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16. Abstract

This report reviews the second year of work on the Washington State Highway Commission Department of Highways project Central Avalanche Hazard Forecasting (WSDH Agreement Y-1700) to test the feasibility and effectiveness of central avalanche forecasting for the Cascade Mountain passes and adjacent area. The possibilities and techniques for improving both mountain weather and related avalanche forecasts for use by WSDH during winter operation in the mountain passes were further explored, and, secondarily, the usefulness of an area-wide forecasting service to other cooperating agencies. This report defines and significant changes from the first year of operation in collection, assimilation or transmission of snow, weather and avalanche data by the Forecasting Office, and details modifications of the data network itself, especially new instrumentation and telemetry equipment. Weather and avalanche forecasting accuracy and reliability are assessed by comparing daily weather and avalanche forecasts with field data. The conceptual framework and analytical methods used by forecasters to deduce current and probable future avalanche activity from the available data network input and current and extrapolated meteorological data are presented. A general preliminary guide to forecasting methodology for the Washington Cascades is defined and discussed.

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CENTRAL AVALANCHE HAZARD FORECASTING

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FINAL REPORT

Research Project Y-1700 Phase 2

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Washington State Highway Commission
Department of Highways
in cooperation with
US Department of Transportation
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June 1977

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1. INTRODUCTION

This report reviews the second year of work on the Washington State Department of Highways project Central Avalanche Hazard Forecasting (WSDH Agreement Y-1700) to test the feasibility and effectiveness of central avalanche forecasting for the Cascade Mountain passes and adjacent area. Results of the first year are given in Washington State Highway Department Research Program Report 23.2 (1976), which describes in detail the organization of a data network to support the Forecasting Office and the mode of operation of that office. The second year of this project further explored the possibilities and techniques for improving both mountain weather and related avalanche forecasts for use by WSDH during winter operation in the mountain passes and, secondarily, the usefulness of an area-wide forecasting service to other cooperating agencies.

This report defines any significant changes from the first year of operation in collection, assimilation or transmission of snow, weather and avalanche data by the Forecasting Office, and details modifications of the data network itself, especially new instrumentation and telemetry equipment. Weather and avalanche forecasting accuracy and reliability are assessed by comparing daily weather and avalanche forecasts with field data.

The conceptual framework and analytical methods used by forecasters to deduce current and probable future avalanche activity from the available data network input and current and extrapolated meteorological data are presented. Although these methods are still under active development, are influenced by ongoing international activity in the field and are augmented yearly by forecasting experience, a general preliminary guide to forecasting methodology utilized by project forecasters for the Washington Cascades is defined and discussed.

Since one of the goals of this work has been 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, a general work-plan and staffing guideline for a future operational forecasting service are outlined.

2. GOAL OF RESEARCH AND GENERAL METHOD OF OPERATION

The primary purpose of the project has been to provide WSDH 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 impact of these weather trends on avalanches affecting 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 potential (both present and future), timing of avalanche control missions, deployment of maintenance and avalanche crews, and timing of protective highway closures for passes with uncontrolled avalanche areas (e.g., Washington, Cayuse and Chinook Passes).

The avalanche problem affecting highways in Washington covers a relatively large geographical area along the Cascade Mountain crest, with significant avalanche activity threatening all major east-west highways within the State which cross the Cascades. In all, over 240 avalanche paths affect nearly 150 miles of State highways encompassing six mountain passes: Stevens, Snoqualmie, Chinook, Cayuse, Washington and White. These avalanche paths cover an extremely varied terrain, with starting zone elevations ranging between 3,000 and 8,000 feet (915 to 2415 meters), path lengths between 100 and 10,000 feet (30 to 3050 meters) and vertical fall distances from 50 to 5,000 feet (15 to 1525 meters). The relatively wide geographical spread of the mountain passes and widely varying elevations of major path starting zones also results in significantly different snow, weather and avalanche patterns between pass areas and even between individual avalanche paths. Table 1 summarizes the yearly mean snowfall/total precipitation for selected Cascade stations, together with the greatest monthly and seasonal totals of record and year of occurence. During most years, a cool and wet maritime climate predominates in mountain areas west of the Cascade crest, and a much more continental (colder and drier) climate prevails on the eastern side of the Cascades.

This geographic variability in snow, weather and avalanche conditions in the mountain passes of the Washington Cascades required a wide data network

TABLE 1. Yearly mean snowfall/total precipitation amounts (in inches) from selected Cascade Mountain stations and greatest monthly and seasonal snowfall record in inches and year of occurrence (Climatological Handbook, 1969).

	Stations					
	Blewett Pass	Mt. Baker	Paradise	Snoqualmie Pass	Stampede Pass	Stevens Pass
Yearly Mean Snowfall	200.5	525.3	576.3	435.7	448.1	475.5
Total Precip	22.43	94.76	100.28	104.44	79.87	71.12
Period of Record	1909-49	1926-50	1916-65	1909-65	1943-65	1939-65
September	4.0 1933	23.0 1933	26.0 1920	5.0 1933	3.0 1961	5.0 1961
October	20.0 1912	51.8 1931	77.2 1956	44.0 1956	47.9 1961	87.0 1961
November	55.0 1910	196.0 1948	190.0 1948	131.0 1915	138.5 1945	139.3 1958
December	118.5 1933	165.0 1949	168.0 1964	177.0 1912	163.3 1949	158.5 1961
January	92.5 1936	145.0 1939	363.0 1925	265.0 1964	192.9 1946	233.0 1964
February	89.0 1949	186.0 1937	227.5 1956	252.0 1910	181.7 1949	166.0 1956
March	70.0 1936	192.5 1928	206.0 1917	222.0 1955	154.8 1955	148.0 1956
April	11.0 1922	144.2 1937	116.1 1955	87.4 1955	90.9 1945	78.5 1960
May	6.0 1933	53.0 1927	62.0 1927	30.3 1943	32.1 1944	26.5 1960
June	0 -	11.0 1933	47.5 1917	5.0 1917	9.4 1954	3.0 1962
July	0 -	0 -	5.0 1921	0 -	2.1 1962	1.5 1955
August	0 -	0 -	6.0 1951	0 -	0 -	0 -
Seasonal Max.	292.0 1935-36	699.0 1948-49	988.5 1955-56	797.0 1949-50	632.7 1945-46	691.5 1963-64

of mountain weather and avalanche reporting stations in the Cascades for the project to be effective. This reporting network was established and instrumented during the Fall of 1975, prior to the first year of project operation, following many of the guidelines and recommendations proposed by Wilson (1975). It was based on an earlier informal data network initiated by the University of Washington in 1971 (WSDH Agreements Y-1301 and Y-1637) and continued through the 1974-75 winter. Results of research stemming from that work may be found in WSDH research program reports (1972-75).

The mountain weather and avalanche data network employed in the first year of operation was re-established the second year, with some upgrading and/or modification of field instrumentation. As a result of a very light winter in 1976/77, data input from many stations was sporadic or non-existent due to substantial manpower cutbacks and the lack of significant snow or avalanche activity to report. When weather and avalanche conditions did finally change in late February to a more normal Cascade winter, most 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 most 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. A brief summary of each data station, together with a description of any major changes in field instrumentation from last year's data collection network, is given in section 3.1.

As in the first year of operation, a working knowledge of the current condition of the snowpack was considered essential in formulating viable avalanche forecasts. To this end, snowpack observations in the form of snowpits (excavated at avalanche release sites to determine weak layers or sliding surfaces) and fracture-line profiles were again made at the various pass areas throughout the winter by the project staff to gain better insight into the late-developing avalanche potential. In the first year of operation 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. However, during this past winter with the very late arrival of any significant snowpack in most Cascade areas, consequent WSDH manpower curtailments and rescheduling of USFS Snow Rangers away from ski areas reduced snowpack input from field observers to near zero throughout much of the season (especially on the major passes of Stevens and Snoqualmie). Such reports would have been useful to forecasters in judging more general avalanche potential in the Cascades.

The unusually late and light snowfall this past winter also dictated significant changes from a normal winter in emphasizing where current snowpack information was most critical. During a normal winter, snowpack information is most critical from Stevens, Snoqualmie and White Passes, since Washington, Cayuse and Chinook Passes are closed for the winter when avalanches block the highway. However, this year no reported avalanches occurred affecting the roadways on Stevens, Snoqualmie or White Passes (with minimum avalanche potential at these areas most of the season), while the primary hazard areas were Washington, Cayuse and Chinook Passes, which remained open to traffic. A further discussion of the problems associated with such a winter in terms of current snowpack and avalanche information and resulting avalanche forecasts is given in sections 3.2 and 4.4.

The project was again housed in space provided by the National Weather Service (NWS) in Seattle. 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 equipment utilized during the 1976/77 operation are discussed in section 4.1. The daily routine for the on-duty project forecaster followed closely the guidelines established during the first year of operation, although modifications which were made are explained in section 4.2. The actual NWS maps and data utilized by project forecasters varied very little from the first year. A Table of available NWS information is described completely in section 3.3 of last year's report.

The project issued weather and avalanche forecasts twice daily from December 6, 1976, through April 15, 1977. The form of these forecasts is discussed in section 4.2, and an explanation and outline of the avalanche forecasting methodology employed during the past two seasons in section 4.3. Some of the more basic and important components included in the daily forecasts are discussed and analyzed quantitatively in section 4.4, including a comparison with the results of some of last year's quantitative analyses. A specific case study of the operation and output of the Forecasting Office during a major avalanche-generating situation is also discussed (section 4.4.2) with emphasis on weather and avalanche forecasting for Washington and Cayuse Passes. Selected daily forecasts for this case study appear in Appendix A. Based on user and project staff input through the course of the year, recommendations for more effective Forecasting Office operation are given in section 5.2.

3. SOURCES OF DATA

3.1 Mountain Weather and Avalanche Data

During the first year (1975/76) of Forecasting Office operation, snow, weather and avalanche reports wre obtained by phone (or teletype for the passes in 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), Washington Pass (WSDH), Crystal Mountain (USFS/ski area), and Paradise (NPS). Reports from these stations during the first year were received 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 to the NWS office 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 for the first year of operation 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 are given in Figure 1.

This mountain weather and avalanche data network employed in the first year of operation was re-established the second year (1976/77), along with improvement of field instrumentation and input in accordance with some of the specific recommendations included in last year's report. The most significant instrument modification was the installation at Stevens Pass of a completely automatic remote meteorological station, with wind direction and speed, temperature and precipitation sensors, and with telemetered hourly recorded read-out capabilities in the Forecasting Office in Seattle and similar capabilities planned for the WSDH Berne Snow Camp (see Appendix C). Installation this past year of a wind sensor at the Hurricane Ridge telemetry site provided further field meteorological data to the project forecasters through a manual phone-radio telemetry link devised by Phil Taylor, project engineer. With the exception of these improvements, data input from most reporting stations was received and recorded at the Forecasting Office in the same form as last year when winter and significant snowfall did finally arrive in late February. Prior to this time, field data were non-existent at many stations or else non-reportable due to WSDH manpower cutbacks and/or ski area closures. In the station by station outline below, only the instrumentation upgrading or other significant changes from last year's data network are discussed in any detail. Recommendations for a more effective future operation of the data network are set forth in section 5.1.

3.1.1 Primary Reporting Stations

a) Stevens Pass. Incoming snow, weather and avalanche data from this station was extremely sparse this year. Snow and weather data which were obtained from the new WSDH study plot just to the west of the Summit on the old highway continued to be of high quality and excellent reliability, and showed good agreement with USFS data from the old study site. The form utilized for recording these data was the same as that used in the first year (WSDH Research Program Report 23.2, pp. 7-8), with some items deleted unless specifically requested by forecasters.

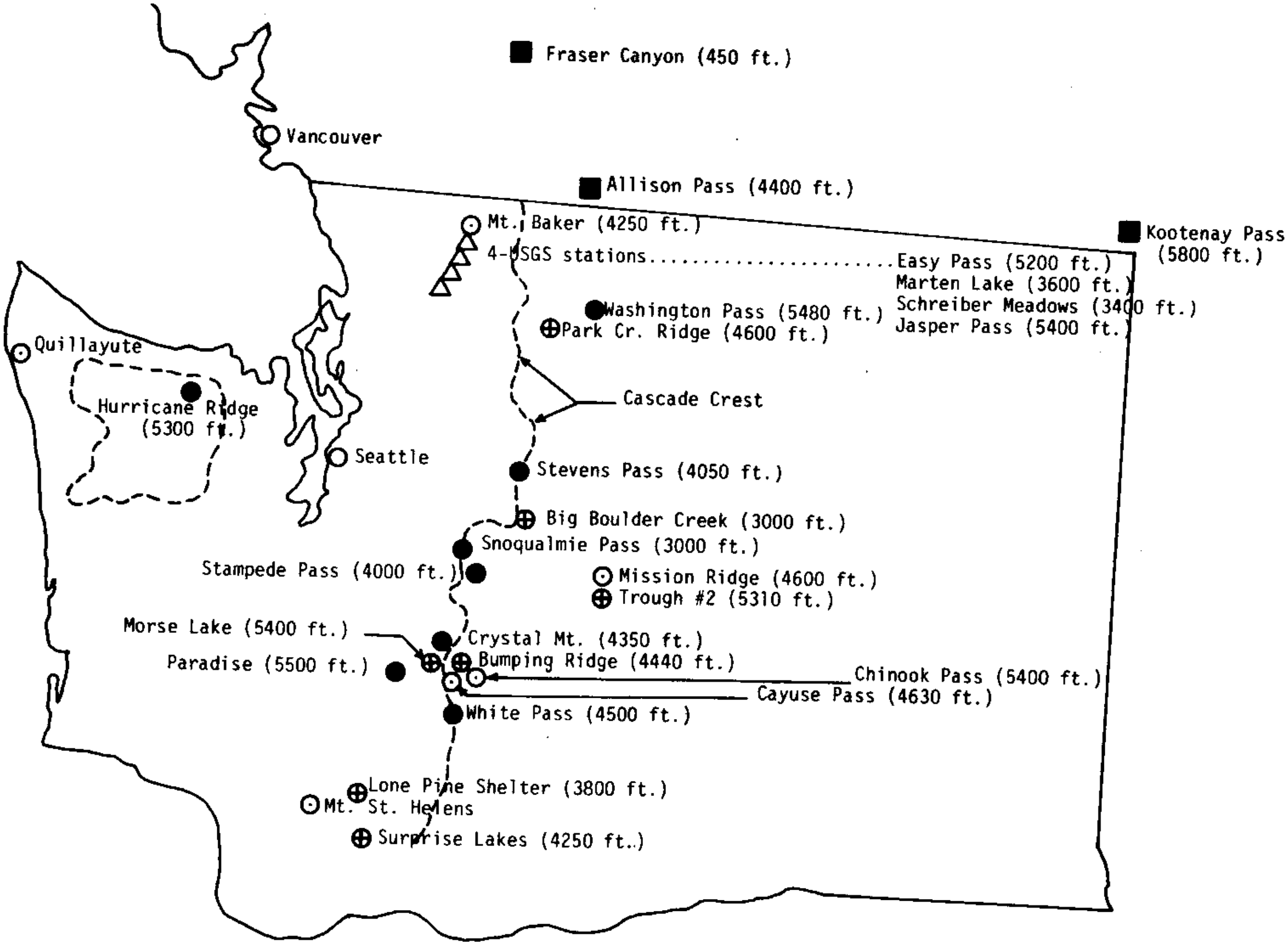


Figure 1. Location and elevations of primary (●) and secondary (⊙) reporting stations in Washington. Also shown are British Columbia Department of Highway stations (■), USGS stations (△), and SCS remote telemetry stations (⊕) which may be included in future data collection schemes. The SCS stations appear 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.

Communication with this area was generally via SCAN-line telephone, although teletype communication was also possible throughout much of the season due to the installation by the phone company of an eight-level teletype link between Berne Snow camp and the Forecasting Office. Through this installation, unattended receipt of hard-copy weather and avalanche forecasts by WSDH personnel at the Snow Camp at all hours was possible, with similar capabilities for snow and weather data transmission back to the Forecasting Office. (See also sections 4.1 and 5.2 of this report.)

b) Snoqualmie Pass. Due to the light snow year, no regular snow and weather observations were received at the Forecasting Office from this WSDH observation station. Only sporadic informal phone discussions were held with WSDH Snoqualmie Pass avalanche personnel during the winter, and these involved only the general snow conditions, depths and weather forecasts for this area. It is assumed that had the winter been a more normal one, the usual high quality snow, weather and avalanche observations would have been available on at least a daily basis. However, no avalanches affected this highway at all during the past winter and snow conditions here during much of the season did not even warrant much concern regarding avalanche potential. For future operational forecasting the format for reception of snow, weather and avalanche data from this area is anticipated to follow closely the format given in last year's report (pp. 9-11).

c) Crystal Mountain. When this ski area finally did open on March 2, USFS and professional ski patrolmen provided reliable daily snow, weather and avalanche data to the Forecasting Office. In addition, the phone link with the Summit House at Crystal Mountain, installed by area management, was again available. In normal years this latter capability would be very useful for project forecasters in determining the timing of warming trends at other more northern Cascade areas, but was little used in this light winter. Necessary instrumentation for this summit operation included a Foxboro dual channel recording thermograph and a VOM (voltage-ohm-meter) wired into the existing wind system to give instantaneous wind read-outs. Communication with the area for both daily and on-demand data was via commercial telephone, if initiated by the area, and via the University of Washington WATS system, if initiated at the Forecasting Office.

As in the first year of operation, daily snow and weather data were recorded at both a lower elevation (4350 feet) and upper elevation (6300 feet) study plot, and were recorded at the Forecasting Office on the modified USFS standard report form shown and described in last year's report (pp. 17-18). The Snow Ranger (USFS) and professional ski patrol also provided periodic snowpit analyses to the Forecasting Office which proved very useful in forecasting.

d) Paradise/Mt. Rainier. National Park Service (NPS) personnel provided reliable daily snow, weather and avalanche data from this exposed station on the southwest slopes of Mt. Rainier, and in addition provided brief snowpit studies as requested when sufficient manpower was available. Communication with this area was via telephone and the general form in which information was received by the Forecasting Office was the standard USFS snow and weather reporting form.

With the cooperation of NPS personnel the automatic recording temperature and wind system installed and utilized during the first year of operation was re-installed during the autumn of 1976. 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. As mentioned in last year's report, the wind system, although reliable and useful for local weather and avalanche forecasting for the Paradise area, again 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 at Quillayute, and was 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 probable that the wind system here will remain a useful tool for local avalanche and weather forecasting only.

e) Washington Pass. As in the first year of forecast operation, full-time WSDH weather and avalanche observers continued to record data from this site throughout the winter season. The reporting form utilized here was the slightly modified USFS standard snow and weather reporting form used at Crystal Mountain. While giving the forecasters an indication of snowfall amounts, types, and temperatures (both high, 7000 feet, and Pass level, 5500 feet) in the northern Cascades, snow and weather data received from this station were not directly used in forecasting for the operational passes to the south. Wind data from this site were generally not reliable due to problems with the land-line telemetry from the top of Cutthroat Ridge where the sensors were located. Major avalanche-generating storm situations or warming periods usually approached Washington state from the southwest or west, although storms which skirted to the north were usually indicated through precipitation or sky cover records at this northeast Cascade station.

A test forecasting program planned for this past winter at this area became an operational forecasting program when the Pass remained open throughout the season (except for limited avalanche closures) due to an unusually light snow year. As a result, real-time data from this area became critical to forecasters, and reliable information communication between the observers and the forecasters was essential. To meet these ends, twice daily snow, weather and avalanche observations were transmitted to radio operators in either Okanagan (weekdays) or Yakima (weekends, after the 24-hour/day radio operator was initiated), where they were then either transmitted on-demand to the Forecasting Office or left on the message tape at the Forecasting Office by WSDH personnel. In turn, project forecasters generally gave quick weather and avalanche synopses to the radio operators to give the WSDH avalanche observers. This communication system worked out fairly well for this light winter, but more direct communication with the avalanche observers would greatly add to the forecaster's knowledge of snow, weather and avalanche conditions at the Pass. Such direct communication would be quite essential for operational forecasting for this area if the Pass were to remain open during a more normal winter. In-depth discussion of any kind between forecaster and observer is entirely too time-consuming and error-prone if an intermediary must transmit all questions and answers.

f) White Pass. As in the first year of operation, data input this past year from this WSDH station was generally via radio to Yakima and then SCAN phone to the Forecasting 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 second year of operation was again excellent. The format of data input from this site was the same as in the first year of operation and is detailed in last year's report (pp. 14-18). Instrumentation utilized by this area was installed in the autumn of 1976 by project staff, who also conducted instruction in observation techniques for maintenance personnel at that time.

g) Stampede Pass. Hourly temperature, precipitation and wind data were received at 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 (see Table 1). However, along with the Stevens Pass telemetry, the continuous weather input from this station gave project forecasters excellent data on which to base and update general and local weather forecasts.

h) Snow-line Reports. With the absence of daily in-depth snow and weather reports from certain WSDH passes and/or ski areas for much of the season, the WSDH Snow-line Reports (reports of road and weather conditions at major highway passes) were utilized extensively by project forecasters in verifying or updating snow, weather and avalanche forecasts for the various pass areas. At times, these reports gave forecasters the only early morning information obtainable on new/total snow depths and temperatures in certain pass areas, especially following a major storm. As a result of this often heavy reliance on WSDH Snow-line Reports by project forecasters, some recommendations regarding their content are given in section 5.1.

i) Remote telemetry--Stevens Pass. In the first year of operation difficulties in communication with WSDH field personnel at Stevens Pass severely hampered the snow and weather feedback process necessary for operational forecasting for this area. These communication difficulties stemmed partly from a very bad phone system (beaver destruction of phone company land lines was a large problem, often resulting in shorted lines, significant line static and wrong numbers), partly from the range limitations of field radios, and partly from 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, during high avalanche hazard periods when current hourly snow and weather data from this area were needed most by forecasters to update local avalanche advisories and forecasts, control personnel responsible for such data were involved in active control work and not able to observe or transmit data.

As a result of these data communication problems, and in order to have snow and weather input from this generally high hazard area available at all hours at the Forecasting Office, project staff constructed and installed a remote, automatically telemetered meteorological instrumentation system in the Stevens Pass area during the autumn and early winter of 1976. Wind direction and wind speed sensors were placed on top of a 40-foot Rohn tower installed on the northeast edge of the

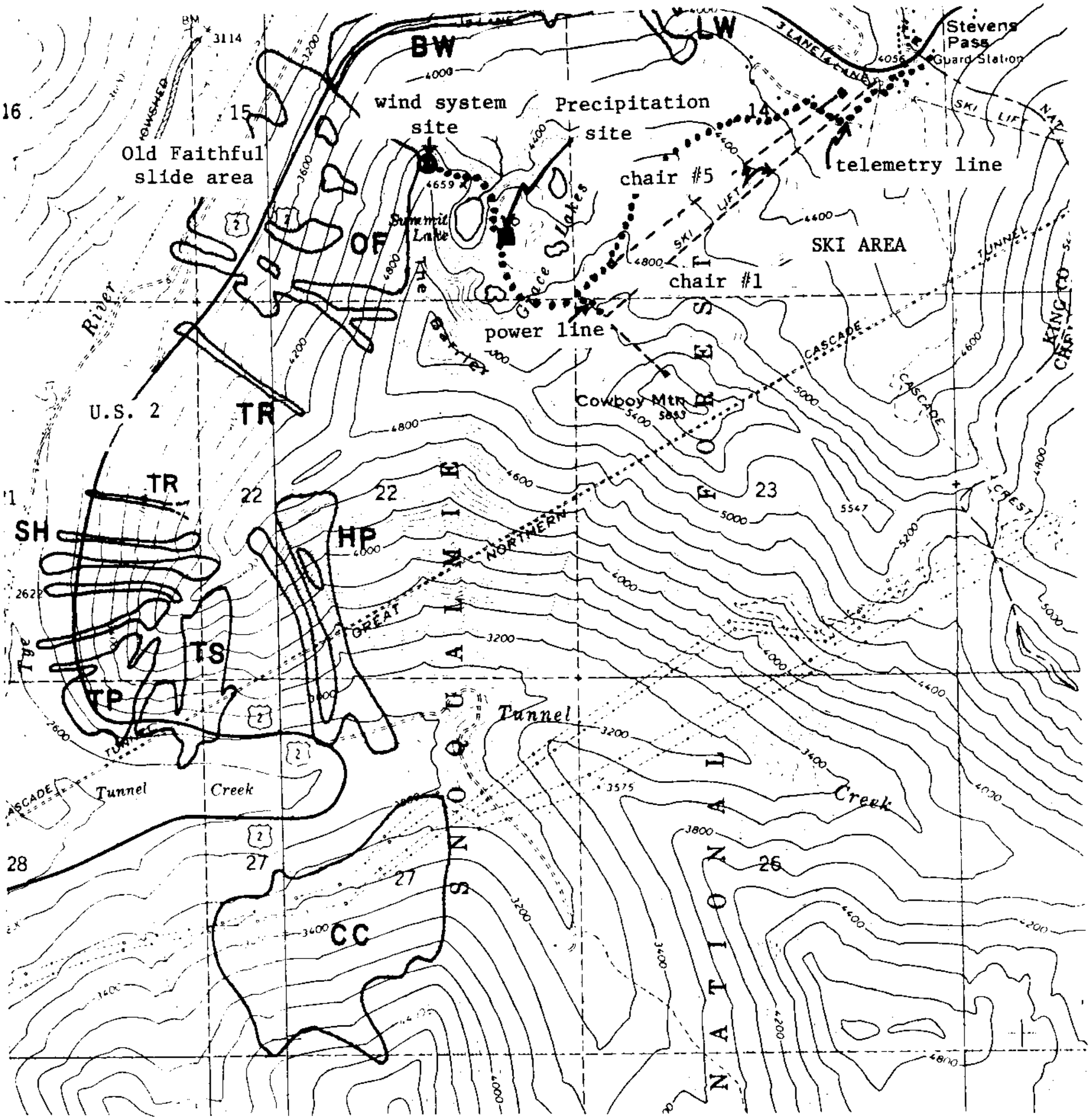
Old Faithful ridgeline (a very active avalanche area affecting the Stevens Pass highway) at the 4800 foot level. An existing radiation-shielded temperature thermistor (earlier utilized by WSDH personnel prior to a break in the telemetry line), located in a nearby fir tree along the same ridgeline, was connected to the telemetry system to provide high altitude temperature data. Another new, similarly shielded, thermistor was installed at the Pass level (4000 feet) on the USFS snow study platform to give lower altitude temperature input to the Forecasting Office. Finally, a heated precipitation gage, newly designed, tested and constructed by project staff, was placed on top of a 20-foot Rohn tower (with wind baffles) which was installed in a tree-shielded low wind area in the Summit Lakes Basin to the southeast of the anemometer site. See Figure 2 for more specific locations of these instrumentation sites.

Although the past season was relatively light in comparison with most Cascade winters, sufficient snowfall and winds (in heavy riming situations) were experienced to give the instrumentation system a vigorous test. During the course of the season, the newly designed anemometer system did not rime-up and reliably indicated wind speeds near the Old Faithful slide area and at Stevens Pass in general (see Appendix C for a detailed description of this wind speed system). Minor modifications (e.g., improvement of heat transfer and lowering of initial starting speed) of the anemometer system are anticipated before further use, but the concept appears to be quite reliable. The precipitation gage used at the Summit/Grace Lakes Basin site consisted of a standard tipping bucket rain gage mechanism incorporated into a newly designed and constructed "snow precipitation gage." In general, the modified precipitation gage operated quite well with resolution to .01 inch. See Appendix C for a more technically detailed description of this system.

Temperature-sensing units at both the high (anemometer site) and low elevation (Pass level USFS snow study plot) sites consisted of standard temperature thermistors housed in double-radiation shields designed by Phil Taylor, project engineer. In all instances these units have proved very reliable.

Telemetry equipment used in the automatic transmission of data was housed in the ski area lift shack at the top of Chair #5. A detailed description and outline of this equipment and the telemetry operation is given in Appendix C. Phone calls for Stevens Pass data were initiated automatically every hour at the Forecasting Office by a one-number dialer system (a combination of phone company and project engineered equipment). An automatic answering device at the top of Chair #5

FIGURE 2. Remote telemetry sites at Stevens Pass.



answered the call and keyed a scanning device which then sequentially transmitted sensor output (already encoded--voltages converted to frequency) over the phone line to awaiting decoders and recorders at the Forecasting Office and at Berne Snow Camp.

j) Remote telemetry--Hurricane Ridge. In addition to re-installation of the shielded temperature thermistor at Hurricane Ridge, a modified wind speed sensor was also installed at this site in the autumn of 1976, following the recommendations in last year's report (p. 20 and Appendix C). The wind speed sensor was newly designed and constructed by project staff and is the same type of sensor installed for the Stevens Pass telemetry system. The sensor and transmitter were bolted to an existing telephone pole at the Hurricane Ridge generator building, and were exposed to all but rarely occurring east-northeast winds, where the pole interfered. The telemetry to transmit the sensor input to the Forecasting Office followed the same operation as last year.

Due to the light snow year, it is uncertain whether or not the anemometer system had a true test in regard to the heavy riming problem usually experienced at this site. Operation of the telemetry system was quite reliable overall (especially temperature values), but some recorded wind values were substantially lower than those expected through meteorological considerations alone. It is possible that high wind separation from the ground occurs downstream from the anemometer site, creating eddies on the summit, but this is not substantiated by Park personnel. Another season of wind measurement at this site (with some equipment modifications as discussed in section 5.1) appears necessary before consideration of possible sensor re-location. Substantial static in the anemometer line may have caused distortion of the wind speed signal and this problem needs to be corrected before real analysis of the received wind speed values is possible. However, with completion of the recommendations for improving this telemetry system, it is believed that reliable real-time weather information received from this site would give forecasters significant lead-time on forecasts for storm situations moving toward the Cascades from the west.

3.1.2 Secondary Reporting Stations

a) Sno-Country Stevens Pass. This ski area provided reliable back-up information to WSDH observations regarding new snowfall, temperature, winds, current weather and avalanche occurrences during morning avalanche control. Twenty-four hour and current weather information was usually available prior to 0630 from the area 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.

The cooperation of all ski area personnel at Stevens Pass was excellent regarding transmission of avalanche and snowpack information to the Forecasting Office, and project forecasters were allowed access to all lifts throughout the season to gather snowpack information. Ski patrol personnel also allowed forecasters to accompany them on morning control missions, which gave forecasters an excellent opportunity not only to study the snowpack and its susceptability to artificial avalanche control methods, but also to gain the necessary feel for the general snowpack stability in this area. Assistance with instrument installation early in the season by the ski area through their sharing of helicopter time and by the help of their electrician was greatly appreciated by project staff.

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 also utilized by project forecasters for information relative to the timing and magnitudes of storms which tracked primarily from the northwest. Unfortunately, this information was generally not available 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 very useful for future weather and avalanche forecasting for SR-20 (North Cascades Highway), if this highway remains open year-round.

c) Mission Ridge. Snow and weather reports from this ski area on the eastern slopes of the Cascades were not received at all this past year as the ski area did not open. Based on the first year of operation, however, snow and weather reports from this area must be made available earlier in the day (by 0830-0900) and on a more complete and regular basis in order for this station to be useful to forecasters. A further consideration in the usefulness of Mission Ridge is that equivalent data should be available in the autumn of 1977 from a nearby telemetering Soil Conservation Service Station at Trough #2.

d) Soil Conservation Service. Discussions with the Snow Survey Supervisor (Robert T. Davis) at the Soil Conservation Service (SCS) office in Spokane in the autumn of 1976 and spring of 1977 indicated that data from seven remote telemetry stations in the Cascades should be available by the autumn of 1977 on at least a daily basis. The location and elevation of these stations is shown in Figure 1. Telemetry to be utilized for this data reception by SCS is via meteor burst, low band, radio frequency with receiving base stations in Boise, Idaho, and Salt Lake City, Utah. Data interrogation is expected once or twice daily and should be received real-time at the Portland NWS River Forecast Office by CBTT (Columbia Basin Teletype) and stored at the SCS office in Portland and at CROM (Columbia River Operations Management) offices. However, due to retrieval problems in accessing real-time data received at Portland, it is anticipated that daily weather data (including wind, temperature, precipitation, snow weight --from pillow, and snow density--from isotopic profiler) should be available by 0830-0900 at the SCS office in Spokane. Mr. Davis has offered to have such data available at his office in the morning if initial radio transmission permits. It is also possible that such data may be transmitted to the Forecasting Office by teletype from Spokane at some time in the future.

e) U.S. Geological Survey. Weather (temperature and precipitation) data from USGS stations (locations and elevations given in Figure 1) continues to be available through the USGS office in Tacoma. At present, the need for such data in the Mt. Baker area has not yet been defined by project staff. If and when the need arises, however, such data, interrogated at least twice daily, could be obtained through either a phone call to the USGS hydrological office in Tacoma (through John Cummans) or through NWS teletype.

f) Atmospheric Environment Service, Canada. The British Columbia Department of Highways contributes daily weather observations to AES from three southern B.C. mountain passes (Allison, Fraser Canyon, and Kootenay--see Figure 1). If future forecasting projects attempt real-time avalanche and weather forecasting for Washington Pass on the North Cascades Highway in a normal winter situation, important data could be obtained from these stations through the cooperation of AES.

g) Government Camp and Hood Meadows, Oregon. To aid in forecasting for the southern Washington Cascades, daily snow, weather and avalanche data (recorded on standard USFS data forms) from Government Camp and Hood Meadows (near Mt. Hood), Oregon, were transmitted to the Forecasting Office by USFS Snow Rangers or ski area personnel during the late months of the past winter at the request of the USFS. In turn, short weather and avalanche forecasts for the Mt. Hood or southern Cascade area were available to these same personnel on the recording or directly from the forecaster. Data from these outlying areas was also transmitted on-demand from the Forecasting Office to the USFS avalanche forecaster in Seattle, who utilized the data in composing public advisories for the southern Washington Cascades (especially Mt. St. Helens). Given the light, late snow year this past season, the usefulness of data received from these southern stations in terms of operational forecasting remains undetermined. These stations could prove to be of significant value in terms of regional forecasting, but another more normal year of forecasting operation will be necessary before more realistic determinations can be made.

3.2 Field Snowpack Data

A major problem during the past year in gathering field snowpack data was that while trained snow and avalanche personnel were available to measure and transmit snowpack properties at Stevens and Snoqualmie Passes (where no avalanches affecting the highway were recorded), no personnel were available at Cayuse or Chinook Pass, where avalanche activity did affect the highway. Project forecasters had either to meteorologically reconstruct the snowpack at Cayuse Pass in conjunction with their own snowpits, or infer the snowpack from other snowpits at nearby areas. Both of these methods are fairly tentative without verification through field input or discussion with field personnel on a regular basis. Further, at Washington Pass, where field personnel were available for snowpack analysis, communication through an intermediary limited data which could be reliably and realistically transmitted; also, project forecasting staff were unable to spend as much time as necessary at this distant Pass area. It is understood that in a more normal season when these Pass areas (Cayuse and Washington Passes) are closed, field snowpack data from these sites is obviously not critical in the forecasting operation. But if these Passes are kept open during the winter in the future, some arrangements should be made to have WSDH personnel transmit regularly at least some basic snowpack properties (e.g., snow surface, new snow above weak layers, etc.). Such regular data transmission coupled with increased time in the field for project forecasters would greatly alleviate problems of insufficient snowpack data from Washington and Cayuse Passes during operational winters. Recommendations regarding snowpack and avalanche information communication via radio-phone with Washington Pass are given in Section 5.1.

An in-depth discussion of how field snowpack data is utilized in avalanche forecasting methodology may be found in section 4.3. A general discussion of field snowpack data is contained in last year's report.

3.3 Meteorological Data

National Weather Service maps, satellite pictures and selected teletype data were used by project forecasters, including current and prognostic weather maps received via the National Weather Service Facsimile Circuit (NAFAX) or the Forecast Center Facsimile Circuit (FOFAX). Table 2 gives the reception schedule of these various maps, along with the schedule of teletype products.

The avalanche forecasting methodology used in conjunction with these NWS products is discussed in section 4.3; a more lengthy discussion of meteorological data in general may be found in last year's report.

4. FORECASTING

4.1 Staffing and Equipment

As in the first year of operation, the forecasting staff was occupied early in the season with establishing the field reporting network and planning the office organization. The field network required recalibration and reinstallation of instruments used during the first year, as well as the construction of new sites and instruments at Stevens Pass and Hurricane Ridge. Extensive revision and improvement of the Forecasting Office operation was undertaken based on experience gained during the first year and to accommodate new data and communications equipment.

During the operational phase, the office was manned from 0600 to 1500 PST during low hazard periods. Scheduling was established to give effective 24 hour coverage during high hazard periods. During the months of September-December and April the project staff consisted of Mark B. Moore, UW Research Scientist/Meteorologist, and Richard T. Marriott, UW graduate student/Research Assistant. During the months of January-March when the greatest activity is ordinarily expected, the staff was enlarged with the addition of Frank W. Reanier, Consultant/Senior Meteorologist. Flexible hours and staff rotation were necessary to handle the heavy workload at the Forecasting Office during any but the most quiescent weather situations, due to the expanded data input and the enlarged forecast duties.

TABLE 2. Facsimile Charts

Schedule of charts used at the Forecasting Office, received on the National Weather Facsimile Circuit (NAFAX) or Forecast Center Facsimile Circuit (FOFAX).

Time (PST)	Facsimile Chart
0053	Prognostic Chart 24-hr. 850 mb./700 mb.
0107	Pacific Surface Analysis (FOFAX)
0154	Prognostic 30 hr. 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	Vorticity plus 500 mb. 00, 12, 24, 36 hr. barotropic progs.
0642	500 mb. analysis
0656	850 mb. analysis
0706	24 hr. precipitation
0707	Pacific Surface Analysis (FOFAX)
0716	700 mb. analysis
0720	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
0755	L.F.M. 24 hr. prog. (same data as above)
0900	300 mb. analysis
1054	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 (FOFAX)
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	00, 12, 24, 36 hr. barotropic 500 mb. progs. and vorticity
1846	500 mb. analysis
1858	700 mb. analysis
1903	Pacific Surface Analysis (FOFAX)
1908	850 mb. analysis
1940	L.F.M. prog. Vorticity plus 500 mb. surface pressure plus 1000-500 mb. thickness, relative humidity, 12 hr. QPF plus vertical velocity

TABLE 2. Facsimile Charts (continued)

Time (PST)	Facsimile Chart	
2201	300 mb. analysis	
2221	500 mb. analysis	
2246	Prog. 36 hr. 500 mb.	
2252	00, 13, 24, 36 hr. baroclinic (Primitive Equation--P.E.) progs. --500 mb. and vorticity	
2313	Prog. 36 and 48 hr. surface, clouds and precipitation	
2337	Surface analysis--6 hourly	
	Schedule of Products Received via Teletype	
0730	FOUS 72	Forecast--6 hourly data from LFM Numerical Model, including temperature, relative humidity, wind speed and direction
1930	FOUS 72	Vertical velocity, precipitation, etc.
1000	FOUS 43	Forecast--6 hourly values derived from LFM Numerical Model
2200	FOUS 43	
1040	FOUS 50	Trajectory Forecast--700, 850 mb. and surface
2240	FOUS 50	(Temperature and Dewpoint)
Hourly	Weather observations (clouids, visibility, pressure, temperature, dewpoint, wind, weather, precipitation amount, etc.) from Canadian and NWS Washington, Oregon and other northwest state reporting stations	

In the second year of operation it was found that a minimum of three full time forecasters are necessary to adequately staff the Forecasting Office during all hazard periods, especially if project forecasters were to gain any significant firsthand field input. Project forecasters attempted to spend a minimum of one or two days per week in the field to maintain familiarity with snowpack conditions, to increase their knowledge of local snow and weather features, and to conduct occasional instrumentation inspection and maintenance. It is the general consensus that improved weather and avalanche forecasts can be produced when forecasters have regular in-person contact with the areas for which they are forecasting. This is particularly true in the present program where detailed forecasts for small areas are being produced. The forecasting of meteorological quantities on the relatively small scales involved require intimate knowledge of local topographic effects. This kind of knowledge requires personal observations under all conditions to be developed to an optimal level. The necessity of firsthand experience with the current snowpack in evaluating the potential effects of forecast weather on the avalanche probability is a fact of current avalanche forecasting technology. Even with the past light snow year, the project staff were often pressed for manpower, since technically only two and one-half full time positions were provided, requiring large amounts of uncompensated overtime. This problem is not unusual in research situations but cannot be sustained in an operational program.

Due to diminished floor space available within the Map Room of the NWS and the expanded need for space by project personnel, it was necessary to move the project forecast desk into the Port Meteorological Office which is adjacent to the Map Room. Though this location initially seemed less advantageous than the one occupied during the first year of operation, access to a larger more private area proved to be very useful, particularly with the addition of several new pieces of hardware.

Communications equipment, both for the receipt of data and for the dissemination of forecasts continued to comprise the bulk of the Forecasting Office hardware. Based on recommendations from the first year of operation, four phone lines (combined WATS and SCAN) were installed. Two were used for voice communications and two were used for machine data transmission or receipt.

Of the two phones used for voice communications, one was used for conversations between the forecaster and field personnel and the second line was hooked into an automatic answering and recording system (described in section 4 of last year's report), which contained the latest weather and avalanche forecasts and allowed for the recording of observations or comments from field personnel. Additionally, the forecaster telephone was equipped with an automatic forwarding device which transferred incoming calls to the recording line when the forecaster was unavailable.

This arrangement was satisfactory, allowing individuals access to the current forecasts at all times without interrupting the forecasters, while still allowing field personnel direct contact with the forecaster whenever the situation warranted. The problem of busy phone lines, which was a frequent complaint during the first year, was alleviated even though the number of users of the project forecasts has expanded to groups outside of the regular reporting network (e.g., Maintenance crews from Chinook and Cayuse Passes, ski areas, etc.).

The relocation of the forecast desk outside of the Map Room meant project forecasters had to be away from the desk, and consequently the phones, for extended periods while preparing the weather forecast. To remedy this problem, the phone company installed a light in the Map Room which flashed whenever a call was being received. Unfortunately, it was found that the light was not sufficiently conspicuous in a brightly lit room to attract attention most of the time, and many phone calls were missed. A possible solution may simply be to place an extension phone in the Map Room (see section 5.1).

Based on recommendations from the first year of operation, a teletype link to the Stevens Pass maintenance camp at Berne was installed in the NWS communications room using one of the two data lines. Due to phone company delays, this link was not established until early February. Initially the teletype was to be a one-way line to Berne; however, shortly after its inauguration it was found that the link was two-way and served as a useful line of communication for the transmission of observations and messages when no one could be reached by phone.

The system simply required the sender to dial the number of the other teletype which then automatically answered and was ready to receive any messages. Ordinarily, the forecaster punched the forecast onto a paper tape prior to phoning Berne. This tape could then be fed thru the teletype at a much greater speed than it was originally typed, minimizing the length of the long distance phone call.

Later in the season it was discovered that the Forecasting Office teletype was compatible with computer equipment at the maintenance office in Wenatchee which allowed the sending of a hard-copy forecast to District 2 Maintenance Headquarters. Unfortunately, the auto-answer features could not be properly utilized with this arrangement. The jury-rigged system that was created required the forecaster to call Wenatchee on a standard phone line when the forecast was ready and then wait by the teletype for them to call back so that a switch could be thrown to send the forecast. This system often required that the forecaster wait 5-15 minutes to complete the transmission of the forecast. This created a logistical problem since the teletype was located in the communications room, placing the forecaster away from the phone leading to more missed calls. The solution of these problems will probably require the placement of an extension phone near the teletype and procurement of teletype equipment in Wenatchee that is compatible with the present auto-answer capability of the Forecasting Office teletype (see section 5.1).

It was originally hoped that the Forecasting Office teletype could be used to send hourly observations from the NWS to Berne using prepunched NWS tapes. This was to replace the old "Service A" teletype at Berne that had previously received NWS "public loop" information. However, it was found that the NWS machine tapes were not compatible with any currently available teletype equipment from the phone company. Thus, if NWS weather data is to be sent using the teletype without the very time-consuming process of repunching tapes, it will be necessary to find a private supplier of NWS-compatible machines. See section 5.1 for details.

Instruments for the receipt of weather data telemetered from the project sites on Hurricane Ridge and Stevens Pass constituted the remainder of the Forecasting Office hardware. The Hurricane Ridge display was essentially unchanged from that described in last year's report; however, the information was improved by the addition of a wind speed sensor. The data from Hurricane Ridge were obtained on an on-demand basis. The system operated smoothly most of the year with minor problems (see secion 5.1).

The Stevens Pass telemetry (see Appendix C) was received in the Forecasting Office on the fourth phone line, separate from all other office functions. A "one number dialer" was triggered automatically once hourly (or on demand when desired) in the Forecasting Office. This would call an automatic answering device located at the Pass which set a series of events in motion which led to the receipt of various meteorological quantities on a chart recorder on the forecaster's desk.

The Stevens Pass telemetry functioned very well during the season and proved to be an invaluable aid in weather and avalanche forecasting. Some difficulties were experienced but generally the field equipment functioned better than had been expected for its first year of operation. One problem lay in the tendency of the SCAN system to "miss making a proper connection" when calling the Pass. Often the connection would not be made and the Forecasting Office recorder would simply display line noise. This resulted in missed observations, usually when something interesting was happening. Overcoming this problem will require a system which will continue to dial until a proper connection is made (see section 5.1).

4.2 Daily Routine

Operations of the Forecasting Office in Seattle for the 1976/77 winter began on December 6, 1976, and ended April 15, 1977. As previously noted, the office was ordinarily manned from 0600 to 1500 PST during low hazard periods with provisions for up to 24-hour-a-day effective coverage during high hazard or rapidly changing conditions.

The daily routine was modified from that of the first year of operation due to changes in the timing of NWS forecast packages and increased input from the project field network. Also, several improvements were instituted to help streamline the production of the early morning forecast. The daily worksheet originally used during the 1975/76 season was expanded to three separate forms due to increased hourly local input (e.g., Stevens Pass telemetry, etc.) and due to the increased length of the forecast. These forms are shown in Figures 3, 4 and 5. The form shown in Figure 3 was modified during the season since new Quantitative Precipitation Forecast (QPF) guidance from the Bonneville Power Authority was anticipated; however, project forecasters found this new guidance to be of dubious value and it was removed from the form. The general routine and guidelines for the completion of the worksheet and a basic interpretation of the various data follows:

- Log Stevens Pass temperatures, precipitation, and wind velocity from the paper chart record at three-hour intervals (one-hour intervals during storm periods), beginning at midnight Greenwich Mean Time (1600 PST). Log present value of temperature and wind speed from the Hurricane Ridge sensors. It was generally attempted to interrogate the Hurricane Ridge sensors at least once an hour during the hours that the Forecasting Office was manned.
- Log temperatures and present weather from the 0630 PST highway Pass reports received at NWS via teletype from WSDH Station #10. Unfortunately, new snow and total snow on the ground were not available until the 0930 PST Pass report, at which time they were logged. These reports regularly included Snoqualmie, Blewett, Stevens, and White Passes. Due to the light snow year additional reports were available from Washington, Chinook (most of the winter), and Cayuse Passes. Mt. Baker reported on the 0930 report only. Paradise (Mt. Rainier) data was received by telephone. Stampede Pass reports were received hourly from NWS observers via teletype. Temperature and present weather were taken from the 0600 report while new snow and total snow depths were reported on the 0400 PST report, as well as new snow water equivalents. Additionally, NWS estimated 24-hour water equivalents for the next two days for Stampede Pass and Diablo Dam were noted.
- Log Stampede Pass temperatures, precipitation, wind velocity, and the surface pressure gradient between Sea-Tac Airport and Yakima at three-hour intervals (hourly intervals during storm periods), beginning at midnight Greenwich Mean Time (1600 PST). The pressure gradient gives a general indication of the direction and magnitude of pass winds.

FIGURE 3. Forecasting Office Work Sheet.

AVALANCHE CENTER WORK SHEET **Revised 12/2/76**

___/___/___ (date) ______ (time) PST

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

(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)

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

NWS Cascade / Olympic Mtn. Forecast (0430 - 1030 - 1630 PST):

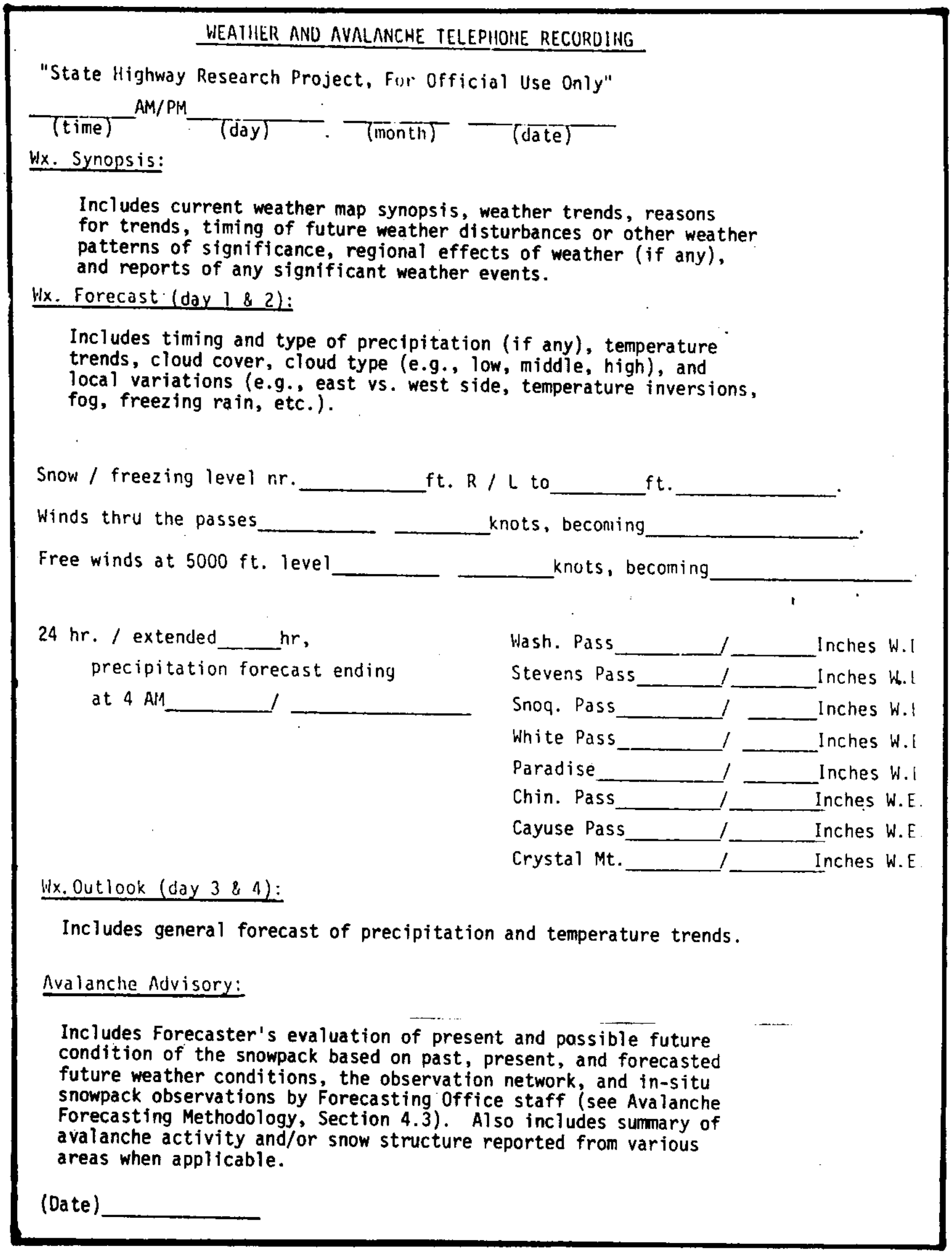
Notes:

Date ___/___/77

FIGURE 4. Hourly Weather Log Form.

		HOURLY WEATHER LOG									1976 - 1977					SNOW DEPTH SMP
MONTH		TEMPERATURE (°F)				WIND					PRECIPITATION (IN.)				Press. Grad.	
DATE PST	TIME	Stevens Pass		HR	SMP	Stevens Pass (4800')		HR (5300')	SMP (4000')		Stevens Pass		Snoq. Pass	SMP	SEA-YKM	
	Z / 24-HR PST	4050'	4800'	5300'	4000'	DIR	MPH	SPEED	DIR	KTS SPEED	4750'	NWS 4000'	NWS 3000'	NWS 4000'	MB	
	09Z / 01															
	12Z / 04															
	15Z / 07															
	18Z / 10															
	21Z / 13															
	24Z / 16															
	27Z / 19															

FIGURE 5. Weather and Avalanche Telephone Recording Form.



WEATHER AND AVALANCHE TELEPHONE RECORDING

"State Highway Research Project, For Official Use Only"

________AM/PM________ . ________ ________
(time) (day) (month) (date)

Wx. 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), and reports of any significant weather events.

Wx. Forecast (day 1 & 2):

Includes timing and type of precipitation (if any), temperature trends, cloud cover, cloud type (e.g., low, middle, high), and local variations (e.g., east vs. west side, temperature inversions, fog, freezing rain, etc.).

Snow / freezing level nr.________ft. R / L to________ft.________.

Winds thru the passes________ ________knots, becoming________.

Free winds at 5000 ft. level________ ________knots, becoming________.

24 hr. / extended_____hr,
precipitation forecast ending
at 4 AM________/ ________

Wash. Pass________/________Inches W.I
Stevens Pass________/________Inches W.L
Snoq. Pass________/________Inches W.I
White Pass________/________Inches W.I
Paradise________/________Inches W.I
Chin. Pass________/________Inches W.E.
Cayuse Pass________/________Inches W.E
Crystal Mt.________/________Inches W.E

Wx. Outlook (day 3 & 4):

Includes general forecast of precipitation and temperature trends.

Avalanche Advisory:

Includes Forecaster's evaluation of present and possible future condition of the snowpack based on past, present, and forecasted future weather conditions, the observation network, and in-situ snowpack observations by Forecasting Office staff (see Avalanche Forecasting Methodology, Section 4.3). Also includes summary of avalanche activity and/or snow structure reported from various areas when applicable.

(Date)________

- Note the latest NWS forecast, normally issued at 0430 PST, for the Olympics and Cascades.

- Check moisture patterns and log freezing levels, inversions, and 850 mb level winds (approximately 500 feet) from the following radiosonde observatories: Quillayute, Washington (UIL), Spokane, Washington (GEG), Vernon, B.C. (YVK), Port Hardy, B.C. (YZT), Salem, Oregon (SLE), and the Canadian Weather Ship (C7P) located near 50° North and 145° West. Frequently, on weekdays additional soundings were available from Seattle (Portage Bay), Washington (SEA) and Gray's Field/Fort Lewis, Washington (GRF). Additionally, the depth of the arctic air mass at Vernon and Prince George, B.C., was noted, if present.

- Log FOUS 72 data, forecast values of various weather parameters for Seattle generated by the NWS-NMC LFM computer model for six-hour intervals out to 48 hours from 0400 PST. These data include the forecast average relative humidity (RH) for the layer from the surface up to 700 mb (approximately 9000 feet), the forecast vertical velocity (VV), the forecast thickness value (HH) between the surface and the 500 mb pressure surface (approximately 18,000 feet) from which freezing levels can be approximated, direction and speed of the mean wind in the boundary layer (DDFF) (this extends from the surface to near 4000 feet for Seattle), the mean potential temperature of the boundary layer (TB), and the six-hour precipitation amount (PTT). All of the above data are forecast a second time early in the evening for 48 hours starting at 1600 PST.

  (In mid-March a new freezing level guidance was made available by NWS-NMC. This product, lebelled FOUS 43, was derived from the same model as the FOUS 72. It supplied freezing levels at 6-hour intervals over Seattle for 48 hours. Similar information had previously been derived by hand in a less elaborate fashion using the thickness (HH) and the mean potential temperature of of the boundary layer (TB).)

- Check satellite pictures which are received several times per hour. Note location and speed of frontal bands, cloud types, and trends in motion and intensity. Additionally, new specialized pictures using computer enhancement were available which gave indications of temperatures and vertical velocities within the clouds. The use of these pictures is still experimental but they occasionally proved to be helpful.

- Check all current analyses of weather conditions at the surface and upper levels of the atmosphere. Check all available hand and computer generated maps of forecast weather conditions (normally for 12 hour intervals out to 48 hours, plus 72, 84, and 96 hours).

- Based on the above, plus discussions with other forecasters, write a brief synopsis of current and projected weather patterns, including location and velocity of weather fronts, trends of upper air patterns that may effect their motion, temperature trends, etc.
- Make a detailed weather forecast for the Cascade and Olympic Mountains to 48 hours and formulate a general outlook for 48-96 hours. The first 48 hours should include sky cover, precipitation (type and intensity), timing of frontal passages, wind velocity and expected changes at both the pass level and in the free air at 5000 feet, freezing (snow) levels, 24 hour water equivalent of new snow or rain expected during the next two days for six individual passes, plus Paradise and Crystal Mountain. (Occasional forecasts were made for Government Camp, Oregon, on an experimental basis.) The 48-96 hour outlooks contained indications of temperature and precipitation trends in terms of the climatological mean for that period. Estimates of timing of any precipitation or temperature changes were also given. Included with all of the above were indications of any expected geographical variations.
- Based on most recent pass reports, weather trends, avalanche activity, snowpack analyses, reports from field personnel, etc., formulate an avalanche advisory. This takes the form of an area by area narrative when necessary. A complete description of the forecast methodology used is given in Section 4.3. Additionally, include any pertinent reports of avalanche activity experienced as an indicator of possible trends throughout the Olympics and Cascades.
- Place new forecast on tape recording. Punch forecast onto teletype tape and send to Stevens Pass and Wenatchee.
- Continue to log incoming data from various stations in the field network. Participate in NWS map discussion, where forecasters and meteorologist specialists discuss the present weather situation, weather trends, reliability of numerical forecast products, etc. Continue to review new forecast packages from NWS-NMC as they come in and update the forecasts as necessary.
- Write summary of present and forecast weather and avalanche conditions, including important details that may have influenced the forecast or which may be of concern to future forecasts. This report is used in-house both as an aid to forecasters when there is a personnel change and as an aid in evaluating forecast accuracy after the season ends.
- Complete various forecast verification forms. These include estimates of the freezing level and avalanche activity for 6 hourly periods, a qualitative evaluation of the previous day's weather forecast, and a daily evaluation of the water equivalent forecasts. All of these data are used in-house to aid forecasters.

- Constantly update or amend the present forecast as the situation warrants. Under extreme conditions of severe weather or avalanche activity, issue special alerts to user agencies by telephone (see Figure 6 for the current notification list). These are normally issued when rapid changes in the weather are expected to lead to avalanche-generating situations.
- Interspersed with all of the above, receive user phone calls, discuss forecasts, and receive observations.

With this daily routine forecasters were able to have a completed forecast available between 0800-0900 PST. This is in contrast to the first year of operation when the forecast was not available in its completed form until 1000-1100 PST. This improvement is a reflection of both improved Forecasting Office organization and earlier receipt of critical NWS-NMC forecast products (see Table 2). A second complete forecast was normally issued at about 1500 PST, based on information received during the day. In changing situations this forecast was sometimes delayed until after 1600 PST to allow forecasters to examine new radiosonde data that becomes available at 1600 PST. The regular issuance of two complete forecasts was a further improvement over the first year of operation. Updates of the forecasts were issued at anytime the situation warranted.

Though critical periods were rather limited during the past winter, experience gained from two years of operation has indicated that continuity and familiarity with existing weather and avalanche conditions requires several hours of overlap between forecasters when it is necessary to man the office for extended periods. Often under changing conditions it is required that forecasters be on duty at least through 1600-1800 PST to examine radiosonde observations and to monitor continuing field data input and issue alerts when necessary. It has been the practice to date under these circumstances for a single forecaster to cover the entire day. If it appears that the situation may become critical and require extended manning of the office, the forecaster on duty may contact a stand-by forecaster who would be briefed on the present situation. If the situation continues to develop, the duty forecaster then informs the stand-by forecaster that he will be needed at the Forecasting Office. The stand-by forecaster is briefed after his arrival and the two forecasters work together for several hours to insure

Figure 6. Weather Alerts and Avalanche Warnings Call List.

		Time Contacted
STEVENS PASS	Berne Snow Camp WSDH	
	Snow Ranger (Glen Katzenberger)	
	Larry Dronen	
SNOQUALMIE PASS	WSDH Hyak Radio	
	WSDH Summit House	
	Al Bennett	
	Snow Ranger (Ed Waggoner)	
WHITE PASS	WSDH Maintenance Station	
CRYSTAL MOUNTAIN	Ski Patrol (Bob Bartlett)	
	Snow Ranger (Hugh Koetje)	
MT. RAINIER	Headquarters (Longmire) (Pete Thompson)	
	Paradise (Walt Dabney)	
MT. BAKER	WSDH via Station #10	
	Snow Ranger (Mike Dolfay)	
OLYMPIC NATIONAL PARK	Headquarters (Port Angeles)	
USFS	Public Avalanche Warnings (Paul Frankenstein at home)	
WASHINGTON PASS	WSDH radio (weekdays) (weekends)	

the necessary continuity and familiarity with the existing and forecast weather and avalanche conditions. The importance of maintaining this continuity in producing reliable forecasts is increasingly recognized by workers in this field.

4.3 Avalanche Forecasting Methodology

4.3.1 Introduction

The codification of avalanche forecasting techniques is still in a state of development. An avalanche forecasting methodology outline can help to convey the ideas and processes inherent in producing an avalanche forecast, but a certain feel involved in the forecast product is more the result of time and exposure to the mountain avalanche environment than of written guidelines. Much on-the-job training and experience in the forecasting office and in the field is still necessary and forecasting expertise cannot be conveyed by written guidelines alone (see Armstrong and Ives, 1976, Ch. 3).

The avalanche forecasting methodology outline presented here is a synthesis of actual technique (avalanche science) and the intuitive art of forecasting. The conceptual framework and analytical methods involved in avalanche forecasting are still under active development; this current project represents a foreward step.

In this discussion of our avalanche forecasting methodology, it is assumed that the forecaster has a relatively large field observation and meteorological data base from which to formulate the forecast. More specifically, the forecaster should have field data input at least daily from a substantial mountain weather and avalanche reporting network (as described in section 3.1) and have access to hourly precipitation, temperature and winds for strategic forecast areas. The forecaster should also have available past, current and prognostic surface and upper level synoptic weather maps, including satellite imagery, for the general forecast area. Finally, it is assumed that the forecaster has the capability of communicating at any time with field personnel, in order to get their assessment of avalanche hazard and up-dated observations. The forecaster must also spend substantial time in the field, gaining necessary subjective and objective data for the mountain snowpack and the areas for which he must forecast.

During this project the forecasters have not attempted to forecast slides on a path by path basis. Path by path forecasting is simply not presently feasible from a central forecasting office removed some distance from the forecast areas. Too much in-depth data and on-site inspection and analysis of individual slide paths is required for such specific forecasting, and WSDH avalanche crews are currently handling this final step in avalanche analysis quite adequately. The forecasters are certainly aware of, and often forecast for, certain high-potential slide paths (e.g., Old Faithful on Stevens Pass and Cutthroat Ridge on Washington Pass), but are not specifically formulating forecasts for these paths alone. The actual categories of forecasting, all of which are dependent on the current snowpack, weather and projected weather to some degree, include regional (i.e., north or south, east or west) avalanche activity, activity by aspect, elevation and frequent versus infrequent paths. It is then up to the various WSDH avalanche crews to use the forecast product in assessing avalanche hazard on individual paths and initiating control work, if any.

In the context of this project, forecasts are made only for avalanche potential or probability for the various Cascade areas. Actual avalanche hazard analysis (the probable or expected effect of avalanches on people or structures) is deferred to on-site avalanche personnel of cooperating user agencies. In this discussion, avalanche activity forecast, avalanche potential forecast and avalanche probability forecast are used interchangeably, but all three are distinct from an avalanche hazard forecast.

Figure 7 presents an outline of the basic steps necessary for a forecaster to follow in arriving at either a positive (increasing or immediate potential) or negative (diminishing or deferred potential) avalanche activity forecast. In the discussion of this outline, various statements and/or questions that the forecasters consider to determine stability or instability of the snowpack at a specific area are given. Some questions, answerable yes or no, may indicate strong or weak stability or instability, depending on the particular situation; universal guidelines regarding answers to these questions are not presently possible, each new case having its own peculiarities. Other questions ask where and how stability/instability exists rather than if or

FIGURE 7. Avalanche forecasting methodology outline.

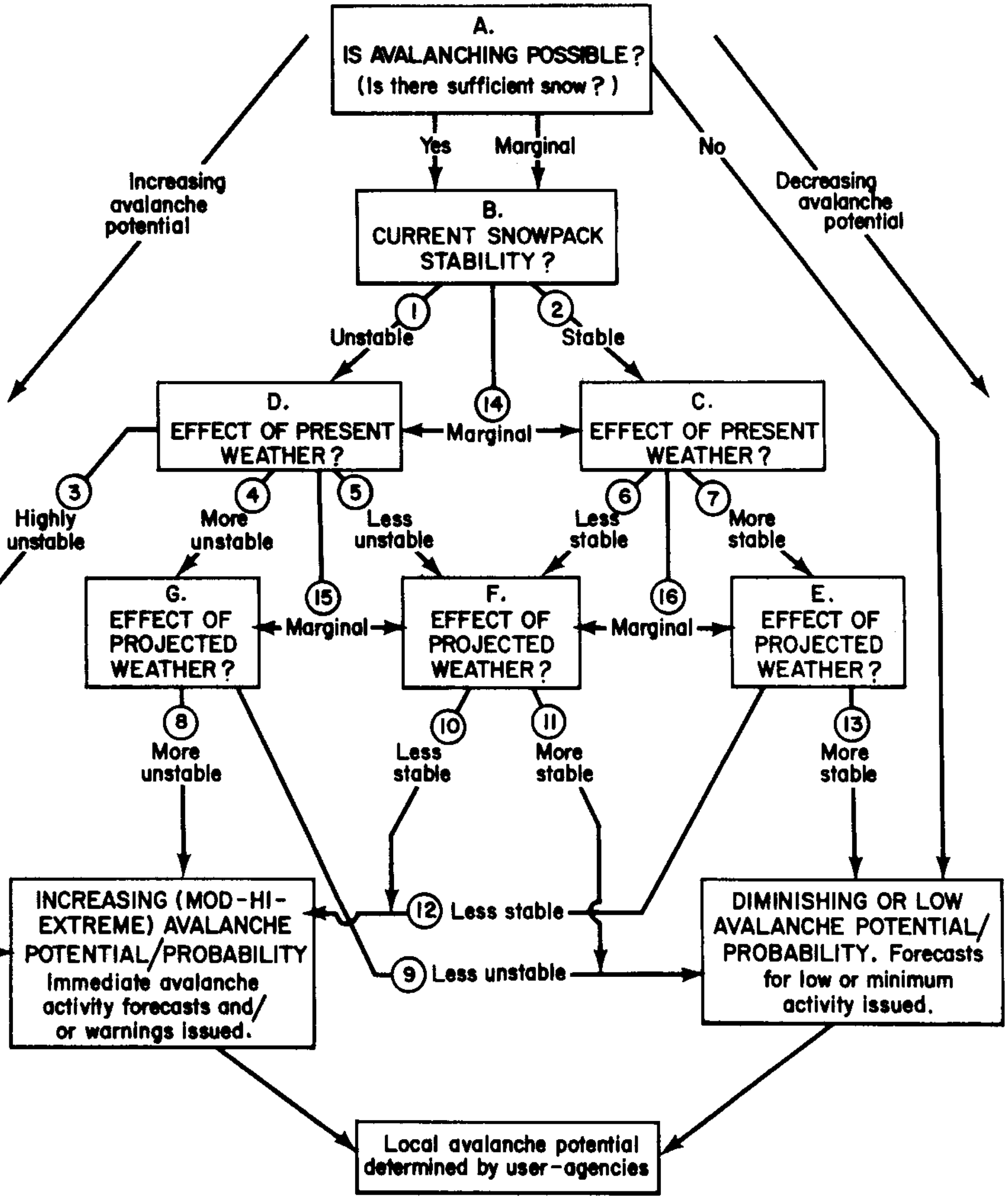


TABLE 3. Explanation of numerals appearing in Figure 7. (Avalanche Forecasting Methodology Outline.) Numerals describe the state of the snowpack.

1--a currently unstable snowpack (mod-hi potential, possibly extreme)
2--a currently stable snowpack (lo potential)
3--an unstable snowpack which is becoming highly unstable through the effects of the present weather (hi-extreme potential, increasing)
4--an unstable snowpack which is becoming even more unstable through the effects of the present weather (mod-hi potential, increasing)
5--an unstable snowpack which is becoming more stable (less unstable) through the effects of the present weather (mod-hi potential, diminishing)
6--a stable snowpack which is becoming less stable through the effects of the present weather (lo potential, increasing)
7--a stable snowpack which is becoming more stable through the effects of the present weather (lo potential, decreasing)
8--an unstable snowpack which is becoming more unstable through the effects of the present weather and is expected to become even more highly unstable through the effects of the projected weather (mod-hi potential, increasing with time)
9--an unstable snowpack which is becoming more unstable through the effects of the present weather but is expected to stabilize through the effects of the projected weather (mod-hi potential, diminishing with time)
10--a stable snowpack which is becoming less stable through the effect of the present weather and is expected to become more unstable through the effects of the projected weather (lo-mod potential, increasing with time); or
--an unstable snowpack which is becoming more stable through the effect of the present weather, but is expected to become more unstable through the effect of the projected weather (mod-hi potential, currently diminishing, but increasing again in time)
11--a stable snowpack which is becoming less stable through the effect of the present weather, but is expected to become more stable through the effect of the projected weather (lo-mod potential, currently increasing, but diminishing with time); or
--an unstable snowpack which is becoming more stable (less unstable) through the effect of the present weather and is expected to become even more stable through the effect of the projected weather (mod-hi potential, currently diminishing, and further diminishing with time)
12--a stable snowpack which is becoming more stable through the effect of the present weather but is expected to become less stable through the effect of the projected weather (lo potential, currently diminishing, but increasing with time)
13--a stable snowpack which is becoming more stable through the effect of the present weather and is expected to become even more stable through the effect of the projected weather (lo potential, currently diminishing, and further diminishing with time)
14--16 these are all indications of a borderline (marginal) snowpack, which is neither decidedly stable or unstable, but could become either as a result of current (14) or projected (15-16) weather. For example, this marginal category could refer to a snowpack whose upper layer consists of a large

TABLE 3. Explanation of numerals appearing in Figure 7 (continued)

amount of recently deposited, fairly homogeneous, unconsolidated cold snow which has experienced some sluffing, a snowpack situation which may occur fairly often in the Cascades. It is not really stable as it has not yet consolidated (settled or densified), nor is it really unstable as sluffing has brought about some stabilization through tension release. However, a rapid warm-up with or without significant rain or snow could quickly make this snowpack very unstable, while prolonged near but below freezing temperatures with little or no precipitation could be a very stabilizing influence allowing the snowpack to rapidly settle without further sliding. Such borderline stability may also be the case with wind slabs whose stability and possible release is often closely related to temperature trends during and following formation, as well as bonding to underlying layers and rates of build-up.

how much. In this sense, this discussion is both an outline of the forecasting procedure and a tabulation of some of the more important and relevant processes which go into the avalanche forecasts generated by the Forecasting Office.

The next logical step to be developed in this methodology is a tabulation of the quantitative guidelines considered necessary in assessing avalanche potential in the Washington Cascades. While such numerical data are still being investigated by project forecasters through operational forecasting, their discussion here is beyond the scope of this report. Rough numerical guidelines currently utilized are given below in the text where applicable. It is anticipated that a summary table listing situation by situation quantitative guidelines for a significant part of avalanche forecasting in the Washington Cascades can be devised at some time in the near future.

4.3.2 Discussion

Following the outline in Figure 7, the capital letters heading the sub-sections below refer to similarly-labeled blocks in the outline; circled numerals appearing in Figure 7 referring to physical states of the snowpack are explained in Table 3. The existence of various snowpack-weather feedback loops in Figure 7 is taken for granted. If a given avalanche potential (or expected avalanche activity) forecast would be changed drastically by an unforseen change in the expected weather pattern (the long-range map prognoses did not pan out), it is assumed that the forecaster would modify his forecast and decrease or increase the anticipated avalanche potential accordingly. Marginal snowpack-weather feedback loops are also tacitly assumed as being utilized by forecasters in consideration of the effects of the projected weather (E-G) on the snowpack, although not listed specifically in Figure 7. Here marginal snowpack stability determinations are re-analyzed in light of projected weather until either a stable or unstable forecast configuration is reached.

The first question with which the avalanche forecaster needs to be concerned when assessing avalanche potential for each area under consideration is:

A. IS AVALANCHING POSSIBLE? (Is there sufficient snow?)

The response answers the basic question of whether or not the avalanche season has actually started in the area under consideration by the forecaster. To adequately answer this question, the forecaster must consider a number of other questions involving field station input and avalanche history.

- Avalanche path history and terrain features. What is the history--long-term and recent--of slide path(s) or area(s) in question regarding critical depth(s) of snow on the ground before the first slides occur? How much snow is usually required to smooth out the rocks, stumps, logs, brush in the particular paths involved (see, for example, Perla and Martinelli, 1976, Table 4, p. 96)? The answer is often best found by visual inspection. Has the critical depth been reached? Results of a 25-year study of snow depth and avalanches by WSDH avalanche personnel at Stevens Pass indicate that 80 inches total snow is required at the study plot before the Old Faithful (especially #4) slide areas deposit snow on the roadway. Similar WSDH studies at Washington Pass indicate 40 inches total snow at the Pass is the typical depth before usual winter closure of this roadway occurs. (Washington Pass is uncontrolled for avalanches and usually closed every winter.) In any case, a yes answer to the critical depth question indicates to the forecaster that additional snowpack information (B. below) is necessary for accurately evaluating the current avalanche potential.
- Recent changes in path history. Have slide path(s) recently enlarged or smoothed their potential sliding area (e.g., timber in debris)? Will this affect how early these areas can slide?
- Early season snow stability. Is the snowpack unstable enough (possibly depth hoar in early season) to slide without all the anchoring points being covered (see B. below)?
- Snow stability on smooth slide paths. If the slide paths are relatively smooth (medium to high angle rock face or meadow, smooth scree slopes, etc.), what is the stability of the overlying snow (see B. below). Can a warm-up or addition of new snow/rain release this snow on smooth slopes?

It is expected that step A. be considered primarily during the early part of the avalanche season, although the occurrence of ground or deep climax avalanches may cause repetition of the processes above. In the absence of such slides, however, especially in the Cascades where a deep snowpack experiencing primarily direct action slides is the rule, B. below is the general starting point for evaluation of avalanche potential once the season is underway.

B. CURRENT SNOWPACK STABILITY?

Once the forecaster has determined that there is sufficient snow in the areas under study to slide, he needs to know or evaluate the current stability of that snow. Is it stable or unstable in its present state, or is it borderline, depending on the effect of the present and future weather? To determine this present state of the snow, the forecaster considers three complementary methods of gathering necessary snowpack information. The first and most reliable method, but often hardest to obtain in potential slide areas, is direct observation of snow structure, and it considers:

- Stratigrapny and stability of snow from recent snowpits. Here the forecaster compiles and assesses snowpit information supplied by other project forecasters in the field, as well as by WSDH, USFS and ski area personnel throughout the Cascades. Points to be considered when analyzing these data include:

    - Existence of weak layers or sliding surfaces. Are there mechanically weak layers (e.g., depth hoar, buried surface hoar, low density snow ($\leq .07$ gm/cm^3) underlying wind slab) or potential sliding surfaces (e.g., rain crusts, ice lenses with weak bonding to overlying snow) in the snowpack?
    - Location of instabilities--weak layers or sliding surfaces--in the snowpack. Do these weak layers/sliding surfaces exist above or below possible stabilizing effects of vegetational anchoring? If below, perhaps strong anchoring may at least partially compensate for the structural weakness.
    - Magnitude of instability. How much snow lies above weak layers? Above anchor points? Above potential sliding surfaces? That is, how much snow could potentially be involved in a future slide?

    If mechanically weak layers do exist in the snowpack, how weak are they? If potential sliding surfaces exist, how strong are they? How impermeable to meltwater? How weak is the bond to overlying snow? In these cases application of a tilt board or straight-edge in the snowpit wall may help to find and qualitatively estimate the magnitude of weakness or instability, while results of shear frames or ram penetrometers may also be useful in assessing snowpack instability. See also the snowpack discussion (section 3.2) and Perla (1969).

    - Temperature-gradient instability. Does a strong temperature gradient (>0.1°C/cm or 10°C/m) exist in the snowpack? Over how much of the snowpack does it extend? What is the surface air temperature? Can radiation cooling of snow surface be expected? What is the 20-cm snow temperature? If there is already evidence of temperature-gradient (TG) metamorphism, how advanced is it? How weak is the TG layer?
    - Regional/local variations in instabilities; terrain modification of instability. If some type of instability is evidenced, is it

general throughout the Cascades, or is it only on certain aspect or elevations? Is it only in the north or the south; on the east side of the Cascades, the west side? In uncontrolled areas only? That is, is there a general or a limited instability in the Cascades (based on snowpit data alone)?

- Effects of future weather. For a given condition of the snowpack, what will have to occur weather-wise to make it either unstable or stable (see C-G below)?
- Snow settlement. What has the snow settlement been? Three feet of snow fell but only 27 inches reported above old base (25% settlement) would surely indicate increased stability. New snow settlement of 10-25% generally indicates stabilization, with the lower limit (10%)referring to settlement of relatively high density (.10 gm/cm^3) new snow, and the upper limit (25%) applying to relatively low density (.07 gm/cm^3) new snow settlement. It should be noted that direct measurements of new snow settlement are rarely available --usually the entire snowpack settlement (total snow depth) is reported. Forecasters analyzing the settlement percentage of new snow must therefore take into account such factors as the total snowpack (how consolidated was it before the new snow) and how much snow has fallen in the recent past (before the new snow) and how much it has settled.

If no recent snowpits are available at the area in question, the forecaster attempts to make a snowpack extrapolation based on the most recent and closest snowpit available. In this extrapolation he compares the topography surrounding the closest pit with the area in question, while also closely considering regional variations in instabilities. Can the results of this pit be extrapolated to a nearby area? Is a current snowpit closer to this avalanche area critically needed?

In the absence of snowpits near or in questionably unstable avalanche areas, or as an aid in interpreting existing snowpit information, the forecaster considers the second method of assessing current snowpack stability, extrapolation:

- Stability of snow at one area through inference from nearby areas.
  - Differences in avalanche activity. Have other adjacent areas slid (from field reports)? What are the differences in past activity (if known)? Are these other areas controlled (ski area or WSDH) or uncontrolled, and is the area in question controlled or uncontrolled?
  - Differences in stabilizing influences. Have other areas experienced substantial snowpack settlement or other stabilizing factors (e.g., sluffing)? Would these also be expected at the area in question?

  - General meteorological/topographical differences. What are the significant meteorological differences (if any) between area in question and nearby known areas which would yield differences in present snow stability? That is, more or less wind, snowfall, different average temperatures?

If no recent snowpit data are available or if field snowpack information needs augmentation or explanation for the area in question, the forecaster utilizes the final method for estimating snowpack stability, inference from observed weather:

- Snowpack stability and stratigraphy through meteorological reconstruction.
  - Variations in meteorological parameters. What are the significant variations in past wind, temperature or snowfall/rainfall patterns which created the present snowpack? Have there been regional or local variations in these patterns? Here the forecaster consults past field instrumentation and reporting station input, as well as past synoptic surface and upper level maps (especially 850 and 700 mb--approximately 4500 feet and 10,000 feet, respectively) where necessary.
  - General effect of meteorological variations on snowpack; specific stabilizing, de-stabilizing influences on snowpack. What sort of instability could be expected from the meteorological parameters mentioned above when considered together with reporting station snowpack and weather data, and the topography surrounding the slide areas in question?

    Have there been recent stabilizing meteorological influences such as lowering temperatures and/or freezing levels with or without precipitation, extended warm-ups with significant avalanching, or rain followed by cooling? Are there de-stabilizing influences such as rising temperatures and freezing levels with or without precipitation, high rates of precipitation, strong winds?
  - Wind slab formation. Was there a great deal of wind during the last storm that could have produced slabs? That could have scoured out certain slide areas and loaded others? Was there any wind transport of snow between storms?
  - Recent snowfalls and temperature trends. How long ago was the last major snowfall? At what temperatures did it occur? At what trend in temperature?
  - Low temperature snowfall; wind transport of cold, loose snow. Have the temperatures been relatively low (<25°F, <-5°C) since the last storm? Have westerly (or easterly--especially through the passes) winds since the storm transported loose surface snow onto lee slopes? Do past surface snow reports from field stations indicate this is possible? Are cold temperatures inhibiting relaxation of a possibly unstable snowpack in avalanche areas? Has surface sluffing occurred to help stabilize a cold, recently deposited snowpack?

- Surface hoar, depth hoar. Has past weather been favorable for surface hoar formation (clear skies, cold nights, not extremely low humidity), depth hoar formation (thin snowpack with extended periods of cold temperatures)? How much new snow is meteorologically deduced to lie above such possible weak layers?
- Accumulated snowfall; effects of future weather. Did recent new snow, if any, fall over a number of days and not slide, with recent accumulations now up to a meter (three feet)? Will the next storm bring a warm-up with heavier, denser snow and/or rain and release the recent new snowfall (see C-G below)?

C-D. EFFECTS OF PRESENT WEATHER?

Once the current physical state of the snowpack has been determined, the forecaster must analyze how this snowpack (stable or unstable or marginal) will respond to the present weather affecting it in order to put out a current avalanche activity forecast. In this context, present weather includes wind, precipitation, temperature, sky cover and solar radiation which affect the snowpack within a few hours (past or future) of the present moment.

Short-term meteorological effects on the snowpack may often be estimated on the basis of field instrumentation data (e.g., sudden surges of precipitation, changes in wind direction or velocity, temperature variations or trends) or more directly from field observer input (change in sky cover producing change in surface snow texture, solar radiation releasing small wet sluffs, start of avalanche cycle due to warm-up, etc.). Such field data are augmented by current surface and upper level weather maps (especially 850, 700 and 500 mb maps), as well as satellite imagery, which give the forecaster a meteorological guide to possible short-term effects of a given weather situation on the existing snowpack. More specifically, in forecasting the effects of the present weather on the snowpack (current avalanche probability forecast), the forecaster will be concerned with such points as:

- General snowpack condition. If the present snowpack is stable or unstable, is this a regional or otherwise qualified condition? Is this condition limited to controlled slopes, certain aspects, certain elevations? For example, a warm-up with freezing level to 4500 feet may have stabilized new snow through slides or settlement below that elevation but not above. Solar radiation on a clear day with low freezing levels (below 2000 feet) may have caused stabilization (through small, west slides) on south and west aspect slopes but not on north and east aspect slopes. Strong winds may have scoured certain avalanche areas and loaded others (verify through field reports).

- Old snowpack stability. Given a foot of new snow, will a slide involve only the new snow or the older snow, too? How much of the old snow? Perhaps the entire snowpack right down to the ground or very near it due to some surface hoar that formed under light snow cover and cold nights earlier in the season (especially north and east facing slopes)? How much new snow (weight) is needed to cause release of an old unstable snow layer (are estimates of shear strength available)?

- Old snow surface and old-to-new snow bonding. What is the surface of the present snowpack? Sun crust? Rain crust? Ice layer? Surface hoar? Graupel? Will current new snowfall bond well to the old snow or slide easily on it? If it is snowing now, what was the old snow surface, snow temperature, air temperature when the snow started? How strong is the new-to-old snow bond (check through field input)? Is current weather producing an unstable layer, such as a mechanically weak or strong, smooth surface, for future snow to slide on? Has there been light snowfall at low temperatures and no winds, or rain followed by cooling and clearing weather? (Both refer to 15 or 16 in Table 3 and Figure 7.)

- Effect of snowfall on snowpack. If it is snowing now, how long has it been snowing? At what temperatures and what trend in temperatures. At what intensity and trend in intensity? How much new snowfall, new water equivalent has been deposited on the old snowpack? What is the current precipitation rate and how long should this continue? Is a really strong zonal flow--heavy orographic precipitation--indicated on 850 and 700 mb pressure maps? Is one inch water equivalent or more expected with this storm?

  Are there significant layers within the new snow being deposited due to variations in wind direction, velocity, precipitation rates, or rapid temperature changes (>10°F/hr)? Is the new snowfall creating wind slab due to deposition during high winds (>10 mph) (4 or 6 in Figure 7)? Is cold, low density snow ($\leq .07$ gm/cm^3) being deposited which could later fail in shear with application of a heavy snow load? Are cold temperatures (<25°F) expected after snowfall stops which may inhibit relaxation of the new snow until a future warm-up? Are present snowfall, wind, and temperature effects such that avalanche potential is rapidly becoming critical (3 in Table 3)?

  During present or recent frontal passage over the Cascades, have significant amounts (>1-2 cm) of graupel (pellet snow, very heavily rimed crystals) occurred which could act as a lubricating layer for future snow to slide on?

- Effect of rainfall on snowpack. In general, what sort of snowpack structure did the last snowpit show? Is a complete change in the upper layers occurring due to a current warm-up with rain? Is more than one inch of rain expected? Will the wet snowpack be freezing soon and how deep? Is weakening of a substantial part of the snowpack occurring with the rain? An example of a marginally stable snowpack under transition: future cooling with diminishing rain could stabilize the whole snowpack (depending on the freezing level), while continued rain with further warming could release the whole snowpack.

- Increasing instability in absence of precipitation: winds, warm-ups, inversions, solar effects, temperature gradients. If no new snow is expected, have the air temperatures been low (<25°F) since the last storm, and are easterly winds (especially through the passes) transporting the old snow into critical slide paths and loading them up before the next frontal passage? Are strong west winds now loading some paths and scouring others? Is the snow surface loose enough for wind transport to be effective? In some areas? In all areas? If substantial snow build-up is occurring because of high winds, could a rise in air temperatures effect release of this snow? Is a temperature rise occurring now (3 in Table 3 and Figure 7)?

  Is a warm-up evident on 850, 700 mb pressure/temperature maps ahead of a front off the coast? Are rising air temperatures indicated on the Hurricane Ridge thermistor or on the upper elevation Stevens Pass thermistor? Are temperature inversions expected in the short-term over the Cascades which could give WSDH pass personnel incorrect or late assessment of avalanche hazard?

  Is a melt-freeze (or sun) crust being produced by refreezing of snow following radiation-induced surface melt (a stabilizing effect now, but a potential sliding surface later)?

  Are the temperatures low enough and the snowpack thin enough to start or continue temperature-gradient (TG) weakening of the snowpack? Could this be occurring only in certain areas (maybe only in the northeast Cascades at high elevations)?

- Variation in recent avalanche path history. Have certain avalanche paths slid recently and others not? Is this a regional, or local variation? Is this variation due to earlier snowfall, temperature, or wind differences between or within areas? In what way will this affect the current avalanche activity forecast--diminish activity in some areas, increase it in others? Is this variability in previous avalanching related to elevation or aspect?

A note on Cascade meteorology: following passage of a cold front through the Cascades, a ridge of high pressure (may be strong or weak) generally builds behind the front off the coast and then drifts slowly eastward, often building and stagnating over eastern Washington. Since the Cascades present an orographic barrier to a high to low pressure air flow at the surface, pass winds immediately following the front are usually westerly (high pressure to west of Cascades), but may soon thereafter become light to moderate easterly (high moves into eastern Washington). With arrival of a new front on the coast, east to west pressure gradients at the surface increase, causing increasingly strong (>15 mph) east winds through the passes.

As a pool of cold dry air often exists on the eastside of the Cascades (maintained primarily by radiative cooling, continental cold air flow from the north following fronts, and through isolation from moderating maritime influences of the Pacific Ocean and Puget Sound), this air is drawn up from the eastside by the local windflow patterns and further cooled as it is lifted through the passes. If warm air aloft preceding the next front arrives at the Cascades at this time, pass temperatures (in the cold, easterly air) may be 10-20°F below free air temperatures (in the warm air to the west) at the same altitude. Free air winds in the warm air mass above the inversion may also be exactly the opposite (westerly) to those winds (easterly) within the inversion.

G. EFFECT OF PROJECTED WEATHER?

After the present snowpack stability and the effects of the present weather on this stability have been determined by the forecaster to generate a current or short-term avalanche potential forecast, the effects of the projected weather on the snowpack need to be considered for an extended forecast. The effect of the projected weather on the snowpack basically involves influence on the current snowpack of weather trends forecast on prognostic NWS maps. As might be expected, the accuracy of weather forecasts decreases substantially with time, with specific timing of individual weather disturbances and associated changes in meteorological parameters not realistically reliable beyond 48 hours. General weather trends in precipitation and temperature are often, but not always, reliably available from 72, 84 and 96 hour upper level (500 mb) maps. In any case, these maps represent the outside forecast limits of current weather technology on a day to day basis, although monthly weather outlooks are possible through a combination of climatological and other parameters.

During this project, forecasts of the specific effects of future weather on the snowpack have extended anywhere from a few hours up to 36-48 hours into the future. Forecasts of this nature have been based on a variety of NWS prognostic map packages, satellite imagery and teletype data, which are listed in Table 2 in Section 3.3. These meteorological data have provided the forecaster with tools indicating the future state of wind, temperature, precipitation and sky cover in the Cascades, all essential parameters to consider in avalanche forecasting. Together with knowledge of the current snowpack conditions, current mountain weather and international guidelines (e.g., Mellor, 1968; Perla and Martinelli, 1976; ICSI International Avalanche Atlas (in preparation); Avalanche Classification, 1973) regarding the effect of the parameters above on the snowpack, the forecaster operationally forecasts future general, regional or local avalanche activity. As mentioned in the introduction to this section, path by path forecasting still remains in the hands of local WSDH or USFS avalanche observers and Snow Rangers, who concentrate on the variations within their own local snowpack while interpreting project forecasts according to their needs.

In issuing avalanche activity forecasts concerning the effects of projected weather on the snowpack, the forecaster needs to state as accurately as possible location, timing, duration and intensity of expected avalanche activity, why this is expected, and when it may diminish. To determine these potential activities, the forecaster considers in depth the following:

- General, regional or local effects of projected weather. Given various possible current conditions of the snowpack, are weather prognoses (500 mb, 700 mb, 850 mb) generally indicating stabilizing or de-stabilizing effects on this snowpack? That is, should avalanche potential increase or decrease with time based on expected weather? Should this be a general (throughout the Cascades) or regional or local trend? How rapidly should the activity diminish? Increase? What changes can be expected beyond 24 hours? Will the effects of an expected weather disturbance start in the north and move south or vice versa? If certain pass areas have been recently controlled or are being controlled, how will this affect the avalanche activity forecast (e.g., avalanche potential to diminish in controlled areas, with no new snow expected in next 24 hours)? What are the results of control on the highway, in ski areas? If natural slides are occurring or are expected to occur, will this decrease the avalanche potential? Will slides occur in all areas at the same time? Or in different areas at different times?

- Effects of projected precipitation. What is the timing and intensity of expected precipitation?* Will it occur as rain or snow? What temperature trends can be expected during the precipitation? What is or will be the condition of the base snow when the expected precipitation starts? Rain crust? Ice layer? Surface hoar?

  Following a front, is there substantial cool, moist unstable air which will be orographically lifted over the Cascades to produce large amounts of precipitation? Convective clouds associated with this type of flow situation behind a front are frequently displayed very well in infrared satellite pictures.

  From analysis of 850 and 700 mb flow charts, should any regional variations of precipitation (intensity) be expected? If so, how will these precipitation variations affect the old snowpack stability? The newly deposited snowpack stability? If snow is currently occurring in the Cascades, how long should it continue? At what trend in intensity, temperatures? How will this affect the snowpack? When will a stable snowpack become critically unstable as a result of new snowfall alone? Such critical instability would be dependent on such factors as bonding of new to old snow and snowfall/precipitation intensity.

  If rain is forecast or presently occurring in the Cascades, to what elevation will it or does it extend? How long should it extend to that level? At what intensity? How susceptible is snowpack stability to the present or expected rainfall? A large amount of unconsolidated new snow would be very susceptible to avalanche release by rainfall, while a well-consolidated, homogeneous snowpack would probably withstand large amounts of rainfall before critical instability and subsequent release resulted. When, if at all during forecast period, will rain change to snow or vice versa? At what elevations?

  Could heavy rain release even a moderately stable snowpack? Do impermeable ice layers/rain crusts exist within the snowpack which could be lubricated by heavy rains? How far down are these layers? How quickly would rain penetrate the snowpack to these layers? Is there any regional variation in the snowpack making some areas more susceptible to rain than others?

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* For this information, satellite imagery correlated with surface maps gives a good indication of what the source of moisture (tropical, north Pacific, etc.) for a given weather disturbance is (how wet it could be), and what its past motion has been. Prognostic 500 mb maps are useful in analyzing the future trajectory of the disturbance, as weather disturbances are often "steered" by the 500 mb flow. Following and during a frontal passage, 850 and 700 mb prognostic pressure charts are useful tools in determining the intensity of orographic precipitation which can be expected, especially when used in conjunction with satellite pictures.

If there is cold easterly flow at the passes (possibly transporting snow) and a warm-up occurring aloft, is freezing rain possible? When should it occur and for how long? Are low level air flow and precipitation patterns expected such that upslope precipitation on the eastern side of the Cascades could become a problem? Or will the more usual heavy westside, upslope precipitation occur?

- Effects of projected temperatures and/or freezing levels. What is the timing and magnitude of any expected warm-ups?* Are regional (north versus south, east versus west) variations in freezing levels expected? Should the warming affect certain areas before others? How will this affect the avalanche activity forecast?

  Is the snowpack unstable enough so that warming alone (rise in freezing level and air temperatures above freezing) may precipitate slide release? Or are warming and precipitation (rain perhaps) necessary before avalanche hazard becomes extreme? Warming alone near the freezing point may quickly (within a few hours) cause release of a large amount (12 inches) of newly-deposited, unconsolidated snow. For a well-consolidated, old snowpack, substantial warming (near the freezing point) plus rain may be necessary before natural avalanching of the snowpack occurs.

  A note of explanation is required here on warm-ups as both stabilizing and avalanche-triggering events. A large amount (12 inches or more) of new, unconsolidated cold snow may initially be very susceptible to avalanche release through warming (melt-induced weakening of crystalline bonds and/or contacts and subsequent loss of tensile strength). Snowpack settlement due to warming may on the other hand lead to increased stability. However, once avalanche release or settlement has occurred through warming, the slope may become quite stable. Further periods of extended warming or warming with rain may be necessary to cause (additional) sliding of this slope. Thus, warm-ups (temperatures rising above 0°C) may act either to stabilize or de-stabilize the snowpack according to the physical state of the snowpack itself. Depending on the length of the warm-up and the initial condition of the snowpack, a given snowpack may experience alternating periods of instability and stability because of the warm-up. Initial slope instability through warming is usually followed by stability after slides or settlement have released snowpack stresses. The snow may become unstable again with prolonged warming, usually yielding wet loose or wet slab slides, most common in the spring.

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* Observe radiosonde temperature versus altitude plot from Quillayute (UIL), Gray's field/Ft. Lewis (GRF), Seattle (SEA)and Canadian Weather Ship (C7P). Use 850 and 700 mb prognostic pressure/temperature maps and prognostic 1000-500 mb thickness fields which indicate future positions of warm and cold air masses. NWS FOUS 72 (FOUS 60 before) also has thicknesses out to 48 hours, twice daily, and this year NWS FOUS 43 has freezing levels forecast similarly.

If TG weakening of the snowpack is currently occurring, how long can this be expected to continue? How weak will this make the snowpack? This feature must be closely watched even after moderating temperatures and a deeper snowpack lessen the TG process, as significant deep slab instability may persist for substantial periods of time before possible ultimate release. It is very difficult to specifically forecast slides resulting from this instability with current snowpack technology.

Are weather conditions expected that would allow for substantial surface hoar formation which could become a problem (mechanically weak layer) with expected snowfall deposition, especially on north and east facing slopes?

Are continuous above-freezing air temperatures for 24 hours or longer expected in the starting zones of major avalanche paths? Will a cloud cover prevent the surface snow from stabilizing through radiational cooling at night and continue free-water percolation through surface snow melt during this period? How susceptible is the snowpack in these avalanche paths to prolonged above-freezing air temperatures? Do weak shear layers or smooth sliding surfaces exist beneath 12 inches or more of recent new snow--either would be quite susceptible to de-stabilizing effects of prolonged above-freezing air temperatures. How close are the observed current snowpack temperatures to 0°C?

- Effects of projected winds. What is the expected wind direction and velocity at the 5000 foot level (850 mb) for the next 24, 36, 48 hours? Are significant changes in either velocity or direction expected? Are winds opposite to the free air winds expected through the passes?

  Considering acceleration effects over ridge tops, should forecast winds (>10 mph) alone be sufficient to load lee slopes? How quickly? How much new or loose snow is available for transport as deduced from recent snowpits or expected snow surfaces? Is this a regional or elevation-related problem? That is, is snow available for transport in some areas at some elevations and not at others?

  If snowfall is occurring or expected to occur with winds, how will this affect the deposition patterns? How will this affect the activity forecast?

- Effect of projected sky cover. Will solar radiation over the next 24, 36, 48 hours initiate wet loose or slab release of new snow on south, east or west aspect slopes? Could sun-induced new snow released from trees trigger slide activity on slopes below? Will expected increasing sky cover at night significantly change the snow cover radiation balance and act to trigger deep slab or other instability after prior destabilization through a prolonged period of clear warm days with freezing levels above 7000 feet and clear nights with surface snow stabilizing each night by refreezing through radiational cooling? (See section 4.4.2 for a more in-depth treatment of this topic.)

4.4 The 1976/77 Winter

The winter of 1976/77 was abnormal. Record or near record light amounts of precipitation were recorded from September through February at all stations through the Cascades and Olympics. Typical of the winter was the snow depth at Stevens Pass, which at one point in mid-February was 18% of the 20 year mean. Snowpacks were generally quite shallow or almost non-existent until late February.

The source of this unusual weather lay in an almost stationary upper level flow. The situation that typified most of the winter is shown in Figure 8. The patterns basically consist of the superposition of two phenomena. One is the long wave ridges (high pressure areas) and troughs (low pressure areas), designated H and L in Figure 8. The features are generally long lasting, slow moving phenomena that control the position of the "storm tracks." Superposed on this pattern is the effect of shortwave ridges and troughs. These are relatively fast moving, short-lived features that are closely associated with surface fronts. The motion of these features are guided by the long wave pattern.

During most of the winter of 1976/77 a long wave ridge sat nearly stationary, near or at the Pacific coast. As depicted in Figure 8, this had the effect of shunting almost all storms to the north of Washington into British Columbia and Southern Alaska. Those storms which moved directly into the ridge rapidly dissipated and seldom gave more than an increase in high cloudiness or an occasional drizzle. This type of situation often occurs during a normal winter; however, the persistence of the long wave ridge in this position for such an extended period was something which had not been previously observed.

Finally, in late February this persistent ridge began moving to a position to the east of Washington, allowing Pacific storms to reach Washington. Notably, the long wave ridge remained sufficiently close to Washington to weaken these storms as they reached the state, and, as a result, the bulk of the precipitation experienced in the mountains during February and March was associated with post-frontal orographic shower activity in the cold unstable air following the fronts. This situation led to the accumulation of a significant snowpack and the first substantial avalanche activity of the season.

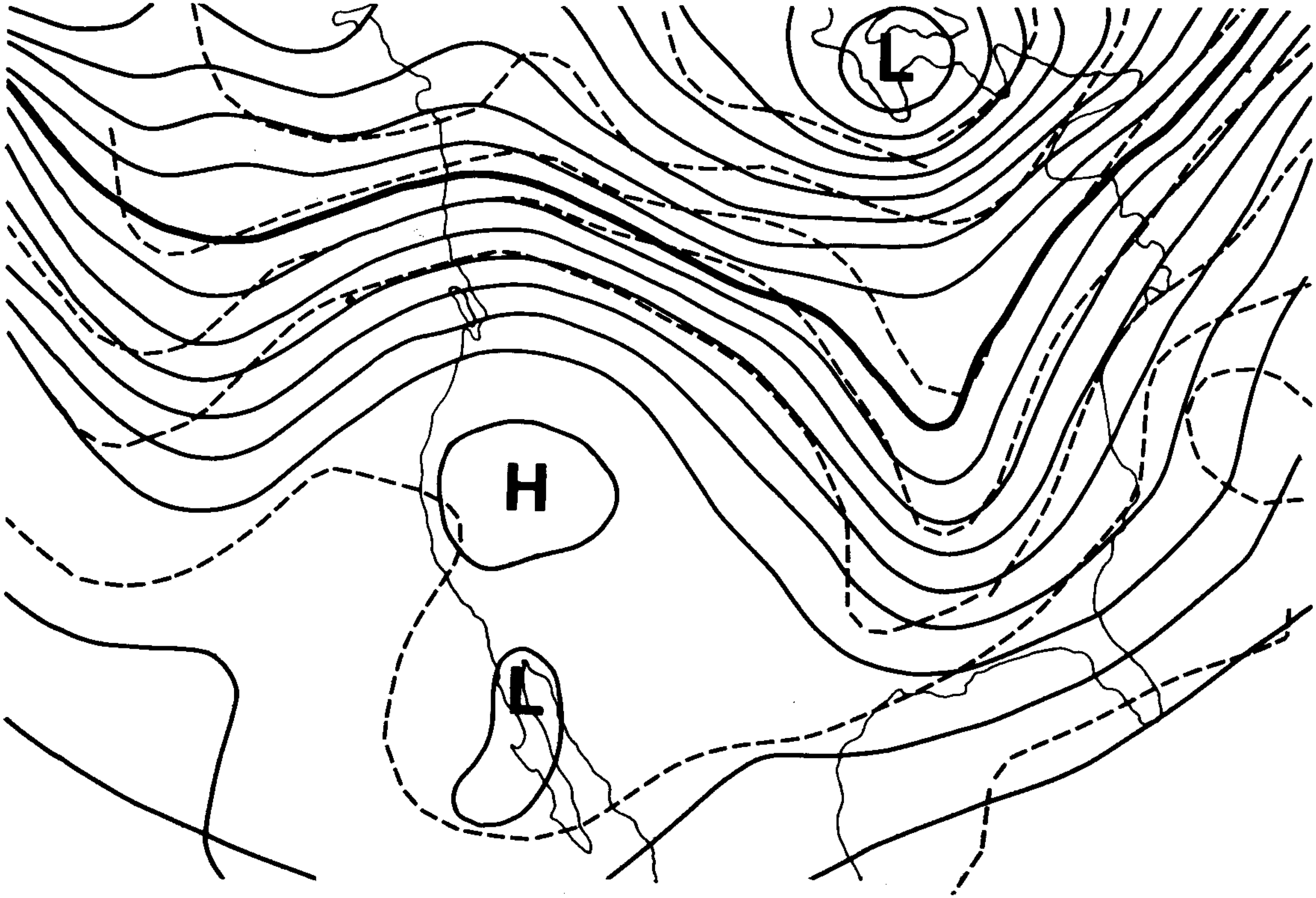

FIGURE 8. 500 mb map.

4.4.1 Discussion of Forecasts

Several changes were made in the Forecasting Office product for the second year of operation. At the request of the WSDH, it was planned to forecast weather and avalanche activity specifically for Washington Pass. As the winter progressed, this became the prime operational forecast point, and, in turn, became one of the most active feedback points. As a result, forecast experience with this Pass has now probably progressed to the level of that for Stevens, Snoqualmie and White Passes after the winter of 1975/76.

Additionally, a concerted forecast effort was directed towards Chinook and Cayuse Passes part way through the winter as the need became apparent; however, lack of substantial feedback from these passes left forecasters unsure of the accuracy obtained.

Several other changes in the forecast product were instituted on the basis of recommendations of field personnel and project forecasters. In order of appearance in the forecast (see Figure 5):

- The winds at the pass level were included as a standard part of the forecast.
- The quantitative precipitation forecasts (QPF) being regularly issued were increased from three stations (Stevens, Snoqualmie, and White Passes) to six stations (adding Washington Pass, Paradise, and Crystal Mt.) and finally to eight stations (adding Chinook and Cayuse Passes).
- A QPF for the second 24 hours (extending QPF's out to 48 hours) was added for all stations.
- An extended outlook for roughly 72-96 hours was made a standard part of the forecast.
- A minimum of two complete forecasts were issued per day.

An attempt was made in-house to improve the verification procedure by the use of a special form for the forecasting of freezing levels and avalanche activity for 6-hour intervals, plus a summary of the accuracy of the overall forecast written by the forecaster the following day (see Figure 9). The material on this form was not issued directly but served as a guide in the writing of the disseminated forecasts. The use of these data for the purposes of verification of forecast accuracies is discussed in the appropriate sections below:

FIGURE 9. Forecast Verification Form (revised 1/7/77).

Forecast FREEZING LEVELS (Hundreds of feet):
Date:

Time Location	18Z	00Z	06Z	12Z	18Z	00Z
UIL (Olympic)						
Cascades						
:						

Remarks:

Forecast AVALANCHE ACTIVITY (Use Code):

Time Location	18Z	00Z	06Z	12Z	18Z	00Z
Washington Pass						
Stevens Pass						
Snoqualmie Pass						
White Pass						

Remarks:

Evaluation of Forecast:

- Weather and weather trends. Weather and weather trends were given in a narrative form for both short term (present to 48 hours) and the long term (48-96 hours) forecasts as described in section 4.2 and Figure 5. The general accuracy of the short term forecasts were summarized by the forecasters on the verification form, Figure 9. This provided a better picture of the accuracy of the forecasts than was obtainable during the first year of forecasting when this form was not in use. Unfortunately, as this summary is itself a qualitative description of the observed weather, it does not offer itself to quantitative evaluation of accuracy. However, a review of this, plus discussion with field personnel, allow some general comments.

  It was the general consensus that the weather forecasts were quite accurate in predicting general cloud cover, general precipitation timing, and freezing levels, but several significant problems were often sited. Among these were timing and intensity of local shower activity, and "false alarms" several times about major weather changes. The problem of local showers activity cropped up several times during the winter when large, relatively isolated cells sat over one area for a lengthy period and dropped locally large quantities of precipitation. Forecasting this type of activity more than several hours in the future is far beyond meteorological technology; however, improvements are presently being made in forecasting the motion and intensity of isolated severe storms using high resolution satellite imagery and weather radar for short periods of several hours. It is hoped that these improvements can be gradually incorporated in the Forecasting Office as the proper data becomes available and familiarity with its use increases.

  The problem of misforecasting major weather changes during the winter of 1976/77 was the direct result of the anomolous nature of the winter. The numerical models used by the NWS-NMC from which forecasts of these kinds of changes are made were frequently very much in error, particularly for the longer term forecasts. This is partly due to the fact that these models include climatological weighting in the computation of future flow patterns. As the past winter was far from the climatological norm, the models were simply inapplicable at times. It should be noted that forecasters became quite conservative in interpreting any projected changes these models forecast, but even so, the forecasts that were finally arrived at were occasionally too optimistic in announcing that "winter has finally arrived."

- Freezing levels. The problem of accurate determination of freezing levels within mountainous regions was covered at length in Section 4.3.1.b of last year's report. As during the first year, the only consistently reliable measure of the free air freezing levels came from radiosonde measurements taken at 0400 and 1600 PST above Quillayute, near Forks on the Washington coast, and above Geiger Field near Spokane, Washington. Soundings taken at Portage Bay (Seattle) and Grays Field (Ft. Lewis) were occasionally available at 0700 PST, but these were not taken consistently enough to be used for verification. They frequently served the forecaster by giving an indication of the eastward progression of new air masses. It is generally accepted that the measurements taken at Quillayute are more representative of the free air temperatures in the Cascades than those taken at Geiger.

  On the verification form (Figure 9), the freezing levels for 6-hour intervals was forecast separately for the Olympics and Cascades. Further geographical distinctions were made in the forecast areas as the situation dictated. Frequently the freezing levels forecast for the two ranges were the same or only slightly different. The freezing levels forecast for the Olympics should be essentially identical to those measured at Quillayute, particularly since the westerly flow often present tends to drift the balloons directly over the Olympics. Thus, it was felt that a comparison of the Quillayute measurements with those forecast for the Olympics would be an excellent measure of the degree of accuracy that is being obtained in the freezing level forecasts. This worked better than using Cascade freezing levels as a criteria to check forecasts.

  Figure 10 displays a plot of the forecast and observed freezing levels for the Olympics/Quillayute. Comparison with Figure 10 in last year's report shows that the agreement is generally improved this year. This is probably due in part to the fact that the forecast and observed quantities being compared are from the same area. Specifically, for the winter of 1976/77 the average error in the forecast freezing level for the Olympics was 1056 feet with a standard deviation of 895 feet. Some of this error is introduced by the twice daily nature of the observations. In instances where rapid changes are taking place, mistiming the change in freezing levels by the space of an hour or two can introduce an effective error of several thousand feet in the computation of the mean error, thus over-exaggerating the extent of the forecast error. Hence the value given above should be considered the upper limit of the mean error.

- Winds. Free winds at the 850 mb level (5000 feet) and winds through the passes were routinely forecast twice daily. The free winds at the 850 mb level are helpful in determining possible wind effects in the higher starting zones, while the pass winds serve the same purpose for the lower starting zones. The actual winds affecting any particular

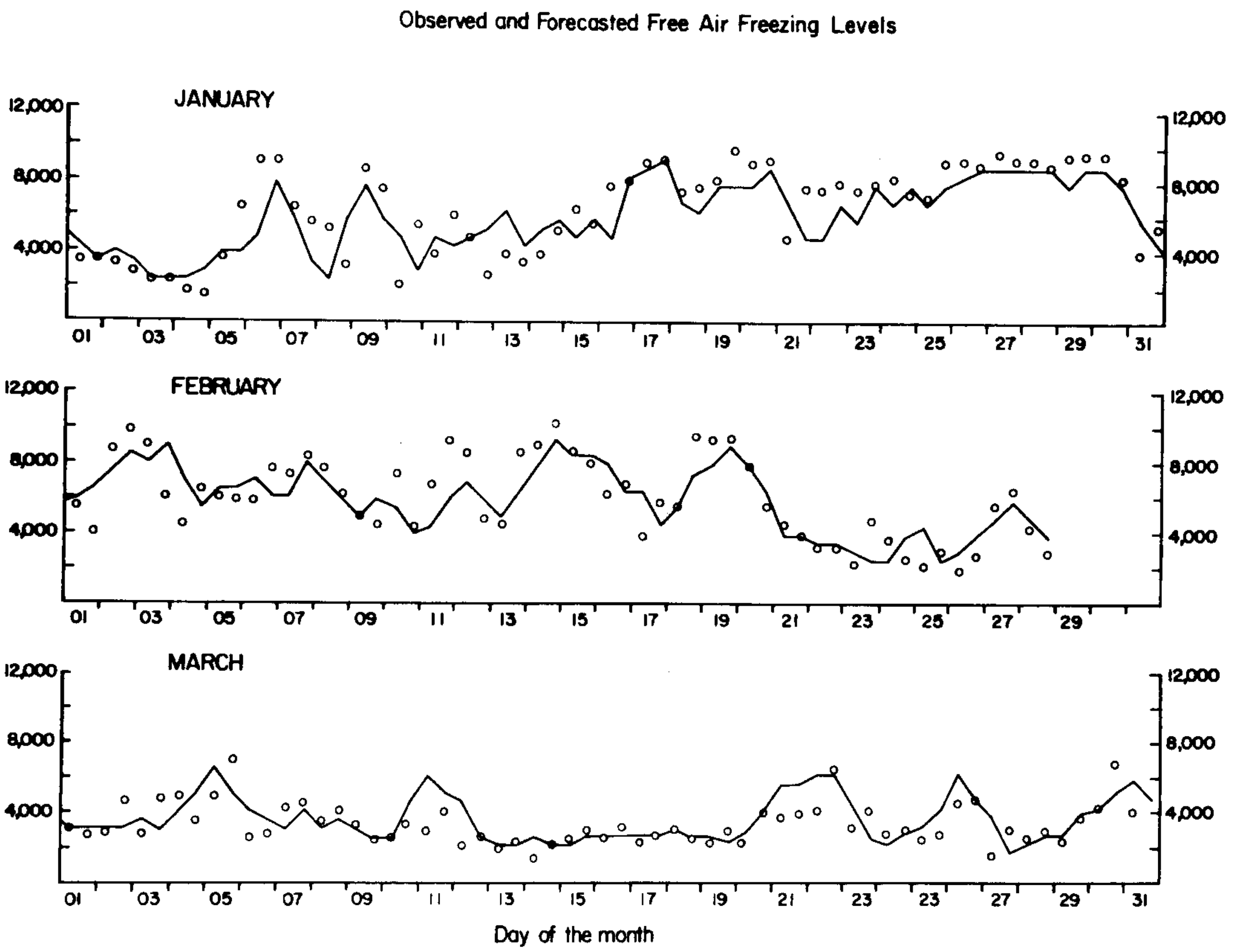

FIGURE 10. Forecasted and observed freezing levels for Olympics. Solid line represents forecasts and circles represent observed values.

location will be very much a function of the local topography; however, field personnel are often able to empirically determine the effects of a given forecast wind on individual paths based on operational experience.

The problems involved in verifying forecasted winds stems from a lack of compatibility between the forecasted quantities and those observed. The winds which are forecasted are average winds for a period of time; whereas, the wind observations are instantaneous values. A further problem with the 850 mb winds is that observations are only available from soundings taken at Quillayute, which supply instantaneous values twice daily at 4 a.m. and 4 p.m. A more detailed description of these problems is given in section 4.3.1 of last year's report.

A general comparison of 850 mb winds forecasted with those observed at Quillayute was made. There was quite good agreement between forecasted and observed wind directions. Wind speeds forecasted showed acceptable agreement with those observed showing the same trends, although there was occasionally a significant difference between the instantaneous values observed and the forecast. These are the results that would be expected, as the wind directions observed should be fairly stable over a period of time, while instantaneous values of wind speed would be expected to vary considerably.

Generally, the forecasted winds the second year showed better correlation with those observed than was seen from the first year's results. This may possibly be due to the static conditions that prevailed during most of the winter, when changes in wind velocity took place relatively slowly.

As pass winds were regularly forecasted during the second year of operation, it was possible to verify their accuracy. Pass winds were forecasted for varying intervals determined by the timing of expected changes in wind velocity. Normally the wind speed is forecast for 5-10 knot intervals, depending on the degree of variability expected. Often this is further qualified with a forecast for higher gusts. Pass winds were observed on an hourly basis from Stampede Pass and project telemetry at Stevens Pass. As with the 850 mb winds, the values that were received were instantaneous.

The agreement between forecasted and observed wind directions was excellent. Pass winds are essentially east-west in nature due to channeling effects, though variations from this are seen during very light winds when local effects can predominate. These were the only times that there was any significant differences noted, except for very brief periods during changing conditions. Wind speeds were also quite good, though there appeared to be a tendency to overestimate the expected wind speeds.

The chief difficulty noted in pass wind forecasts are the occasional high gusts of wind that are reported in association with severe weather, such as frontal passages and local intense showers. An improvement in these forecasts may be expected as forecasters gain increasing experience and familiarity with localized weather patterns.

- Precipitation quantities. The estimated water equivalent of precipitation for two consecutive 24 hour periods beginning at 0400 PST was routinely given as a quantitative precipitation forecast (QPF) for eight points in the Cascades (see section 4.2). The QPF was arrived at as a subjective combination of the following: the NWS forecasted QPF for Stampede Pass, the NWS FOUS 72 (see section 4.2), forecasted surface and upper level flows, and knowledge of the general meteorology of each of the areas. As during the first season, it was attempted to forecast the QPF to within ±1/8 inch of the observed value when the total was less than or equal to one inch; however, after reviewing the first year's forecasting results, it was decided that ordinarily if the QPF was greater than one inch the forecast would be for a ±1/4 inch range.

  Several new problems arose in the evaluation of the QPF accuracy for the winter of 1976/77. At Stevens and Snoqualmie Passes manpower cutbacks due to the light snowfall made observations infrequent or nonexistent at times which required obtaining water equivalent observations from secondary sources. At Stevens Pass observations from the Highway Department study plot were supplied regularly until the end of February when reassignment of personnel made this impossible. Two alternative sources were used. Precipitation quantities were available most days from the new telemetry system; however, due to problems with the new equipment, there were gaps in the measurements. In this case values from the NWS hydrologist's precipitation gage located on the west side of Stevens Pass were substituted. These are received once daily at 0700 PST through the River Forecast Center in Portland, Oregon.

  At Snoqualmie Pass regular reports were never available due to the light winter, necessitating the use of the NWS weather station at Stampede Pass, located several miles south and east of Snoqualmie Pass and about 1000 feet higher. To gain information on precipitation amounts on the west side of the Pass, data from the NWS hydrologist's gage located on the west side of the Pass near the Kittitas County Sewer District headquarters was used. This information was available once daily through the NWS DARDC system. It should be noted that both of the NWS hydrologist's gages only report readings to the nearest one-tenth of an inch versus the normal meteorological observations which are to the nearest one-hundredth of an inch.

  Further problems both new and old were also encountered. At Chinook and Cayuse Passes no water equivalent measurements are made so no attempt was made to verify the forecasts for these passes. Additionally, the lack of a precipitation gage at White Pass continued to hamper the quantitative analysis of the White Pass data. The water equivalents reported from here come totally from snow weight off of the 24-hour snow stake. Thus any rainfall or snow melt prior to the observations drains away and goes unmeasured. As a result, the White Pass values are only a lower limit on the amount of precipitation received.

Tables 4-8 summarize the accuracy of the QPF's for the period December 6, 1976, to April 14, 1977. Statistics for each individual month, as well as total statistics for the season are given for Washington, Stevens, Snoqualmie, Stampede, and White Passes. Only days on which measurable precipitation was observed were included in the computations. A separate verification was carried out for the first and second 24 hour QPF's. The verification was further broken up into QPF's issued in the morning forecast and those issued in the afternoon forecast. Each Table has nine numbered columns which describe the following:

Column 1--the number of days with measurable precipitation for which observations were available;
2--the mean error of the forecasts in inches of water equivalent;
3--the standard deviation of the mean error (68% of all of the forecast errors lay within one standard deviation of the mean);
4--the percentage of days on which the observed value lay within the forecast ± 1/8 inch range;
5--the percentage of days that lay within ± 1/4 inch range;
6--the percentage of days that lay within ± 3/8 inch range;
7--the percentage of days on which the observed value lay <u>more</u> than 1/2 outside the forecast range;
8--the accumulated error in inches; and
9--the total observed precipitation.

It should be noted that the QPF's for the second 24 hour period were not always included on the morning forecast due to the time constraints in preparing the morning forecasts. Additionally, it was also occasionally deleted from the afternoon forecast when a forecaster felt that there was no sound basis on which to make the forecast. This had the effect of making the forecast QPF's for the second 24 hours seem more accurate than they actually were, as doubtful situations were excluded from the forecast statistics by the condition of "no forecast."

Table 4 shows the results for Washington Pass. The accuracy for the first 24 hour period exhibits quite a bit of variability. This partly reflects the unusual weather encountered during much of the winter. The large error seen in December is partly the result of forecasters becoming familiarized with the new forecast area. The values given for February and March are probably the most representative as these months began to approach a normal winter. The mean error is in the neighborhood of 0.2 inches which is consistent with results for other passes during these first two years of forecasting. As would be expected, the afternoon forecasts were slightly more accurate than the morning forecasts. Similarly, the accuracy of the second 24 hours was somewhat less than that for the first 24 hours, although the accuracy of the second 24 hours is probably overstated as mentioned before.

TABLE 4. Accuracy of QPF's - Washington Pass.
(12/6/76 - 4/14/77)

	1*	2	3	4	5	6	7	8	9
December									
1st 24 hrs AM	10	.34	.33	20%	30%	60%	40%	3.41	4.17
PM	9	.26	.32	22%	56%	67%	33%	2.30	
2nd 24 hrs AM	8	.06	.14	75%	88%	88%	12%	0.49	
PM	7	.29	.42	57%	71%	71%	29%	2.00	
January									
1st 24 hrs AM	12	.12	.15	50%	75%	83%	17%	1.39	2.83
PM	12	.05	.10	75%	92%	92%	8%	0.56	
2nd 24 hrs AM	7	.02	.04	71%	100%	100%	0%	0.17	
PM	11	.14	.17	45%	64%	73%	27%	1.57	
February									
1st 24 hrs AM	16	.20	.24	38%	50%	75%	25%	3.19	5.35
PM	16	.15	.24	56%	56%	81%	19%	2.47	
2nd 24 hrs AM	10	.16	.30	40%	70%	90%	10%	1.58	
PM	16	.17	.26	31%	63%	81%	19%	2.76	
March									
1st 24 hrs AM	27	.22	.22	26%	48%	60%	41%	5.89	7.10
PM	27	.20	.20	26%	48%	67%	33%	5.30	
2nd 24 hrs AM	15	.20	.24	33%	67%	67%	33%	2.93	
PM	27	.24	.27	30%	56%	67%	33%	6.44	
April									
1st 24 hrs AM	5	.08	.10	60%	60%	100%	0%	0.53	0.45
PM	5	.06	.09	60%	80%	100%	0%	0.29	
2nd 24 hrs AM	5	.10	.14	60%	80%	80%	20%	0.85	
PM	5	.08	.09	40%	80%	100%	0%	0.40	
Season									
1st 24 hrs PM	69	.16	.20	43%	61%	77%	23%	10.92	19.90
2nd 24 hrs PM	66	.20	.25	36%	62%	74%	26%	13.17	

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*See text for explanation of column labels.

TABLE 5. Accuracy of QPF's - Stevens Pass.
(12/6/76 - 4/14/77)

	1*	2	3	4	5	6	7	8	9
December									
1st 24 hrs AM	15	.22	.30	47%	53%	73%	27%	3.37	7.20
PM	12	.25	.29	42%	50%	67%	33%	3.00	
2nd 24 hrs AM	14	.16	.23	43%	72%	71%	29%	2.26	
PM	9	.23	.35	45%	67%	67%	33%	2.11	
January									
1st 24 hrs AM	13	.12	.23	38%	85%	85%	15%	1.55	5.52
PM	13	.09	.13	38%	85%	85%	15%	1.18	
2nd 24 hrs AM	7	.03	.05	71%	100%	100%	0%	0.20	
PM	13	.18	.33	54%	69%	85%	15%	2.38	
February									
1st 24 hrs AM	15	.32	.36	27%	40%	47%	53%	4.73	8.21
PM	15	.28	.37	27%	53%	67%	33%	4.20	
2nd 24 hrs AM	9	.31	.50	44%	56%	67%	33%	2.76	
PM	14	.30	.44	43%	57%	65%	36%	4.17	
March									
1st 24 hrs AM	13	.23	.39	21%	50%	86%	14%	3.41	5.98
PM	13	.21	.37	23%	54%	92%	8%	2.75	
2nd 24 hrs AM	6	.14	.10	17%	50%	83%	17%	0.85	
PM	13	.28	.47	8%	54%	77%	23%	3.70	
April									
1st 24 hrs AM	8	.07	.05	13%	100%	100%	0%	0.59	1.10
PM	8	.09	.12	50%	88%	88%	12%	0.73	
2nd 24 hrs AM	8	.12	.11	25%	63%	88%	13%	0.99	
PM	8	.11	.10	25%	75%	88%	12%	0.86	
Season									
1st 24 hrs PM	61	.19	.27	34%	64%	79%	21%	11.86	28.01
2nd 24 hrs PM	57	.23	.35	35%	63%	76%	24%	13.22	

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*See text for explanation of column labels.

TABLE 6. Accuracy of QPF's - Snoqualmie Pass. (12/6/76 - 4/14/77)

	1*	2	3	4	5	6	7	8	9
December									
1st 24 hrs AM	13	.28	.49	38%	69%	69%	31%	3.66	9.20
PM	13	.31	.44	46%	54%	62%	38%	4.08	
2nd 24 hrs AM	12	.39	.47	33%	42%	50%	50%	4.63	
PM	11	.38	.50	45%	55%	55%	45%	4.14	
January									
1st 24 hrs AM	11	.24	.36	45%	73%	73%	27%	2.65	6.10
PM	11	.21	.33	45%	73%	73%	37%	2.28	
2nd 24 hrs AM	5	.04	.06	60%	80%	100%	0%	0.20	
PM	11	.32	.50	36%	55%	73%	27%	3.52	
February									
1st 24 hrs AM	14	.32	.34	21%	36%	57%	43%	4.51	9.10
PM	14	.31	.34	29%	43%	50%	50%	4.39	
2nd 24 hrs AM	9	.39	.40	11%	44%	44%	56%	3.54	
PM	13	.38	.39	23%	38%	46%	54%	5.00	
March									
1st 24 hrs AM	20	.24	.29	25%	40%	70%	30%	4.79	13.00
PM	21	.23	.29	24%	48%	62%	38%	6.23	
2nd 24 hrs AM	9	.32	.29	11%	44%	56%	44%	2.87	
PM	21	.30	.38	27%	45%	82%	18%	2.54	
April									
1st 24 hrs AM	2	0	0	100%	100%	100%	0%	0.00	0.70
PM	2	.07	.02	0%	100%	100%	0%	0.15	
2nd 24 hrs AM	2	.03	.03	50%	100%	100%	0%	0.05	
PM	2	.03	.03	50%	100%	100%	0%	0.05	
Season									
1st 24 hrs PM	61	.26	.33	33%	54%	62%	38%	17.13	38.10
2nd 24 hrs PM	58	.33	.42	32%	49%	68%	32%	15.25	

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*See text for explanation of column labels.

TABLE 7. Accuracy of QPF's - Stampede Pass.
(12/6/76 - 4/14/77)

	1*	2	3	4	5	6	7	8	9
December									
1st 24 hrs AM	12	.21	.30	42%	58%	67%	33%	2.53	7.98
PM	12	.22	.24	25%	50%	58%	42%	2.66	
2nd 24 hrs AM	11	.23	.35	55%	64%	73%	27%	2.58	
PM	10	.27	.35	30%	60%	70%	30%	2.75	
January									
1st 24 hrs AM	13	.09	.12	46%	69%	92%	8%	1.13	4.81
PM	13	.09	.15	46%	77%	92%	8%	1.17	
2nd 24 hrs AM	7	.03	.04	71%	100%	100%	9%	0.19	
PM	13	.15	.28	62%	69%	85%	15%	1.90	
February									
1st 24 hrs AM	15	.27	.31	27%	40%	60%	40%	4.11	8.07
PM	15	.24	.32	33%	53%	67%	33%	3.58	
2nd 24 hrs AM	9	.24	.28	44%	44%	67%	33%	2.13	
PM	14	.30	.36	36%	43%	64%	36%	4.16	
March									
1st 24 hrs AM	23	.28	.34	25%	35%	52%	48%	6.42	11.64
PM	24	.26	.34	33%	46%	58%	42%	6.23	
2nd 24 hrs AM	9	.24	.21	11%	44%	56%	44%	2.17	
PM	24	.30	.40	17%	38%	63%	38%	7.27	
April									
1st 24 hrs AM	7	.10	.08	29%	71%	100%	0%	.69	.94
PM	6	.15	.16	50%	50%	83%	17%	.88	
2nd 24 hrs AM	6	.09	.06	33%	67%	100%	9%	.53	
PM	7	.12	.09	14%	71%	86%	14%	.83	
Season									
1st 24 hrs PM	70	.21	.27	35%	54%	68%	32%	14.52	33.44
2nd 24 hrs PM	68	.25	.33	31%	52%	71%	30%	16.87	

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*See text for explanation of column labels.

TABLE 8. Accuracy of QPF's - White Pass. (12/6/76 - 4/14/77)

	1*	2	3	4	5	6	7	8	9
December									
1st 24 hrs AM	2	0	0	100%	100%	100%	0%	0	0.88
PM	2	.05	.05	50%	100%	100%	0%	0.10	
2nd 24 hrs AM	2	.05	.05	50%	100%	100%	0%	0.10	
PM	2	.05	.05	50%	100%	100%	0%	0.10	
January									
1st 24 hrs AM	0	-	-	-	-	-	-	-	0
PM	0	-	-	-	-	-	-	-	0
2nd 24 hrs AM	0	-	-	-	-	-	-	-	0
PM	0	-	-	-	-	-	-	-	0
February									
1st 24 hrs AM	5	.27	.17	0%	20%	60%	40%	1.36	1.78
PM	5	.25	.19	20%	20%	80%	20%	1.23	
2nd 24 hrs AM	3	.07	.10	67%	67%	100%	0%	1.22	
PM	5	.14	.12	40%	40%	100%	0%	0.72	
March									
1st 24 hrs AM	13	.21	.26	23%	62%	62%	38%	2.98	6.57
PM	13	.23	.28	15%	54%	69%	31%	3.05	
2nd 24 hrs AM	3	.01	.01	67%	100%	100%	9%	.02	
PM	13	.26	.35	15%	54%	62%	38%	3.36	
April									
1st 24 hrs AM	1	0	0	100%	100%	100%	0%	0	0.18
PM	1	0	0	100%	100%	100%	0%	0	
2nd 24 hrs AM	1	0	0	100%	100%	100%	0%	0	
PM	1	0	0	100%	100%	100%	0%	0	
Season									
1st 24 hrs PM	21	.21	.22	19%	52%	74%	24%	4.38	9.41
2nd 24 hrs PM	21	.20	.25	28%	57%	76%	24%	4.18	

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*See text for explanation of column labels.

There was a slight tendency to overestimate the amount of precipitation for most months; however, in March the precipitation forecasts were consistently much over that observed: 4.56 inches overestimated versus 0.74 inches underestimated.

Though this was the first year of operational QPF's for Washington Pass, the results show the same level of forecast accuracy that has been achieved at other areas.

The results for Stevens Pass are shown in Table 5. The accuracy for the first 24 hours is very comparable to that obtained during the first year of forecasting. In fact, the season totals are almost identical to those from 1975/76. Again the afternoon forecasts are slightly more accurate than the morning forecasts, and the first 24 hours is more accurate than the second 24 hours. Unlike the first year's results, the second year's forecasts consistently underestimated the precipitation quantities, particularly in February when 0.73 inches were over estimated and 3.47 inches were underestimated.

Table 6 displays the results for Snoqualmie Pass. Since this used the data from the NWS hydrologist's gage which was of uncertain accuracy for these computations, Table 7 is also included giving the results for Stampede Pass which is located nearby. Only one QPF is given for both of these stations due to their proximity. Comparing the results from the two stations, it is apparent that, although there are variations in the results, both stations are reasonably similar in behavior. This is notable since there were significantly more days at Stampede Pass with measurable precipitation due to its greater accuracy. Generally, the results were very similar to those recorded during the first year of forecasting; however, there appears to have been a marked increase in the forecast accuracy in the ± 1/8 inch and ± 1/4 inch ranges, the accuracy almost doubling in the former case.

Table 8 shows the results for White Pass. There was significant precipitation recorded with the exception of the month of March. Precipitation was not recorded during January indicating whatever precipitation fell, fell as rain. Comparison of the forecast accuracies for March of both years shows a decreased accuracy during the second year of forecasting. However, the bulk of the forecast errors were overestimates of the precipitation amounts which could have resulted from the lack of a precipitation gage at the site. The season totals for both years, however, show some improvement over the second year.

Due to the unusual nature of the past winter, it is difficult to draw meaningful conclusions from a comparison of the first and second years of forecasting precipitation quantities. The same level of accuracy was maintained for all areas for both seasons, which is an encouraging sign that the forecasting schemes being employed should be reliable from year to year. It is the general concensus that a slow increase in the QPF accuracies may be expected from year to year as forecasters gain familiarity with the peculiarities of the various areas. Unfortunately, it is unlikely that there will be a large increase in accuracy until some form of objective QPF guidance becomes available to forecasters. Presently, the ± 1/8 inch QPF's appear to be useful to field personnel without modification, although universally more consistent accuracy is hoped for.

- Avalanche advisories. Avalanche advisories continued to be issued in a narrative form as a standard part of the Forecasting Office product essentially unchanged from the first year of operation (see section 4.3.1.e of last year's report). As an aid in verification, forecasters estimated avalanche activity over six hour intervals using a simple ordinal scale: 0-no activity; 1-sluffs not affecting the highway; 2-slides not affecting the highway; 3-sluffs affecting the highway; and 4-slides affecting the highway. This was a standard part of the verification form (Figure 9) and was not disseminated. Unfortunately, due to the extremely light snowfall recorded during the winter of 1976/77, there was virtually no activity reported throughout most of the winter except at very high elevations in the backcountry. The only significant slide activity affecting the highways occurred in late February through early April at Washington, Chinook, and Cayuse Passes. Of these three passes, complete data on avalanche occurrence was only available from Washington Pass.

Table 9 shows the accuracy of avalanche advisories for Washington Pass for the period of February 26, 1977, through April 15, 1977. The numbers labeling the columns and rows correspond to the ordinal classifications described above. Classification #3 is deleted as it is not possible to easily differentiate a small slide affecting the highway from a sluff in the observations, hence they are lumped together under #4. A good degree of accuracy was achieved in forecasting activity affecting the highway. In four out of six instances where slides hit the highway, they were forecast, and general slide activity was forecast in the remaining two. There was a tendency to over-forecast the potential, nine forecasts of slides affecting the highway when only slides occurred. Normally this type of error is the result of a forecaster knowing an instability exists in the snowpack, but not being able to pinpoint the exact moment of release.

Since only a limited amount of additional experience with the avalanche advisories was gained during the second year of operation, it is not possible to evaluate the forecasts any further than was done the first year. It should be noted that the forecasting experience gained during the last winter's operation at Washington Pass will prove invaluable in any future forecasting for that area. Summarizing the conclusions given in last year's report: the avalanche advisory serves as a general evaluation of current snowpack conditions and stability. It can serve as a general aid or starting point for the evaluation of the local avalanche hazard by WSDH avalanche crews or ski area control teams. However, detailed evaluation of current hazard on a path by path basis still requires a trained observer on the spot.

TABLE 9. Accuracy of Avalanche Advisories for Washington Pass.
Period of interest - 2/26 - 4/15/77.

OBSERVED / FORECAST	NO SLIDES	SLIDES	SLIDES AFFECTING HIGHWAY	SLUFFS
NO SLIDES (0)	20	0	0	1
SLIDES (2)	2	1	1	0
SLIDES AFFECTING HIGHWAY (4)	0	9	4	1
SLUFFS (1)	5	0	0	1

Many times the advisory can serve these individuals by informing them of activity or snowpack structure observed elsewhere, thus allowing them to anticipate their local situation. The advisory does seem to provide sufficient information for indivuals who are involved in determining the avalanche hazard for large regions. It is generally felt that the advisory helps them in making decisions concerning public warnings and deployment of personnel.

4.4.2 Case Study, April 3-8, 1977

This case study provides a good example of a spring slide cycle in the Washington Pass area, 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.

Due to an unusually light snow year in the Cascades, none of the primary pass areas (Stevens, Snoqualmie or White Passes) experienced any avalanching affecting the roadway at all. Washington Pass, however, due to its abundance of steep, smooth (rock-face) slide paths, experienced significant avalanche activity even during this light snow year. The slides which affected the highway at Washington Pass during this period of interest resulted from a combination of factors: recent new snowfall at cold temperatures, very warm air temperatures and high freezing levels for a prolonged period, significant changes in the radiation balance of the snowpack due to a changing cloud cover, and existing weaknesses (due to earlier TG metamorphism) in the snowpack creating deep slab instability. During the week of April 3-8, all of these factors played a significant role in the observed avalanching.

Meteorologically speaking, a very stable upper level (500 mb) air flow pattern persisted over the United States for the entire period. A large high pressure ridge drifted very slowly eastward over the northwest, while a deep low pressure area covered most of the mid-west and east coast. As a result of this large-scale pressure pattern, a very warm and stable air mass dominated weather in the Washington Cascades from April 3-7.

Prior to this period of warm air invasion into Washington, a series of weather disturbances in a relatively strong, cold, zonal flow had deposited large amounts of snow in most Cascade areas on March 26 and 27. In fact, heavy orographic precipitation occompanying these fronts brought 12-40 inches of new snowfall to Cascade stations on March 26 and 27, with lighter snowfall amounts occurring on March 31 at many areas (see Table 10 for snowfall summary). Freezing levels throughout this pre-warming precipitation period (March 27-April 1) remained relatively low (see Table 11) as did reported air temperatures, especially in the Washington Pass area (see Table 12).

During the precipitation period of March 27, the snowpack (62-inch total) at Washington Pass approached within 1 inch of its maximum seasonal depth (63 inches were reported earlier on March 10), but the emphasis for forecasting was more on physical changes which had occurred earlier in the season within the snowpack. With a very thin snow-cover (less than three feet) in the Washington Pass area until late February, prolonged periods of very cold temperatures (<20°F) in January had created a very weak TG layer at the bottom of the snowpack. The physical stage was therefore set by April 1 for the manifestation of the effects of the April 2-7 warm-up on the existing snowpack.

Project forecasters were considering possible de-stabilizing effects of the anticipated warm-up and rising freezing levels on the snowpack as early as April 1 (see Appendix A for the April 1-8 forecasts). Although prior avalanching at Washington Pass had occurred with the heavy snowfall on March 26 and 27, the avalanching was not severe, and substantial snow remained in the Washington Pass starting zones from the late March snows.

Considerable warming with rising freezing levels was forecast for and occurred in western Washington the afternoon and evening of April 2 (see Table 11), and reported maximum/minimum temperatures for various Cascade stations the following day and night confirmed the arrival of a very warm air mass at all areas in the Cascades (see Table 12). Avalanche advisories (see Appendix A) issued by project forecasters on April 2 indicated increasing avalanche potential for Washington Pass by the afternoon of April 3, with slides expected to affect the roadway. These forecasted slides involving at first only the recent March snows did in fact occur (see the avalanche summary for Washington Pass in Table 13), but did not reach the roadway.

The initial slides which occurred at Washington Pass on April 3 were most probably a result of melt-induced weakening of only the recent March snowfall, and possible free-water lubrication of lower sliding surfaces,

TABLE 10. Snowpack Summary April 3-8, 1977.
Reported at morning observations for preceding 24 hours (trace water equivalents not included).

STATION	INCHES OF SNOWPACK DEPTHS		INCHES OF SETTLEMENT		AMOUNT OF SNOWFALL	
	4/3	4/8	TOTAL	%	INCHES	DATE
Washington Pass	54	45	9	16	10	3/27
					5	3/28
					1	4/1
Paradise	123	99	24	19	18	3/27
					12	3/28
					4	3/29
					14	4/1
					1	4/2
Stevens Pass	70	53	17	24	13	3/27
					27	3/28
					3	4/1
Cayuse Pass	110	86	24	22	15	3/27
					6	3/28
					7	4/1
					5	4/2
Mt. Baker	113	89	24	21	12	3/27
					1	3/28
					2	4/1

TABLE 11. Observed freezing levels March 27-April 8, 1977. Taken at Quillayute from radiosonde twice daily (MSG indicates missing observation).

DATE	TIME (PST)	FREEZING LEVEL (Ft.)
3/27	0400	1400
	1600	2900
3/28	0400	2400
	1600	2700
3/29	0400	2200
	1600	3500
3/30	0400	4200
	1600	6700
3/31	0400	3900
	1600	MSG
4/1	0400	4800
	1600	5600
4/2	0400	7500
	1600	10200
4/3	0400	11300
	1600	10800
4/4	0400	10700
	1600	10400
4/5	0400	10400
	1600	10200
4/6	0400	9900
	1600	10100
4/7	0400	9600
	1600	9700
4/8	0400	4100
	1600	3300

TABLE 12. Daily maximum/minimum temperatures (°F) March 27-April 9, 1977. Temperatures listed are for 24-hour period preceding morning (0600-0800) report time. (MSG indicates missing observation.)

	STATIONS							
	WASHINGTON PASS lower - 5500'		WASHINGTON PASS upper - 7000'		PARADISE 5500'		CRYSTAL MTN. base - 4400'	
DATE	Max.	Min.	Max.	Min.	Max.	Min.	Max.	Min.
3/27	31	19	27	12	29	15	36	21
3/28	23	18	21	12	24	18	38	21
3/29	27	16	23	14	28	14	32	22
3/30	34	18	30	15	34	19	36	18
3/31	36	18	28	17	38	20	39	22
4/1	33	21	27	14	31	22	36	27
4/2	MSG	MSG	MSG	MSG	36	19	38	20
4/3	36	23	34	18	35	25	39	29
4/4	53	28	43	32	53	32	48	29
4/5	56	35	54	37	58	42	55	36
4/6	59	38	54	33	62	43	57	36
4/7	57	40	48	43	62	46	59	36
4/8	52	37	50	32	65	32	51	35
4/9	45	23	39	18	34	22	42	23

TABLE 13. Avalanches at Washington Pass April 3-8, 1977.

DATE	EST. TIME	AVALANCHE PATH	STANDARD USFS AVALANCHE CLASSIFICATION	DESCRIPTION OF RUN
4/3	PM	Cutthroat Ridge (all paths)	WL-N-2	through mid run-out
		Whistler Mtn. (all paths)	WL-N-2	through mid run-out
		Kangaroo #4	WL-N-3	to upper track
		Liberty Bell and Spire Gulch (all paths)	WL-N-1 and 2	to upper track
		moderate bank sluffs		
4/4	AM	Cutthroat Ridge (all paths)	WL-N-1 and 2	all small
		Liberty Bell (all)	WL-N-1	slides not
		Spire Gulch	WL-N-1	to road
4/5	PM	Cutthroat Ridge (all)	WL-N-1	- - -
		Kangaroo # 6	SS-N-2	to upper track
4/6	AM/PM	Cutthroat Ridge #7, 10	WL-N-2	to shoulder of highway between 1100 and 1330
4/7	1100	Cutthroat Ridge # 4	WS-N-2	to within 100' of highway
	1100	Cutthroat Ridge # 10	WL-N-2	to shoulder
	1230-1330	Helicopter Meadows	WS-N-3	to valley floor; 3-6' fracture
	"	Cutthroat Ridge # 8	WS-N-3	across road; 6x50'
	"	Cutthroat Ridge # 7	WS-N-2	small amount to road
4/8	1155	Liberty Bell # 3	WL-N-3	across road; 6x30'
		Liberty Bell # 2	WL-N-3	into road; 2x20'

an interaction of the first two contributory factors to avalanching mentioned above. However, as high freezing levels and very warm daytime and overnight temperatures continued through April 4 and 5 at Washington Pass (see Tables 11 and 12) and throughout the Cascades, increasingly deeper layers of the snowpack became weakened through melt and freewater percolation. As a result, more avalanching of deeper layers in the snowpack occurred in the Washington Pass area on April 4 and 5 (see Table 13).

The avalanche forecasting methodology, discussed in section 4.3, was used in determining the avalanche potential in this situation (see especially section 4.3.2, E-G). Here all of the basic questions to be considered by the forecaster (i.e., B through G in section 4.3.2 and illustrated in Figure 7) came into play: what is the current physical state of the snowpack, and what is or will be the effect of the current and projected weather on this snowpack? Forecasters were definitely considering the effects of the current and projected weather on April 4 and 5, and forecasts issued on the morning of April 5 indicated concern over a fast-approaching isothermal snowpack at Washington Pass combined with potentially weak TG layers near the ground.

This concern over an isothermal, melt-weakened snowpack (decreasing tensile strength) on the morning of April 5 was reinforced that afternoon through slide activity and snowpack reports from field personnel. Stevens Pass reported wet slab slides to the ground (initiated by wet, loose point releases) on Skyline Ridge (a south-southeast aspect slope in the Stevens Pass area), crossing the old highway around noon on April 5; and snowpack reports from Washington Pass the same day indicated snowpack temperatures between -0.5°C and -0.2°C and rising. Additional snowpack information from climbers on Mt. Rainier and from Paradise Rangers also indicated very rotten, isothermal snow in the upper layers of the pack with significant wet loose and wet slab slide activity on the mountain and on the roadway. An avalanche slid to the Paradise road during the afternoon, blocking part of one uphill lane. Although substantial snowpack settlement was occurring throughout the Cascades during this period (see Table 10), the increasing instability of the snowpack due to melt and freewater percolation outweighed the usual stabilizing effect of significant settlement. Avalanche advisories issued late on April 5 and 6 continued to stress increasing avalanche potential due to expected continuation of very warm air temperatures, high freezing levels, little overnight cooling, and penetration of substantial solar radiation into the snowpack.

With yet more avalanche activity reported at Washington Pass on April 6, forecaster emphasis on April 6 and 7 remained on the current and projected effect of warming on the already unstable snowpack. But an expected decrease in avalanche activity due to cooling temperatures and lowering freezing levels anticipated on April 8 was also mentioned in the afternoon forecast on April 6, as forecasters hoped to advise field personnel of a potentially stabilizing snowpack (expected on April 8 and 9) as soon as possible. Cooling temperatures and lowering freezing levels had been forecast as early as the morning of April 5 on the extended forecast. Yet even with anticipated cooling, the current slide cycle was far from being over.

After four days of continuous above-freezing air temperatures in the starting zones of all the major Washington Pass avalanche paths, the Cutthroat Ridge paths (Nos. 4, 7, 8 and 10) released around noon on April 7 (all wet slab slides) and either crossed the road or closely approached the shoulder. Nearby Helicopter Meadows slide path also released a wet slab to the valley floor (2400 foot vertical, 7000 foot length) during the same time (see Table 6). Apparently melt had now reached the weakened TG layers in the lower part of the snowpack. Snowpits dug at Crystal Mountain on the morning of April 7 by professional ski patrolmen on south and east aspect slopes near the 6000 foot level substantiated the now apparently widespread arrival of an isothermal "rotten snow" condition to the entire Cascade snowpack (at least below 7,000 feet).

With the substantial cooling and lowering freezing levels expected on the morning of April 8 and the fact that most slide paths on Washington Pass had self-stabilized through earlier sliding and/or settlement, avalanche advisories on the afternoon of April 7 and morning of April 8 called for decreasing avalanche potential at Washington Pass on the morning of April 8. However, these forecasts did not consider a relatively later arrival of the anticipated cold air mass in the northeast Cascades, nor did they take into account a change in the radiation balance of the snow surface due to increasing cloudiness in the Washington Pass area late in the night on April 7. Previous evenings during this week had been accompanied by warm air temperatures but clear nights, thus allowing for radiational cooling and possible refreezing of the upper snowpack at night (and in any case substantially slowing any overnight snow-melt occurring in the surface snow layers). With overnight cloudiness on April 7 preventing significant radiational cooling of the surface snow, and with above freezing air temperatures persisting in the starting zones through noon on April 8, the Liberty Bell slide paths (Nos. 2 and 3) released (wet-loose) on April 8, crossing and closing the highway. The afternoon forecast on April 8 reflected this change of events, but by late afternoon below freezing air temperatures covered all of the Cascades above 4000 feet and finally avalanche activity, as expected, declined rapidly.

This case study of a "spring" avalanche cycle at Washington Pass provides an overview of the Forecasting Office operation during a high avalanche activity period. During this time (April 3-8), project forecasters were in fairly constant communication with maintenance and avalanche personnel at the Washington Pass avalanche area, and in addition all weather and avalanche forecasts issued were sent to WSDH supervisory personnel in Wenatchee via teletype to keep key operations personnel informed of the avalanche potential. Weather and avalanche situations such as this throughout the past two winters have given project forecasters excellent training and provided insight into techniques for effective avalanche forecasting for all of the pass areas.

5. RECOMMENDATIONS

5.1 Field Operations

- Stevens Pass. It is strongly recommended that requirements for remote/field telephone installations in the future be conveyed to the phone company in writing several months in advance of expected operational need and that the phone company be requested to assign one individual (telecommunications specialist) who would deal on a knowledgeable level with project telecommunication requirements.

In order to maintain current levels of data flow for future operation of the telemetry system:

  - Replace the lower section of telemetry land line (approximately 5000 feet within ski area from Snow Ranger's quarters to top of Chair #5). Re-trenching by the sewer company resulted in the loss of over half of the initial pairs of wires available for telemetry. Unreliability of USFS lines for the remainder of the distance dictates that new telemetry lines be installed and buried for future reliable data transmission from this remote site to the Forecasting Office and to Berne Snow Camp.
  - Complete burial of existing telemetry and power lines across Summit/Grace Lakes Basin (uncompleted last season), and replace some sections of power line (approximately 3000 feet, most of which is State surplus) in the same area. It is <u>essential</u> that this work be completed as part of an ongoing operational program in order to maintain current levels of data input from this area.

Additional instrumentation recommended for this site which would upgrade its usefulness:

  - Install a slow-scan television (high resolution model) of total snow depth stake (to be installed) at the remote precipitation site in the Summit Lakes Basin. Television transmission would utilize existing automatic data telemetry from the precipitation site to the Forecasting Office. This system would be helpful as sunshine detector (shadow of stake would be evident), as well as snowfall/settlement monitor if used in conjunction with interval snow stake.

- <u>Snoqualmie Pass</u>
  - High (Denny Mountain, 5600 feet) and low (Pass level, 3000 feet) elevation temperatures from existing shielded thermistors should automatically be telemetered hourly to the Forecasting Office. These data are already received automatically at either the WSDH avalanche office at the Pass or at the base of the Alpental ski area.
- <u>Hurricane Ridge</u>
  - Install a RF filter in the anemometer line to cut down undesired noise, and/or install shielded cable.
  - Expand the scale used for wind speed to cover the entire range of voltages.
  - Modify telemetry system input at the Forecasting Office from manual on-call to automatic hourly read-out on existing recorder. This would provide for automatic all-hours reception of this valuable weather data and is <u>very strongly recommended</u>.
  - Add more adequate radiation shielding for the temperature sensor. Although temperature values in general appeared accurate and reliable, significant unexpected temperature rises during morning hours (0800-1000) on clear days indicated that better radiation shielding is necessary for the temperature sensor.

  - Add modified precipitation gage (see Appendix C) to Hurricane Ridge site, to be telemetered with existing radio/phone telemetry equipment to Forecasting Office. This addition is strongly recommended.
  - Design and install radiometer or other solar radiation sensing device at the Hurricane Ridge summit site with input telemetered automatically hourly to the Forecasting Office (using existing radio/phone telemetry equipment).

- White Pass. Improvements for this area are recommended to facilitate the measurement of precipitation quantities. (The current method uses a vertical snow sample obtained from a snow stake through insertion of an 8-inch snow can, which is then weighed on a spring scale. The water equivalent of snow is read directly off of a conversion chart.) Install a recording weighing-bucket precipitation gage with wind baffle for measuring precipitation (both rain and snow). The gage orifice should be heated to prevent canopying of snow (power is available at the maintenance shed). The entire precipitation apparatus could readily be installed on the existing instrumentation tower in the snow study plot to the northwest of the maintenance shed.
- Washington Pass. The usefulness of this reporting station would be greatly increased by improved communications. If it becomes necessary to forecast operationally for this Pass, direct communications with the Forecasting Office will be a necessity. Establish a test radio-phone through Okanogan for direct communications between the forecaster and the observer.
- Paradise/Mt. Rainier. Telemeter automatically hourly via phone line to the Forecasting Office in Seattle temperature from existing shielded thermistor on NPS ski dorm telephone/instrument pole. Install a modified tipping bucket snow/rain gage with wind baffle in NPS snow study plot on existing instrument tower and telemeter precipitation automatically hourly via phone lines (as in Stevens Pass instrumentation system) to Forecasting Office in Seattle.
- Crystal Mountain. Upgrade and improve snow sample collection and weighing equipment, particularly at the Green Valley Snow Study Plot.
- Snow-line Reports. Recommended improvements in reporting format:
  - Transmit daily throughout the season new and total snow depths on the 0600-0630 report (quite often this past season this information was not available until the 0900-0930 report). This snow information can be critical in making accurate evaluations of the avalanche potential and/or recommendedations of road closures during a storm situation. This is especially true early and late in the season when avalanche crews are cut back. In the early morning hours (0600-0800) forecasters do not have sufficient information concerning new snowfall in the Cascades to make a good evaluation of the situation, particularly given the high possibilities of large regional snowfall variations

in the Cascades. Often a WSDH supervisor will call the Forecasting Office around 0800 and want some advice on the avalanche situation, and all the information the forecaster has is what the weather forecast will be, without any real solid idea of how much snow has already fallen at a certain area since the morning before. Consistent transmission of new and total snow data on Snow-line Reports every morning at 0600-0630 would greatly alleviate this problem.

- Transmit total and new snow received since the last report on every Snow-line Report (in addition to 0600-0630 report discussed above). New snow depth updates while a storm is in progress are critical in avalanche and mountain weather forecasting, while reports of total versus new snow amounts give forecasters a good idea of snowpack settlement. These two snow observations should be extremely simple to make by WSDH maintenance crews, and require very little time and effort. Total and interval snow stakes are inexpensive to construct, relatively easy to install, and require very little maintenance. During the winter, cleaning of the interval snow stake board and replacement of the same on a new flat snow surface after each observation are the only requirements. At the very least, highway maintenance crews can closely observe a total snowstake and make rough estimates of new snow amounts they are having to scrape off the highway. Forecasters who are trying to recommend road closures and/or forecast avalanche activity should not have to second-guess new snowfall amounts on the basis of "chains required" or other indirect observations (e.g., "snowing and blowing").

5.2 Forecasting Office

- Replace current flashing light "paging system" in Forecasting Office with keyed extension phone.
- Modify or augment existing Esterline-Angus miniservo recorder to include automatic timing stamp or mark for clarity of observation times.
- Extend teletype system for hard-copy of forecasts to WSDH maintenance supervisory offices and USFS avalanche forecast office.
- Modify or replace existing Stevens Pass (Berne Snow Camp) and Forecasting Office teletypes to both send and receive modes (ASR teletypes), for two-way observation transmission.
- Further modify or replace all teletype equipment for compatability with all existing NWS teletypes.
- Install digital equipment for conversion of analog to digital columnar read-outs for all telemetry input. Possible interfacing of this digital read-out with teletype equipment for automatic re-transmission through teletype network.

5.3 Operational Project

These recommendations give minimum guidelines for a work plan and staffing requirements.

5.3.1 Work Plan (September 1 through September 30 of the following year, by functional time periods).

- September 1 - November 15
  1. Arrange communication facilities for data telemetry and for Forecasting Office operation.
  2. Maintain, calibrate, and install field and office instrumentation and telemetry equipment, including replacement of defective equipment.
  3. Conduct forecaster orientation and review regarding instrumentation, any new National Weather Service products, forecasting techniques, and requirements of cooperating agencies regarding forecast output.
  4. Set up and implement observational data network.
  5. Conduct workshops (on-site) for observers.
  6. Set up Forecasting Office.
- November 15 - April 15
  1. Operation of Forecasting Office, including field snowpack research necessary for avalanche forecasts.
  2. Maintain communication and coordination with cooperating agencies.
  3. Maintain field instrumentation.
  4. Compile data evaluation of forecast accuracy and research possible methods to improve forecast accuracy.
  5. Compile data file and summary.
- April 15 - May 31
  1. Remove and store instrumentation sensors and other field telemetry equipment.
  2. Review instrumentation and project possible replacements where required.
  3. Review year's operation.
  4. Prepare recommendations and proposals for next year.
  5. Maintain communication and coordination with cooperating agencies.
  6. Compile data evaluation of forecast accuracy.
  7. Complete data file and summary.
  8. Prepare and submit yearly report.
- June 1 - September 30
  1. Coordinate printing and distribution of approved yearly report.

5.3.2 Staffing (September 1 through September 30 of the following year, by functional time periods).

- September 1 - November 15
  1. Two avalanche weather forecasters, 2-1/2 mos. each at 100%
  2. One instrumentation engineer, 1-1/2 mos. at 100%
  3. One program assistant, 2-1/2 mos. at 25%
  4. One field assistant, 1/2 mo. at 100%
  5. One machinist, 1/2 mo. at 100%
- November 15 - April 15
  1. Two avalanche weather forecasters, 5 mos. each at 100%
  2. One consultant/senior meteorologist, 3 mos. at 100%
  3. One instrumentation engineer 1/2 mo. at 100%
  4. One program assistant, 5 mos. at 25%

  Two avalanche weather forecasters will staff the office November 15-January 1 and April 1-15. During the height of the avalanche season (January 1 to April 1), three forecasters are required to adequately staff the Forecasting Office due to greater staffing requirements during storm situations, increased need for snow and avalanche field observations, more frequent instrument maintenance inspections, and closer personal contact with data network observers.
- April 15 - May 31
  1. Two avalanche weather forecasters, 1-1/2 mos. each at 100%
  2. One program assistant, 1-1/2 mos. at 25%
- June 1 - September 30
  1. One program assistant, 4 mos. at 25%

Total staffing requirements:

Two avalanche weather forecasters, 9 mos. each at 100%
One consultant/senior meteorologist, 3 mos. at 100%
One instrumentation engineer, 2 mos. at 100%
One program assistant, 13 mos. at 25%
One field assistant, 1/2 mo. at 100%
One machinist, 1/2 mo. at 100%

6. CONCLUSIONS

This contract over the past two years has addressed the questions of whether it is possible to establish a viable central forecasting office for mountain weather and avalanche conditions in the Cascade Mountains, and, if so, how this should be done. The answer to the first question is plainly yes. A forecasting center has been in operation for two years and has demonstrated that it provides a useful service to both WSDH and other cooperating agencies. The second question has also been answered by demonstrating that specialized forecasting of this kind depends on a complete operations system rather than a single individual or technical solution.

There are five essential elements to a central avalanche and mountain weather forecasting system. Each of these has been developed and tested during the past two years. The details of these elements have been setforth at length in the body of this report and in last year's Interim Report. In summary they are:

- A data acquisition network. This includes both human observers from WSDH staff and cooperating agencies as well as automated telemetry. The key elements are the sensors for measuring such parameters as wind, precipitation and air temperature, and technical methods and data-logging procedures of the observers, and the knowledgeable choice of which snow and weather elements are essential for the areas in question. On-site examination of snow structure by forecasting personnel is a critical part of the data acquisition.
- A data transmission facility. Primary communication for this project has been based on the telephone. Direct and frequent discussions between observers and forecasters are very important. Automatic tape recordings for message reception and relay play an important role. The direct data telemetry has also been designed to work through commercial telephone line, permitting automated and manual interrogation of distant field stations with immediate data return.
- Access to high-quality meteorological data and forecasts. The National Weather Service in Seattle has been a major participant in the Forecasting Office operation, providing desk space and access to the full spectrum of data flow and consultation with working meteorologists in a major NWS forecasting office. Without such access, the project forecasters would be severely handicapped in preparing their specialized forecasts for the mountain passes.
- Trained and experienced forecasters working with a rational methodology. Professional and graduate-student meteorologists with various backgrounds in weather service and avalanche forecasting have developed specialized skills relevant to the Cascade Mountains over the past two winters. They have worked from established forecasting methods to make improvements both in application of mountain meteorology and in the basic methodology for avalanches. A systematic formulation of avalanche forecasting methods has been made for the first time. This is an outstanding accomplishment for the project and for the science as a whole, as well as for the immediate goals of the contract.

- A system for disseminating the forecasts to the intended users. A combination of telephone and teletype has served the immediate needs of the WSDH at the mountain passes. The same automatic tape recorders used for data acquisition have also been part of the dissemination scheme. The information output from the project reaches the general public through the USFS, one of the cooperating agencies.

In sum, we conclude that an operational central forecasting program can work if it is based on an integrated system which balances in correct proportion these components. If one or more of the components is missing, it cannot succeed.

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APPENDIX A

Weather and Avalanche Forecasts, April 1-8, 1977

STEVENS PASS

WSDH AVALANCHE CNTR

4/1/77 0830 PST

WX SYNOPSIS

STATIONARY HI PRESSURE AT THE SURFACE AND ALOFT COVERS THE EASTERN PACIFIC AND THE GULF OF ALASKA KEEPING WASHINGTON IN A NORTH-NORTHWESTERLY FLOW. SMALL DISTURBANCES IN THIS FLOW ARE PASSING JUST NORTH OF THE STATE GIVING A LITTLE BOOST TO THE PRECIPITATION. THERE IS ENUF MOISTURE IN THE FLOW TO KEEP SKIES PARTLY CLOUDY WITH A FEW SHOWERS BETWEEN DISTURBANCES. THERE ARE EARLY INDICATIONS OF A SIGNIFICANT WARM-UP LATE SATURDAY OR EARLY SUNDAY.

WX FORECAST

SCATTERED SHOWERS OF RAIN OR SNOW TODAY AND EARLY SATURDAY. INCREASING CHANCE OF SHOWERS LATE SATURDAY AFTERNOON AND EVENING.

SNOW LEVEL: 3500 FT TODAY
4000 FT SATURDAY

WINDS THRU THE PASSES: WESTERLY 5-15 KTS TODAY AND SAT

FREE WINDS AT 5000 FT LEVEL: NORTH-NORTHWESTERLY 20-30 KTS TODAY AND SAT

QPF:

24 HRS ENDING	4AM SAT	4AM SUN
WASH PASS	<.25	.25
WHITE PASS	"	"
CHINOOK PASS	"	"
CRYSTAL MT	"	"
STEVENS PASS	.25	.25-.5
SNOQ PASS	"	"
CAYUSE PASS	"	"
PARADISE	.25-.5	"

EXTENDED OUTLOOK (SUN-TUES)

TEMPERATURES NEAR OR SLIGHTLY ABOVE NORMAL SUN COOLING MON AND TUES WITH LIGHT AMOUNTS OF PRECIP THRUOUT THE PERIOD

AVALANCHE FRCST

THE SNOW PACK IS GENERALLY STABLE HOWEVER THE POSSIBILITY OF A WARM UP LATE SAT OR EARLY SUNDAY COULD INCREASE THE HAZARD ABOVE 6000 FT WHERE TEMPS HAVE BEEN BELOW FREEZING SINCE THE LAST MAJOR SNOWFALL.

30 DAY OUTLOOK FOR APRIL

BELOW AVERAGE TEMPERATURES. BELOW AVERAGE PRECIP.

END RICHOUT

WSDH AVALANCHE CNTR

4/1/77 1600 PST

WX SYNOPSIS

HI PRESSURE AT THE SURFACE AND ALOFT COVERS THE EASTERN PACIFIC AND THE GULF OF ALASKA. THE UPPER LEVEL RIDGE IS NOW BEING FORECAST TO MOVE SLOWLY EASTWARD OVER THE WEEKEND. THIS WILL HAVE THE EFFECT OF DRYING AND WARMING THE WEATHER THROUGH MONDAY.

WX FORECAST

PARTLY CLOUDY WITH A CHANCE OF A FEW SCATTERED SHOWERS TODAY AND SATURDAY. WARMING TREND SATURDAY AND SUNDAY.

SNOW LEVEL:	3500 FT TODAY 4500 FT SAT MORN 5500 FT SAT NIGHT
WINDS THRU THE PASSES:	WESTERLY 5-15 KTS TODAY AND SATURDAY BECOMING LIGHT AND VARIABLE SAT EVENING
FREE WINDS AT 5000 FT LEVEL:	NNW 15-25 KTS TODAY BECOMING 10-20 KTS SAT

QPF: LESS THAN 1/4" W.E. ALL STATIONS BOTH SAT AND SUN EXCEPT PARADISE WHICH WILL HAVE 1/4" FOR 24 HRS ENDING 4AM SAT

EXTENDED OUTLOOK (SUN-TUES)

WARMING TREND WITH TEMPERATURES NEAR OR ABOVE NORMAL BY MONDAY WITH LITTLE OR NO PRECIP

AVALANCHE FRCST

FOR SNOQ PASS NORTHWARD: THE SNOW PACK IS GENERALLY STABLE HOWEVER WARMING TEMPERATURES LATE SATURDAY AND EARLY SUNDAY COULD INCREASE THE HAZARD ABOVE 6000 FT WHERE TEMPS HAVE BEEN BELOW FREEZING SINCE THE LAST MAJOR SNOWFALL.

FOR SOUTH OF SNOQ PASS: MOD-HEAVY AMOUNTS OF SNOW OVERNIGHT HAS CREATED A MOD-HIGH HAZARD ABOVE4000 FT.

CAYUSE PASS: SOME SLIDES INTO THE HIGHWAY MAY OCCUR TODAY HOWEVER THIS HAZARD SHOULD DECREASE SATURDAY AS THE PACK IS STABILIZING ~~WITH THE WARM TEMPS OF TODAY AND~~ WITH SURFACE SLUFFING AND SOME SMALL SLIDES TODAY.

END RICHOUT

WENATCHEE RDECD BEV
HAVA A GOOD WEEKEND
YOU TOO
STEVENS PASS

STEVENS PASS

AVALANCHE FRCST

0900 PST, APRIL 2, 1977

WX. SYNOPSIS *****

GRADUAL EASTWARD PROGRESSION OF A LARGE HI PRESSURE SYSTEM IN THE E PACIFIC IS XPECTD TO OCCUR OVER THE WEEKEND. THIS MOTION OF THE HI PRESSURE WILL RESULT IN A SUBSTANTIAL RISE IN FREEZ LVLS AND WARMING AIR TEMPS SAT AND SUN, W/ THE RDG PUSHING MOST PRECIP WELL TO THE N OF THE STATE THRU MON.

WX FRCST*****

VARIABLE HI CLDNESS SAT AND SUN W/ PATCHY VALLEY FOG IN MORNINGS. OTHERWISE FAIR AND WARMER THRU SUN.

FREEZ LVL NR 6000 FT SAT RSG TO NR 7500 FT SAT EVE AND TO 9000 FT SUN MORN.

WINDS THRU THE PASSES W 10-15 KTS, BECMG STRONGER SAT NITE.

FREE WINDS AT 5000 FT LVL N-NW 10-20 KTS, DECRG ON SUN.

24-HR QPF ENDING AT:	4AM SUN	4AM MON
ALL AREAS	<1/4	<1/4

XTENDD WX. OUTLOOK MON-WED: LITTLE OR NO PRECIP XPECTD W/ TEMPS ABOV NORML.

AVALANCHE ADVISORY *****

FOR SNOQ PASS NORTHWARD: THE SNOPACK IS GENERALLY STABLE, HOWEVER, WARMING TEMPS ASSOCIATED W/ A RSG FREEZ LVL COULD INCR THE HAZARD ABOV 6000 FT, ESP ON N AND E ASPECT SLOPES, WHERE TEMPS HAVE BEEN BLO FREEZING SINCE LAST MAJOR SNOFALL. THE HAZARD ON WASH PASS SHUD INCR SGFCTLY BY SUN MORN W/ SLIDES AFFECTING THE ROADWAY BY SUN AFT.

FOR SNOQ PASS SOUTH: MODERATE AMTS OF NEW SNOW RECD THURS HAVE STABILIZED CONSDRBLY FRI W/ SFC SLUFFING AND SMALL SLIDES. HWVR, THE HAZARD SHUD INCR ABOV 6000 FT TDA AND SUN W/ THE RISING FREEZ LVLS. RECOMMEND CHINOOK PASS REMAIN CLOSED THRU WARM-UP AND CAYUSE PASS SLIDES W/ HI STARTING ZONES NR 6000 FT BE CLOSELY MONITORED.

END/MARKOUT

STEVENS PASS

AVALANCHE FRCST

1300 PST, SATURDAY, APRIL 2, 1977

WX. SYNOPSIS ******

NO CHANGE FROM 0900

WX FRCST ******

CHANCE OF A FEW SCTTERED SNO SHWRS SAT AFT, MAINLY N, DECRSG SAT EVE. VARIABLE HIGH CLOUDS SUN, OTHERWISE MOSTLY FAIR AND WARMER, W/ PATCHY VALLEY FOG IN MORNINGS.

FREEZ LVL NR 6500 FT RSG TO NR 7500 FT SAT EVE AND TO 9000 FT SUN MORN.

WINDS THRU THE PASSES W 10-15 KTS, CONTINUING THRU SUN.

FREE WINDS AT 5000 FT LVL N-NW 10-20 KTS, DECRSG LATE SUN.

24-HR QPF ENDING AT:	4AM SUN	4AM MON
ALL STATIONS	<1/4	<1/4

EXTENDD WX OUTLOOK MON-WED: NO CHANGE FROM 0900.

AVALANCHE ADVISORY *****

NO CHANGE FROM 0900.

END/MARKOUT

AVALANCHE FRCST

0830 PST, SUNDAY, APRIL 3, 1977

WX SYNOPSIS *****

A VERY STRONG HI PRESSURE AREA AT THE SFC AND ALOFT IS CONTINUING TO SLOLY DRIFT E IN THE E PACIFIC. WARM AND DRY AIR ASSOCIATED W/ THIS SYSTEM WILL CONTINUE OVR THE CASC THRU MON. THE FREEZ LVL ON THE CST AT QUILLAYUTE AT 4AM THIS MORN WAS 11,300 FT, AND IS XPCTED TO REMAIN NR 11-12,000 FT THRU MON. A GRADUAL FLATTENING OF THE RDG IS XPECTD OVR THE NXT FEW DAYS W/ A CHANCE OF SOME LITE PRECIP BY MID-WEEK.

WX FRCST *****

PTLY CLOUDY SUN MORN W/ PATCHY VALLEY FOG. MOSTLY FAIR AND VERY WARM SUN AFT AND MON W/ VARIABLE HI CLDINESS.

FREEZ LVL NR 9000 FT RSG TO NR 10,000 FT THIS AFT AND TO NR 11,000 FT BY THIS EVE.

FREE WINDS AT 5000 FT LVL N 10-15 KTS.

WINDS THRU THE PASSES W 10-20 KTS, DECRG ON MON.

24-HR QPF ENDING AT:	4AM MON	4AM TUES
ALL STATIONS	<1/4	<1/4

XTENDD WX OUTLOOK TUES-THURS: MOSTLY DRY AND WARM, XCPT CHANCE FEW SHWRS WED, MAINLY N.

AVALANCHE ADVISORY *****

FOR WASH AND CAYUSE PASSES: THE AVAL HAZARD IN BOTH AREAS SHUD INCR SIGFTLY BY THIS AFT W/ CLEARING SKIES, WARMING TEMPS, AND VERY HI FREEZ LVLS. SLIDES MAY AFFECT THE RDWYS BY THIS AFT AS THE UPPR LAYERS OF THE SNOPACK LOSE STRENGTH BY MELT AND FREEWATER PERCOLATION.

THE GENERAL AVAL HAZARD IN THE CASC BLO 6000 FT IS LO, BUT IN SOME AREAS OVERNITE CLDINESS PREVENTED RADIATIONAL COOLING AT THE SFC, AND AS A RESULT SFC AIR TEMP HAVE BEEN ABOV FREEZ FOR CLOSE TO 24 HRS. SUCH XTENDD WARMING OFTEN RESULTS IN A VERY UNSTABLE SNOPACK.

THE HAZARD CONTINUES HI ABOV 6000 FT AS THE WARM TEMPS AND RSG FREEZ LVLS CONTINUE TO WEAKEN THE SNOPACK (UPPR SNOPACK). THIS SITUATION SHUD MODERATE SOMWHAT ON MON AS THE SNOPACK SETTLES AND DENSIFIES AND OVERNIGHT COOLING UNDER CLEARING SKIES FORMS A CRUST.

END/MARKOUT

STEVENS PASS

AVALANCHE FRCST

1300 PST, SUNDAY, APRIL 3, 1977

WX SYNOPSIS *****

NO CHANGE FROM 0830.

WX FRCST *****

MOSTLY FAIR AND VERY WARM SUN AFT AND MON W/ VARIABLE HI CLDINESS AND AREAS OF VALLEY FOG MON MORN.

FREEZ LVL NR 9500 FT RSG TO NR 10,000 FT THIS AFT AND TO NR 11,000 FT BY MON MORN.

WINDS THRU THE PASSES W 10-15 KTS, BECMG LITE AND VARIABLE ON MON.

FREE WINDS AT 5000 FT LVL N 10-15 KTS, DECRG MON.

24-HR QPF ENDING AT:	4AM MON	4AM TUES
ALL STATIONS	<1/4	<1/4

XTENDD WX OUTLOOK TUES-THURS: MOSTLY DRY AND WARM AS RDG CONTINUES ALONG CST. CHANCE FEW SHWRS WED, MAINLY N.

AVALANCHE ADVISORY:

NO CHNG FROM 0830, XCPT ADD: A LACK OF RECENT INFORMATION FROM WASH OR CAYUSE PASS MAKES UPDATING OF THIS ADVISORY DIFFICLT.

END/MARKOUT

LARRY DROVEN--JUST A QUESTION: I WAS NOT ABLE TO REACH ANY RADIO OPERATOR AT WENATCHEE OVER WEEKEND. HAVE THEY BEEN DISCONTINUED AS OF APRIL 1? IS THERE ANY OTHER WAY FOR US TO GET WX AND AVALANCHE REPORTS FROM WASH PASS ON WEEKENDS, OTHER THAN SNOLINE? I WILL BE FRCSTING MON, SO YOU CAN LEAVE A NOTE ON THIS THING. THANKS--HOW'S YOUR SITUATION AT STEVENS WITH A FAST BECOMING ISOTHERMAL SNOPACK? ANY COMMENTS? AGAIN THANKS. MARKOUT.

AVALANCHE FRCST

0900 PST, MONDAY, APRIL 4, 1977

WX SYNOPSIS *****

A STAPLE UPPR LVL FLOW PATTERN HAS BEEN ESTABLIXHED OVR THE UNITED STATES W/ A STRONG RDG OVR THE NW AND A DEEP LO COVERING MOST OF THE MID-WEST AND EAST CST. HENCE OUR WARM, DRY WX W/ FREEZING LVLS NR 10-11,000 FT ARE XPCTD TO CONTINUE THRU TUES. AIR TEMPS OF 53 DEG WERE REPTD AT PARADISE AND HURRCN RDG THIS MORNING AT 8AM. A WK FNT IS XPCTD TO PENETRATE THE RDG LATE TUES BUT SHUD BRING LTTL MORE THAN SOME HI CLDINSS ON WED.

WX FRCST *****

MOSTLY FAIR AND CONTINUED QUITE WARM W/ PATCHY VALLEY FOG IN MORN.

FREEZ LVL NR 10,000 FT REMAINING BETWEEN 10-11,000 FT THRU TUES.

WINDS THRU THE PASSES W 5-15 KTS, BECMG LITE AND VAR THIS AFT AND LITE E LATE MON.

FREE WINDS AT 5000 FT LVL N 10-15 KTS, BECMG LITE NE LATE MON.

24-HR QPF ENDING AT:	4AM TUES	4AM WED
ALL STATIONS	<1/4	<1/4

XTENDD WX OUTLOOK WED-FRI: LITTLE OR NO PRECIP XPCTED AS RDG CONTINUES TO DOMINATE WA WX. TEMPS REMNG ABOV NORML.

AVALANCHE ADVISORY *****

FOR WASH AND CAYUSE PASSES: XTENSIVE WET LOOSE SLIDING TO MID AND UPPER ~~LOWER~~ TRACKS SUN AFT STBILIZED MOST SLOPES CONSDBLY AT WASH PASS, ~~AND SMALL BANK SLUFFS DEPOSITED SMALL AMTS OF SNO IN THE RDWY SUN AFT AT WASH PASS.~~ SIMILAR ACTIVITY MAY BE XPCTD W/ FURTHER WARMING THIS AFT, W/ SMALL AMOUNTS OF SNO DEPOSITED IN THE RDWY, NOT BLOCKING TRAFFIC.

FIELD INSTRUMENTATION INDICATES ABOVE FREEZ AIR TEMPS OVERNITE AT THE 5000 FT LVL, AND ALTHO A THIN SFC CRUST FORMED OVERNITE DUE TO RADIATIONAL COOLING, THE SNOPACK CONTINUES TO WEAKEN DURING THE DAY, RAPIDLY APPROACHING A WEAKENED ISOTHERMAL CONDITION. AS A RESULT, THE GENERAL AVAL HAZARD IN THE CASC BLO 10,000 FT CONTINUES MODERATE, ALTHO THIS CONDITION SHUD MODERATE BY TUES NITE W/ MOST SLOPES SELF STABILIZING THRU SLIDES AND/OR SETTLEMENT.

END/MARKOUT WENATCHEE RECD BEV
THANKS, MARKOUT

AVALANCHE FRCST

AVALANCHE FRCST

1400 PST, MONDAY, APRIL 4, 1977

WX SYNOPSIS *****

A STABLE UPPR LVL FLO PATTERN HAS BEEN ESTABLISHED OVER THE U.S., W/ A STRONG RDG OVR THE NW AND A DEEP LO COVERING MOST OF THE MID-WEST AND EAST CST. HENCE OUR WARM DRY ~~BYH~~ WX W/ FREEZ LVLS NR 10-11,000 FT ARE XPCTED TO CONTINUE THRU TUES. AIR TEMPS IN THE 50'S AT THE 5000 FT LVL IN THE CASC THIS AFT ARE EVIDENCE OF THE WARMING. A WK FRONT IS XPCTED TO PENETRATE THE RDG LATE TUES, BUT SHUD BRING LITTLE MORE THAN SOME HI CLDINESS TO WA ON WED.

WX FRCST *****

MOSTLY FAIR AND CONTINUED QUITE WARM W/ PATCHY VALLEY FOG IN MORN.

FREEZ LVLS NR 10,000 FT REMNG BETWEEN 10-11,000 FT THRU TUES.

WINDS THRU THE PASSES LITE AND VARIABLE, BECMG LITE E LATE MON.

FREE WINDS AT 5000 FT LVL N-NE 10-15 KTS, BECMG LITE W LATE TUES.

24-HR QPF ENDING AT:	4AM TUES	4AM WED
ALL STATIONS	NEAR 0	NEAR 0

XTENDD WX OUTLOOK WED-FRI: CHANCE OF A LITTLE PRECIP BY THE END OF THE WEEK AS RDG FLATTENS, W/ TEMPS CONTG ABOV NORML.

AVALANCHE ADVISORY *****

FOR WASH AND CAYUSE PASSES: XTENSIVE WET LOOSE SLIDING TO MID AND ~~LOWER~~ UPPER TRACKS SUN AFT STABILIZED MOST SLOPES CONSDBLY AT WASH PASS. SIMILAR ACTIVITY MAY BE XPCTED W/ FURTHER WARMING THIS AFT, W/ SMALL AMOUNTS OF SNO DEPOSITED IN THE RDWYS. ~~N~~.

FIELD INSTRUMENTATION INDICATES ABOVE FREEZING AIR TEMPS OVERNITE AT THE 5000 FT LVL, AND ALTHO A THIN SFC CRUST FORMED OVERNITE DUE TO RADIATIONAL COOLING, THE SNOPACK CONTINUES TO WEAKEN DURING THE DAY, RAPIDLY APPRCHG A WEAKENED ISOTHERMAL CONDITION (ESPECIALLY IN UPPR LAYERS). AS A RESULT, THE GENERAL ~~AVMM~~ AVAL HAZARD IN THE CASC BLO 10,000 FT CONTINUES MODERATE, ALTHO THIS CONDITION SHUD MODERATE BY TUES NITE W/ MOST SLOPES SELF STABILIZING THRU SLIDES AND/OR SETTLEMENT.

END/MARKOUT

CORRECTIONS: OMIT THE N IN AVALANCHE ADVISORY, 1ST PARAGRAPH AT THE END. AND IN 2ND PARAGRAPH, AVALANCHE ADVISORY, THE AVMM SHUD BE AVAL AND THEN HAZARD. OK?

AVALANCHE FRCST

0900 PST, TUESDAY, APRIL 5, 1977

WX SYNOPSIS *****

THE LARGE BLCKG RDG ALOFT CONTINUES TO DRIFT SLOLY EWD OVR THE NW, WHILE FRONTS PASSING OVR THE TOP OF THE OFFSHORE SFC HI ARE GRADUALLY ERODING IT. AS A RESLT, THE FLO ALFT OVR WA IS XPCTED TO BECM MORE SW BY THURS, ALLOWING FOR AN INCRSG CHANCE OF PRECIP BY THURS, ESP IN THE NORTH. NO MAJOR STORMS ARE XPCTED THRU FRI, HWVR, AS THE FRST WX DSTRBNCS PENETRATING THE RDG ARE XPCTD TO BE QUITE WK.

WX FRCST *****

MOSTLY FAIR AND WARM TUES AND WED, W/ SOME PATCHY VALLEY FOG IN MRNINGS. INCRSG HI CLDINESS LATE WED.

FREEZ LVL NR 10,5000 FT REMNG BETWEEN 10-11,000 FT THRU WED.

WINDS THRU THE PASSES LITE E 5-10 KTS.

FREE WINDS AT 5000 FT LVL NE 10-15 KTS, BECMG LITE S LATE TUES AND STRONGER SW ON WED.

24-HR QPF ENDING AT:	4AM WED	4AM THURS
ALL STATIONS	NEAR ZERO	NEAR ZERO

XTENDD WX OUTLOOK THURS-SAT: CHANCE OF A LITTL PRECIP, MAINLY THURS, AS RDG MOVES E. TEMPS GRADUALLY LWRG BY THE WEEKEND W/ LWRG FREEZ LVLS.

AVALANCHE ADVISORY *****

WARM TEMPS W/ VERY HI FREEZ LVLS HAVE CAUSED STABILIZATION OF THE UPPER SNOPACK IN MOST SLIDE AREAS ON WASH AND CAYUSE PASSES THRU EITHER WET LOOSE SLIDING OR SETTLEMENT. CONTINUED WARM TEMPERATURES THRU WED MAY RESULT IN FURTHER SMALL WET, LOOSE SLIDES AND SLUFFS FROM CUTBANKS, BUT THESE SHUD DIMINISH W/ TIME. RECOMMEND, HWVR, THAT SNOPACK TEMPS BE MONITORED FOR APPRCH TO ISOTHERMAL 0 DEG CELSIUS CONDITION, AS WEAK LOWER LAYERS EXIST NR THE GROUND AT MANY AREAS DUE TO EARLIER TEMP GRAD WKNING, AND SUCH CONDITIONS COULD RESULT IN WET SLAB SLIDES TO THE GROUND.

[illegible]ECD BEV
10-4 MARKOUT

AVALANCHE FRCST

1300 PST, TUESDAY, APRIL 5, 1977

WX SYNOPSIS *****

THE LARGE BLCKG RDG ALFT CONTINUES TO DRIFT SLOLY E OVR THE NW, WHILE WX DISTRBNCES PASSING OVR THE TOP OF THE OFFSHR SFC HI ARE GRADUALLY WKNING IT. AS A RESULT, THE FLO ALFT OVR WA IS XPCTD TO BECM MORE SW BY THURS, ALLOWING FOR AN INCRSG CHANCE OF PRECIP BY THURS, ESP IN THE N, AND GRADUALLY LWRG FREEZ LVLS. NO MAJOR STORMS ARE XPCTED THRU FRI, HWVR, AS THE 1ST WX DISTRBNCS PENETRATING THE RDG ARE XPCTD TO BE QUITE WEAK.

WX FRCST *****

NO CHANGE FROM 0900.

XTENDD WX OUTLOOK THURS-SAT: INCRSG CHANCE OF PRECIP THURS AND FRI AS RDG MOVES FURTHER E AND DEEP LO MOVES SE OFF CST. TEMPS GRADUALLY LWRG BY WEEKEND W/ LWRG FREEZ LVLS.

AVALANCHE ADVISORY *****

FIELD SNOPACK REPORTS INDICATE THAT THE SNOPACK IN MANY AREAS IS VERY CLOSE TO A WEAKENED AND CRITICAL ISOTHERMAL CONDITION. SLIDES WERE REPORTED RELEASING THIS MORNING TO THE GROUND ON SKYLINE RDG IN THE STEVENS PASS AREA. WITH CONTINUED WARM ABOV FREEZ AIR TEMPS XPCTED THRU THE NEXT 24 HRS IN THE MAJOR STARTING ZONES OF MOST SLIDE AREAS IN THE CASCADES, WET SLAB SLIDES TO THE GROUND MAY BE POSSIBLE THIS AFT THRU WED AFT. THIS SITUATION APPRS PARTICULARLY CRITICAL AT WASH, CAYUSE, CHINOOK PASSES AND PARADISE, ALTHO A HIGH HAZARD MAY EXIST THRUOUT THE CASC ABOV 5000 FT.

END/MARKOUT

STEVENS PASS

WSDH AVALANCHE CNTR

4/6/77 0900PST

WX SYNOPSIS

VERY WARM TEMPERATURES SHUD CONTINUE THRU THURS AND POSSIBLE INTO FRIDAY AS THE UPPER LEVEL RIDGE CONTINUES TO DRIFT SLOWLY EASTWARD. SOME COOLING SHOULD BE IN EVIDENCE FRIDAY WITH INCREASING CLOUDINESS AND SLOWLY LWERING FREEZING LEVELS. A WEAK PACIFIC STORM NOW NEAR 140 WEST SHUD MOVE INTO THE AREA LATE FRIDAY AND BRING AN INCREASING THREAT OF PRECIP MAINLY TO THE NORTH PORTION OF THE STATE. ADDITONAL STORMS SHUD BEGIN TO MOVE THRU THE STATE DURING THE WEEKEND THO IT IS TO EARLY TO BE SURE OF THE TIMING AND STRENGHT OF THESE DISTURBANCES.

WX FORECAST

MOSTLY FAIR TODAY AND THURS WITH SOME VALLEY FOG OVERNIGHT. A LITTLE WARMER TODAY. INCREASING HI CLOUDS THURSDAY AFTERNOON.

FREEZING LEVEL: NEAR 10000 FT BOTH DAYS

PASS WINDS: LIGHT EASTERLY 5-10 KTS BOTH DAYS

5000 FT WINDS: SOUTHWEST 10-20 KTS TODAY INCREASING THURSDAY

QPF: FOR ALL STATIONS BOTH DAYS <1/4"

EXTENDED OUTLOOK (FRI-SUN)

COOLING TREND BEGINNING FRIDAY. COOLER SAT AND SUN WITH A CHANCE OF A LITTLE PRECIP LATE FRIDAY AND AGAIN LATE SAT OR SUN.

AVALANCHE FRCST

THE CHANCE OF WET SLIDES OR SLUFFS INTO THE HIGHWAY AT WASH, CHINOOK, AND CAYUSE PASSES CONTINUES TODAY.

THE HAZARD ABOVE 5000 FT CONTINUES HI TODAY PARTICULARLY ON VEGETATION FREE SLOPES AND SLOPES WITH A SOUTHERN ASPECT IN THE EARLY MORNING BUT ON ALL ASPECTS BY LATE MORNING THRU THE AFTERNOON. ALTHOUGH SFC SLUFFS AND SLIDES HAVE HELPED STABILIILIZE THE UPPER LAYERS OF THE SNOWPACK CONTINUED WARM TEMPERATURES, WITH ABOVE FREEZING TEMPS OVERNIGHT IN MANY AREAS, AND STRONG SOLAR INSOLATION WILL CONTINUE TO WARM THE PACK TODAY AND INCREASE THE DEPTH OF THE ISOTHERMAL LAYERS. THIS WILL HAVE THE EFFECT OF INCREASING THE CHANCE OF DEEPER SLIDES.

RECOMMEND CLOSE MONITORING OF SNOWPACK TEMPERATURES TO FOLLOW THE DEPTH OF THE WARMUP IN THE SNOWPACK, PARTICUARLY WHEN IT IS APPROACHING ANY POTENTIAL SLIDING LAYER SUCH AS AN OLD RAIN CRUST OR AN ICE LAYER OR THE GROUND.

END/RICHOUT

AVALANCHE FRCST

WSDH AVALANCHE CNTR

4/6/77 1500 PST

WX SYNOPSIS

THE UPPER LEVEL RIDGE IS CONTINUING TO MOVE SLOWLY EASTWARD AND AN UPPER LEVEL TROF IS NOW DEEPENING OF THE WEST COAST TODAY. WARM TEMPS SHUD CONTINUE THRU THURS AND BEGIN TO COOL ON FRIDAY. TEMPS SHUD BE MUCH COOLER ON SAT. THE FIRST IN A SERIES OF PACIFIC STORMS IS EXPECTED TO MOVE INTO WASH LATER FRIDAY GIVING A LITTLE PRECIP PROBABLY AS LIGHT RAIN AT MOST AREAS. ADDITONAL STORMS MAY MOVE THRU THE STATE LATER IN THE WEEKEND.

WX FORECAST

CONTINUED FAIR AND WARM TODAY WITH PATCHY VALLEY FOG TONIGHT. MOSTLY FAIR THURSDAY WITH INCREASING HI CLOUDS AND SLIGHTLY COOLER DAYTIME TEMPERATURES. INCREASING CLOUDS FRI MORNING WITH A CHANCE OF RAIN BEGINNING FRIDAY AFTERNOON AND COOLER TEMPERATURES.

FREEZING LEVEL:	NEAR 10000 FT TODAY AND THURS
PASS WINDS:	LIGHT EASTERLY 5-15 KTS TODAY AND THURS
5000 FT WINDS:	SOUTHWESTERLY 10-20 KTS TODAY INCREASING THURS
QPF:	FOR ALL STATIONS BOTH DAYS <1/4"

EXTENDED OUTLOOK(SAT-MON)

MUCH COLDER SAT AND SUNDAY WITH A CHANCE OF PRECIP MAINLY LATE SAT AND SUN AND AGAIN LATE MONDAY

AVALANCHE FRCST

THE CHANCE OF WET SLIDES OR SLUFFS INTO THE HIGHWAY AT WASH, CHINOOK, AND CAYUSE PASSES CONTINUES TODAY.
THE HAZARD ABOVE 5000 FT CONTINUES HI TODAY PARTICULARLY ON VEGETATION FREE SLOPES AND SLOPES WITH A SOUTHERN ASPECT IN THE EARLY MORNING BUT ON ALL ASPECTS BY LATE MORNING THRU THE AFTERNOON.
ALTHOUGH SFC SLUFFS AND SLIDES HAVE HELPED STABILIILIZE THE UPPER LAYERS OF THE SNOWPACK CONTINUED WARM TEMPERATURES, WITH ABOVE FREEZING TEMPS OVERNIGHT IN MANY AREAS, AND STRONG SOLAR INSOLATION WILL CONTINUE TO WARM THE PACK TODAY AND INCREASE THE DEPTH OF THE ISOTHERMB LAYERS. THIS WILL HAVE THE EFFECT OF INCREASING THE CHANCE OF DEEPER SLIDES.
RECOMMEND CLOSE MONITORING OF SNOWPACK TEMPERATURES TO FOLLOW THE DEPTH OF THE WARMUP IN THE SNOWPACK, PARTICUARLY WHEN IT IS APPROACHING ANY POTENTIAL SLIDING LAYER SUCH AS AN OLD RAIN CRUST OR AN ICE LAYER OR THE GROUND.
COOLING TEMPERATURES FRIDAY AND ONLY LIGHT AMOUNTS OF RAIN EXPECTED FRIDAY SHOULD BEGIN TO DIMINISH THE HAZARD BY LATER IN THE DAY.

END/RRICHOUT

WSDH AVALANCHE CNTR

4/7/77 0900 PST

WX SYNOPSIS

THE UPPER LEVEL RIDGE IS NOW OVER IDAHO AND IS CONTINUING TO MOVE EASTWARD. THE UPPER LEVEL TROF OFF THE ~~THE~~ COAST HAS DEEPENED CONSIDERABLY OVERNIGHT AND IS NOW FORECAST TO DIG FURTHER SOUTH FOR THE NEXT TWO DAYS. THIS DEVELOPMENT WILL SPLIT THE FLOW SENDING STORMS BOTH TO THE NORTH AND THE SOUTH WITH WASH. ONLY BEING BRUSHED BY THEM. A COLD FRONT IS NOW LOCATED NEAR 130 WEST AND SHUD MOVE INTO THE AREA FRIDAY BRINGING LIGHT PRECIP TO MOST AREAS IN THE FORM OF RAIN.

WX FORECAST

MOSTLY FAIR AND WARM TODAY WITH INCREASING HI CLOUDS. INCREASING CLOUDINESS TONIGHT WITH A CHANCE OF A FEW SHOWERS LATE TONIGHT IN THE SOUTH CASCADES MOVING NORTHWARD. INCREASING CHANCE OF RAIN OR SNOW FRIDAY AFTERNOON BECOMING SHOWERY ON SATURDAY. COOLER BOTH FRIDAY AND SATURDAY.

SNOW LEVEL: 9000 FT TODAY
7000 FT EARLY FRIDAY
5000 FT FRIDAY AFTERNOON
4000 FT SAT MORNING

PASS WINDS: EASTERLY 5-15 KTS TODAY, BECOMING EASTERLY 10-20 KTS W/ HIER GUSTS LATE TONIGHT AND FRI MORNING

5000 FT WINDS: SOUTHWEST 10-20 KTS TODAY
SOUTH-SOUTHWEST 15-25 FRIDAY

QPF:

24 HRS ENDING	4AM FRI	4AM SAT
STEVENS PASS	.25	.25-.5
SNOQ PASS	"	"
WHITE PASS	"	"
CHINOOK PASS	"	"
CRYSTAL MT	"	"
CAYUSE PASS	.25-.5	.5-.75
PARADISE	"	.75-1.0
WASH PASS	<.25	.25

EXTENDED OUTLOOK (SUN-MON)

CHANCE OF A FEW SHOWERS BOTH DAYS, TEMPERATURES SLIGHTLY BELOW NORMAL

AVALANCHE FRCST

CHANCE OF WET SLUFFS OR SLIDES INTO THE HIGHWAY TODAY AT WASH, CHINOOK, AND CAYUSE PASSES WITH CONTINUED WARM OVERNIGHT TEMPS AND EXPECTED WARM TEMPS TODAY. THE HAZARD SHOULD DIMINISH CONSIDERABLY BY MIDDAY TOMORROW AT WASH PASS DUE TO MUCH COOLER TEMPS AND ONLY LITE AMOUNTS OF PRECIP EXPECTED. THE HAZARD COULD REMAIN HIGH AT CHINOOK AND CAYUSE PASSES AS LARGER AMOUNTS OF PRECIP ARE EXPECTED IN THE FORM OF RAIN

THE GENERAL HAZARD ABOVE 5000 FEET CONINUES HI TODAY BUT SHUD DIMINISH TO LOW-MOD IN THE NORTH CASCADES AND MOD-HI
IN THE SOUTH CASCADES TOMORROW
CLOSE MONITORING OF THE SNOWPACK TEMPERATURES TO KEEP TRACK OF THE DEPTH OF THE WARM UP IS RECOMMENDED AGAIN TODAY

END/RICHOUT

WSDH AVALANCHE CNTR

4/7/77 1600 PST

WX SYNOPSIS

NO CHANGE FROM 0900

WX FORECAST

MOSTLY FAIR AND WARM TODAY WITH INCREASING HI CLOUDS. INCREASING CLOUDINESS TONIGHT WITH A CHANCE OF A FEW SHOWERS LATE TONIGHT IN THE SOUTH CASCADES MOVING NORTHWARD. INCREASING CHANCE OF RAIN OR SNOW FRIDAY MORNING CONTINUING FRIDAY AFTERNOON AND BECOMING SHOWERY FRIDAY NIGHT AND SATURDAY.
COOLER BOTH FRIDAY AND SATURDAY.

SNOW LEVEL: 9000 FT TODAY
7000 FT EARLY FRIDAY
5000 FT FRIDAY AFTERNOON
4000 FT SAT MORNING

PASS WINDS: EASTERLY 5-15 KTS TODAY, BECOMING WESTERLY 10-20 KTS W/ HIER GUSTS LATE TONIGHT AND FRIDAY

5000 FT WINDS: SOUTHWEST 10-20 KTS TODAY
SOUTH-SOUTHWEST 15-25 FRIDAY

QPF:

24 HRS ENDING	4AM FRI	4AM SAT
WASH PASS	<.25	.25
STEVENS PASS	"	.25-.5
SNOQ PASS	"	"
WHITE PASS	"	"
CHINOOK PASS	"	"
CRYSTAL MT	"	"
CAYUSE PASS	.25	.5-.75
PARADISE	"	"

EXTENDED OUTLOOK (SUN-TUES)

CHANCE ~~CAHNCE~~ OF A FeW SHOWERS THRU THE PERIOD BUT GREATEST AMOUNTS OF PRECIP WILL BE NEAR THE END OF THE PERIOD. TEMPS WILL BE NEAR NORMAL.

AVALANCHE FRCST

NO CHANGE ~~CAHNGE~~ FROM 0900

END/RICHOUT

WSDH ALANCHE CNTR

4/8/77 0900 PST

WX SYNOPSIS

A COLD UPPER LEVEL TROF IS MOVING QUICKLY INTO THE STATE THIS MORNING WITH A WEAK SURFACE COLD FRONT. FREEZING LEVELS HAVE DROPPED DRASTICALLY IN THE OLYMPICS AND WILL LOWER RAPIDLY DURING THE DAY TODAY IN THE CASCADES. THE GENERAL FLOW IS PRINCIPALLY FROM THE SOUTH SO LITTLE OROGRAPHIC PRECIP IS EXPECTED KEEPING PRECIP QUANTITIES GENERALLY LIGHT EXCEPT AT SOME SOUTHERN STATIONS. THE LATEST FORECASTS CONTINUE TO INDICATE A SPLIT IN THE UPPER LEVEL FLOW HOWEVER THEY KEEP WASHINGTON CLOSER TO THE NORTHERN STROM TRACK WHICH WILL LEAVE THE STATE OPEN FOR ANOTHER STORM EASTER DAY.

WX FORECAST

RAIN OR SNOW THIS MORNING TURNING TO SNOW AT MOST AREAS BY LATE THIS AFTERNOON OR EVENING. SNOW CONTINUING TONIGHT AND TURNING TO SHOWERS EARLY SAT MORNING AND DIMINISHING SAT AFTERNOON WITH SOME PARTIAL CLEARING. INCREASING CLOUDS AGAIN LATE SATURDAY NIGHT.

SNOW LEVEL : 5000 FT THIS MORN
4000 FT THIS AFT
3000 FT EARLY TONIGHT
2500 FT SAT

PASS WINDS: WESTERLY 15-25 KTS W/ HIGHER GUSTS TODAY
WESTERLY 5-15 KTS W/ HIGHER GUSTS IN THE VICINITY OF SHOWERS ON SAT

5000 FT WINDS: SOUTHERLY 25-35 KTS TODAY
SOUTHWESTERLY 15-30 KTS SAT

QPF:

24 HOURS ENDING	4AM SAT	4AM SUN
WASH PASS	.25	<.25
STEVENS PASS	.25-.5	.25
SNOQ PASS	"	"
WHITE PASS	"	"
CHINOOK PASS	"	"
CAYUSE PASS	.5-.75	.5-.75
PARADISE	.75-1.0	"

EXTENDED OUTLOOK (SUN-TUES)

PERIODS OF RAIN OR SNOW MAINLY SUN AND TUES. TEMPS NEAR NORMAL.

AVALANCHE FRCST

RAPIDLY COOLING TEMPERATURES AND LIGHT AMOUNTS OF PRECIP AT MOST AREAS SHUD STABILIZE THE SNOWPACK IN ALL AREAS. SOME SURFACE SLUFFING OF NEW SNOW MAY OCCUR LATE TONIGHT AND SATURDAY AT HIGHER ELEATIONS BUT NO ACTIVITY OF SIGNIFICANCE IS EXPECTED THRU SAT.

END/RICHOUT

STEVENS PASS

WSDH AVALANCHE CNTR

4/8/77 1630 PST

WX SYNOPSIS

A WEAK COLD FRONT MOVED THRU THE CASCADES TODAY BRINGING A LITTLE PRECIPITATION BUT LARGE TEMPERATURE DROPS. SHOWERS ASSOCIATED WITH THIS FRONT SHUD CONTINUE THIS AFTERNOON AND EVENING HOWEVER ANOTHER BURST OF PRECIP IS FORECAST FROM SATELLITE PICTURES WHICH SHOW A LOW CENTER OFF THE COAST WITH ASSOCIATED LARGE AMOUNTS OF CONVECTIVE ACTIVITY. THIS SHUD MOVE THRU THE CASCADES LATE TONIGHT AND EARLY SAT.

WX FORECAST

SNOW TODAY AND TONIGHT BREIFLY MOD-HEAVY IN SHOWERS, CONTINUING EARLY SAT AND DIMINISHING SAT AFTERNOON AND EVENING. INCREASING CHANCE OF SNOW AGIN SUNDAY MORNING

SNOW LEVEL: 3000 TONIGHT
2500 EARLY SAT
2000 LATE SAT MORN

PASS WINDS WESTERLY 10-20 KTS WITH HIER GUSTS TODAY AND SAT

5000 FT WINDS: SOUTH-SOUTHWESTERLY 25-35 KTS TODAY BECOMING WEST SOUTHWEST 10-20 SAT MORNING

QPF: 24 HRS ENDING 4AM SAT 4AM SUN

WASH PASS	.25-.5	.25
STEVENS PASS	.5-.75	.25-.5
SNOQ PASS	"	"
WHITE PASS	"	"
CHINOOK PASS	"	"
CRYSTAL MT	"	"
PARADISE	1.0-1.25	.5-.75
CAYUSE PASS	"	"

EXTENDED OUTLOOK (MON-WED)

PERIODS OF RAIN OR SNOW TEMPERATURES NEAR NORMAL

AVALANCHE FRCST

RAPIDLY COOLING TEMPERATURES AND LIGHT AMOUNTS PRECIP AT MOST AREAS SHUD STABILIZE THE SNOWPACK THRU OUT THE STATE,HOWEVER, SLIDES AT WASH PASS THIS AFTERNOON INDICATE THAT THE INSTABILITY IN THE PACK DUE TO THE WARM TEMPERATURES WILL REMAIN PRESENT IN AREAS UNTIL THEY AREATBELOW FREEZING LONG ENOUGH TO COOL THE PACK.
COOLING SHUD BE SUFFICIENT IN ALL AREAS BY SATURDAY.
SLIDING OF NEW SNOW SHUD NOT BECOME A SIGNIFICANT HAZARD BEFORE LATER SUNDAY AFTER THE ARRIVAL OF THE NEXT FRONT.
RECOMMEND REVIEW OF THE CLOSURE OF WASH PASS SATURDAY MORNING TO DETERMINE IF SUFFICIENT COOLING HAS OCCURED THERE TO DECREASE THE HAZARD.

END/RICHOUT@

APPENDIX B

Project Participants (in addition to those from the University)

ATMOSPHERIC ENVIRONMENT SERVICE (Canada)
G. H. Muttit, Officer-in-Charge
Pacific Weather Central
416 Cowlie Crescent
Vancouver International Airport South
Vancouver, B.C.

B.C. DEPARTMENT OF HIGHWAYS
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Department of Highways
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Victoria, B.C., V8V 2M3

CRYSTAL MOUNTAIN
Bob Bartlett, Pro Patrol Leader, Professional Patrol and
Bill Steele and Don Christiansen, Mountain and Area Managers
Crystal Mtn., WA 98022

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

MISSION RIDGE
Chris Daly, Pro Patrol
Box 1765
Wenatchee, Washington

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

MT. RAINIER NATIONAL PARK
Walt Dabney and Visitors Center Staff
(Rick Kirschner, Bill Swift, John Leohr)
John Parks, Asst. Supervisor, Pete Thompson,
Visitor Protection Specialist
Mt. Rainier National Park
Longmire, Washington

NATIONAL WEATHER SERVICE
Dr. Arthur N. Hull, MIC and NWS staff
Lake Union Bldg.
1700 Westlake North
Seattle, Washington

OLYMPIA NATIONAL PARK
Roger Allin and Jack Hughes
Port Angeles, Washington

APPENDIX B (continued)

SOIL CONSERVATION SERVICE
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SNOQUALMIE PASS
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P. O. Box 262
Hyak, WA 98026

Chuck Wagner (USFS Snow Ranger)
North Bend Ranger Station
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North Bend, WA 98045

STEVENS PASS
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Gordy Burlingame), WSDH
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Glen Katzenberger (USFS Snow Ranger)
Skykomish, Washington

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

US FOREST SERVICE
Paul Frankenstein
Snow Avalanche Forecaster
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Seattle, Washington

US GEOLOGICAL SURVEY
John Cummans, Sub-District Chief
1305 Tacoma Avenue South
Tacoma, WA 98402

WASHINGTON PASS
Frank Almquist and Donna Daniels
Winthrop, Washington

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

APPENDIX C

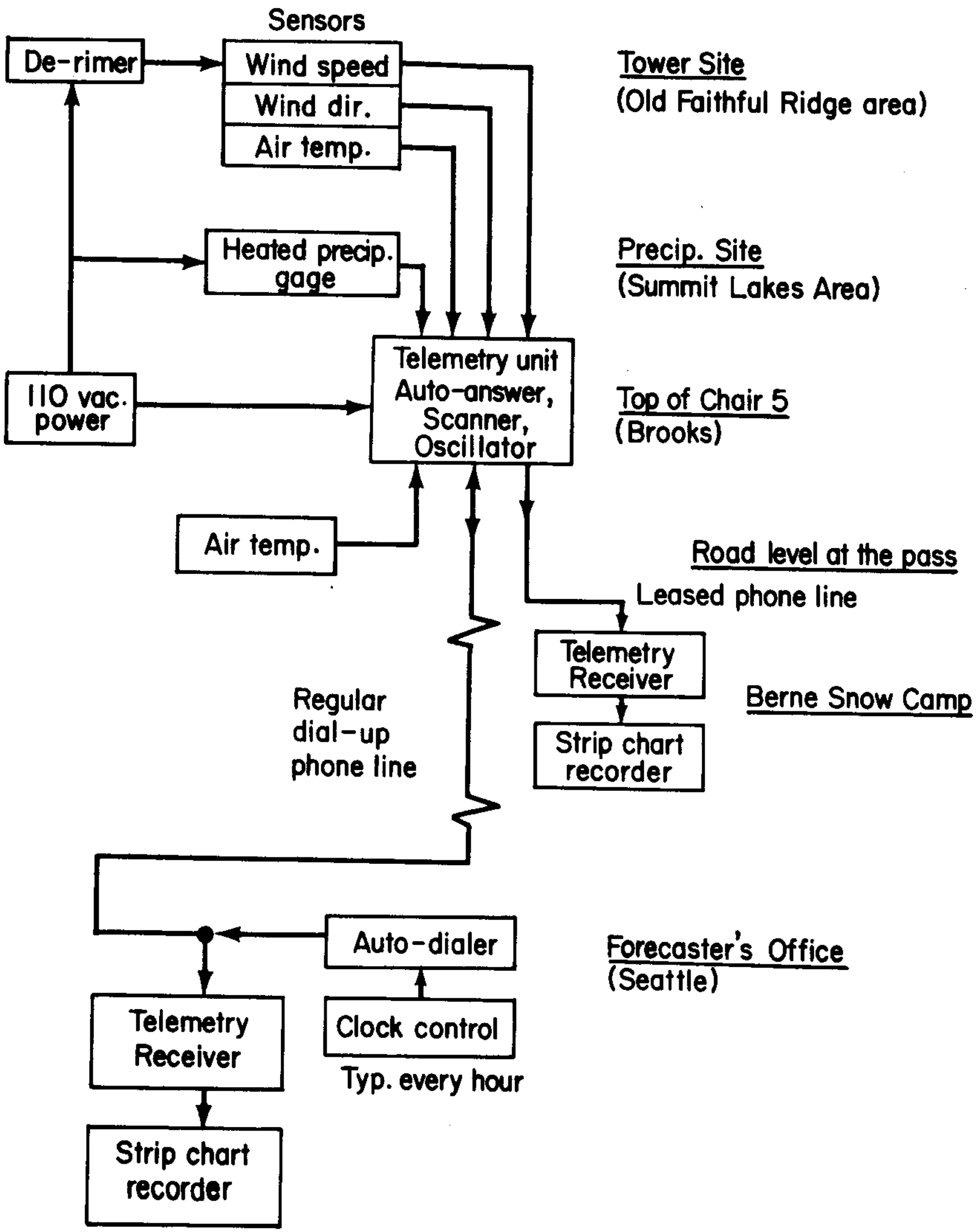
Stevens Pass Telemetry System

This system provides the avalanche forecaster in Seattle with automatic hourly meteorological data from the Stevens Pass area via telephone lines, and is shown in the block diagram of Figure 11. Sensor inputs from the Old Faithful Ridge tower, the Summit Lakes area, and the Pass road level are connected by buried land lines to the telemetry unit located in the lift shack at the top of Chair 5 (Brooks). The telemetry unit is connected by phone line back down to the Pass. The sensors are interrogated from Seattle utilizing a telephone auto-dialer under clock control, activated automatically every hour, or manually, as desired. The phone call is routed to the telemetry unit, which automatically answers, scans the input sensors in sequence, and returns the data over the phone lines as a frequency modulated signal. The signal is received in Seattle, converted back to analog, and presented on a strip chart recorder (see Figure 12 for a sample record). At the end of the transmission sequence the auto-answer and dialer units reset, and the system awaits the next activation.

As seen in Figure 11, the data signal was also planned to be received at the Berne Snow Camp by a line leased from the telephone company. During the winter 1976/77, this line was never operational, so this read-out was re-located to the USFS Office at the Pass Summit. Following is a more technical description of the more important components of this system.

- Wind Speed Sensor. This is an experimental University of Washington design, illustrated in Figure 13, consisting of an aluminum disk rotor heated electrically from beneath (through radiation and turbulent conduction) to achieve rime-free operation. Heaters are Chromalox Type A Rings; GE Calrod units were also utilized. Power is approximately 1200 watts and is controlled by a Thermologic Mini-Term Series 4200 Probe and Proportional Controller. An Electric Speed Indicator Model WS-301 Speed Transmitter was used with no modification so that the standard cups could replace the experimental disk if desired. In this case, standard de-riming heat lamps were available. Due to its higher mass, the experimental sensor does require slightly higher minimum wind speed for initial cup rotation (<4 mph will not turn the cups) than commonly used speed sensors, but this does not appear to be a problem in avalanche forecasting where winds >10 mph are most effective in wind transport of loose snow.

FIGURE 11. Stevens Pass Telemetry System.



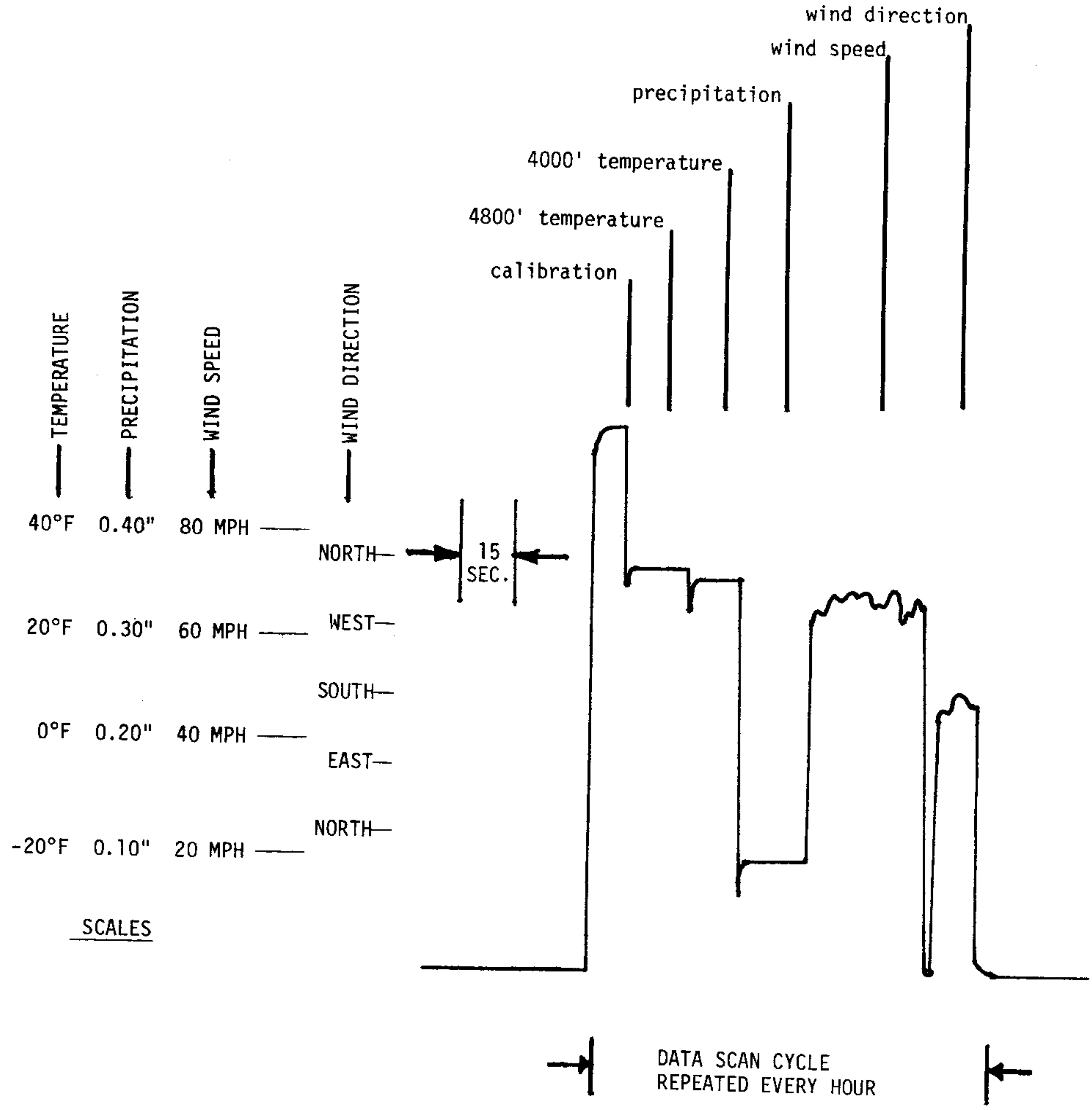
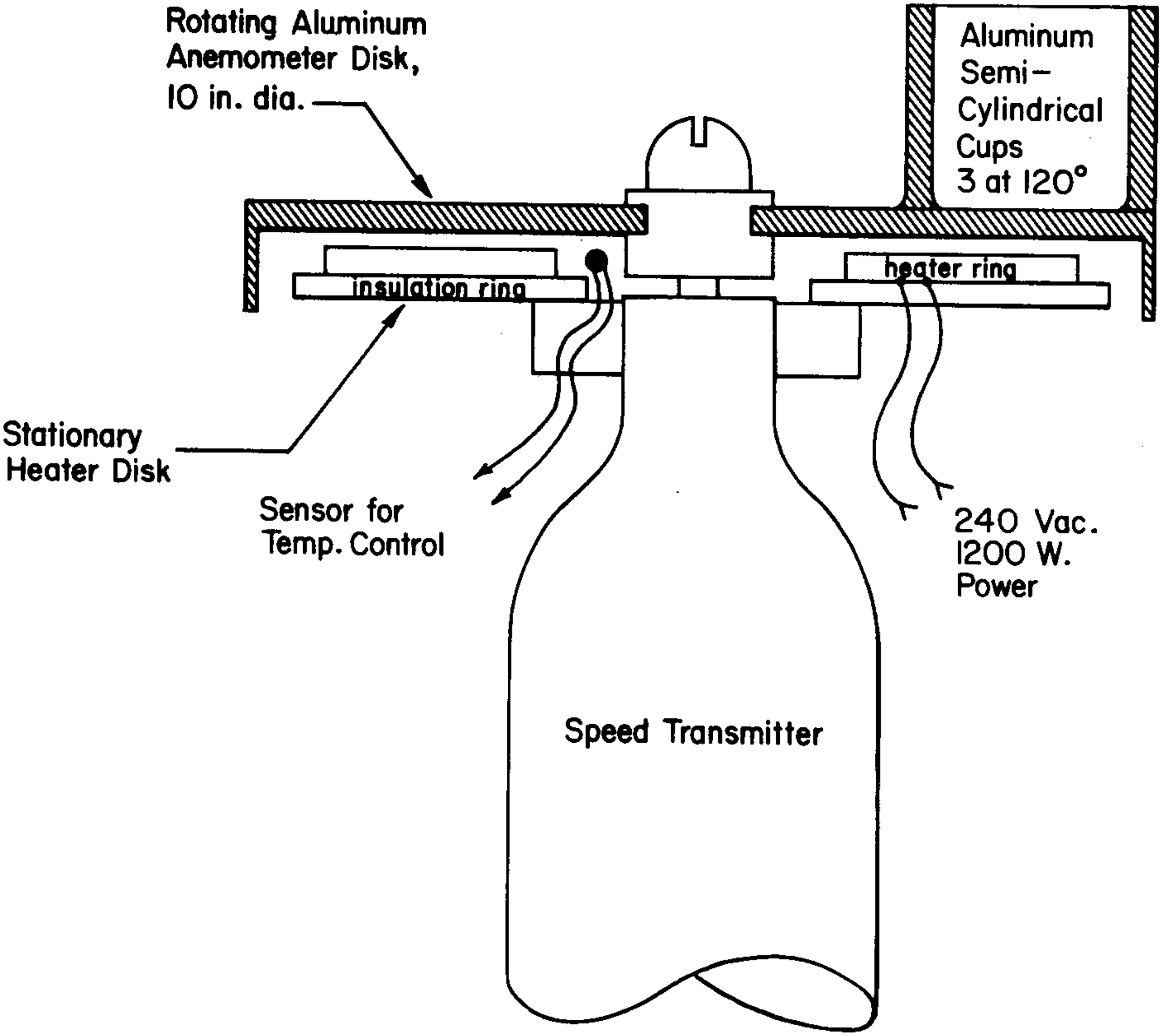


FIGURE 12. Output from Stevens Pass.

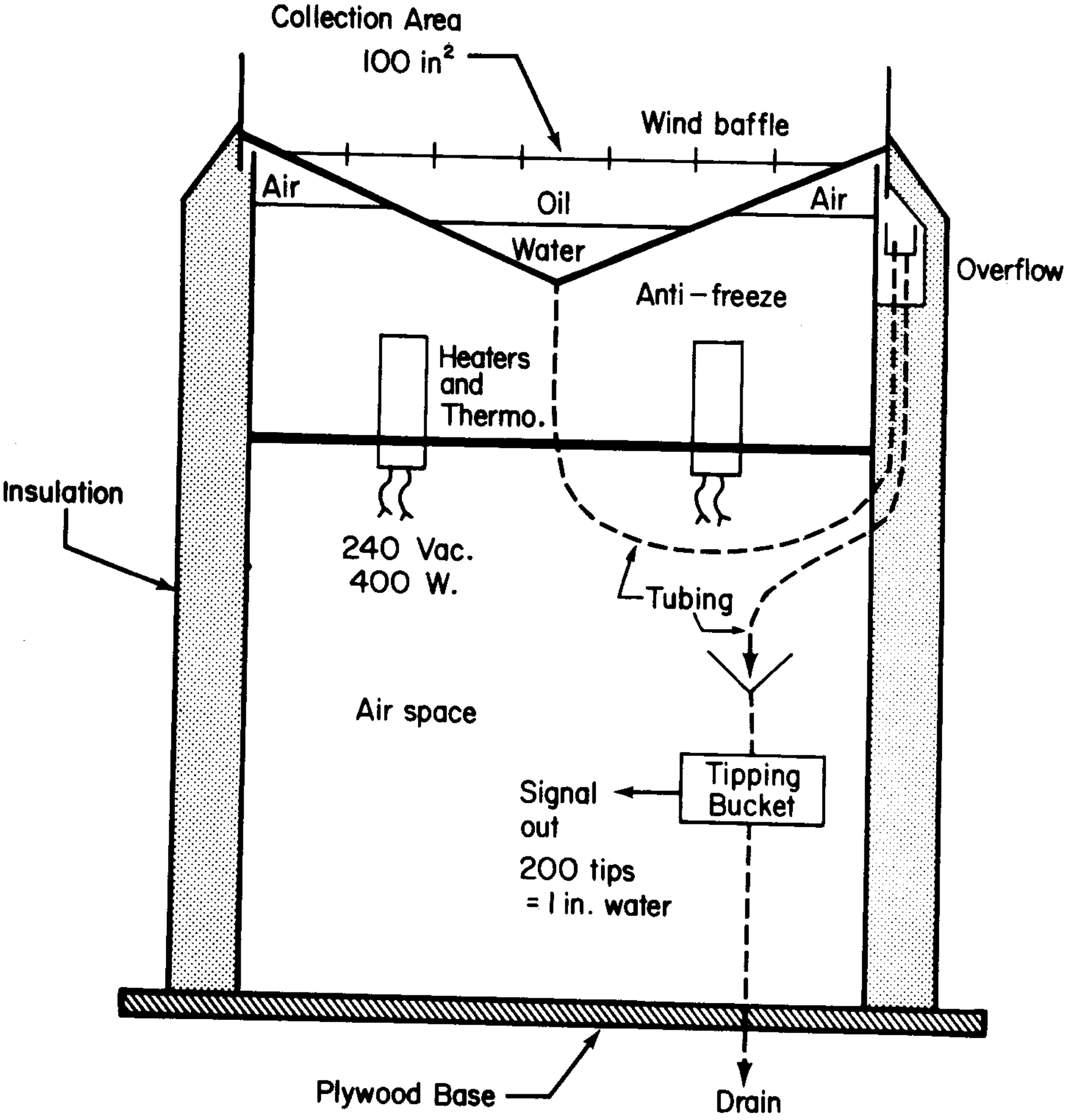
FIGURE 13. Wind speed sensor.



Operation was successful, and minor improvements in design are planned for any future operation.

- Wind Direction Sensor. Electric Speed Indicator Co. Model F420-C-2R. These sensors are mounted on a 40 foot Rohn tower, guyed and braced, in the Old Faithful Ridge area.
- Air Temperature Sensors. YSI Thermistor, University of Washington bridge circuit and double radiation shield housing.
- Heated Precipitation Gage. This is also an experimental design by the University of Washington (illustrated in Figure 14). Incoming frozen precipitation is melted as it settles through a heated oil bath, collecting in the funnel bottom which is connected by tubing to an overflow device. Equilibrium is such that an equivalent amount of water dribbles away to the measuring device, a Metrology Research Model 302 tipping bucket mechanism (200 contact closure tips representing 1 inch of water on the collection area). The oil bath is heated by thermal conduction from a lower pan filled with anti-freeze solution, and containing Chromalox Type RIN Immersion Heaters, with a Chromalox Thermoswitch acting as a thermostat. Total heating available is about 400 watts. A 50 watt light bulb was placed in the air space under the pan and was adequate to prevent freezing of the tipping bucket mechanism, the waste drain, and the connecting tubing. A "blue-foam" sleeping pad from Recreational Equipment Inc. was used as an insulating layer around the gage. A Weather Measure Model P565 Wind Shield was mounted with the gage on a 20 foot Rohn tower in the Summit Lakes area.
- Instrument Towers. The instrumentation towers at the Old Faithful ridgeline/anemometer site and at the Summit Lakes Basin/precipitation site were installed in late autumn, with consideration given to expected snow creep, high winds and/or tower riming. The tower support system at both sites consisted of a 500 pound reinforced concrete base with imbedded lag bolts to which the hinged tower base plate is bolted. At the more exposed anemometer site, 27 foot tubular aluminum side struts with concrete bases were attached to the tower at an angle near the 20 foot level to help prevent possible snow creep and wind damage. The towers, themselves, are composed of 10 foot triangular Rohn tower sections (#25 AG), and guyed with 3/16 inch steel cable. Examination of the tower systems after the winter showed no signs of weakness and in general the towers appeared to be of adequate strength for use in an extreme mountain environment.
- Telemetry Land Lines, Power Cables. Instrumentation telemetry utilized six-pair, armored, direct burial wire (19 AWG) which was buried in the autumn by polaski and shovel over most of the distance from the top of Chair #5 in the ski area to the instrument sites, through the Grace/Summit Lakes Basin. Very uneven and soggy ground prevented usage of conventional ditch-digging equipment. A combination of existing and newly-installed USFS wire was utilized from the top of Chair #5 to the Snow Ranger's quarters at the base of the ski area

FIGURE 14. Heated Precipitation Gage.



where the phone lines to Seattle and the Berne Snow Camp are located. Any splices necessary in these lines were soldered and taped firmly with electrical tape and a waterproof, self-sealing rubber compound tape. Junction boxes hoisted into trees along the burial route provided field staff access to the line if necessary during the winter season. Necessary power for heating instruments during the winter was provided by the ski area management and electrician. Power hookup was made at the top lift station of Chair #1 in the ski area, where circuit breakers and a step-up power transformer were installed. Stepdown power transformers were required at both instrument sites. These transformers were custom designed and supplied by Tierney Electrical Manufacturing Co. Power lines utilized were rated for direct-burial, and were a combination of 8-1, 10-2 and 12-2 power cables. The 12-2 cable was surplus, in poor condition, and needs replacement. These lines were buried over much of their distance to minimize problems with snow creep and rodents.

- Telemetry Unit. Major components are a Bramco Model AA-1 Auto Answer, a Singer RC4-8 Cam Scanner with A18 gear set, and a Richard Lee Co. Model TX-1 RM transmitter. Precipitation gage bucket tips are accumulated with a Haydon Stepping Motor No. 31316 coupled to a Bowons 3435S single-turn, continuous rotation potentiometer. Standard Power, Inc. CPS-15 Series power supplies were used. In addition, a Bramco Model ME42C Tone Encoder was used to activate the Berne Snow Camp recorder.
- Forecasting Office, Seattle. The clock control used here was a Midtex Cyclemaster Model 620-7595, with an Industrial Timer C5F-5M relay. The Auto-Dialer and its associated Model CBT Data Coupler were leased from Pacific Northwest Bell. A Singer RC4-4 Cam Timer with A18 gear set was used for control. The telemetry receiver is a Richard Lee Co. Model RX-1 FM Data Receiver, and the strip chart recorder was an Esterline Angus Model MS401 BB Miniservo.
- Berne Camp Read-out. Utilizes similar Singer Cam Timer, FM Data Receiver, and chart recorder as above. In addition, a Bramco Model MD42c/P Tone Decoder was used to initiate data recording on command from the telemetry unit as it received a call.

The telemetry system performed satisfactorily, although some difficulties were encountered in using some pre-existing buried land lines. These would need to be replaced for any future operation. Continued development in the sensor technology initiated here is important to insure data quality during stormy weather.

This scheme for automatic analog data transmission over the phone lines has a great deal of inherent flexibility, and should easily accommodate future changes in the avalanche data network.

ACKNOWLEDGMENTS

It cannot be emphasized enough that the success of this project depends in great measure upon the interest and cooperation of WSDH personnel in the field and the variety of people from cooperating government agencies and ski areas. While the project can be characterized as a mutually beneficial one to all participants, it can also be said that the project cannot succeed without the vital contributions made by these competent and interested people.