APPROACHES TO MEASURING "TRUE" SNOWFALL

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Introduction

For the past 2,500 years, man has utilized gages to measure precipitation (Biswas, 1967). It would seem that the accurate measurement of precipitation under all conditions would be a relatively simple undertaking. However, as early as the 13th century AD, the Chinese were concerned with the problems of improving precipitation measurements (Needham, 1959). By the 19th century, it became quite apparent that the catch of precipitation gages was affected by many variables (Abbe, 1887).

Wind has the strongest influence on precipitation gage catch and an increase in wind speed will generally result in a decrease in gage catch, especially for solid forms of precipitation. Wilson (1954) has indicated that the deficiency of precipitation gage catch could approach 80 percent when the precipitation is in the form of snow.

The last one hundred years has seen numerous attempts by researchers to develop gage shields to minimize or compensate for the wind-caused deficiencies in gage catch (Kurtyka, 1953). Thomas Stevenson (1842) of Scotland appears to have been the first to utilize a gage shield. In the United States, the first work on gage shields was done by Joseph Henry (1853). Notable work on gage shields was accomplished by both Francis E. Nipher (1878) and J. C. Alter (1937). These gentlemen developed precipitation gage shields which bear their names and are in widespread use today.

Investigations by Warnick (1956) as to the effectiveness of gage shields have shown quite conclusively that the catch characteristics of precipitation gages under snow conditions are improved by the installation of gage shields. The Alter shield is generally preferred for snow conditions because the free swinging metal leaves are less likely to cause interference in gage operation due to capping (Weiss and Wilson, 1957). It is also true, however, that no shield in use today has completely solved the wind problem. A gage shield will reduce the wind-caused error in precipitation measurements but will not eliminate it.

It has become evident in recent years that one of the limiting factors in the accuracy of improved conceptual water models being developed for continuous simulation of streamflow is an inability to accurately measure snowfall either on a point or areal basis. Because of this application and the importance of more accurate snowfall measurements to many water resource studies in general, the Hydrologic Research and Development Laboratory of the National Weather Service has a project underway to reduce wind effect at the gage site and another to develop a technique for adjusting observed precipitation. It is hoped that these two projects, one in Wyoming and the other in Vermont, will ultimately provide better methods for measuring "true" precipitation especially snowfall.

The Wyoming Project

Gage, site, and large scale eddies all tend to influence the solid precipitation catch of a gage. Proper site protection however, can reduce the turbulence and eddy currents near the gage and will result in a more consistent and reliable snowfall measurement (Peck, 1972). Snowfall measured at a well-protected site is probably quite close to the actual point snowfall (Brown and Peck, 1962).

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The National Weather Service (NOAA, 1970) has stated that a suitable gage location has surrounding uniform protection with a height above the gage not exceeding twice the distance from the gage to the protecting objects. An example of a suitable site is a small circular clearing in a dense coniferous forest. Unfortunately, suitable gage locations seldom exist where precipitation data are required especially in mountainous areas. Israelsen (1967), in his study of the reliability of precipitation gage measurements, has concluded that most errors in measuring snowfall with precipitation gages are a result of improper gage siting.

The Wyoming project has as its major goal the investigation of the possibility of shielding precipitation gages from adverse wind effects by the use of artificial wind barriers (i.e. snow fences) for site protection. Alter shields are being used in conjunction with various fence combinations at this site in an attempt to minimize the effect of wind. The objective is to duplicate, as nearly as possible, the precipitation catch at a well-protected site in a forest opening with the catch of a gage located in an open windy area, protected only by Alter shields and snow fences. The use of artificial wind barriers to produce well-protected precipitation gage sites at desired locations could reduce precipitation measurement errors due to poor gage siting.

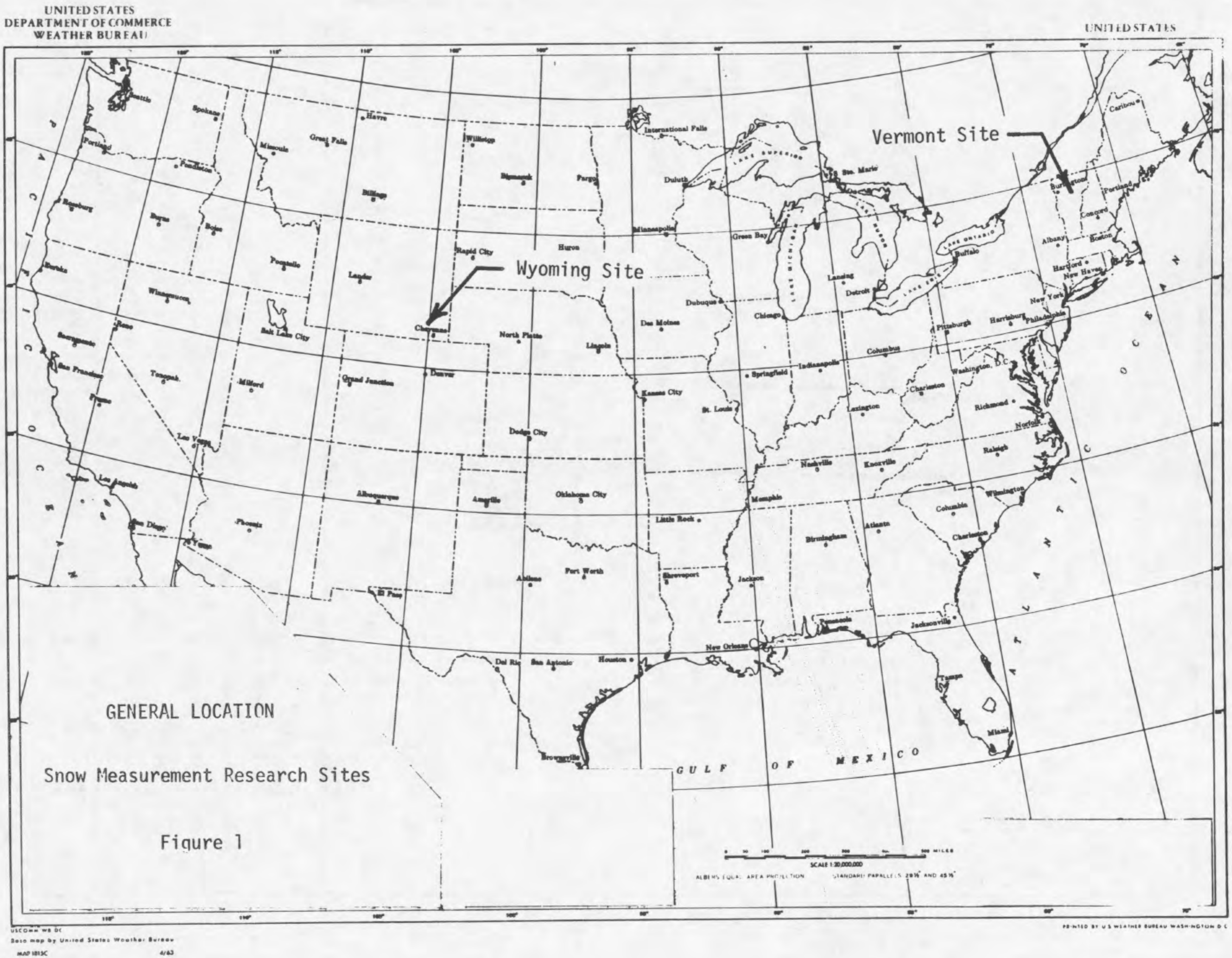
Gage shields which are properly installed do increase the gage catch efficiency but the effects of fences on gage catch have not been as well documented. Bastamoff (1928) stated that fence eddies cause relocated snow to be deposited into the protected gages thus giving overcatch. Russell (1927) however, found little or no effect on the gage catch due to fences with a slight tendency to decrease rather than increase catch. Wild (1885) stated that a fence enclosure provided additional catch about equivalent to that of a Nipher shield, but he felt that the fence caused too much disturbance in the air flow about the gage. Riesbol (1938) stated that a fence enclosure had no effect on precipitation catch.

The site of the Wyoming study, conducted by the University of Wyoming under contract with the National Weather Service, NOAA, is located between Cheyenne and Laramie in southeastern Wyoming at an elevation of 8,100 feet. The area is open and subject to winds of high speed and long duration (Fig.1).

The installation consists of nine precipitation gages plus associated equipment such as anemometers, wind direction recorders, hygrothermographs, time-lapse cameras, etc. (Fig.2). The protective fencing is standard 50 percent density vertical lath snow fence in 4-1/2 and 8-1/2 foot heights.

Five shielded gages (nos. 1 to 5) are located at various distances downwind from two parallel snow fences (8-1/2 and 4-1/2 foot, respectively). Two gages (6 and 7) are located in the open with gage 7 having an Alter shield Gage 8 is shielded and is located downwind of a series of four 8-1/2 foot snow fences. Considerable prior research has been done on snow fence design and behavior and this, in general, determined fence spacing and gage placements (Pugh, 1950) (Pugh and Price, 1954).

The fence protection for gage 9 was developed based on the first year of operation of the site. The gage protection consists of two concentric circles of 4-1/2 foot fencing inclined at 45° and 60° (Fig.3). Wind tunnel model tests were utilized in an attempt to optimize this scheme for minimum wind speed and turbulence in the vicinity of the gage orifice. This configuration of fencing has the advantage that relocated snow is accelerated under and past the gage thus eliminating drifting problems in the gage vicinity. In addition, less space, material, and time are involved for its installation as compared to the more extensive fence protection schemes (Larson, 1971).



GENERAL LOCATION

Snow Measurement Research Sites

Figure 1

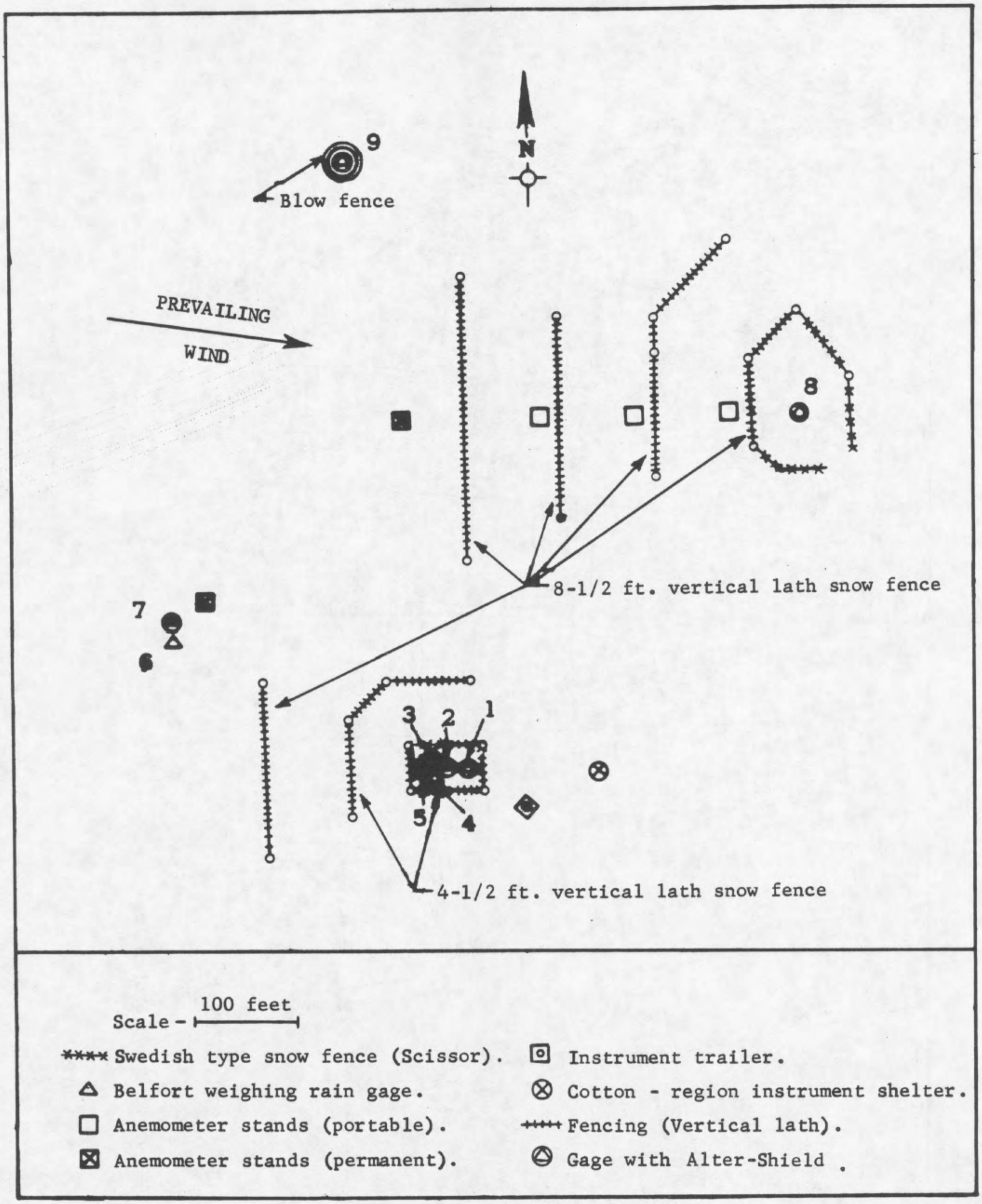


Figure 2 - Wyoming Site Map.

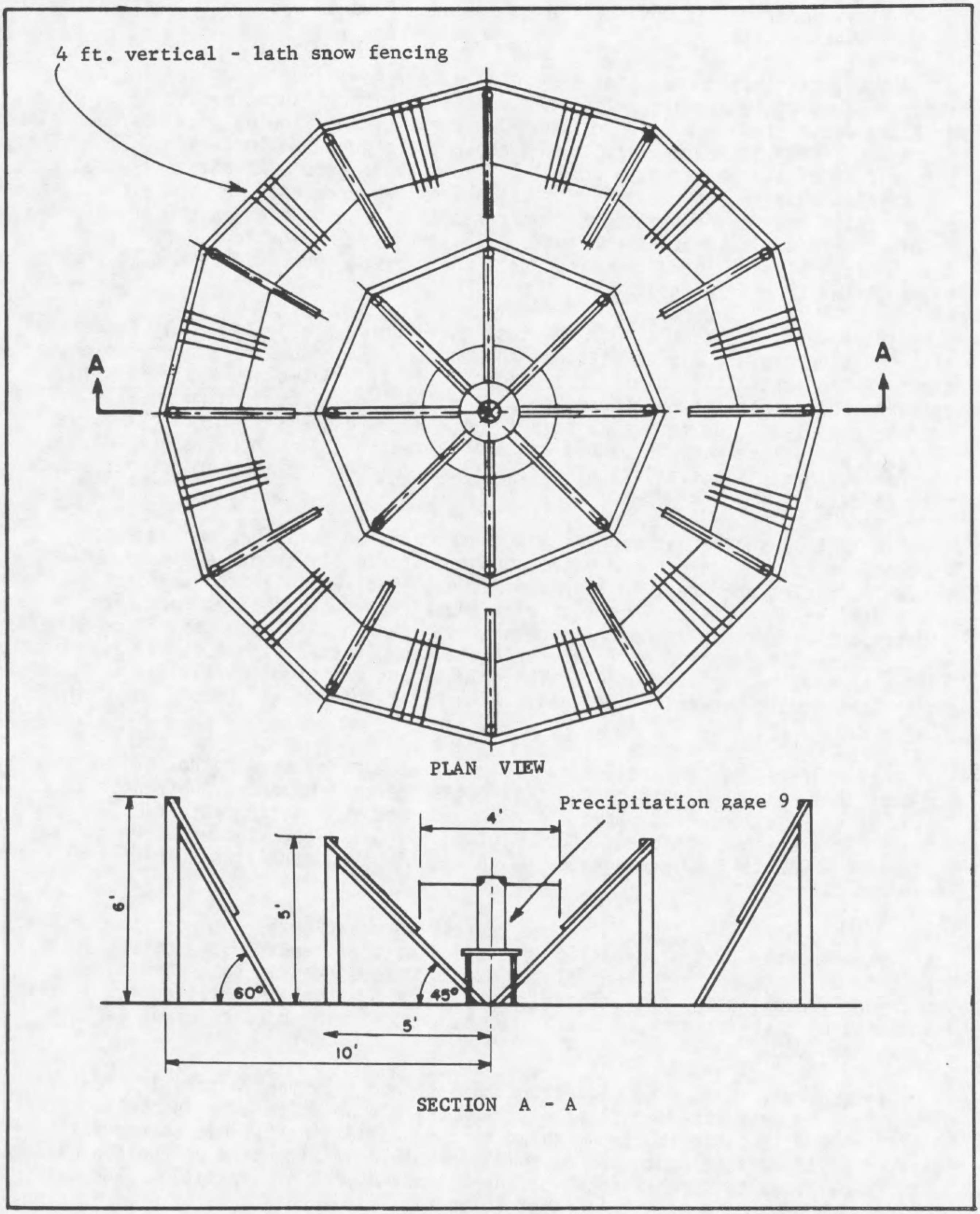


Figure 3 - Blow fence design -- Gage 9, Wyoming Site

Five control gages are provided for determining true or standard snowfall data for comparisons with the catchs of the test gages. All control gages are shielded and are located in clearings in coniferous forests with exposures rated as fairly well-protected to protected (Brown and Peck, 1962). The primary control gage (USFS-2) is located just south while other control gages are located east and west of the research site.

It was recognized that site shielding with fences involves a problem of attempting to minimize windspeeds and turbulence without inducing the catch of drifting (relocated) snow. More than 90 percent of the blowing snow has been shown to be contained within the first meter above the ground (Mellor, 1965). Therefore, the orifice of all gages was placed 4-1/2 feet above ground and it is assumed that the shields continue to provide protection from gage eddies. To reduce the amount of relocated snow being transported past the test gages, gages 1 to 5 and 8 are provided with upwind protective fences. The fences, in addition to reducing the mean horizontal wind speed downwind, trap the blowing snow and prevent it from being lifted to orifice height.

The results are that all of the test gages which are protected by fences and Alter shields exhibit higher seasonal snow catchs than gages with no fence protection or with just Alter shield protection (Table I). A two-way analysis of variance shows that the null hypothesis (i.e., all gages performing equally well) must be rejected. The test statistic for the gages exceeds the critical value at a significance level of .05 with 9 and 531 degrees of freedom (25.71 > 1.88). Therefore, there is a statistically significant difference in storm catchs between test gages.

The F test shows that significant differences do exist between gages but it does not tell which gage or gages perform differently from the others. The Duncan multiple range test (Miller and Freund, 1965) was utilized to identify where these differences exist. This test will identify groups of gages for which no significant difference in performance exists. The results show that gage 6, which has no Alter shield or fence for protection, catchs significantly less precipitation than all other test gages. The primary control gage (USFS-2) is included in the group which contains only gages with Alter shields and fences for protection (Gages 2,3,5, and 8).

A linear regression analysis of the storm catchs of the control gage (USFS-2) on the storm catchs of each of the test gages (Gages 1-9) shows that gages 1, 2, 3, 5, 8 and 9, all of which have Alter shields and fences for protection, have higher correlation coefficients (.979 to .988) and smaller standard error of estimates (.022 to .080) than gages which do not have both Alter shields and fences for protection.

The b coefficient (slope) in the regression equation is an indicator of the test gage location which most closely duplicates the standard gage site. That is, the gage with the b coefficient closest to 1.00 consistently has storm catchs most nearly duplicating the standard gage. Gage 8, which is shielded and is also protected by a series of four 8-1/2 snow fences, has the b coefficient (1.06) closest to 1.00.

In general, under wind conditions encountered thus far in this particular study (i.e. a mean storm wind speed of 12 mph), it seems that an unshielded precipitation gage will catch about one-third to one-half of the "standard" snowfall; a gage with its orifice protected by an Alter shield or with site protection will catch two-thirds to three-fourths of the "standard". A precipitation gage with its orifice protected by an Alter shield and its site protected by snow fencing will catch about the equivalent of the "standard" snowfall.

TABLE I

Precipitation Totals

Location: Wyoming
Period: Sept 1970 - May 1971
Storms: n = 60 (snow)

Gage	Alter Shield	Fence Protection	Precipitation Total (inches)	Inches per storm	% Standard
1	yes	yes	15.89	.26	88.32
2	yes	yes	16.43	.27	91.32
3	yes	yes	16.66	.28	92.60
4	no	yes	12.88	.21	71.59
5	yes	yes	16.54	.28	91.93
6	no	no	8.35	.14	46.41
7	yes	no	12.07	.20	67.09
8	yes	yes	17.61	.29	97.88
9	yes	yes	13.84	.23	76.93
USFS-2*	yes		17.99	.30	100.00

* standard

The Vermont Project

In 1957, the Agricultural Research Service (ARS) established a research watershed in the Sleepers River Basin in northern Vermont near Danville (Fig.1). The National Weather Service in cooperation with the ARS beginning in 1966 has conducted several snow research experiments in the watershed.

In 1968, it was decided to initiate a research effort to evaluate various techniques for determining ground "true" precipitation. The primary emphasis of this study to date has been on the dual-gage approach for calculating "true" storm catch. This method is based on the premise that a relationship exists between the catch of unshielded gages, rigid shielded gages, and true catch (Hamon, 1971; Struzer, 1969). Hamon's equation for this relationship takes the following form

$$\ln(\frac{u}{A}) = B \ln (\frac{u}{s})$$

where u = catch of unshielded gage, s = catch of rigid shielded gage, A = "true" catch and B = calibration coefficient. The B coefficient has been determined to be relatively constant for most ranges of windspeed, for both liquid and solid precipitation (Hamon, 1970).

The Vermont project has had four sites in operation to provide data for precipitation studies. Two of these sites, X-2 and X-4, were deemed suitable for use in evaluating the dual-gage approach. Site X-2 has rigid shielded, unshielded and Alter shielded gages at 10 foot heights while the X-4 site has similar gages at 15-foot heights. These two sites are located approximately 150 yards apart with site X-2 having slightly more protection than site X-4. The rigid shields at these two sites were constructed by constraining the leaves of a standard Alter shield at 30 degrees with the vertical.

A well-protected site (Brown and Peck, 1962) to obtain "ground true" precipitation data was established just east of sites X-2 and X-4 by cutting a 30 foot diameter opening in a dense coniferous forest. This opening was encircled by a 10 foot high polyethylene wind screen. A weighing-recording precipitation gage with Alter shield was installed inside the enclosure along with a totalizing anemometer. There appears to be no wind effect on the gage at this site. The effect of the opening in the trees on the amount of precipitation falling on the ground true site during precipitation events is not certain. There is no evidence however, that relocated snow from the forest canopy is deposited in the gage after the precipitation event ceases.

Data from twenty snow and mixed storms of the 1970-71 season at site X-4 were used to determine a value for the B coefficient for use in the dual-gage equation. A best fit regression line through the origin where $X = \log (\frac{U}{S})$ and $Y = \log (\frac{U}{A})$ resulted in a B value of 1.80 for this data. The correlation coefficient for this analysis was .83.

The dual-gage relationship was then applied to site X-2 for twenty-two snow and mixed storms during the two winter seasons 1969-70 and 1970-71. A calculated ground true was determined for these storms using known data from the unshielded gage, the rigid shielded gage, and the dual-gage relationship. The results are that the unshielded gage catches 21.39% less than the standard gage, the Alter shielded gage catches 14.28% less, while the dual-gage approach overestimates the standard gage by .18% (Table II).

A linear regression analysis of the measured standard catch on the precipitation catch calculated from the dual-gage approach results in a correlation coefficient (r) of .988 and a standard error of estimate of the measured catch on the calculated catch ($S_{y.x}$) of .079.

In order to test the hypothesis that the mean storm catch of measured ground true, calculated ground true, the unshielded gage, and the Alter shielded gage are all equal, the two-way classification analysis of variance was again utilized. The F test showed that the null hypothesis (i.e. all storm means equal) had to be rejected. The test statistic for the gages was 18.05 which exceeded the critical value at a significance level of .05 with 3 and 63 degrees of freedom.

The Duncan multiple range test was again used to identify where the differences in performance exist. Three distinct groups of storm means were identified substantiating what is perhaps evident from Table II. The group with the smallest storm mean contained only the unshielded gage. The group with the next largest storm mean contained the gages with the Alter shield and rigid shield. The third group contained the storm means of ground true and the dual gage approach.

A plot of the ratio of storm precipitation values (i.e. unshielded, Alter shielded, and dual-gage) and ground true versus wind speed is shown in Figure 4. Exponential curves constructed through the data mean point out the disasterous effect of wind on the catch of an unshielded gage and the improvement in gage catch characteristics with the addition of an Alter shield. The change in the gage catch ratio through the use of the dual-gage approach for this site and data is also apparent.

Another method for obtaining ground true precipitation data that is being investigated at the Vermont site is the profile method. In this method it is assumed that similar gages will have decreasing precipitation catchs with increasing heights above ground level due to increasing wind speeds. A logarithmic plot of gage height versus gage catch could thus be fit with a straight line and extrapolated to the level of the existing snow cover to determine ground true catch.

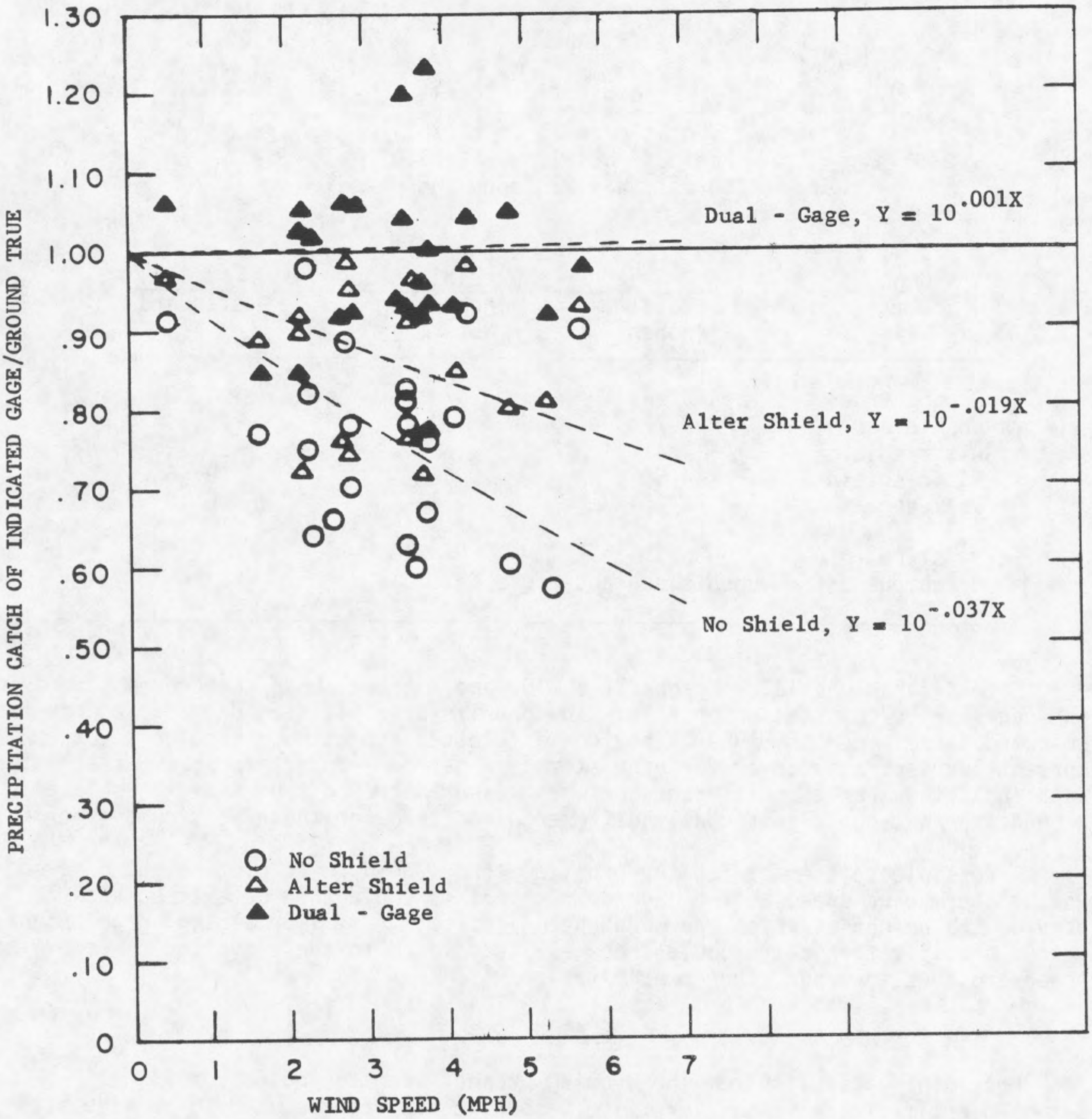


Figure 4 - Gage catch ratios vs. wind speed (mph), Site X-2, Danville, Vt., Snow and mixed storms.

TABLE II

Precipitation Totals

Location: Vermont (X-2)
Period: Nov 1969 - Feb 1971
Storms: n = 22 (snow and mixed)

Gage	Precipitation		
	total (inches)	inches per storm	% standard
Ground true*	16.18	.74	100.00
Unshielded	12.72	.58	78.61
Alter shield	14.41	.65	85.72
Rigid shield	14.50	.66	89.45
Dual-gage**	16.21	.74	100.18

* standard
** computed from unshielded and rigid shielded data

Site X-4 has unshielded gages at 6, 10, and 15 feet above the ground to provide the necessary precipitation profile. The profile precipitation data for twenty-five selected storms from the 1969-71 period was plotted and extrapolated to the then current level of snow cover for each storm. A paired - t test for the extrapolated data indicated that the difference between measured ground true and extrapolated ground true was not significantly different from zero for these particular storms.

A possible refinement for the profile method would be to plot height of gage versus storm wind speed at the gage orifice. This could then be extrapolated to provide the height at which the wind speed is zero. A similar plot of gage height versus percipitation catch could then be extrapolated to the elevation of zero wind speed and thus to ground true precipitation.

Conclusions

Preliminary results from the Wyoming project seem to indicate that well designed artificial wind barriers (i.e., snow fences) can be used to provide site protection for precipitation gages approximately equal to a "well-protected" natural site. The Vermont project indicates that the dual-gage approach and the profiling method for calculating "ground true" precipitation seem to have considerable merit.

It should be emphasized that the methodology and results discussed here are preliminary in nature. It is not the intention to imply that site shielding as used in the Wyoming study or the dual-gage approach and profiling method from the Vermont study are directly applicable for other sampling situations. The purpose, at this point in time, is to investigage all reasonable avenues of approach to improving snowfall measurements and in the future to arrive at some reliable method for measuring or otherwise determining "true" snowfall for most situations.

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