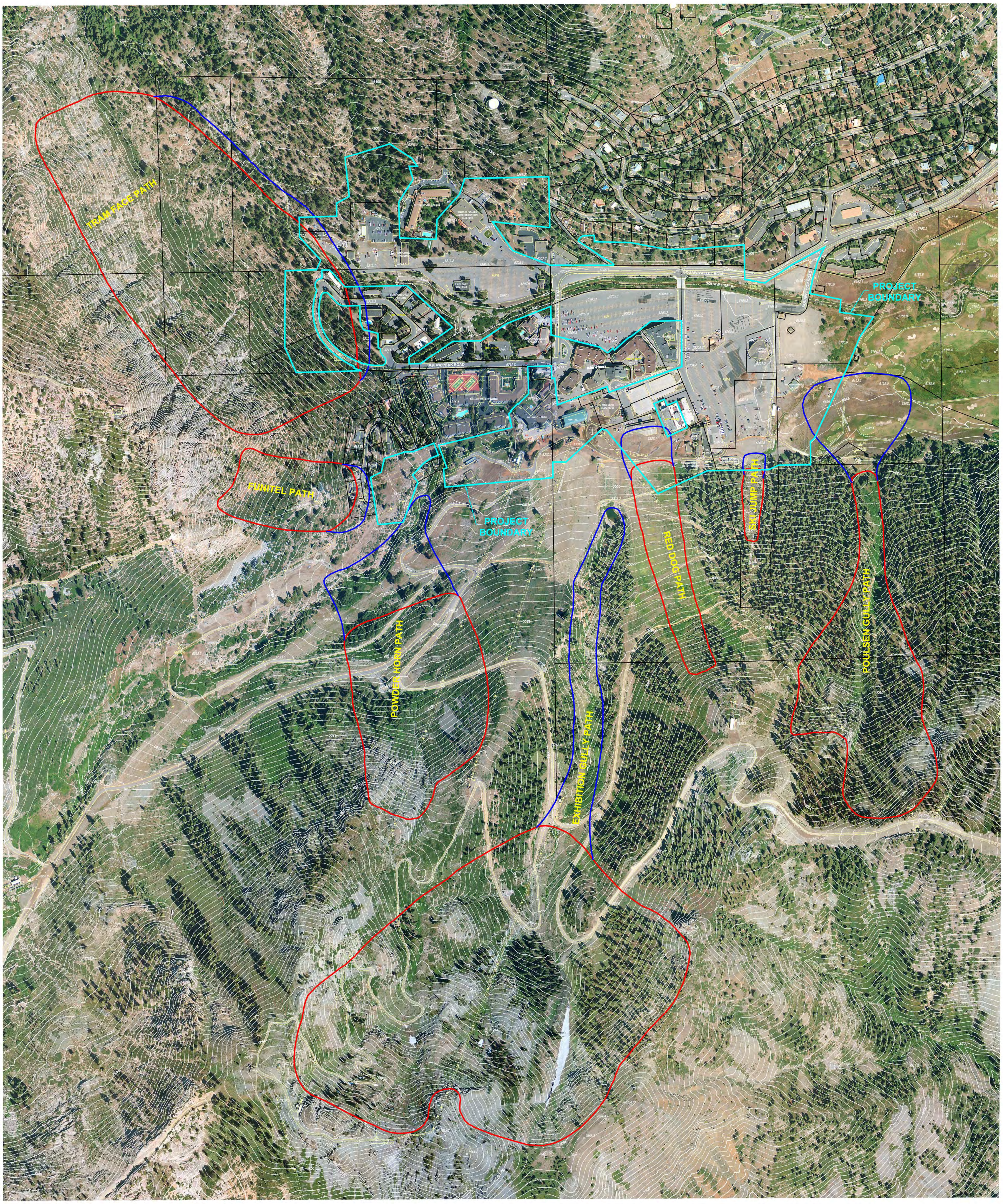
Appendix I

Sample Avalanche Hazard Map for an avalanche hazard assessment for proposed expansion of the Village at Squaw Valley

Courtesy of Larry Heywood



LEGEND

HEYWOOD POTENTIAL AVALANCHE HAZARD AREAS

- (red line) HIGH HAZARD AREA
- (blue line) POTENTIAL HAZARD AREA

SCALE: 1"=300'

0 75 150 300 600 900

AVALANCHE HAZARD MAP
HEYWOOD POTENTIAL AVALANCHE HAZARDS
SQUAW VALLEY

A PORTION OF
SECTION 29, 30, 31 & 32, T.16 N., R. 16 E., M.D.M.
OLYMPIC VALLEY
PLACER COUNTY, CALIFORNIA
SCALE: 1"=300' NOVEMBER 14, 2012

ANDREGG GEOMATICS
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X: \ldd2\1413101\dwg\C3D_1413101EX—Avalanche—study—121109.dwg

PREPARED AT THE REQUEST OF:
LARRY HEYWOOD
SNOW AND SKI SAFETY CONSULTANT

DATE OF AERIAL PHOTOGRAPHY AND TOPOGRAPHY:
AUGUST 2011, 20 FOOT CONTOUR INTERVALS

BOUNDARY SHOWN HEREON IS APPROXIMATE BASED ON LIMITED AND ARCHIVAL FIELD SURVEYS AND THE PLACER COUNTY GIS LANDNET

AVALANCHE PATH LOCATIONS PROVIDED BY LARRY HEYWOOD

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Appendix J

Evaluation of the California State Highway 88 Avalanche Control Program Carson Pass and Carson Spur

Courtesy of Larry Heywood

EVALUATION OF THE CALIFORNIA STATE HIGHWAY 88
AVALANCHE CONTROL PROGRAM
CARSON PASS AND CARSON SPUR

June 2009

Prepared by;

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SCOPE & GOALS OF THE EVALUATION

This evaluation was conducted at the request of Mr. Joel Allen, Regional Manager of District 10 of the California Department of Transportation. The purpose of the Evaluation was to provide an assessment of the current avalanche control program on California State Highway 88. The scope and goals of the Evaluation were to include:

- Evaluation of Current Practices
- Assessment of the Programs Capabilities and Limitations
- Validation of Program's strengths and successes
- Survey and Assessment of equipment and installations
- Make recommendation on areas of improvement or modernization
- Develop an Action Plan for implementation of recommendations

EVALUATION METHODOLGY

The Evaluation included surveys, assessments and review of the following.

- Review of the Program's current Manual of Operations
- Review of the Program's historical weather observation, snowpack observations, avalanche control, and related records
- Review of the 1972 Norm Wilson Carson Pass Avalanche Report
- Review of the Program's Explosive use procedures, storage procedures, explosive use records, explosive safety and compliance procedures and documentation and explosive training records.
- Review of the Programs Avalanche Rescue Procedures
- Survey and assessment of the Program's weather observation instrumentation
- Survey of the avalanche terrain and avalanche paths affecting the Highway
- Survey and assessment of the Locat installations and operation
- Survey and assessment of the Gas X installations, maintenance and operating procedures
- Calculation of a Simplified Avalanche Hazard Index

The Evaluation included in-depth meetings and discussions with Cal Trans staff. Mr. John Carnell and Mr. Rob Bickor were an invaluable resource during the Evaluation. They assisted me during my survey of the operation and terrain and provided valuable insight regarding the Program's operation. They also made available the Program's written Manuals, records and procedures. I also met with Mr. Matthew Leach, Area Superintendent and Mr. Cliff Bettencourt, Caples Lake Station Supervisor.

PROGRAM EVALUATION

The Highway 88 Avalanche Program has a long history of successful operation. It has an exemplary safety record that reflects the dedication and knowledge of the Highways staff over the past four plus decades. The State has made significant investments in the installation of the Gas X and Locat systems in many ways leading other states in investments in avalanche control systems. The current avalanche control staff are experienced, knowledgeable and are a great resource and asset to the Program. The Programs strengths are many and are founded on the long dedication and interest of the Programs staff.

The basic avalanche control operation of weather and snowpack observation and analysis, avalanche hazard forecasting, road closures and avalanche control using the systems available is performed in a timely and professional manner. This has resulted in both a safe program and keep the closures of the Highway to a minimum. The real and documented strength of the program is that it keeps the traffic moving.

Listed below is a discussion and recommendations of some specific areas within the Program that could use upgrading, modernization and/or additional focus. Some of the recommendations would help bring the Program in line with the generally accepted practices for similar programs in the United States. Other recommendations are offered that should provide for improved, more efficient and or safer operation.

<u>Manual of Operation</u>

The current Manual of Operation and other SOPs for the Highway Avalanche Program are dated and does not accurately reflect the current operating procedures. **It is recommended that the Programs Manuals and SOPs be reviewed and updated or revised as necessary to reflect the current operating conditions and procedures.**

<u>Weather, Snowpack and Observations and Record Keeping</u>

It is recommended that the avalanche control staff develop weather, snowpack and avalanche observation protocols and record keeping methods that meet the *Observational Guidelines for Avalanche Programs in the United States.* It is suggest that this information be presented in a place and a format that is easily available and understandable by other staff members. This can assist and encourage the development and continuance of a snow culture that promotes other staff interest in avalanche safety. **It is also recommended that the Avalanche Control Program be assigned a dedicated room for conducting their operations.**

<u>Weather Observation instrumentation</u>

Accurate and timely weather observation are critical to accurate forecasting of the avalanche hazard to the Highway. Currently the Highway 88 Program utilizes weather observations available from third party agencies through the web and some manual observations. This approach does not provide all the specific real time data necessary and usually available to Programs of this type. Accurate and site specific information of this type not only improves the accuracy of the avalanche forecasting process but also provides a record of the parameter considered. **It is recommended that Cal Trans install automated weather instrumentation sites at both the Caples Lake Maintenance Station and a location near the avalanche starting zones on the Carson Spur.** The system should include the necessary hard and software technology necessary to access, assimilate and store the observation data.

<u>Gas X Maintenance</u>

The Gas X Exploders are the primary method of avalanche control on Highway 88. Although the Program supplements the control provided by the Exploders with explosive hand charging and has a Locat system available as a backup to the Gas X system, the reliance on the Gas X system cannot be overstated. Generally the system has been reasonably reliable. Historically Cal Trans has relied on an outside contractor to perform the annual and major maintenance. This has resulted in inconsistent maintenance and reliability.

Recently with the addition of more dedicated staff time and resources, Cal Trans staff has taken on much of both the routine as well as major maintenance and upgrades of the Gax X installations on Highway 88. This has resulted in a notable improvement in the reliability of the system. Failure of the system to operate when needed can result in compromised safety of workers and the public and extended closures of the Highway. With the resent involvement of Cal Trans staff in the maintenance of the system, reliability has increased from a historic successful firing rate of 82% to 93% for this past winter. Additional benefits of Cal Trans staff maintaining the system is improved familiarity of the system, the ability to repair the system quickly in the event of a failure and most importantly a sense of ownership in the system. The staff involved in this process continues to gain knowledge and familiarity on the system and has modernized the system. This knowledge and experience could serve as a model and resource for Gas X installations on other highways in California. **It is recommended that this program of in-house maintenance and upgrading of the Gas X system be continued and that adequate staff time be allotted during the non winter season to accomplish required maintenance.**

Staffing Requirements

Historically the staffing for the Highway Avalanche Control Program has relied primarily on maintenance staff conducting the required avalanche duties on an as needed basis. There has not been a designated full time avalanche control staff. Generally this approach has worked adequately with the primary duties getting done. What this system of staffing failed to adequately support was an appropriate level of weather and snowpack observations and analysis and an appropriate system of record keeping that meets the *Observational Guidelines for Avalanche Programs in the United States.* This system of staffing has also challenged the ability of staff to conduct routine maintenance of avalanche control equipment, staff training, and other related duties. Recently this situation has been improved with the addition of one designated avalanche worker and more time allotted for a second part time support worker. With this recent addition of focused staff the Program has seen significant improvement, modernization and innovation.

Most other western State DOTs with avalanche control programs employ avalanche specialists who's primary duties are focused on the operation, maintenance and training of the avalanche control program. Washington, Utah, Colorado, Alaska, Wyoming and Idaho DOTs all follow this model. Most of the staff in these programs are career avalanche specialists by interest, training and experience. This is a model that Cal Trans should consider and explore.

To develop the skills and experience necessary to Avalanche forecasting and control takes time. Critical to the long term success of this type of program is a continuity of knowledge and skills within the staff. Generally this type of continuity can only be developed and maintained with a mentoring process where inexperienced or less experienced staff work with experienced staff. This takes an investment in time and resourses.

It is recommended that at a minimum two designated avalanche workers be assigned to the Highway 88 Avalanche Control Program. Staffing for the future should consider a three person crew with one assigned to each shift. This would allow for developing a continuity of knowledge, skills and experience into the Program. **It is also recommended that the avalanche control staff be allotted necessary time and resources during the non winter season to allow for necessary maintenance and upkeep of the Program.**

Some of the duties necessary to be performed by dedicated avalanche control staff include:

Revise and update the Program's Manual of Operation and other SOPs
Implement an up dated system of Snow and Weather Observations that conforms to *Snow, Weather, and Avalanches: Observational Guidelines for Avalanche Programs in the United States*
Conduct routine snow pack analyses, including standardized stress test
Develop, implement and maintain a record of standard snow and avalanche observations
Maintain weather observation instrumentation
Conduct avalanche control operations
Implement recommendation of this report
Conduct staff training in avalanche safety, rescue and for program support
Program development
Perform routine equipment maintenance
Equipment inventory
Assist other Districts with Gas X Maintenance

Avalanche Rescue Plan

The existing Cal Trans Avalanche Rescue Plan for Highway 88 has not been updated for some time and does not adequately reflect the current operating realities. **It is recommended that an updated Avalanche Rescue Plan be developed. This should, at a minimum, include the following components:**

Worker safety and rescue
Public rescue
Employee Training
Rescue equipment requirements and maintenance
Outside rescue resources
Relationships with other agencies
Utilization of new technology

Equipment

Currently the designated Highway avalanche control workers do not have a dedicated vehicle to perform their duties. This situation has at times limited their ability to perform their job duties. Frequently their duties require them to work under very extreme weather and road conditions. The ability to perfume their duties and respond to emergencies is critical. **It is**

recommended that the avalanche control team be assigned a dedicated appropriate vehicle. This vehicle would be used to perform their duties including:

Observation of avalanche activity on the Highway
Observation of weather, winds and snowpack
Response to avalanche emergency or rescue
Use as avalanche rescue equipment storage cache
Transport of explosives
Transport of personnel for maintenance duties
Mobile mount for future installation of Avalanche Pipe

Avalanche Atlas Development

An Avalanche Atlas provides information of Avalanche Paths within a specific area. The usual format includes photographs of the avalanche path, information of the physical characteristics of the path and information of the frequency of avalanches producded by the path. Additional information can include the identification of the trigger points, type of weather and snowpack conditions that produce avalanches and notes on historical avalanches. An Avalanche Atlas can be a useful if not indispensible tool for maintaining consistency in the identification of avalanche paths, proper recording of avalanche occurrence size and identification the determination of the effectiveness of avalanche control operations. The Atlas can be a useful training tool for educating workers and maintain continuity and consistency within a programs knowledge base.

The existing Avalanche Program for Highway 88 has developed a good and useful knowledge base on the components of a formal Avalanche Atlas. Much of this information is not easily and readily available to all personnel at the Caples Lake Station. The development of an Avalanche Atlas for Highway 88 would greatly assist in the general understanding of maintenance personnel at the Station and would be a useful tool for maintaining continuity of the existing knowledge base for the future. **It is recommended that an Avalanche Atlas be developed for the Highway 88 Avalanche Program.**

Expansion of Gas X Exploder Program

The Gas X Exploder installation on Highway 88 was one of the first in North America and remains one of the largest and most complex installations in North America. During its lifetime it has undergone expansion and modification to improve it's capabilities to provide for better protection of the Highway and improve the efficiency of the avalanche control operations. It is the nature of these types of programs that the limitations of the installation and opportunities to improve the efficency of the operation continue to reveal themselves with time. For the avalanche control staff working at Highway 88 this has been an ongoing process.

Currently there are a couple of areas and avalanche paths that are not effectively controlled by Gax X exploders. To control these areas requires the Highway avalanche control workers to place explosive hand charges into the avalanche start zones of these areas. This is a time consuming process that can affect the consistency and effectiveness of the Program. To remedy this deficiency avalanche control staff has identified locations within the Chutes 10, 11 and 12 that could be more effectively controled with either the addition of additional exploders as well as the relocation of existing exploders. **It is recommended that Highway 88 avalanche control staff and Cal Trans determine the appropriate options for additional exploders and start the process for procurement and installation.**

Apron Control

The Apron is a fairly continuous slope below the cliffs along the Carson Spur. This slope can and has produced avalanches that reach the Highway. The current system of avalanche control with Gas X, Locat and explosive hand charges does not provide for the delivery of explosives to the Apron slopes below the cliffs. During periods of heavy snowfall and high avalanche activity the current inability to adequately control these slopes has resulted in uncontrolled avalanches reaching the Highway. **It is recommended that a mobile explosive delivery system be installed to control these slopes.**

AVALANCHE HAZARD INDEX

The Avalanche Hazard Index (AHI) assesses the avalanche risk to traffic. It is a numerical expression of the avalanche hazard on a road. The index is determined by calculating the probability of moving and waiting vehicles being hit by various types of avalanches and multiplying the probability with a weight according to the severity of damage. Calculation of the AHI considers several factors, including:

- Average winter daily traffic
- Traffic speeds
- Average length of avalanche debris on the roadway centerline
- Vehicle braking
- Avalanche frequency
- The number of avalanche paths at the road
- The distance between the avalanche paths

This method has been applied on most highways in the United States, Canada and New Zealand to quantify the avalanche hazard for roads. The AHI provides a comparison of the avalanche hazard between different roads and the level of control that is applied and acceptable. Highways are categorized with respect to the AHI into the following categories:

- Very Low
- Low
- Moderate
- High
- Very High

There is a North American Practices in Highway Operations that details by Hazard Category the customary personnel staffing requirements, explosive control requirements, weather and snow pack observations requirements and other types of avalanche control requirements.

To calculate the AHI for a particular highway requires detailed information and data that is not currently available for Highway 88. At the recommendation of this author Caples Lake Cal Trans personnel have initiated a program to develop the data and information required to develop an AHI for Highway 88. Once this data and information is developed it will provide an opportunity to more accurately compare the AHI for Highway 88 with other North American highways with avalanche hazards. **It is recommended that the AHI for both Carson Pass and Carson Spur be calculated. This will require the collection and development of the data and inputs to make the calculation.**

Simplified Avalanche Hazard Index

The calculation of the AHI requires data about the average width and frequency of occurrence of two types of avalanches at each individual avalanche path. Because this information often is difficult to obtain, a simplified hazard index was developed for the comparison of the hazard among roads and control measures applied. Although this method is not as accurate or reliable as the detailed AHI method it nevertheless provides useful information of the scale of the Avalanche Hazard on a Highway.

The simplified avalanche hazard index (SAHI) is:

SAHI = A x p x N/100

where;

A = average annual number of avalanche that cover the full width of the road (sum of all paths)
P = average number of avalanche paths per road kilometer
N = average daily winter traffic volume (vehicles per day)

The inputs for the calculation of the SAHI for Highway 88 have been based on the historic record of avalanche occurrences accumulated for the Highway. **Based on this calculation the SAHI for Highway 88 falls into the Very High category.**

According to the North American Practices in Highway Operations the following measures are recommended and usually applied for highways that are categorized with a Very High Index:

<u>Personnel</u>	**Full – and – part time personnel in forecasting and control operations**
<u>Explosives</u>	**Active control with multiple fixed & mobile explosive systems**
<u>Data</u>	**Multiple remote alpine weather stations & alpine snow plot observers**
<u>Closures</u>	**Short control closures with occasional preventative closure**

The Highway 88 Avalanche Control Program should be in conforming with these Practice recommendations.

CONCLUSIONS AND RECOMMENDATIONS

The avalanche hazard to Highway 88, the workers who maintain the Highway and the public using the road is well documented. Based on the SAHI the Highway has a Very High avalanche hazard. The combination of the intensity and severity of the winter storms, the intense and sustained snowfall, the frequency of avalanche occurrences on the Highway, and the number of avalanche paths affecting the Highway, results in Highway 88 having one of the highest avalanche hazards for a highway in the United States. Further support of this observation is the calculated SAHI of Very High for the Highway.

To meet the challenges presented by this hazard, Cal Trans and the past and current staff at the Caples Lake Maintenance Station has developed an Avalanche Control Program that has performed well in meeting the challenges presented by this hazard. The Program's safety record is exemplary. The Program has evolved based mostly as a result of the practical experience of the avalanche control personnel working at the Caples Lake Maintenance Station. Using a combination of ingenuity, trial and error and common sense the program has developed procedures and methods that have proven successful. Generally this process has taken place without much interaction with other western state's avalanche programs and other avalanche professionals.

This in-house evolution has resulted in some gaps in the Program. Although this appears to have not compromised the safety of the workers or public, it has resulted in the program not operating at the same standard as some other western state avalanche programs. Central to the shortcomings of the program have been the time constraints placed on avalanche control staff. Until recently there has not been designated full time winter staffing.

A primary consideration going forward should be the recognition that the Avalanche Hazard on Highway 88 is significant and requires the formalized focus that other State DOT's have developed. This includes appropriate staffing levels for avalanche control personnel, conformance with avalanche industry standards of snow and weather observations, standardized record keeping, and meeting the recommendations of the North American Practices for Highway operations for programs with a Very High Index.

ACTION PLAN AND PRIORTIES

Many of the recommendations made in this Evaluation can be developed and implemented by the existing avalanche control staff. Utilizing these staff members should result in the development of methods and procedures that meet the specific needs of the Program and fit within the capabilities of the time and resources available. It is recommended that the process utilize the resources of an outside consultant familiar with generally accepted practices. The role of the consultant should be to act as an information resource, provide guidance on generally accepted practices and to review and provide input on manuals, SOPs,and procedures that are developed.

Primary to the development and implementation of many of the recommendations in this evaluation is establishing necessary staffing levels and providing staff with an appropriate vehicle.

Phase II

Develop a program for conforming with the *Observational Guidelines for Avalanche Programs in the United States.* This should include:

- Develop and implement procedures for Snow, weather and avalanche observation and record keeping
- Implement and record standard snowpack tests as defined in the *Guidelines*
- Update and revise the Manual of Operations and other SOPs
- Update the Programs Avalanche Rescue Plan

Phase III

Develop an Avalanche Atlas

Calculate a detailed Avalanche Hazard Index, aquire the necessary date and inputs

Develop options for avalanche control on the Apron

Design, procure and install automated weather instrumentation