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16. Abstract

This report summarizes the first year of activity under Washington State Department of Highways project Central Avalanche Hazard Forecasting (Agreement Y-1700) to test the feasibility and effectiveness of central avalanche forecasting for the Cascade Mountain Passes and adjacent territory. This project explores the possibilities of improving both mountain weather and related avalanche forecasts for use by the WSDH during winter operations in the mountain passes, and, secondarily, explores the usefulness of an area-wide forecasting service to other, cooperating agencies. The eventual aim of this work is to establish the technical and administrative framework for an operational, on-going mountain weather and avalanche forecasting service for Weatern Washington under the joint support of interested public agencies.

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CENTRAL AVALANCHE HAZARD FORECASTING

by E. R. LaChapelle and
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INTERIM REPORT

Research Project Y-1700 Phase 1

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Prepared for
Washington State Highway Commission
Department of Highways
in cooperation with
US Department of Transportation
Federal Highway Administration

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1. INTRODUCTION

This report summarizes the first year of activity under Washington State Department of Highways (WSDH) (Agreement Y-1700) project Central Avalanche Hazard Forecasting to test the feasibility and effectiveness of central avalanche forecasting for the Cascade Mountain Passes and adjacent territory. Heretofore, avalanche forecasting in the Cascade Mountains has been done locally on an area-by-area basis by Highway Department personnel and by forest rangers and professional ski patrolmen at individual ski areas. This project explores the possibilities of improving both mountain weather and related avalanche forecasts for use by the WSDH during winter operations in the mountain passes and, secondarily, explore the usefulness of an area-wide forecasting service to other, co-operating agencies. At the end of the first winter of operation, this effort has been sufficiently successful and well-received to encourage planning for continuation of the research into the winter of 1976/77. The eventual aim of this work is to establish the technical and administrative framework for an operational, on-going mountain weather and avalanche forecasting service for Western Washington under the joint support of interested public agencies.

This report describes in detail the organization of a data network to support the Forecasting Office and the mode of operation of that Office itself. The intent here is to explain just how the essential snow, weather and avalanche data are collected and transmitted, how specific mountain weather and related avalanche forecasts are prepared using this data flow, together with that obtained by close interaction with the National Weather Service, and how the developed information is communicated to users in the field. Emphasis is placed on technical details of the data network, forecasting routines and information flow. Daily weather and avalanche forecasts are compared with actual field experience and preliminary assessment made of the overall accuracy and reliability. Omitted from the present discussion and reserved for thorough treatment in the second-year report to be prepared in 1977 is a review of the conceptual framework and analytical methods used to deduce current and probable future avalanche activity from the available network and meteorological data. These methods are still under active development, are being influenced by ongoing international activity in this field, and have yet to be codified as a general forecasting guide related to Cascade snow conditions. An excellent fund of experience was developed by project personnel in 1975/76 and will be augmented in the coming year. This experience, coupled with the current state of knowledge about fundamentals of avalanche formation, will serve as the basis for preparing a guide to forecasting methodology.

2. GOAL OF RESEARCH AND GENERAL METHOD OF OPERATION

The primary purpose of the project, Central Avalanche Hazard Forecasting, was to provide both maintenance and avalanche control personnel of the major mountain passes in Washington with current local and regional weather synopses and forecasts, along with the expected effect of these weather trends on the avalanche hazard to the highways. The weather and avalanche information made available by the project was utilized by Highway Department personnel for such functions as on-site evaluation of avalanche hazard (both present and future), timing of avalanche control missions, and deployment of maintenance and avalanche crews.

To implement the project, a network of mountain weather and avalanche reporting stations was needed to furnish field weather and avalanche data to the Forecasting Office in Seattle. Such a reporting network was established and instrumented during the Autumn of 1975, following many of the guidelines and recommendations proposed by Norman A. Wilson (1975). It was based on an earlier informal data network initiated by the University of Washington (WSDH Agreements Y-1301 and Y-1637) in 1971 and continued through the 1974-75 winter. Results of research stemming from this work may be found in WSDH research program reports (1972-1975).

These field stations provided weather and avalanche observations to the Forecasting Office and in turn were given current and projected weather and avalanche analyses. These stations included WSDH avalanche and weather observation stations on the major mountain passes, and cooperating agencies: U.S. Forest Service (USFS), National Park Service (NPS), and private ski areas. This data collection network is described more fully in section 3.1 in terms of its operation during the 1975-76 winter. Descriptions of the various forms in which weather and avalanche data were received by the Forecasting Office and recommendations for more effective future operation in regard to field data and instrumentation are also presented in section 3.1 and in summary at the end of this report (section 5.1).

A working knowledge of the current condition of the snowpack was also considered essential in formulating viable avalanche forecasts. To this end snowpack observations in the form of snowpits and fracture-line profiles (snowpits excavated at avalanche release sites to determine weak layers or sliding surfaces) were made at the various Pass areas throughout the winter by the project staff to gain better insight into the developing avalanche hazard. Various snow tests done routinely by WSDH avalanche personnel and USFS Snow Rangers provided additional snowpack input which was useful for the duty forecaster in estimating stability of the snowpack and potential magnitudes of any avalanche problems. A further discussion of the usefulness and operational methods for acquiring essential snowpack data follows in section 3.2.

Operationally, the project was housed in space provided by the National Weather Service (NWS) in Seattle (Lake Union Bldg., 1700 Westlake North). This arrangement gave project forecasters immediate access to all pertinent NWS maps, satellite imagery and teletype data, and in addition provided project forecasters close contact with NWS forecasters and their expertise. Staffing of the office and necessary equipment for its operation are discussed in detail in section 4.1. A daily routine for the on-duty project forecaster was established to best utilize the available information from both the NWS and from field stations in effective formulation of a mountain weather and avalanche forecast. This forecast was updated or amended throughout the day as necessary, based on new map or field data. A discussion of the Forecasting Office operation and the daily routine of the forecasters is given in section 4.2. A summary of the actual NWS data utilized and the times such data were available to the forecasters is given in section 3.3.

During its initial year of operation, the project issued weather and avalanche forecasts at least once daily from December 6, 1975, through April 9, 1976. The form of this daily forecast is given and discussed in section 4.2. Some of the more basic and important components included in the daily forecasts are discussed and analyzed quantitatively in section 4.3. A specific case study of the operation and output of the Forecasting Office during a major avalanche-generating situation is also discussed (4.3.2). Selected daily forecasts appear in Appendix A of this report. Toward the end of the winter a questionnaire was distributed to the major cooperating personnel to help assess the project and obtain suggestions, criticisms and/or recommendations regarding the operation of the Forecasting

Office. A summary of the recommendations is discussed in section 5.

3. SOURCES OF DATA

3.1. Mountain Weather and Avalanche Data

Snow, weather and avalanche observations were obtained by phone (or teletype for the passes via WSDH snow-line reports*) at least once daily from the following primary field stations (listed with sponsoring agency): Stevens Pass (WSDH), Snoqualmie Pass (WSDH), White Pass (WSDH), Crystal Mountain (USFS/ski area), Paradise (NPS), and Washington Pass (WSDH). Of these areas, Stevens, Snoqualmie and White Passes were considered the most important in terms of forecasting since they comprise the major cross-state highway system. Reports from these stations were received generally much more often than once daily during critical avalanche periods. Stampede Pass, an automatic meteorological observation station (AMOS) staffed by NWS personnel during daylight hours and sending hourly weather and snowpack reports for the NWS via teletype, was also considered an excellent primary data source. Current air temperatures were also telemetered via radio and phone link to the Forecasting Office from Hurricane Ridge in the Olympic Mountains on a demand basis, providing much-needed current temperature data during periods of warm-air invasions into Washington. Weather and avalanche data were also available from the following secondary field stations during periods of interest on an other than daily basis: Sno-Country Stevens Pass (USFS/ski area), Mission Ridge (USFS/ski area) and Mt. Baker (USFS/ski area). The location and elevation of all of these stations is given in Figure 1 and a station by station analysis in terms of data input and instrumentation follows. (See Appendix B for a list of project participants.)

In general, data input from the various areas followed the snow and weather recording forms already in existence at these areas (with minor recommended changes by project personnel in certain cases) to eliminate

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*WSDH snow-line reports (reports of road and weather conditions at major Washington highway passes) were received at the Forecasting Office through NWS teletype three to four times daily and were used extensively by project forecasters. Standardization of meteorological observations used in these reports and possible inclusion of interval (or total) snow data at each report time are definitely recommended for future snow-line operation.

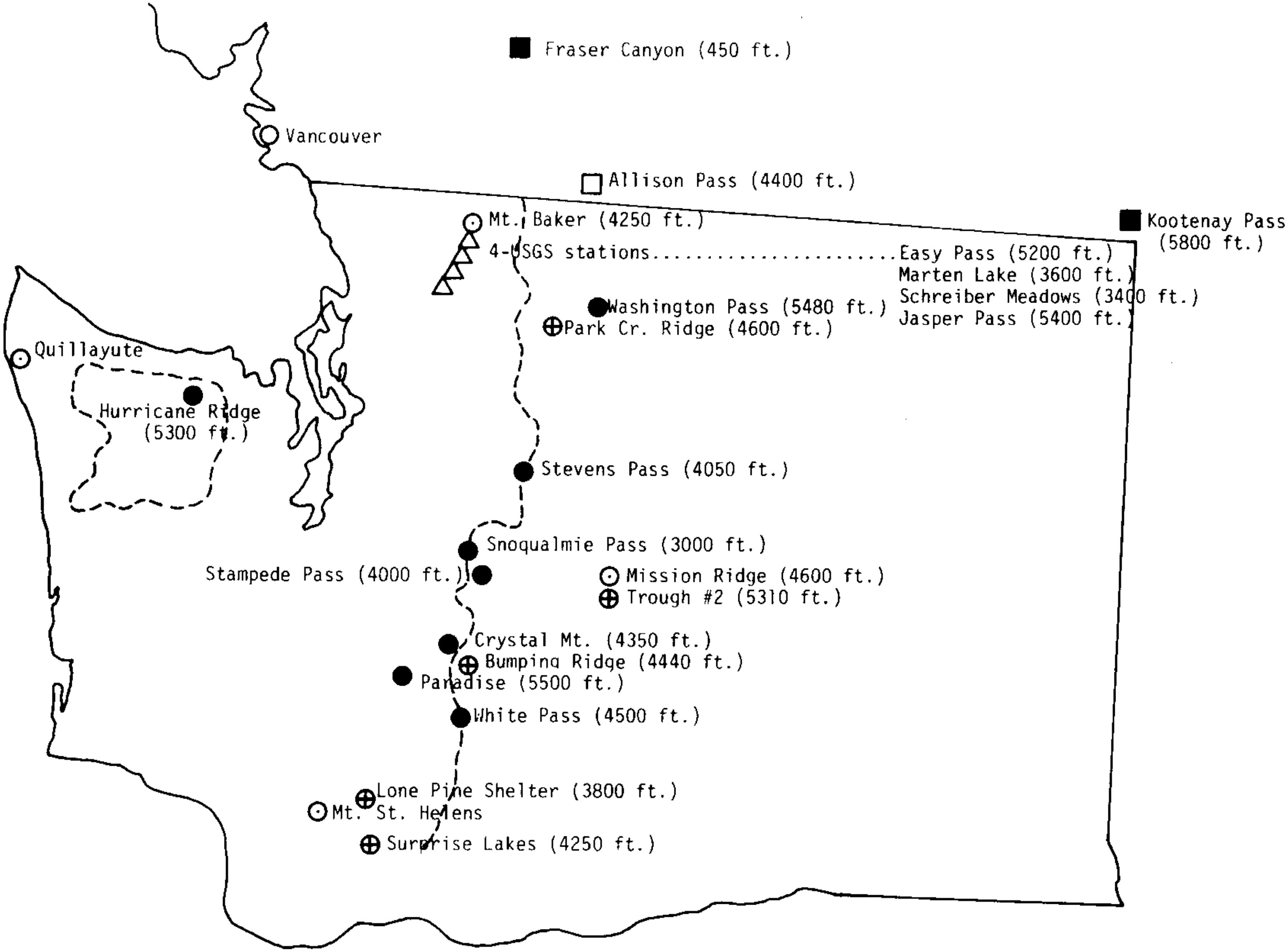


Figure 1. Location and elevations of primary (●) and secondary (⊙) reporting stations in Washington. Also shown are British Columbia Department of Highway stations (■), USGS stations (△), and SCS remote telemetry stations (⊕) which may be included in future data collection schemes. The SCS stations appear particularly important if hourly or 4-hourly real-time data becomes available, while B.C. Department of Highways (through AES) and USGS stations could prove to be valuable for future forecasting efforts involving Washington Pass.

any additional paperwork for the cooperating agencies. This procedure unfortunately led to a conflicting system of English versus metric units. Subsequent conversion to compatible units at the Forecasting Office was time-consuming. Also, the quantity and detail of snow and weather data received from certain areas was often greater than forecasters could readily assimilate and use, while current avalanche data were at times lacking. It is hoped that standardization of units and streamlining of the recording forms will help to alleviate these problems in any future operation of the project.

3.1.1. Primary Reporting Stations

a) Stevens and Snoqualmie Passes. High quality snow, weather and avalanche observations were taken at both of these Passes by trained WSDH avalanche personnel or in cooperation with USFS personnel. See Figures 2, 3 and 4 for the format and descriptions of these snow, weather and avalanche observations as received by the Forecasting Office from these two areas. These observations were taken at the minimum once daily and generally updated three or four times daily during critical avalanche periods.

Communications between the Forecasting Office and these Passes was generally via SCAN-line and/or commercial telephone (comtel). Toward the end of the winter a phone-radio patch through WSDH Station 10 in Seattle to Stevens Pass field personnel was also made available to augment phone lines to that area. These communication capabilities proved adequate for most avalanche situations. During avalanche control periods, however, it was still often difficult to reach WSDH Stevens and Snoqualmie Pass personnel in the field. It was precisely these times when forecasting personnel needed continuous (at least hourly) wind, precipitation intensity and amounts, and temperature readings from these areas in order to more effectively update local weather forecasts and avalanche advisories.

In the case of Snoqualmie Pass, the availability of hourly wind, temperature and precipitation data from nearby Stampede Pass somewhat compensated for any lack of quantitative meteorological or snow data from Snoqualmie Pass itself during critical periods. Qualitative weather reports were also available from the 24-hour/day radio operator at the WSDH Hyak maintenance station.

Figure 2. Sample reporting form for WSDH Stevens Pass observations--includes explanations of observations and equipment utilized.

		1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18
DATE	TIME	Temperature Data						Precipitation							Data				
		°F	°F/°F	Therm. °C			°F/°C	CM	CM	gr/cm²	CM	CM	gr/cm²	gr/cm²	Dens.	Int'l code	CM/HR	MM/HR	IN.
		Pr.	max/min	RT	O.F.	T.P.	Fox./20cm	Total	24HR	W.E.	Storm	Int.	W.E.	Int/Acum	Int.	Cryst.	S.I.	P.I.	P.G.

19	20	21	22	23	24	25	26	27		
WIND	SKY	SNOW		1 KG.	STABILITY		Baro.			
M.P.H.	Precip	LEVEL		RAM	Shear	Ratio	Press.	Snow		
DIR./VEL.	Type	E.	W.	CM	CM	wt./str.	mb.	Surf.	REMARKS	BY:

Stevens Pass observational data was recorded by WSDH personnel from a variety of differing elevations and aspects throughout the pass area. Temperature data was received from three different thermistors, as well as from standard in-glass thermometers and a recording thermograph. Precipitation and some temperature data was recorded at the USFS study plot at the pass summit through January 31st, 1976, and at a new WSDH study plot just to the west of the summit on the old highway for the remainder of the 1975-76 winter. Correlation of data from the two sites showed good agreement in temperature and precipitation.

Explanation of Data

(1) present air temperature (°F) at observation from the study plot minimum in-glass thermometer.

(2) maximum and minimum daily air temperatures (°F) recorded at study plot from standard in-glass thermometers (Weathermeasure).

(3) present air temperature (°C) telemetered from thermistor (Hydro-tech) at the state radio tower on Skyline Ridge (4850 ft.--1455 m.) to WSDH Schmidt Haus at summit.

Figure 2. (continued)

(4) present air temperature (°C) telemetered from thermistor (Hydro-tech) near the starting zone of Old Faithful slide area (4800 ft.--1440 m.) on west side of pass to read-out on highway. This thermistor was not operational during most of 1975-76 winter due to break-in-line on 12/19/75; the thermistor in the ski area, at top of Big Chief chair lift (4800 ft.), was used instead.
(5) present air temperature (°C) telemetered from thermistor (Hydro-tech) near the starting zone of Tunnel Point slide area (4500 ft., 1350 m.) on west side of pass to read-out on highway.
(6) present air temperature (°F) from recording thermograph (Foxboro) in Schmidt Haus, and 20-cm. snow temperature (°C) from dial-type stem thermometers (Tel-Tru).
(7) snowpack total depth (cm.) at study plot from master snow stake
(8), (10), (11) 24-hr., storm and interval snowfall accumulation from appropriate snow stakes.
(9), (12) new snow weight or pressure (gm/cm^2) as determined from 24-hr. and interval snow board samples.
(13) cumulative water equivalent from the interval snow board (sum of (12) data).
(14) density of interval snow sample (gm/cm^3).
(15) snow crystal type (falling snow) according to the International Snow Crystal Classification.
(16), (17) snowfall intensity (cm/hr) and precipitation intensity of equivalent liquid water (mm/hr). Snowfall with a density of .10 and falling with a snowfall intensity of 15 cm/hr would have a precipitation intensity of 15 mm/hr.
(18) cumulative total precipitation recorded by a telemetered tipping bucket rain gage--USFS plot--or a weighing bucket rain (precipitation) gage (Belford Instruments) at the WSDH study plot.
(19) present windspeed and direction as measured at state radio tower north of summit (4850 ft.) and telemetered to Schmidt Haus. Direction noted in azimuth degrees and speed in mph.
(20) sky conditions and precipitation types and intensities (coded) as noted at observation. Sky conditions: clear O, scattered ◑, broken ●, overcast ⊕, fog F. Precipitation types: snow = S, rain = R; intensity: very heavy ++, heavy +, moderate _, light -, very light --.
(21), (22) estimate of snow level to east and west of summit.
(23) depth of penetration (cm) of a 1 kg. ram penetrometer into the snowpack.
(24) present depth from surface (cm) of pertinent weak shear layers in the snowpack, determined by tilt board application.
(25) stability ratio of weight above a weak shear layer to the shear strength of that layer (determined by weighing the layer in question and using a shear frame on the shear layer).
(26) present barometric pressure (mb) at the pass summit determined from microbarograph readings.
(27) snow surface characteristics at observation in study plot, and clarifying remarks for any entries. Snow surface coding as follows: P--powder, C--corn snow, pellets, D--damp, W--wet, W--slush, T+--thick crust, T---thin crust, X--wind-packed.

Note: it is anticipated that a shorter form will be used at the forecast office for reporting observations from Stevens Pass in future operation. It is also hoped that in future operation a standardized system of units may be used for all reports, not some values in English and some in metric.

Figure 3. Sample reporting form for WSDH Snoqualmie Pass observations as received at the avalanche forecast office in Seattle--includes explanations of observations and equipment utilized.

			TEMPERATURE					SNOW DEPTH				
DATE	TIME		3,000'	3,800	5,600	MAX MIN	DP RH	TOTAL	24 HR	INT.	PERIOD	SHOOT
	FROM	TO	°F	°F	°F	°F °F	°F %	CM	CM	CM	CM	CM
			1	2	3	4	5	6	7	8	9	10

* PERIOD ACCUMULATION

SNOW PHYSICAL PROPERTIES										WIND			
W.E.	W.E. *	DENS'T	S.I.	P.I.	SKY &	CRYSTAL TYPE	SNOW	SNOW LEVEL	1-KG R	DIR.	VEL.	OBSER	TO FCST
gr/cm²	gr/cm²	gr/cm³	cm/hr	cm/hr	PRECIP	INT'L CODE	SURFACE	FEET	CM	0°-360°	MPH	INITIAL	TIME IN
11	12	13	14	15	16	17	18	19	20	21	22		

Snoqualmie Pass snow data were recorded by WSDH observers at a summit study plot (3000 ft.) located just north of the old highway maintenance shed. Temperature and wind from the surrounding area were telemetered to a central office for field personnel in the shed.

Explanation of Data

(1) present air temperature(°F) from a Foxboro recording hygrothermograph at the summit house or a minimum in-glass thermometer at the study plot.

(2) present air temperature (°F) telemetered from thermistor (Hydro-tech) thermistor at 3800 foot level on abondoned radio tower at top of Snoqualmie Summit ski area.

(3) present air temperature (°F) at top of Denny Mountain, Alpental ski area. Telemetry to WSDH summit house from ski area not operational during 1975-76 winter.

Figure 3. (continued)

(4) 24-hour maximum and minimum air temperatures as recorded by standard in-glass thermometers in instrument shelter at study plot.
(5) dew point temperature (not reported during 1975-76 winter) and relative humidity measured by recording hygrothermograph (Foxboro) at summit house.
(6)--(10) total, 24-hr, interval, period and shoot snow depths as measured at various snow stakes in the summit study plot. The period snow stake generally corresponds to snowfall deposited by a single storm, while the shoot stake measures snowfall accumulated between control measures.
(11), (12) water equivalent of snowfall or new snow weight as determined from interval and period snow stakes, respectively.
(13) snow density (gm/cm^3) from interval snow stake.
(14), (15) snowfall intensity (cm/hr) and precipitation intensity of equivalent liquid water (mm/hr) as determined from interval snow stake and weight of new snowfall.
(16) sky conditions and precipitation types and intensities (see Figure 2, (20) for coding).
(17) snow crystal type (falling snow) according to the International Snow Crystal Classification.
(18) snow surface characteristics (coded) at observation in study plot (see Figure 2, (27) for coding).
(19) estimated snow level at pass area.
(20) depth of penetration (cm) of 1 kg ram penetrometer into the snowpack.
(21), (22) present wind direction and speed telemetered from sensors on abondoned radio tower (3800 ft.) to summit house. Direction noted in azimuth degrees and speed in mph.

Note: additional clarifying (or other) remarks recorded separately.

Figure 4. Avalanche control and occurrence chart for WSDH Stevens and Snoqualmie Passes slide activity.

This is a duplicate of the standard USFS avalanche recording chart, and is basically self-explanatory. Avalanche path abbreviations were derived from Avalanche Atlases (1974, 1975) encompassing the WSDH pass areas. These atlases were used extensively by project forecasters to determine locations, elevations and aspects of avalanche chutes in the pass areas.

DAY OF MONTH	TIME OF CONTROL OR OCCURRENCE (1)	AVALANCHE PATH AND/OR TARGET NAME	AVAL. PATH NUMBER (IF ASSIGNED)	CONTROL MEASURES (2)	STANDARD AVALANCHE CLASSIFICATION (3) TYPE HS SS WS L WL	TRIGGER N, AS, AE, AA, AL, AO	SIZE: 1-5	RUNNING SFC: O or G	AIRBLAST - J	TYPE OF MOTION (4)	FRACTURE LINE (SLABS ONLY) DEPTH FT.	LAYERS (5
8 9	10 11 12 13	14 15 16 17 18 19 20 21 22 23 24 25 26 27 28 29 30 31 32	33 34 35	36 37 38	39 40	41 42	43	44	45	46	47 48	49

% OF TOTAL AVAL. AREA THAT SLID	LOCATION OF STARTING POINT (6)	VERTICAL FALL DISTANCE FT.	LOC. OF DEBRIS (7)	IF AVALANCHE REACHED A ROAD: MAX. DEPTH ON CENTER LINE FT.	IF AVALANCHE REACHED A ROAD: LENGTH OF CENTER LINE COVERED FT.	REMARKS (Please use for clarifying statements about any entries. Note unusual or interesting events, give details on avalanche accidents, make dollar estimates on avalanche damage, etc. If necessary, use more than one line.)
50 51 52	53 54	55 56 57 58	59	60 61	62 63 64 65	

Plans by the NWS to telemeter precipitation from the recording precipitation gage at the Snoqualmie Pass summit area to the Seattle office by the 1976-77 winter should definitely help the quality of weather forecasts for this area in future forecast operations.

At Stevens Pass, some difficulties in communication resulted from range limitations for field radios and also the lack of a 24-hour/day radio operator (at the Berne Snow Camp) to serve as a focal point for reaching field personnel. Further, there is no nearby NWS meteorological station for backup of WSDH observations at Stevens Pass, so that when data were not available this past year, forecasters either relied on snow-line reports (which were not standardized and did not give hourly precipitation, temperature or wind read-outs), contact with ski area personnel (at Sno-Country Stevens Pass), or extrapolation of available Snoqualmie and/or Stampede Pass data in order to estimate the local weather forecasts for Stevens Pass and evaluate the current or projected avalanche hazard.

For these reasons, a primary recommendation of all personnel concerned with the forecasting project is the installation in the Stevens Pass area of a complete (precipitation, temperature and wind) automatic meteorological station with at least hourly recorded read-out capabilities in the Forecasting Office in Seattle. Dual read-outs--one at the Pass for WSDH personnel and one in the Forecasting Office--would maximize the usefulness of any such meteorological installation. The actual placement of such a station is currently being considered carefully by both WSDH and project personnel to give maximum benefit and access to data input from areas where such information is particularly critical. An installation near the starting zones of the Old Faithful avalanche path is one site possibility. Another more economical alternative is to utilize (at least partially) existing WSDH or USFS sensors and telemeter these read-outs via phone line to the Forecasting Office. A phone telemetry system similar to that employed this year for the Hurricane Ridge temperature read-out could be utilized, with the necessary telemetry equipment located in the basement of the USFS Snow Ranger's house at the Summit where current sensor read-outs are located.

b) White Pass. Prior to the 1975-76 winter this major cross-state highway area had no meteorological instrumentation to speak of, and relied on uncertain ski area equipment and observations for meteorological and snow data. During the Fall of 1975, an instrument tower was constructed by WSDH personnel in a study plot behind the maintenance shed and suitable instrumentation was installed in the plot for basic temperature and precipitation data. Wind sensors were not installed due to a lack of a reliable location and possible telemetering problems from a remote location. Maintenance personnel were instructed in observation techniques for meteorological, snow, and avalanche data during the Fall, and the format and description of these observations as recorded at the Pass and received at the Forecasting Office are shown in Figures 5 and 6.

Data input from this area was generally via radio to Yakima and then SCAN phone to the Office by the Yakima radio operator. Direct communication with WSDH pass personnel was through the microwave system serving that area. Observations were taken three times daily at shift changes, and the reliability and continuity of data received from this station in its initial year of operation was excellent. An automatic meteorological station at this area with data received automatically at the Forecasting Office is not currently a pressing requirement, but should definitely be considered if an avalanche control program is initiated at this Pass area sometime in the future.

c) Crystal Mountain. USFS and ski area professional patrol provided reliable daily snow, weather and avalanche data to the Forecasting Office, and in addition a phone link-up with the summit house at Crystal Mountain (installed by the area management at our suggestion) provided on-demand wind, temperature, and current snowfall data from the full-time winter resident. This capability was very useful for project forecasters for timing the warming trends at other more northern Cascade areas. Necessary instrumentation for this summit operation, provided by the project, was installed with excellent cooperation from the ski area and the USFS during the Fall of 1975. Communication with the area for both daily and on-demand data was via comtel if initiated by the area and via the University of Washington WATS system if initiated at the Forecasting Office.

Daily snow and weather data at the ski area were recorded at both a lower elevation and upper elevation study plot, and were recorded at the Forecasting Office on the modified USFS standard report form in Figure 7. The Snow Ranger and professional ski patrol at Crystal Mountain also provided periodic in-depth snowpack analyses (snowpits) to the Forecasting Office which proved useful in correlation with snowpacks of other areas and in forecasting for this area. It must be realized, though, that the

Figure 5. Sample reporting form for WSDH White Pass observations as received at the avalanche forecast office in Seattle--includes explanations of observations and instruments utilized.

		TEMPERATURE			PRECIPITATION						
DATE	TIME	MAX.	MIN.	PRES.	Begin	End	Total	24-HR		INTERVAL	
MO/DA	24 HR	°F	°F	°F	24 HR	24 HR	IN.	SNOW IN.	H_2O IN.	SNOW IN.	H_2O IN.
		1	2	3	4	5	6	7	8	9	10

WEATHER	WIND		SNOW SFC.	AVALANCHES			OBSER	TO FCST	REMARKS
	FORCE	DIR.		SITE	TIME	SIZE	INIT.	TIME/INIT	
	MPH	8-pt.							
11	12	13	14	15	16	17			18

Explanation of Data

(1), (2) 24-hr maximum and minimum temperatures(°F) recorded from standard mercury and alcohol in-glass thermometers housed in standard weather shelter on top of instrument platform. Platform constructed of wood beams and stands approximately 25 feet high in study plot.

(3) present air temperature (°F) from recorder (Rustrak) readout of shielded thermistor (Hydro-tech) located on north side of tree west of maintenance shed.

(4), (5) beginning and ending of well-defined precipitation periods (24-hr clock).

(6), (7), (9) total, 24-hr, and interval snow depths (inches) as observed from master, 24-hr and interval snow stakes in study plot.

(8), (10) water equivalent (inches) of new 24-hr and interval (generally 8-hr) snow depths. After vertical snow sample from 8 inch snow can is weighed on spring scale, the water equivalent of this snow is read directly off a conversion chart. For this size can, the weight of water in kg is multiplied by 1.22 to obtain inches of water.

Figure 5. (continued)

(11) current sky conditions and precipitation types and intensities (see Figure 2, (20) for coding, except add FR for freezing rain).

(12), (13) current wind direction and speed estimated by WSDH personnel at the pass. Direction noted on eight-point scale (N, NW, W, etc.) and speed in mph (estimated with aid of Beaufort scale of wind).

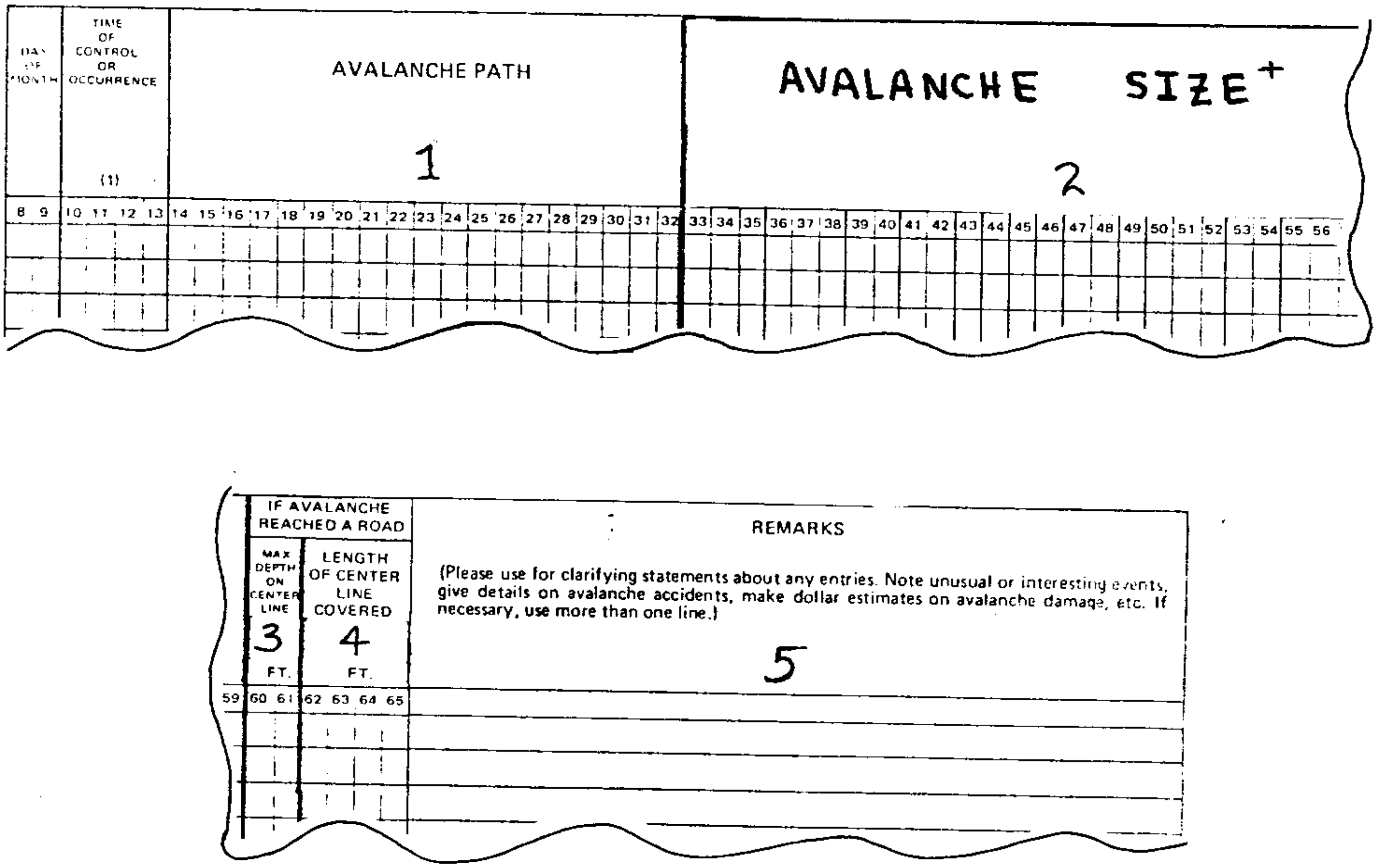
(14) current snow surface (coded) in the study plot at observation (see Figure 2, (27) for coding).

(15), (16), (17) avalanche occurrences, timing and size--significant occurrences generally logged on separate avalanche occurrences chart (see Figure 6).

(18) remarks or clarifications of any data.

The study plot for the WSDH reporting station is located just northwest of the White Pass maintenance shed in a cleared area. The maintenance shed is located approximately one mile west of the summit on US 12 at elevation 4400 feet.

Figure 6. Avalanche occurrence chart for WSDH White Pass.



Explanation of Data

(1) avalanche path as listed in the WSDH White Pass Avalanche Atlas; cutbank slides are logged as such on east or west side of pass.

(2) avalanche size: A--slide path ran but did not reach roadway; B--slide trickled onto roadway, reached roadway but did not obstruct traffic; C--slide ran to centerline, one lane of traffic blocked; D--slide covered entire roadway, but did not run beyond road; E--slide covered entire roadway and continued beyond roadway.

(3) maximum slide depth (ft.) on centerline.

(4) length (ft.) on centerline covered.

(5) clarifying remarks.

Figure 7. Sample reporting form for Crystal Mountain observations received at the avalanche forecast office in Seattle--includes description of form and types of instruments used.

Area ________ Month ________

	1	2	3	4	5	6	7	8	9	10	11
		TEMPERATURE					PRECIPITATION*				
		24 HOURS ENDING AT OBSERVATION		AT TIME OF OBSERVATION							
DAY OF MONTH	TIME OF OBSN.	MAX °F	MIN °F	AIR TEMP. °F	20 CM BELOW SNOW SFC °C	DEPTH OF SNOW ON THE GROUND* IN.	NEW SNOW DEPTH 1/2 OF IN.	WATER EQUIV. OF NEW SNOW 1/100 OF IN.	WATER FROM RAIN 1/100 OF IN.	NEW SNOW TYPE BY 6-HR PERIODS (1) 0-6 hrs 06-12 12-18 18-24	INTENSITY BY 6-HR PERIODS (2) 0-6 hrs 06-12 12-18 18-24
	10 11 12 13	14 15 16	17 18 19	20 21 22	23 24 25	26 27 28	29 30 31	32 33 34	35 36 37	38 39 40 41	42 43 44 45
					–		.	.	.		
					–		.	.	.		
					–		.	.	.		

12								13				14*	15
WIND DIRECTION AND SPEED* SIX-HOUR AVERAGES TIME PERIOD								Present Weather					REMARKS
00-06hrs		06-12		12-18		18-24							
(ENTER 99 FOR VARIABLE DIRECTION)								Wind	Sky Cover	Weather	Snow Surface		
DIR (00-36)	MPH	DIR (00-36)	MPH	DIR (00-36)	MPH	DIR (00-36)	MPH						
46 47	48 49	50 51	52 53	54 55	56 57	58 59	60 61	62 63 64 65	66 67 68	69 70 71	72 73		

The modified USFS standard report form here is mostly self-explanatory. Crystal Mountain snow and weather observations were made at both a lower (4400 ft.) and upper (6300 ft.) study plot. Temperature (col. 2-5) and precipitation (col. 6-11) values were recorded at both plots, while wind direction and speed (col. 12) were determined from sensors located at the summit house (6860 ft.).

Standard in-glass thermometers were used for air temperature values (col. 2-4) at both plots, while dial-type stem thermometers recorded 20-cm snow temperatures (col. 5). Snow depths (col. 6-7) were read from standard master and interval snow stakes. Weighing bucket rain gages at both sites were used in conjunction with new snow depths (weights) to determine water

Figure 7. (continued)

equivalent of snow (col. 8) and water from rain (col. 9), if any. Observations by the USFS snow ranger and professional ski patrol at the base only determined snow types and intensities (col. 10-11). Present weather (col. 13) was recorded only at the base at observation time.

Avalanches in the ski area (col 14) were generally recorded on a separate USFS avalanche form, and an asterisk in this column (at the forecast center) was used to denote that significant slide activity had occurred on this day. Since ski areas generally experience so many avalanches with their control activities that reporting of individual slides is impractical, avalanche reports from Crystal Mountain were restricted to : (a) if natural avalanches occurred before control commenced, (b) aspects and ranges of sizes and types of natural occurrences, and numbers (few or many) of occurrences, and (c) approximate number of artificially triggered slides, plus their range of aspects, sizes and types.

It should be noted that all-hours observations of wind, temperature and weather were available from the live-in resident at the summit house.

location of Crystal Mountain to the east of Mt. Rainier gives this area anomalous weather and snowfalls at times throughout the year and makes local forecasting for this area extremely difficult.

d) Paradise. NPS personnel provided reliable daily snow, weather and avalanche data from this exposed station on the southwest slopes of Mt. Rainier. Communication with this area was via WATS or comtel and the general form in which information was received by the Forecasting Office was the standard USFS reporting form (very similar to Figure 7).

With the cooperation of NPS personnel, a fairly reliable automatic recording temperature and wind system was installed near the "ski dormitory" at the Visitors Center area in the Fall of 1975. These readings, coupled with previous NPS instrumentation at Paradise, gave project forecasters good qualitative information regarding storm snowfall intensities, densities and temperatures, and a good feel for the magnitude of orographic precipitation for the Cascades during non-frontal periods. The wind system, although reliable and useful for local weather and avalanche forecasting for the Paradise area, did not couple well with the free winds (either direction or force) at the same elevation as observed by radiosonde observations in Seattle and on the coast (Quillayute), and were therefore less useful than previously thought in terms of general forecasting for the Cascades. Significant channeling of winds seemed to occur in the valley leading up to Paradise from the west, and in general the wind force appeared lower than expected during high west wind periods. At times this force anomaly could be due to riming on the cup sensors, but this phenomenon does not explain all of the observed variations. Relocating the sensor nearby does not appear to be a viable solution to this problem, as the current placement seems to be one of the most exposed for west winds. It is possible that the wind system here should remain a useful tool for local avalanche and weather forecasting only.

e) Washington Pass. Full-time WSDH weather and avalanche observers continued to record snow, weather and avalanche data from this site throughout the winter season. While giving the forecasters an indication of snowfall amounts and types, temperatures and winds in the northern Cascades, these data were not directly utilized in forcasting for the operational Passes to the south. Major avalanche-generating storm situations or warming periods usually approached Washington from the southwest or west, and with observations from this area generally once a day via radio-phone relay, information from this station even for northwest-approaching storms was of marginal value to project forecasters on a real-time basis. Communication was further limited during weekends when the main communication link with the Pass (via the WSDH Okanagan radio operator) was not operational at all. In terms of future possible year-round Pass operation, however, the data recorded during the past winters and in future winters will give forecasters essential background information necessary to achieve accurate and effective forecasts for this area. A test forecasting program for Washington Pass is contemplated for the project operation in 1976/77.

f) Hurricane Ridge. The telemetered temperature sensor (thermistor) system installed at Hurricane Ridge on the northwest ridge of the Olympic Mountains in the late Fall of 1975 and operational in February of 1976, gave forecasters a valuable early warning tool for forecasts of general warm-ups affecting the Cascades. In its current operating modes, the thermistor system is linked via NPS radio to Olympic National Park Headquarters in Port Angeles, where an automatic phone patch was used. Here the incoming audio signals representing temperature values were transmitted automatically over the phone on demand, so that interrogation of the thermistor was accomplished via WATS or comtel line from the Forecasting Office. The incoming audio signals at the Forecasting Office were then retranslated to their corresponding temperature outputs. (See Appendix C for more detailed technical description of the Hurricane Ridge telemetry system.) Initial attempts to telemeter sensor output directly from the sensor site to the roof of the University of Washington Atmospheric Sciences building or the roof of the NWS building proved unreliable due to uncertain signal propagation across the eastern ranges of the Olympic Penninsula. The development of this telemetry link was made possible by the excellent cooperation of the National Park Service, which made its communication network and some of the essential equipment available to the project.

The telemetering system at Hurricane Ridge was designed to accommodate various other sensor inputs, and it is recommended that wind force, direction and precipitation intensity also be telemetered from this site in any future forecast operations. Such information on a real-time basis would give forecasters significant lead-time on forecasts for storm situations moving toward the Cascades from the west. A very severe riming problem for the wind sensors at this area could possibly be eliminated by development and trial operation of a different concept in anemometer design currently being studied at the University of Washington. Also, given the excellent reliability from the temperature telemetry system during its initial year of operation, it is recommended that future improvements of the project operation include installation of a similar temperature sensing system on Mt. St. Helens in the southern Cascades near the 7-8000 foot level (the Dog's Head is a possible site) or on the southern edge of the Olympic Mountains at a site yet to be determined.

g) Stampede Pass. Hourly temperature, precipitation and wind data were received from this station via NWS teletype at the Forecasting Office. The exposure to prevailing winds is excellent and reliability of all data is outstanding. The only real problem in terms of local forecasting with this station is its distance from active starting zones of slide paths affecting the highway (I-90) and its location to the east and south of Snoqualmie Pass, where less snowfall is generally recorded than at the Pass itself despite the higher elevation of Stampede Pass. However, its continuous weather feedback at all times gave project forecasters excellent data on which to base and update general weather forecasts.

3.1.2 Secondary Reporting Stations

a) Sno-Country Stevens Pass. The ski area provided reliable back-up information to WSDH observations regarding new snowfall, temperature, winds, current weather and avalanche occurrences during morning control. Twenty-four hour and current weather information was usually available prior to 0630 from the Snow Ranger, and avalanche information from the Ski Patrol after 1000 hours at the ski area. Updates on current weather from the Snow Ranger at the Pass were available at varying times throughout the day and generally after 1800 from the Ranger's home.

b) Mt. Baker. Snow and weather data from this area were received via WSDH snow-line reports, although direct contact with USFS personnel (or an after-hours phone recording) regarding wind, temperature, and snowfall for Mt. Baker was utilized by project forecasters for information relative to timing and magnitudes of storms which tracked primarily from the northwest. Unfortunately, this information was not available generally until late morning, by which time the initial weather and avalanche forecast had already been disseminated by the Forecasting Office. However, availability of this information could prove to be vital for future weather and avalanche forecasting for SR-20, if this highway does become a year-round operation.

c) Mission Ridge. Snow and weather reports from this ski area were received by the Forecasting Office via commercial telephone from the Ski Patrol on a sporadic and often incomplete basis, generally well after the initial morning forecast was issued and often not until evening. In order for this station to be useful for forecasts, reports must be made available earlier in the day and on a more complete and regular basis. A further consideration in the usefulness of Mission Ridge is that equivalent data should be available from a nearby telemetering Soil Conservation Service (SCS) station at Trough #2 (see section 5.1. (e) for further discussion of SCS data for the 1976-77 winter).

3.2. Field Snowpack Data

In general, snow is deposited in layers, due to breaks between or during storms or in terms of variations in snowfall intensity, snowfall type, wind direction and speed, and temperature. Such varying snow deposition usually leads to variations in strength of bonding between or within different layers, which can be important determining factors in snowpack instability and possible resulting avalanche release.

Fracture-line and other snow profiles give a fairly detailed picture of the current physical state of the snowpack in terms of temperature, density, mechanical strength and layering variations with depth, and are therefore useful analytical methods for determining snowpack stability. As an example, mechanically weak snow layers, which can act as lubricating layers for avalanche release, show up well in snow profiles by generally low ram resistances and low density readings and are also usually obvious in snow stratigraphy observations. Likewise, strong layers such as rain crusts and ice layers, which are often found as sliding surfaces in avalanche releases, are usually readily observed by high ram resistances, high densities and through various strength tests on the snowpit wall. Also, strong temperature gradients, which may adversely affect the mechanical strength of the snowpack are readily observed by temperature measurements in the snowpit wall. Thus, observed depth variations of temperature, density, ram resistance and stratigraphy in snowpits and fracture-line profiles at slab avalanche release sites yield much insight into possible relationships between snowpack properties and avalanche release.

During the winter of 1975-76, snowpack reports were generally fed back to the Forecasting Office in the form of formal snowpit studies or fracture-line profiles at a defined slide area. Hasty snowpits (quick snowpits excavated to roughly determine snowpack layering and instabilities) dug at various areas also gave valuable information as to possible sliding surfaces, lubricating layers and varying types and depths of local snow accumulations. For example, slide paths with different aspects or elevations were often loaded at different rates (wind-slab deposition on lee slopes versus slope scouring on exposed windward slopes) and by possibly completely different precipitation types (e.g., rain versus snow) which led to considerable differences in snowpack layering between adjacent areas. A good current working knowledge of the snowpack was also essential for forecasters in promoting meaningful daily discussions with WSDH avalanche personnel through rapid assimilation of snow test data provided by these same personnel.

3.3. Meteorological Data

The success of any avalanche forecasting program is largely dependent upon the availability of reliable weather maps to on-duty forecasters. These maps should not only present the current temperature and wind fields, frontal positions and other important meteorological factors both at the surface and aloft, but should also depict fairly reliably the future positions and values of these quantities.

In avalanche and weather forecasting, current and prognostic maps and field data are highly interdependent. Throughout this past winter, weather feedback from primary reporting stations in the Cascades gave project forecasters excellent checks on their interpretation of current weather maps. Upgrading and revision of weather forecasts based on new field and current weather map data was basic to the forecasting procedure. During critical avalanche periods prognostic maps were as important as current maps, for when used in conjunction with reports of current observed mountain weather conditions, they generally gave the forecaster a good idea of such factors as how long the current precipitation or winds should continue, when the next surge of precipitation should occur, and when a possible warm-up should be expected. Satellite pictures of the earth's atmosphere were also utilized extensively by the forecasters, for they provided excellent confirmation and weather information on positions, magnitudes and motions of fronts, convective cloud activity and upper air flow patterns.

Most weather maps, satellite pictures and selected teletype data received at the NWS office in Seattle were utilized by project forecasters. Current and prognostic weather maps were received via the National Weather Service Facsimile Circuit (NAFAX) or the Forecast Center Facsimile Circuit (FOFAX). Table 1 gives the reception schedule of these various maps, along with the schedule of teletype products utilized by project forecasters. The current maps at any given pressure level are based on measured atmospheric quantities (wind, temperature, etc.) while the prognostic maps are based on sets of equations which extrapolate current quantities into the future. Satellite pictures were generally received at the Forecasting Office every half hour, and these varied in resolution (1/2 mile to 2 miles) and type (visible or infrared images depending on time of day and light conditions).

4. FORECASTING OFFICE OPERATION

4.1 Staffing and Equipment

During the first few months (September-November) of the project, forecasting staff were occupied with (a) the task of setting up and instrumenting a viable data network (3.1) and (b) preparing forms and graphs necessary for efficient assimilation of both incoming meteorological data and mountain weather, snowpack and avalanche data. The forms and types of these data are described in earlier sections (3.1, 2 and 3). Additionally, the form of forecast to be issued by the forecaster was considered carefully by project staff in terms of exactly how the forecast could best serve the needs of WSDH field personnel. Post-season quantitative analysis of the accuracy or reliability of the forecasts issued was also a major consideration in composing the forecasting form.

During the operational phase of the forecast season (December 6-April 19) the Forecasting Office was manned seven days/week from 0700 to 1500 P.S.T. during low hazard periods and had effective 24-hour/day coverage at high hazard periods. Project staff included Frank (Bud) W. Reanier

TABLE 1. Facsimile Charts

Schedule of charts used at the Forecasting Office--received on National Weather Facsimile (NAFAX) Circuit unless noted # which indicates receipt on Forecast Center Facsimile Circuit (FOFAX).

Time (PST)	Facsimile Chart
0053- - - - - -	Prognostic Chart 24-hr. 850 mb./700 mb.
0107- - - - - -	Pacific Surface Analysis #
0154- - - - - -	Prognostic 30hr. Surface and 36-hr. 1000-500 mb. thickness
0339- - - - - -	300 mb. Analysis
0349- - - - - -	12Z-12Z Quantitative Precipitation Forecast (QPF) 1st day, next day
0420- - - - - -	Prog. 72-hr. 500 mb.
0523- - - - - -	Minimum Temperatures
0533- - - - - -	Surface Analysis--6 hourly
0618- - - - - -	500 mb. Analysis
0640- - - - - -	850 mb. Analysis
0650- - - - - -	Vorticity plus 500 mb. 00, 12, 24, 36 hr. Barotropic progs.
0706- - - - - -	24-hr. Precipitation
0707- - - - - -	Pacific Surface Analysis #
0756- - - - - -	700 mb. Analysis
0813- - - - - -	Limited Fine Mesh 12-hr. Prog. --Vorticity plus 500 mb. surface pressure plus 1000-500 mb. Thickness, Relative Humidity, 12-hr. Precipitation and Vertical Velocity
0856- - - - - -	L.F.M. 24-hr. Prog. (same data as above)
0930- - - - - -	300 mb. Analysis
1052- - - - - -	Vorticity plus 500 mb.--00, 12, 24, 36 hr. Baroclinic progs.
1105- - - - - -	Prog. 48-hr. 500 mb. and Vorticity
1113- - - - - -	Prog. 36 and 48-hr. Surface, Clouds and Precipitation
1137- - - - - -	Surface Analysis--6 hourly
1253- - - - - -	Prog. 72-hr. 500 mb.
1316- - - - - -	Pacific Surface Analysis #
1339- - - - - -	500 mb. Analysis
1349- - - - - -	Prog. 30-hr. Surface and 36-hr. 1000-500 mb. Thickness
1414- - - - - -	Daily Extended Outlook--24-hr. Precipitation Charts plus Maximum and Minimum Temperature Charts
1604- - - - - -	Daily Extended Outlook--500 mb. 96-hr. prog. plus Surface 5-day mean temperature anomaly and total precipitation
1654- - - - - -	Prog. 24-hr. 850 mb./700 mb.
1735- - - - - -	Surface Analysis--6 hourly
1820- - - - - -	500 mb. Analysis
1842- - - - - -	850 mb. Analysis
1852- - - - - -	00, 12, 24, 36-hr. Barotropic 500 mb. progs. and Vorticity
1903- - - - - -	Pacific Surface Analysis #
2001- - - - - -	700 mb. Analysis
2101- - - - - -	L.F.M. Prog.--Vorticity plus 500 mb. Surface pressure plus 1000-500 mb. Thickness, Relative Humidity, 12-hr. QPF plus Vertical Velocity
2156- - - - - -	300 mb. analysis
2216- - - - - -	500 mb. Analysis
2242- - - - - -	Prog. 36-hr. 500 mb.
2252- - - - - -	00, 12, 24, 36-hr. Baroclinic (Primitive Equation--P.E.) progs.--500 mb. and Vortictiy
2313- - - - - -	Prog. 36 and 48-hr. Surface, Clouds and Precipitation
2337- - - - - -	Surface Analysis--6 hourly

Table 1. (continued)

- -

Schedule of Products Received via Teletype

1044- - - - - -	FOUS 60	Forecast--6 hourly data from Numerical Model (Primitive Equation) includes Temperature, Relative Humidity, Wind speed and direction,
2244- - - - - -	FOUS 60	Vertical Velocity, Precipitation, etc.
1040- - - - - -	FOUS 50	Trajectory Forecast--700, 850 mb. and surface
2240- - - - - -	FOUS 50	(Temperature and Dewpoint)
Hourly - - - - - - - - - - - -		-Weather Observations (Clouds, Visibility, Pressure, Temperature, Dewpoint, Wind, Weather. Precipitation amount, etc.) from Canadian and NWS Washington, Oregon and other northwest state reporting stations

(consultant/senior meteorologist), Mark B. Moore (UW research scientist/ assistant meteorologist), and Richard T. Marriott (UW graduate student/ research assistant). Flexible hours and staff rotation were necessary to accommodate long hours of coverage during severe storm situations, as well as for providing real-time supportive field snowpack data--supplied by forecasting staff in the field--to the on-duty forecaster.

A minimum of two full-time personnel and one part-time relief forecaster was necessary to adequately staff the Forecasting Office during all hazard periods, especially considering the fact that effective avalanche forecasting was best achieved when the forecaster had a good first-hand working knowledge of the snow-pack. Project forecasters tried to spend at least two to three days/week in the field throughout the winter to assess snowpack stability and layering and to become more familiar with the aspects, elevations, types and response to current weather of avalanche chutes in each area. This field time was particularly essential during the early part of the winter when new snowfall was only gradually smoothing out terrain irregularities and continuous sliding surfaces were just beginning to be established, for then neither time nor avalanche hazard were critical and avalanche areas could be carefully and safely studied.

Communication equipment comprised the majority of Forecasting Office hardware. As communication with field personnel by project forecasters was primarily via phone line, a University phone (combined WATS and SCAN line) was installed at the Forecasting Office. Such a phone system yielded maximum communication time with field personnel at the lowest possible cost.

During high avalanche hazard periods, field avalanche personnel needed continuous (24 hours/day) availability of the most recent avalanche forecasts, and an all-hours Forecasting Office receptacle for their observation updates on avalanche activity and weather. To achieve these goals, a telephone answering and recording set (Code-a-phone 370) was installed and attached to the phone at the Office in December at the start of the 1975-76 winter operation.

This device provided automatic dissemination of forecasts and recording of incoming observations during a forecaster's absence from the Office. Operationally, after project forecasters taped their most recent forecast onto an endless loop cassette (maximum 180 second outgoing message) in the Code-a-phone and set the device to automatic answer, the machine then automatically answered the phone, repeated the recorded forecast and recorded any incoming observations (maximum 30-minute incoming message) from field personnel. Departing forecasters could therefore leave their last forecast on the tape for any calls during their absence and then play-back any observations received after their return. The unit proved to be very dependable and entirely satisfactory throughout the winter's operation. (A different unit yielded some initial difficulty in the early-season operation and was replaced with the model discussed above.)

Additional office communication equipment required for reception and translation of the temperature signal from Hurricane Ridge has been previously described and detailed (see section 3.1 and Appendix C).

Due to a high rate of field to office communication during high hazard periods and the accompanying inability of field personnel to reach the Forecasting Office at these times (the line was often busy), it is recommended that two phones be installed at the Forecasting Office in future operations. One phone would be reserved for the taped forecast and for non-urgent incoming observations, while the other would be answered by the forecaster during duty hours for more pressing weather and avalanche observations or forecasts. During off-duty hours, both phones would be answered by the automatic answering and recording device.

A further recommendation for future more efficient operation of the forecast project is transmission via phone-teletype link of "hard copies" (i.e., typed paper copies) of the weather and avalanche forecasts to WSDH Stevens and Snoqualmie Passes only. Frequently when avalanche hazard is high and WSDH avalanche personnel are actively engaged in control missions or otherwise severely pressed for time, immediate availability of hard copy of forecasts that can be taken in the field and read while in transit to control or observations sites could be critical to control timing. Immediate access to hard copies also would eliminate memory lapses or lack of forecast updates or related avalanche information that might otherwise be missed because phone calls to the Forecasting Office were not possible. Problems can be significant when field personnel try to quickly recall what was said on a three-minute tape, especially when the forecaster must speak quickly to put all the important information on the tape. Hard copies of issued forecasts would also be readily available for "after the fact" correlative studies and/or observation of forecast trends by Pass personnel.

A more economical alternative to the phone-teletype link for permanent or semi-permanent retention of forecasts is a small cassette recorder for each Pass area with plug-in capabilities to the phone earpiece. However, the many advantages of the phone-teletype link due to time saved during critical periods and immediate availability and permanency of the forecast record would be lost.

4.2. Daily Routine

Operation of the Forecasting Office in Seattle for the 1975-76 winter began on December 6, 1975, and ended on April 9, 1976. The office was manned from 0700-1500 P.S.T. each day during low hazard periods and had effective 24-hour/day coverage at times when hazard was high.

A standard early morning daily routine was established by project forecasters for the most effective utilization of NWS data in the daily forecast formulation. A daily work-sheet was used to log the most useful weather data and to write the taped forecast. This daily work sheet is shown in Figure 8. General guidelines for completion of the work-sheet and a basic interpretation of the various data follows (the numbers given below correspond to the appropriate sections found in Figure 8):

(1) Log temperature, weather (present), new snow, total snow on the ground from 0630 P.S.T. highway Pass reports received via teletype (Weather Service local loop) from WSDH Station #10. These reports include Snoqualmie, Blewett (Swauk), Stevens and White Passes. Mt. Baker report is not received until the 0930 collection. Paradise (Mt. Rainier) data is received by phone. Stampede Pass hourly reports are received by teletype and the 0400 P.S.T. data is logged with highway Pass reports for comparison. Both Stevens and Stampede Pass report water-equivalent of the 24-hour precipitation which gives a rough check on the new snow depth and density.

Total snow depths of most reporting stations were displayed graphically to quickly display overall (or regional) snowfall trends and snowpack settlement. Hourly Hurricane Ridge temperatures were also called for and logged both on the worksheet and on a graphic display after the sensor system was in operation.

(2) Log Stampede Pass temperatures, precipitation, wind, plus the surface pressure gradient--Seattle minus Yakima--at three hour intervals (beginning at 00Z, 03Z, 06Z, . . .18Z, 21Z--Greenwich mean time). This gradient determines the low level air flow through the

Figure 8. Work Sheet and Forecast Form

AVALANCHE CENTER WORK SHEET   Revised 1/13/76

_____/_____/ 76 (date)   _____ PST (time)

(1)	(Temp)°	(Wx)	(NewSnow)"	(Total Snow)"	(W.E.)"	(Max/Min)°	(4) (QPF-Tda /Tmrw) (0400-0400 PST)
SNOQUALMIE	___	___	___	___			
BLEWETT(SWAUK)	___	___	___	___			
STEVENS	___	___	___	___	___	___/___	
WHITE	___	___	___	___			
BAKER	___	___	___	___			
STAMPEDE	___	___	___	___	___	___/___	___/___
PARADISE	___	___	___	___	___	___/___	

(5) (1200Z)(0000Z)	FRZG LVL'	5000 Ft.(850 mb) Wind (Direction/Speed)(1200Z)(0000Z)
UIL(797)	___/___	___/___
GEG(785)	___/___	___/___
ZT(109)	___/___	___/___
VK(115)	___/___	___/___
GRF(207)(1500Z)	___	___/
SLE(694)	___/___	___/___
C7P(50N145W)	___/___	___/___

Depth Arctic Air _____

SEA(793)(1500Z) _______ (Frzg Lvl)

(6) FOUS 60 (0000Z) | (1200Z)

Time		RH%	.VV	HH	DDFF	TB°	PTT	RH%	.VV	HH	DDFF	TB°	PTT	Time
04P	SEA													16P
10	18													22
16	24													04
22	30													10
04	36													16
10	42													22
16	48													04

850 Mb. Chart (1200Z)(0000Z) Advection ?? WARM / COLD / NONE

(2) Surface Pressure Gradient SEA- YKM = mbs. - SMP Temp. / SMP WIND /3,6 Hrly Pcpn

	(15Z)	(18Z)	(21Z)	(00Z)	(03Z)	(06Z)	(09Z)	(12Z)
(wind)								
(pcpn)	°	°	°	°	°	°	°	°

(3) CASCADE OLYMPIC MOUNTAIN Fcst: (0430 - 1030 - 1630 PST)

- -

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

_______ AM/PM (time) _______ (day) _______ (month) _______ (date)

(7)&(8) "SYNOPSIS: Includes current weather map synopsis, weather trends, reasons for trends, timing of future weather disturbances or other weather patterns of significance, regional effects of weather (if any).

Figure 8 (continued)

(9) **FORECAST:** Includes timing and type of precipitation (if any), temperature trends, winds at the passes, local weather variations (e.g., east vs. west side, temperature inversions, fog, freezing rain, etc.), weather outlook.

SNOW (FREEZING) LVL NR.________ FT. RISING / LOWERING TO ________ FT. ________.
WINDS AT 5000 FT. LVL ________ ____ KNOTS, BECOMING ________________.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS ______ INCHES W.E.
ENDING AT 4 AM ________ SNOQUALMIE PASS ______ INCHES W.E.
WHITE PASS ______ INCHES W.E.

---

(10) AVALANCHE ADVISORY: Includes forecaster's evaluation of the present and possible future condition of the snowpack based on past and present mountain weather, input from the observation network, on-the-site snowpack observations by avalanche center staff, and expected future weather and weather trends. This snowpack condition may be noted as changing with slope aspect, elevation, from east to west side (of the passes), from chute to chute (frequent vs. infrequent sliders), and from area to area. Also includes results of avalanche control work done at various areas (or natural slide activity) if dissemination of such information appears useful.

(Date)___/___/76

Passes which many times is exactly opposite to the winds in the free air or over the ridges. The Stampede Pass winds and pressure gradient were also logged graphically on an hourly basis along with 850 mb. winds from Quillayute and Ft. Lewis to give forecasters a quick overview of (changing) wind patterns.

The Stampede Pass temperature was also logged graphically along with the Hurricane Ridge temperature and Quillayute freezing level to provide forecasters with a tool for observing warm-ups and temperature trends.

(3) Next check the latest (0430 PST) NWS forecast for the Olympic and Cascade Mountains (issued three times daily).

(4) Check the QPF (Quantitative Precipitation Forecast) made by the National Meteorological Center (NMC) and the Lead Forecaster (mid-watch) at Seattle for the various Cascade points, especially Stampede Pass.

Update and modify QPF after examining new computer prognostic charts, plotted radiosonde data, and four additional hours of weather observations, etc. (after the original QPF was made).

(5) Check moisture patterns and log freezing levels, inversions and 850 mb. (approx. 5000 feet) winds from the following RAOB (Radiosonde Observation) stations in British Columbia and the Pacific Northwest: Quillayute (UIL), Spokane (GEG), Seattle (SEA), and Gray Field/ Ft. Lewis (GRF) in Washington, Vernon (VK) and Port Hardy (Z1) in British Columbia, Salem (SLE) in Oregon, and Weather Ship (C7P--Canadian) in the Gulf of Alaska near 50 degrees north and 145 degrees west. Also check the depth of the arctic airmass if present in Prince George and Vernon, British Columbia.

850 mb. winds from GRF and UIL (and at times SEA) were displayed graphically with Stampede Pass winds for quick wind correlations between the free air and mountain air flow. UIL freezing levels were also logged with Hurricane Ridge and Stampede Pass temperatures for displaying pertinent temperatures and temperature trends at a glance.

(6) Log "FOUS 60" data (forecasts made by the NWS computer for various weather parameters for Seattle). These include the average relative humidity (RH) in three layers of the atmosphere, the vertical velocity (VV), thickness values (HH) between two constant pressure surfaces (from which the freezing levels can be approximated), the

direction and speed of the mean wind (DDFF) in the boundary layer of the model (which is about the 4000 foot level for Seattle), the mean potential temperatures (TB) of the boundary layer and the amount of precipitation forecast (PIT). All of the above data are forecast in six hourly increments out to 36 hours, twice daily.

(7) Check satellite pictures coming in each hour. Note location and speed of frontal bands, altitude and type of clouds, etc.

(8) Check all recent current and prognostic weather maps (see Table 1 for a list of these maps and their time of reception at the Forecasting Office).

Write a brief synopsis of the current and projected weather patterns, including location and speed of weather fronts, blocking upper level ridges, cold lows aloft, temperature inversions, etc.

(9) Make a detailed weather forecast for the Cascades and Olympic Mountains to 48 hours and an outlook in general terms for the 3rd through the 5th day. The 48 hour forecast should include sky cover, precipitation (type and intensity), timing of frontal passages, wind shifts, wind speed and direction, freezing level (or snow level), free air wind for the starting zones (approximately 5000 feet), water equivalent of snow (or rain) next 24 hours for each individual Pass.

(10) Based on most recent Pass reports, weather trends, avalanche occurrences, snowpack analyses, etc., available, formulate avalanche advisory for inclusion in taped telephone recording. A list of factors considered by forecasters when composing this advisory is given in Table 2.

(11) Log incoming data from field reporting stations (on forms discussed in 3.1 and graphically) either from recorder or directly over the phone (continues throughout the day). Update or amend initial forecasts based on new field data or new map analyses. Initiate "weather alert" when necessary and call all cooperating stations to advise of probable avalanche-generating situations (especially expected rapid warm-ups and/or rain). (The weather alert checklist is shown in Figure 9.)

(12) During high hazard periods, write brief "in-house" (not disseminated to users) snowpack summary containing estimation of the

TABLE 2. Major factors considered by forecasters in preparing avalanche advisories

(1) Snowpack stratigraphy in area of forecast slide paths.

(2) General knowledge of previous snowpack layering from meteorological reconstruction.

(3) History of slide path: (a) recent, (b) long-term.

(4) Slide path aspect.

(5) Location of slide path--east or west side of Cascade crest.

(6) Immediate topography surrounding slide paths in question (from personal experience and avalanche atlas).

(7) Current and projected (a) wind, (b) temperature, (c) precipitation intensity for the slide path area.

(8) Present and past snow surfaces in slide path area from WSDH (and other) observations (couples with (1)).

(9) Elevations of starting and run-out zones of each slide path.

(10) Depth of snowpack in starting zones--for early-season avalanche forecasting, this gives an idea of how much vegetation is still left in upper zones to stabilize snowpack.

(11) Snow crystal types reported.

(12) Ram (1 kg.) penetration into snowpack--to evaluate quantity of snow involved in possible slides.

(13) Avalanche activity observed in nearby areas.

Figure 9. Weather Alert Checklist. These stations were called immediately when forecasters expected any extreme avalanche-generating situations. Weather alerts were also stressed on the taped forecasts.

SNOQUALMIE PASS:	WSDH Hyak Radio Operator (Al Bennett) Snow Ranger, Alpental (Ken White)
STEVENS PASS:	Berne Snow Camp WSDH (Steve Reister) Snow Ranger (Glen Katzenberger)
MT. RAINIER:	Headquarters, Longmire (Pete Thompson) Paradise, Ranger (Walt Dabney)
CYRSTAL MTN.:	Ski Patrol (Bill Steele) Snow Ranger Office
WHITE PASS:	WSDH Snow Ranger
MT. BAKER:	WSDH via Seattle Station 10 Snow Ranger (Mike Dolfay) Ski Area
OLYMPIC NAT'L PARK:	Headquarters, Port Angeles
WASHINGTON PASS:	Via WSDH Okanogan radio
USFS AVALANCHE WARNINGS:	(Public - Paul Frankenstein)

snowpack stability, layering, avalanche situation, and the effect of these variables on possible future weather trends. This summary provided the next day's forecaster with a readily available, concise statement on the important snow and avalanche conditions as they were observed and analyzed by the previous day's forecaster.

With this established daily routine, forecasters were generally able to give brief informal (non-recorded) weather synopses, forecasts and avalanche advisories by 0800-0900 of each morning. A more detailed forecast package was usually recorded by 1000-1100 (the daily NWS staff weather discussion usually occurred around 0900), while afternoon weather and avalanche updates were available and recorded by 1500, if such updates were deemed necessary.

During low hazard static weather periods when weather analyses and updates were not vitally required by WSDH personnel, forecasters often recorded only one forecast package at 1500 PST. Informal weather and avalanche discussions, though, were held with field personnel throughout the day.

During high hazard periods, in addition to the morning (1100) and afternoon (1500) recorded forecasts, another recorded forecast was usually available by 2100, with the Office being manned for consultation, discussion, etc., from approximately 1900-2100 hours. Continuity and familiarity with ongoing weather and avalanche situations was stressed by having only one on-duty forecaster often operate during both regular and evening hours on a given day. On other days, time overlap between on-duty personnel achieved the same continuity and provided a welcome relief from lengthy hours.

4.3 The 1975-76 Winter

4.3.1 Discussion of Forecasts

Evaluation of the first year of operation of the Forecasting Office divides naturally into the accuracy and usefulness of the forecasts. The usefulness of the forecasts has been considered in discussions with field personnel and through a questionnaire sent out to all participating agencies. In considering the quantitative accuracy of the forecasts, difficulties were encountered due to the generally qualitative nature of the Forecasting Office product and the difficulty in measuring the exact quantities forecast.

The Forecasting Office product (see Appendix A) can be broken into five general factors: Weather and weather trends; freezing (snow) level; winds; quantitative precipitation forecast; and avalanche situation. In evaluating the accuracy of the forecasts only freezing levels, winds, and precipitation are amenable to direct numerical evaluation, while weather and avalanche advisories are narratives subject to interpretation. Though a complete summary of the weather and avalanche situation was attempted in the written forecasts, the interpretation by field personnel was also modified by discussion with the forecasters, so that their subjective evaluation of the individual forecast is probably the only complete measure of the accuracy and usefulness of the forecasts.

a) Weather and Weather Trends

The weather and weather trends were given in a narrative form which is described in section 4.2. Though the weather of the preceding day was discussed with the observers each morning, no accurate log was kept in the same terms as the forecasts, which precludes a day by day evaluation of the general forecast; however, the question of weather forecast accuracy was discussed with field personnel and it was treated in the questionnaire--the results of which are shown, in part, in Table 3.

The general opinion of persons using the forecasts was that the forecasts were fair to good and that improvement in the forecast accuracy was seen during the winter as forecast experience with the individual areas increased.

b) Freezing Levels

The accurate determination of freezing levels within the mountainous regions is a complicated and difficult problem, and one which has not been adequately solved. Generally, an air mass is characterized by free air temperatures which do not take into account local terrain features. The free air temperatures are regularly measured by radiosondes sent up from specific stations at twelve hour intervals--4 a.m. and 4 p.m. PST. There are two regularly reporting radiosonde stations in the state of Washington located at Quillayute Airport near Forks west of the Olympic Mountains and at Geiger Airport near Spokane. Both of these stations are located several hundred miles from the Cascades. These stations, plus several in Canada

TABLE 3. Extracts from Forecasting Office Questionnaire

- How would you characterize the reliability of the weather forecasts?

  1 excellent, 2.5 good, 2.5 fair, 0 poor, 0 other

- How would you characterize the reliability of the avalanche forecasts?

  1 excellent, 2 good, 1 fair, 0 poor, 2 other

- How would you characterize the reliability of the precipitation forecasts?

  1.5 excellent, 1.5 good, 1.5 fair, 1.5 poor, 0 other

The numbers indicate the number of respondents selecting the given answer. The number .5 was given to a category when the answer was given as variable (e.g. fair to good)

The following organizations returned the questionnaire:

1) WSDH Stevens Pass Avalanche Crew
2) WSDH Snoqualmie Pass Avalanche Crew
3) WSDH White Pass Maintenance Crew
4) USFS Mt. Baker-Snoqualmie National Forest - Seattle Office
5) USFS Stevens Pass
6) Crystal Mountain Pro Patrol

and the Pacific Ocean, serve as general indicators of air mass temperatures, but they are not necessarily representative of the temperatures within the Cascades, particularly when the weather situation is changing.

To further complicate the situation, the temperatures within the mountains are strongly influenced by local features. One of the most persistent problems in determining the freezing levels within the Passes is associated with easterly flows. During the winter a frequent feature of the local weather situation is the presence of a pool of cold, dry air on the eastside of the Cascades maintained principally by radiative cooling and by its isolation from the moderating maritime influences of the Pacific Ocean and Puget Sound. When the surface pressures are higher on the east side of the Cascades than on the west (as is often the case prior to the arrival of a low pressure system) this air is drawn up from the eastside and further cooled as it is lifted through the passes. This causes an inversion which can give pass temperatures 10^{o}-20^{o}F below free air temperatures at the same altitude. This situation often is the cause of freezing rain within the passes.

Measured temperatures within the mountains are also strongly affected by local surface heating and cooling which can give temperatures many degrees different from the free air temperatures.

During significant storms local freezing levels should be dominated principally by air mass temperatures and thus free air freezing levels serve as a guide to local temperatures and the type of precipitation that may be expected. Also, general warmings that frequently lead to general avalanche activity are characterized by warm free air temperatures, though this is complicated by the easterly flow situation. The Forecasting Office forecast the free air freezing levels (snow level is ordinarily taken to be 1000 feet below the freezing level) for the Cascades daily and as frequently as there were significant changes. This forecast was then interpreted by field personnel in the light of their local situation. Quantitative evaluation of these forecasts is not directly possible due to the lack of any reliable free air temperature measurements within the Cascades. The forecasts were compared to the radiosonde observations at Quillayute and Geiger, as well as freezing levels extrapolated from the temperatures at Stampede and White Passes and a thermograph located at 6700 feet at Crystal Mountain, Washington. It was found that local effects dominated the temperatures measured within the Passes, making them essentially useless for verification. The radiosonde observations showed (see Figure 10) that the forecasted freezing levels were generally within 1500 feet of those measured at Quillayute, but they frequently differed from the Geiger soundings. It is reasonable that the Quillayute sounding is more consistent with temperatures within the Cascades than Geiger, as the latter if often dominated by the cold air pool previously discussed.

Differences which were noted between the Quillayute sounding and the forecasted values were generally associated with warm air masses moving from the west or southwest. These situations sometimes caught forecasters unaware due to the 12 hour interval between free air soundings. This situation was partially rectified when the Hurricane Ridge temperature sensor became operational in mid-February.

Crystal Mountain proved to be a good indicator of freezing levels when the freezing level was within ±2-3000 feet of its elevation, as it is free from the easterly flow problem. Though errors due to local effects and extrapolating were present, the indication is that the trends within the Cascades were fairly accurately forecast.

The feelings of the field personnel were that the storm time freezing levels and timings were generally accurate, but improvement in forecasting temperatures within the Passes is very necessary. No attempt was made this year to forecast Pass temperatures as they are affected by the easterly flow. This problem will be investigated to determine if some method of forecasting the magnitude and duration of these cold air invasions exists or can be developed.

c) <u>Winds</u>

The forecasting of winds evolved during the winter from a "simple" forecast of the free winds at the 5000 foot level to a forecast including winds at the Pass levels. The winds in the mountains are strongly influenced by local topography which can change the wind direction and accelerate or decelerate the wind speed. The general flow at the Pass levels is limited to roughly an east-west direction due to the channeling effects of the Passes, but the speed and direction at elevations slightly higher, involving many avalanche starting zones, is less clearly constrained and very much a function of small scale local topographic features. The wind patterns are further complicated by the easterly flow through the

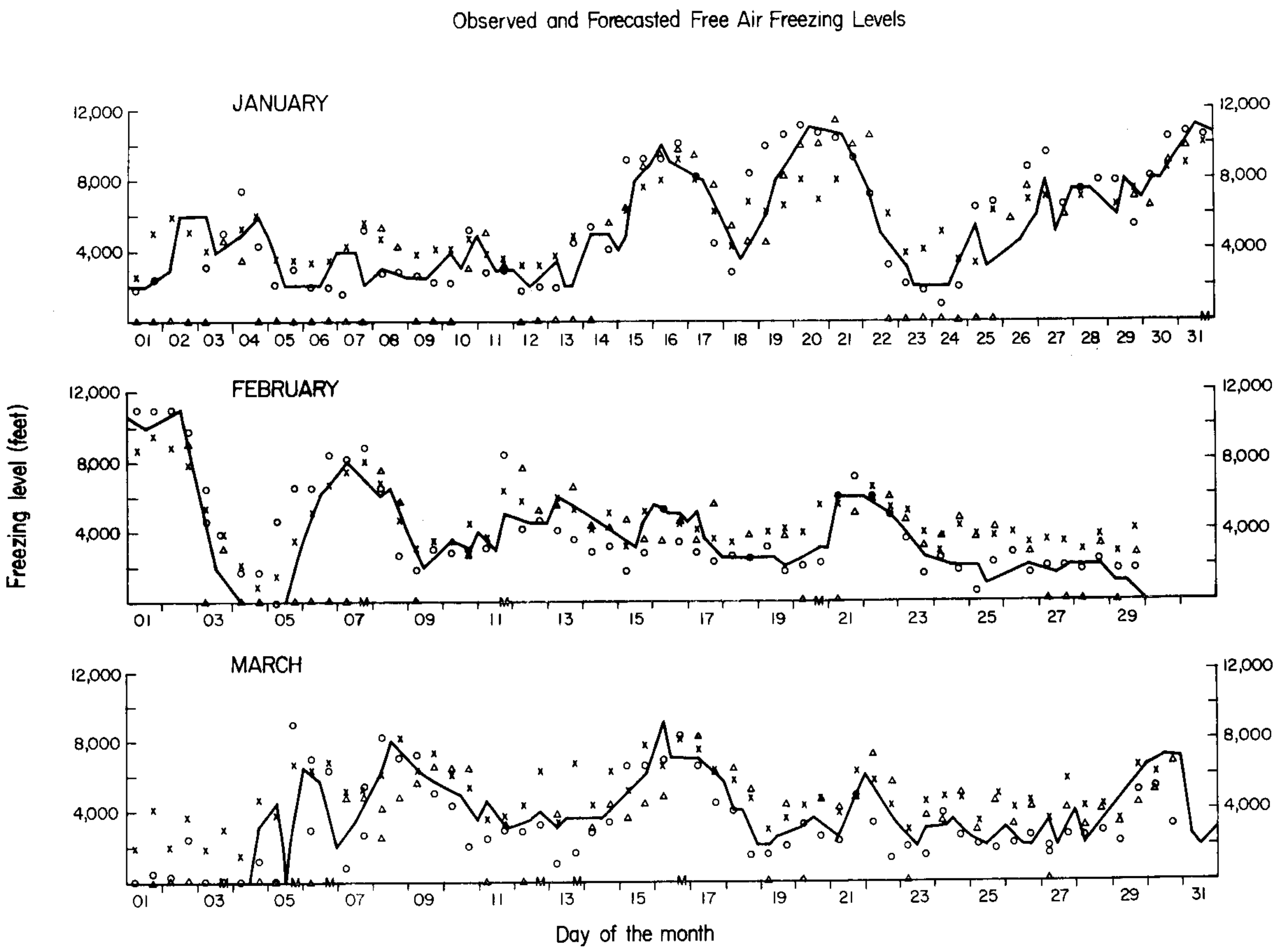


Figure 10. Forecast and observed freezing levels. (O indicates Quillayute; Δ indicates Geiger; X indicates extrapolated data from Crystal Mt.; —— indicates forecast; and M indicates missing data)

Passes which is often opposite that several hundred feet higher, above the inversion.

Initially the Forecasting Office issued forecasts of free winds at the 5000 foot level only. The thought was that field personnel, who are familiar with individual avalanche chutes, could judge the effects of a given wind situation on a given starting zone. As the winter progressed, it was found desirable to include a forecast of the winds at the Pass level as a further aid. This forecast was never incorporated into the forecasting form and was, therefore, not always included.

Evaluation of these forecasts are complicated by many of the same factors effecting the evaluation of the freezing level forecasts. Firstly, there are no measurements of the free wind velocities available except from the distant radiosonde stations at twelve hour intervals. Secondly, in the case of the winds at the Pass levels, stations only reported the winds at the time of observation, which was only once daily in many cases, and may not have indicated the wind conditions over several hours. This problem was somewhat alleviated at Stampede Pass which gave hourly values of the wind velocities plus peak gusts from slightly above Snoqualmie Pass.

A comparison of forecasted free winds at the 5000 foot level with those observed at Quillayute for the winter shows a general agreement between forecasted winds and wind trends and those observed by radiosonde. The wind forecasts were made for roughly 12 hour periods or at intervals of significant change. The soundings, unfortunately, represent only an instantaneous value out of 12 hours, which will obviously lead to some discrepancies. Despite the problems of comparison, the agreement is fairly acceptable.

Pass level winds were only forecast on a regular basis during March. A comparison of the forecasted winds with those observed at Stampede Pass shows a fair agreement, though there were several days with strong winds when a forecast was not made that would have aided the evaluation.

Forecasts for the 5000 foot free winds appear to have been sufficiently accurate and useful to continue unchanged; however, inclusion of Pass level winds with greater accuracy is very desirable. It is a forecast problem that is closely tied to the easterly flow situation and will be studied with it.

d) Precipitation Quantities

The estimated water equivalent of precipitation in a 24 hour period from 4 a.m. to 4 a.m. PST was given as a quantitative precipitation forecast (QPF) for each of the three major mountain passes. The QPF was arrived at as a subjective combination of the following: the NWS forecasted QPF for Stampede Pass, the NWS FOUS 60(See Section 4.2), forecasted surface and upper level flows, and knowledge of the general meteorology of each of the Passes. During the first season it was attempted to forecast the QPF to within $\pm$ 1/8" of the observed value.

Evaluation of the QPF is straightforward for Stevens and Snoqualmie Passes as they normally reported their 24 hour accumulations at 0430 and 0530 PST, respectively. The White Pass data were complicated by the fact that no precipitation gauge was available. Water equivalents reported from White Pass are based upon melted snow from the 24 hour stake, thus any precipitation that fell as rain or snow which melted was lost from the measurement. Hence, the White Pass values can be considered to be the lower limit of the amount of precipitation that the station received.

Tables 4-6 summarize the accuracy of the QPF's for the period December 24, 1975, through April 9, 1976. The statistics for the individual months of January, February, and March are presented, as well as the total statistics for the season. The accumulated error represents the sum of absolute values of the excursion of the observed values outside the forecast 1/4" range. Mean error per day is the average error for each forecast. The standard deviation represents the deviation of the observed errors from the mean error. Sixty-eight percent of the forecast errors lay within one standard deviation of the mean. The number of days with observations represents the days that precipitation quantities were reported to the Forecasting Center. Total observed precipitation is the total water equivalent reported to have fallen.

Table 4 gives the results of the study for Stevens Pass. The forecast accuracy throughout the winter seems to be fairly consistent. The tenedency of the forecast was to overestimate the amount of water equivalent. In fact of days that were misforecast, four out of five were overestimated. This can readily been seen in Figure 11. On days with precipitation greater than 1", the forecast accuracy decreases, and on these days the tendency was to underestimate the received water equivalent. Column 6 shows that

TABLE 4. Accuracy of QPF's for 12/24/75 through 4/9/76 - Stevens Pass

	1	2	3	4	5	6	7	8
January								
All Days w/ precipitation	3.96	.23	.30	17	13.04	29%	53%	65%
Days w/ precip. greater than 1"	1.06	.21	.33	5	8.74	60%	60%	60%
February								
All Days w/ precipitation	4.49	.23	.25	20	11.96	40%	50%	60%
Days w/ precip. greater than 1"	2.02	.29	.26	7	7.89	14%	43%	43%
March								
All Days w/ precipitation	3.36	.14	.21	.24	8.40	38%	67%	79%
Days w/ precip. greater than 1"	-	-	-	-	-	-	-	-
Season								
All Days w/ precipitation	13.52	.19	.24	70	38.65	34%	57%	69%
Days w/ precip. greater than 1"	3.52	.25	.26	14	19.18	29%	50%	50%

1 Accumulated error (inches)

2 Mean error per day (inches)

3 Standard Deviation (inches)

4 Number of days with observations

5 Total observed precipitation (inches)

6, 7, 8 % of days forecast correctly to within $\pm$ 1/8", $\pm$ 1/4", and $\pm$ 3/8" respectively

Note: 1 - 4 are based upon the deviation from the forecast range of $\pm$ 1/8".

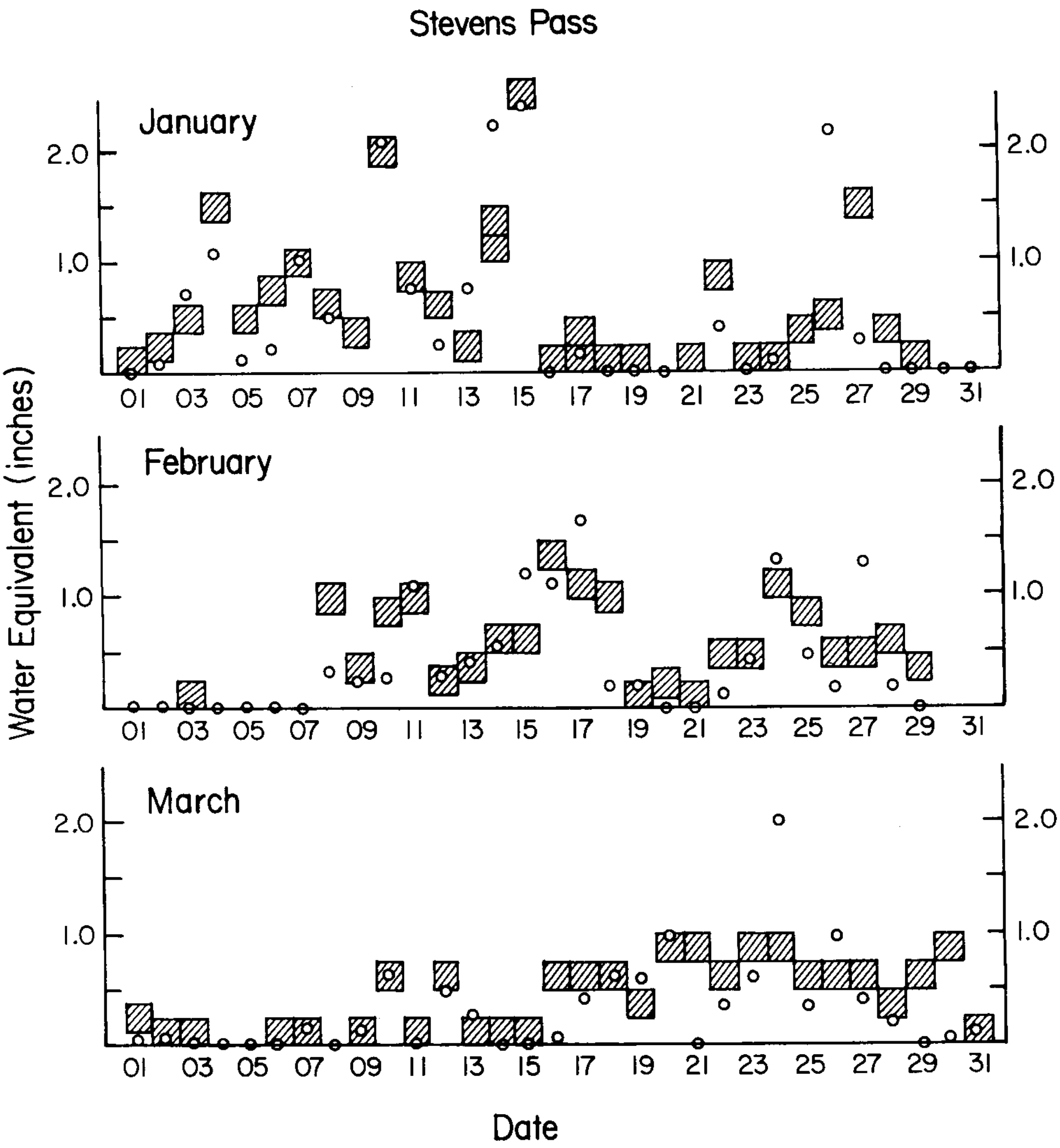


Figure 11. <u>Forecast and observed 24-hour water equivalents for Stevens Pass</u>. (Shaded box indicates forecast range; no box indicates 0" water equivalent forecast; O indicates measured water equivalent; M indicates missing data.)

the attempt to forecast the QPF to within $\pm$1/8" was successful less than 50% of the time; however, the accuracy in the larger ranges was considerably greater.

Table 5 shows the results for Snoqualmie Pass. The errors at Snoqualmie Pass appear to be larger than those at Stevens Pass or White Pass. There appears to be some improvement in the forecast accuracy as the season progressed. The same tendency to overestimate the water equivalent is seen--three out of four days with errors were overestimates. The errors on days with water equivalents greater than 1" are almost twice those on all days combined. This is partly the effect of over half of these days occurring in January when the forecast accuracy was extremely low. The tendency to underestimate the quantity of precipitation on these days was even greater than at Stevens Pass as can be seen in Figure 12. In the case of Snoqualmie Pass the forecast accuracy of 50% or greater was not realized for the $\pm$ 1/8" range or the $\pm$ 1/4" ranges.

Table 6 shows the results for White Pass. The errors at White Pass were the smallest of the three Passes and the tendency to overestimate the water equivalents was less (see Figure 13), though this may partly be the result of the precipitation gauge problem mentioned earlier. One large error occurred in the forecast for February 17. Only 1" water equivalent was forecast while 4.2" was received. This was 3" less than that received at the other Passes and was a very anomolous occurrence. The statistics for White Pass shown within the parentheses are those with this day excluded. The forecast accuracy definitely improved during the winter; however, the error in forecasting for days with greater than 1" precipitation was much greater than that for all days combined. This is a problem that will require some further study. Fifty percent accuracy in the forecasts is seen to have been obtained for the ranges $\pm$1/4 and $\pm$3/8".

The general evaluation of field personnel (see Table 3) was that the QPF is probably the most important part of the forecast; however, they feel that greater accuracy will be required before this parameter can be used to its greatest advantage. It seems to be universally felt that an improvement in the forecast accuracy of this parameter is the single most desirable improvement that can be made in the forecasts.

The results of this study, however, show that forecasting the QPF within $\pm$1/8" 50% of the time does not appear possible with the present

TABLE 5. Accuracy of QPF's for 12/24/75 through 4/9/76 - Snoqualmie Pass

	1	2	3	4	5	6	7	8
January								
All days w/ precipitation	5.24	.40	.30	13	12.40	8%	16%	23%
Days w/ precip. greater than 1"	3.12	.52	.38	6	9.50	17%	17%	17%
February								
All days w/ precipitation	4.06	.24	.20	17	8.12	23%	47%	53%
Days w/ precip. greater than 1"	.73	.73	.00	1	1.36	0%	0%	0%
March								
All days w/ precipitation	4.09	.26	.28	16	10.32	25%	44%	69%
Days w/ precip. greater than 1"	1.98	.50	.30	4	5.23	0%	0%	17%
Season								
All days w/ precipitation	13.65	.28	.26	48	31.58	19%	40%	48%
Days w/ precip. greater than 1"	6.11	.51	.31	12	17.06	9%	9%	17%

1 Accumulated error (inches)

2 Mean error per day (inches)

3 Standard Deviation (inches)

4 Number of days with observations

5 Total observed precipitation (inches)

6, 7, 8 % of days forecast correctly to within $\pm$ 1/8", $\pm$ 1/4", and $\pm$ 3/8" respectively

Note: 1 - 4 are based upon the deviation from the forecast range of $\pm$ 1/8".

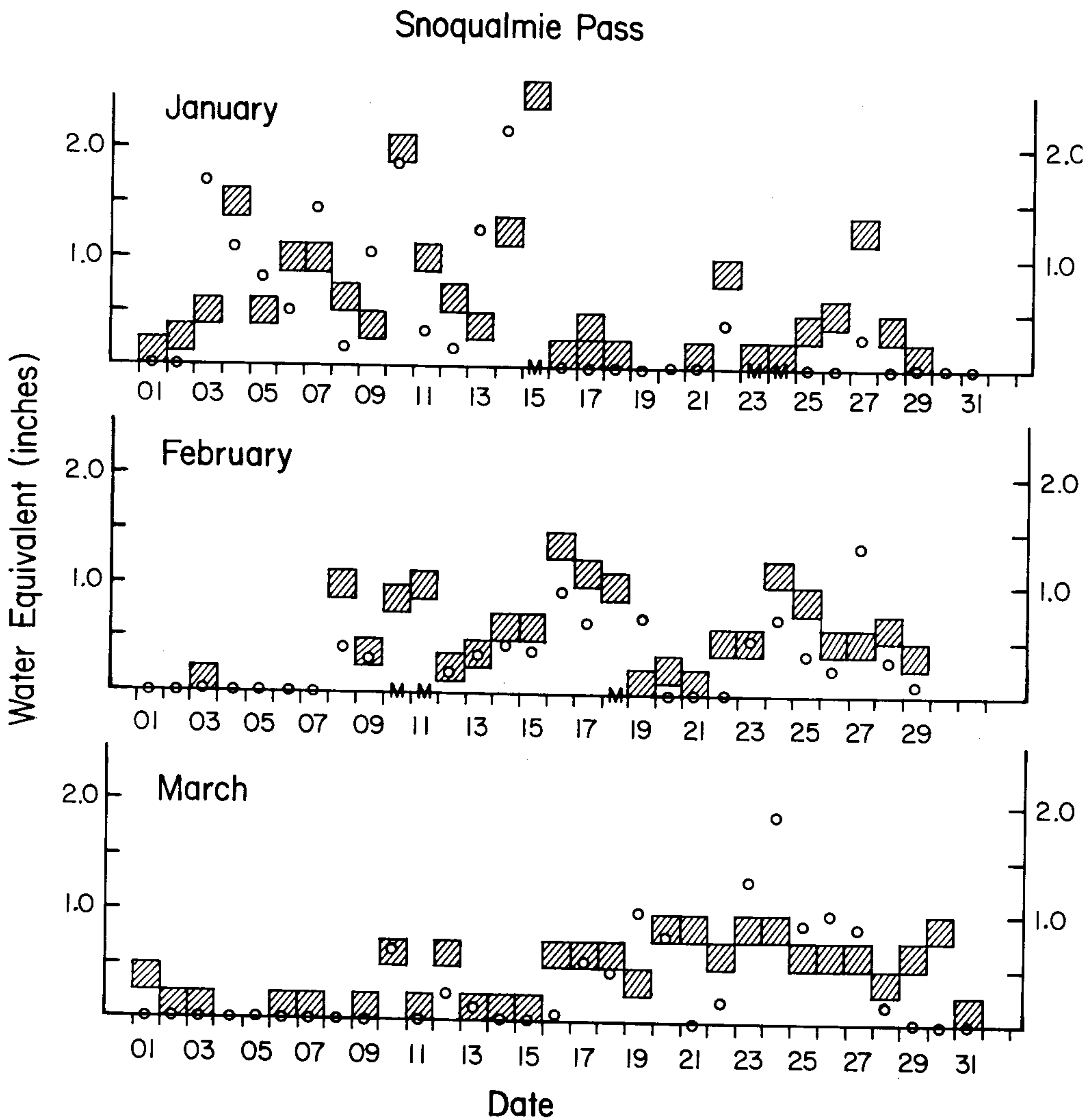


Figure 12. Forecast and observed 24-hour water equivalents for Snoqualmie Pass. (Shaded box indicates forecast ranges; no box indicates 0" water equivalent forecast; 0 indicates measured water equivalent; M indicates missing data.)

TABLE 6. Accuracy of QPF's for 12/24/75 through 4/9/76 - White Pass

	1	2	3	4	5	6	7	8
January								
All days w/ precipitation	1.78	.16	.22	11	6.20	27%	64%	82%
Days w/ precip. greater than 1"	.75	.75	.00	1	1.25	0%	0%	0%
February								
All days w/ precipitation	5.91 (2.71)	.40 (.19)	.82 (.27)	15 (14)	12.32 (8.12)	40%	60%	67%
Days w/ precip. greater than 1"	4.21 (1.01)	.70 (.20)	1.25 (.26)	6 (5)	9.67 (5.47)	33%	50%	50%
March								
All days w/ precipitation	1.40	.13	.15	11	5.00	55%	55%	91%
Days w/ precip. greater than 1"	-	-	-	-	-	-	-	-
Season								
All days w/ precipitation	10.14 (6.94)	.25 (.18)	.52 (.22)	40 (39)	24.72 (20.52)	38%	55%	73%
Days w/ precip. greater than 1"	7.39 (4.19)	1.05 (.70)	1.33 (1.03)	7 (6)	10.92	29%	43%	43%

1 Accumulated error (inches)

2 Mean error per day (inches)

3 Standard deviation (inches)

4 Number of days with observations

5 Total observed precipitation (inches)

6, 7, 8 % of days forecast correctly to within ± 1/8", ± 1/4", and ± 3/8" respectively

Note: 1 - 4 are based upon the deviation from the forecast range of ± 1/8".

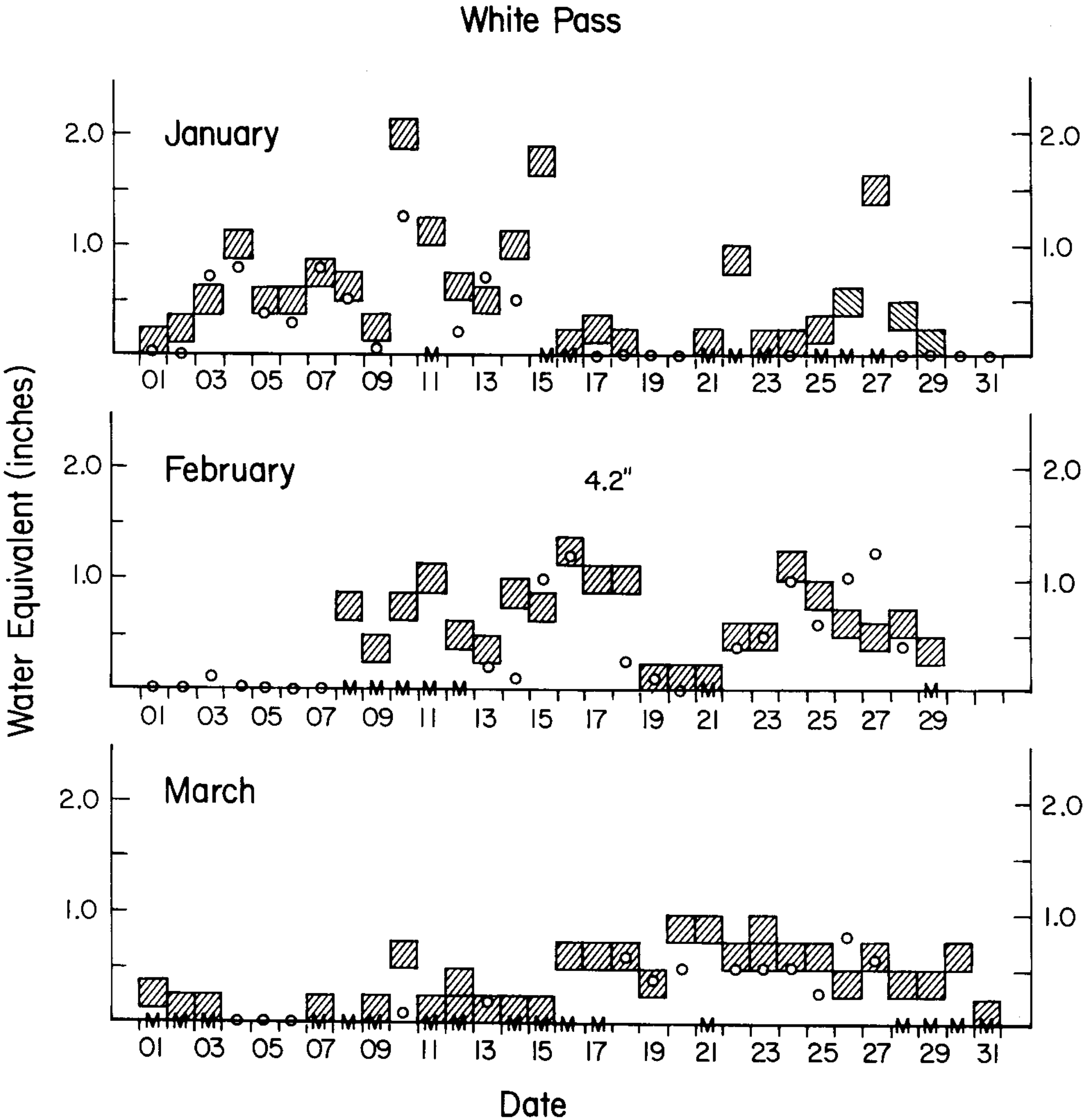


Figure 13. Forecast and observed 24-hour water equivalents for White Pass. (Shaded box indicates forecast range; no box indicates 0" water equivalent forecast; 0 indicates measured water equivalent; M indicates missing data.)

forecasting scheme. The problem lies partly in the subjective way that the QPF is presently evolved and partly in the present state of the art in mountain meteorology. Both statistical methods and improved numerical models are being studied, and it is hoped that these will lead to an improvement in the operational forecast accuracy.

e) Avalanche Advisories

The Forecasting Office issued avalanche advisories once daily or as frequently as the situation warranted (see section 4.2). These advisories took the form of a narrative in which the forecaster evaluated the general snowpack stability and the factors that could affect it and forecasted the avalanche hazard to the highway. The advisories were intended to act as a general guide to field personnel, who would be making a more detailed analysis of the conditions within their local area. Evaluation of the forecast accuracy of these advisories required breaking the advisories into specific categories (e.g., No Slide, Slides, Slides Effecting Highway, and Sluffs) which required a subjective evaluation of the advisory at times, and finally, a comparison with observed slide activity.

Table 7 shows the number of days forecast and observed to fall into the above mentioned categories at Stevens Pass*. The forecast accuracy appears to be fairly good. There were no slides affecting the highways on days that the forecast called for no activity. This is an indication that only the degree of activity was misjudged. Further, of the 13 days on which slides affected the highway during this study, 6 of these were forecast. General avalanche activity not affecting the highway was successfully forecast on 30 out of 42 days it was reported.

One difficulty in the analysis is that the classification of sluffs is rather vague to be used in a quantitative evaluation, as the line between sluffs and small slides is often arbitrary. There are undoubtedly many instances of small sluffs not affecting the highway which are not recorded or simply go unobserved. A similar comment may be made about slides occurring during times of low visibility, particularly during storms, when the evidence of a small slide may be buried under new snow. Both of these facts contribute errors to the evaluation of the forecast accuracy.

The opinions of field personnel about the advisories were varied (see Table 3). Those individuals directly involved with avalanche control

*Complete Snoqualmie Pass Avalanche data were not available at this writing. Due to the light snow year, insufficient activity was reported at White Pass for a meaningful evaluation.

TABLE 7. Accuracy of avalanche advisories for Stevens Pass

FORECAST \ OBSERVED	NO SLIDES	SLIDES	SLIDES AFFECTING HIGHWAY	SLUFFS
NO SLIDES	29	9	0	1
SLIDES	16	30	5	1
SLIDES AFFECTING HIGHWAY	2	3	6	0
SLUFFS	8	2	2	1

for the highways felt that the advisories were satisfactory as far as they went, but that they were not of the detailed nature that is required for control work (i.e., when to shoot which avalanche chute, etc.). It was felt by all concerned that an observer at the Pass who is involved in only evaluating the local avalanche hazard could achieve a more detailed analysis; however, it was also felt that the Forecasting Office product taken as a whole was able to assist in this process. By contrast, individuals involved in administering large areas (e.g., National Parks, National Forests, etc.) found the advisories to be adequate to their needs.

4.3.2 Case Study: January 10-16, 1976

This case study is very typical of the winter season in the Washington Cascades, and includes a discussion of the observed weather and avalanche conditions and the response of the Forecasting Office to the changing weather which produced the observed avalanches.

High pressure at the surface covered most of southern British Columbia, Washington and southeastward into the intermountain area during this period. The extremely cold arctic airmass was well to the north in British Columbia and east of the Canadian Rockies. The (Pacific) polar front, which produces most of the weather in the Pacific Northwest, was near but generally a little south of Washington state with minor waves on the polar front moving rapidly onshore under a strong westerly flow associated with the "jet stream" at the higher levels. Cold Pass temperatures (maximums in the mid-twenties--Fahrenheit) and low freezing levels (at or below 3000 feet over the Cascades) were very much in evidence January 11-13. Though some of the weather fronts appeared rather weak, meteorologically speaking, there was ample moisture in the unstable air mass between these fronts to produce moderate amounts of low density orographic snowfall as the air was forced upward in the westerly flow across the Cascades.

This pattern began to change on January 13 with a deepening storm in the eastern Pacific pumping warmer air northward toward Washington ahead of the low pressure center. The 0400 PST radiosonde observation at Quillayute on January showed a freezing level of 5400 feet (1620 meters). This moderate warmup on January 14 triggered numerous slides and was followed by an extreme warmup on January 15-16 with freezing levels both days above 9300 feet (2790 meters) and additional avalanche activity.

This situation which led to the observed extensive but rather typical avalanche cycle in the Cascades was due primarily to a combination of easterly wind transport (redeposition of dry snow) followed by a warmup and heavy rain.

The last extreme warmup of 1975 occurred on December 28-29 with freezing levels 3,000 feet or below through January 4, except for one very brief warming on the morning of January 2 (6,000 foot freezing level). Easterly winds through the passes (approximately 3,000-4,000 feet) kept the temperatures there well below freezing until another brief warming with rain on the morning of January 4 (7,000 foot freezing level). From January 2 to January 15 snow pack increased daily in depth (total on ground) until the next extreme warmup of January 15-17.

By January 10 the total snowpack (72-144 inches in reporting areas) on the ground was ample to smooth out most irregularities in the slide paths. Most active slide paths on Stevens Pass had been controlled with apparently good results on January 6, 8, and 10. Starting zone temperatures in the Passes remained in the 20's or below with relatively low density snow accumulations until warmer temperatures in the storm of January 10-11 brought heavy amounts of new high density snow with 9-18 inches (22-45 cm.) reported on the morning of January 11. On January 11-12, moderate to strong westerly winds with cold temperatures brought heavy amounts of low density orographic (upslope) snow. Continued cold temperatures with winds shifting to strong easterly on January 13 and early morning of January 14 transported considerable quantities of snow into many major avalanche chutes at all of the major Passes. With a wind shift back to westerly on the morning of January 4, and with warming and rapidly rising feezing levels on January 14 and 15 accompanying increased precipitation, slope loading rapidly became critical and the observed avalanching ensued. The following summary shows the 24-hour new snowfall and density reported each morning from field observation stations:

January 11	9-18 inches	High density
12	10-17 inches	Low density
13	2-4 inches	Low density
14	10-12 inches	Low density Becoming high in afternoon
15	7-20 inches	High density Followed by rain

The response of project forecasters to the changing weather conditions which produced the heavy avalanching at the Pass and ski areas on January 14, 15 and 16 is best shown through the weather and avalanche advisories issued by the Forecasting Office. These forcasts attempted to keep field personnel as aware of the general weather and avalanche situation as the acquisition of new map and field data allowed. Detailed weather forecasts were extended as far as possible into the future without sacrificing accuracy, and avalanche advisories attempted to include in general terms the forecaster's estimate of the potential effects of changing weather on the snowpack stability at each Pass area. Avalanche advisories issued from January 12-16, including special "weather alerts," are shown in Appendix A.

Information on the ice and rain-soaked refrozen layers referred to in the above advisories were derived from both field snowpit data obtained by project personnel and continuing discussions throughout the period with WSDH field personnel. The most recent snowpits (January 5 and 8) excavated prior to the avalanche cycle under discussion are shown in Figures 14 and 15. In both snowpits, the existence of the strong ice and refrozen layers is clearly evident from high density and high ram resistances at these surfaces. Snowpits such as these gave project forcasters useful bases from which to estimate not only general snowpack stability and potential sliding surfaces, but also possible quantities of snow to be involved in future slides, especially considering the lubricating effects of rain.

At this point it is also interesting to include a snowpack analysis formulated in-house (see section 4.2 (12)) by the duty forecaster on January 11. The possibility of future problems with a warmup were already being considered, and the usefulness of the snowpit and snowpack data obtained in the field is obvious:

> Snowpack analysis, Sunday, 1/11/76, 1230 PST: from conversations with Stevens and Snoqualmie Passes this morning, it appears as if the warmup Saturday night followed by cooler temperatures today produced a thin rain crust (or melt-freeze crust) underneath the new snow which fell this morning. Snowfall reports of graupel falling on top of this crust should produce a fairly unstable surface for future snowfalls to slide on. However, this thin crust is very weak, and large snowfall amounts (and high rates of loading) could break through this layer involving lower layers.
>
> It is anticipated though, that snowfall rates today and Monday will not be high enough to break through this layer. Thus slides anticipated may slide on this layer, lubricated by the graupel.
>
> From both passes' 1 kg. ram penetration, it appears that 30-50 cm. of unconsolidated snow exists between this light rain crust and underlying heavier crusts, at least in chutes which have been

Figure 14. Snowpack Data - Snoqualmie Pass.

Fracture-line snow profile taken at Snoqualmie Pass on 1/8/76. Variations with snow depth of density (▲), temperature (●), ram resistance (⊐) and stratigraphy (on left of Figure) for the particular time and area indicated are shown.

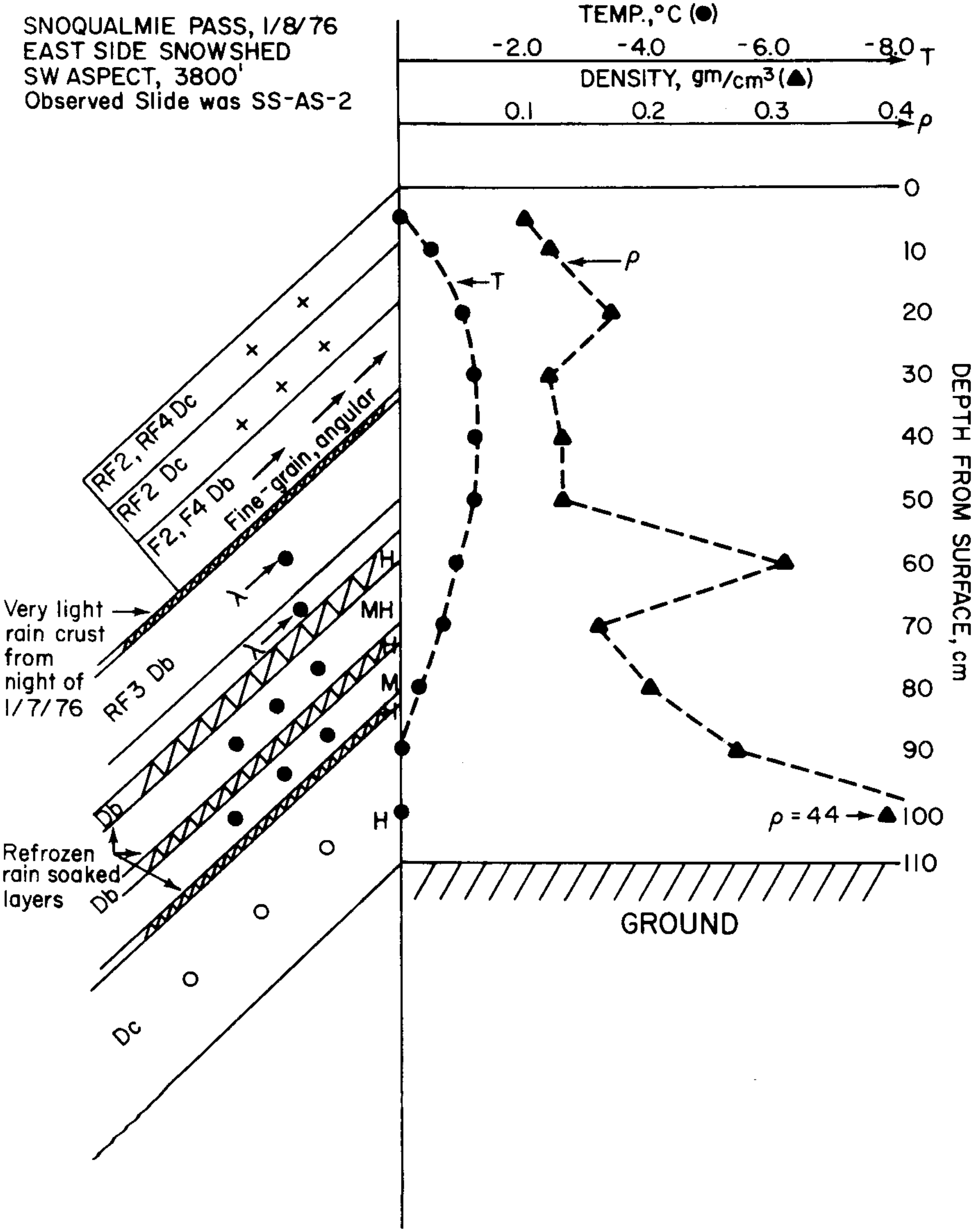
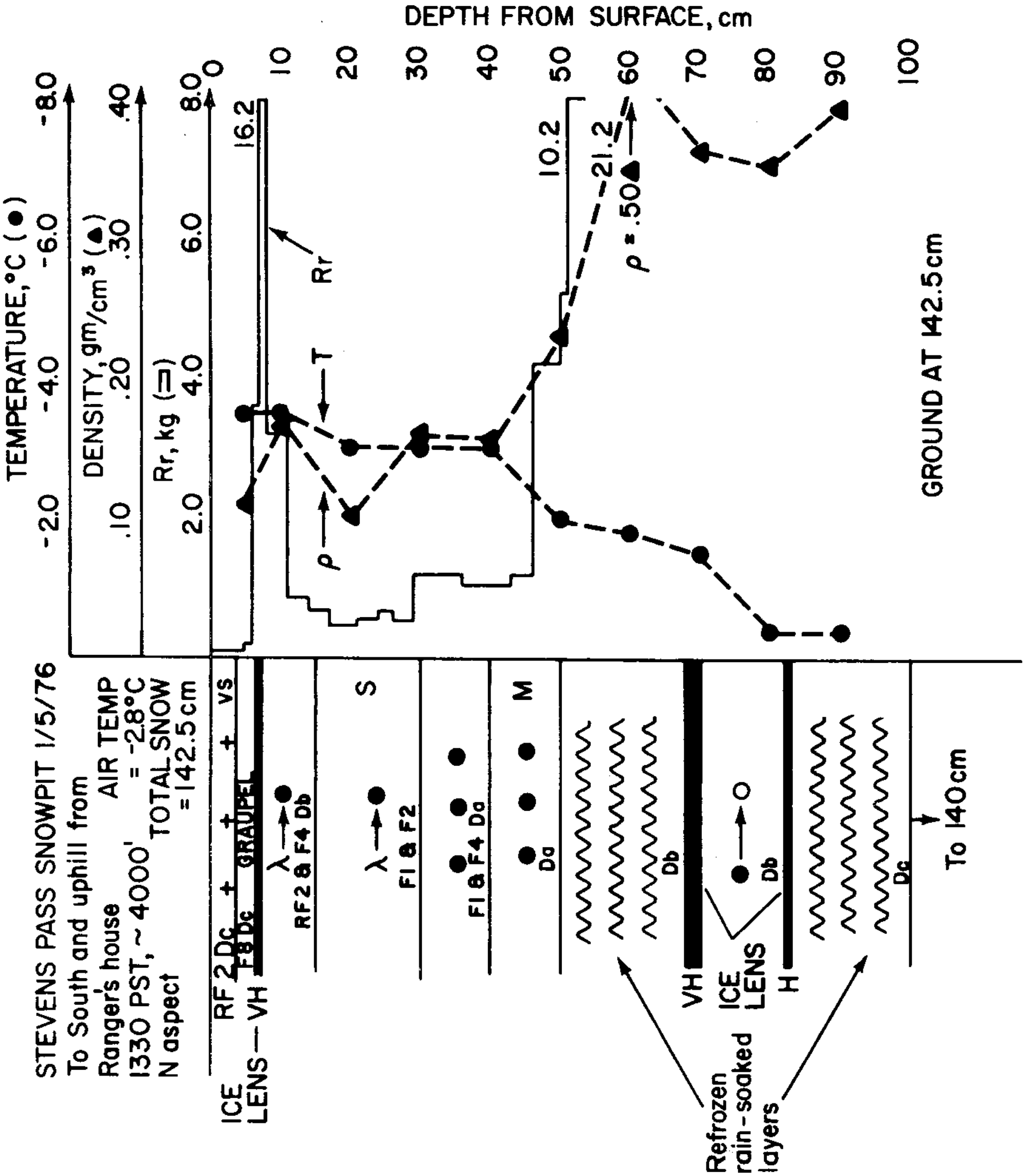


Figure 15. Snowpack Data - Stevens Pass.

Prifle taken on 1/5/76. See Figure 14 for explanation of snow profile data.



uncontrolled, and have not exhibited natural sliding. As more unconsolidated snow builds up above these lower rain crusts, a major warmup with rain could produce slides on both frequent and infrequent sliders, or at least these should be considered in future major warmups, given the small amount of avalanche activity reported from heavy snow and the warmup last night.

5. SUMMARY OF RECOMMENDATIONS

5.1. Field Operations

Some of the following recommendations have been discussed in detail in earlier sections, as noted.

(a) Installation of a complete automatic meteorological station in the Stevens Pass area with at least hourly recorded read-out capabilities in the Forecasting Office in Seattle, or phone telemetry link-up with existing USFS or WSDH sensors with similar read-out capabilities in Seattle (3.1.1 a)).

(b) Installation of wind direction and speed sensors, and precipitation gage at Hurricane Ridge to be hooked up to existing telemetry link from this site to the Seattle forecast office (3.1.1 f)).

(c) Installation of temperature sensor on Mt. St. Helens (7-8000 ft. level) with necessary radio to phone telemetry for recorded read-out capability in the Seattle forecast office. A temperature sensor site on the southern edge of the Olympic Mountains at the 5-6000 foot level is a possible alternative (3.1.1. f)).

(d) Standardization of units for observational data (3.1). As USFS standard reporting forms are in wide use throughout the western United States and utilize the English system (except for 20 cm. snow temperature reported in degrees Celsius), it is recommended that WSDH stations likewise use (or at least report) English units until such time as USFS observations change to metric. As WSDH personnel at Stevens Pass are currently filling out the USFS standard form for the USFS west-wide data and avalanche network, reports of observational data in English units from this station should not present a problem.

(e) Inclusion of Soil Conservation Service (SCS) and Atmospheric Environment Service (AES), Canada, observational data in the data network. It is anticipated that SCS telemetry from their remote stations (as listed in Wilson's research report (1975)) should be completed this summer (1976). Observations from the SCS stations are programmed for daily read-outs with hourly and on-call capability. Many of the proposed SCS sites are scheduled to provide wind speed and direction and precipitation in addition to temperature. Five of the SCS sites scheduled for completion this year which would provide data of value to the network are (see Figure 1 for their location in Washington): Trough #2 (south of Wenatchee, elevation 5310 ft.), Surprise Lakes (Lewis River drainage, elevation 4250 ft.), Lone Pine shelter (Lewis River drainage, 3800 ft.), Park Creek Ridge (near Lake Chelan, 4600 ft.), and Bumping Ridge (near Bumping Lake, 4440 ft.). Other sites of interest to future forecasting projects are scheduled for later installation.

The British Columbia Dept. of Highways contributes daily weather observations to AES from three southern B.C. mountain passes (Allison Pass, 4400 ft., Fraser Canyon, 450 ft., and Kootenay Pass 5800 ft.--see Figure 1 for location). If future forecasting projects attempt real-time avalanche and weather forecasting for Washington Pass on the North Cascades Highway (State Route 20), important data could be obtained from these stations (and USGS stations in the Mt. Baker area--see Figure 1).

5.2 Forecasting Office

(a) Installation of two phones at the Forecasting Office--one specifically for the taped forecast, and one for direct communication with the on-duty forecaster (see section 4.1).

(b) Installation of telephone-teletype system from the Forecasting Office to WSDH Stevens and Snoqualmie Passes for transmission of "hard copy" forecasts, weather alerts, updates, etc. (see section 4.1). A more economical alternative is portable cassette recorders with plug-in capabilities to the phone earpiece for recording of forecasts, but many of the advantages of hard copy reception and transmission would be lost.

6. BIBLIOGRAPHY

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APPENDIX A

Weather and Avalanche Forecasts

The following sequence of weather analyses and avalanche advisories covers the period January 10-16, 1976, and is discussed as a forecasting case study in section 4.3.2 of this report.

APPENDIX A (continued)

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"
1230 AM/PM Sat. Jan. 10
(time) (day) (month) (date)

"SYNOPSIS: A fast moving weather system is passing through the Cascades bringing heavy accumulations of snow. Overnight totals ranged from 2 inches at White Pass to 8 inches at Snoqualamie Pass. Winds were light to moderate except at Crystal Mountain, which reported a gust of 68 mph at 0820 this morning. A vigorous storm is forming immediately behind the present front and is expected to move onshore by this evning bringing additional heavy snow tonight and Sunday.

FORECAST:

Snow heavy at times through this afternoon diminishing slightly this evening and increasing again tonight and continuing on Sunday.

SNOW (~~FREEZING~~)LVL NR. 2000 FT. today / RISING / ~~LOWERING~~ TO near 3000 FT. tonight and Sun.
WINDS AT 5000 FT. LVL W 20-30 KNOTS, ~~BECOMING~~ today, diminishing*.

24 HOUR PRECIPITATION FORECAST:	STEVENS PASS	2	INCHES W.E.
ENDING AT 4 AM Sun.	SNOQUALMIE PASS	2	INCHES W.E.
	WHITE PASS	2	INCHES W.E.

AVALANCHE ADVISORY: Heavy snow accumulations are expected throughout the Cascades today. Sluffing on cutbanks should become likely this afternoon. The expected decrease in snowfall intensity this afternoon should be short-lived allowing very little stabilization of the new snow. Heavy snowfall tonight may cause frequent sliders to run on the rain crust of last Wednesday or old rain crusts exposed by control work during the last week. Control measures are recommended on frequent slide paths by early evening prior to the heavy accumulation of the next storm to prevent natural slides by morning. Particular attention should be given to those paths whose release zones are at higher elevations and load under a west wind. Winds at higher levels may be appreciably different from those observed on the passes due to an easterly flow at the surface in advance of the front.

*this evening, but becoming W 25-35 knots Sunday morning.

1/10/76

Weather alert for warming to 5500 feet issued 1615 PST, 1/10/76.

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

2000 ~~AM~~/PM Sat. Jan. 10
(time) (day) (month) (date)

"SYNOPSIS: The second of two weather systems which have moved into Washington today has moved rapidly onshore this evening bringing warming aloft. The 4 PM sounding at Quillayute gave a freezing level of 5300 feet. The second front has passed Quilayute as of 1900 this evening and it should move through the Cascades before midnight. A cold easterly flow through the passes may create an inversion giving some freezing rain. Satellite pictures show a large showery region behind the front which should give snow showers in advance of yet another storm expected by late Sunday.

FORECAST:

Snow tonight, heavy at times turning to showers occasionally heavy early Sunday continuing on through Sunday.

SNOW (~~FREEZING~~) LVL NR. 3500-4000 FT. ~~RISING~~ / LOWERING TO 3000 FT. on Sunday.
WINDS AT 5000 FT. LVL W 20-30 KNOTS, ~~BECOMING~~ today, diminishing*.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS 2 INCHES W.E.
ENDING AT 4 AM Sun. SNOQUALMIE PASS 2 INCHES W.E.
WHITE PASS 2 INCHES W.E.

AVALANCHE ADVISORY:

Same as 1230 advisory.

*this evening, but becoming W 25-35 knots Sunday morning

APPENDIX A (continued)

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

2200	~~AM~~/PM	Sat.	Jan.	10
(time)		(day)	(month)	(date)

"SYNOPSIS: A strong Pacific cold front should move rapidly across the Cascades by midnight. A cooler air mass will follow with gusty winds and orographic precipitation continuing tonight, decreasing Sunday. Another front is expected to develop and move through Sunday evening.

FORECAST: Heavy snow tonight decreasing Sunday morning. Snow incrasing again Sunday afternoon and night.

SNOW (~~FREEZING~~) LVL NR. 4000 FT. ~~RISING~~ / LOWERING TO 3000 FT. Sunday morning

WINDS AT 5000 FT. LVL W ____ KNOTS, BECOMING SW 30 knots on Sunday

12 ~~24~~ HOUR PRECIPITATION FORECAST: STEVENS PASS 1 - 1½ INCHES W.E.

ENDING AT ~~4 AM~~ 10 AM Sunday — SNOQUALMIE PASS 1 - 1½ INCHES W.E.

WHITE PASS 3/4 INCHES W.E.

AVALANCHE ADVISORY: General cooling tonight and good settlement should stabilize snowpack in general, but heavy amounts of drier snow with high transport winds will cause slabs to form, and slides may reach the road by Sunday noon if not controlled, especially on Stevens Pass and Mt. Rainier.

APPENDIX A (continued)

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1000 AM/~~PM~~ Sunday Jan. 11
(time) (day) (month) (date)

"SYNOPSIS: Moderate precipitation amounts are expected in the Cascades for the next 24-36 hours as a strong westerly flow both at the surface and aloft should produce considerable orographic snowfall. This major westerly belt is expected to drop further southward by late Monday with strongest onshore flow and heaviest precipitation in Southern Oregon and Northern California. However, a frontal system at 170° longitude is moving toward the coast and should again increase precipitation amounts late Monday night, mainly in the southern Cascades.

FORECAST: Snow today, locally heavy, gradually decreasing this evening and Monday. Snow flurries Monday. Increasing snow Monday nite, mainly south.

SNOW (~~FREEZING~~)LVL NR. 2000 FT. ~~RISING~~ / LOWERING TO 1500 FT. by Mon., morning
Free WINDS AT 5000 FT. LVL W 20-30 KNOTS, ~~BECOMING~~ .
24 HOUR PRECIPITATION FORECAST: STEVENS PASS 3/4-1 INCHES W.E.
ENDING AT 4 AM Mon. SNOQUALMIE PASS 1 INCHES W.E.
WHITE PASS 1-1¼ INCHES W.E.

AVALANCHE ADVISORY: Considerable settlement reported at all areas overnight tended to stabilize earlier snowfall. However, moderate amounts of low density low temperature snowfall today and this evening should be highly susceptible to expected strong wind transport. Unstable slab conditions should be anticipated on all N and E aspect slopes with the new snowfall. With this expected snowfall and high winds, frequent slides which load under west winds may reach the roadway this evening if uncontrolled. Sluffing from cutbanks is also probable. Stevens and Snoqualamie Passes both reported significant amounts of graupel deposited on the wet snow layer from last night, and this layer could be an excellent lubricating layer for slides.

1/11/76

APPENDIX A (continued)

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1700 ~~AM~~/PM	Sunday	Jan.	11
(time)	(day)	(month)	(date)

"SYNOPSIS: Moderate precipitation amounts are expected in the Cascades for the next 24-36 hours as a strong westerly flow both at the surface and aloft should produce considerable orographic snowfall. This major westerly belt is expected to drop further southward by late Monday, with stronger onshore flow and heaviest precipitation in Southern Oregon and Northern California. However, a frontal system now at 165° longitude is moving toward Washington and should again increase precipitation amounts early Tuesday, mainly in the south Cascades.

FORECAST:

Snow this evening gradually decreasing Monday morning. Snow flurries Monday. Increasing snow Tuesday morning, mainly south.

SNOW (~~FREEZING~~) LVL NR. 2000 FT. ~~RISING~~ / LOWERING TO 1500 FT. by Mon. morning

Free WINDS AT 5000 FT. LVL W 15-25 KNOTS, BECOMING 10-20 knots Monday.

24 HOUR PRECIPITATION FORECAST: STEVENS PASS 3/4 - 1 INCHES W.E.

ENDING AT 4 AM Mon. SNOQUALMIE PASS 1 INCHES W.E.

WHITE PASS 1 - 1¼ INCHES W.E.

AVALANCHE ADVISORY: Considerable settlement at all areas overnight Saturday and early today tended to stabilize earlier snowfall. Gradually decreasing snowfall and winds tonight and Monday should decrease avalanche hazard, although cold temperatures should prevent already unstable lee slopes from stabilizing. Expected sluffing in lowering winds may reach roadway on some paths but should also reduce hazard on major paths. No major slide paths are expected to reach the roadway at this time, although Stevens and Snoqualamie Passes both reported significant amounts of graupel deposited on the wet snow from Saturday night and this layer could be an excellent lubricating layer for future slides.

APPENDIX A (continued)

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1200 AM/~~PM~~ Mon. Jan. 12
(time) (day) (month) (date)

"SYNOPSIS: The cold unstable air mass will continue snow showers today decreasing tonight. The next major storm is moving eastward across the Pacific and the heaviest precipitation will move inland south of Washington with the front reaching the Washington coast Tuesday night or Wednesday. Warming ahead of this front will occur Tuesday.

FORECAST: Occasional snow showers today decreasing tonight. Cloudy and warmer Tuesday with snow increasing Tuesday afternoon or Tuesday night.

Outlook Wednesday: cooler with snow showers.

SNOW (~~FREEZING~~) LVL ~~NR.~~ Below 1000 FT. RISING / ~~LOWERING TO~~ 2500 FT. Tues. morning
WINDS AT 5000 FT. LVL S 20 KNOTS, BECOMING W 15 knots Tuesday.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS ½ - 3/4 INCHES W.E.
ENDING AT 4 AM Tues. SNOQUALMIE PASS ½ - 3/4 INCHES W.E.
WHITE PASS ½ - 3/4 INCHES W.E.

AVALANCHE ADVISORY: Heavy accumulations of new snow the past two days should be controlled by Tuesday morning, with the possibility of a warm-up Tuesday releasing fairly large quantities of new snow, sliding on old rain soaked layers and lubricated with some graupel which occurred during warm-up Saturday evening.

1/12/76

APPENDIX A (continued)

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1500 ~~AM~~/PM Mon. Jan. 12
(time) (day) (month) (date)

"SYNOPSIS: The cold air mass will continue snow showers this afternoon decreasing tonight. The next major storm is moving eastward across the Pacific and the heaviest precipitation will move inland south of Washington, with the front reaching the Washington coast Tuesday night or Wednesday. Warming ahead of this front will occur Tuesday.

FORECAST:

Same as 1200 AM.

SNOW (~~FREEZING~~) LVL NR. 1000 FT. RISING / ~~LOWERING TO~~ 2500 FT. Tues. morning.
WINDS AT 5000 FT. LVL NW 20 KNOTS, BECOMING W 15 knots Tues. .
24 HOUR PRECIPITATION FORECAST: STEVENS PASS ½-3/4 INCHES W.E.
ENDING AT 4 AM Tues. SNOQUALMIE PASS ½-3/4 INCHES W.E.
WHITE PASS ½-3/4 INCHES W.E.

AVALANCHE ADVISORY:

Same as 1200 AM.

1/12/76 Update

APPENDIX A (continued)

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1030 (time) AM/PM Tues. (day) Jan. (month) 13 (date)

"SYNOPSIS: The first in a series of Pacific storm fronts is weakening along the Washington/Oregon coast this morning causing only a little precipitation. Another weather front is expected to reach the coast tonight. Warmer air aloft should spread eastward tonight but below freezing temperatures will continue in the passes with higher pressure in Eastern Washington.

FORECAST:

Cloudy with a little snow in southern Cascades today spreading into all areas tonight. Snow increasing Wednesday.

SNOW ~~(FREEZING)~~ LVL NR. 1000 FT. RISING / ~~LOWERING~~ TO 3000 FT. tonight
WINDS AT 5000 FT. LVL S 30 KNOTS, BECOMING SW Wednesday.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS ¼ INCHES W.E.
ENDING AT 4 AM Wed. SNOQUALMIE PASS ¼ - ½ INCHES W.E.
WHITE PASS ½ INCHES W.E.

AVALANCHE ADVISORY:

Chance of warming aloft tonight but only small amount of precipitation expected with it. Continuing settlement should tend to stabilize heavy amounts of unconsolidated new snow of past few days.

1/13/76

APPENDIX A (continued)

Update Special "Weather Alert for Warming" (freezing levels rising to near 5000 feet) phoned to all areas by 1515 P.S.T.

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

3 (time) ~~AM~~/PM Tues. (day) Jan. (month) 13 (date)

"SYNOPSIS: A series of Pacific weather fronts are moving rapidly toward the Washington coast. The first dissipated along the coast this morning while the second was causing precipitation over most of Western Washington at 2 P.M. this afternoon. The third front will approach the coast Wednesday. Precipitation amounts will be generally light to moderate tonight with no orographic or upslope winds. Light easterly winds through the passes.

FORECAST:

Occasional snow tonight increasing Wednesday. Chance of some freezing rain in the passes tonight. Outlook Thursday: continued warm and wet.

SNOW (~~FREEZING~~) LVL NR. 1000 FT. RISING / ~~LOWERING TO~~ 4000 FT. by Wed. morning.
WINDS AT 5000 FT. LVL S ___ KNOTS, BECOMING SW Wednesday.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS ½ - 3/4 INCHES W.E.
ENDING AT 4 AM Wed. SNOQUALMIE PASS ½ - 3/4 INCHES W.E.
WHITE PASS ½ - 3/4 INCHES W.E.

AVALANCHE ADVISORY: Continued settlement should stabilize heavy amounts of unconsolidated new snow of past few days, but warm-up in passes tonight may release some small slides not already controlled in the passes. Slides across the road to Paradise possible if warm-up occurs.

1/13/76 Update

APPENDIX A (continued)

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1000 AM/PM	Wed.	Jan.	14
(time)	(day)	(month)	(date)

"SYNOPSIS:

One front passed through the Cascades about 1000 this morning. Another weather front is expected tonight with very little break in between. Easterly winds through the passes should shift to westerly by noon with rain to 4000 feet. Precipitation mainly along west slopes this afternoon.

FORECAST:

Occasional snow and rain through Thursday. Precipitation decreasing this afternoon then increasing again tonight and Thursday morning.

SNOW (~~FREEZING~~) LVL NR. 4000 FT. ~~RISING / LOWERING TO ______ FT.~~ ______.
WINDS AT 5000 FT. LVL SW 30-35 KNOTS, ~~BECOMING~~ ______.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS 1-1½ INCHES W.E.
ENDING AT 4 AM Thursday SNOQUALMIE PASS 1-1½ INCHES W.E.
WHITE PASS 1 INCHES W.E.

AVALANCHE ADVISORY: Heavy amounts of new snow since midnight and easterly winds loaded most chutes this morning followed by warming with rain. This should cause most slide paths to run on old refrozen rain-soaked layer with enough volume to cross highway on both East and West sides. Sixteen inches of new snow at Lake Wenatchee is a good indicator that slides in Tumwater Canyon will occur with warmup today.

1/14/76

APPENDIX A (continued)

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

4	~~AM~~/PM	Wed.	Jan.	14
(time)		(day)	(month)	(date)

"SYNOPSIS: A strong warm front moved through the Cascades before noon and will be followed by another weather front which is causing precipitation over Western Washington this afternoon. The cold easterly pass winds through the passes are westerly now.

FORECAST: A little cooling is expected tonight with the freezing level lowering to 4000 feet, and snow level near 3000 feet.

Outlook: Occasional snow continuing through Thursday. Heavy amounts tonight and early Thursday.

SNOW (~~FREEZING~~) LVL NR. 4000 FT. ~~RISING~~ / LOWERING TO 3000 FT. tonight
WINDS AT 5000 FT. LVL SW 25 KNOTS, ~~BECOMING~~ ________.
12 HOUR PRECIPITATION FORECAST: STEVENS PASS 1 INCHES W.E.
ENDING AT 4 AM Thursday SNOQUALMIE PASS 1¼ INCHES W.E.
WHITE PASS 1 INCHES W.E.

AVALANCHE ADVISORY: Heavy amounts of new snow since Tuesday evening should continue to slide as the heavy wet snow continues. Estimated accumulations of two feet since midnight Tuesday night should be heavy enough to break through older layers and slide on old refrozen rain-soaked layers with additional slides across highway tonight. Strong southwesterly winds should load NE and E aspect slopes in the starting zones tonight. For any additional information tonight please call Bud Reanier at home 206-242-7817.

1/14/76 Update

APPENDIX A (continued)

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

9 (time) ~~AM~~/PM Wed. (day) Jan. (month) 14 (date)

"SYNOPSIS:

Same as 4 PM.

FORECAST:

Same as 4 PM

Outlook: Heavy snow tonight and Thursday morning.

SNOW (~~FREEZING~~) LVL NR. 3000 FT. RISING / ~~LOWERING TO~~ 4000 FT. Thurs. morning
WINDS AT 5000 FT. LVL SW 30 KNOTS, ~~BECOMING~~ ____.
12 ~~24~~ HOUR PRECIPITATION FORECAST: STEVENS PASS 1½ INCHES W.E.
ENDING AT 4 AM Thurs. SNOQUALMIE PASS 1½ INCHES W.E.
WHITE PASS 1½ INCHES W.E.

AVALANCHE ADVISORY: Heavy amounts of new snow since Tuesday evening should continue to slide as the heavy wet snow continues. Estimated accumulations of two feet since midnight Tuesday night should be heavy enough to break through older layers and slide on old refrozen rain-soaked layers with frequent slides across highway again tonight or Thursday morning. Strong southwesterly winds should load NE and E aspect in the starting zones tonight.

1/14/76 Update

APPENDIX A (continued)

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1230 ~~AM~~/PM Thurs. Jan. 15
(time) (day) (month) (date)

"SYNOPSIS: A warm front with a SE-NW orientation is slowly moving northward through the Cascades today raising freezing levels to 9-10,000 feet and bringing heavy orographic precipitation. 24-hour W.E. ranged from .82" at Crystal Mountain to 4.25" at Paradise. Stampede Pass received 1.13" between 4 AM and 10 AM. A flat ridge is building over Washington which will diminish though not end precipitation on Friday. A new storm is developing and may bring more rain by Saturday.

FORECAST:

Rain or snow early today turning to rain heavy at times through this evening and diminishing late tonight and early Friday. Outlook for Sat.: continued warm and wet.

~~SNOW~~ (FREEZING)LVL NR. 8000 FT. RISING / ~~LOWERING TO~~ 9-10,000 FT. later today
WINDS AT 5000 FT. LVL SW 20-30 KNOTS, ~~BECOMING~~
24 HOUR PRECIPITATION FORECAST: STEVENS PASS 2.5 INCHES W.E.
ENDING AT 4 AM Friday SNOQUALMIE PASS 2.5 INCHES W.E.
WHITE PASS 1.5-2.0 INCHES W.E.

AVALANCHE ADVISORY: Heavy accumulations and warming temperatures have caused many frequent sliders to release during the last 36 hours giving some stabilization. Continuing heavy rains and very warm temperatures may penetrate the snowpack to lower ice layer and cause additional slides on slopes which have already avalanched during the present cycle. Significant possibility exists that a new series of avalanches will involve large quantities of snow and reach the highways. Control work at Stevens Pass Ski Area this morning gave 18-24" fractures on chutes which gave similar results yesterday. Specific control recommendations cannot be made due to incomplete data on this available cycle.

1/15/76

APPENDIX A (continued)

Update Special weather alert for freezing levels rising to 9000 feet and heavy rains phoned to all areas by 1715 P.S.T.

- -

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1900 ~~AM~~/PM Thurs. Jan. 15
(time) (day) (month) (date)

"SYNOPSIS: A warm front with a SE-NW orientation is continuing to move northward through the Cascades tonight with freezing levels remaining at 9-10,000 feet and some locally heavy orographic precipitation. Stampede Pass received 1.12" between 10 AM and 4 PM. A flat ridge is building over Washington which will dominate though not end precipitation on Firday. A new storm is developing and may bring more rain by Saturday and some cooling.

FORECAST:

Rain diminishing tonight and becoming showery on Friday.

Outlook for Saturday: Increasing precipitation and some cooling.

~~SNOW~~ (FREEZING)LVL NR. 9000 FT. RISING / ~~LOWERING~~ TO 9-10,000 FT. later today
WINDS AT 5000 FT. LVL SW 20-30 KNOTS, ~~BECOMING~~ ______.
12 HOUR PRECIPITATION FORECAST: STEVENS PASS ½ INCHES W.E.
ENDING AT 4 AM Fri. SNOQUALMIE PASS ½ INCHES W.E.
WHITE PASS ¼-½ INCHES W.E.

- -

~~AVALANCHE ADVISORY~~:

Preliminary 24-hour precipitation forecast ending at 4 AM

Saturday	Stevens Pass	½ inches	W.E.
	Snoqualamie Pass	½ inches	W.E.
	White Pass	¼-½ inches	W.E.

AVALANCHE ADVISORY:

Heavy accumulation and warming temperatures have caused many frequent sliders to release during the last 36 hours giving some stabilization. Continuing heavy rains and very warm temperatures may penetrate the snowpack to lower ice layers and cause additional slides on slopes which have already avalanched during the present cycle. Significant possiblity exists that a new series of avalanches could involve large quantities of snow and reach the highways. Specific control recommendations cannot be made due to incomplete data on this avalanche cycle.

1/15/76 Update

APPENDIX A (continued)

- -

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

0900 (time) AM/~~PM~~ Fri. (day) Jan. (month) 16 (date)

"SYNOPSIS: A strong ridge of high pressure aloft covers all the Pacific Northwest. The nearest weather front is about 600 miles off the coast and is expected to bring more rain Saturday. The freezing level is extremely high at 9,000 feet and will only drop to about 7000 feet Saturday with the rain.

FORECAST: Continued warm. Partly cloudy today. Increasing clouds tonight. Rain Saturday. Winds thru the passes becoming easterly Saturday.

~~SNOW~~ (FREEZING)LVL NR. 9000 FT. ~~RISING~~ / LOWERING TO 7000 FT. Sat. .

WINDS AT 5000 FT. LVL SW ____ KNOTS, ~~BECOMING~~ increasing to 30 knots Sat.

24 HOUR PRECIPITATION FORECAST: STEVENS PASS < ¼ INCHES W.E.

ENDING AT 4 AM Sat. SNOQUALMIE PASS < ¼ INCHES W.E.

WHITE PASS < ¼ INCHES W.E.

- -

AVALANCHE ADVISORY: Heavy rains of the past 24 hours have saturated the new snowfall of earlier this week and melt and settlement has decreased the snowpack 1-1½ feet. The snowpack should be relatively stable at this time.

1/16/76

APPENDIX A (continued)

Update

(Telephone Recording) "STATE HIGHWAY RESEARCH PROJECT, FOR OFFICIAL USE ONLY"

1300 ~~AM~~/PM Fri. Jan. 16
(time) (day) (month) (date)

"SYNOPSIS:

Same as 0900

FORECAST: Continued warm. Partly cloudy today. Increasing clouds tonight. Chance of rain Saturday or Saturday night. Winds through the passes becoming easterly Saturday.

~~SNOW~~ (FREEZING)LVL NR. 9000 FT. ~~RISING~~ / LOWERING TO 7000 FT. Sat.
WINDS AT 5000 FT. LVL SW 15 KNOTS, ~~BECOMING~~ ______.
24 HOUR PRECIPITATION FORECAST: STEVENS PASS < ¼ INCHES W.E.
ENDING AT 4 AM Sat. SNOQUALMIE PASS < ¼ INCHES W.E.
WHITE PASS < ¼ INCHES W.E.

AVALANCHE ADVISORY:

Same as 0900.

1/16/76 Update

APPENDIX B

Project Participants

1. AES: G. H. Muttit, Officer-in-Charge
   Pacific Weather Central
   416 Cowlie Crescent
   Vancouver International Airport South
   Vancouver, British Columbia

2. B.C. DEPARTMENT OF HIGHWAYS: G. L. Freer, Senior Avalanche Coordinator
   Department of Highways
   Parliament Bldg.
   Victoria, B.C. V8V 2M3

3. CRYSTAL MTN: Bill Steele, Pro Patrol Leader, Professional Patrol and
   Don Christiansen, Area Manager
   Crystal Mtn
   Crystal Mtn, WA 98022

   Hugh Koetje (USFS Snow Ranger)
   White River Ranger Station
   Enumclaw, Washington

4. MISSION RIDGE: Chris Daly, Pro Patrol
   Box 1765
   Wenatchee, Washington

5. MT. BAKER: Mike Dolfay (USFS Snow Ranger)
   Glacier Ranger Station
   Glacier, WA 98244

6. MT. RAINIER NATIONAL PARK: Walt Dabney and Visitors Center Staff (Dave Lange, Rick Kirschner, John Loehr), John Parks, Asst. Supervisor; Pete Thompson, Visitor Protection Specialist
   Mt. Rainier National Park
   Longmire, Washington

7. NWS: Larry Zimmerman, Chief
   NWS, Lake Union Bldg.
   1700 Westlake North
   Seattle, Washington

8. OLYMPIC NATIONAL PARK: Roger Allin and Jack Hughes
   Port Angeles, Washington

9. SCS: Robert T. Davis, Snow Survey Supervisor
   Room 360, US Court House
   Spokane, WA 99201

APPENDIX B (continued)

10. SNOQUALMIE PASS: Al Bennett, Craig Wilbur, Greg Squires
WSDH
P. O. Box 262
Hyak, WA 98026

Ken White (USFS Snow Ranger
North Bend Ranger Station
P. O. Box AA
North Bend, WA 98045

11. STEVENS PASS: Steve Reister (and avalanche crew) (Larry Dronen, Larry Nellis, Bill Hilton, Gordy Burlingame)
WSDH
P. O. Box 98, Dept. H
Wenatchee, WA 98801

Glen Katzenberger (USFS Snow Ranger)
US Forest Service
Skykomish, Washington

Merle Brooks, Ski Area Manager
Beau Draper, Ski Patrol Leader
Sno-Country Stevens Pass
P. O. Box 98
Leavenworth, WA 98826

12. USGS: John Cummans, Sub-District Chief
1305 Tacoma Avenue South
Tacoma, WA 98402

13. WASHINGTON PASS: Frank Almquist and Donna Daniels
Winthrop, Washington

14. WHITE PASS: Bill Martin, Supervisor, and White Pass Maintenance Crew
WSDH
P. O. Box 341
Packwood, WA 98361

APPENDIX C

Hurricane Ridge Telemetry

During the winter of 1975-76 the system described here was used to telemeter air temperature measurements from Hurricane Ridge (northern Olympics, altitude 5300 feet) to the Forecasting Office at the National Weather Service office in Seattle. The measurement is made by manually interrogating the sensor through a regular SCAN phone line and standard Park Service communications radios located in Port Angeles and at the repeater on Hurricane Ridge. The sensor responds immediately, giving the forecaster a direct visual reading of the existing temperature, supplementing the regular twice-daily radiosonde temperature data obtained from Quillayute. During critical storm periods, for example, hourly readings may be made.

Referring to the attached block diagram, the system operation is as follows: Using a touch-tone phone the Seattle forecaster dials the telemetry phone number at Park Headquarters, Port Angeles. This phone automatically answers, connects to the Park Service radio network, and monitors any voice traffic that may be on the air. Finding the radio busy for more than about 30 seconds, the forecaster would hang up and dial again later. The remote phone hangs up automatically after about one minute. If, however, the forecaster finds the channel clear he interrogates the sensor by pressing one of his touch-tone digits (pre-arranged) for about one second. This tone (tone A on the diagram) is decoded at the Port Angeles site, and in turn keys the radio transmitter which sends its own one second tone (B) to the Hurricane Ridge repeater, turning on the telemetry unit. The telemetry scanner then sequences through an automatic cycle lasting 7-8 seconds, consisting of the air temperature (5 seconds) and calibration inputs (2 seconds) which are converted to frequency, and pass through the output relay to modulate the Hurricane Ridge repeater transmitter. The scanner resets automatically after about 20 seconds.

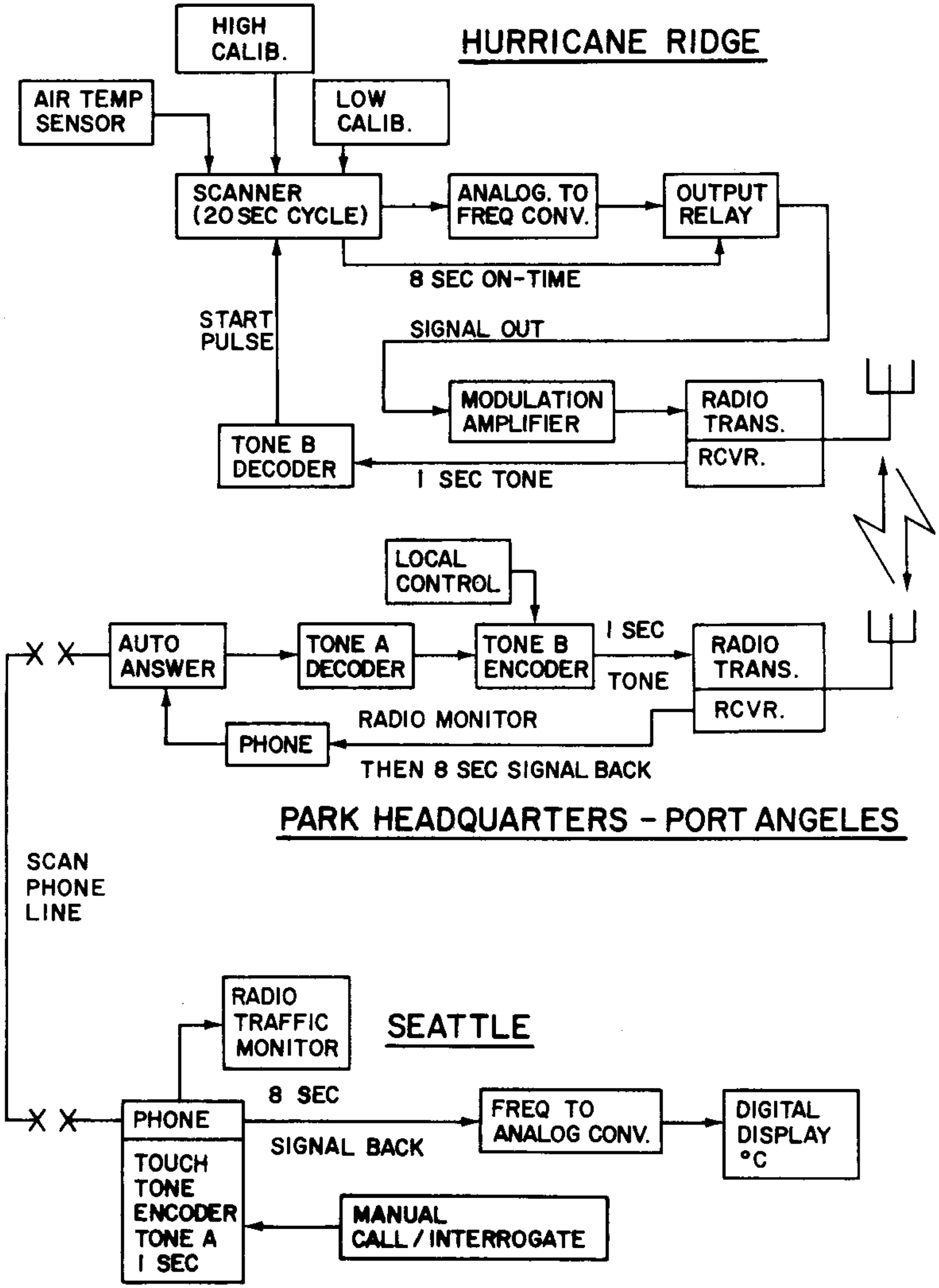
The transmitted signal is received back at Park Headquarters, and the audio portion is sent over the phone line to the Seattle forecaster where it is converted back to analog voltages and displayed in sequence in degrees Celsius on a small digital panel meter located beside the phone. The forecaster then hangs up, and the Port Angeles auto-answering unit resets

APPENDIX C (continued)

shortly thereafter. After about one minute the process can be repeated if desired. The system was used as sparingly as possible, however, in order to minimize interference with routine Park Service communications.

Mr. Ron Richmond of Olympic National Park was especially helpful in setting up the radio link. Park Service personnel were also able to manually interrogate and read out air temperature from Park Headquarters, which helped them schedule maintenance trips to Hurricane Ridge during the winter.

APPENDIX C (continued)



Hurricane Ridge telemetry system diagram shows the method for telemetering air temperature from Hurricane Ridge to the Forecasting Office in Seattle. A combination telephone and radio link is utilized.

ACKNOWLEDGMENTS

The success of this project has been determined in large measure by the participation and cooperation of a variety of people and organizations. Appendix B lists these people and organizations, and our appreciation of their participation in this project can only be amplified by saying that we hope they have benefited as we have. Should this project continue in the future, its success will again depend on the active participation of competent and interested people as it did this past year.

LIST OF ABBREVIATIONS USED IN THIS REPORT:

AES:	Atmospheric Environment Service (Canada)
FOFAX:	Forecast Center Facsimile Circuit
NAFAX:	National Weather Facsimile Circuit
NPS:	National Park Service
NWS:	National Weather Service
QPF:	Quantitative Precipitation Forecast
RAOB:	Radiosonde Observation
SCS:	Soil Conservation Service
USFS:	United States Forest Service
WSDH:	Washington State Department of Highways