THE COLORADO AVALANCHE WARNING PROGRAMME

K. Williams

Introduction

In November 1973, a formal avalanche warning programme for Colorado first became a reality as a cooperative venture between the U.S. Forest Service and the National Weather Service. The objective of the programme is to warn the public of unusually dangerous avalanche conditions, with warnings aimed primarily at persons travelling the back-country, where most serious avalanche accidents occur (Williams 1975).

In the past two winters, more than 100 avalanche warning bulletins have been issued for the Colorado mountains. Media coverage and public acceptance of the warning programme have been encouraging, and in future years, we look to increased public reliance on avalanche warnings as our credibility becomes established. In this paper, we will look at what it takes to set up and run such a programme.

Overall Concept and Operation

The avalanche warnings result from analysis of data received from a network of observing sites throughout the Colorado mountains (Fig. 1). At each site, an observer transmits daily readings of weather, snow, and avalanche conditions to the central forecasting office (Avalanche Warning Center) in Fort Collins. (The central forecast office could be at any location having full telephone facilities, teletype communications, and quick computer access.) The winter season from November through May is covered by the programme.

Essential mountain weather forecasts can be provided by either the National Weather Service, a contract meteorologist, or by the avalanche forecaster himself if he has the skills and necessary data. These forecasts include the intensity and duration of storms, quantitative snowfall amounts for mountain zones, speed and direction of mountain-level winds, and temperatures. The method or agency providing the best forecast accuracy should obviously be used in the warning programme.

Overall manpower requirements are:

1. at least one observer at each mountain site who can take observations daily, and who can be reached by phone 7 days a week if necessary.

2. two avalanche forecasters at the forecast office.

3. a weather forecaster and

4. a technician who can install, repair and calibrate the instruments.

Presently the technician's job is performed by the avalanche forecasters.

The role of the avalanche forecaster will be viewed in more detail, but it must be emphasized that the forecaster at present is not working with a numerical hazard model of any sort. (One of the active research programmes of the USFS Avalanche Project is to develop such a model.) Rather, he must digest a large amount of data to arrive at a judgment, based on experience, of the overall avalanche danger for a given portion of the mountains. The forecaster's job, therefore, requires previous experience and knowledge of avalanches.

Field Sites and Observers

The network of mountain sites used in the avalanche warning programme is an outgrowth of the U.S. Forest Service Westwide Avalanche Network, which has been responsible for gathering weather and avalanche data from all over the western United States for the past 10 years (Judson 1970). In Colorado, this network includes observation sites at ski areas, mining operations, mountain highway passes, and mountain communities. The major data collection sites are as follows (Fig. 1): ski areas--Steamboat, Loveland Basin, Arapahoe Basin, Keystone, Breckenridge, Copper Mountain, Vail, Aspen Mountain, Aspen Highlands, Snowmass, Crested Butte, Monarch, Telluride, and Wolf Creek; mining companies--Urad-Henderson Mine and Camp Bird Mine; mountain highway passes--Berthoud, Loveland, Monarch, Red Mountain, and Wolf Creek; mountain communities--Winter Park and Silverton; and miscellaneous sites-Bear Lake in Rocky Mountain National Park, Grizzly Reservoir, and Gothic.

The observers at the majority of these locations are strictly volunteers for our programme, and consist of

professional ski patrolmen, mining company employees, and highway employees. The observers are paid at Winter Park, Berthoud and Loveland Passes, Red Mountain Pass, Grizzly Reservoir, and Gothic. In establishing some of these sites, we have tried to take advantage of any remote locations where winter residents live. Therefore, the total number and locations of the observing sites may change slightly from winter to winter.

The responsibilities of the observers are as follows: To take daily readings of total snow depth, amount of new snow and its water equivalent, maximum, minimum, and current air temperature, snow temperature, and windspeed and direction (or, if not equipped with wind instruments, an estimate of snow transport by the wind). Each observer also makes daily observations of avalanche occurrence in his area, and makes his own estimate of the avalanche hazard. Snowpits are dug whenever warranted (or requested by the avalanche forecaster) to yield information on snowpack stratigraphy. The observer records all this information on a data chart, then telephone it to the central forecast office (Fig. 2).

Role of the National Weather Service

The National Weather Service (NWS) office in Denver provides updated weather forecasts several times a day for the Colorado mountains. These are transmitted routinely over the Colorado Weatherwire, and are received via teletype at the avalanche forecast office. NWS forecasters can be reached any time, day or night, by the avalanche forecaster for the latest weather information. In addition, the NWS carries the avalanche warnings on a recorded telephone message and on their VHF radio weather broadcasts.

Data Links

The main link between the avalanche forecaster and the field sites is the telephone. Several remote mountain sites (Gothic and Wolf Creek Pass) use radios to transmit their daily data to an intermediate site, which can then telephone these data to the avalanche forecaster. The Fort Collins forecast office is equipped with a recording code-a-phone to receive incoming phone calls from field observers. This is a special toll-free incoming WATS line which any observer can call any time, day or night, to leave data or messages. If the avalanche forecaster is at the office, he can answer the phone and talk to the observer directly. If not, the observer leaves his message on the code-a-phone. This combination of incoming WATS line and code-a-phone is a higly efficient money-saver, since

messages can be received 24 hours a day, 7 days a week, with no need for operator-assisted long distance calls.

The forecast office is also equipped with a "send-receive teletype" directly tied to the Colorado Weatherwire. Some of the information received is:

1. weather forecasts for Colorado and surrounding States.

2. daily weather reports from widespread Colorado communities via the Colorado Amateur Radio Network.

3. daily Ski Country USA reports and

4. mountain highway conditions.

The teletype is also used to send avalanche warnings to all subscribers of the Weatherwire at once. The message is sent out directly from the forecast office.

Role of the Avalanche Forecasters

From November through May, avalanches know no time schedule. This makes the job of avalanche forecasting a continuous one for the winter, although there can be prolonged periods of stable snow conditions when the forecasters can work at other duties. But because of the potential for working evenings and weekends, the job requires that a least two persons share the responsibility. During lengthy periods of storms and avalanches, the job is too demanding for a single forecaster. The two forecasters must work out a time-sharing schedule so they can spell each other from time-to-time.

The main responsibility of the avalanche forecaster is to make daily contact with as many mountain observers as is necessary to get a complete picture of avalanche conditions throughout the Colorado Rockies. This is done by making and receiving phone calls, making full use of the code-a-phone recorder, and monitoring the teletype information. The forecaster must then weigh all the field observations--snowpack structure, amount of new snow and wind, avalanche occurrence, and field observers' estimate of hazard--with a mountain weather forecast to arrive at his own estimate of the avalanche hazard. When he feels the hazard is sufficiently high, he issues a warning covering the affected mountain area. He updates the warning bulletins once or twice daily until the hazard has abated, and then terminates the warning.

Warning Dissemination

The warning bulletins are typed and sent by the avalanche forecaster over the teletype, which gets the message instantly to all subscribers to the Colorado Weatherwire. This audience includes most of the major radio and TV stations and daily newspapers in Colorado. Bulletins are normally sent twice daily (11:00 a.m. and 4:00 p.m.) to ensure good news media coverage. With the cooperation of the news media, the warnings are then broadcast to the public. The wording and content of the avalanche warning bulletins is covered thoroughly by Judson (1975). Figures 3 and 4 are examples of bulletins issued last winter.

In addition to news media broadcasts, the warnings are carried in the Denver area on the National Weather Service VHF radio weather and on code-a-phone recordings by the NWS and the U.S. Forest Service. Upon receiving an avalanche warning, the USFS in Denver notifies all affected Forest Service offices in the State so that they might further spread the word.

An Orographic Snowfall Model

Beginning in November 1975, we have had use of an important new forecasting model for Colorado mountain snowfalls. This computer model provides 12- and 24-hour quantitative precipitation forecasts for any location in the Colorado Rockies. It must be emphasized that this model predicts only precipitation due to forced orographic lifting; precipitation due to other lifting mechanisms--cyclonic, frontal, and convective--is not included. However, the orographic lifting mechanism is, by far, the most important in producing winter mountain snowfalls. (The other lifting processes are important occasionally, especially convection in the spring, but the skilled forecaster will be able to add these contributions to the orographic amount.)

This model was developed (with Forest Service research funds) by Owen Rhea as his doctoral dissertation in atmospheric science at Colorado State University (Rhea 1975). As a starting point, elevations at 2.5 km grid points for all the Colorado mountains were obtained from U.S. Geological Survey topographic maps. These data were then averaged over a 10 km grid to construct a smoothed topography (Fig. 5A). Armed with this elevational contour map in the computer, the modeller can then trace an air trajectory across the contours to produce an irregular pattern of lifting and sinking. With initial conditions of wind speed,

direction, temperature, humidity, air mass stability, and an estimate of precipitation efficiency, he can then calculate, through a set of equations, the rate and amount of lifting and, hence, the amount of precipitation that each mountain range barrier extracts from the air. The natural result is that the first major mountain barrier struck by an airstream is generally going to receive the heaviest snowfall, with subsequently lesser amounts falling on downstream mountain ranges due to lesser amounts of remaining available water.

The above is a brief description of how the orographic snowfall model works. But, in practice, how is it used by the forecaster? Wind direction is the crucial parameter in determining where the orographic effect will show itself, i.e., which areas are the windward lifting zones and which are leeward and therefore shadowed. Other parameters determine the strength of the lifting process and the amount of precipitation. Therefore, the initial step was to generate a set of model precipitation-pattern maps. Twelve maps were produced, one for each 30° of azimuth of wind direction (30°, 60° .... 360°) and each depicting a "calibration storm" from that wind direction. The "calibration storm" concept is to select, and maximize, an initial set of values for wind speed, temperature, humidity, etc., on the upwind perimeter of Colorado and then run the computer model for each of the 12 major wind directions. The result is a pattern of relative precipitation amounts--an isohyetal map--that is unique for each wind direction. Figures 5 B, C, and D show the orographic precipitation pattern for wind directions of 210°, 270°, and 330° respectively. The forecaster is thus equipped with 12 maps of equal calibration showing him where to expect the heaviest down to the lightest relative snowfall amounts in the next 12 or 24 hours for a given wind direction. (There are seven increments of precipitation from lightest to heaviest.)

The next step is to select the appropriate map and calibrate the precipitation contours for each particular forecast period. This requires a skilled forecaster with daily access to the National Weather Service's Limited-area Fine Mesh (LFM) model predictions. Briefly, the steps taken by the forecaster are these: First, he obtains the 1200Z (0500 LST in Colorado) 12- and 24-hour forecast maps of 850, 700, 500, and 400 mb wind, temperature, and humidity. Based on the large-scale prediction maps, a set of correction factors (dependent upon wind speed, temperature, and duration and depth of moist flow) is applied to the "calibration storm" map corresponding to the predicted 700 mb wind direction. This yields a set of expected precipitation

contour values for the specified time period (12 or 24 hours). Some forecaster judgment is required to determine the duration and areal extent of precipitation. (Occasionally, the forecaster must choose two direction maps, for e.g., 240° for the southern half of Colorado and 270° for the northern half, to represent accurately a varying wind field.) The forecaster is now ready to make quantitative snowfall predictions for specific mountain locations.

Last winter the forecaster's skill score while testing this method was more than twice as good as the NWS forecasts (Rhea, personal communication), an impressive improvement. Consequently, the Rhea model is one of the more important tools with which the avalanche forecaster can arm himself.

Future Outlook

The Colorado Avalanche Warning Programme will continue to rely heavily on daily observations from a number of field sites and on analysis and synthesis of the data by an experienced avalanche forecaster. In the next several years, however, we anticipate several advances that will improve the programme:

1. The orographic precipitation model will be fine-tuned through continued use to give even better forecasts.

2. A computerized snowpack stability model is being developed which would be a further tool for the avalanche forecaster.

3. Automated data sampling with telemetry into the avalanche forecast office will soon be a reality. As an example, for the winter 1976-77 we will be sampling blowing snow, wind, temperature, and precipitation at Berthoud Pass, and telemetering these data direct to Fort Collins.

4. We have plans to add a toll-free telephone number at the forecast office so that anyone in Colorado can call to receive a recorded message covering avalanche warnings, snowpack conditions, a weather forecast, and other pertinent data that would be helpful to back-country travellers.

5. The Colorado programme will probably soon be expanded to include the contiguous mountain areas of northern New Mexico and southern Wyoming.

There may come a time when most of the mountainous West is covered by some type of warning programme. Programmes of varying degrees are already operating in portions of Alaska, California, Utah, Idaho, and Washington (LaChapelle and Fox 1974, Reanier 1976).

As a conclusion, let's pose the question: Can the Colorado Avalanche Warning Programme save lives? By no means can we expect any warning programme to halt avalanche fatalities altogether. This is unrealistic for numerous reasons:

1. avalanche forecasting will never attain 100% accuracy.

2. not everyone will hear avalanche warnings when broadcast.

3. a certain number of people will ignore the warnings anyway.

4. some experienced skiers or mountaineers know well the dangers involved but are willing to accept risks for the thrill of succeeding. But not all will succeed.

For the majority of the public, however, the programme not only gives accurate information on general avalanche danger, but serves to increase avalanche awareness among the listeners. It helps put the thought of avalanches in the minds of mountain recreationists where before the thought was seldom entertained. For this reason alone, it is reasonable to say that, yes, in the long run, the Colorado Avalanche Warning Programme will save lives.

References

Judson, A. 1970. A pilot study of weather, snow and avalanche reporting for Western United States. In: Ice Engineering and Avalanche Forecasting and Control. National Research Council of Canada, Associate Committee on Geotechnical Research. Technical Memorandum No. 98, Ottawa, pp. 123-134.

Judson, A. 1975. Avalanche Warnings: Content and dissemination. USDA For. Serv. Res. Note RM-291, 8 p. Rocky Mtn. For. and Range Exp. Stn., Ft. Collins, Colo.

Lachapelle, E.R. and Fox, T. 1974. A real-time data network for avalanche forecasting in the Cascade Mountains of Washington State. In: Advanced Concepts and Techniques in the Study of Snow and Ice Resources: an Interdisciplinary Symposium. Monterey, Calif., Dec. 1973. National Academy of Sciences, Washington, D.C. pp. 339-345.

Reanier, F.W. 1976. Central avalanche hazard forecasting. Joint Scientific Meeting on Mountain Meteorology and Biometeorology, Interlaken, Switz. June 1976.

Rhea, J.O. 1975. A simple orographic precipitation model for hydrological and climatological use. Am. Geophys. Union Conf. on Analysis of Precipitation for Hydrological Modeling. Davis, Calif. June 1975.

Williams, K. 1975. Avalanche fatalities in the United States, 1950-75. USDA For. Serv. Res. Note RM-300, 4 p. Rocky Mt. For. and Range Exp. Stn., Ft. Collins, Colo.

Discussion

MARRIOTT: What do you mean by 80% accuracy in your precipitation forecasts?

WILLIAMS: It is a skill score based on predicting intervals of precipitation.

KUCERA: What are your snowfall intervals?

WILLIAMS: We forecast water equivalent, not snow. Our water to snow ratio is about 7%. We use intervals of about 5 mm of water.

LACHAPELLE: What upper-air wind level do you use in your model?

WILLIAMS: 700 mb.

MOORE: Suppose you have a windflow pattern with southwest flow in southern Colorado, and northwest flow in northern Colorado, which direction do you use in your model?

WILLIAMS: We would distribute the wind according to the weather map. Only in rare cases is there a storm in Colorado without a well-defined wind pattern. The precipitation model will not work for these rare cases.

REANIER: Do you feel that you could improve your precipitation forecast if you were located closer to a major Weather Service station, like the Weather Office in Denver, for example?

WILLIAMS: Yes, we would have access to more tools.

MARRIOTT: What is the time run on your model?

WILLIAMS: One-half hour after receiving Weather Service information.

SALWAY: I am not quite clear on how you get from your precipitation model to an avalanche forecast. You mentioned that you use Atwater's factors. Do you have any way of rating these factors?

WILLIAMS: We mainly use new snow and sustained wind speeds in a purely subjective synthesis of the data. We do not have a mathematical model, although we are working to develop a model that will replace at least a portion of the subjectivity.

WIERINGA: Do your warnings give details of elevation and exposure?

WILLIAMS: Not yet, we cover only broad geographic areas. Occasionally, however, we specify that the hazard exists only above timberline.

ANDERSON: How specific should the forecast be? Should it identify specific slopes, and exposures?

WILLIAMS: As far as the public is concerned, we feel the more specific the forecast, the better.

SIMMS: Can the general public call you to get forecast information?

WILLIAMS: We release our bulletins through the National Weather Service. Our number is unlisted and we have not in any way encouraged the public to call us. We are, however, in contact with ski areas, and trade information. In the future, we hope to install a toll-free phone to be called by the public.

DALY: I noticed that in your presentation both examples of your warnings were issued at 2:00 p.m. Is this your standard time of release?

WILLIAMS: Not necessarily. We may issue an initial warning any time we receive input, even midnight. After the initial warning, we issue an update twice daily, 11:00 a.m. and 4:00 p.m., the times of best media coverage.

SAIDLARR: As a ski-tourer, I would be interested in receiving a forecast around the clock to help prepare trips.

WILLIAMS: In my paper, I describe how we plan to set up a toll-free number that tourers can call to get pertinent information. They use such a system in Switzerland. I believe they have a similar system in the State of Washington.

HOTCHKISS: Do you have any plans to expand your model to adjacent areas, like Utah?

WILLIAMS: Yes, we would like to work in other areas, the Wasatch, Uintas, Tetons, Bridger's, etc.

KANZLER: How soon can you broaden your scope of operations to these other areas?

WILLIAMS: As soon as the model is proven and we have adequate money and manpower.

FREER: Have you had any problems with liability as a result of accidents when warnings were not in effect?

WILLIAMS: Not yet. There is a legal precedent that the National Weather Service is not liable for incorrect forecasts.

PERLA: Have you tried to verify whether or not your warning programme is effective by comparing increased fatalities since the programme went into effect with the increase in back-country usage?

WILLIAMS: We have thought about this, but we have not been able to obtain reliable statistics for the increase in back-country usage. As a matter of interest, during the past two winters, we had four avalanche fatalities when warnings were not issued, and six fatalities when warnings were in effect.

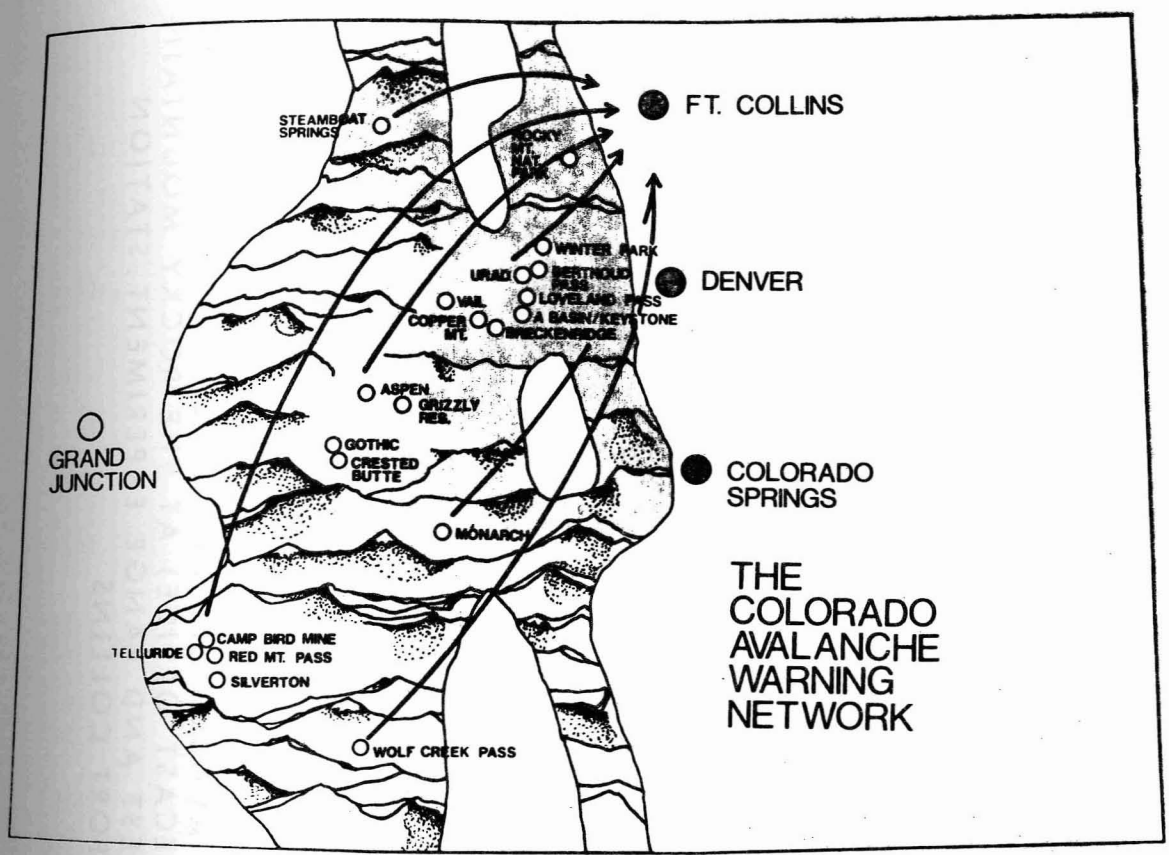

FIGURE 1 THE COLORADO AVALANCHE WARNING NETWORK, PORTRAYING DATA TRANSMISSION TO THE CENTRAL FORECAST OFFICE IN FORT COLLINS

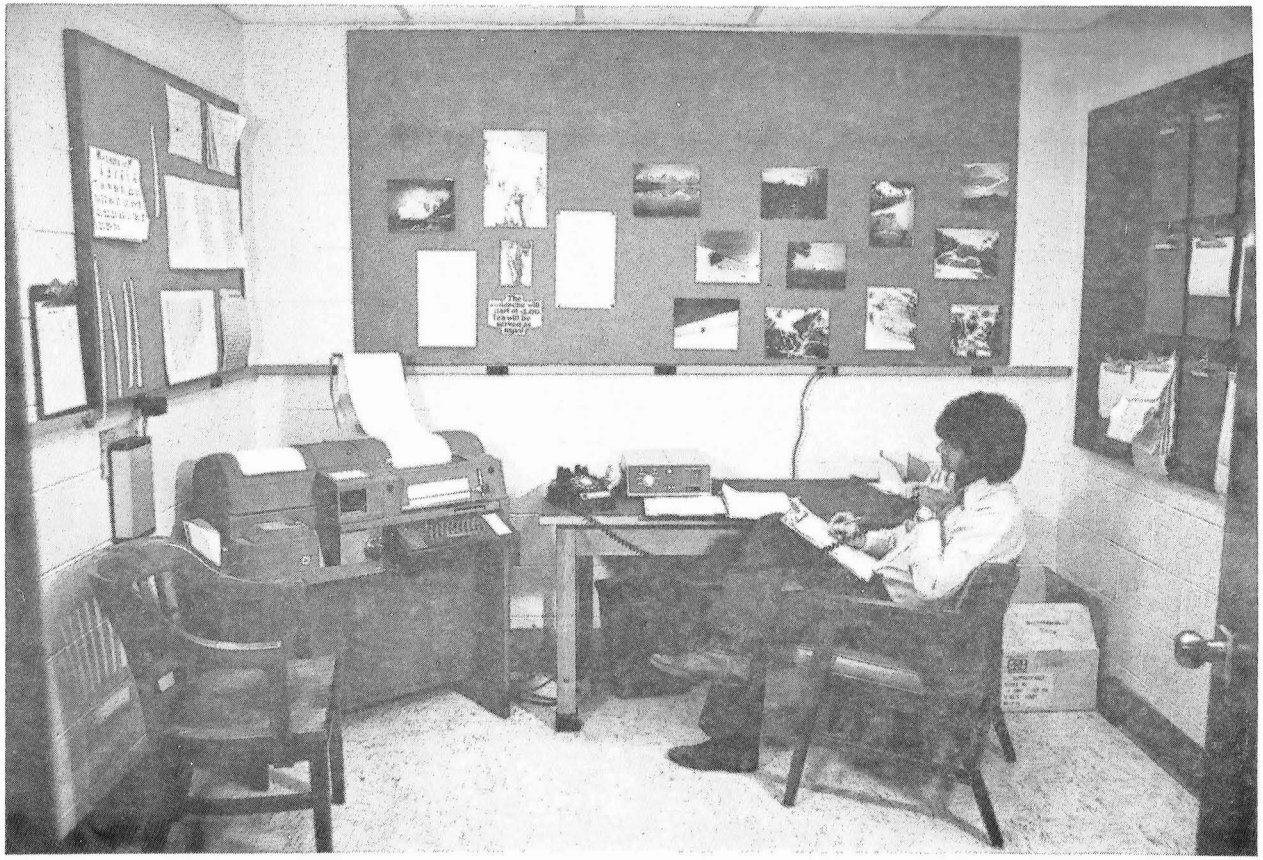

FIGURE 2 THE AVALANCHE WARNING CENTER (CENTRAL FORECAST OFFICE) AT THE ROCKY MOUNTAIN FOREST AND RANGE EXPERIMENT STATION IN FORT COLLINS

ZCZC
AVUS RWRC 022100

AVALANCHE WARNING BULLETIN NO. 1
IMMEDIATE BROADCAST REQUESTED
US FOREST SERVICE FT COLLINS COLO
ISSUED 2 PM MST TUESDAY MARCH 2, 1976

SOUTHWESTERN COLORADO MOUNTAINS

AN AVALANCHE WARNING IS NOW IN EFFECT FOR THE SOUTHWESTERN COLORADO MOUNTAINS SOUTH AND WEST OF A LINE FROM MONTROSE TO ALAMOSA. THE WARNING IS VALID THRU THURSDAY MARCH 4.
HEAVY SNOWFALL AND HIGH WINDS HAVE CREATED DANGEROUS AVALANCHE CONDITIONS IN THE SAN JUAN MOUNTAINS.

MORE THAN 3 FEET OF SNOW HAS FALLEN AT WOLF CREEK PASS AND MORE THAN 2 FEET AT RED MT. PASS. ONLY TWO SMALL AVALANCHES HAVE BEEN REPORTED IN THE AREA THUS FAR, BUT NUMEROUS AVALANCHES CAN BE EXPECTED AS SNOWS AND WINDS CONTINUE.

BACKCOUNTRY TRAVELERS SHOULD AVOID KNOWN AVALANCHE PATHS, STEEP SLOPES, AND GULLIES.

FURTHER AVALANCHE BULLETINS WILL BE ISSUED AS CONDITIONS WARRANT.

WILLIAMS USFS FT COLLINS

ZCZC
AVUS RWRC 052300

AVALANCHE WARNING TERMINATION, BULLETIN NO. 7
IMMEDIATE BROADCAST REQUESTED
US FOREST SERVICE FT COLLINS COLO
ISSUED 4 PM MST FRIDAY MARCH 5, 1976

SOUTHWESTERN COLORADO MOUNTAINS

THE AVALANCHE WARNING FOR THE SOUTHWESTERN COLORADO MOUNTAINS HAS BEEN TERMINATED. NO AVALANCHES HAVE BEEN REPORTED IN THE LAST 36 HOURS. 50 AVALANCHES FELL IN THE SAN JUAN MOUNTAINS SINCE AVALANCHE WARNINGS WENT UP THERE LAST TUESDAY, BUT THE AVALANCHE DANGER HAS NOW MODERATED.

THE SNOWPACK IN ALL THE COLORADO MOUNTAINS IS NOW IN NORMAL STABILITY CONDITIONS. THIS MEANS THAT THERE IS NO WIDESPREAD AVALANCHE DANGER BUT SCATTERED POCKETS OF UNSTABLE SNOW REMAIN. THEREFORE WEEKEND BACKCOUNTRY TRAVELERS SHOULD USE CAUTION AND BE WARY OF STEEP SNOW-COVERED SLOPES AND GULLIES.

THIS IS THE FINAL BULLETIN ON THIS AVALANCHE SITUATION.

WILLIAMS/BACHMAN USFS FT COLLINS

FIGURE 3 TOP: EXAMPLE OF INITIATION OF AVALANCHE WARNING. BOTTOM: EXAMPLE OF TERMINATION OF AVALANCHE WARNING

ZCZC
AVUS RWRC 102300

.....SPECIAL AVALANCHE STATEMENT.....
IMMEDIATE BROADCAST REQUESTED
U.S. FOREST SERVICE FORT COLLINS COLORADO
ISSUED 1630MDT SATURDAY APRIL 10 1976

....AVALANCHE DANGER FROM SPRING SNOWSLIDES IN COLORADO.....

RECENT WARM WEATHER HAS BROUGHT SNOW TEMPERATURES TO THE MELTING POINT IN MUCH OF COLORADO'S HIGH COUNTRY. THE MOUNTAIN SNOW COVER IS BEGINNING TO WEAKEN AND MANY WET SPRING AVALANCHES ARE BEING OBSERVED.

THIS DANGEROUS CONDITION WILL PERSIST DURING PERIODS OF ABOVE FREEZING TEMPERATURES FOR THE REMAINDER OF THE SPRING SEASON.

INTENSITY AND MAGNITUDE OF AVALANCHING WILL VARY, BUT BACKCOUNTRY TRAVELERS SHOULD EXERCISE CAUTION AT ALL TIMES, AVOIDING KNOWN AVALANCHE PATHS, STEEP SLOPES AND GULLIES.

ADDITIONAL STATEMENTS WILL BE ISSUED AS CONDITIONS WARRANT.

BACHMAN/WILLIAMS USFS FORT COLLINS

FIGURE 4 EXAMPLE OF SPECIAL AVALANCHE STATEMENT

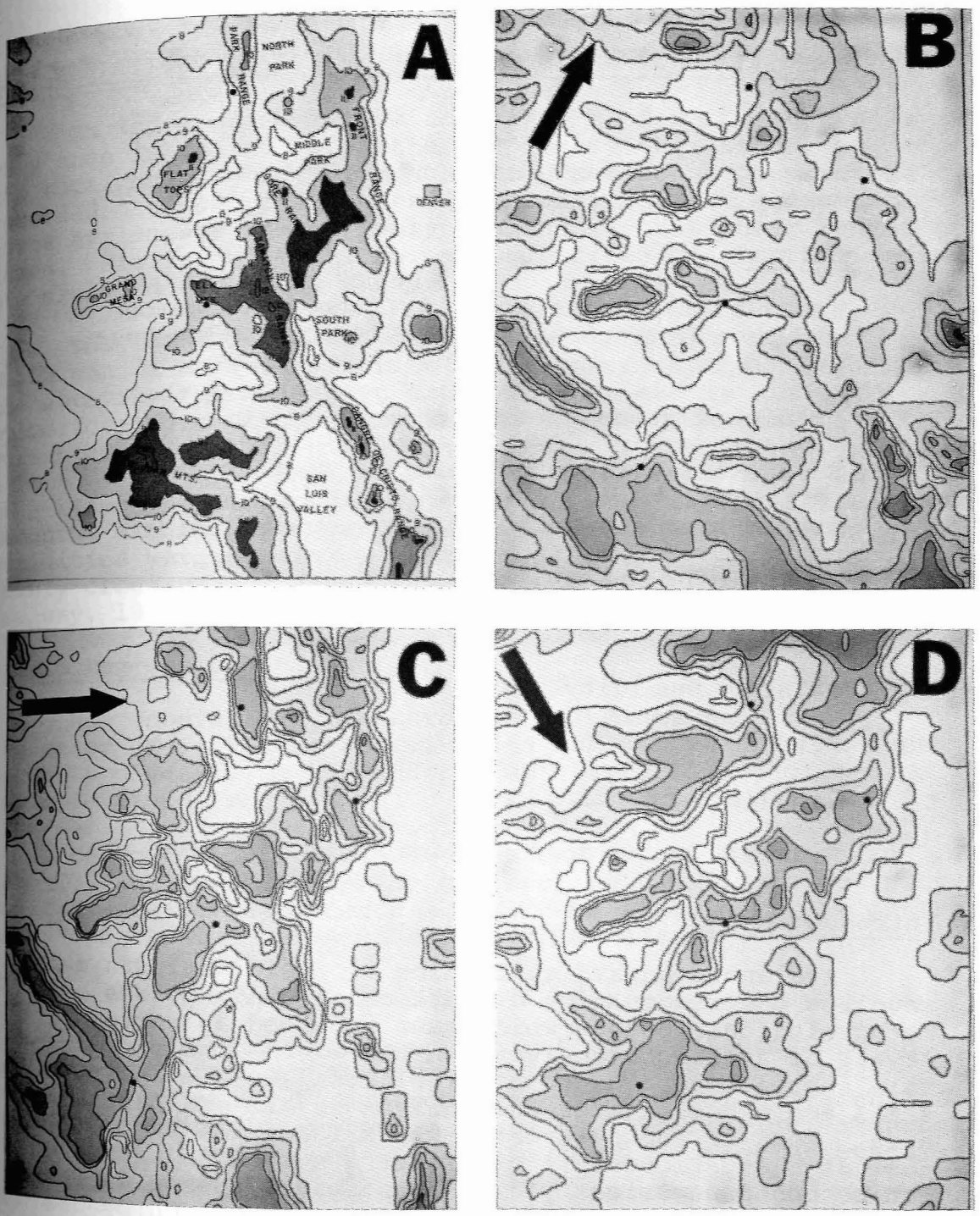

FIGURE 5 A) TOPOGRAPHIC MAP OF COLORADO ROCKIES SHOWING ELEVATIONS IN THOUSANDS OF FEET. THE FOUR REFERENCE DOTS FROM LOWER LEFT TO UPPER RIGHT ARE RESPECTIVELY: RED MT. PASS, GOTHIC, BERTHOUD PASS, AND STEAMBOAT SKI AREA. B), C), AND D) ARE THE RESPECTIVE PRECIPITATION MAPS FOR WIND DIRECTIONS 210°, 270°, AND 330°. DARKER SHADES INDICATE HEAVIER SNOWFALL.