PRECIPITATION IDENTIFICATION FOR HAZARD REDUCTION

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16. ABSTRACT

The results of a 2-year project to investigate the feasibility of automatically detecting precipitation type for highway hazard-reduction programs in the Cascade Mountains of Washington State are reported. The project investigated available technology for remote identification of precipitation type, selected a suitable sensor for testing, and compared field and laboratory tests with visual observations. Modifications of the hardware and software were conducted to optimize the use of precipitation identification (PID) sensors in operational hazard-reduction programs.

A PID sensor was installed at the Washington State Department of Transportation (WSDOT) observation station at Snoqualmie Pass, and was connected to automatic data-logging equipment. Another PID was equipped for mobile use and tested at mountain sites in Alaska, other areas of Washington, and in Japan.

Data from each sensor were compared against visual observations. The results of this analysis showed adequate performance from the PID. The analysis also showed that the PID data can be a valuable asset to the hazard mitigation programs along mountain highways, particularly when combined with data-loggers, totaling precipitation gages, and computer graphics.

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PRECIPITATION IDENTIFICATION
FOR
HAZARD REDUCTION

by

Sue A. Ferguson
USDA Forest Service
Pacific Northwest Research Station
4043 Roosevelt Way NE
Seattle, WA 98105

Technical Contact

Steve Breyfogle
Snoqualmie Pass Avalanche
Washington State Department of Transportation

Prepared for

Washington State Transportation Commission
Department of Transportation

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This final report summarizes work completed over a 2-year period on the evaluation of precipitation identification sensors for hazard reduction programs. Particular emphasis is given to avalanche control and snow-stability forecasting applications. It is expected, however, that the results could be applied to a variety of traffic safety problems which are caused by precipitation. Field tests of a cost-effective, infrared sensor indicate reliable performance. Hardware configuration of the sensor was modified for use in typical field observation programs. Software programs were developed to interface the sensor with common data-logging equipment, format sensor data for snow-layer modeling programs, and meaningfully display sensor output. The gage appears to provide a valuable tool for hazard mitigation programs.

DISCLAIMER

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PRECIPITATION IDENTIFICATION FOR HAZARD REDUCTION

SUMMARY

This report summarizes a 2-year project. The first phase investigated available technology for remote identification of precipitation type. Next, a precipitation identification (PID) sensor was selected for testing. Later, field and laboratory tests were compared with visual observations. Modifications of the hardware and software were conducted to optimize the use of PID sensors in operational hazard-reduction programs.

A survey of available PID sensors showed that a variety of techniques to determine the phase of precipitation are being developed. Only a few of the PID sensors that are available commercially, however, were found capable of operating reliably in remote mountain locations. Of these, only one was sufficiently cost effective for hazard reduction programs, and it was selected for preliminary tests.

The test sensor, called HYDROS, was installed at the Washington State Department of Transportation (WSDOT) observation station at Snoqualmie Pass, and was connected to automatic data-logging equipment. Another HYDROS was equipped for mobile use and tested at mountain sites in Alaska, other areas of Washington, and in Japan.

Data from each sensor were compared against visual observations. The results of this analysis showed adequate performance from the HYDROS, especially when compared with other commercially available PID sensors. The analysis also showed that the HYDROS data can be a valuable asset to the hazard mitigation programs along Washington's mountain highways, especially when combined with data-loggers, totaling precipitation gages, and computer graphics.

CONCLUSIONS AND RECOMMENDATIONS

1. <u>Theoretical PID models:</u> No existing theoretical models were found to perform successfully in the Washington Cascade passes where easterly pass winds cause frequent temperature inversions.

2. <u>Precipitation identification sensors:</u> Infrared sensors appear to be most economical and are most capable of functioning successfully in remote winter environments.

3. <u>Output format:</u> For avalanche hazard mitigation programs, PID sensors need the following output data: (1) total rain accumulated each hour, and (2) total snow-water equivalent accumulated each hour. In addition, the sensors need the

ability to monitor instantaneous output through a telephone modem or radio link.

4. <u>Precipitation identification algorithms:</u> HYDROS discriminates between precipitating solid (snow, flurry) and liquid (rain, mist) particles only. Sleet, ice pellets, hail, graupel, and freezing rain are not separately distinguished.

5. <u>Sleet identification:</u> HYDROS classifies sleet (a mixture of rain and snow) as rain when it falls like rain, but classifies sleet as snow when it falls like snow. Sleet interacts with road or snow surfaces like rain or snow, depending on the ratio of water to ice, which seems to correspond with its falling characteristics and HYDROS's discrimination.

6. <u>Ice pellet, hail, and graupel identification:</u> HYDROS appears to correctly identify graupel as snow but may occasionally identify ice pellets and hail as rain if the falling particles are small-diameter with rapid fall velocities.

7. <u>Influence of wind:</u> There appears to be little or no effect from wind on HYDROS's ability to accurately identify precipitation type.

8. <u>PID sensor location:</u> Currently, the HYDROS requires AC or DC power, nearby data-logger or computer, and telephone, radio, or short-haul modem access. About 1 amp of power is necessary to heat the HYDROS lenses. Other power requirements to operate the data processor are small (20-250 ma). Future testing is required to determine if the lenses can operate unheated so the unit can be recharged with a simple solar panel.

9. <u>Accuracy of precipitation identification sensors:</u> Infrared-type PID sensors appear to function adequately in harsh winter environments.

INTRODUCTION

There are three main objectives for remotely identifying precipitation type in highway hazard mitigation programs. The first addresses a need to improve response procedures for large, simultaneous avalanche events. The second objective is to provide data for predicting snow stability over large areas with theoretical models. The third objective is to determine the relation of precipitation type to visibility and road traction that may affect traffic safety.

Because of the investigators' technical background, this project concentrated on the first two objectives. It is highly probable, however, that a precipitation-identification gage, which works for these objectives, also can provide significant data to help solve other traffic safety problems.

Avalanche Control Response Procedures

All western states are faced with the difficult task of improving avalanche control response procedures as population and use of mountain highways continually increase. Improved avalanche control is critical in the Washington Cascades because of a unique aspect of weather that exists there. Mid-winter rain storms are frequent in the coastal mountain ranges and often snowfall can change to rain almost instantaneously in the Washington Cascade passes. This occurs when persistent temperature inversions from easterly pass winds are quickly eroded by dynamic storm fronts. Under such conditions, numerous large and dangerous avalanches can begin within minutes after the precipitation type change.

Methods to forecast these kinds of rapid changes in precipitation type have improved dramatically over the past few years. Unfortunately, these predictions are only approximations because the depth and strength of inversions, and the slope and strength of approaching fronts, cannot be known exactly with today's technology. Forecasts are accurate only to within 1/2 to 1 hour, 6 to 24 hours in advance (1). This uncertainty does not always allow enough time to close roads or deploy avalanche control personnel in the most efficient manner, especially for the large number of avalanches that may release spontaneously with a precipitation type change.

Currently, precipitation type changes are monitored by visual observation. This is a difficult task, because the inversion and frontal characteristics common in the Cascade passes cause precipitation types to change in complex patterns. Figure 1 shows a schematic, cross-sectional diagram of typical precipitation patterns that may occur in the Cascade passes. Figure 1a shows the large horizontal and vertical variation in precipitation types that is possible during a moderate easterly pass-wind inversion. Moments later, that pattern can change dramatically, as illustrated in Figure 1b. Observers are unable to notice changes in precipitation type at all of the widely spaced avalanche paths in time for the most efficient deployment of avalanche control measures during major storm cycles. A method of remotely monitoring precipitation changes would help solve this problem. In addition, historical records of precipitation type and amount can be compared with avalanche occurrence records to develop a better understanding of these large and dangerous avalanche cycles.

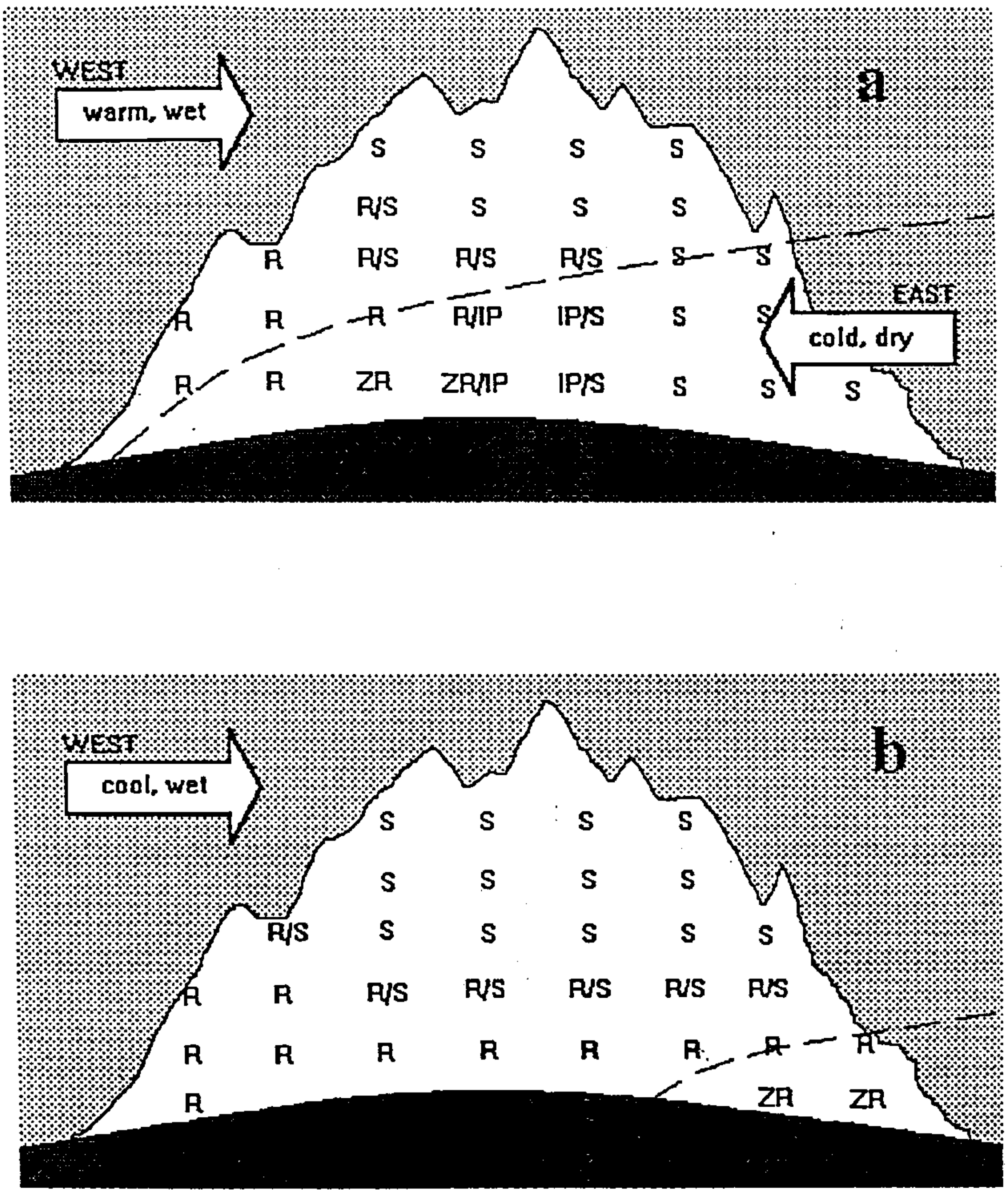

Figure 1. Cascade pass precipitation patterns. Dashed line shows temperature inversion boundary. S=snow, R=rain, ZR=freezing rain, and IP=ice pellet. a) During moderate inversion. b) Moments after inversion was eroded.

Snow-Stability Forecasting

In addition to instantaneous avalanche initiation by rain-on-snow events, there are a variety of other conditions that cause snow to avalanche in mountain areas. One way of determining snow stability is to gather data on the vertical and horizontal structure of snow layering. Usually, this involves a cumbersome method of digging a hole in the snow to gather a number of physical and mechanical measurements on each layer. These snow pits are only representative of specific sites and times, require a significant amount of time to perform, and conditions are difficult and often hazardous while obtaining pertinent data from required elevations and slope exposures.

An alternative to digging numerous snow pits is to use computer programs that model snow-layer stratigraphy. Currently available models require hourly weather data as inputs, including accumulations of each precipitation type.

Hourly weather data are available through existing mountain-located automated weather stations. The sensors at these stations record total precipitation, temperature, relative humidity, wind, and snow depth. There are no direct measurements of precipitation type. If snow stratigraphy models are to be used for assessing snow stability in large areas, there must be a way of remotely monitoring precipitation type.

PREVIOUS WORK

Conditions that cause solid precipitation to reach the ground before melting depend on vertical gradients of temperature and dew point, particle size, and particle fall speed. A complex interaction of these parameters determines the precipitation type. Because of this complexity, only rough estimates of precipitation type are possible through indirect correlations. Direct measurement of precipitation type is difficult because different types share many of the same physical characteristics.

Indirect Correlations

There has been some effort to relate precipitation type to upper atmosphere conditions (2,3). These relative comparisons do not consider the low-level temperature inversions that are common in the Cascades. For example, Figure 2 shows the probability that precipitation type is snow in a Cascade mountain pass (Stampede) for observed upper-air temperatures (850 mb) from the closest radiosonde observation, which is on the Pacific coast (Quillayute). When pass winds are from the east (bringing cold, Arctic air into the pass) the probability of snowfall at Stampede significantly increases, even when 850-mb temperatures are well above freezing.

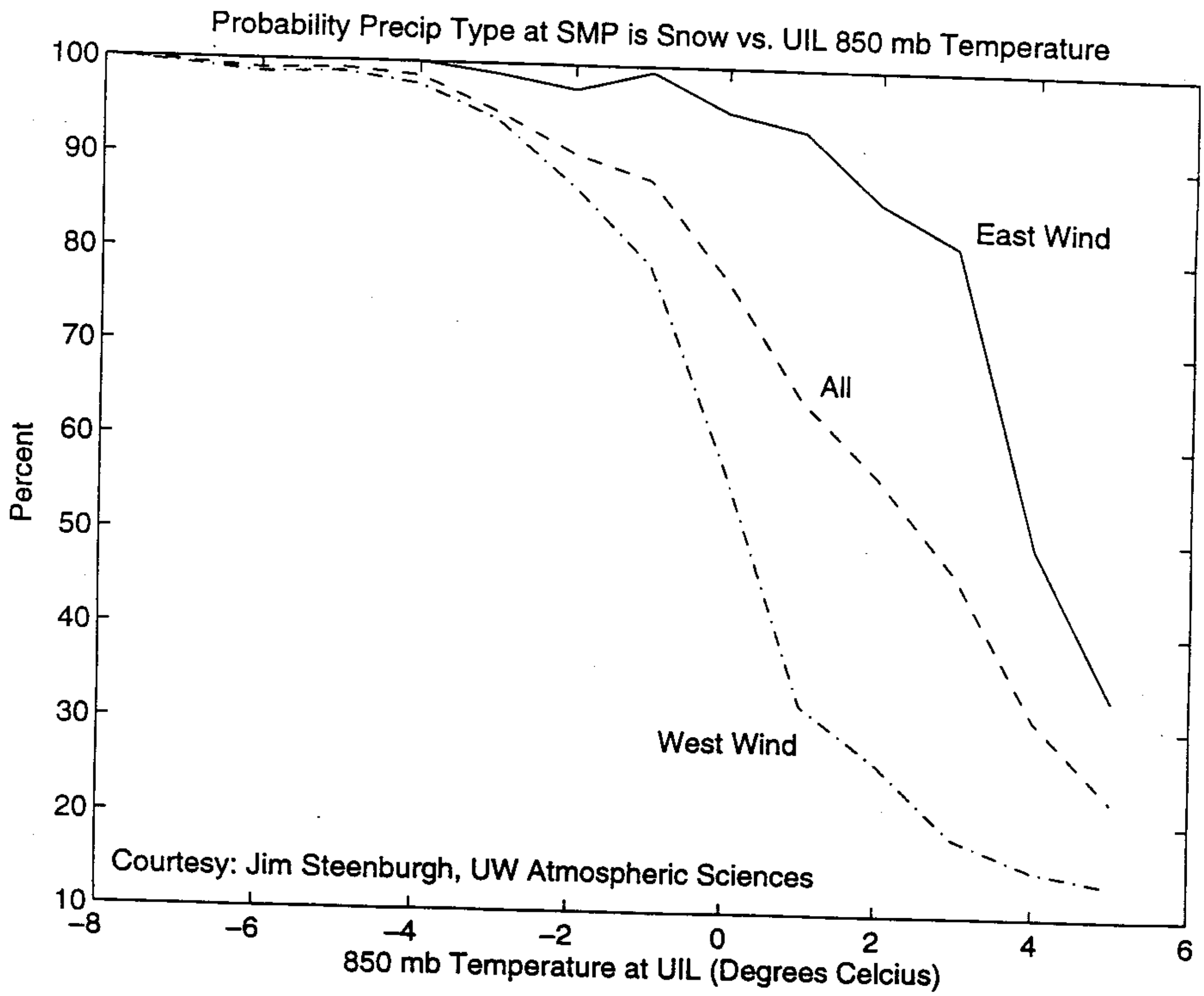

Figure 2. Probability of precipitation type at Stampede Pass, Washington, versus 850-mb air temperature at Quillayute, Washington.

In addition to poor correlations between the upper atmosphere and Cascade pass precipitation type, upper-air data are gathered only twice a day from stations (such as Quillayute and Spokane) that are quite far from mountain precipitation sites. Their designated observation times do not always coincide with precipitation periods. Therefore, accurate predictions of precipitation type from upper atmospheric conditions are not possible.

Measurements of ground-level air temperature most often have been used to determine precipitation type. Significant research to study the relation of air temperature to precipitation type has been conducted in Japan, where heavy snowfalls affect the large population and automated snow-melt systems are used to clear roadways. For example, Tamura found that the temperature range for snowfall in Nagaoka, Japan, ranged from -6 °C to 6 °C (4). Sugai (5) also found that snow accumulated at ground temperatures as high as 6 °C. The average threshold temperature for the snow-to-rain transition ranged from -0.4 to 2.6 °C for 13 observation sites in Japan. This range of threshold values is too large for accurate rain-snow predictions in an operational hazard-reduction program.

Measurements of snow depth also have been used to help identify precipitation (Mark Moore, *personal communication*). When snow depth is increasing, accumulating precipitation is obviously of the solid type. On the other hand, solid precipitation could be accumulating when snow depth is remaining constant or actually decreasing. This would occur if the rate at which the snowpack settles is greater than the snow accumulation rate. This phenomena is common in the Cascades. Therefore, a strict reliance on snow depth as an indication of precipitation type is not feasible.

Direct Measurement

Sensors developed to more accurately measure precipitation type consider latent heat, conductivity, impact noise, opacity, and fall speed. Latent heat devices measure the amount of thermal changes in a heated bath of water. Conductivity sensors place conductors on a heated plate so that accumulating snow will bridge the circuit and cause a small current. Tests on acoustic signals of falling precipitation are just beginning, using a sensitive microphone attached to a heated plate. Opacity of falling snow has been detected by using simple video cameras, and recent work is being conducted to digitize the images for remote monitoring and data storage. Light beams also have been used to determine the reflectance of falling particles. These sensors are summarized in a recent paper by M. Tamura (6) for Japan's automated, road snow-melt program.

Fall speed can be determined by using vertically oriented radar. Also, falling particles through a horizontal light beam disrupt the beam in characteristic frequencies that depend on its terminal velocity. Terminal velocities for snow range from about 0.5 to 1.5 m/s, with graupel falling at speeds of about 1.0 to 2.5 m/s (7). Rain falls at speeds centered around 7 m/s (8). Solid and liquid precipitation also can have distinctly different sizes. Rain drops usually are a few hundred microns in diameter (8), whereas snow particles can range in size from several hundred microns to several thousand microns (7). Snowflakes (aggregates of snow crystals) can be several millimeters in diameter. Therefore, a sensor that can measure both size and fall speed is more accurate than one which measures just one or the other.

The new weather radars (NEXRAD) that are being installed around the country by the National Oceanic and Atmospheric Administration (NOAA) can locate bands in the atmosphere where precipitation type is changing. Unfortunately, the only existing NEXRAD for Washington State is located on Camano Island. The signal from this radar is blocked by the high terrain that surrounds the Cascade passes and probably cannot see reflective patterns within the pass. A second radar is planned for installation in Spokane, which will help but not solve the Cascade viewing problem.

Only two, on-site, precipitation identification sensors were found to be available commercially in the United States. Both use an infrared laser beam to determine fall speed and particle size. The two sensors have been tested at length in laboratories and at field stations of low elevation. One, the LEDWI sensor (9) is being installed at all newly automated observation stations (ASOS) by the National Weather Service (NWS), a division of NOAA. The sensor costs about $15,000 and requires a concrete mounting base. The HYDROS (10) costs about $3,000 and can be mounted on any existing tower or pole. HYDROS was chosen for this project's testing because it is significantly less expensive than the LEDWI, has more versatile installation options, and seemed to perform equally in manufacturer's tests.

PROCEDURES

After the review of available PID sensor technology was completed, a HYDROS sensor was purchased for testing. Figure 3 illustrates the dimensions and components of a HYDROS precipitation identification gage. HYDROS is designed to operate in a local or remote mode. In local mode, it can be linked directly to a computer. Parameters that determine its discrimination algorithm can be changed, and a history of particles that have passed through the beam can be reviewed. In remote mode, HYDROS outputs precipitation type and intensity after temperature and relative humidity are given as inputs.

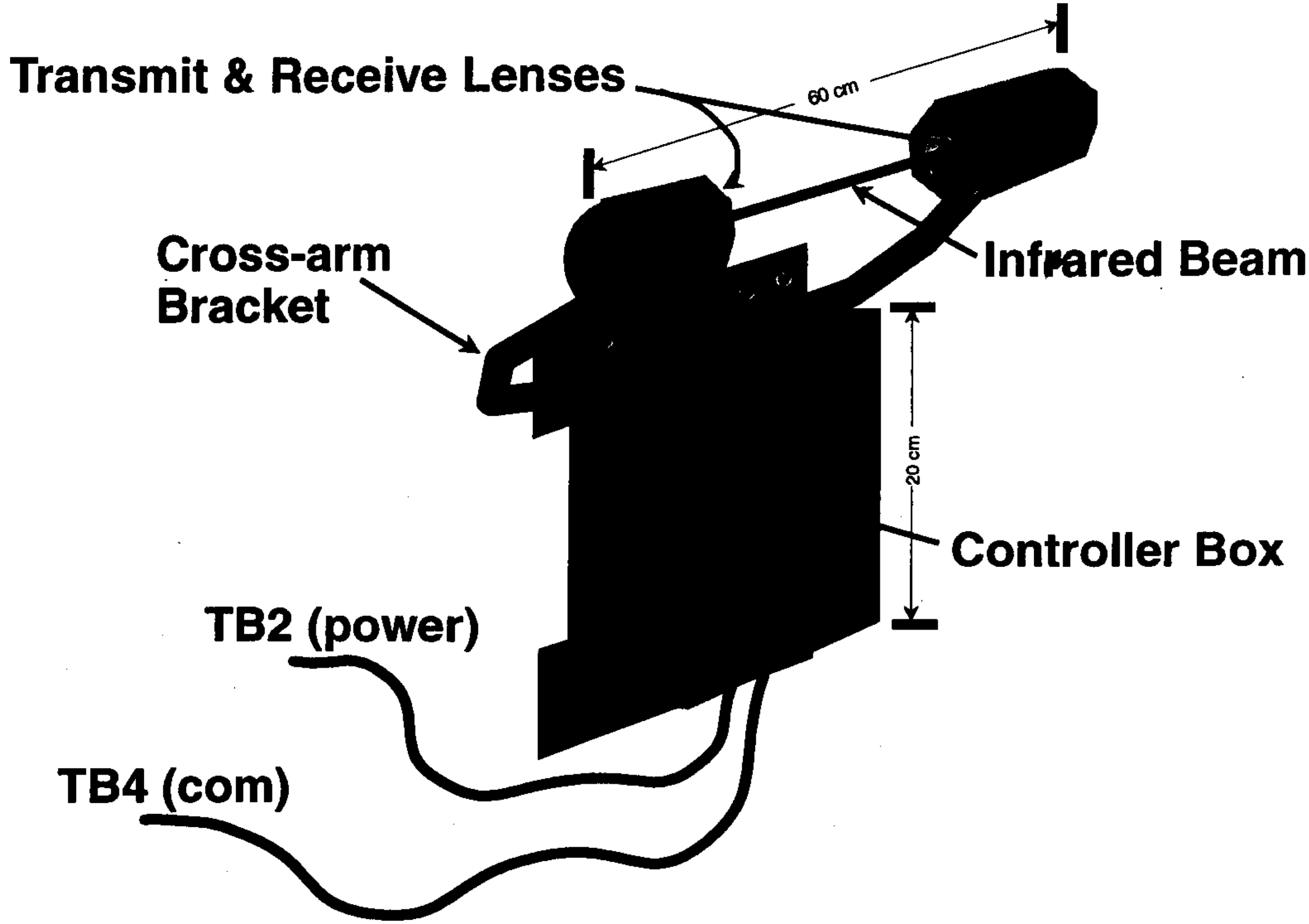

Figure 3. Schematic of HYDROS precipitation identification gage.

HYDROS discriminates precipitation type into six categories, as shown in Table 1.

Table 1. HYDROS precipitation categories.

1 = none (no precipitation)
2 = yes (precipitation unidentified)
3 = rain
4 = snow
5 = mist
6 = snow flurry

Remote Mode

One HYDROS was installed at the WSDOT Snoqualmie Pass observation station. It was connected to a CR10 programmable data-logger (11) to test its ability to operate remotely. Relative humidity and temperature sensors were connected to the CR10 so that it could be programmed to initiate a response from HYDROS by automatically sending current air temperature and relative humidity every 20 seconds. A totaling precipitation gage also was connected to the CR10 to determine water equivalent values of precipitation particles.

For every increment of accumulation[1] that was recorded from the totaling precipitation gage, a histogram of precipitation type was stored. Every hour, current precipitation type and the incremental histograms were summed to show the last hour's water-equivalent accumulation of snow and rain. The data were

[1] The WSDOT avalanche programs use 0.01" as an increment standard for their totaling-precipitation gages.

downloaded several times a day into a WSDOT computer-archive file by way of a telephone modem. A sample of the output format is shown in Table 2. Output was compared with visual observation from WSDOT avalanche crew members at least once each day.

Table 2. Sample of raw data from CR10 data-logger with HYDROS in remote-mode operation. The order of data are site identification number, Julian date, local time, battery voltage, air temperature (°C), relative humidity, hourly precipitation accumulation (inches water equivalent), current precipitation type (see Table 1), hourly water equivalent of snow, and hourly water equivalent of rain.

```
7,69,1200,12.04,4.611,93.5,.02,5,0,.02
7,69,1300,12.05,4.322,89.8,.05,5,.001,.049
7,69,1400,12.04,3.99,92.9,.03,1,.001,.029
7,69,1500,12.04,4.12,89.7,0,2,0,0
7,69,1600,12.04,2.65,91.6,.01,5,.005,.005
```

Local Mode

A second HYDROS was configured in local mode for transport to different observation stations. Data from this mobile HYDROS were acquired during laboratory tests and from field studies in Alaska, various Washington locations, and Japan then logged directly into a portable computer. Table 3 shows the format of local-mode data from HYDROS. Particle sizes are reported in hexadecimal numbers as dimensionless values that are proportional to particle frequency and speed, not a direct measure of particle diameter. Average size is the average of the last 64 particles. Storm intensity is given in a range from 0 to 99, with 99 being the maximum intensity. Air temperature is in degrees farenheit. Relative humidity is in percent.

Table 3. Sample output of HYDROS local-mode data.

Time 13:27
Date 01/14/92

Precipitation type	Snow
Particle size	001A
Average size	006E
Storm intensity	99
Air temperature	0032
Relative humidity	0098

Configuration Parameters

The HYDROS PID sensor identifies the type of particles passing through its infrared laser by using discriminant algorithms, which are based on adjustable set points for particle-per-second, particle size, and rain-snow threshold temperature. To determine how to adjust these set points for optimal use in the Cascades, a survey of the precipitation regime at Snoqualmie Pass was conducted. This helped to determine the range and frequency of precipitation types. The survey analyzed 10 years of daily observation records from the WSDOT Snoqualmie Pass observation station between the winter seasons 1981-82 and 1991-92. Within this period, there were over 1,500 daily observations. Precipitation occurred at the time of observation (0700 PST) on 498 of those days.

Results of the precipitation survey for Snoqualmie Pass are shown in Figure 4. The graph of precipitation type versus temperature

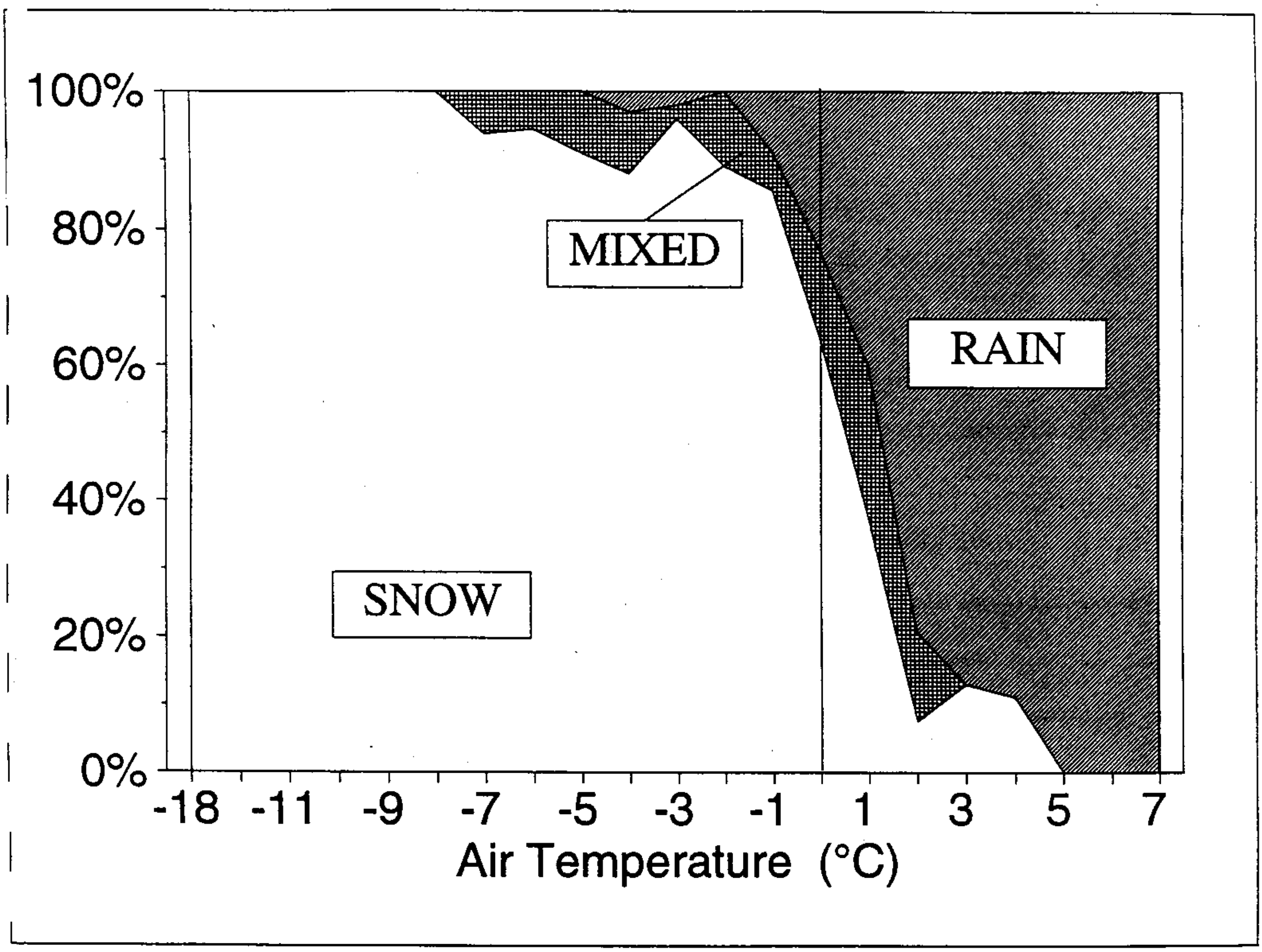

Figure 4. Precipitation type vs temperature at Snoqualmie Pass.

includes a mixed category of sleet (both rain and snow observed simultaneously) and freezing rain. From Figure 4, it is clear there is a broad threshold temperature for precipitation type, from -8 °C to +5 °C. Below -8 °C, 100 percent of precipitation fell as snow. Above +5 °C, 100 percent of precipitation fell as rain. The mean threshold temperature, where there is a 50-percent chance of either rain or snow falling, occurs at +1 °C.

Precipitation data from Snoqualmie Pass were compared with those accumulated in Japan by Tamura (1990) and Sugai (1992). At Snoqualmie Pass, snowfall occurs at temperatures up to 5 °C. Data acquired in Japan also shows snowfall at temperatures up to 5 °C, with some stations seeing snowfall up to 6 °C.

In Japan, there were only a few stations where rain accumulated at temperatures below 0 °C. At these locations, when air temperatures were below 0 °C, less than 10 percent of the precipitation accumulated as rain. In addition, there was no rain observed at temperatures below -1 °C. In contrast, at Snoqualmie Pass, up to 20 percent of the precipitation can accumulate as rain at temperatures below 0 °C, and rain is observed when temperatures are as low as -5 °C.

The above results confirm the uniqueness of Cascade precipitation patterns. It made clear that the rain-snow set points for the discriminant algorithms needed changing from the manufacturer's settings before HYDROS could function properly in the Cascades. The high set point required a factory change from 2.8 °C to 5 °C. The low set point was changed from -2.8 °C to -8 °C by the user in the HYDROS user-interface setup table.

Performance Evaluation Tests

A significant amount of precipitation data were accumulated during a visit to the Japanese Science and Technology Agency, National Institute for Earth Science and Disaster Prevention, Nagaoka Institute for Snow and Ice Studies in Nagaoka, Japan. Several days of snow, sleet, and soft hail (graupel) allowed a number of visual observations to be compared with HYDROS's identification data.

One day of observation (January 14, 1993) from the Japanese test site was chosen to investigate the accuracy of HYDROS in determining precipitation type. The other days were used to test the gage's sensitivity to adjustments in the algorithm set points.

For the HYDROS accuracy test in Japan, there were 189 observations of precipitation as an intense storm caused a mixture of sleet and snow. There were no periods during the day when pure rain was observed. Sequential observations were acquired at variable increments from about 1100 hours to 1800 hours, local time. The PID gage was located at the Nagaoka Institute's field observation station. Therefore, in addition to visual observations, HYDROS's data could be compared with a wide array of the Institute's automatic weather sensing devices which operate there. Table 4 matches visual observations with HYDROS's observations, and the associated precipitation type numbering system was used for graphical display.

Table 4. Precipitation type classification.

CATEGORY	OBSERVATION	HYDROS	DESCRIPTION
0	no precip	1 none	
1	R-	5 mist	
2	R	3 rain	RAIN
3	R+		
4	ZR		
5	R/S		
6	IP-		TRANSITION
7	IP		(MIXED)
8	IP+		
9	SG-		
10	SG		
11	SG+		SNOW
12	S-	6 flurry	
13	S	4 snow	
14	S+		
15	unknown	2 yes	

In addition to the Japanese tests, the gage was installed at remote sites on the Juneau Icefield, in Alaska, for a period of about 3 weeks. Unfortunately, this area experienced an unprecedented period of dry weather. It afforded, however, two brief tests of scattered drizzle. HYDROS can detect particles down to 100 microns in diameter and many drizzle particles are near 100 microns. Therefore, HYDROS had difficulty detecting drizzle in these brief tests.

The effective fall speed of particles may be altered under high winds. This could cause rain that is driven horizontally through the PID detecting beam to look like snow. Because the beam is 3.3 mm wide and 1.0 mm high, however, the manufacturer has minimized the effect of changing horizontal fall components. In addition, because the discriminent algorithms identify precipitation type by particle size, as well as fall speed, only unusually large, wind-driven water droplets can be misclassified. To ensure that wind effects are small, a couple of simple tests were performed. In the first test, a vehicle-mounted sensor operated for several hours during 1 day of variable precipitation types. Vehicle speeds varied from 0 to 50 mph. No effect on the HYDROS output was observed. Quantitative effects were difficult to analyze, however, because the precipitation type naturally changed frequently during the observation period. In a second test, at the laboratory, water droplets were sprayed vertically (like typical rainfall) and horizontally (like wind-driven rainfall) through the detecting beam. In both tests, the HYDROS identified the droplet spray as rain, indicating no effect from wind.

To help determine if HYDROS performed similarly to the higher-priced LEDWI, data were gathered from the NWS Stampede Pass observation station. Stampede Pass has a similar topographic configuration to Snoqualmie Pass and is less than 16 km to the southeast. Observations from this station were available through the NWS Seattle Forecast Office at hourly increments for 3 weeks. There were 142 observations of precipitation during this period.

The Snoqualmie Pass site was used to set up the hardware and software configurations for remote operation. Numerous problems were encountered (see Equipment section below) that delayed usable data gathering until February 9 - April 12, 1994. This late in the season, there are not as many sharp changes in precipitation type. Also, air temperatures usually are warmer and less fluctuating than during early- or mid-winter conditions. There were, however, about 200 observations of snowfall, and 40 observations each of rainfall and sleet during this period.

DISCUSSION

Equipment

In connecting HYDROS to the CR10 data-logger, several modifications of both instruments were needed. A special integrated circuit was purchased for the CR10 so that its control ports could be programmed for serial communication. An optical isolator was installed between the CR10 and HYDROS to convert logic levels for proper serial communication. Contracting Technology, Inc. (the manufacturer of HYDROS), was asked to modify an integrated circuit so the HYDROS response time could match slower signal responses that may be encountered and to reduce power consumption for remote operation.

Other compatibility problems were solved after much trial and error. For example, the 5-volt power supply from the CR10 was first used to supply the HYDROS. It was found that the CR10 supply is not sufficient to drive the HYDROS's 5-volt power requirements. This caused interference between the serial and control ports on the CR10 and corrupted the data set from the entire first season. The problem was solved after meeting with the two manufacturers and learning of undocumented power requirements.

Another problem caused the HYDROS's intensity output to drop to zero after a short amount of time. At first, it was suspected that the problem was in the way the unit is grounded. Later, after noticing that the time of failure was dependent upon the actual rate of precipitation, it was discovered that a chip within the HYDROS was not fully reprogrammed after a requested modification. Once it was fixed, the problem was resolved. The problem, however, meant that no intensity data were available until the end of the second season.

The physical design of the HYDROS caused initial problems as well. It's boxy, white construction caused snow to rapidly accumulate on its cross-arm bars and lens hoods. During one storm, the cross-arm bars filled with snow and blocked the detecting beam within 1 hour. At other times, snow accumulation on the lens hoods eventually drooped over and blocked the detecting beam. Wrapping heater tape around the unit solved the problem, but restricted the gage to being located where abundant power is available. The manufacturer was alerted to the problem and promptly redesigned the unit.

The current sensor design (shown in Figure 3) is well suited for remote operation. The unit is painted black to help melt snow before it accumulates. The cross-arm bars are well away from the detecting beam and angled away from the beam in such a way that vertically accumulating snow cannot block the beam. The round lens hoods shed snow easily. In addition, the control box was made more accessible. This unit was available for testing the entire second season and performed well.

Eventually, all of the hardware and compatibility problems were solved. Figure 5 shows the wiring diagram that is necessary when interfacing the HYDROS precipitation identification gage with the CR10 data-logger.

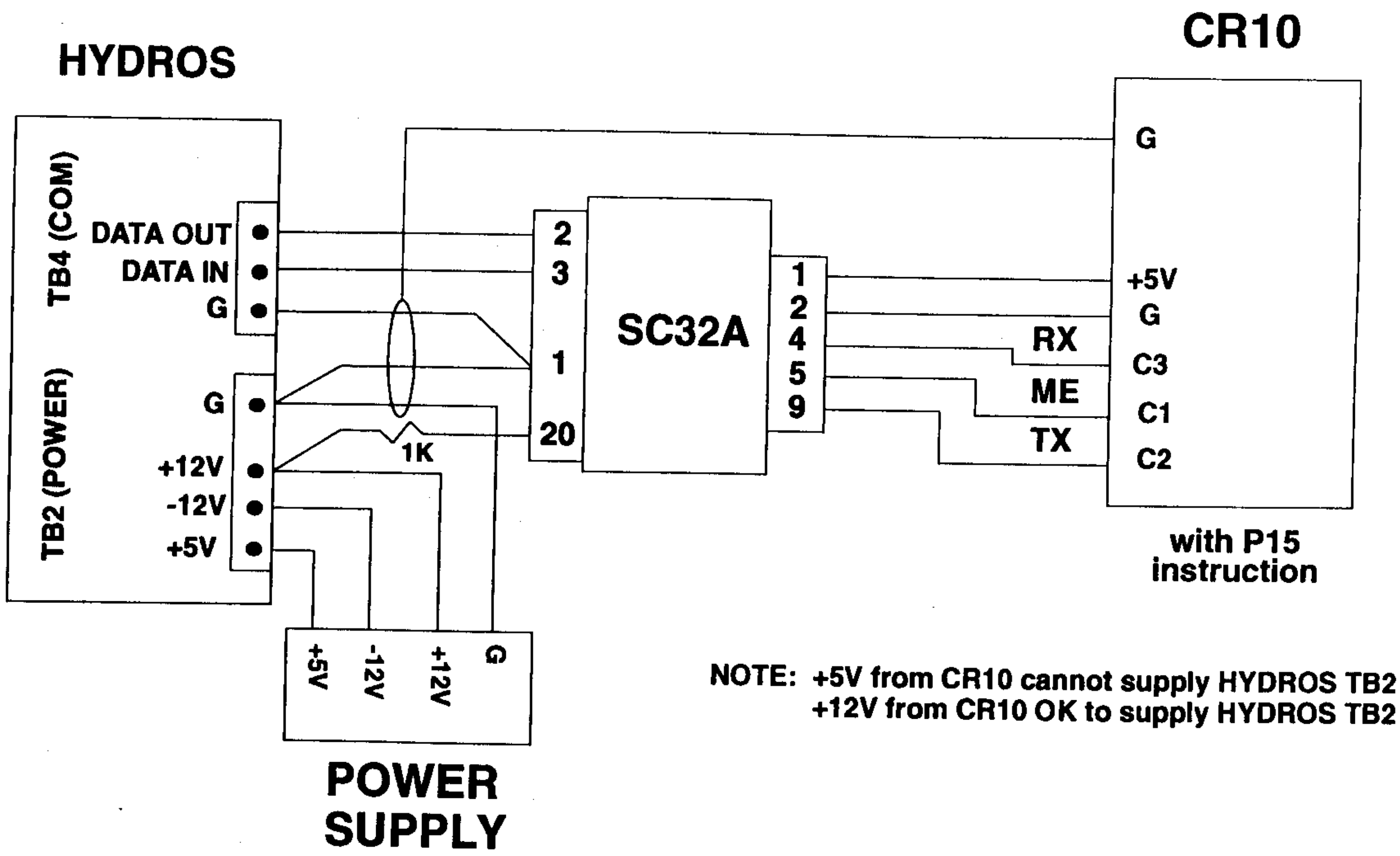

Figure 5. Wiring diagram for connecting the HYDROS precipation identification gage with a CR10 data-logger.

Accuracy

An analysis of the Japanese test-site data showed that the HYDROS performed reasonably well during complex weather patterns. Figure 6 is a plot of HYDROS's precipitation type data and coincident visual observations for January 14, 1993. Hydros data are marked with | and visual observations are marked with o. They agree when the symbols overlap within the same category of snow, mixed, or rain. Precipitation type classifications follow those outlined in Table 4.

HYDROS never reported precipitation when none was observed. Precipitation was observed six times when HYDROS recorded none. When it was snowing, HYDROS classified correctly 65 percent of the time. When it was sleeting, HYDROS classified 73 percent as rain, 16 percent as snow, and 7 percent as unknown.

Comparison with other available weather data showed that during the period when sleet was observed (about the first 100 observations), 45 mm of precipitation fell, but no snow accumulated on the ground. During this time, HYDROS reported mostly rain. It is assumed that HYDROS classified mixed precipitation as rain during the period when there was a high ratio of water to ice in the sleet mixture and no snow accumulated on the ground.

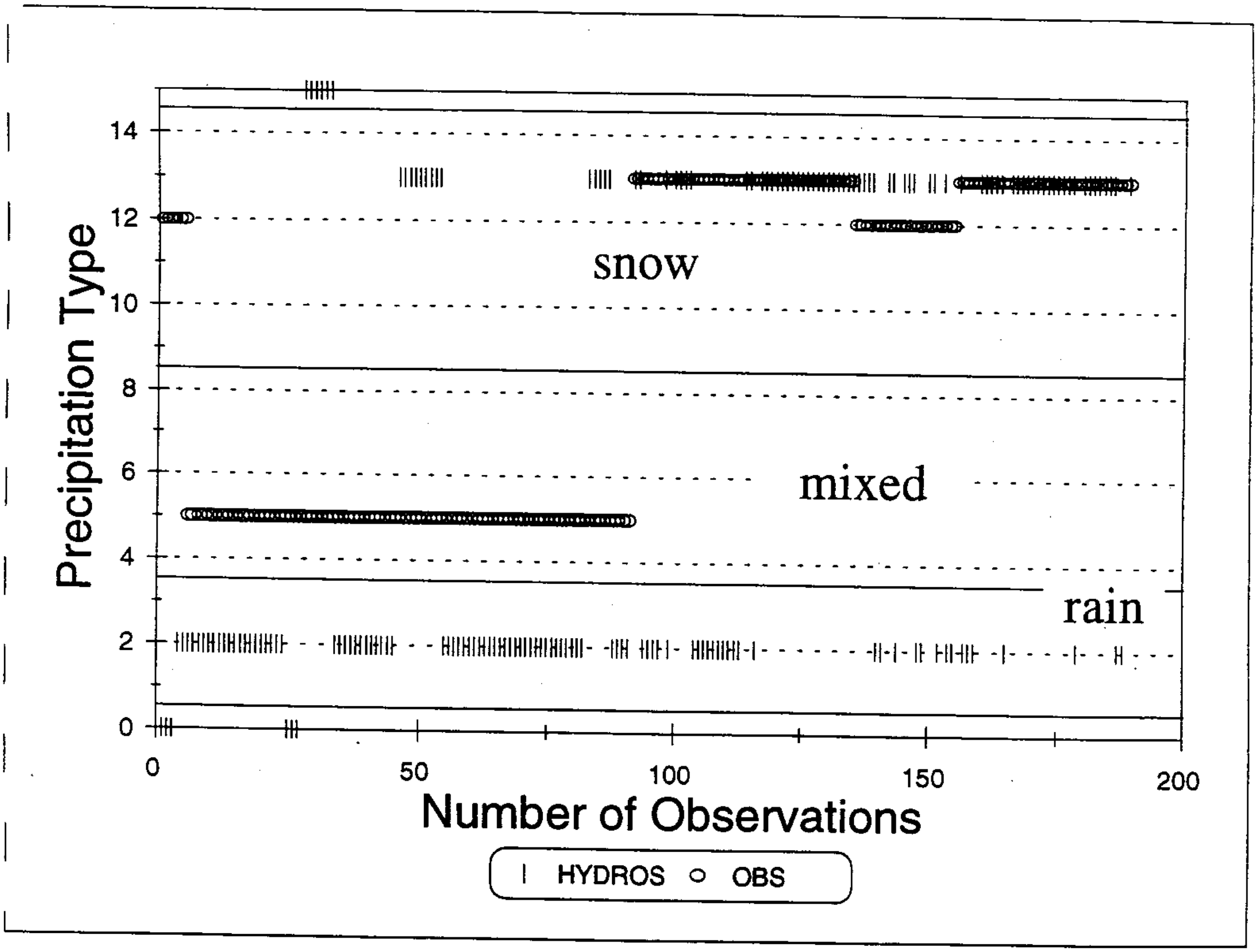

Figure 6. Hydros precipitation type data and coincident visual observations (Japan, 1/14/93).

The next period of observations (from about 100 to 140) was mostly snow. HYDROS continued reporting some periods of rain. The density of snow accumulating during this time was about 250 kg/m^3, rather high for newly fallen snow, but indicative of warm, wet snow. After this (from about observation 140 to 189) HYDROS misclassified less often and accumulating snow density during this time was 100 to 150 kg/m^3, which is more typical of dry snow. It appeared that HYDROS correctly identified snow when there was a low water-ice ratio in the precipitation and ground accumulations did occur.

These crude comparisons suggest the HYDROS discrimination algorithms may be appropriate for identifying the precipitation types that affect snow or ground surfaces. The fact that the HYDROS gage does not have a classification for mixed types of precipitation may work to the advantage of hazard mitigation programs. For example, mixed types that are identified by HYDROS as rain usually interact with the snow or road surface like a liquid; so it makes sense that it is identified as liquid precipitation. Alternatively, observed sleet that is identified by HYDROS as snow usually interacts with the existing snow or road surface like snow. Also, the computerized snow-stratigraphy models need inputs of rain or snow, and cannot interpret mixed categories.

Figure 7 shows similar data from the Stampede Pass LEDWI precipitation identification gage. This gage recorded precipitation nine times when none was observed. Precipitation was observed 15 times when LEDWI recorded none. When it was raining, LEDWI was correct 84 percent of the time. When it was snowing, LEDWI was correct 87 percent of the time. During the two observations of mixed precipitation, LEDWI was nearly correct once and incorrectly classified the precipitaton as rain once.

The comparisons between the National Weather Service ASOS gage and this project's test gage indicate some confidence in the ability of HYDROS to identify precipitation types. Although HYDROS scored lower than the more expensive LEDWI, testing conditions were unequal. HYDROS was tested under very difficult conditions, with near and slightly above freezing temperatures, wet snow, and sleet; LEDWI tests occurred during clearly varying temperatures and precipitation types.

Neither gage can identify freezing rain. When freezing rain is precipitating, it falls like rain. It only can be identified by additional sensors on the depositional surface. These type of sensors are available and mostly used for road and runway surface applications (12).

At the Snoqualmie Pass site, a totalling precipitation gage was used to determine water equivalent of HYDROS's observed snow and

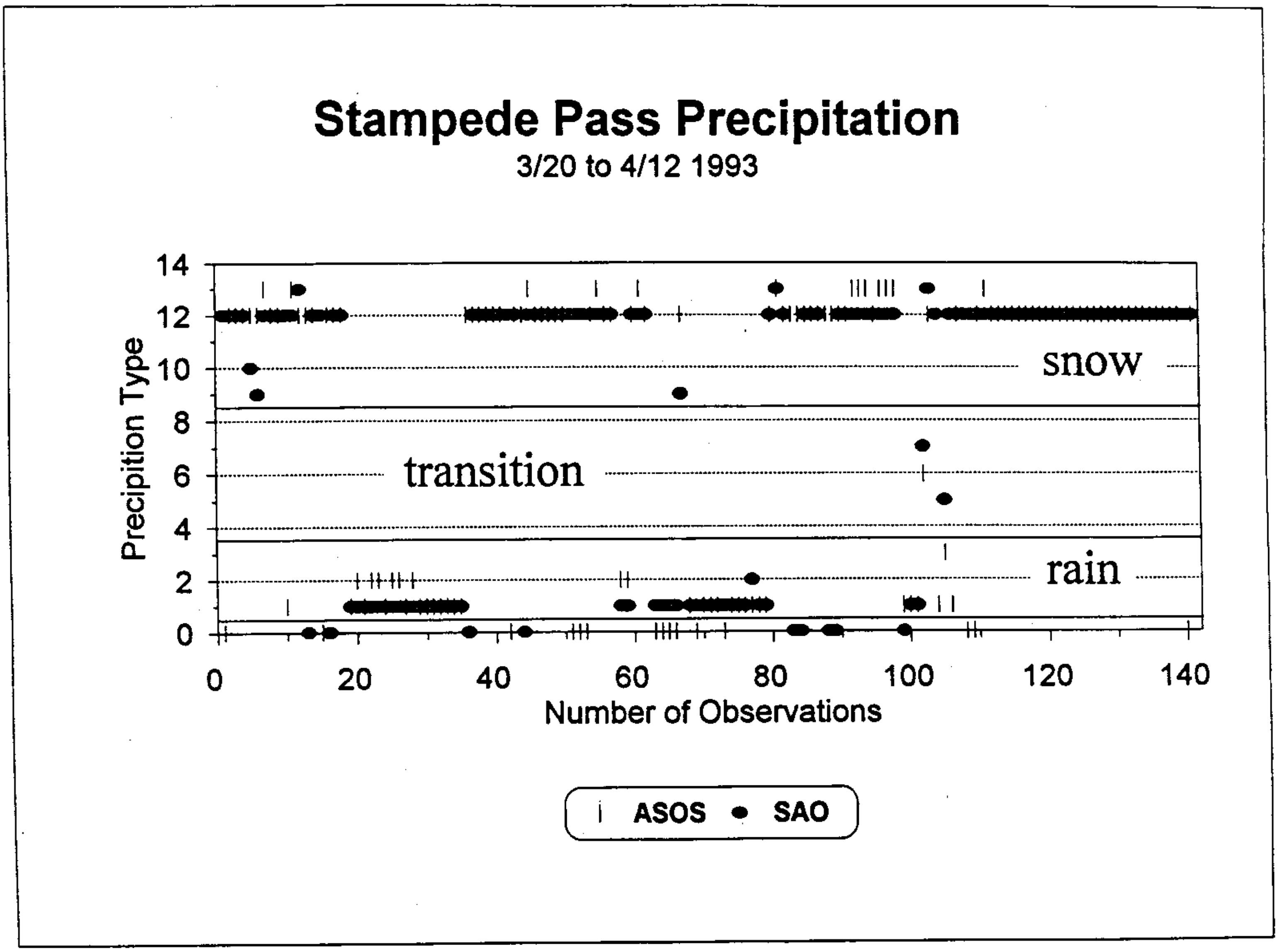

Figure 7. LEDWI precipitation type data and coincident visual observation (Stampede Pass, 3/20/93-4/12/93).

HYDROS's observed rain. Hourly output from a histogram of HYDROS's data were compared with time-specific visual observations. This meant that some misclassification is possible if a different precipitation type occurred during the hour than was observed at a moment in time by visual identification. With that caveat in mind, it is interesting to note that the average percent of HYDROS-identified rain, during the hour near visual observations of rain, was 96. Conversely, the average percent of rain was 44 when there were visual observations of sleet and rain was identified an average of 1% of the time when there were visual observations of snow. The HYDROS output data are shown graphically in Figures 8, 9, and 10 for visual observations of rainfall, sleet, and snowfall, respectively. A more complete picture of precipitation identification accuracy can be obtained by viewing individual storm cycles with visual observations that are coincident with HYDROS data. Figure 11 shows several precipitation events that occurred March 16-18, 1994. The following summarize the output:

2400-0200, 3/16	Rain observed and rain recorded.
0800-1100, 3/16	Some sleet, but mostly snow was observed. HYDROS recorded 30-percent, 3-percent, and 8-8-percent rain during each hour.
1400-1800, 3/16	Snow observed and snow recorded.

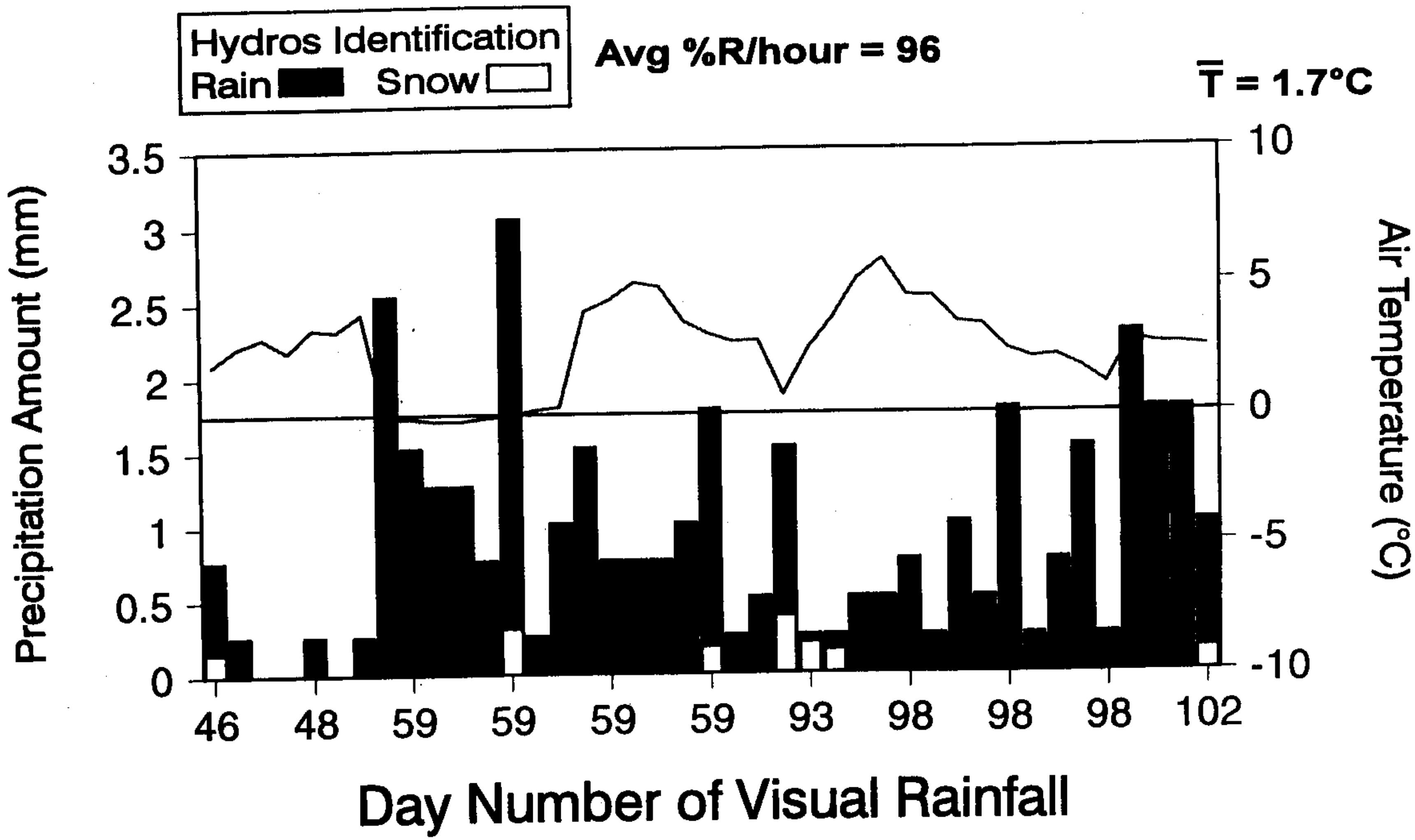

Figure 8. Precipitation accumulation and HYDROS identified type during periods of observed rainfall (2/9/94-4/12/94).

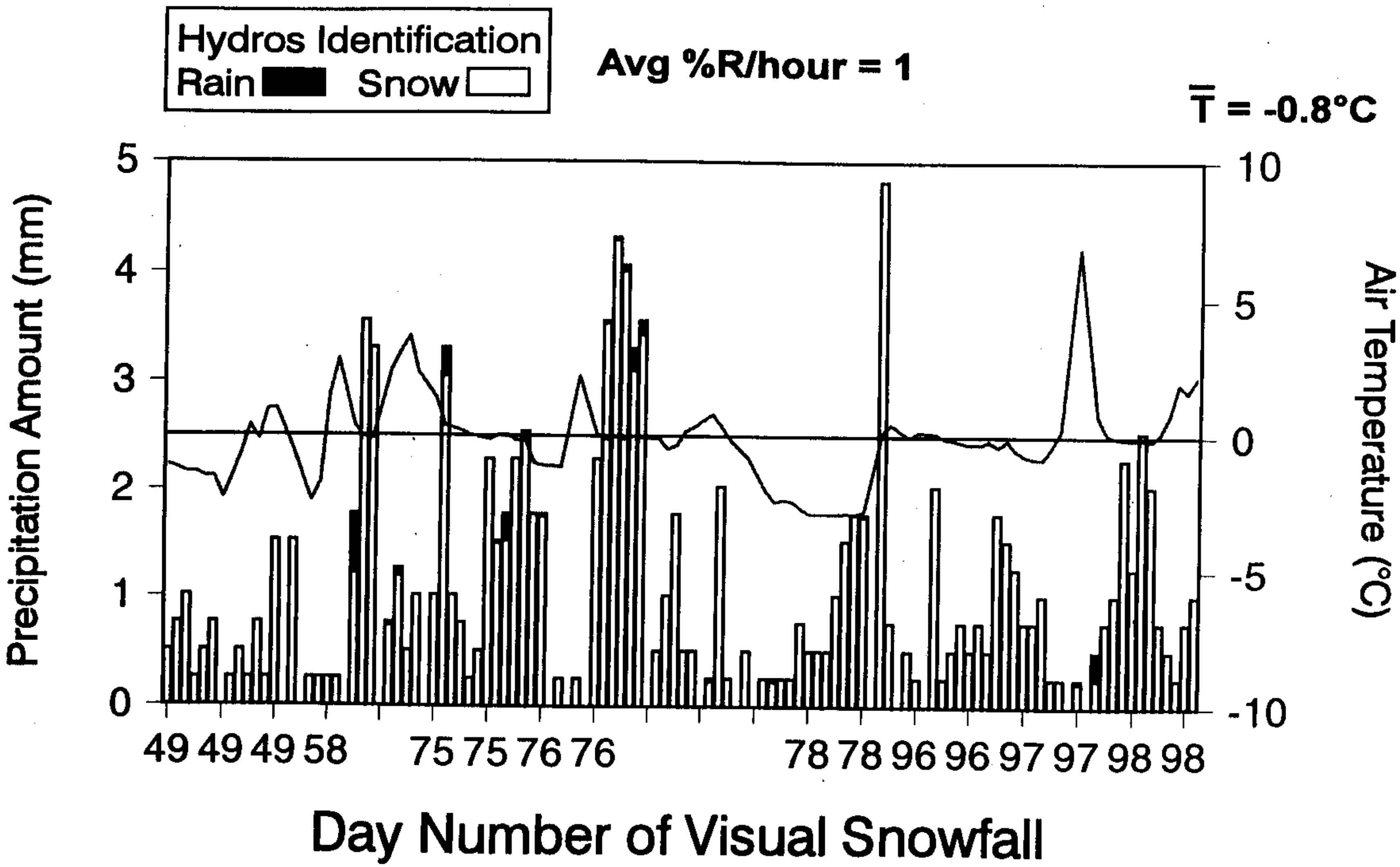

Figure 9. Precipitation accumulation and HYDROS identified type during periods of observed snowfall (2/9/94-4/12/94).

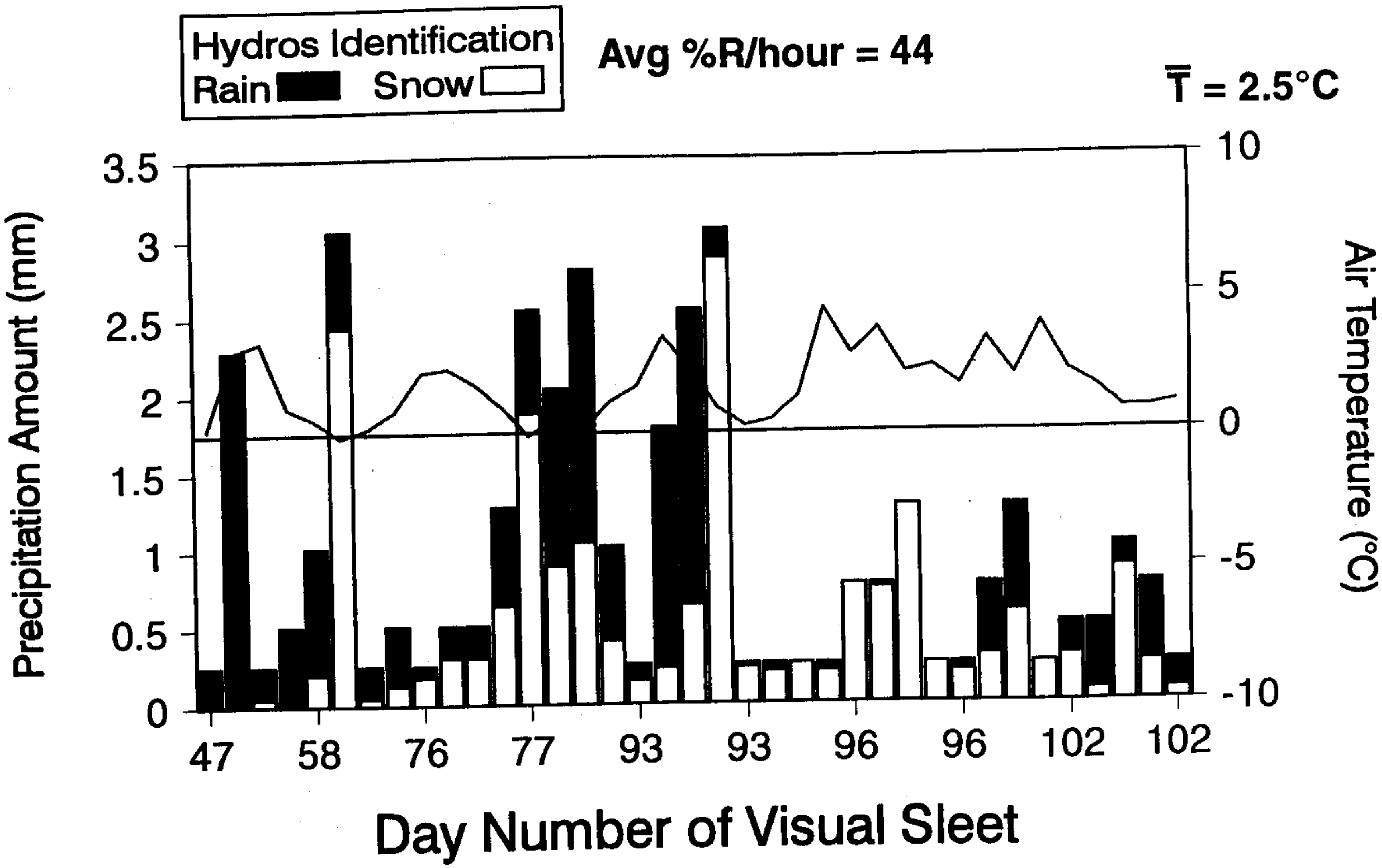

Figure 10. Precipitation accumulation and HYDROS identified type during periods of observed sleet (2/9/94-4/12/94).

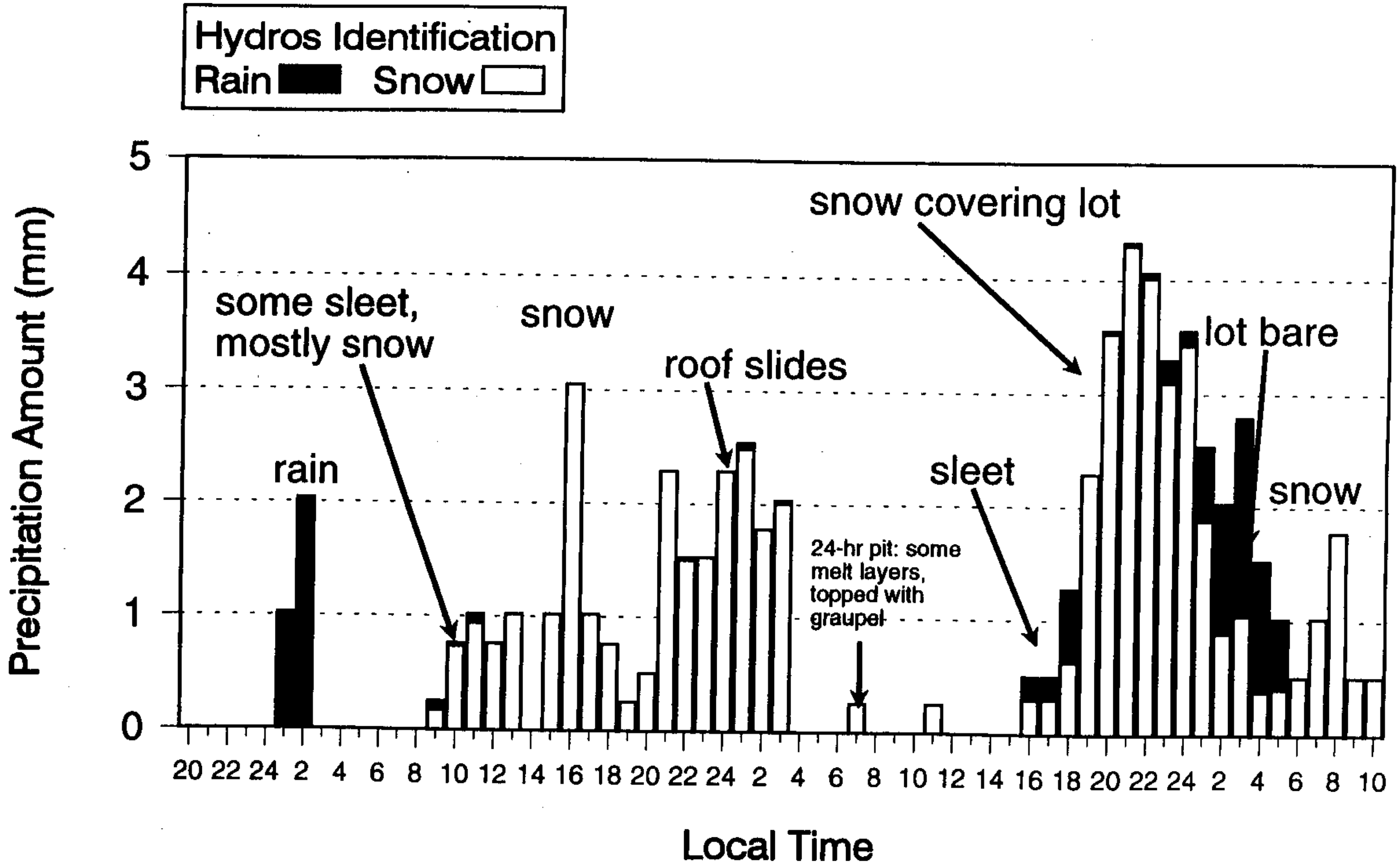

Figure 11. Sequential precipitation accumulation and HYDROS identified type during the period March 16-18, 1994.

2100-0300, 3/16-17	Snow sliding off roofs was heard. HYDROS recorded about 2-percent rain during 3 hours overnight.
0700, 3/17	Snow layering showed buried melt layers (from previous day's rain and sleet) with graupel on surface.
1500-1800, 3/17	Sleet observed and HYDROS recorded 40-percent, 40-percent, and 60-percent rain during each hour.
about 2200, 3/17	Observed that previously bare parking lot was covered with snow. HYDROS recorded snowfall beginning after 1800, with less than 1-percent rain in subsequent hours until 2300.
about 0300, 3/18	Observed that previously snow-covered parking lot was muddy. HYDROS recorded increasing amounts of rain after 2400, with 60-percent to 75-percent rain from 0200 to 0400.
0700, 3/18	Snow observed and snow recorded.

APPLICATION AND IMPLEMENTATION

The results of this project indicate that precipitation identification sensors may be a useful tool for hazard mitigation programs.

To fully implement the gage, it is useful to tie its output to a totaling precipitation gage. To do so, the data logger should be set to store a histogram of precipitation type every time the totaling gage increments. A flow chart illustrating such a program is shown in Figure 12.

Monitoring the data-logger allows instantaneous views of precipitation type and intensity. The most practical way to view output, however, is in cumulative graphs like that shown in Figure 11. This can be accomplished using simple graphing routines on the raw data, or through standard graphic packages.

The two gages purchased for the project were handed over to the WSDOT avalanche program and the Northwest Avalanche Center. The first prototype, which required heater tape to function properly, is installed at the WSDOT's Grace Lakes observation site, which is within Stevens Pass and near the Old Faithful avalanche paths. The second, improved sensor is installed mid-way at the Alpental Ski area, near the Denny Mountain avalanche paths within Snoqualmie pass. The second gage will operate 1 year with the

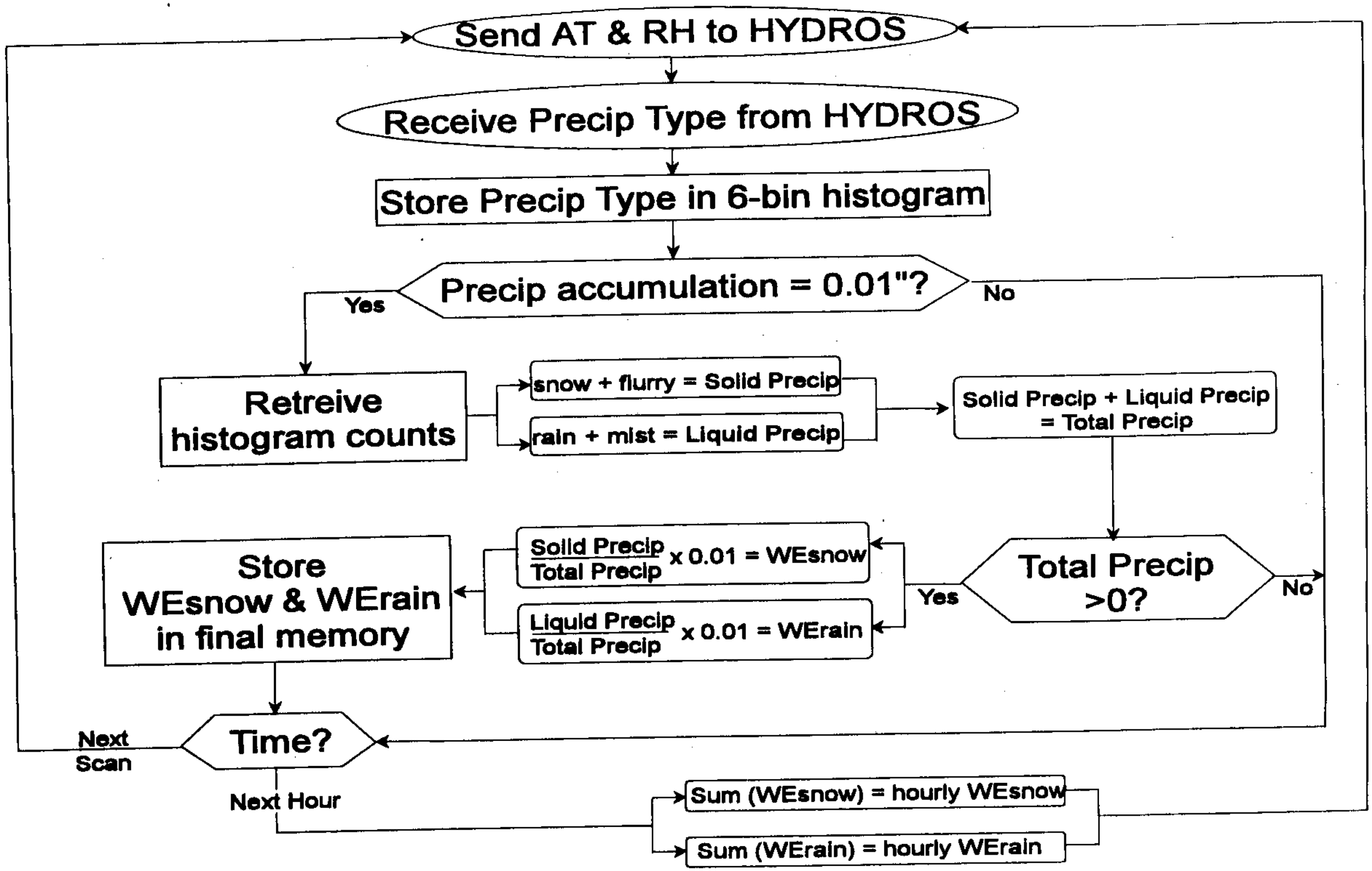

Figure 12. Flow chart of CR10 program that coordinates HYDROS output data with a totaling-precipition gage.

lenses unheated to test its ability to function with less power. Avalanche crews at both passes and the avalanche forecasters at NWAC will be able to use the HYDROS output.

It is important to build confidence in precipitation identification gages. Not only can the data assist in avalanche hazard mitigation programs, but also may benefit traffic safety programs. The type of gage being tested for this project is priced so reasonable that several gages may be installed at several locations along a highway, and at several elevations near avalanche-starting zones.

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REFERENCES

1. Ferguson, S.A., Moore, M.B., Marriott, R.T., and Speers-Hayes, P., "Avalanche Weather Forecasting at the Northwest Avalanche Center, Seattle, Washington, U.S.A.," Journal of Glaciology, Vol. 36, No. 122, 1990.

2. Murray, R., "Rain and Snow in Relation to the 1000-700 mb and 1000-500 mb Thickness and Freezing Level," Meteorological Magazine, Vol. 81, p. 5-8, 1952.

3. Lamb, H.H., "Two-way Relationships Between the Snow or Ice Limit and 1000-500 mb Thickness in the Overlying Atmosphere," Q.J.R. Meteorological Society, Vol. 81, p. 172-189, 1955.

4. Tamura, M., "Snow and Rain Fall Frequencies in Nagaoka," Journal of the Japanese Society for Snow and Ice, Vol. 52, No. 4, 1990.

5. Sugai, H., "Detection of Snow or Rain in the Winter Season," presented at International Glaciological Society Symposium on Snow and Snow-Related Problems, Nagaoka, Japan, 14-18 September, 1992.

6. Tamura, M., "Classification and Characteristics of Snow Detecting Sensors for Melting Snow," Hokuchiinetsu Branch of the Japanese Society of Snow and Ice, Vol. 10, 1992.

7. Hobbs, P.V., Ice Physics, Clarendon Press, Oxford, 1974.

8. Wallace, J.M., and P.V. Hobbs, Atmospheric Science: an Introductory Survey, Academic Press, New York, 1977.

9. Scientific Technology, Inc., 205 Perry Parkway, Suite 14, Gaithersburg, Maryland 20877.

10. Contracting Technologies, Inc., 6270 Highway 61-67, Imperial, Missouri 63052.

11. Campbell Scientific, Inc., 815 West 1800 North, Logan, Utah 84321-1784.

12. Kelley, J.M., "Solutions to Improve Ice and Snow Control Management on Road, Bridge, and Runway Surfaces," National Research Council, Transportation Research Board Record No. 1276, 1990.