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PRECIPITATION MEASUREMENTS ON WIND-SWEPT SLOPES

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Abstract--Precipitation catch for three calendar years is compared for four types of gage installation on a wind-swept south-facing slope with a 22° gradient at elevation 5500 ft. The 1950 precipitation catch by (1) weighing-recording gage with the orifice and a Alter type wind shield sloped parallel to the ground surface, (2) unshielded non-recording gage with orifice sloped parallel to the ground surface, (3) weighing-recording gage with horizontal orifice and Alter type wind shield, and (4) unshielded U. S. Weather Bureau standard gage with funnel removed was (1) 62.90, (2) 53.34, (3) 39.82, and (4) 27.64 inches, respectively. In 1951 the respective catches were (1) 61.38, (2) 52.94, (3) 35.91 and (4) 25.67 inches; and in 1952 they were (1) 39.62, (2) 35.01, (3) 27.09, and (4) 15.91 inches. Indications are that gage (1) probably did not overestimate precipitation amounts and that there is a relationship between wind velocity and magnitude of differences in catch between gages.

Introduction--The accurate measurement of precipitation is quite difficult. The problems encountered are increased by rugged terrain, exposure to wind, and the occurrence of a large proportion of the precipitation in the form of snow.

One of the principal causes of inaccuracy or variation in measuring precipitation on wind-swept slopes is the turbulence produced by the gage in the moisture-bearing wind stream. Some of the precipitation which should fall into the gage is carried over it because of an increase in pressure and consequent upward deflection of the air stream on the windward side and a decrease in pressure and marked acceleration of the air stream over the top of the gage [BROOKS, 1938a; KREIN, 1952].

The desirability of using wind shields to minimize air turbulence over a gage orifice has been demonstrated repeatedly. Relatively few of these studies were concerned with snow and still fewer included severe conditions of wind and topography. However, in almost every case it was shown that gage catch was materially increased by using a wind shield.

The Nipher [BROOKS, 1938b] and Alter [ALTER, 1937] types of shields have proved the most successful of the many types devised. The Nipher shield is the better of the two for rain but unsuited for snow when left unattended. The large flat surface collects snow which may later blow into the gage, or accumulating snow may bridge the receiver orifice. Slat-type Alter shields have been most successful for snow and are widely used on snow gages in the mountainous areas of the West [BERNARD and CODD, 1940]. The shield consists of sheet-metal slats loosely attached to a supporting ring approximately 40 inches in diameter. The apparent action of the shield is to close toward the gage and deflect the air stream downward enough to compensate for upward deflection caused by the gage [KREIN, 1952].

Another source of measurement error is the difference in angles at which the plane of the gage orifice and a sloping ground surface intercept precipitation. The error becomes large when precipitation falls at an appreciable angle from vertical into a gage with a horizontal orifice exposed c a steep slope. Tilting the gage improves the precipitation catch on slopes [STOREY and HAMILTON, 1943] because it intercepts precipitation on the same plane as the ground surface. The catch is then multiplied by the secant of the angle between the plane of the orifice and the horizontal to correct for slope and thus express precipitation on a horizontal basis. The same result can be obtained by cutting the gage orifice to the same angle as the slope, eliminating the need for slope correction. STOREY and HAMILTON [1943] suggested that this type of gage be called a "stereo" gage. They, with PAGLIUCA [1934], indicated that tilted gages are aerodynamically superior to stereo gages, however.

A number of gaging sites in a precipitation gage network on the Priest River Experimental Forest in northern Idaho are steep and exposed to winds. Gages developed for these more severe sites combine the advantages of stereo orifices and wind shields of the Alter type. Both the orifice and shield are parallel to the ground surface. Stereo orifices are used because some of the gages are of the weighing-recording type and not adapted to tilting. PAGLIUCA [1934] suggested slanting the gage and shield parallel to the slope for measuring snow, and HAYES and KITTREDGE [1949] used a tilted gage with Nipher shield for rain. The Priest River gage is thus essentially like the previously suggested forms but differs in using the slat-type shield which is better adapted to snow. As this combination is relatively uncommon, a test installation was operated for three years beginning in the fall of 1949 to compare the performance of this gage with three other types of gages. Early results of the test were reported by HELMERS [1952]. The concluding results are described below.

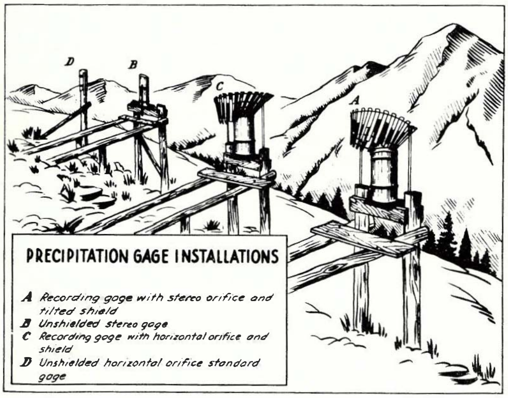

Fig. 1--Sketch of precipitation gage test installation

Gage installations and results--The gage installation (Fig. 1) was located at an elevation of 5500 ft on a windy south-facing slope with a 22° gradient, and included: (A) recording gage with stereo orifice and tilted shield, (B) unshielded non-recording gage with stereo orifice, (C) recording gage with horizontal orifice and shield, and (D) unshielded standard gage (8 by 24 inches non-recording) with horizontal orifice.

It is estimated that 50 pct or more of the annual precipitation at the test site occurs as snow. Gage orifices were all about ten feet above the ground surface to keep the gage bases just above the maximum snow-pack depth. Precipitation catches were usually measured weekly during precipitation periods but less frequently during 1952 and during the summer months of light precipitation.

Table 1 summarizes the annual catches for the three years of record. The differences in catch between gages are expected to vary between years due to differences in wind and in the proportion of precipitation falling as snow. In spite of these possible sources of variation in catch, the four gages ranked about the same in magnitude of catch during the two years of nearly equal precipitation. Precipitation for 1952 was roughly 40 pct less than for the previous two years and catches by the non-standard gages were from 10 to 30 pct higher as compared with the standard gage.

Table 1--Summary of 1950-1952 annual precipitation catch by four types of gage installation

Gage	Installation	Measured precipitation			Comparison with standard gage		
		1950	1951	1952	1950	1951	1952
		inch	inch	inch	pct	pct	pct
A	Recording gage with stereo orifice and tilted shield	62.90	61.38	39.62	228	239	249
B	Unshielded stereo gage	53.34	52.94	35.01	193	206	220
C	Recording gage with horizontal orifice and shield	39.82	35.91	27.09	144	140	170
D	Unshielded horizontal orifice standard gage	27.64	25.67	15.91	100	100	100

The rank in magnitude of annual catch was observed for practically every measurement period (Fig. 2). The principal exceptions were due to heavy snow storms when both stereo orifices became partially or completely bridged with snow. Other occasional exceptions were attributable to weighing errors or to very small storms, the total precipitation of which was near the limits of accuracy of the gage weighing devices.

The observed tendency of stereo gages to bridge earlier than the horizontal orifice gages tends to support the previously noted [STOREY and HAMILTON, 1943; PAGLIUCA, 1934] aerodynamic inferiority of stereo gages.

Gage catch was compared with snow-pack water equivalent to determine, if possible which gage was most efficient. These comparisons were not wholly successful, however. Rain and wind effects

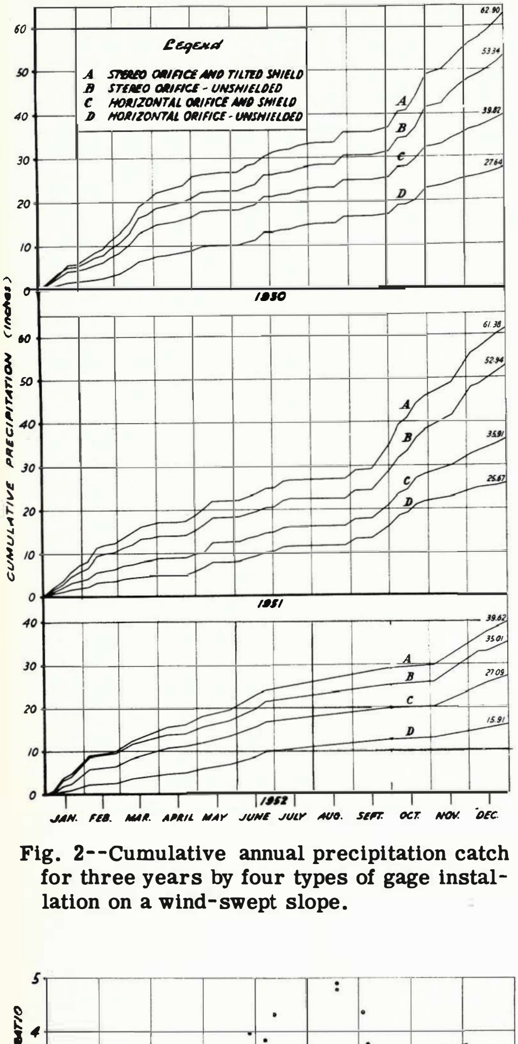

Fig. 2--Cumulative annual precipitation catch for three years by four types of gage installation on a wind-swept slope.

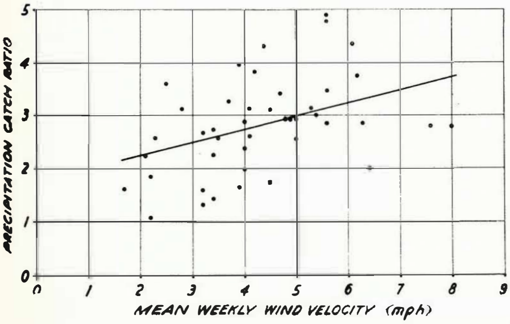

Fig. 3--Relationship of the precipitation catch ratio (catch by stereo gage with tilted shield to catch by unshielded standard gage) to mean weekly wind velocity

on the snow pack sometimes eliminated a sound basis for comparison. Apparent water equivalent gains were reliable only when there were no losses due to percolating rain or snow-melt water and when there was no wind erosion of snow. One of the more reliable comparisons of gage catch with snow-pack water equivalent gain includes the period from February 9 to March 8, 1950. Precipitation catch by the stereo gage with tilted wind shield was about 6.05 inches. The snow-pack water equivalent gain was 7.9 inches during the same period. March 23 to April 5, 1950, was another period of little wind erosion. The gage received about 2.8 inches of precipitation while the snow pack gained 3.2 inches of water. The gage orifice was about six feet above the snow surface on February 9 and March 23, and four feet on March 8 and April 5. These comparisons indicate that the most efficient gage of the four tested is probably the most accurate.

Gage catch consistently exceeded water equivalent gain in 1951. From February 2 to March 12 the gage accumulated 3.60 inches of precipitation but the snow pack gained only 2.4 inches water equivalent. The 1951 period, however, was windy as compared to the 1950 period as shown by Table 2.

Table 2--Comparison of daily wind travel during February 9 to March 8, 1950, and February 12 to March 12, 1951

Daily wind travel	February 9 to March 8,1950	February 12 to March 12,1951
mile	no. days	no. days
Less than 100	16	8
100 to 200	5	16
Over 200	0	4
No record	6	0
Total	27	28

During windier periods some wind-blown snow is very likely deposited in the gages at the same time that the snow pack is eroded. The gage orifice was about six feet above the snow surface during the 1951 period above.

Wind was recorded from a three-cup anemometer. This type of anemometer is unsuited to winter conditions and was often immobilized by snow, ice, and rime, resulting in fragmentary records. Available data, however, tend to support the observation of PAGLIUCA [1934] and others that the effectiveness of wind shields increases with increasing wind velocity. A significant ($r = 0.39$) relationship was found between mean weekly wind velocity and the ratio of the catch of the stereo-tilted shield gage to that of the unshielded standard gage with horizontal orifice (Fig. 3). The precipitation catch ratio of the first gage to the second (assuming the ratio is a linear function of mean weekly wind velocity, mph) was

$$\text{catch ratio} = 1.78 + 0.24 \times \text{mean weekly wind velocity, mph}$$

according to the best wind records available.

Summary--Precipitation catch for three calendar years is compared for four types of gage installations on a wind-swept south-facing slope at 5500 ft elevation. Precipitation catch by a standard eight-inch gage with a horizontal orifice was consistently low. The catch of a standard gage was increased by adding a horizontally mounted Alter type wind shield. Cutting the gage orifice to an angle equal to the slope gradient ("stereo-orifice") resulted in a greater catch, however, than adding a horizontally mounted wind shield. The greatest catch was obtained by a stereo gage with a windshield tilted parallel to the slope gradient.

Precipitation catch by the stereo gage with the tilted wind shield agreed well with snow-pack water equivalent gain during periods when wind did not erode snow cover or deposit drifting snow into the gages. Conclusive comparisons were not available, however. The stereo gage with tilted shield is presumed to be the most accurate of the gages tested.

The effectiveness of the wind shield increased with increasing wind velocity.

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