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EXPERIMENTS WITH WINDSHIELDS FOR PRECIPITATION GAGES

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Abstract--Under cooperative encouragement from several Federal agencies, the Engineering Experiment Station of the University of Idaho has been studying the principles, development, and use of high-altitude precipitation gages. A low-speed wind tunnel has been used to study the effect of wind on the catching characteristics of model storage precipitation gages. A snow storm was simulated with sawdust, and various gage designs without windshields and with different type windshields were studied. Special techniques with photography were used to evaluate the value and improvement in performance of various windshield designs. Field studies have also been conducted at two remote mountain locations on prototype gages and shields similar to those studied in the laboratory. Results indicate reductions in catch due to the action of winds, and new shields proposed for use are showing an improvement in the consistency of catch both in studies in the wind-tunnel and in the field.

Introduction

Late in 1948 the Engineering Experiment Station of the University of Idaho was invited by representatives of the U. S. Bureau of Reclamation to conduct research on the development and use of high-altitude precipitation gages and windshields for these gages. The project was pointed up by the need for improving runoff forecasts. Recent floods and an accelerated program for the development of water resources have contributed in focusing closer attention to the problems of runoff forecasting and river regulation. Improved precipitation measurement records must be provided to insure better forecasts. The particular purpose of the program at the University of Idaho is to study the performance of existing gages and try to improve the accuracy and consistency of the precipitation catch by improving windshield designs.

Previous studies

It has long been recognized that winds have considerable influence on the catch of various types of precipitation gages. BROOKS [1938] concluded that unshielded gages can be deficient in catch by five to 50 pct or more, the higher deficiencies occurring in cases of snow measurements made in windy locations. ALTER's [1937] studies with shielded and unshielded gages likewise indicated that wind currents tend to decrease the amount of precipitation a gage will catch. Earliest use of a shield to correct for the influence of the wind might be credited to Joseph Henry of the Smithsonian Institution in 1853. About 1879 F. E. Nipher made a notable contribution with his trumpet-shaped metal shield which was fastened directly to the gage. This widely accepted shield gives good results when measuring rainfall, but it is unsatisfactory in the measurement of snowfall at unattended gages because of the tendency for snow to collect on the flat top of the shield and either fall into the gage or bridge over the gage orifice. By 1937, J. C. Alter had developed the Alter-type shield which is especially adapted to the measurement of snowfall and is at the present time being widely used. The individual baffles of the Alter shield are designed to prevent the collection of snow on the shield and gage. In this respect the shield is fairly successful, although some difficulty is still experienced with sleet and ice freezing to the assembly.

Testing program

Work on this project (Special Research Project 17) has been carried out in two phases; first, a laboratory study of scale models and shapes in a specially constructed, low-speed wind tunnel; and second, actual field tests at mountain locations.

Air-flow pattern study--Under the laboratory program a wind tunnel was constructed (see Fig. 1) to investigate air-flow patterns around models of various gage-and-windshield shapes and combinations. Two ships' ventilating fans are the wind source. These fans discharge air into a diffuser section and then through a diverging section into the tunnel throat. The throat is four by four feet in cross section. A honeycomb baffle system in the throat just forward of the test section cuts down turbulence and provides a relatively smooth flow of air. Variable speed fans provide a range of wind velocities in the tunnel up to 15 mi/hr. The test section is located

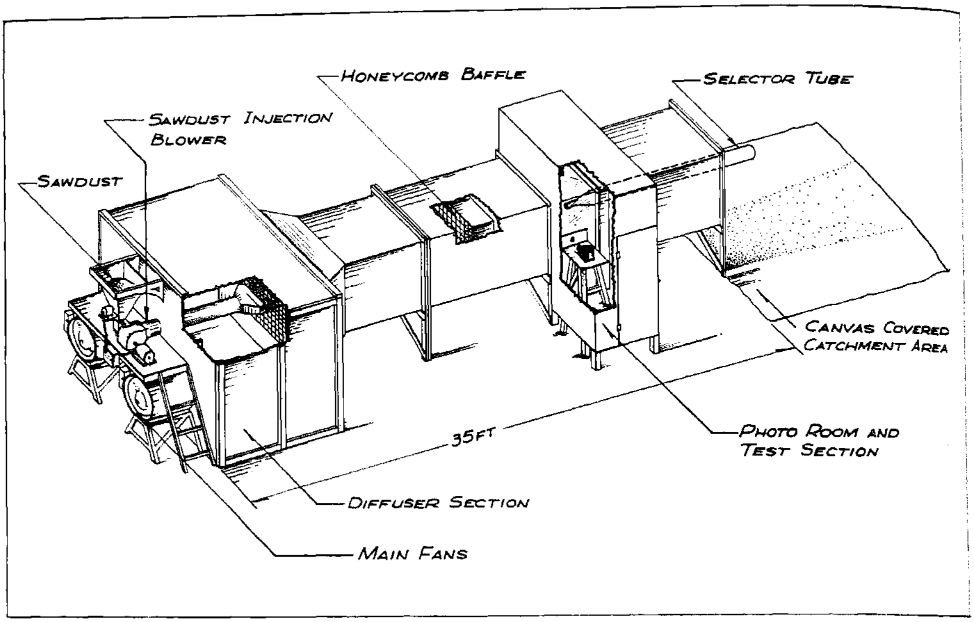


Fig. 1--Schematic drawing of low-speed wind tunnel used to study model precipitation gages under simulated snowstorm conditions

about ten feet from the open end of the tunnel in a light-tight room. A glass top and side panel are provided in the test section to give a means for observing, lighting, and photographing the models being tested.

Sawdust was injected into the airstream of the tunnel to define the air-flow patterns and was also used as artificial snow in studying the quantitative catch of the model gages. In Figure 1 a cutaway in the tunnel shows how this sawdust was fed from a hopper with controlled feed into a separate blower and through an injector tube equipped with vanes and splitters to give a uniform distribution of sawdust particles as they flowed into the throat section.

A jet of smoke was also used to study air-flow patterns. Titanium tetrachloride vapor introduced into the moist air passing through the tunnel produced a dense white smoke, titanium dioxide, which defined the air-flow pattern.

On a very cold day (about -17° F) in January, 1952, it was possible to blow actual snow through the tunnel. The snow used was a very dry, low-density snow. Figure 2 shows a picture of an unshielded gage with the three different methods used to define the air-flow patterns. Pictures here indicate why there is a deficiency in catch during a snowstorm when there is a wind blowing. Note the tendency for the path lines of the sawdust particles, smoke, and actual snow to blow upward owing to updrafts along the elements of the gage. Various windshield shapes and designs were tested in the wind tunnel to get an improved air-flow pattern over the gages. The method of mounting the gage and windshield is shown in Figure 3, a photograph taken through the glass wall of the wind tunnel. Figure 4 is a group of photographs illustrating the air-flow behavior around a few of the unsatisfactory designs tried. Figure 5 shows the air-flow pattern around three of the more satisfactory windshields. The swinging baffle type of shield proved to give the most encouraging air-flow pattern. Note that the bottom two photographs in Figure 5 show the path lines continuing downward in a normal manner as the "sawdust snow" passes over the gage orifice. Half-scale model gages used in the tests were of four basic types; Sacramento storage gage, Standpipe storage gage, Stevens Type Q-12 recording gage, and a Standard eight-inch diameter can gage. When a particular shield combination showed promise of improvement in the air-flow condition, a further test was made of the catching characteristics of the gage.

Comparative catch study--To provide a more quantitative means of comparing the performance of different gage-and-shield combinations, the models were tested in an artificial snowstorm. Sawdust was injected into the tunnel at a controlled rate, and the amount of sawdust caught in the gage

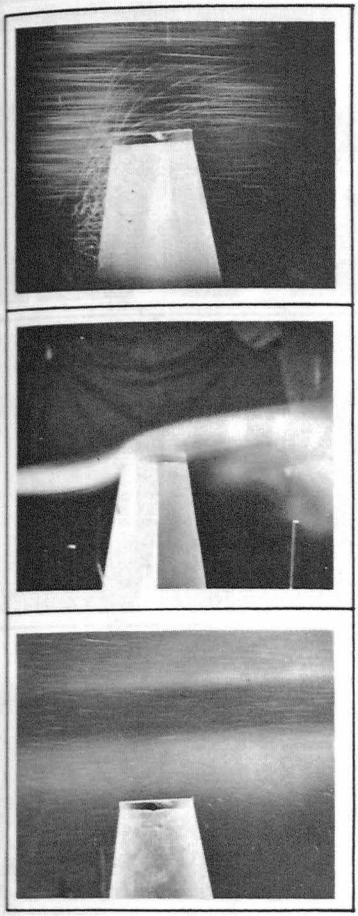


Fig. 2--Air-flow patterns around top of model Sacramento precipitation gage; (a) blowing sawdust, (b) titanium dioxide smoke, (c) actual snow

was carefully weighed. A typical run consisted of allowing 15 kg of finely divided "sawdust snow" to blow through the tunnel at a fixed rate such that it required 20 minutes to complete a test. The amount of sawdust snow collected in the gage compared to the catch of other gage-and-shield combinations became a useful measure of the effectiveness of the particular combination. Hundreds of such tests have been made. Early results indicated the swinging baffle shield to be superior, and much of the latest work has been concentrated on improvement of the old Alter design. Data presented under Results indicate the value of these tests.

Theoretical true-catch study--Because it is undoubtedly possible to overshield a gage, a means was devised for determining the theoretically true catch of sawdust snow that should be falling through an imaginary horizontal area equal to the area of the four-inch diameter orifice of the model gage. A selector tube and a special photographic arrangement was used in this series of tests. The selector tube was a long, thin-walled metal tube open at both ends (see Fig. 1). The forward end of the tube had a diameter of about 1 1/2 inches. From the forward end the tube diverges gradually to a diameter of about six inches. Owing to the increase in cross-sectional area, the wind speed inside the tube was reduced sufficiently so that all the sawdust snow was dropped inside the tube. The amount of sawdust caught during a given period of time could then be determined by weighing the sawdust in the selector tube. The selector tube was streamlined so that it caused no noticeable disturbance of the air-flow pattern and was always positioned so that it sampled the sawdust passing through the tunnel just at the height of the model gage's orifice. Reference to Figure 4 will show that in all these tests the direction of the undisturbed particles of sawdust is downward in the direction of flow owing to the action of gravity. Recognizing that this drift angle was consistent and duplicated, a phenomena commonly found with falling snow, a study was made of the drift angle and the particle velocity. With this information it was possible to relate the catch of sawdust going through a unit vertical area (that measured by the selector tube)

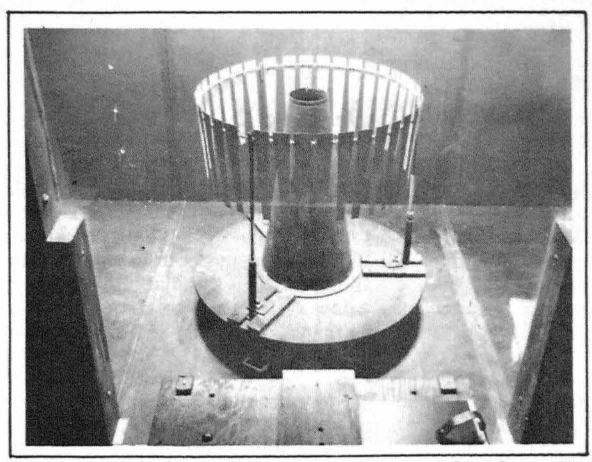


Fig. 3--Model precipitation gage with windshield mounted in wind tunnel ready for comparative catch test to be conducted (modified Alter I windshield)

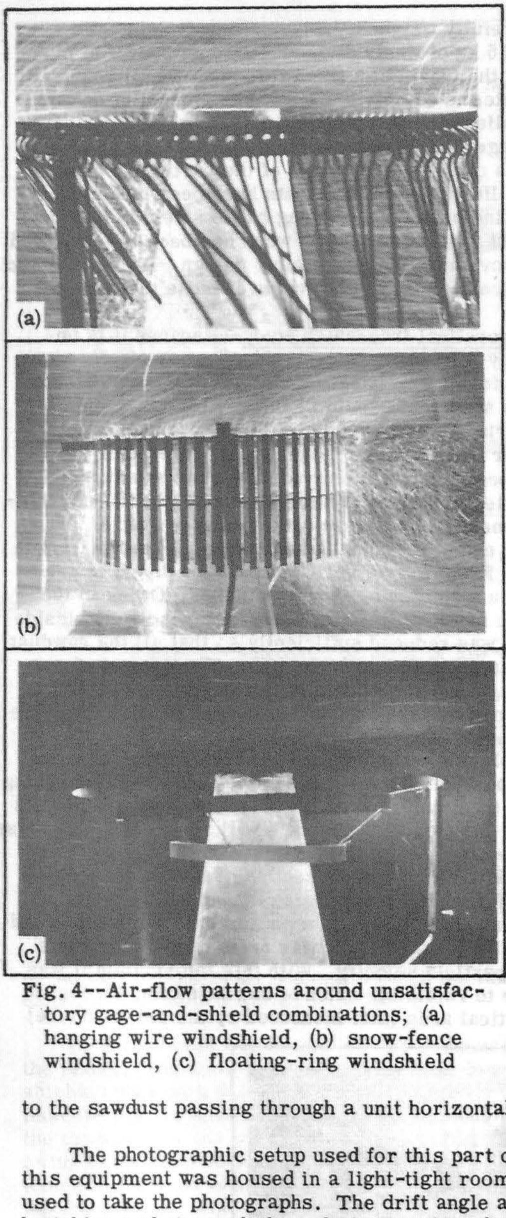


Fig. 4--Air-flow patterns around unsatisfactory gage-and-shield combinations; (a) hanging wire windshield, (b) snow-fence windshield, (c) floating-ring windshield

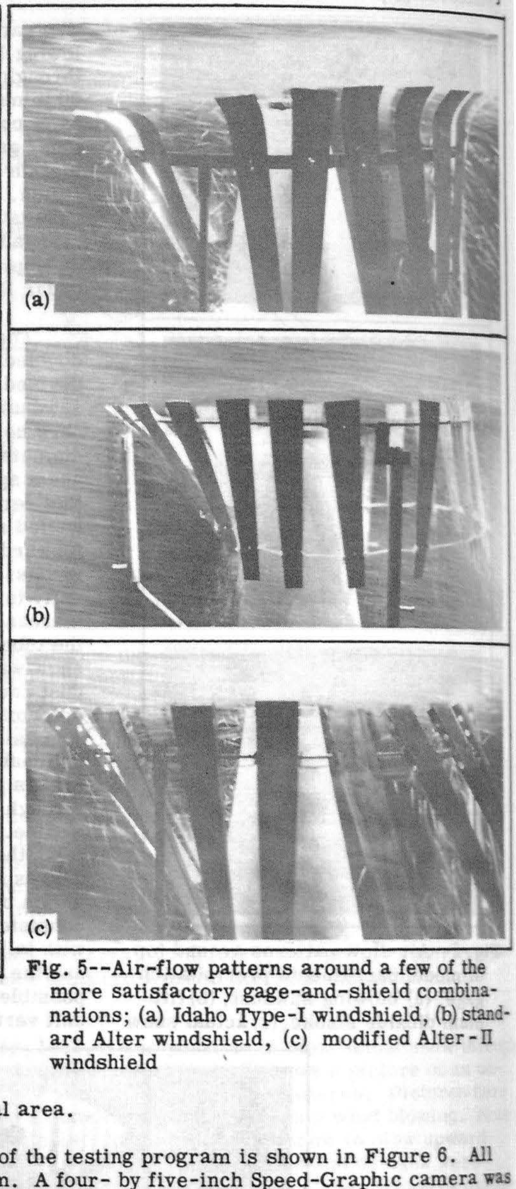


Fig. 5--Air-flow patterns around a few of the more satisfactory gage-and-shield combinations; (a) Idaho Type-I windshield, (b) standard Alter windshield, (c) modified Alter-II windshield

to the sawdust passing through a unit horizontal area.

The photographic setup used for this part of the testing program is shown in Figure 6. All this equipment was housed in a light-tight room. A four- by five-inch Speed-Graphic camera was used to take the photographs. The drift angle and velocity of the sawdust particles were defined by taking a photograph through the rotating wheel shutter against a gridwork background. This grid was scribed on a very thin sheet of metal mounted vertically in the tunnel as shown in Figure 7. Lighting was provided by means of synchronized flash bulbs in a special reflector (see Fig. 6). The rectangular reflector had double slits at the bottom in order to limit the width of the zone lighted. The width of this zone was about equal to the diameter of the gage orifice. By keeping the lighted zone narrow, and by using a low ''f'' setting on the camera to limit the depth of field, it was possible to obtain a photograph that showed only the sawdust snow immediately in front of the grid at the position of the orifice of the gage.

The rotating wheel shutter allowed light to get through to the camera only when one of the holes was in front of the lens of the camera, and as a result, the path lines of the sawdust particles appear as a series of dashes on the photograph. This is illustrated in Figure 8. Actual length of the dashes was found by comparing with the known distances on the gridwork. The dash length represents the distance the particle traveled while a hole of the rotating shutter was in

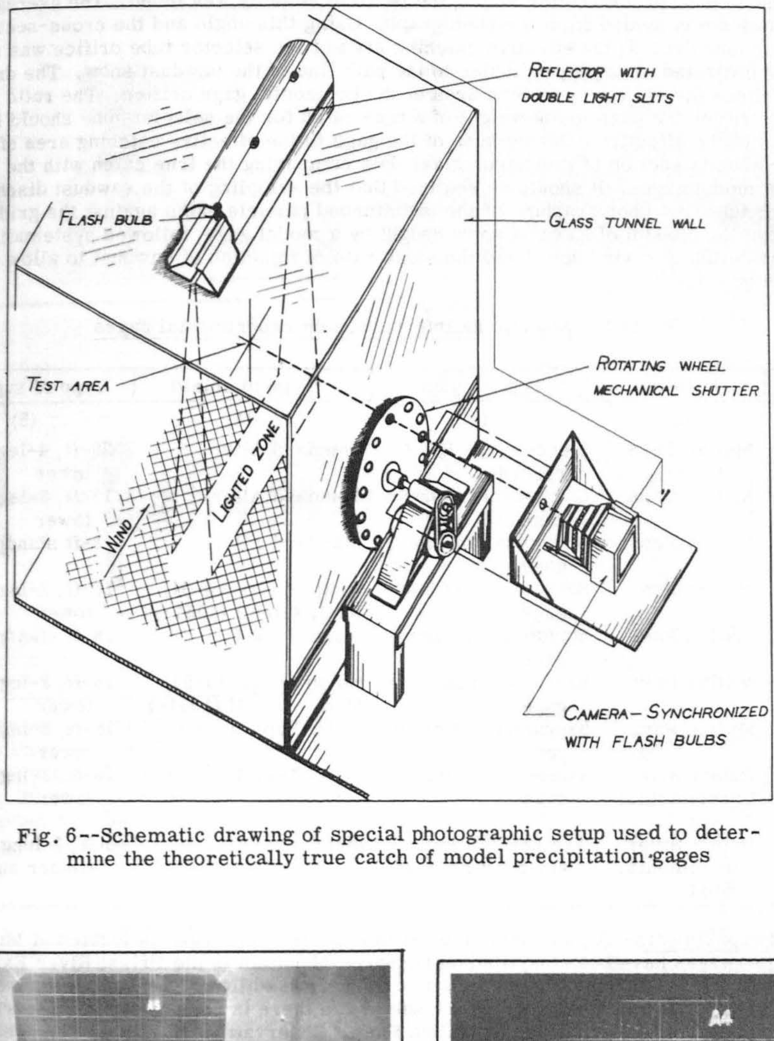


Fig. 6--Schematic drawing of special photographic setup used to determine the theoretically true catch of model precipitation gages

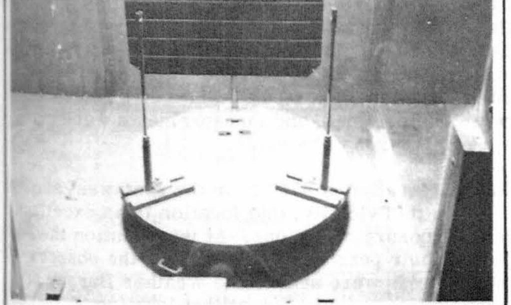


Fig. 7--Photograph showing sheet-metal gridwork mounted in the wind tunnel test section

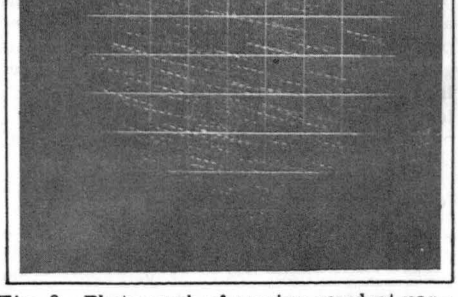


Fig. 8--Photograph of moving sawdust particles taken through rotating wheel shutter against special gridwork background

front of the camera. Hence, knowing the length of the dashes, number of holes in the shutter, and the rotational speed of the shutter wheel, the particle velocity was found. The average drift angle of the particles was scaled from the photograph. Using this angle and the cross-sectional area of the selector tube orifice, the effective catching area of the selector tube orifice was computed. This is the projected area perpendicular to the path line of the sawdust snow. The drift angle likewise defines the effective catching area of the horizontal gage orifice. The ratio of the weight of a true catch for the gage to the weight of a true catch for the selector tube should be the same as the ratio of the effective catching area of the gage to the effective catching area of the selector tube. The Results section of this paper gives data comparing the true catch with the actual catch of different model gages. It should be realized that the sampling of the sawdust discharge with the selector tube, the photographing of the undisturbed particle paths against the gridwork, and an actual test of the amount of sawdust snow caught by a model gage, followed systematically in order at the same setting for wind speed and the same rate of injection of sawdust to allow direct comparisons to be made.

Table 1--Descriptive information on experimental gages

Gage	Location	Type of gage	Type of shield	Type of support
(1)	(2)	(3)	(4)	(5)
1	Mullan Pass	Stevens type Q-12 recorder	Standard Alter	20-ft, 4-legged tower
2	Mullan Pass	Sacramento storage gage	Standard Alter	15-ft, 3-legged tower
3	Mullan Pass	Standpipe storage gage	Standard Alter	18-ft standpipe
4	Mullan Pass	Sacramento storage gage	Ring type (1948-51) Mod. Alter I (1951-)	15-ft, 3-legged tower
5	Mullan Pass	Standpipe storage gage	Idaho Type I	18-ft standpipe
6	Mullan Pass	Sacramento storage gage	No shield (1949-51) Mod. Alter II (1951-)	15-ft, 3-legged tower
7	Mullan Pass	Sacramento storage gage	Idaho Type II	15-ft, 3-legged tower
8	Priest River Experimental Forest	Sacramento storage gage	Idaho Type II	15-ft, 3-legged tower
9	Priest River Experimental Forest	Weather Bureau standard 8"-gage	Idaho Type II	8-ft, 2-legged timber support

Field experiments--A plot containing seven experimental gages is located at Mullan Pass, Idaho, and two gages have been installed on Gisborne Mountain in the Priest River Experimental Forest. Table 1 gives information on the types of gages installed. The Mullan Pass station is at an elevation of 6000 ft and is situated on a ridge where there is normal exposure to wind. Figure 9 shows a group of these field gages at Mullan Pass. Observations at this station are made by personnel from a nearby Civil Aeronautics Administration Station. The recorder gage at this station has been inoperative much of the time, and the standpipe gages have frozen solid during part of the season, so the continuity of some of the records has been destroyed. At this station an attempt has been made to correlate the precipitation catch of particularly heavy storms or storm periods with the snow that falls on the ground near the gages. At the beginning of a storm period, gage readings were taken and a canvas-covered board was set flush with the old snow surface. Immediately after the storm, an eight-inch diameter snow tube was pushed into the snow that collected on the snow board, the weight of the snow was determined, and measurements were made of the precipitation caught in the gages to allow a comparison to be made.

The Gisborne Mountain station is located at an elevation of 5500 ft on the southwest slope of the mountain. Because rime ice conditions are bad in this vicinity, this location is an excellent place to study the gages and shields under extreme exposure conditions. At this location the Forest Service has several other gages in operation and their personnel has made all the observations. In addition, two improved experimental windshields were sent to the Weather Bureau at Silver Springs, Maryland, for testing at a research station in operation at that location.

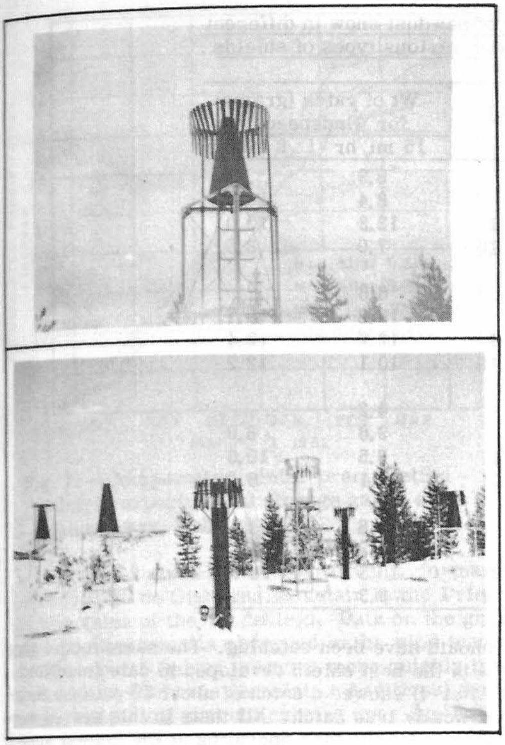


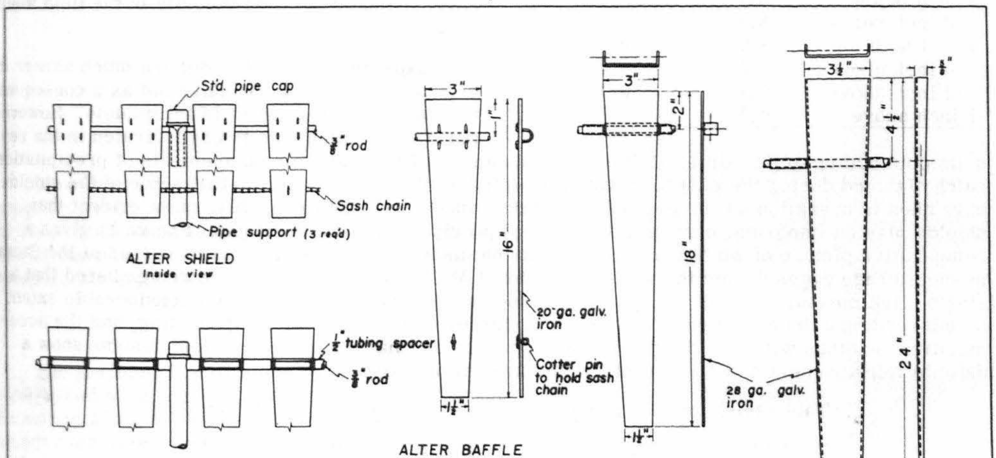
Fig. 9--Experimental precipitation gages at Mullan Pass Testing Plot; (a) Sacramento storage gage with modified Alter-I windshield, (b) standpipe storage gage in the foreground with Idaho Type-I windshield

Results

Results from the model study in the laboratory on comparative catch, indicate direct improvements can be expected in the performance of windshielded precipitation gages. Table 2 shows the comparative catch of a number of the combinations. From these studies two basic designs have been recommended for use and further field testing. Figure 10 is a drawing giving dimensions of the two proposed new shields and also data on a standard Alter shield for comparative purposes. All results to date indicate that there is no need for restraining chains on the new designs. The spacer arrangement is definitely advantageous in preventing any bunching of baffles. The freedom of rotation on these new designs is considerably better than on the old Alter design.

Experiments conducted in the wind tunnel to determine the proper height of the baffle above the top of the gage revealed definite indications as to what height the top of the baffle should be. Table 3 gives data on the catch of sawdust snow in a Sacramento gage with various heights of the baffles above or below the orifice of the model for both an Alter shield and a modified Alter I shield. The results indicate that the top of the baffle should be placed about one-half inch above the top of the gage orifice on a prototype installation.

True-catch studies with the selector tube and the photographs against the gridwork revealed that the model Sacramento gage without a shield was catching about 27 pct of what it



Item	Alter	Mod. Alter I	Mod. Alter II
Number of baffles	24	33	27
Diameter of support ring	38	44	50

Fig. 10--Comparative dimensions and details for Alter windshield and modified Alter windshields

Table 2--Comparative catch of sawdust snow in different model precipitation gages with various types of shields

Gage type	Windshield type	Wt of catch (grams) for windspeeds of	
		15 mi/hr	8 mi/hr
Sacramento	None	5.3	....
	Alter	8.4	10.4
	Mod. Alter I	12.3	10.0
	Mod. Alter II	7.9	8.5
Standpipe	None	6.6	....
	Alter	10.8	10.7
	Mod. Alter I	12.2	12.4
	Mod. Alter II	10.1	12.2
Stevens Q-12	None	4.2	....
	Alter	9.6	8.9
	Mod. Alter I	8.5	10.6
	Mod. Alter II	8.1	6.2
Standard	None	6.8	....
	Alter	9.8	....
	Mod. Alter I	10.3	....
	Mod. Alter II	9.3	....

Table 3--Comparative sawdust catch of shielded model Sacramento gage with various heights of the top of the baffles above or below the top of the gage

Baffle locations with respect to top of gage	Alter shield catch	Mod. Alter I shield catch
	gm	gm
1 inch below	8.5	9.2
1/2 inch below	8.8	9.3
Level with top	8.9	9.4
1/4 inch above	8.9	10.4
1/2 inch above	8.3	9.9
1 inch above	6.7	8.9

should have been catching. The same model gage with the best shield developed to date (modified Alter-I) showed a catch of about 60 pct of a theoretically true catch. All tests in this series were made with the fans operating at the fastest speed.

Particle velocities in the tunnel were found to be 16.5 mi/hr at the fastest speed of the fans. Consideration of the significant forces acting as the gravitational and inertia forces, indicates the corresponding particle velocity in the field would be 23.3 mi/hr.

Experiments in the field are much slower in producing significant results and as a consequence, that phase of the project is incomplete. However, some interesting trends are indicated in the results obtained up to this time. Table 4 is a summary of the weight measurements of precipitation catch obtained during the past four winter seasons at Mullan Pass. Note that some of the shields have been in operation on the gages for only one season (see Table 1). It is quite evident that shields play an important part in the amount of precipitation that is caught. Figure 11 gives a comparative picture of winter precipitation catch made by stick measurement in four of the Sacramento storage gages during the winter 1951-52 at Mullan Pass. It should be remembered that a single stick measurement of the contents of such a gage can be in error to a considerable extent by misreading a depth as much as 1/16 inch. However, the error is compensating, and the accumulative readings will give the desired accuracy. Note that the two new shield designs show a definite improvement and consistency in the amount of catch.

Table 4--Summary of winter precipitation records at Mullan Pass

Period	Precipitation in gage[a]					
	2	3	4	5	6	7
	inch	inch	inch	inch	inch	inch
9/17/48-4/15/49	38.4	47.4	33.9	45.3	...	...
9/16/49-4/7/50	57.3	Frozen	52.5	60.6	46.0	44.5
9/16/50-4/6/51	50.5	52.3	45.1	49.7	41.9	48.0
9/11/51-4/5/52	46.1	.....	49.6	43.5	49.5	44.8

[a]See Table 1 for type of shield on the respective gages.

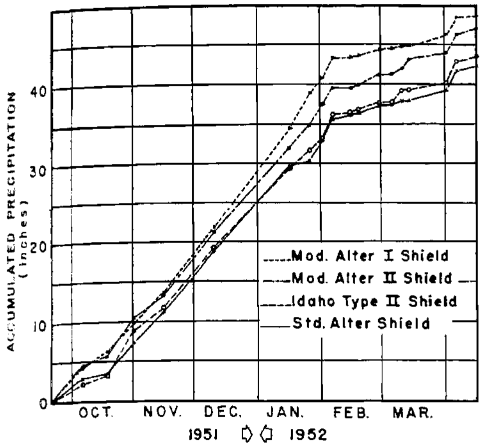


Fig. 11--Comparative winter precipitation catch in experimental storage gages at Mullan Pass, Idaho

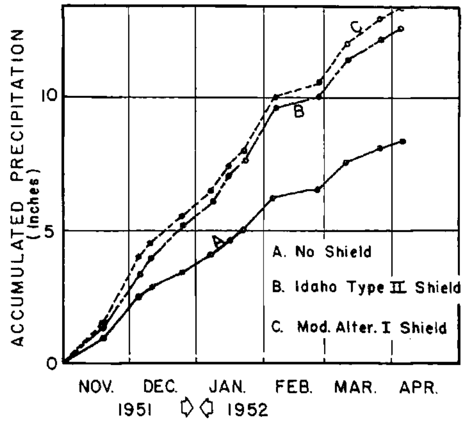


Fig. 12--Comparative winter precipitation catch in experimental U. S. Weather Bureau standard gages at Priest River Experimental Forest, Idaho

Figure 12 gives the comparative performance of three U. S. Weather Bureau standard rain gages located on Gisborne Mountain in the Priest River Experimental Forest. Here is shown the definite value of the windshield. Data on the gage with the modified Alter-I shield indicates the same positive results observed in the wind tunnel. Observations indicate that the Idaho Type II shield becomes frozen up much more quickly than the new shield and probably would cap over on occasions at Gisborne Mountain. Additional field testing is necessary to indicate whether the new shield design will prevent capping over due to formation of rime between the gage and shield.

Table 5--Snow tube measurements of precipitation compared to precipitation catch in experimental gages at Mullan Pass Experimental Plot

Period	Precipitation in gage				Snow tube
	2	4	6	7	
	inch	inch	inch	inch	inch
3/20/50-3/30/50	0.6	1.6	2.0	2.4	1.9
11/27/50-12/8/50	3.2	2.5	3.3	3.8	3.2
12/19/50-1/5/51	5.5	4.8	4.0	5.0	5.6
12/10/51-1/15/52	9.9	12.5	10.5	9.5	11.0

Snow-board measurements are not conclusive and need more careful observation than the program would permit. The results of a few measurements are indicated in Table 5. Notice some of the periods were long, and no record was kept of the drifting during the period. Constant attention at one of these boards for a very heavy storm might reveal a good standard with which to compare the gage measurements.

Conclusions

The performance of model precipitation gages under simplified and idealized conditions in a slow-speed wind tunnel has defined the air-flow behavior around the gages and gives definite information about the inconsistencies observed in records of snow catch in precipitation gages. The relative-catch studies of the amount of sawdust snow collected in a model gage have been an excellent guide for determining improvement in the design of given gage-and-shield combinations.

The limit of what is a theoretically true catch in a particular model gage has been defined in the wind tunnel through work with a sampling tube and a special photographic arrangement. From these various experiments, two windshields have been designed which promise to give better performance than shields in use at the present time. Both field and laboratory results appear to substantiate the value of the new designs. However, further field testing should be carried on to prove the performance of the shields. It is recommended that the various interested groups use these designs in independent tests.

Acknowledgments--Acknowledgment is here given for the assistance of the various federal agencies cooperating on this project. The Weather Bureau, Civil Aeronautics Administration, and the Forest Service have been very helpful in the field testing program. The Bureau of Reclamation and Corps of Engineers have both given much encouragement during the progress of the project. This project, Special Research Project 17, is made possible under the University of Idaho's Special Research Program and is under the direction of Allen S. Janssen, Director of the Engineering Experiment Station.

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DISCUSSION

Walter T. Wilson (U. S. Weather Bureau, Washington, D. C.)--With notably little precedent Warnick has ingeniously produced some important and practical results in his work on performance of precipitation gages. In general he concludes that shielding of gages is necessary in windy storms and recommends that the Alter shield be modified by using a larger diameter supporting ring, more and longer baffles, and substituting for the restraining chain a set of annular spacers between the baffles around the supporting ring.

In the wind tunnel the air flow was fairly smooth, with no large eddies, and at prototype speeds of about 11 to 23 mi/hr. Sawdust snow entered the airstream horizontally. It would be interesting to note the results of sawdust falling into the air stream, perhaps in a manner more analogous to precipitating snow. As one might expect, Figure 2 shows differences between the smoke trajectory and the paths of sawdust particles which portray respectively the air stream and the movement of particles acted on more by gravity. If the average drift angle were found to be different for different wind speeds and for different positions along the trajectory of the sawdust, the optimum position of the shield might be indeterminate. The windshield in a natural exposure should have a shape and position which will give good average results for different wind speeds and degrees of turbulence.

Except for snow sometimes being stickier than sawdust the analogy seems good, at least for qualitative exploration. The density and size of snow flakes vary widely. In general, Warnick's determination of deficiencies in catch with high wind speeds agrees quantitatively with those of other investigators. However, in Table 2 the difference in wind speed shows less difference in catch than might be expected. An analysis of Tables 2 and 5 would probably disclose considerable variance, unexplained by either wind speed or type of gage.

As stated by Warnick, comparisons between gage catch and snowboard-and-tube data are inconclusive. In nature turbulence increases with height above the ground or snow surface, and gages with orifices high enough for deep snow can hardly fail to have deficient catch at times. It can well be imagined how much sawdust would remain on a snowboard in the wind tunnel.

Although Warnick may feel that he has reached a point of diminishing returns in his laboratory study of gage shields it is hoped that controlled experiments on gage performance will continue with the impetus he has given. Perhaps the effects of natural exposures of gages, and size and distance of obstructions, for example, can be evaluated. While Warnick's determination of true catch in the wind tunnel seems reasonable, prototype problems of turbulence, areal sampling and rugged terrain indicate possibly less need for approaching true-catch performance than for obtaining a consistent and reliable index relationship.