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IV. 4. A PILOT STUDY OF WEATHER, SNOW, AND AVALANCHE REPORTING FOR WESTERN UNITED STATES

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INTRODUCTION

The present network consists of 42 mountain stations where snow avalanches are observed and controlled each winter. At 21 of these areas, the avalanche problem is rated serious. Avalanche specialists at many of these high hazard areas make additional observations on weather and snow conditions, which determine when traffic restrictions are needed and avalanche control action is necessary. Only 10 of the high hazard areas have the full complement of instruments. Most areas are under the supervision of the Forest Service, U. S. Department of Agriculture, and are associated with large ski resorts, but several mining corporations and 5 districts of the Colorado State Highway Department are active participants.

Reporting stations located in 11 Western States and Alaska (Figure 1) cover 25° of latitude. The network represents a wide variety of weather, snow, and avalanche conditions. Station elevations vary from near sea level in coastal Alaska to 3450 m in the central Rockies. The observation sites are close to the zone of maximum precipitation in their respective ranges, and the first two winters of operation have produced an interesting set of data.

The primary objectives of the pilot network are: to determine the practicability of providing the basic weather, snow, and avalanche information needed for day-to-day avalanche control, and to generate the long-term records needed to develop an avalanche danger rating scheme. Ultimately, the rating scheme might be used to establish an avalanche warning service for the Western United States. The network is a joint effort of the administrative and research branches of the U. S. Forest Service.

FORMS

One of the first tasks was to design and field test a new set of weather and avalanche forms to assure completeness and uniformity of the data. In earlier years, a single large wall form was used for all data. This form handled the weather data easily, but did not provide sufficient space for avalanche data. Two forms, one for weather and the other for avalanches, were developed and tested at 6 stations during the 1967-68 winter. These were modified and used at 20 stations during the following winter. The present forms represent a compromise between what would be ideal for automatic data processing and what is preferred in the field. Data entered are a combination of numbers and letters. For instance, letters are used on the weather form (Figure 2) to denote wind directions, descriptions of new snow crystals, and part of the precipitation intensity entries. All other data are entered as numbers. On the avalanche form (Figure 3), most of the avalanche classification, flow characteristics, and fracture line descriptions are made with letters. Both sets of forms are printed on self-duplicating paper so an original and one copy are available. This has worked especially well with the larger avalanche forms, where use of standard carbon paper would be impractical.

OBSERVATIONS

Weather and snow conditions

Total snow depth, temperature extremes, snowfall and its water equivalent, new snow crystal types, and an estimate of snow transport are recorded every 24 hours, usually early in the morning. Precipitation intensity and windspeed and direction are entered as 6-hour averages. The water equivalents of the new snowfalls are usually obtained by weighing snow cores from a snowboard. When drifting results in an uneven distribution of snow in the measurement area, water equivalent is read from the chart on a standard recording gauge. Windspeed and direction are entered as averages of the first 15 minutes of the first, third, and fifth hour in each 6-hour period. Average precipitation intensities for 6-hour periods are designated as light, moderate, or heavy on the basis of observed snowfall rates or from the trace on a recording precipitation gauge.

Snow pits are periodically dug in avalanche starting zones to examine the upper 1.5 to 2 meters of the snow cover. Presence of buried layers of graupel, hoar, ice, loose cohesionless grains, slush, or of other features known to favour avalanches, are coded and entered on the weather form by exposure and elevation. Test skiing on small, accessible slopes offers a direct method of evaluating stability of surface layers; it also suggests when additional snow pits are warranted.

Avalanches

Observations of avalanche occurrence and control are as important as those on weather and snow conditions. Information entered on the avalanche form includes: name of avalanche, time and date of release, avalanche classification, motion and flow characteristics, fracture line shape and height, per cent and part of avalanche path affected, location of starting point, vertical fall distance, depth and length of avalanche snow deposited on the highway, and other pertinent remarks. When control action is taken, but no avalanche results, the time, date, name of the avalanche, and type of action (number of shots or ski passes) are recorded.

The avalanche classification includes: type of avalanche -- hard slab, soft slab, or loose snow; the trigger -- artificial or natural (artificial is further divided into ski, artillery, avalauncher, or hand-placed charge); location of avalanche running surface -- ground or snow layer; a subjective size designation; and a notation for air blast. For instance, an avalanche classified as SS-AA-4-OGJ would indicate a soft slab (SS), artificially released by artillery (AA), of large size (4), which ran on an old snow surface (O) and later penetrated to the ground (G). The J indicates presence of airblast. Avalanche size is indicated on a scale of 1 - 5; a 1 is used for slides which run less than 50 meters slope distance, while large numbers indicate increasing size with respect to the avalanche path. For example, a size 5 avalanche on a small path indicates a maximum size avalanche for that path, but an avalanche of equal size on a larger avalanche path might rate a 3, because larger avalanches are expected on the bigger paths. This method of relating avalanche size was adopted during the second year of network reporting, when it became evident that some stations were reporting size 2 avalanches which had fall distances of 1000 m, while others reported size 4 and 5 for avalanches which fell less than 500 m.

Actual avalanche sizes can be approximated by noting the height of the fracture line, per cent of the path affected, vertical fall distance, and the type of motion. This rating scheme yields good information on the absolute size of avalanches once all the known paths in the regularly observed areas have been catalogued and described. The present size categories are still subjective, but the range of reporting error has been reduced.

INSTRUMENTATION

Both recording and non-recording instruments are used at network stations. Atmospheric pressure, windspeed, and direction are continuously recorded. Temperature and precipitation are also continuously recorded at some stations; at others they are read at 24-hour intervals.

Wind

Good wind data have always been difficult to get because sensors must be located on exposed sites, often above timberline, where the environment is severe. Icing, lightning, animals, snow creep, water, and bulldozers are common sources of trouble with the cable systems used on this network. Shielded cables offer reasonably good protection from animals, but there is no guaranteed method of preventing lightning damage other than removal of cables when they are not in use. Buried cables give the least trouble, provided weather-proof junction boxes are installed about every 400 m for line testing. Junction boxes are recommended in place of splices because they simplify troubleshooting.

We have tried a number of windspeed and direction sensors under severe conditions, and find the U. S. Weather Bureau's F420C wind system to be the best. These transmitters are now standard for the net. They have proven to be both durable and reliable, after some post-factory modifications are made on the anemometer. The vane is a variable-resistance type and the anemometer is a D. C. generator.

Twin-channel strip chart recorders with an internal resistance of 1400 ohms and a 1 milliamp full-scale pen deflection are used for windspeed and direction. A chart speed of 1 1/2 inches per hour is recommended for ease of reading without undue loss of detail. Hand-wound spring chart drives were found more reliable than electric drives because power outages usually occur during storms, when data are most important. Power supplies and control circuits used with the vane have an output of 6 volts D. C. The anemometer circuit utilizes a 5 K ohm trim potentiometer in series with the recorder and a 2 K ohm trim potentiometer in parallel with the recorder to make it possible to adjust for the resistance offered by long land lines. Both anemometer and vane circuits are fused to protect the recorder from line surges. Line distances from the wind sensors to the recorders at network stations vary from 1-5 km.

Anemometer icing has caused loss of records and instrument damage at exposed sites. The beaded, conical, copper cups used at network stations are very sensitive to icing; 2 cm of soft rime results in a 50 per cent negative error with a windspeed of 15 m sec^{-1}. The soft rime accumulation shown in Figure 4 illustrates the icing problem. It was solved at one Colorado site by using infrared transmitted from the incandescent outdoor lamps shown in Figure 5. Mounted 45 cm below the cups, the three 300-watt lights produce a total radiant flux of 375 W or about 0.5 W cm^{-2} on the cups. The unit is rugged and has withstood windspeeds of 56 m sec^{-1} without damage. Rime accumulations up to 35 cm have been measured on the support tower while the lights kept the anemometer completely ice free.

Other Recording Instruments

Recording hygrothermographs, rain and snow gauges, and microbarographs are standard instruments at stations reporting weather. Installation of 110 V heat-tapes on recording precipitation gauges is recommended to prevent the capping caused by high intensity snow storms. Seven-day clocks are used with battery-operated chart drives. A potentiometric recording rain and snow gauge was recently installed at Jackson Hole, Wyoming, to transmit water equivalents from the upper mountain to the base station. A 12 V power supply, 4 km of shielded cable, and strip-chart recorder are used with this unit. If it performs well, it will be recommended for use at other inaccessible areas where elevational differences require an upper level precipitation measurement.

DATA PROCESSING

The original data sheets from all network stations are mailed to the Alpine Snow and Avalanche Research Project at Fort Collins, Colorado, at the end of each winter month. Upon receipt, they are checked for obvious errors, then the data are put on cards and verified. Two cards are required for each avalanche entry, and for each set of daily weather observations. Summary programs for both avalanche and weather data provide a final verification. Copies of the monthly summaries are mailed back to the field stations on the 15th of each succeeding month. This rapid feedback of data helps to maintain observer interest and has resulted in more complete and accurate reporting. We are accumulating about 11,000 cards each winter. All original data are stored at Fort Collins where they will be transferred to magnetic tape for analysis.

THE RESEARCH OBJECTIVE

The research goal of this program is to develop an objective method of evaluating avalanche hazard during storms, both in areas of intense use where avalanches are frequently controlled, and in the much larger back-country areas where avalanches are uncontrolled. A danger rating scheme similar to the one now used by fire control agencies in the Western United States is contemplated.

Fire control personnel are currently using a series of tables, which have been extracted from regression models, to determine daily indices on moisture content of fuels and an anticipated rate of spread. The observer takes daily readings on air temperature, relative humidity, rainfall, wind-speed and direction. Using these data with the danger rating tables for his area, he obtains a daily index. These data are transmitted via teletype to regional offices of the Forest Service and the Weather Bureau. The fire danger index values are used to determine manpower and equipment needs throughout the West.

We will probably use a similar approach to determine an avalanche hazard rating index, which, when combined with a mountain weather forecast from the Weather Bureau, would provide a valuable working tool for operations personnel who would then be in a position to offer advice on the avalanche potential for back-country areas.

ASSESSMENT AND OUTLOOK

The first two years of operation have provided a good test of the system. Of the 20 stations which report both weather and avalanche conditions, 10 are fully instrumented; the remaining areas should have the recommended instrumentation in about 3 years. Data quality has steadily improved, and the majority of instruments now in use can be recommended with confidence. More than 4,000 avalanche events were reported by the network during the past two winters. Data from 8 stations were of sufficient quality to warrant analysis.

The main shortcoming is the scarcity of qualified and interested observers who can install, calibrate, and maintain the instruments now in use. This becomes painfully apparent each fall when instruments, which have been stored during summer, are placed in operation.

Present research plans are to put the best data on magnetic tape for analysis. Avalanche information will be placed on one tape with weather and snow condition parameters on another. Each tape will have a provision for updating as more data become available. The tapes will be merged and analyzed to establish relationships between weather parameters and natural avalanches. Data from Berthoud and Loveland passes in Colorado will be analyzed first, because they are available for 18 consecutive winters, have good continuity and quality, and provide the rare opportunity of using numerous natural avalanche events. Storm data will be treated in 6-hour blocks, using average windspeed and direction, precipitation intensity, mean temperature, and temperature trends. Data from additional stations will be utilized to verify and broaden the results of the initial study. This information will be used to develop a model, which could be used to evaluate general avalanche conditions on a broad scale. With this information at hand, the experienced field man could further refine the evaluation for his area, depending on local conditions.

* * * *

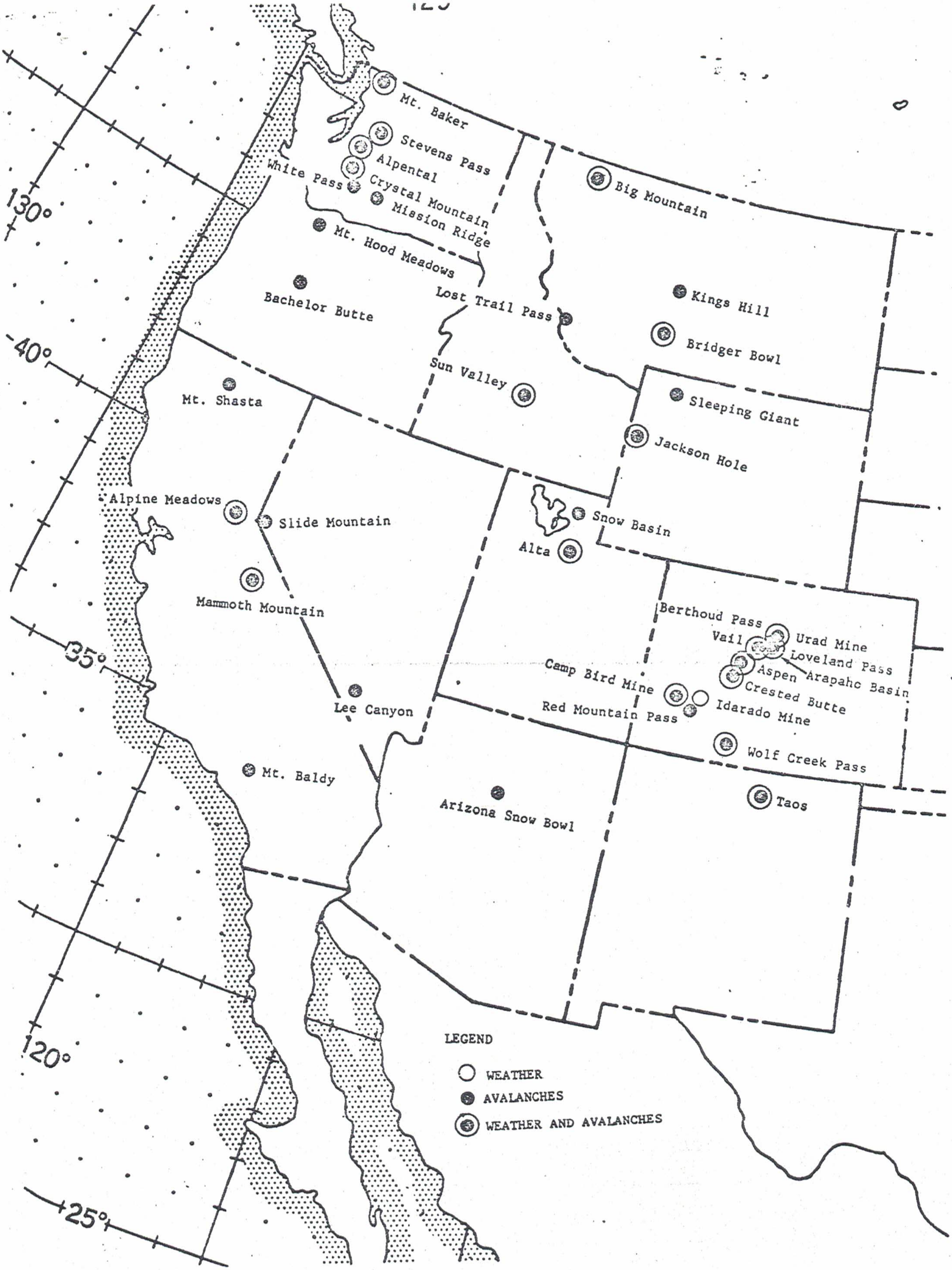

FIGURE 1

PRINCIPAL REPORTING STATIONS ON THE WEST-WIDE NETWORK.

ALTA, UTAH (AREA) STA NO 200
March (MONTH) 1969 (YEAR) TIME OF OBSN 0500

U.S. FOREST SERVICE
MONTHLY SUMMARY OF WEATHER & SNOW CONDITIONS
REVISED 10 68

Hastings
Bassett
(OBSERVERS)

DATE (1)	DEPTH OF SNOW ON THE GROUND* INCHES (2)	TEMPERATURE MAX °F (3)	TEMPERATURE MIN °F (4)	PRECIPITATION* NEW SNOW DEPTH INCHES (5)	WATER EQUIV OF NEW SNOW INCHES (6)	WATER FROM RAIN INCHES (7)	TYPE (SEE KEY BELOW) (8)	INTENSITY** BY 6 HOUR PERIODS (9)	(10)	(11)	(12)	WIND SIX HOUR AVERAGES 00-06 (13)	06-12 (14)	12-18 (15)	18-24 (16)	FASTEST ONE HOUR AVERAGE WINDSPEED AND DIRECTION (17)	BLOWING SNOW RIDGES (18)	STRATIGRAPHY UPPER SLOPES N (19)	E (20)	S (21)	W (22)	LOWER SLOPES N (23)	E (24)	S (25)	W (26)	CLOSURES (SEE KEY BELOW) (27)	TIME OF OBSN IF DIFFERENT FROM ABOVE (28)	REMARKS (29)
1	145	33	19	6.0	.32	0	2	1	1	1	F	6WSW	5W	11W	4V	14WD	0	5								2,6	0630	Cloudy
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SUMS																												
MEANS																												

INTENSITY** BY 6 HOUR PERIODS: SNOW 1 = LGT, 2 = MOD, 3 = HVY, F = FLURRIES; RAIN 4 = LGT, 5 = MOD, 6 = HVY

BLOWING SNOW RIDGES: 1 = LIGHT, 2 = MOD, 3 = HEAVY

STRATIGRAPHY: STARTING ZONE AREAS ONLY. SIGNIFICANT LAYERS BURIED 20-120 CM BELOW SNOW SURFACE. CHOOSE MOST SIG. 1 HOAR 2 GRAUPEL 3 ICE 4 LARGE WET GRAINS 5 OTHER LOOSE COHESIONLESS GRAINS 6 SLUSH 7 FRESH DAMP SNOW DEPOSITED ON COLD POWDER 8 COMBINATION OF TWO OR MORE 1 TO 9 OTHER

NEW SNOW TYPES

1 PLATES
2 STELLARS
3 COLUMNS
4 NEEDLES
5 SPATIAL DENDRITES
6 CAPPED COLUMNS
7 IRREGULAR
8 GRAUPEL
9 ICE PELLETS
10 HAIL

ADD: ' FOR RIME; (FOR CLUSTERS OF CRYSTALS; + FOR BROKEN CRYSTALS; = FOR WET OR PARTLY MELTED CRYSTALS

*PERIOD 9 = 00-06 HOURS; COL 10 = 06-12; COL 11 = 12-18; COL 12 = 18-24

	ELEVATION	LOCATION
MASTER SNOW STAKE		
SNOW BOARD		
ANEMOMETER		
PRECIPITATION GAGE		
TEMPERATURE SHELTER		

CLOSURE KEY: 1 NO CLOSURES; 2 CLOSURES; 3 AREA CLOSED; 4 TOURING OPEN; 5 TOURING NOT RECOMMENDED; 6 TOURING CLOSED

FIGURE 2

THE WEATHER FORM USED AT NETWORK STATIONS IN 1969, ACTUAL SIZE 15 28 BY 36 CM

Red Mtn. Pass, Colo (AREA) 152 STA. NO.

January (MONTH) 1969 (YEAR)

PAGE 1 OF 4

U.S. FOREST SERVICE

N.C. PETERSON
OBSERVERS:

AVALANCHE CONTROL AND OCCURRENCE CHART

REVISED 11/69

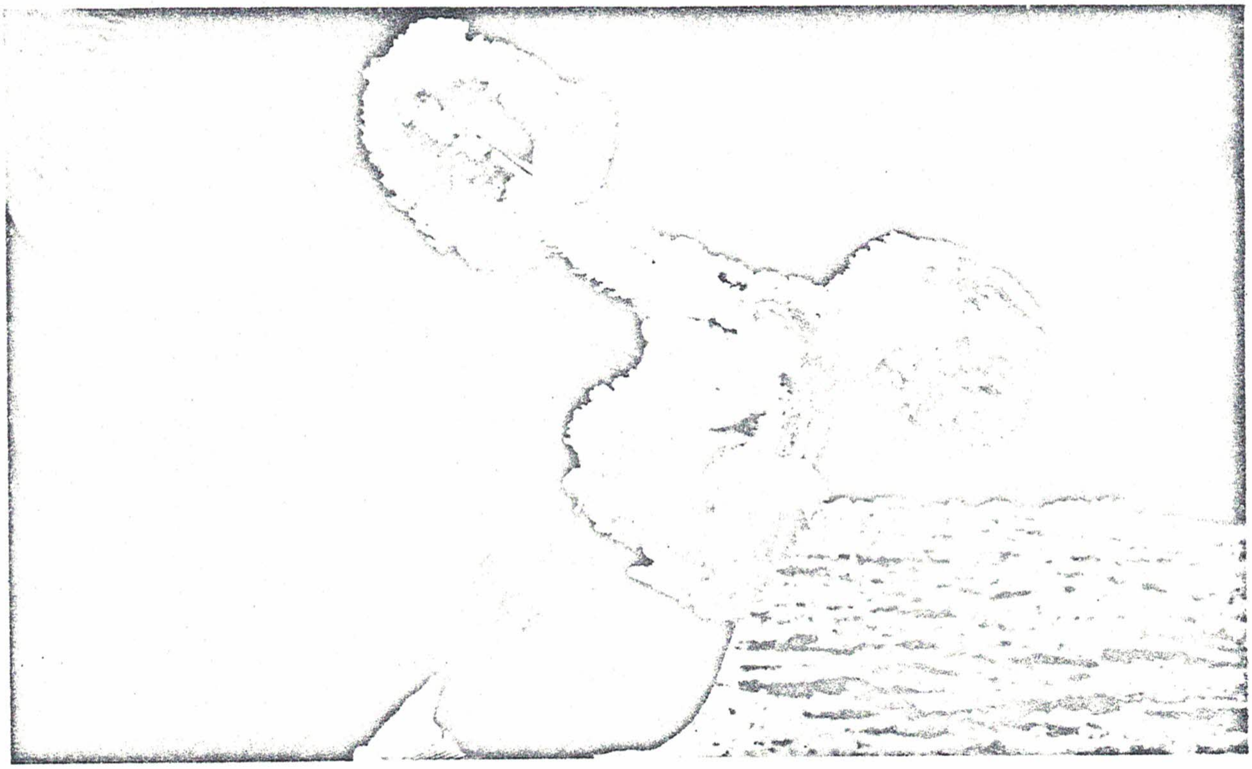
DATE (1)	TIME OF CONTROL ACTION AND OR AVALANCHE (2)	AVALANCHE PATH AND/OR TARGET (3)	CONTROL MEASURES: CALIBER OF ARTILLERY LBS. OF H.E. SKI CONTROL (4)	CONTROL MEASURES: NUMBER OF SHOTS OR SKI PASSES (5)	CONTROL MEASURES: CHECK IF SNOW FRACTURED WITHOUT AVALANCHE (6)	STANDARD AVALANCHE CLASSIFICATION* MINIMUM INFO NEEDED: AVAL. TYPE, TRIGGER, AND SIZE (1-5). SIZE 1 = A SLUFF = SNOW FLOWS < 150 FT. ** EXAMPLES SS-AA-4-OGJ HS-N-2-0 L-AS-1-0 (7)	TYPE OF MOTION S: SLIDING F: FLOWING OR TUMBLING P: AIR BORNE POWDER M: MIXED AIR & GROUND MOTION (8)	FRACTURE LINE (SLABS ONLY): THICKNESS IN FEET AND TENTHS OF FEET ADD E: ESTIMATED M: MEASURED EXAMPLE 3.1E (9)	FRACTURE LINE (SLABS ONLY): SHAPE A: SMOOTH ARC Z: ZIG ZAG (10)	PERCENT OF TOTAL AVALANCHE AREA THAT SLID (11)	LOCATION OF STARTING POINT T: TOP M: MIDDLE B: BOTTOM ADD R, C, OR L TO INDICATE RIGHT, CENTER OR LEFT. (12)	VERTICAL FALL DISTANCE IN FEET (13)	IF AVALANCHE REACHED A ROAD: AVERAGE DEPTH OF SNOW ON THE CENTER LINE FEET (14)	IF AVALANCHE REACHED A ROAD: LENGTH OF CENTER LINE COVERED FEET (15)	REMARKS (BE SURE TO NOTE: ANY CASES OF AIRBLAST AND ANY DAMAGE OR INJURY DUE TO AVALANCHES.) (16)	OBSERVER
22	0900	Muleshoe				HS-N-3		2.0E	Z	50	TR	1000C	8	50	Type of motion not observed	
22	1100	East Riverside				SS-N-4-G						3100C	17	100	Could not see starting zone	
23	1420	Telescope	75H	1		SS-AA-4-O	FMP	4.0E	A	85	T	1500C	12	150		
23	1430	Eagle	75H	4											No action	

*SEE PAGE 46 IN HANDBOOK NO. 194 SNOW AVALANCHES (FSH 2-2332.81)

**
SS-AA-4-OGJ : A SOFT SLAB (SS), ARTIFICIALLY RELEASED BY ARTILLERY (AA), OF LARGE SIZE (4), WHICH RAN ON AN OLD SNOW SURFACE (O), AND LATER PENETRATED TO THE GROUND (G) THE J INDICATES AIR BLAST.
HS-N-2-0 : A HARD SLAB (HS), NATURAL RELEASE (N), SMALL SIZE (2), WHICH RAN ON AN OLD SNOW SURFACE (O).
L-AS-1-0 : LOOSE SNOW (L), ARTIFICIALLY RELEASED BY SKIS (AS), A SLUFF (1) - (SNOW FLOWED LESS THAN 150 FEET SLOPE DISTANCE), RAN ON AN OLD SNOW SURFACE (O).

DIRECTIONS:
1. USE A SEPARATE LINE FOR EACH AVALANCHE AND EACH PATH CONTROLLED.
2. USE AS MANY SHEETS AS NEEDED.
3. START NEW SHEET ON FIRST OF EACH MONTH.

FIGURE 3 AVALANCHE CONTROL AND OCCURRENCE CHART



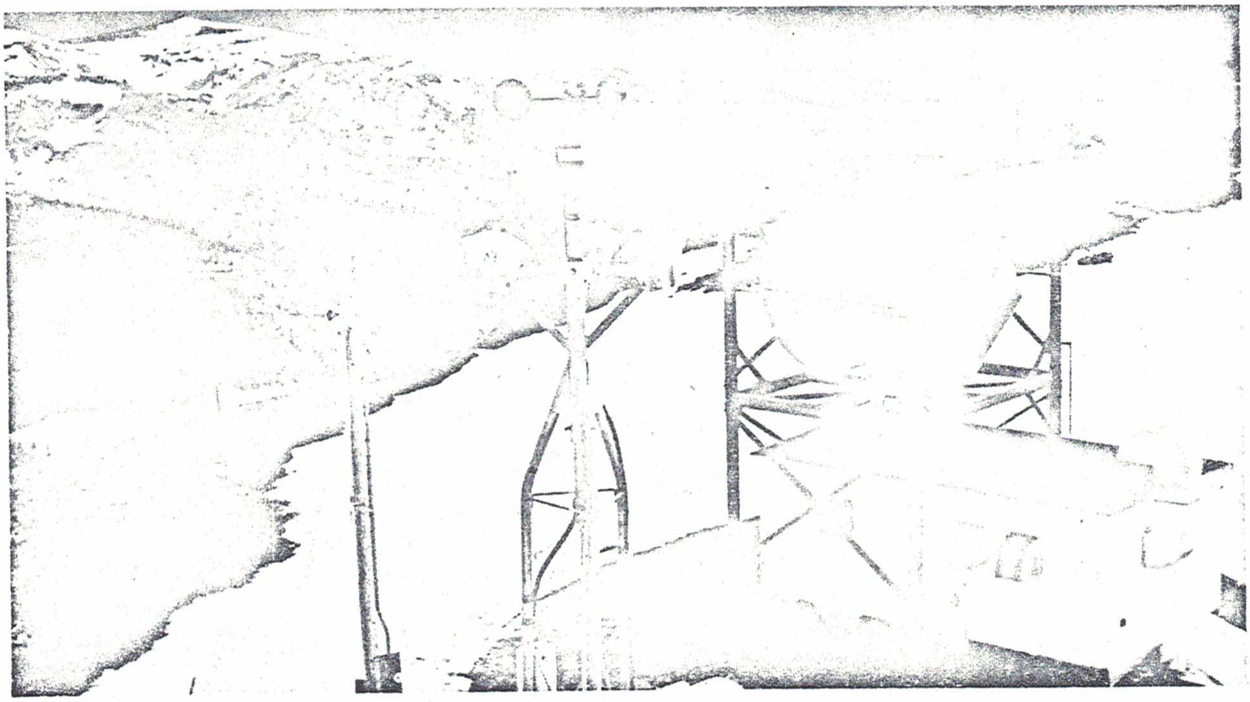


FIGURE 4 (Page 132)

CUP ANEMOMETER COVERED WITH SOFT RIME AT A WIND STATION ON THE CONTINENTAL DIVIDE IN COLORADO

FIGURE 5 (Page 133)

ANEMOMETER DEICING UNIT ON THE 3810 M SUMMIT OF COLORADO MINES PEAK, WEST OF DENVER, COLORADO. THE 3 - 300 WATT INCANDESCENT LAMPS KEPT THIS ANEMOMETER ICE FREE DURING 1968-69 WINTER, EVEN THOUGH ACCUMULATIONS IN EXCESS OF 30 CM FORMED ON THE TOWER

Discussion

T. Nakamura: Do you give the people who observe these items any education on how to distinguish the snow crystal forms and how to classify each snow avalanche?

Author's Reply: Yes. The Forest Service holds regional avalanche training schools each winter where instrumentation and observational techniques are covered, among other things. Magono and Lee's classification for new snow crystals and Sommerfeld's classification outline for snow on the ground serve as guidelines for crystal forms. Specific instructions for taking weather data and classifying avalanches are available to all observers.

T. Nakamura: Were these reporting stations especially built for the present purpose?

Author's Reply: No. Although we talk about reporting stations, they do not consist of a staff and building in the ordinary sense of the word. They are simply observation points, consisting of a few instruments in most cases. Most are located at major ski resorts where avalanche control is under Forest Service supervision. The sites were only recently instrumented, and the observers are people whose primary job is snow safety.

T. Nakamura: Do these stations belong to the same governmental department or are some of them privately owned?

Author's Reply: Slightly more than half of the stations belong to the Forest Service; the rest are run by highway departments or industry.

T. Nakamura: When do you expect to get an avalanche hazard forecasting formula?

Author's Reply: It is too early to say anything definite on this at present. We are just beginning to get quality data, and analysis is not yet underway.