

SNOW SURVEY SAMPLERS AND THEIR ACCURACY

by
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Water equivalent of snow in the western mountains is the most significant parameter in most water supply forecast equations in the western United States and western Canada. Snow surveys taken at index snow courses have provided the basis of these forecasts for more than 35 years.

The earliest procedures for sampling snow in place involved cutting and withdrawing a core of snow with a tube similar to a stovepipe. The snow volume could be computed from the pipe dimensions and its water equivalent found by melting the sample and measuring the water with a dipstick.

This method, while accurate, was not suitable for the deeper dense snowpacks of the West. A tube similar to the present Federal sampler was developed by Dr. J. E. Church in 1909-10. Several refinements were made during the next 25 years. The present 30-inch section of aluminum tube with the 1.485 cutter developed by Clyde in Utah has been the standard Federal sampler in western snow surveys since about 1935. This sampler has been used for over a million snow samples without serious question as to its precision.

There has always been some difficulty in obtaining consistent, accurate samples, but this was attributed to a variety of snow conditions and different men making the measurements. However, if the length of cores was uniform, if the densities of individual samples did not vary, and if enough samples were taken it was assumed that the average result was satisfactory.

REASONS FOR TEST

In testing a number of automatic snow measuring devices at Mt. Hood, Oregon, it was necessary to have a standard with which to compare the automatic reading. The Federal sampler, through its long use, has become the standard, but it was important to know the precision to which snow measurements could be made. This is especially necessary when attempting to evaluate the effectiveness of an automatic gage by comparative means.

The Army Cold Regions Research and Engineering Laboratory, headquartered at Hanover, N. H., has extensive interests in observations of Arctic phenomena and environmental situations.

In 1963 a question arose as to possible limitations of Federal snow survey equipment for accurately measuring water equivalent of snowpack in Arctic environment, characterized by light density and depth hoar over permafrost. CRREL requested the Snow Survey Unit of the Soil Conservation Service

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to make studies in the sub-Arctic, intended to point the way toward the most adequate system for measuring Arctic or sub-Arctic snow.

This work was undertaken and a series of tests were made both at Mt. Hood, Oregon, and in Alaska to determine the relative accuracy of all snow survey equipment in common use. A report titled "Accuracy of Field Snow Surveys in Western United States, including Alaska," (1) authored by Work, Stockwell, Freeman, and Beaumont of the SCS, was prepared for CRREL in June 1964. This paper is based entirely on the report to CRREL, and the author quotes freely from it.

It was determined that a comprehensive study should be made of all factors affecting a snow measurement. All of the commonly used types of snow samplers and their accompanying equipment should be tested and checked against a precise known measure.

Some previous work had been done in testing the accuracy of snow samplers. H. H. Bindon in his paper, "The Design of Snow Samplers for Canadian Snow Surveys," (2) theorized that "The percentage error in measure of water equivalent due to edge effect is inversely proportional to the radius of the cutter." Beaumont and Work in their paper, "Snow Sampling Results from Three Samplers," (3) attributed the higher measurement from the Federal sampler to snow entering through slots.

Several elements affect accuracy of water equivalent determinations by any instrument that cuts snow cores which are weighed. These are:

1. Critical dimensions of tube (diameter of cutting point);
2. Fidelity of scales over working temperature range;
3. Accuracy in reading and recording the various readings;
4. Ability of the tube to cut and hold accurate and representative snow cores.

Points 3 and 4 may be affected by the skill and experience of the individual taking the samples.

LABORATORY TESTS OF EQUIPMENT

Tests of Cutter Diameter

The specifications of the Soil Conservation Service allow tolerance of $\pm .001$ inch for the cutter inner diameter. The effective diameter was set originally at 1.485 inches.

To test item 1, 48 cutting points in field use were tested. Only one was discovered which could have introduced as much as 1.4 percent error into the snow core weights. It was concluded that critical dimensions (cutting point effective inside diameter) do not offer a source for variable error of any recognizable consequence in practical field results of western states' snow surveys.

Fidelity of Scales

It has been field practice to periodically inspect, clean, and then check the calibration of the scales over the entire weighing range. To test general scale accuracy, 29 scales were selected at random from several western states and checked at room temperature. Out of all of the scales calibrated, only one showed an apparent error as great as 5 percent at one reading point. Average error of about 400 readings was less than 1/3 of one percent.

Accuracy of Reading and Recording

The Soil Conservation Service requires that scale readings by its snow surveyors be made at least to the nearest one-half inch. In most of the scale tests made, the scales were read (estimated) to the 1/10 division (equal to 1/10 inch water on 12 $\frac{1}{2}$ foot scale, and equal to 2/10 inch water on 20 foot scale).

Tests were made by several people, both experienced and non-experienced, and using several scales.

Results of the tests showed that snow surveyors, regardless of experience, are unlikely to deviate in their separate readings more than 4/10 scale division in any range of the 12 $\frac{1}{2}$ foot scale. This is within the tolerance of 5/10 inch specified by SCS instructions.

Effect of Temperature on Scale Reading

The effect of temperature upon the calibration of tubular spring balance snow scales had been questioned, so scales were tested over a wide range of temperatures. Tests conducted at a cold storage plant in Portland, Oregon, indicated that lowering temperatures affected different scales in a different manner. On some scales the apparent reading error increased, while on others it decreased. Even so, the maximum error for any of the scales at -14° F. was only 1-6/10 percent.

In order to get an independent opinion of the effect of temperature upon behavior of spring scales, three scales were sent to Dr. R. W. Gerdel, Director of CRREL's Environmental Research Branch at Hanover, N.H. There these three scales were subjected to entirely independent calibration tests by Mr. Roy Bates of CRREL's technical staff, under rigorous temperature variations capable of close control.

Mr. Bates' report stated in part, "In comparing actual weights with those observed using the three sample scales at different cold room temperatures (ranging from a room temperature of 78° F. down to -55° F.), we found that the weights recorded by the sample scales never varied more than a few ounces from actual weights. This is a negligible amount, thus we believe that temperature has very little effect on the scales."

FIELD TESTS (MT. HOOD, OREGON)

Five sampler tubes were used. Two of these were designed for relatively shallow medium density snows of the U. S. far eastern and high plains states. They might also be useful in the Arctic.

Description of Samplers Tested

Federal

The first sampler was the Federal sampler, commonly used in the West, and described previously in this paper.

Two types of Federal samplers were used in one test, one made by Carpenter Machine Works, Seattle, Washington, and the other by Leupold-Stevens Instrument Company, Portland, Oregon. The only material difference between those two samplers was in the cutter point tooth arrangement.

Rosen

The Rosen sampler consists of heavy gage aluminum tubing, each tube 30 inches in length, graduated on outside by inches and half-inches and coupled by threads cut directly in the aluminum tube. Thus there are no enlarged diameters at couplings and the O.D. of the tube is the same at all places above the cutting point. Inner diameter of the cutter is 1.485 inches. Observation of core length is provided by 3/8 inch ports drilled along the tube at one inch, staggered spacings.

Bowman

The Bowman sampler is not commercially available, but several sets have been built for SCS. Its 30-inch tubes of Ryertex are graduated in inches and half inches. They are coupled by male and female threaded couplings also made of Ryertex. An advantage of this tube is the fact that it does not transmit heat or cold as readily as metal, thus it is said to collect better cores when snow and air temperature differ markedly. The inner diameter of the cutting point is 1.485 inches. The Federal tubular scale was therefore used to weigh this sampler.

Adirondack

The Adirondack sampler is constructed of fiberglass with a smooth, sharp stainless steel circular cutter point, theoretically of 2.655 inches I.D. The calipered I.D. of the sampler tested was 2.650 inches.

The sampler, 5 feet in length, was weighed empty and full on a spring balance specially calibrated in tenths of inches of water equivalent. The scale was calibrated by SCS test weights and found to check the theoretical calibration exactly. Graduations at half-inch marks along the outside of the tube define snow depths up to 60 inches.

High Plains

The High Plains snow sampler was developed by the U. S. Army Corps of Engineers. It is of stainless tubing with steel driving handles brazed to the tube. There is no special cutting point, the tube being ground to an edge at the cutting end. The scale is an ordinary spring balance, weighing in fractions of ounces. Snow depth is recorded by measuring down to the snow from top of the tube and subtracting from 48 inches. Because of difficulty in holding cores in this tube and later dislodging the cores, this sampler was tested only once.

Test Procedure

A plot of ground in the forest was levelled and covered with a thin layer of coarse sawdust in the fall of 1963.

A heavy rectangular steel template of 2" x 3" angle iron, 5' x 6' dimension was built. A sharp cutting edge was ground on one side of the angle iron, bevelled in. This cutting edge included the entire 22-foot perimeter of the template.

At time of each test the template was placed on surface of snow which had lain undisturbed from time of first snowfall.

A plank walk 12 inches wide was laid around the outer perimeter of the template. A wooden bridge above the snow surface with footings on the planks spanned the template so that snow samples could easily be taken anywhere inside the template.

In the first test, each of three men took one sample with each instrument in each segment of the template. The samples were considered paired in each sampling segment. Thus 122 total samples were drawn from the 30 square foot area -- and 10 or more by each man for each snow sampler.

The cores of snow withdrawn by each sampler after each individual weighing were dumped into a pail and accumulated for later bulk weighing, along with snow from the pit.

When the snow depth exceeded sampler length, tests with the Adirondack and High Plains samplers were discontinued, although one further test was made with the Adirondack sampler, when snow depth was about 17 feet.

After all the samples were drawn and weighed, the template was pounded down to the sawdust covered surface of the earth. While being driven it was kept level, as gauged by level bubbles on each of the four sides. Thus a block of snow perfectly rectangular with perpendicular walls, and encompassing surface area of 30 square feet was cut.

The cut out snow was shoveled into a 4' x 6' box hung by block and tackle from a 500-pound capacity Chatillon scales. This scale was set to zero tare and the accumulated weight of snow loads from the pit totalled and recorded. The weight of the total snow tube cores taken was added.

Summary of Results

A total of five separate tests were made at Mt. Hood covering a range of snow depths from relatively shallow to very deep. Table 1 illustrates the results of the final test. The following table 2 summarizes the results of the field tests.

The total weight of snow in each test was converted into inches of water equivalent by use of the following expression:
$$\frac{E}{156.03} = X$$

where X = water equivalent inches and E = total weight snow in pounds. Factor 156.03 is the weight of one inch of water over 30 square feet.

In general, the tests showed that the Federal sampler in common use measures a snow water content up to slightly over 10 percent more than actually exists in the snowpack. The percentage error increases with the increase in snow water content. The difference between slotted and unslotted Federal samplers is not significant. Other samplers suitable for use in western snowpacks, the Rosen and Bowman samplers, appear to be more accurate, particularly the Bowman sampler.

The error found in the Federal sampler is apparently caused by the design of the cutter point which must force a greater amount of snow into the tube than the inside diameter of the cutter would indicate. The same tendency for error was confirmed by tests in Alaska.

TABLE 2
S U M M A R Y

SNOW SAMPLER	SAMPLING DATE AND INCHES SNOW WATER EQUIVALENT				
	11/19/63	12/2/63	2/3/64	2/24/64	5/12/64
	8.43	10.84	42.4	51.6	85.4
	Percent Error of Snow Sampler				
Adirondack No.1	+1.9	+2.8	-	-	-0.4
Bowman	+1.8	-0.6	-	-	-
High Plains	-	-3.4	-	-	-
Rosen	+3.2	+0.6	+5.7	+6.4	+2.9
Federal Slotted	+9.0	+6.8	+11.8	+11.2	+10.2
Federal Non-Slotted	-	-	+11.8	+10.8	-
Leupold-Stevens	-	-	-	-	+8.0

FIELD TESTS - ALASKA

Testing methods similar to those used on Mt. Hood were used at 11 separate sites in interior Alaska in March 1964. Comparative snow tube measurements were made at two additional locations.

Samplers tested in Alaska were:

1. Federal Sampler
2. Federal Sampler (without slots)
3. Bowman Sampler (Ryertex plastic)
4. Adirondack Sampler
5. CRREL Sampler
6. Canadian Sampler

The CRREL snow tubes were stainless steel cylinders with a sharpened edge which hold a volume of 500 cc. These tubes are equipped with rubber caps for each end, so the snow sample can be preserved and weighed at a later time.

The Canadian sampler uses the same principle but takes a sample of 250 cc. The stainless steel cylinder is fitted with a handle and samples are normally weighed in the field.

Horizontal samples are taken at equal distances through the snow profile with this equipment. Individual snow samples were weighed on a beam balance reading in grams.

Summary of Results

In analyzing the data from the five locations where results from individual samplers can be compared to the template measurement, it is found that all samplers tend to measure slightly greater water equivalent than is actually present. Snow weights were always very light and a small reading error on the scale could have a considerable effect on the relationship to the standard or template measurement.

Average snow water equivalent (inches) for the test sites compared to the water equivalent computed from weighed snow taken from the template pits are presented in tabular form:

	<u>Template</u>	<u>Federal</u>	<u>Federal no slots</u>	<u>Bowman</u>	<u>Adiron- dack</u>	<u>CRREL</u>	<u>Canadian</u>
SCS Grounds	2.67	2.75	2.87	2.71	2.70	2.90	3.04
Cleary Summit	3.10	3.43	3.39	3.32	2.98	3.08	3.13
Exper. Sta.	2.63	2.92	2.91	2.80	2.75	2.79	2.80
Fort Yukon	2.70	2.81	2.91	2.66	2.68	2.92	
Chandalar	3.24	3.61	3.69	3.44	3.50	3.67	
	*8.40						*8.97
Total	14.34	15.52	15.77	14.93	14.61	15.36	
Average	2.87	3.10	3.15	2.98	2.92	3.07	
Diff. between Sampler and Template		+8.23%	+9.97%	+4.11%	+1.88%	+7.11%	+6.78%

*Total of 3 sites.

The Adirondack sampler appears to be the most accurate, but it was very difficult to obtain good samples with this tube.

Essentially the same results were obtained by the CRREL and the Canadian samplers. Skill and technique are very important in using this equipment. When sampling horizontally into a well developed depth hoar, it is easy to collapse the structure and get more snow in the tube than is actually there.

SUMMARY AND CONCLUSIONS

The popular Federal snow sampler over-measures the water equivalent of snow. The error ranges from an average of about 7 percent in shallow, light density Alaskan snow to as much as 10 to 12 percent in deep snow of higher density.

This fact might become significant to stream forecasters who use quantitative forecast methods based on Federal sampler snow survey results. The fact is not significant in SCS forecast system which uses the snow survey as an index to resultant runoff. The observation, however, can be singularly important in field studies of other devices to measure snow water equivalent, such as pressure pillows or the radio-active isotope gage, where results from Federal samplers have been usually accepted as representing more or less exactly the water equivalent of adjacent mountain snowpack.

It appears that the over-measurement of snow water equivalent by Federal-type samplers (cutter point I.D. 1.485") is related to the shape and arrangement of the cutting teeth. Blunt tooth cutters show the greatest plus error, sharp tooth cutters the least plus error. (Federal vs. Bowman, for instance.) It seems likely that a cutter for the highly portable Federal-type sampler could be designed to reduce or eliminate the plus error, yet retain the present cutter's proven ability to cut and hold cores and penetrate dense snow of great depth.

Widely differing air temperature is shown to offer no appreciable source for error in Federal snow sampler scales. The scales themselves are individually very accurate at room temperature. The studies also show no source of appreciable error attributed to erratic inner cutter point diameter.

Experienced snow surveyors can closely read the tubular scales more consistently than inexperienced people. This effect on accuracy is minor, except in very shallow snow.

No evidence was found that slots in the tubes, as reported earlier, were a contributing source to over-measurement of water equivalent by Federal samplers.

The Rosen tube unquestionably is much the easier to drive in deep dense snow, but it does not relieve itself of its cores nearly as well as the Federal-type sampler.

The Adirondack sampler is shown to be very accurate. However, for snow in excess of 5 feet depth, it is not considered practical under field conditions. Were it provided in lengths greater than 5 feet and of the present diameter, it would be extremely difficult to drive into dense frozen snow, and unhandy to transport on foot. It does not retain its cores with security when withdrawn from the snowpack.

The Bowman sampler is very accurate and appears reasonably practical for field snow survey work where snow depths less than 8 feet are the rule.

In general; it is concluded that the present Federal snow sampler equipment is about as utilitarian as can be found for deep dense western snows, and even for shallow sub-Arctic snow. However, design modification and further test work should reduce the plus error of this equipment.

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REFERENCES:

- (1) WORK, R. A., STOCKWELL, H. J., FREEMAN, T. G. and BEAUMONT, R.T. "Accuracy of Field Snow Surveys in Western United States, Including Alaska." Report by U. S. Soil Conservation Service to CRREL, June 1964.
- (2) BINDON, H. H. "The Design of Snow Samplers for Canadian Snow Surveys." Mimeographed Paper.
- (3) BEAUMONT, R. T. and WORK, R. A. "Snow Sampling Results from Three Samplers" - Bulletin of I.A.S.H. Ville Annee No. 4, 1963, pp. 74-78.

TABLE 1

RESULTS AT MT. HOOD TEST SITE

May 12, 1964; cloudy, very light rain fell intermittently.

Water Equivalent by Template = 85.4 inches.

Observers: Work, Stockwell, Freeman, Whaley, and Kelner	Rosen Sampler (12)*		Federal Sampler (12)*		Leupold-Stevens Sampler (12)*		Adirondack #2 Sampler (5)*					
	Depth	Length Core Equiv.	Depth	Length Core Equiv.	Depth	Length Core Equiv.	Depth	Length Core Equiv.				
All values in inches	195.2	172.8	87.9	196.5	180.8	94.1	194.2	184.4	92.2	195.0	194.3	85.0

Test notes:

- (1) Required 4 men to drive the Federal and L-S samplers, using driving wrench-knee bend technique.
- (2) Four men drove Rosen sampler to ground without driving wrench-knee bend technique. Thus the Rosen was dramatically easier to drive than either the standard Federal or L-S Federal.
- (3) Adirondack samples taken in 60" increments on benches in template pit. At all levels Adirondack had to be pounded down using long heavy 2x4 for pile driver. Cores held by putting metal blade under cutter and cutting snow away from the sampler before lifting it out.
- (4) Very corky snow 140" - 170"; air and snow temperatures, however, were favorable to good sampling; L-S cutter did not hold frozen sawdust plugs as securely as either the Rosen or Federal sampler.

Snow Sampler (make)	Inch W.E.	Dev. from true value (in)	% Diff. from true value
Federal	94.1	+8.7	+10.2
L-S	92.2	+6.8	+ 8.0
Rosen	87.9	+2.5	+ 2.9
Adirondack #2	85.0	-0.4	- 0.4
Template	85.4	0	0

(*) = Number of samples taken.