A COMPARISON OF U.S. AND CANADIAN AIRBORNE GAMMA RADIATION SNOW WATER EQUIVALENT MEASUREMENTS

by

Thomas R. Carroll[1], John E. Glynn[2], and Barry E. Goodison[3]

INTRODUCTION

Background and objectives

In 1979, the U.S. and Canadian National Committees for Hydrology agreed to plan a joint hydrological research activity to study the prairie snowpack. The aim is to provide a better definition of the areal snow water contribution to runoff and consequently enhance the use and management of prairie water resources. The committees identified seven general areas of research which include the areal measurement of snow water equivalent. Primary considerations in this category cover research on:

1. Snow survey using airborne gamma radiation,
2. Stratified snow sampling based on land use,
3. Effects of various cropping practices on areal distributions of snow cover,
4. Mapping areal extent of snow cover by satellite,
5. Microwave studies of snow cover properties, and
6. Snowfall measurements.

In November, 1980, Canadian and American participants developed a project aimed at mapping snow cover over land using passive microwave. The three-level sampling scheme uses ground-based, airborne, and satellite data collection to assess the snow water equivalent measurement problem over the prairies. The three primary objectives of the experiment are:

1. To provide a direct comparison of airborne gamma radiation snow water equivalent measurements made by the Geological Survey of Canada (GSC) system and the National Weather Service (NWS) system with each other and with ground observations,
2. To develop the capability of mapping snow cover (areal extent, depth, and water equivalent) on the Canadian prairies using ground-based, airborne, and satellite information, and
3. To assess the utility of passive microwave data for mapping the depth, water equivalent, and areal extent of snow cover on the prairie.

---

[1] Airborne Snow Survey Program, National Weather Service,
6301 - 34th Avenue South, Minneapolis, Minnesota 55450

[2] National Hydrology Research Institute, Inland Waters Directorate, Ottawa, Ontario
K1A-0E7

[3] Atmospheric Environment Service, 4905 Dufferin Street,
Downsview, Ontario M3H-5T4

Presented at the 51st Annual Western Snow Conference,
Vancouver, Washington - 1983 April 19 - 21.

"Reprinted Western Snow Conference 1983"

The multi-stage remote sensing snow cover experiment was conducted during the week of February 15, 1982. This paper focuses on results related to the first objective; i.e., the comparison of U.S. and Canadian airborne gamma radiation snow water equivalent measurements.

Data collection summary

The experiment was designed to use: (1) ground snow surveys intended for prairie conditions, (2) airborne gamma radiation measurements as "standardized surface measurements" to correlate with NIMBUS-7 scanning multi-channel microwave radiometer (SMMR) data, and (3) NASA airborne SMMR data. It was not feasible to collect adequate ground data along all of the 43 airborne flight lines; consequently, snow surveys were conducted along 13 selected calibration flight lines. Ground measurements of snow depth, water equivalent, density, stratigraphy, temperature, and soil moisture were collected on February 16 - 18, 1982. U.S. and Canadian airborne gamma radiation data were collected on February 16 - 19, 1982. The background (no snow cover) airborne gamma radiation data required to determine the natural terrestrial radioisotope concentration along the flight lines were collected on July 26 - 28, 1982. A U.S. Air Force C-130 collected 1100 km of airborne microwave data on February 17 - 18, 1982. All available NOAA imagery for the week is archived by Atmospheric Environment Service, Downsview. NIMBUS-7 SMMR data are available for February 17. No LANDSAT data are available.

Flight line description

Figure 1 shows the network of flight lines flown by the three aircraft. Ground data were collected on calibration flight lines indicated by a "C". Flight lines follow main highways to facilitate accurate flight line recovery during the background survey and to ease ground data collection. Flight lines were selected to cover the range of snow cover conditions which generally exist over southern Saskatchewan. These variations are a function of location, topography, and land use. For example, line CR450 typically experiences heavier snow accumulation while line CR700 tends to have a more shallow snow cover. Flight lines were also located near other snow study sites.

Line CR100, extending southeast from Regina along Highway 33 through Wascana Creek basin, was selected as the primary calibration line for the two airborne gamma spectrometers. Both aircraft conducted multiple flights over the 130 km line to assess the repeatability of the airborne measurement technique.

Three 25 km segments (CR101C, CR103C, CR105C) were chosen for detailed calibration and intensive ground surveys. Oblique areal photographs were taken in November 1981 and 1982 to assess land use and to select sampling sites.

GROUND DATA COLLECTION AND ANALYSIS

Three teams of three experienced field personnel conducted intensive ground surveys on segments CR101C, CR103C, and CR105C. Sampling sites were located on both sides of east-west section roads, 300 m west of the highway. Representative sample sites were selected using the oblique aerial photos. The major land use classifications were fallow, stubble, cultivated stubble, pasture, and natural prairie. (Steppuhn and Dyck, 1974).

Snow cover measurements

Approximately 80 snow water equivalent and 440 depth measurements were taken at 14 sampling sites along each of the three calibration lines. The ESC-30 snow sampler was used; samples were bagged, tied securely, and weighed later on a laboratory gram balance. One snow pit was dug at each site; the observers recorded snow stratigraphy, crystal shape and size, hardness, and snow pack temperature. A soil moisture sample representative of the top 5 -10 cm was taken using a soil auger or ax depending on soil conditions.

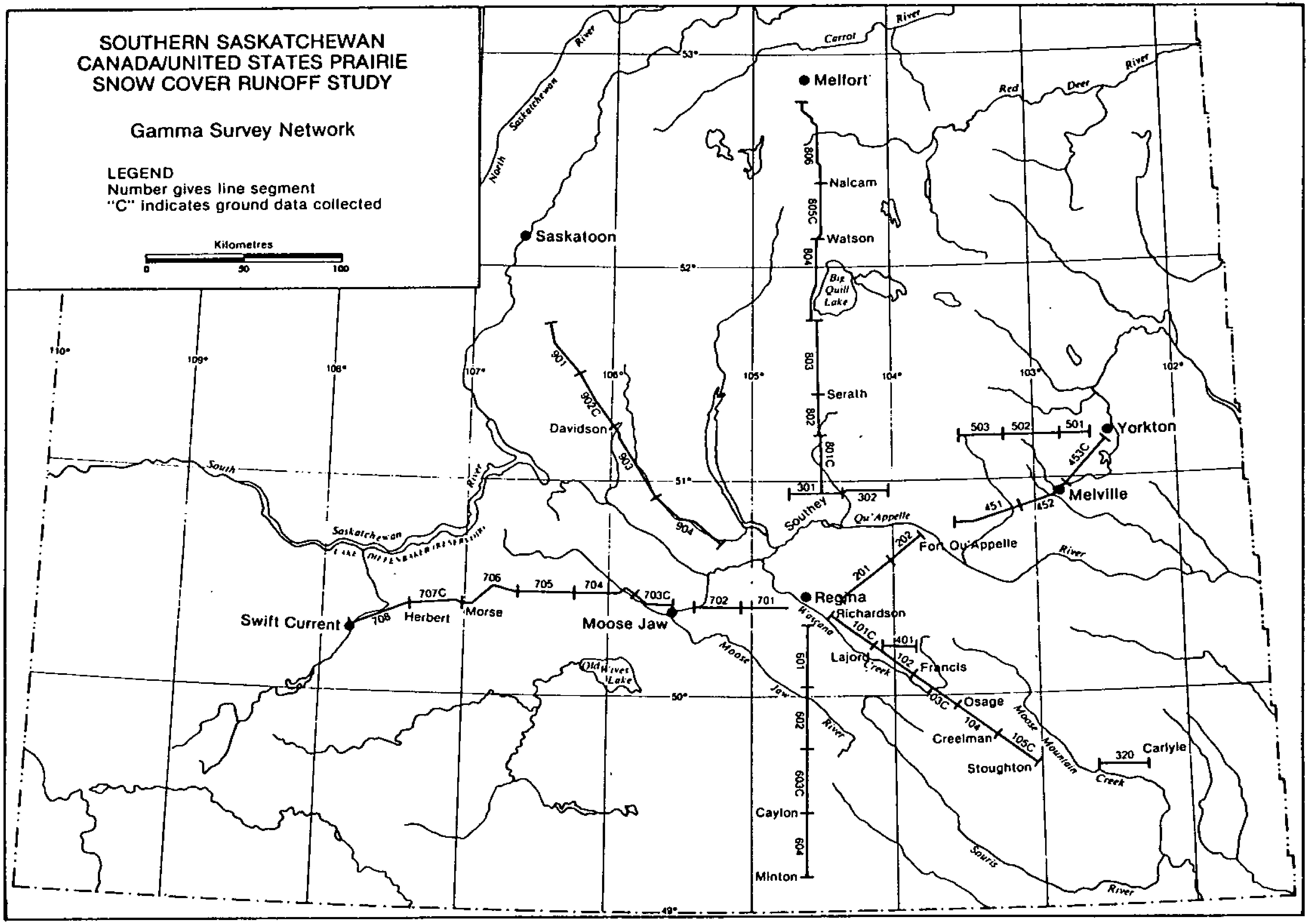


Figure 1. Flight line network in southern Saskatchewan. Flight lines to make airborne snow water equivalent measurements for inter-system and ground-based comparisons.

In addition to the data collected at each sampling site, the Saskatchewan Department of Environment conducted a snowmobile traverse along the length of CR101C, CR103C, and CR105C. Approximately 330 additional snow depths were collected along each flight line at 60 m intervals. A total of approximately 850 depth and water equivalent measurements were made along each of the three intensive calibration lines. This ground data set represents the primary data-base used to assess the errors associated with the airborne snow water equivalent measurement technique.

A less intensive effort was made on additional calibration flight lines to collect representative snow cover and soil moisture data. On average, 50 depth measurements, 20 water equivalent measurements, and 22 soil samples were collected on each of 10 additional flight lines. These data are used to assess the errors associated with the airborne technique, however, they receive only secondary consideration.

A summary of the ground snow water equivalent results for each flight line is given in Table 1. The error for each measurement represents one standard deviation of the snow water equivalent value.

TABLE 1

GROUND SNOW WATER EQUIVALENT MEASUREMENTS

Flight Line No.	SWE(mm) Mean ± Standard Deviation	Number of depth and water equivalent samples taken
CA316C	70 ± 6	32
CA320C	52 ± 4	56
CA401C	46 ± 4 ?	58
CR101C1	72 ± 1	918
CR103C	71 ± 2	802
CR105C	59 ± 2	834
CR453C	29 ± 3	56
CR603C	38 ± 3 ?	72
CR703C	42 ± 3	84
CR707C	47 ± 3	119
CR801C	31 ± 3	126
CR805C	24 ± 5	32
CR902C	23 ± 1	119

Ground snow data on flight lines CA401C and CR603C appear to be an underestimate. The snow water equivalent on flight lines in the immediate vicinity is significantly higher; the independent airborne measurements for the flight lines agree with each other and are significantly higher; both lines were sampled by the same team.

Soil moisture measurements

The airborne technique used to measure snow water equivalent requires some estimate of soil moisture near the surface over the flight line. Consequently, an average of 20 soil samples were collected on each flight line at the approximate time background and over-snow radiation data were collected. A standard gravimetric analysis was conducted to determine the percent soil moisture. The results indicate a mean soil moisture of 28.7 percent and a mean coefficient of variation of 28.2 for data collected on 13 calibration flight lines in February, 1982. The soil samples collected during background data collection in July, 1982 indicate a mean soil moisture of 26.2 percent with a coefficient of variation of 25.7 percent. The effect of soil moisture and associated errors on snow water equivalent measurements has been discussed by Jones and Carroll (1983) and Carroll and Jones (1982).

AIRBORNE DATA COLLECTION AND ANALYSIS

Gamma radiation attenuation technique

The gamma radiation flux near the ground originates primarily from the natural ^{40}K, ^{238}U, and ^{208}Tl radioisotopes in the soil. In a typical soil, 96 percent of the gamma radiation is emitted from the top 20 cm (Zotimov, 1968). After a measure of the background (no snow cover) radiation and soil moisture is made over a specific flight line, the attenuation of the radiation signal due to the snow pack overburden is used to calculate the amount of water in the snow cover over approximately 6 km^2. Three snow water equivalent values are calculated by measuring the attenuation of the gamma radiation flux using data from the K window (1.36-1.56 MeV), the Tl window (2.41-2.81 MeV), and the gross count (GC) energy spectrum (0.41-3.0 MeV). The potassium photopeak is consistently the strongest in the energy spectrum and has been used successfully to measure snow water equivalent in Canada and in the U.S. (Glynn and Grasty, 1980; Peck *et al.*, 1980). The gross count window accumulates an order of magnitude more counts than the K and Tl photopeak windows. Consequently, gross counts are useful when measuring the variability of snow cover along a flight line or a snow cover with 15 to 25 cm of snow water equivalent.

Airborne measurements of terrestrial radiation are complicated by radon gas contributions. Radon (^{222}Rn) is a daughter of ^{226}Ra in the ^{238}U chain. Radon is a gas with a 3.8 day half-life and can diffuse out of the soil into the atmosphere. Its daughters are gamma emitters that emanate from both the ground and the atmosphere. The airborne radon and daughters are highly variable in concentration, so they contribute a varying amount to the gamma spectrum count rate. Their contribution can range from zero to 100 percent or more of the terrestrial fraction. Radon is a heavy element; consequently, the gas tends to concentrate close to ground. Because the spectral shape of radon is similar to that of uranium, an independent measurement is required to distinguish the two sources of radiation.

The principal sources of error in calculating snow water equivalent or soil moisture values using any of the three windows are incorporated in: (1) the measurement of mean areal soil moisture for a flight line, (2) the measurement of air mass (i.e., temperature, pressure, and radar altitude), (3) radiation counting statistics, and (4) the accurate assessment of the radon contribution.

National Weather Service system description

Details of the airborne detection package have been described by Carroll and Vadnais (1980) and Fritzsche (1979). The system consists of five down-looking 10.2 x 10.2 x 40.6 cm NaI (Tl) scintillation detectors; two 10.2 x 10.2 x 20.3 cm up-looking detectors; a Pulse Height Analyzer; and a Hewlett-Packard 9825 computer used to reduce and record the output data onto magnetic tape. The up-looking and down-looking detectors are used to assess the radon gas contribution to the terrestrial radiation spectrum. The effect of radon can be virtually eliminated from the uncollided gamma method. Separating the radon from the gross count, however, is difficult. One practical method of alleviating the radon problem in the gross count has been to use two detectors. The up-detector is shielded from the ground by lead and the down-detector and thus primarily measures the airborne radon. The down-detector measures both terrestrial radiation and radon. The data are then available to write two equations in two unknowns to obtain the ground count rate and the radon count rate (Fritzsche, 1982).

The data acquisition procedure is designed to accumulate and store window data in multiple cycles of 5 second or longer. This provides the capability of analyzing the snow cover distribution along a flight line in approximately 250 m segments. At the end of each flight line the total radiation spectra (0.05-5.1 MeV) accumulated over the length of the flight line for both the up- and down-detectors are stored on magnetic tape. These data are archived on disk for additional analysis.

Techniques have been developed to calibrate airborne gamma radiation detection systems (Fritzsche, 1979; Glynn and Grasty, 1980). Experiments must be performed to determine values for twenty parameters that describe the physical nature of the radiation attenuation process. Multiple high altitude and lake flights are used to obtain background components. Data collected from simulation pads, loaded with varying concentrations of ^{40}K, ^{232}Th, and ^{238}U, give photopeak stripping coefficients and basic system sensitivity.

Multiple altitude flights over land lines provide data necessary to calculate air attenuation coefficients which are subsequently converted to water attenuation coefficients.

Data collection. Ambient radiation data are collected by the detection system and immediately reduced using algorithms to describe the presence of atmospheric radon, high energy cosmic radiation, Compton scattering effects within the radiation spectra, and extraneous background radiation contributed by the aircraft and detection system. Pressure, temperature, and radar altitude data are also recorded and used to calculate the attenuation of terrestrial radiation due to the air mass between the source and sensor (approximately 17 g cm^{-2} at an altitude of 150 m). Uncollided terrestrial radiation count rates are normalized to time and air mass while background radiation and airborne soil moisture data are archived in an airborne data base. The background data are used with the oversnow radiation data to calculate snow water equivalent values in the aircraft immediately after the over-snow radiation data are collected for a given flight line. In this way, real-time snow water equivalent values generated for 30 to 50 flight lines per day can be made available to NWS field offices and other users at the time the aircraft lands each evening. The airborne snow survey data are transmitted in digital form over the telephone from the field to the office in Minneapolis.

Geological Survey of Canada system description

The Geological Survey of Canada uses a Short's Skyvan aircraft for all its airborne radiometric surveys. The system consists of twelve NaI (Tl) 10.2 x 10.2 x 40.6 cm crystals which record data in 256 channels (12 keV) once each second (Bristow, 1979). A radar altimeter digitally records the flight altitude and a clock records the time each second. Air temperature and pressure are recorded at the beginning and end of each flight. The one second data are recorded in real-time on magnetic tape using a Data General Nova minicomputer.

Survey data are corrected for non-terrestrial sources of radiation by using data collected over a nearby lake or river. Because water absorbs all radiation from terrestrial sources, the only sources detected in the spectrometer are cosmic rays, aircraft radio-activity, and radon gas. The aircraft collects radiation data over lakes during each survey so changes in radon concentration during the flight can be detected.

All processing of the data is performed at the GSC headquarters in Ottawa on a Data General Eclipse computer system. Energy calibration of the spectra is performed on the Eclipse to determine the proper gain shift (keV/channel). The background corrected airborne spectra are fitted to pure potassium, uranium, and thorium spectra with an assumed gain shift. The goodness of fit statistic is calculated using a weighted least squares technique. The gain is varied until the goodness of fit is minimized (Grasty, 1982). The snow water equivalent is determined using the thorium, potassium, and gross count windows in a method similar to the NWS procedure (Glynn and Grasty, 1980).

NATIONAL WEATHER SERVICE AND GEOLOGICAL SURVEY OF CANADA AIRBORNE SNOW WATER EQUIVALENT RESULTS

Airborne snow water equivalent measurements are made using the following relationship:

$$SWE = \frac{1}{\alpha}\left[\ln\frac{C_o}{C} - \ln\left(\frac{100 + 1.11M}{100 + 1.11M_o}\right)\right] g\ cm^{-2}$$

where:

C and C_o = Uncollided terrestrial gamma count rates over snow and bare ground,

M and M_o = Percent soil moisture over snow and bare ground,

α = Radiation attenuation coefficient in water, g cm^{-2}.

Individual airborne snow water equivalent values can be calculated using gamma count rates from each of the three windows. It is desirable to calculate a weighted snow water equivalent using values and an associated weight for each of the three windows. Weights (which sum to unity) can be derived that minimize the variance of the weighted snow water equivalent value. In this fashion it is possible to calculate a single best snow water equivalent value using information from each of the three spectral windows. The National Weather Service has derived weights for the K, Tl, and GC windows of 0.35, 0.52, and 0.13 respectively (Jones and Carroll, 1983). The contribution from the Tl window is highest while the contribution from the GC window is lowest. This relationship should be expected since the complicating factor of radon gas, a uranium daughter product, contributes least to the Tl window and most to the GC window. For purposes of system comparison, snow water equivalent values using the NWS derived weights are used. The Geological Survey of Canada is currently conducting research to derive and optimum set of weights which may be a function of detector size.

Table 2 gives a summary of the errors associated with a comparison of the NWS and GSC airborne systems. The two systems agree with a Root Mean Square (RMS) error of 4.5mm. In this analysis, the GSC measurements are compared to the NWS measurements. Consequently, a percent bias of -1.5 percent indicates the GSC airborne measurements are, on average, 1.5 percent lower than the NWS airborne measurements.

Table 2

AIRBORNE SNOW WATER EQUIVALENT MEASUREMENTS (mm)

Flight Line No.	NWS SWE	GSC SWE
CA320C	63 ± 3	62 ± 4
CA401C	75 ± 2	72 ± 2
CR101C	73 ± 2	70 ± 5
CR102	66 ± 2	68 ± 6
CR103C	76 ± 2	74 ± 9
CR104	76 ± 4	78 ± 5
CR105C	71 ± 3	66 ± 4
CR451	30	25
CR452	21	25
CR453C	23 ± 2	13
CR801C	36 ± 4	41
CR802	26	26
CR803	37	33
CR804	26	27
CR805C	32 ± 4	29
CR806	45	55
CR902C	39 ± 3	39

* * * * * *

RMS Error	4.5
Average Absolute Errors	3.5
Average Bias	-0.7
Percent Bias	-1.5
N	17

The airborne measurement for each flight line is the mean of multiple flights. The associated error is the standard deviation of the mean. Where no error is given, only one flight was made. Figure 2 shows the relationship of both the NWS and GSC measurements made over 17 flight lines.

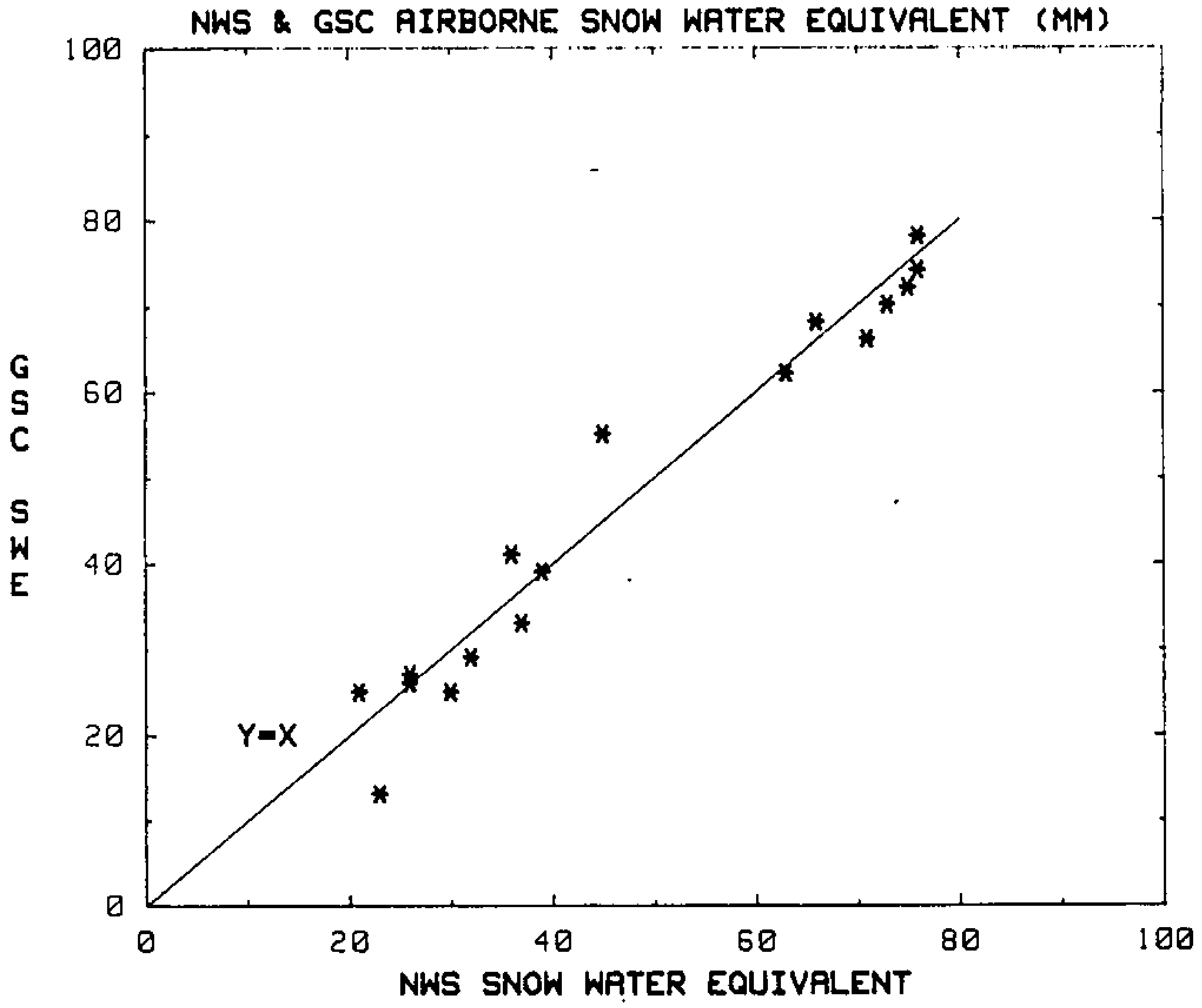


Figure 2. Airborne snow water equivalent measurements made by the NWS and GSC systems agree with an RMS error of 4.5mm. The GSC measurements underestimate the NWS measurements by 1.5 percent.

Table 3 gives a summary of the ground and airborne data collected over the calibration flight line network. The errors represent the standard deviation of the respective measurements. Measurements made on CA401C and CR603C are not included in the error analysis because of questionable ground data. An error analysis combining the NWS and GSC data collected on 11 flight lines indicate that airborne snow water equivalent measurements can be made with an RMS error of 9.0 mm and a bias of 5.0 mm. An error analysis on the three calibration flight lines on which an average of 850 depth and water equivalent samples were collected is also given in Table 3. Combining the NWS and GSC data collected over the flight lines with intensive ground data indicates that the RMS error for both systems is 6.2 mm with a bias of 4.3 mm (6.4 percent). Figure 3 shows the relationship between ground data and airborne measurements made by the NWS and GSC systems.

Table 3

AIRBORNE AND GROUND

SNOW WATER EQUIVALENT MEASUREMENTS (mm)

Flight Line No.	Ground	NWS	GSC
CA316C	70 ± 6	73	
CA320C	52 ± 4	63 ± 3	62 ± 4
CA401C	46 ± 4 ?	75 ± 2	72 ± 2
CR101C	72 ± 1	73 ± 2	70 ± 5
CR103C	71 ± 2	76 ± 2	74 ± 9
CR105C	59 ± 2	71 ± 3	66 ± 4
CR453C	29 ± 3	23 ± 2	13

CR603C	38 ± 3 ?	70 ± 1	
CR703C	42 ± 3	43 ± 1	
CR707C	47 ± 3	54 ± 5	
CR801C	31 ± 3	36 ± 4	41
CR805C	24 ± 5	32 ± 4	29
CR902C	23 ± 1	39 ± 3	39

* * * * * *

RMS Error	8.1	10.0
Average Absolute Error	6.8	8.6
Average Bias	5.7	4.1
Percent Bias	12.1	9.1
N	11	8

* * * * * *

(Data From CR101C, CR103C, and CR105C Only)

	NWS	GSC
RMS Error	7.5	4.6
Average Absolute Error	6.0	4.0
Average Bias	6.0	2.7
Percent Bias	8.9	4.0
N	3	3

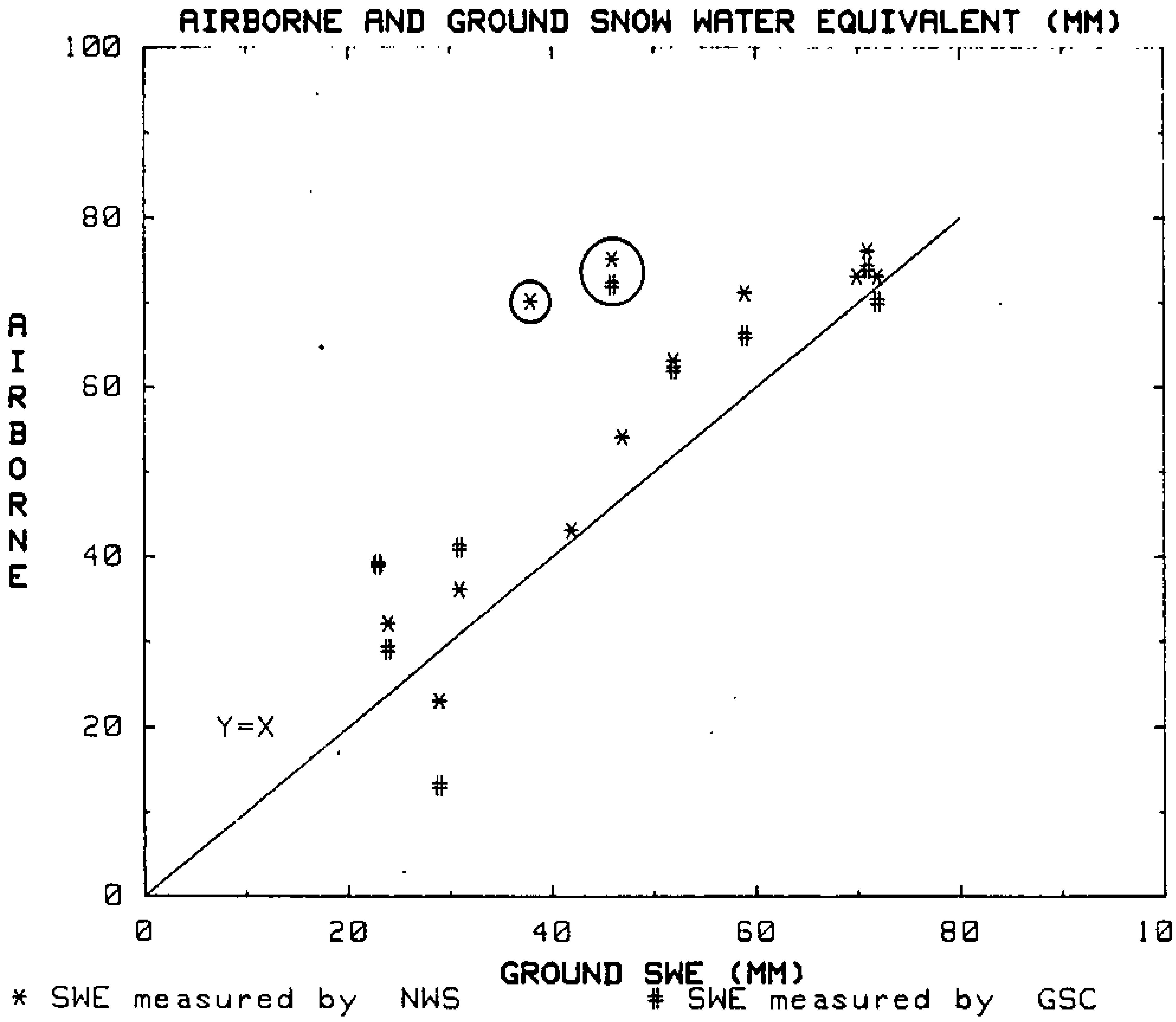


Figure 3. The combined NWS and GSC data collected over 11 flight lines indicate airborne snow water equivalent measurements can be made with an RMS error of 9.0mm and a bias of 5.0mm. (Circled data points not included in analysis.)

Discussion

The airborne snow water equivalent measurements made by the NWS and GSC systems agree more closely with each other (RMS error of 4.5 mm) than they do with the ground observations (RMS error of 8.1 and 10.0 mm, respectively). The airborne NWS and GSC measurements overestimate the ground data by 5.7 mm (12.1 percent) and 4.1 mm (9.1 percent) respectively. This relationship should be expected. Problems with ice layers on the ground, sampling design, ice lens development within the pack, snow sampling equipment, and observer technique render a ground-based mean areal snow water equivalent measurement extremely difficult to obtain. The problem is complicated by the fact that ground measurements collected over less than 2 m^2 are used to infer a mean areal snow water equivalent over an area of 4 to 8 km^2. The various problems associated with groundbased snow sampling tend to contribute to an underestimate of the mean areal snow water equivalent. Consequently, it is tempting to suggest that ground-based sampling may tend to underestimate the snow cover while airborne measurements more accurately reflect the snow cover conditions. Data collected on the intensively sampled calibration flight lines indicate that the ground measurements may underestimate the mean areal snow water equivalent by 4.3 mm or 6.4 percent.

CONCLUSION

During the week of February 15, 1982, the National Weather Service and the Geological Survey of Canada made airborne gamma radiation snow water equivalent measurements on a network of 43 flight lines in central Saskatchewan. Seventeen flight lines were flown by both the NWS and GSC aircraft and provide data for a system comparison. The results indicate that the two systems can make independent snow water equivalent measurements with an RMS error of 4.5mm between systems. In excess of 2500 ground-based snow depth and density samples were collected on three flight lines and indicate that airborne snow water equivalent measurements can be made with an RMS error of 6.2mm and a bias of 4.3mm (6.4 percent). The independent airborne measurements made by different systems agree more closely with each other than either do with the ground. This relationship has also been observed in data collected over a network of 12 calibration flight lines in the Lake Superior basin. A systematic underestimate of the true snow cover by the ground observations is one plausible explanation of the results.

ACKNOWLEDGEMENTS

The prairie snow cover experiment was possible only with the tremendous cooperation of the personnel and agencies involved. Thirteen Canadian and American federal and provincial agencies provided support to the experiment which involved ten "on site" airborne personnel and 21 ground personnel. The following agencies cooperated to provide aircraft resources, ground personnel, satellite data acquisition, and/or funds for the experiment:

Atmospheric Environment Service		
	Hydrometeorology Division	Downsview
	Aerospace Meteorology Division	Downsview
	Scientific Services Division	Regina
Environmental Conservation Service		
	National Hydrology Research Institute	Ottawa
	Water Resources Branch	Regina
Geological Survey of Canada		
	Resource Geophysics & Geochemistry Division	Ottawa
Saskatchewan Environment		
	Hydrology Branch	Regina
Saskatchewan Research Council		
	Engineering Division	Saskatoon
Manitoba Department of Natural Resources		
	Water Resources Branch	Winnipeg

National Weather Service	
Office of Hydrology	Minneapolis
National Aeronautics and Space Administration	
Goddard Space Flight Center	Greenbelt
Johnson Space Flight Center	Houston
U. S. Air Force	
Kelly Air Force Base	San Antonio

The snow cover experiment was possible, in large part, through the efforts of Dr. Edward J. Langham (RADARSAT Project Office, Environment Canada) who organized and directed the early stages of the experiment. In addition, the following individuals deserve special thanks for their contribution to the project: R. Halliday, R. Herrington and staff (Water Resources Branch, Environment Canada); A. Banga and staff (Saskatchewan Department of Environment); A. Warkentin and staff (Manitoba Water Resources Branch); J. Whiting and staff (Saskatchewan Research Council); J. Metcalfe and R. Hopkinson (Atmospheric Environment Service); and the crew of the three aircraft.

The research conducted by John E. Glynn was accomplished while on secondment to the Geological Survey of Canada.

REFERENCES

Bristow, Q. (1979) A gamma ray spectrometry system for airborne geological research. Current research, Part C, Geological Survey of Canada, Paper 79-1C, p. 55-61.

Carroll, T. R. and W. K. Jones (1982) Error assessment of airborne snow water equivalent measurements. Proceedings of the Western Snow Conference, Reno, Nevada, 20-23 April 1982.

Carroll, T. R. and K. G. Vadnais (1980) Operational airborne measurement of snow water equivalent using natural terrestrial gamma radiation. Proceedings of the Western Snow Conference, Laramie, Wyoming, 15-17 April 1980.

Fritzsche, A. E. (1979) The development of an airborne gamma radiation system for snow surveys. WMO workshop on Remote Sensing of Snow and Soil Moisture by Nuclear Techniques, Voss, Norway, 23-27 April 1979.

Fritzsche, A. E. (1982) The National Weather Service gamma snow system physics and calibration. Publication No. NWS-8201, EG&G, Inc., Las Vegas, NV, pp. 37.

Glynn, J. E. and R. L. Grasty (1980) A calibration procedure for airborne gamma ray snow surveys. Proceedings of the Western Snow Conference, Laramie, Wyoming, 15-17 April 1980.

Grasty, R. L. (1982) Utilizing experimentally derived multi-channel gamma-ray spectra for the analysis of airborne data. Presented at the Symposium on Uranium Exploration Methods, Paris, France, 1-4 June 1982.

Jones, W. K. and T. R. Carroll (1983) Error analysis of airborne gamma radiation soil moisture measurements. Agricultural Meteorology 28:19-30.

Peck, E. L., T. R. Carroll, and S. C. Van Demark (1980) Operational aerial snow surveying in the United States. Hydrological Sciences Bulletin 25(1):51-62.

Steppuhn, H. W. and G. E. Dyck (1974) Estimating true basin snowcover. Advanced Concepts and Techniques in the Study of Snow and Ice Resources, Interdisciplinary Symposium, U. S. National Academy of Sciences, Washington, D.C., pp. 314-324.

Zotimov, N. V. (1968) Investigation of a method of measuring snow storage by using the gamma radiation of the earth. Sov. Hydrol. Sel. Pap., Engl. Transl., No. 3, pp. 254-266.

28

Proc Prairie Hyd. Symp. Water Studies Institute
Saskatoon, May 1978

1978

3

CANADIAN SNOW GAUGE MEASUREMENTS

ACCURACY, IMPLICATIONS, ALTERNATIVES, NEEDS

Barry E. Goodison

Atmospheric Environment Service
Downsview, Ontario

1. INTRODUCTION

In Canada, during the last ten years there has been considerable effort directed at modelling the hydrologic cycle on a basin, region, or national scale. A common conclusion from several studies (e.g. Findlay, 1969; Hare and Hay, 1971; den Hartog and Ferguson, 1975) was the apparent undermeasurement of precipitation, particularly snowfall. Recently, the Prairie Provinces Water Board completed a Streamflow Forecasting Study which identified methods and associated networks required to provide water supply and river flow forecasts for the Prairie Provinces. They identified research areas where additional information is necessary to define adequately input parameters for their forecasting methods and models. Included in the requirements were improved methods of snow measurement, including the point measurement of snowfall. Specifically they state that "research is needed to identify new gauge types or gauge shields, and gauge locations which will provide more accurate snowfall data in a plains environment" (PPWB, 1977). However, this step can only proceed after the accuracy of the standard gauges for measuring snowfall is adequately defined.

In Canada, there has been limited field investigation to evaluate the accuracy and comparability of precipitation gauges. Dyck (1969), Ferguson and Pollock (1971), Harris and Carder (1974) have reported discrepancies in snowfall totals obtained using different methods of measurement at the same station. To investigate this problem in greater detail, the Hydrometeorology Research Division of the Atmospheric Environment Service conducted a research program to study the methods of snowfall measurement, particularly those involving precipitation gauges.

This paper will briefly review the results obtained from a study in the Cold Creek basin (40 km northwest of Toronto, near Bolton, Ontario) on gauge accuracy. The use of corrected snowfall data to obtain accumulated precipitation comparable with other measurements of mean basin snow cover will be discussed. The applicability of the derived correction procedures to station data from Cold Creek, Knob Lake (Quebec), Resolute (NWT) and Regina will be summarized. The use of artificial shields, such as the Wyoming, will be reviewed with respect to initial results from field installations in different regions of Canada.

2. ACCURACY OF SNOW GAUGE MEASUREMENTS

The accurate measurement of snowfall water equivalent is difficult, particularly at exposed wind-blown sites. The problem is compounded when one tries to compare data from different types of gauges, located even at a single site. Figure 1 illustrates the problem which users face in determining what the actual snowfall was at that site. Not only did shielded gauges catch more than their unshielded counterparts, but different types of shielded gauges caught very different amounts of snow. Which, if any, was correct? The problem is magnified when areal snowfall is calculated from different gauge installations at variously exposed sites over a basin. Before effective areal analysis can proceed point measurements must be comparable.

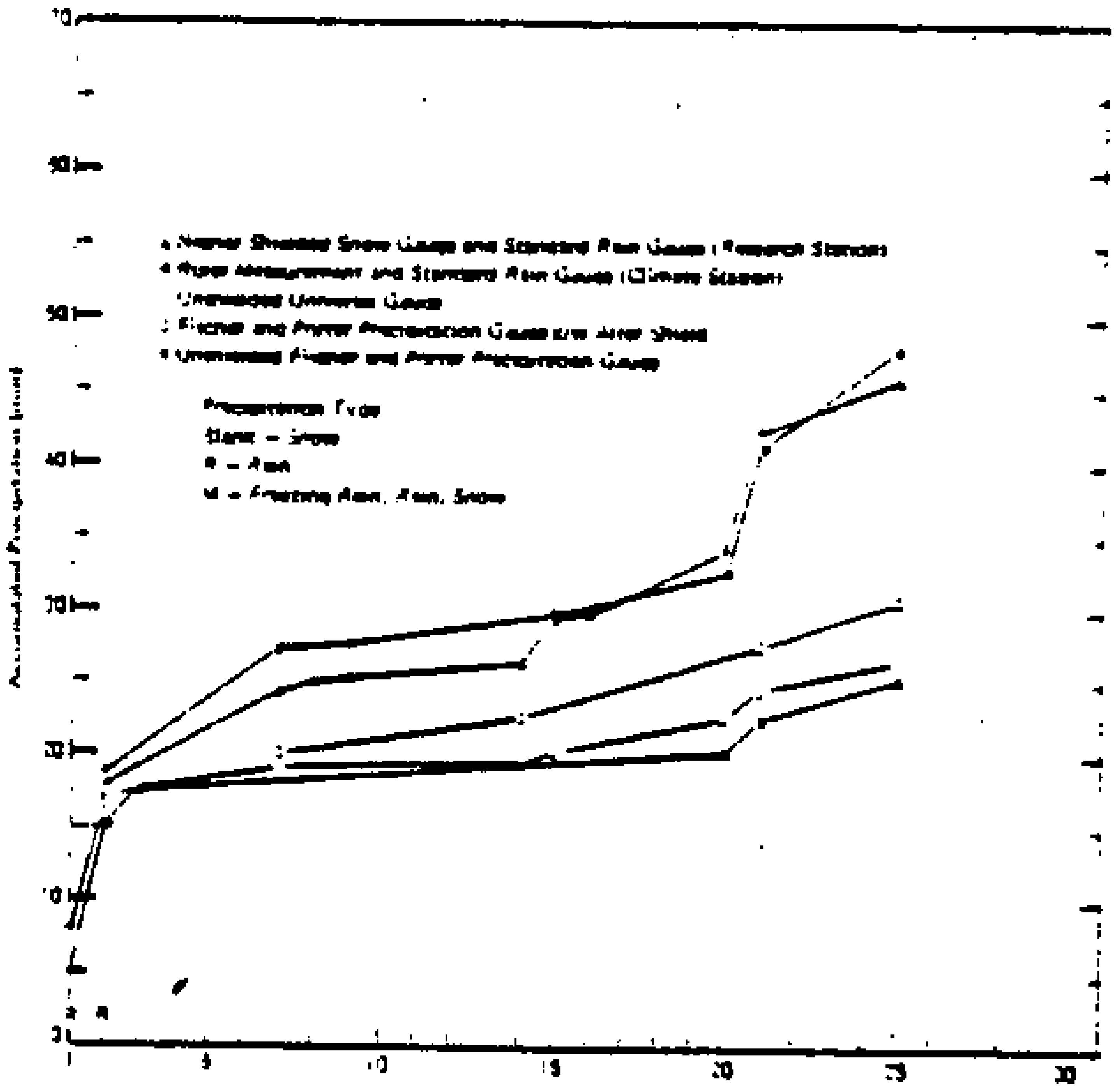


Figure 1. Uncorrected Accumulated Precipitation, Cold Creek Hydrometeorological Station, (Ontario), February, 1973.

The basic method of observation and associated errors used at the Cold Creek Hydrometeorological Research Station to investigate the accuracy of snow gauges are presented in detail in Goodison (1977a) and summarized in

Goodison (1975; 1977b). Gauges evaluated included the Fischer and Porter, Universal (Belfort), Tretyakov and MSC Nipher shielded snow gauge. One of the aims was to try to establish a functional relationship between gauge catch and environmental parameters which could be used to estimate actual snowfall.

Two open and two sheltered sites were used in the study to sample a wide range of wind speeds. Wind speed at gauge height (2 m) was measured at all sites. Mean surface air temperature was continuously recorded at the Research Station. The 700 mb and 850 mb temperatures for storm periods were abstracted from synoptic charts. "Ground true" precipitation was determined by weighing the storm snowfall which accumulated on snow boards located at the two sheltered sites.

For all gauges, wind speed was the dominant environmental parameter affecting gauge catch. Figure 2 summarizes the curves of the ratio of gauge catch to ground true (gauge catch ratio) with respect to wind speed for four types of shielded gauges. The curves are best fit relations based on data from storms with a "ground true" total greater than 5 mm. The results for the Tretyakov gauge are provided for comparison as they are virtually the same as reported by Kuzmin (1975). This agreement lends confirmation to the general accuracy of the method of determining actual snowfall water equivalent and the lack of bias in the experimental procedures. Thus the curves developed for the other gauges should reflect an accurate gauge catch efficiency relation.

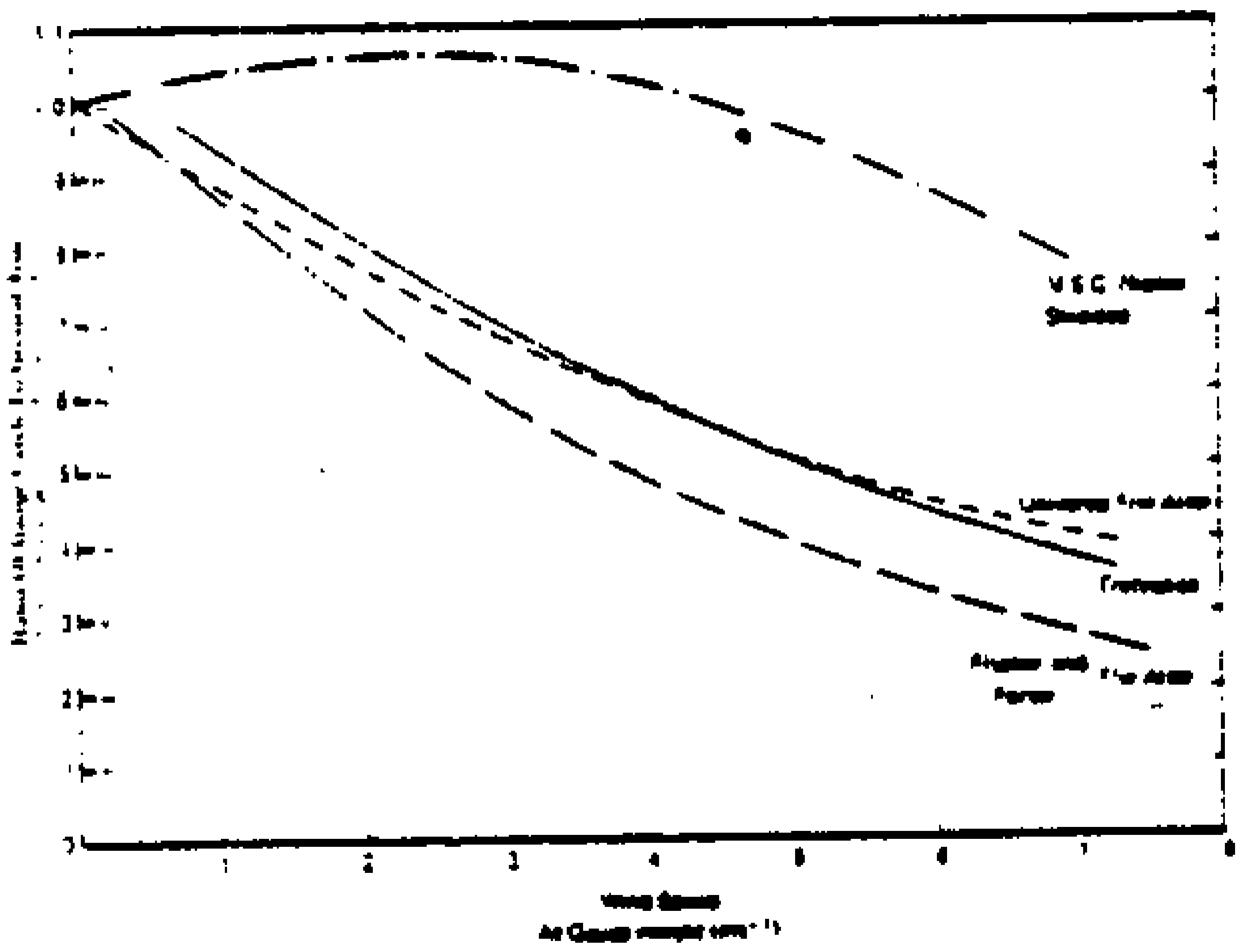


Figure 2. Mean Gauge Catch Ratio as a Function of Wind Speed for Shielded Snow Gauges.

For the Fischer and Porter and Universal gauges, surface air temperature was a statistically significant secondary parameter, but in the Cold Creek tests it contributed only an additional 2% and 1% explanation of variance in the gauge catch models. Consequently, it is not currently incorporated in the gauge correction procedure. In all field tests the shielded and unshielded Fischer and Porter gauges measured less than the respective Universal gauges. This is reflected in seasonal snowfall totals recorded by these gauges (for example, see Figure 1).

The catch for the MSC Nipher shielded snow gauge was very different from the other gauges tested. Of particular note is that for mean storm wind speeds up to 4 ms^{-1}, the Nipher gauge slightly overmeasures actual snowfall, for speeds up to 5.5 ms^{-1} the mean gauge catch is within 10% of true. Based on the data collected surface air temperature was inversely related to gauge catch, but it was not a statistically significant parameter. Instead, the 700 mb temperature was a significant secondary parameter. Operational use of this parameter is still limited for individual gauge locations, and it is not used in the current analysis. A wind plus wind squared term explained 76% of the variance in the Nipher catch ratio.

Although the Nipher gauge exhibits a generally superior catch efficiency, other corrections are necessary. At temperatures near 0°C, wet snow has been observed to build up on the rim of snow collector of the Nipher; during such conditions it is often difficult to determine what should or should not be included in the measurement. It becomes impossible to correct for variations in an observer's judgment in such cases. However, a limited number of observations during such conditions indicate that the gauge catch ratio is about .15 units lower than the mean curve given in Figure 2. Unless this problem is observed and recorded, it is difficult to apply the appropriate correction.

Nipher gauges at sheltered sites have also been observed to cap over completely during heavy snowfalls of wet snow. The solid shield provides a good surface upon which snow can collect; a light gust of wind might blow some of this snow into the collector or the gauge might cap over and prevent snow from entering the gauge. This factor must be considered when siting a Nipher gauge in a basin in a well sheltered site; the effect of wind may be reduced, but the frequency of snow capping may be increased. An individual's judgment and experience in a region must be used to rationalize the siting problem.

Two other Nipher gauge corrections are necessary. Unlike the Universal and Fischer and Porter recording gauges which continuously accumulate all precipitation, even very small amounts, the Nipher gauge contents are melted and poured out into a graduated cylinder for direct measurement as water equivalent. Because of adhesion of the water droplets to the side of the Nipher collector, the poured out total will be less than the true water equivalent in the collector. In the Cold Creek study, both the poured out and weighed contents were measured. From over 140 field measurements the mean retention loss was determined to be 0.15 ± 0.02 mm. Adjustment for the mean retention loss is made by adding 0.15 mm to each observation, excluding traces, before correcting the measured catch for the effect of wind.

Retention losses may not be considered significant by some researchers, and during heavy snowfalls this may certainly be the case. However, in low snowfall regions, such as the Prairies, where there are many observations of small amounts, the retention loss can become significant. At Regina, for example, during the winter of 1976-77

90% of all Nipher measurements were 1.5 mm less and even in the snowier winter of 1977- (up until mid-January) 60% of the observa- ns were less than this value. For both iods the retention loss equalled 15% of the sured Nipher total.

A more difficult problem to assess Prairie or Arctic regions is the large number observations of trace amounts of snowfall. race is a water equivalent total less than) mm (before 1978, less than 0.12 mm). The e may be a very small amount of water which est would wet the collector, or it may be significant (especially if retention losses included), but less than 0.20 mm. Trace unts are not given an absolute value by the spheric Environment Service.

Jackson (1960) and Adams et al. 66) argued that if the observations were made y 24 hours instead of every six, as is the ent procedure at synoptic stations, many these traces would be included as measureable nts. Jackson (1960), in discussing snowfall urements in Northern Canada, suggested that night assume that two traces were equivalent .25 mm. Even if this value were too high, howed that traces of snowfall were too rtant to be ignored in areas where absolute ls are small. Goodison (1977a), in applying ections to Nipher gauge measurements at Lake, assigned a value of 0.07 mm to each e observation. This value was half the ntion coefficient, reasoned to be a con- ative mean value of the possible range in the trace amount. Four observations of trace day would result in a corrected daily total .28 mm. This is in line with the argument dams et al. (1966) that in such instances a ureable total would probably be recorded by Nipher gauge if it were changed only once day. No wind speed correction was applied his value. Field data are currently being ected and analyzed for Resolute, N.W.T. to ine in more detail the quantification of e amounts.

During the last two winter seasons th Regina and Resolute, over 80% of all rvations of precipitation were trace amounts. Regina, during the dry 1976-77 winter, by ing each trace an amount of 0.07 mm, the ured Nipher water equivalent would have increased 39%. For 1977-78, up until mid- ary, the measured total would be increased Exclusive of any consideration of the ct of wind, it is evident that correction retention losses and trace amounts is ired for the non-recording MSC Nipher shielded gauges.

IMPLICATIONS AND ALTERNATIVES

Before demonstrating the applica- of the above corrections, it would be ficial to reflect on the implication of the lts, especially in relation to possible rnative methods of snow measurements. The lts summarized in Figure 2 and discussed above cate that each gauge tested requires unique ection procedures to determine actual pre- tation for that site. It is necessary there- that users of Canadian snow gauge data make themselves aware of the type of gauge used, the shielding and the local site conditions before appropriate adjustments of the data are made. For example, if the gauges are well sheltered, so that the influence of wind is minimized, correction of gauge data may not be necessary. Conversely, if gauges are located at open or partially sheltered sites, wind speed data will be necessary to implement the correction procedures. Currently, especially in basin research, this information may not be readily available for periods of snowfall. It may be necessary to estimate gauge height wind speed from 10 m tower data or for periods other than the period of snowfall. Goodison (1977a) found that because of the form of the Nipher correction curve when mean storm wind speeds were less than 6-7 ms^{-1}, daily mean wind speed in lieu of storm wind speed could be used to correct Nipher gauge data. At synoptic stations, 10 m tower data reduced to gauge height and averaged over corresponding six hour observation intervals can provide a reasonable wind speed estimate. At higher wind speeds and for other types of gauges where gauge catch decreases rapidly with increasing wind speed, even a small difference in the estimated speed compared to the measured speed could result in a significant variation in the estimated total. If accurate snowfall data are required, then the appropriate wind speed measurement should be made at each site.

Although the Nipher gauge has a superior catch efficiency compared to the other gauges, it must be attended daily by an observer. Conversely, an Alter shielded Fischer and Porter gauge has a relatively poor catch efficiency for snowfall, but it is more suited for use in research and experimental basins or at long-term remote observing stations. In a low snowfall plains environment, even if wind speed is measured, the 2.5 mm resolution and poor catch efficiency of the Fischer and Porter gauge make correction of the measurements difficult since individual snowfall events may not be identifiable. In essence the same problem exists for storage gauges. They are generally installed to record seasonal totals; there is no record of individual events. Thus, it would not be possible to correct the measured catch on a storm by storm basis.

The application and utility of the proposed correction procedures must be viewed in relation to current alternative measurements. In Prairie and Arctic regions where seasonal accumulations are of primary interest, snow surveys at peak snow accumulation are carried out. They are a standard against which accumulated snowfall is commonly compared. Surveys designed to represent local landscape variations (e.g. Steppuhn, 1976; Goodison, 1977a; Woo & Marsh, 1977), will provide an accurate estimate of basin snowcover. The question is whether corrected precipitation measurements are comparable with mean basin snow cover calculated from such detailed surveys. If actual variations by landscape are not required, corrected gauge data might prove a useful alternative to the snow surveys.

Another alternative method of measurement involves the use of artificial shields to protect storage or recording gauges and improve the accuracy of snowfall measurement. Artificial shields are currently being tested by the Atmospheric

Environment Service. In Particular, Wyoming shielded gauges are currently installed at selected stations in Canada, including Resolute and Regina. In these installations a shielded precipitation gauge is placed in the centre of two concentric rings of 50% porosity snow fence with the outer ring having a diameter of 6 metres and the inner ring a diameter of 3 m. The inner fence is inclined at 45° from the horizontal, the outer one at 60° to deflect the air flow down and under the gauge. Rechard et al. (1974) reported that on the average, a Wyoming shielded gauge will measure an amount to ± 10% of a gauge measurement from a small forest opening. Different versions of the basic design are being tested as well as different gauge configurations within the Wyoming shield. These are large structures and they cannot realistically be installed for each winter's observations.

As pointed out, the accuracy of these installations can only be evaluated after the assessment of standard installations. The implementation and utilization of artificial shields will only really be of benefit if they provide accurate measurements which require no correction for wind or other environmental factors.

4. APPLICATION AND COMPARABILITY OF GAUGE CORRECTIONS

4.1. Cold Creek Basin, Ontario

Initial testing of the gauge catch corrections was carried out for seasonal precipitation data measured at the Cold Creek Hydrometeorological Station. Table 1 compares the monthly uncorrected and corrected precipitation totals for the Nipher gauge and Alter shielded Universal gauge.

Table 1. Comparison of MSC Nipher Shielded Snow Gauge and Alter Shielded Universal Gauge Measurements, Cold Creek, 1974-1975 and 1975-1976

Month	Nipher			Universal	
	U (mm)	C^a (mm)	T^b (mm)	U (mm)	C^c (mm)
			1974-1975		
Nov.	5.3	5.6	60.0	53.7	59.3
Dec.	26.4	27.2	42.8	33.0	40.2
Jan.	16.1	16.7	50.9	42.3	49.7
Feb.	27.7	27.9	75.1	66.8	74.6
Mar.	27.4	29.6	61.1	42.2	58.2
			1975-1976		
Nov.	9.4	11.4	14.4	7.4	14.7
Dec.	45.0	46.2	62.0	44.7	64.1
Jan.	44.7	47.6	59.0	35.1	57.0
Feb.	19.1	19.0	65.2	52.1	65.1
Mar.	56.7	55.3	113.2	98.3	116.3

Notes:
a - corrected snowfall total.
b - MSC Nipher and MSC standard rain gauge total
c - measured rain, snow and mixed precipitation corrected for storm wind speed.

In 1974-1975 the Universal guage measured 81.5% of the corrected Nipher snow gauge and standard rain gauge total: the corrected Universal total was 96.6%. For only snow events, the Universal measured 66.7% of the corrected Nipher total while the corrected value was 95.5%. For 1975-1976, when there was significantly more snowfall, the Universal to Nipher ratio for total precipitation increased from 0.76 to 1.01 after correction of the measured totals: for only snowfall events the catch of the Universal gauge increased from 63% to 98%. The results demonstrated that corrected winter precipitation totals for the Nipher and Universal gauges for any selected time period were comparable, i.e. within ± 5% (Goodison, 1977a).

A more rigorous approach is to assess the comparability of net accumulated precipitation (precipitation less snowmelt and evaporation) and basin snow cover measurements. Goodison (1977a) provides complete details on the calculation of snowmelt and evaporation losses during the snow accumulation period for the Cold Creek basin. Adequate estimates of snow evaporation were provided using the empirical formula of Williams (1958) which requires daily mean temperature, vapour pressure, and wind speed. Snowmelt losses were measured by a snowmelt index plot. For short melt events during the accumulation period snowmelt plot losses compared favourably with the loss calculated using a degree day factor of 0.91 mm/day based on the daily maximum temperature.

Standard snow courses, which could be measured regularly, provided the snow cover data for the basin; however, the snow course network was specifically designed to sample all land use types. Goodison (1977a) demonstrates that by having snow course measurements from each category, regular, comparable and repeatable measurements can be obtained throughout the winter: by weighting the observations in proportion to basin land use, absolute basin snow cover water equivalent can be calculated. The rationale for the system is similar to that presented by Steppuhn and Dyck (1974) for sampling Prairie and Arctic snowpacks, except specific snow courses are required for repeated winter measurements.

The measured and calculated accumulation from the beginning of snow cover to peak accumulation was assessed for several years. Tables 2 and 3 and Figure 3 summarize results for the 1971-1972, 1973-1974 and 1975-1976 accumulation periods. In 1971-1972 and 1973-1974 the Nipher gauge measurements were corrected using mean daily wind speed measured at gauge height. Precipitation estimated from ruler measurements are included for comparison. Mean basin snow cover, proportionately weighted for land use was calculated from snow course measurements at the end of each survey period. During both accumulation periods calculated mass balance using Nipher gauge data was comparable with that computed from a land use stratified system of snow course measurements.

Figure 3 summarizes the 1975-1976 results on a daily basis and for four different estimates of precipitation. The corrected Nipher and Universal gauge data are comparble with the snow cover estimate, except on the date of the

Table 2. Measured and Calculated Snowpack Mass Balance, Cold Creek, Basin, 1971-1972.

Period	P (mm)	E (mm)	M (mm)	R (mm)	ΔS (mm)	Net Accumulation at end of period[a] (mm)	Snow Survey at End of Period[b] Mean (mm)	Maximum (mm)	Minimum (mm)
Dec 29, 1971– Jan 8, 1972	42.47/0.00	3.62	5.57	M	33.28	33.3 (20.5)	37.9±2.3	44.8±3.5(LG)	28.6±4.0(B)
Jan 8, 1972– Jan 27, 1972	19.43/10.92	8.20	23.22	1.97	-1.07	32.2 (19.1)	35.7±4.1	43.2±5.5(LG)	23.9±8.4(B)
Jan 27, 1972– Feb 9, 1972	25.44/0.00	3.05	0.00	0.00	22.39	54.6 (45.0)	56.9±5.1	72.3±12.2(LG)	42.0±6.2(P)
Feb 9, 1972– Feb 28, 1972	34.18/0.00	6.38	7.13	0.00	21.69	76.3 (62.7)	78.7±5.1	96.6±10.5(LG)	54.1±7.1(P)
Feb 28, 1972– Mar 10, 1972	29.44/7.87	3.50	9.87	0.31	23.84	100.1 (80.6)	103.8±4.2	128.5±8.7(LG)	80.7±5.7(P)
Mar 10, 1972– Mar 27, 1972	31.41/21.08	8.16	14.54	8.01	29.79	129.9 (109.0)	131.6±7.8	163.0±16.8(LG)	91.7±16.5(P)

NOTES:
P — Precipitation (Snow/Rain)
E — Evaporation/Sublimation
M — Snowmelt (degree day calculation)
ΔS — P-E-M
R — East Tributary stream runoff, less base flow
a — Accumulated ΔS (total using ruler measurement for precipitation given in brackets)
b — Snow survey measurement weighted for land use. Basin mean value and mean maximum and minimum by land use type. Error limit is at the .1 level. LG — long grass; B — bush; P — ploughed.

Table 3. Measured and Calculated Snowpack Mass Balance, Cold Creek, Basin, 1973-1974

Period	P (mm)	E (mm)	M (mm)	R (mm)	ΔS (mm)	Net Accumulation at end of period[a] (mm)	Snow Survey at End of Period[b] Mean (mm)	Maximum (mm)	Minimum (mm)
Dec 9, 1973– Dec 22, 1973	38.82/0.00	1.21	.45	M	37.16	37.2 (44.6)	38.8±4.4	40.5±8.8(LG)	33.7±9.0(P)
Dec 22, 1973– Dec 30, 1973	8.85/20.83	.01	29.43	M	-1.75	35.5 (44.3)	34.8±4.7	41.1±6.2(LG)	28.0±8.5(P)
Dec 30, 1973– Jan 12, 1974	21.86/0.00	.73	0.00	M	21.13	56.6 (73.8)	52.7±5.8	63.2±7.7(LG)	40.3±11.9(P)
Jan 12, 1974– Jan 26, 1974	7.33/23.11	-.22	22.81	M	8.35	65.0 (80.0)	66.0±4.8	80.0±7.1(LG)	53.0±7.5(P)

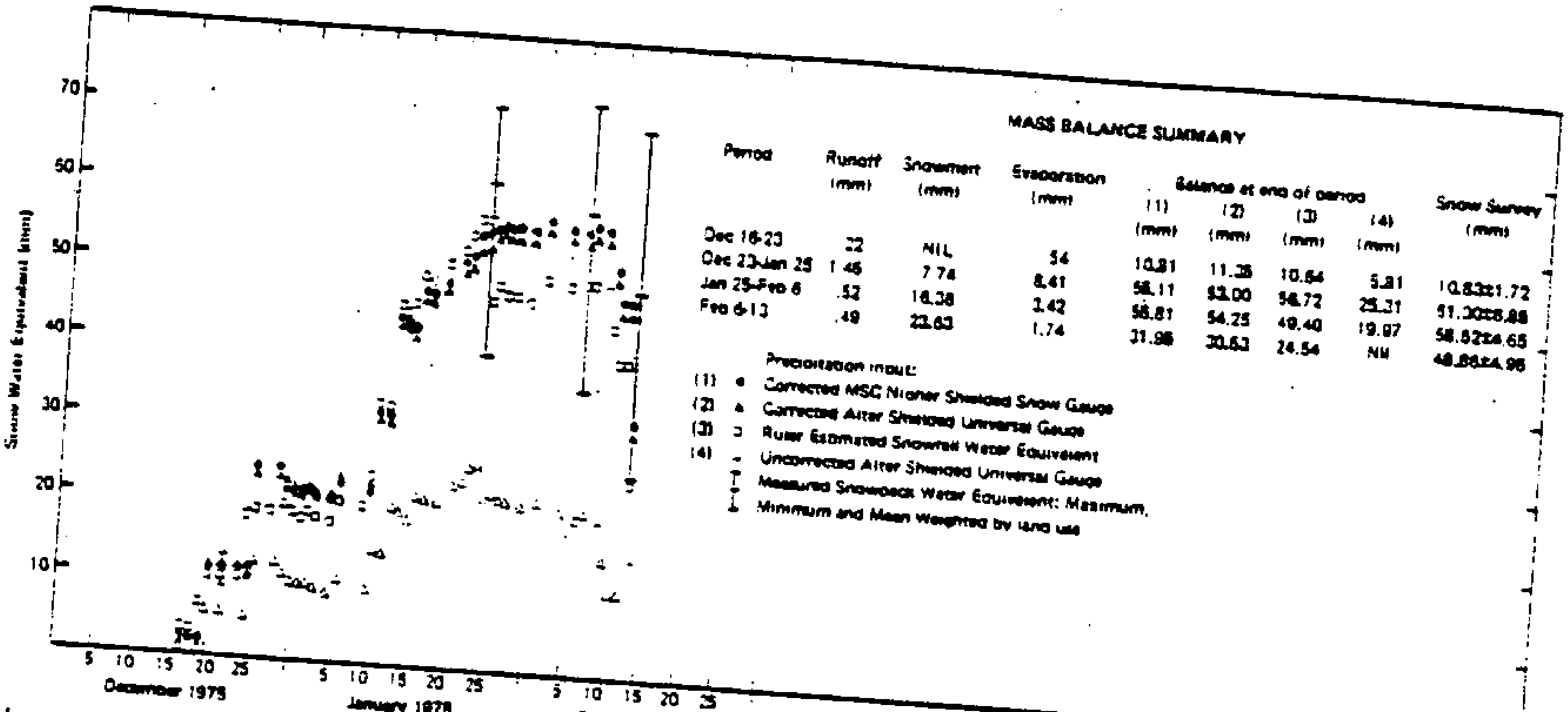
NOTES:
P — Precipitation (Snow/Rain)
E — Evaporation/Sublimation
M — Snowmelt runoff measured by snowmelt index plot (includes rainfall runoff, if any)
ΔS — P-E-M
R — East Tributary stream runoff, less base flow
a — Accumulated ΔS (total using ruler measurement for precipitation given in brackets)
b — Snow survey measurement weighted for land use. Basin mean value and mean maximum and minimum by land use type. Error limit is at the .1 level. LG-long grass; P-ploughed.

the final survey. This is because the snowmelt plot recorded a large snowmelt loss on February 13, but the snow courses had not yet shown a decrease in snowpack water equivalent. This was the beginning of the major ablation period of the season. The inaccuracy and non-comparability of uncorrected Universal gauge data with snow survey measurements is clearly shown. In fact, the daily mass balance calculated using uncorrected Universal gauge data is even less than the mean measured snowpack water equivalent for the land use with the minimum snow cover.

Goodison (1977a) demonstrated that with appropriate adjustments, it is possible to achieve comparable snowfall and snowpack water equivalent measurements in Southern Ontario. One of the adjustments in the correction of precipitation gauge data. The question is whether the gauge correction procedures outlined above, and particularly those for the Nipher gauge, are as useful in other snowfall regions.

2. Knob Lake, Quebec

Adams and Findlay (1966) reported that the MSC Nipher shielded snow gauge undermeasured the true snowfall as defined by detailed basin surveys. A detailed watershed snow survey, weighted for cover types and adjusted for a survey over the basin lakes, indicated the 1964-1965 accumulated winter snowfall was about 23% greater than that measured by the MSC Nipher shielded snow gauge. The undermeasurement of snowfall precipitation was much greater than found for the Cold Creek basin.



MASS BALANCE SUMMARY

Period	Runoff (mm)	Snowmelt (mm)	Evaporation (mm)	Balance at end of period (1) (mm)	(2) (mm)	(3) (mm)	(4) (mm)	Snow Survey (mm)
Dec 16-23	.22	NIL	.54	10.81	11.35	10.64	5.81	10.83±1.72
Dec 23-Jan 25	1.46	7.74	8.41	58.11	53.00	58.72	25.31	51.30±6.88
Jan 25-Feb 6	.52	16.38	3.42	58.81	54.25	49.40	19.97	58.82±4.65
Feb 6-13	.49	22.63	1.74	31.96	30.63	24.54	NM	48.86±4.96

Precipitation input:
(1) ● Corrected MSC Nipher Shielded Snow Gauge
(2) ▲ Corrected Alter Shielded Universal Gauge
(3) ⊃ Ruler Estimated Snowfall Water Equivalent
(4) - Uncorrected Alter Shielded Universal Gauge
Ⅰ Measured Snowpack Water Equivalent: Maximum, Minimum and Mean Weighted by land use

Figure 3. Comparison of Measured and Calculated Snow Cover Water Equivalent, Cold Creek Basin, 1975-1976.

Precipitation observations were made every six hours. For each period when a measurable amount of precipitation was recorded, the mean wind speed was determined from 10.6 m tower data. Examination of wind profile data during snowfalls indicated that the measured tower wind speed should be reduced by 20% to approximate the mean speed at gauge height. The Nipher gauge data was corrected using the procedures outlined previously.

The results of the analysis and a comparison with the Knob Lake watershed surveys are given in Table 4. The correction for trace observations is given separately, and with 325 observations it alone accounts for an 11% increase in measured precipitation. Again it appears that corrected Nipher gauge data can provide an improved measure of actual snowfall.

4.3. Resolute, N.W.T.

The undermeasurement of snowfall in the Canadian Arctic has been a concern of many researchers. The need to have accurate measurements of snowfall and snow on the ground has become more evident with increased economic development in the north. Woo and Marsh (1977) argued that official Atmospheric Environment Service snowfall measurements at Resolute were in serious error. Extensive basin surveys in the area indicated nearly twice as much snow on the ground in May as compared to accumulated winter snowfall measured by the Nipher gauge at Resolute.

To compare with the results of Woo and Marsh (1977), the Nipher gauge measurements were corrected for the winters of 1975-1976 and 1976-1977 using the same procedure as for Knob Lake. The results are summarized in Table 5.

The corrected totals for both years are generally within the errors limits of the basin surveys which were carried out prior to spring snowmelt. The net effect of evaporation-condensation during the winter has not been evaluated. One problem is the large number of trace observations which account for over 40 mm of the increase in the corrected Nipher measurement for each year. Although the correction procedure used provided comparable results, it would be advantageous to confirm the mean value assigned to trace amounts.

Table 4. Corrected Precipitation Totals, Knob Lake, October 20, 1964-March 18, 1965

Date	Measured Nipher (mm)	Nipher Corr. For Wind Speed and Retention (mm)	(% change)	Corr. Snowfall Totals Incl. Trace Amounts (mm)	(% change)
Oct.20-Oct.31	20.83	25.15	+21.0	27.18	+30.5
Nov. 1-Nov.30	64.52	67.56	+4.7	77.98	+20.9
Dec. 1-Dec.31	56.64	63.75	+12.6	68.33	+20.6
Jan. 1-Jan.31	38.61	50.29	+30.3	54.36	+40.8
Feb. 1-Feb.28	52.58	64.26	+22.2	68.33	+30.0
Mar. 1-Mar.18	3.81	5.08	+33.3	7.87	+106.7
Total	236.99	276.09	+16.5	304.05	+ 28.3

Snow Survey Results[a]

Knob Lake Watershed Survey (arithmetic mean)	309.38 mm
Knob Lake Watershed Survey - weighted for cover types	279.40 mm
Knob Lake Watershed Survey - adjusted for white ice and lake snow survey[b]	292.61 mm
Snowcourse close to Laboratory	289.56 mm

Note: a - after Adams et al., 1966.
b - best value for snow actually presented in watershed.

Table 5. Corrected Precipitation Totals, Resolute, N.W.T.

Years	Nipher Measured (mm)	Nipher Corrected (mm)	Basin Snow Surveys* (mm)
1975-1976	63.0	129.3	120 ± 15
1976-1977	31.0	79.4	93 ± 15

* after Woo & Marsh (1977) - a mean of snow storage and probable error for 4 basins.

In the fall of 1977 a Wyoming shielded Universal gauge was installed at Resolute. The "Arctic version" used lightweight nylon snowfencing and there was no Alter shield. Tests at the Woodbridge Research Station have shown no difference between this design and the standard snowfence shield surrounding an Alter shielded gauge. Preliminary results of the Resolute data are summarized in Table 6. Complete wind data are not yet available, so the Nipher is not corrected for wind speed. However, the corrections for retention loss and trace amounts for each month are given.

Table 6. Preliminary Wyoming and Nipher Gauge Measurements, Resolute, 1977.

Dates	Measured (mm)	Nipher Retention (mm)	Trace (mm)	Wyoming Shield (mm)
Sept.	52.9^a	3.6	4.7	47.2
Oct.	20.2	2.6	5.5	20.5
Nov.	1.3	0.5	5.6	7.5
Dec.	2.5	1.5	6.9	10.4

Notes: a including rain of 16.0 mm.

For storms with measured snowfall greater than 2 mm, the Nipher total was 46.1 mm and the Wyoming recorded 30.5 mm. During all large storms the Nipher measured more than the Wyoming. However, in November and December when repeated observations of trace amounts were being recorded every six hours for the Nipher, the Wyoming shielded Universal gauge was accumulating these small amounts resulting in a monthly total greater than the measured Nipher. Since trace amounts are assigned no absolute value, the current procedure of "measuring" the contents of the Nipher gauge every six hours can be a severe detriment to obtaining accurate measurements in a low-snowfall region. A more complete evaluation of the Wyoming data is required to quantify trace amounts, but initial observations give a value of 0.066 mm per trace. Special observation will continue at Resolute for at least one more season.

Regina, Saskatchewan

As noted previously, a research requirement for the Prairie region is argued to be the more accurate measurement of snowfall, particularly through the development of new gauge types or shields. However, this step cannot rationally proceed without assessing the accuracy of the current methods and correction procedures outlined in this paper.

Table 7. Accumulated Precipitation (mm) Regina Airport.

Date	MSC Nipher (1)^a	(2)^b	(3)^c	(4)^d	Regina A Snow Course
			1976-1977		
01/12	4.5	6.8	9.1	0.0	-
15/12	12.9	18.1	21.9	12.3	9.1
01/01	20.0	30.5	36.4	27.3	28.7
15/01	26.6	39.4	47.8	38.7	39.7
01/02	27.7	41.1	50.9	41.3	38.4
15/02	27.7	41.1	51.5	42.4	24.4
01/03	27.7	41.1	52.2	43.1	-
15/03	28.0	41.5	52.5	43.4	-
15/03^f	Wyoming shielded Sacramento storage gauge: 30.5 mm.				
15/03^f	Alter shielded Sacramento storage gauge: 17.3 mm.				
			1977-1978		
01/12	10.3	13.1	15.1	14.9	-
15/12	20.7	28.4	33.0	32.3	-
01/01	36.5	44.3	52.3	52.6	42.9
17/01	42.9	53.0	63.9	63.7	62.0
17/01^f	Wyoming shielded Sacramento storage gauge: 39.6 mm^e.				
17/01^f	Alter shielded Sacramento storage gauge: 32.0 mm^e.				

Notes:
- a - Measured
- b - Corrected for wind speed and retention loss
- c - Corrected including traces
- d - Corrected accumulation from date of complete snow cover
- e - Includes 9.4 mm rain from October and November
- f - Data courtesy of H.F. Cork, Prairie Hydrometeorologist, AES, Regina

Table 7 summarizes precipitation and snow survey measurements at Regina Airport for the last two seasons. During the dry winter of 1976-1977, when many small snowfall events were recorded, the Wyoming shielded Sacramento gauge recorded a higher precipitation total than the Nipher snow gauge. The Nipher gauge data were corrected using a similar procedure as for Knob Lake. After correction its total nearly doubled. The accumulated Nipher total from the date of complete snow cover until peak accumulation now provides reasonable agreement with the Regina Airport snow course measurement. Similar agreement between the corrected Nipher and snow course data are obtained for 1977-1978. However, there is a considerable difference between the measured Wyoming and Nipher totals, with the Nipher exhibiting a higher measured catch. This result is similar to that found at Resolute. When there are many small snowfall events, the Wyoming shielded gauge recorded a higher total than the Nipher. For larger snowfall events the opposite is true. It appears that corrected Nipher data are more comparable with snow cover statistics than are Wyoming shielded gauge data. The Wyoming shield does, however, improve gauge catch over an Alter shielded recording or storage gauge.

The applicability of Wyoming gauge

and corrected Nipher gauge data is best evaluated by those who require accurate snowfall statistics. Do the corrected Nipher measurements provide realistic snowfall totals? Unlike at Cold Creek, snowmelt and net evaporation losses are not included in the analysis. Up to peak accumulation, would the inclusion of these parameters significantly change the comparability of the result? Is the Regina snow course representative of local snow cover? Is it in fact realistic to expect to achieve comparable snowfall and snowpack statistics using a mass balance approach such as used for Cold Creek? Answers to these questions will help determine whether correcting current gauge data is a feasible approach to take in this region. To this end it would also be desirable to test the correction procedures on Universal or Fischer and Porter gauges in the area since these recording gauges are useful when daily observations are not feasible. However, storage gauge data cannot be corrected for undercatch and their use is best restricted to well sheltered sites.

5. SUMMARY

What are the immediate needs of the hydrologist with respect to snowfall data? Do the correction procedures discussed in this paper provide the accurate snowfall data which he apparently requires? This is a very fundamental question which must be answered before further research is carried out on the development of new gauge types or gauge shields.

It has been shown that to obtain comparable precipitation statistics, corrections are necessary. The emphasis in this paper has been on the correction of Nipher shielded snow gauge data since it is the Canadian standard gauge for snowfall measurement. However, other gauges are employed throughout the country, particularly in regional and basin networks. Under similar environmental and site conditions these gauges will provide very different snowfall water equivalent totals. Before effective areal analyses can be performed, the measured data must be made comparable. Otherwise, artificial discontinuities in the areal distribution will result. This is certainly a fact which must be considered if one is comparing gauge data from the United States (Universal gauge) and Canada (Nipher gauge) for international drainage basins.

There is presently a strong emphasis on the continued development and refinement of streamflow forecasting techniques. In many cases this involves the use of complex hydrologic models. The results presented in this paper for various regions of Canada indicate that successful modelling of the snow accumulation phase using precipitation gauge data can be successful only if corrected snowfall data are used in the model. The development of accurate and physically meaningful hydrologic models requires accurate and comparable input data. The use of indices and optimized parameters only limits the transposability of the model to other basins even within the same region.

There will continue to be research by various agencies aimed at improving our methods of snow measurement. There will always be the hope of developing the perfect gauge for measuring snowfall. In reality, however, such a development is likely many years away. In fact it may be asked whether we need a new gauge design or just a modification of our observing procedures? Can the gauge catch correction procedures discussed in this paper meet the needs of Canadian hydrologists? That question can only be properly answered when the hydrologists' requirements are clearly stated. Then, can research programs be planned to respond to those needs.

Acknowledgments

The author is most grateful to Michael Malone and John Metcalfe for their personal initiative, interest and capable support in all phases of the snowfall-snowpack program.

References

Adams, W.P. and B.F. Findlay, 1966: Snow measurements in the vicinity of Knob Lake, central Labrador-Ungava. *Hydrological Studies in Labrador-Ungava*, McGill Sub-Arctic Research Paper No. 22, McGill University, 96-113.

Adams, W.P., W.R. Cowan, F.F. Findlay, J.S. Gardner and R.J. Rogerson, 1966: Snowfall and snow cover at Knob Lake, central Labrador-Ungava. *Hydrological Studies in Labrador-Ungava*, McGill Sub-Arctic Research Paper No. 22, McGill University, 114-140.

den Hartog, G. and H.L. Ferguson, 1975: National water balance maps of evapotranspiration and precipitation. *Proceedings, Canadian Hydrology Symposium - 75*, Winnipeg, August 11-14, 1975, 511-525.

Dyck, G.E., 1969: *Comparison of Snow Measurements.* B.Sc. Thesis, University of Saskatchewan, 41 pp.

Ferguson, H.L. and D.M. Pollock, 1971: Estimating snowpack accumulation for runoff prediction. *Runoff from Snow and Ice*, 8th Canadian Hydrology Symposium, 7-28.

Findlay, B.F., 1969: Precipitation in Northern Quebec and Labrador: An evaluation of measurement techniques. *Arctic*, 22, 140-150.

Goodison, B.E., 1975: Snow studies at Cold Creek: testing and evaluation of gauges used in Canada for fresh snowfall measurement. *Proceedings, Canadian Hydrology Symposium - 75*, Winnipeg, Aug. 11-14, 1975, 26-35.

Goodison, B.E., 1977a: *Snowfall and Snow Cover in Southern Ontario: Principles and Techniques of Assessment.* Ph.D. thesis, University of Toronto, 403 pp.

Goodison, B.E., 1977b: Accuracy of Canadian snow gauge measurements. *Proceedings, Second Conference on Hydrometeorology*, AMS, Toronto, October 25-27, 1977, 220-224.

Hare, F.K. and J.E. Hay, 1971: Anomalies in the large-scale annual water balance over northern North America. *Canadian Geographer*, 15, 79-94.

Harris, R.E. and A.C. Carder, 1974: Rain and snow gauge comparisons. *Can. J. of Earth Sciences*, 11, 557-564.

Jackson, C.I., 1960: Snowfall measurements in northern Canada. *Quart. J. Roy. Met. Soc.*, 86, No. 368, 273-275.

Prairie Provinces Water Board, 1977: Streamflow Forecasting Study: Research Requirements. Report of the Committee on Hydrology, 87-90.

Rechard, P.A., R.E. Brewer and A. Sullivan, 1974: Measuring snowfall, a critical factor for snow resource management. *Advanced Concepts and Techniques in the Study of Snow and Ice Resources.* U.S. Nat. Acad. Sci., Washington, 706-715.

Steppuhn, H., 1976: Areal water equivalents for prairie snowcover by centralized sampling. *Proc. West. SnowConf.*, 44, 63-68.

Steppuhn, H. and G.E. Dyck, 1974: Estimating true basin snowcover. *Advanced Concepts and Techniques in the Study of Snow and Ice Resources.* U.S. Nat. Acad. Sci., Washington, 314-324.

Williams, G.P., 1958: Evaporation from snow covers in Eastern Canada. *Proc. East. Snow Conf.*, 15, 18-30.

Woo, M. and P. Marsh, 1977: Error analysis in the determination of snow storage for a small high Arctic basin. Proceedings, *Second Conference on Hydrometeorology*, AMS, Toronto, Ontario, October 25-27, 1977, 239-244.

Proc Eastern Snow Conference, 1978

ACCURACY OF SNOW SAMPLERS FOR MEASURING SHALLOW SNOWPACKS: AN UPDATE

B.E. Goodison

Atmospheric Environment Service
Downsview, Ontario

ABSTRACT

The accuracy of various snow samplers and their consistency in sampling shallow, variable, ice-layered snowpacks are assessed. Samplers evaluated included the Federal, Bowman, McCall, Canadian MSC and Adirondack. The tests were conducted on 1.25 m x 2.50 m control plots at selected sites in Southern Ontario. Results confirm the tendency for most samplers to overmeasure by up to 10%. Ice lenses and layers in the snowpack increase the variability of the results. The McCall and Adirondack samplers consistently provided the most accurate measurements. Comments on the samplers' individual performance, on the correction of snow tube data, and on the continuing effort to develop a universal snow sampler are included.

INTRODUCTION

The snow sampler is the basic instrument of all agencies involved in snowpack measurement, but a universal or standard sampler is not available. The basic snow sampler consists simply of a graduated tube with a cutter fixed on the lower end, to provide easier penetration of the snowpack, and a spring balance to weigh the tube and its contents. Large diameter samplers (cutter area approximately 40 cm^2) are a single tube for use in shallow snowpacks; smaller diameter tubes (cutter area approximately 11 cm^2) are in sections for easier portability and are used in deeper snowpacks. Accessories include a driving wrench or turning handle, weighing cradle, and spanner wrenches for uncoupling sections of tube.

Work et al. (1965) and Freeman (1965) reported on tests carried out to assess the accuracy of snow samplers and accessories used in deep mountain snowpacks (greater than 250 mm snow water equivalent). They found that most snow samplers overmeasured true snow water equivalent. They also found that the relative errors caused by inner cutter point diameter, individual scale accuracy through normal field temperature ranges, and scale reading errors associated with different observers were small. The most important factor in determining the absolute accuracy of a sampler was felt to be its ability to cut and hold an accurate snow core.

These tests focused on the small diameter samplers and on their performance in deep snowpacks. There is a need, however, to assess the variety of snow samplers used by agencies for sampling shallow snowpacks. In 1974, the Hydrometeorology Research Division of the Atmospheric Environment Service initiated a study to assess the accuracy and general performance of snow samplers for sampling the wide variety of snowpack conditions encountered in the shallow snow covers of Eastern Canada. Large spatial and temporal variations in snowpack properties are common with ice lenses and layers creating particularly difficult sampling conditions. There was a need to assess the relative performance of different samplers under difficult sampling conditions and to determine their accuracy and consistency in sampling shallow, variable, ice-layered snowpacks.

In the past, instrument error may have been considered small, or not significant, and not a serious problem when the data were being used solely as indices of snow cover. However, today, snow sampler or snow course measurements are being used as a "base" or "standard" against which other ground based techniques (e.g. nuclear snow gauges, snow pillows) or airborne and satellite sensors (e.g. airborne gamma-ray spectrometry, active or passive microwave systems) are compared and calibrated. At the same time they still provide data used as a primary input for hydrologic models. The accuracy and comparability of the equipment must be known if snow samplers are to provide a reliable, uniform standard for comparison with other techniques. In addition, if a "universal" sampler is to be developed for use throughout North America, the performance of present equipment must first be known.

EXPERIMENTAL METHOD

The samplers tested were: Canadian MSC, Federal, Federal L-S (8 tooth cutter), Bowman, Adirondack, and McCall. During the 1977-1978 winter two metric cutters (area 10 cm^2) were tested, one being 2.54 cm long, the other 5.1 cm long. The physical characteristics of the basic samplers tested are summarized in Table 1. Figure 1a and 1b illustrate the variety of cutters and tubes tested. In Canada, the MSC sampler was developed specifically for use in shallow snowpacks, and it was recommended by the Atmospheric Environment Service for use in regions where snowpack accumulation is less than one metre (Bindon, 1964). In the Eastern United States the Adirondack sampler is commonly used. Both of these samplers are "large" diameter samplers. All the others are "small" diameter tubes, with the primary difference between each of these being the type of cutter.

TABLE 1

SNOW SAMPLER CHARACTERISTICS

	Standard[a] Federal	Federal[b] L-S	Bowman[c]	McCall[d]	Canadian MSC[e]	Adirondack[f]
Material	Aluminum	Aluminum	Plastic or Aluminum	Heavy Gauge Aluminum	Aluminum	Glass Fiber
Length of tube (cm)	76.2	76.2	76.2	76.2	109.2	153.7
Theoretical I.D. of cutter (cm)	3.772	3.772	3.772	3.772	7.051	6.744
Number of teeth	16	8	16	16	16	None-Stainless Steel Circular Cutter Edge
Depth of snow that can be sampled (cm)	>500	>500	>350	>500	100	150
Retains snow cores readily	Yes	Yes	Yes	Yes	No	No

Notes:
[a] Standard sampler used in Western United States and Canada.
[b] Identical to "standard federal" but has 8 tooth cutter.
[c] Cutter has alternate cutter and raker teeth and may be mounted on plastic or standard aluminum tubing. It is more an experimental rather than operational sampler.
[d] Used in dense snow or ice. It is a heavy gauge aluminum tube with a 3 cm cutter with straight flukes. It may be driven into the pack with a small slide drop hammer, producing an ice-pick effect.
[e] Atmospheric Environment Service large diameter sampler used in shallow snow packs.
[f] Large diameter fiberglass sampler commonly used in Eastern United States.
[g] Most snow samplers in North America use inches and tenths as their basic units of measurement. Values in this table are corresponding metric equivalents.

In assessing the samplers, the following questions were considered:

(1) how accurate is the snow sampler?

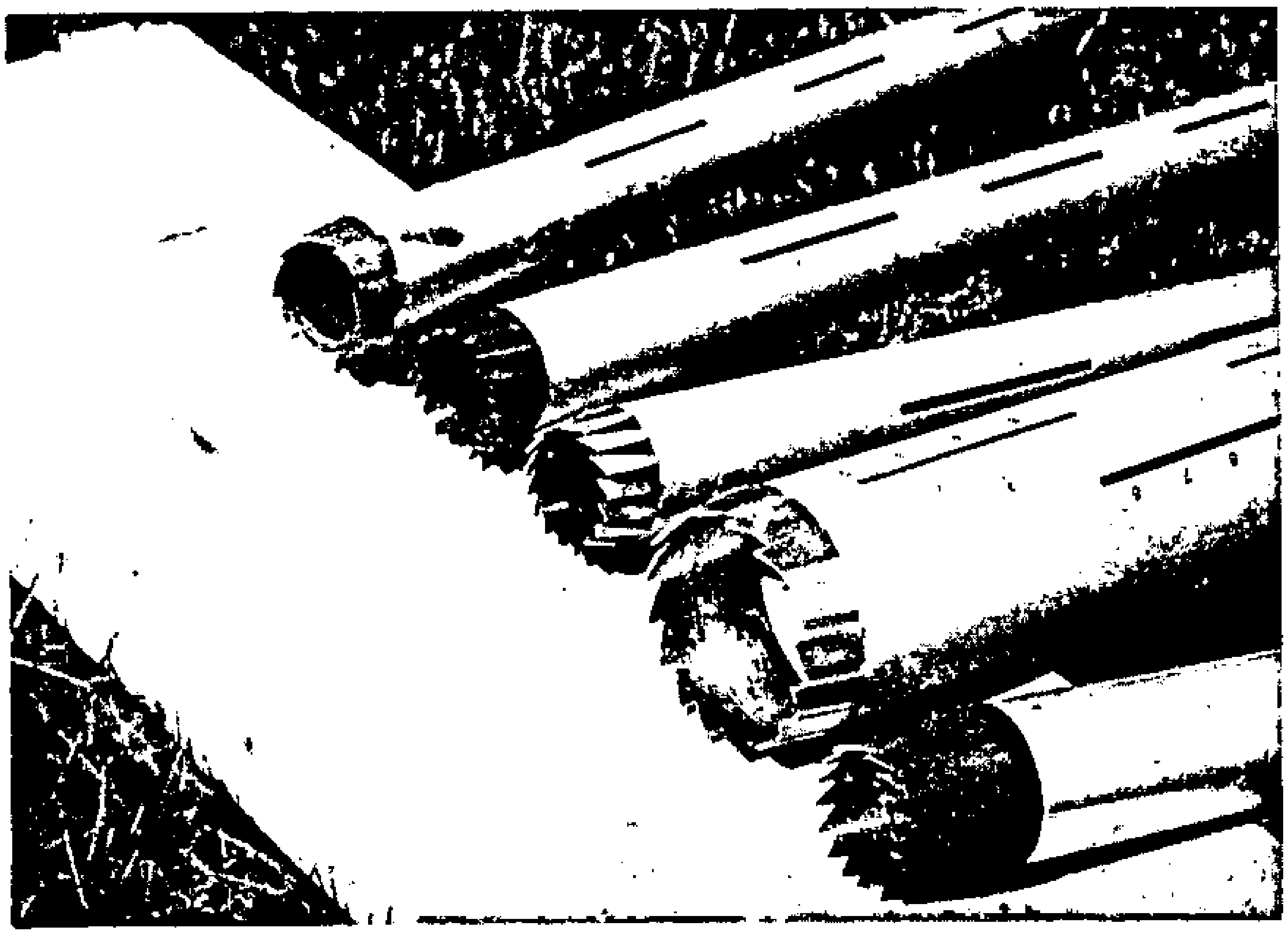


Figure 1a: Snow Cutters tested, from left to right: Federal L-S (8-tooth), Bowman, Federal, Canadian MSC, McCall.

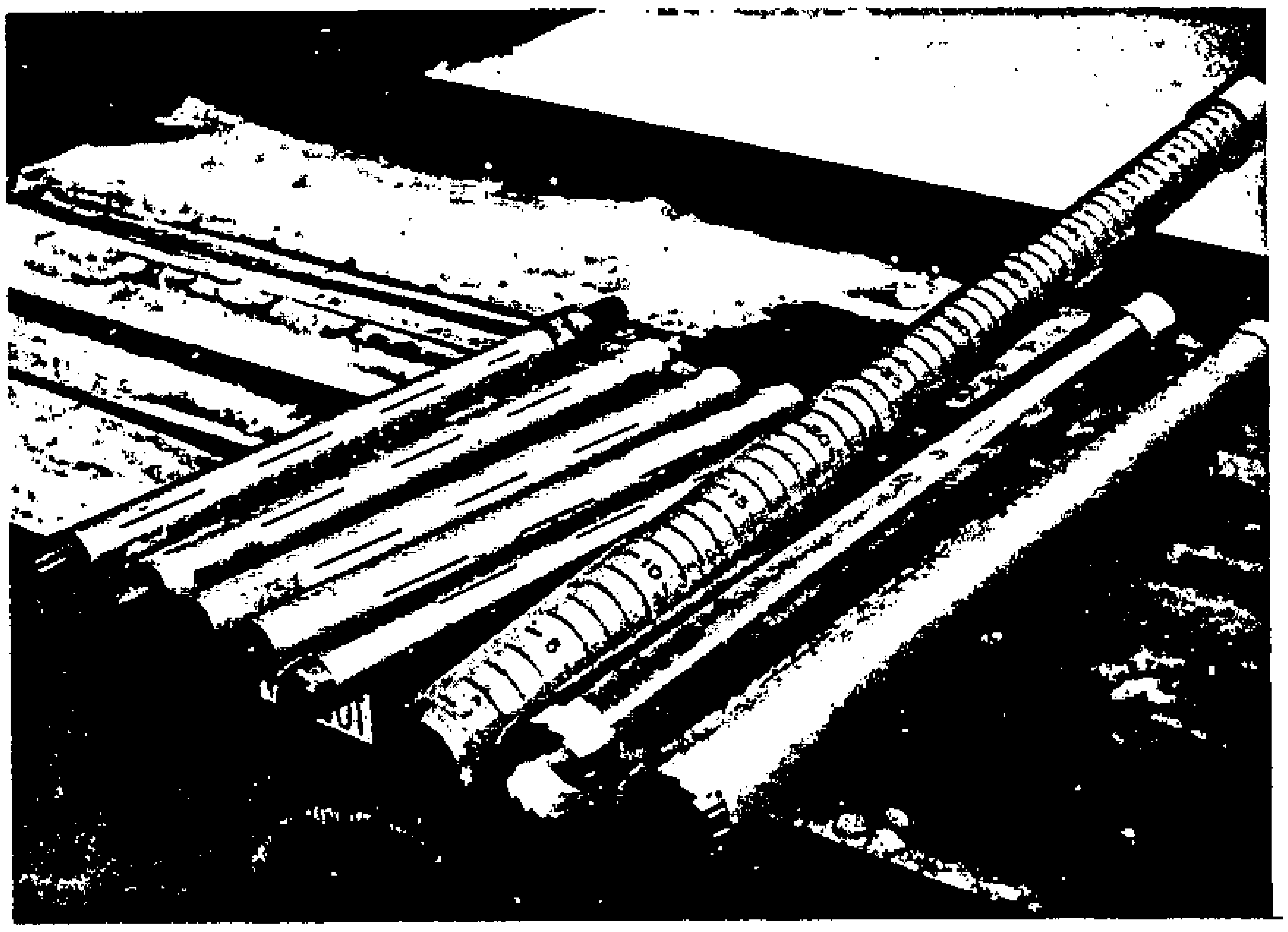


Figure 1b: Snow Samplers, from left to right: McCall, 5.1 cm metric cutter, 2.54 metric cutter, Federal, Federal L-S, Adirondack, test sampler - polycarbonate tube, Canadian MSC.

(2) are the data obtained with one type of sampler comparable with that from another?

(3) are the results significantly different from each other and from the "true" water equivalent or density at the point sampled.

To investigate the problem, the emphasis of the experiment had to be on "point" measurement in order to minimize the effect of natural spatial variability. Bray (1973) reported on the variability of depth and water equivalent which could be expected over a flat open site of only 40 m x 40 m. He found the range of coefficient of variation for depth to be from 12% - 20% and for water equivalent to be from 15% to over 30%, depending on snowpack structure. The variability was greatest when there were ice lenses in the pack or an ice layer at the surface of the ground. Similar variations in snowpack conditions existed in the Southern Ontario study area. To minimize the effect of natural snow cover variations, 1.25 m x 2.50 m control plots were established in partially sheltered locations. The size of the test plot ($3m^2$) is similar to the area around a snow survey marker on a snow cover.

Each snow plot had a 2.5 cm sheet of styrofoam as a base to ensure that a solid "plug" would be taken with each sample. This would prevent the loss of any of the snow core. In this experiment, only the Adirondack sampler (model tested had a bung cutter) had difficulty in repeatedly securing a plug, especially if ground ice layers were present. Each plot had T-bar fence posts around the edge which permitted six solid aluminum sheets to be inserted vertically down the sides of the plot to define the area to be sampled. The sides were positioned at the time of sampling.

A minimum of six regularly spaced samples were taken with each sampler; two observers shared the sampling to minimize the possibility of observer bias. The samples were bagged and then weighed on a precision gram balance indoors. After the sampling was completed, extra depth measurements were taken with a graduated rod. The snow remaining on the plot was shovelled off the styrofoam, put in large plastic bags and weighed on a precision triple beam balance (20 kg maximum; accuracy $\pm \frac{1}{2}$g). Any ice layer on the styrofoam was easily scraped off of it. The sum of this weight of snow and the weight of the samples gave the true weight of snow on the plot. Snow water equivalent and density were calculated from the measured weight and depth of snow and the area of the plot. Figure 2a and 2b illustrate the clearing of a snowplot. Plots were cleared at different times during the winter in order to sample a variety of conditions.

RESULTS OF SNOW SAMPLER COMPARISONS

Depth variations over the plots were generally small, with the mean co-efficient of variation for all tests being 5% (range: 2% - 12%). For shallow snow depths, the results indicate, however, that even over a control plot, or at a "point", the standard error can be 1%-3% of the mean depth.

Table 2 and 3 summarize the test results for water equivalent and density, respectively. Any depth sampling bias which might affect the water equivalent estimate for a particular sampler can be eliminated by analyzing the density variations. In most cases the percentage difference from true was similar for both density and water equivalent since depth variations over the plot were small. An example of depth variations affecting the results is the MSC test of 20/3/75t.

For shallow snowpacks where complete snow cores are taken, the three snow samplers most commonly used in Eastern Canada (MSC, standard Federal, Federal L-S) provided a positively biased estimate of true snow water equivalent. The MSC and standard Federal gave similar results, with a measurement error from -2% to +13%. The Federal L-S 8-tooth sampler produced the largest overmeasurement of water equivalent (+10%) with the last three tests in 1976 giving a particularly large positive bias. The Adirondack sampler measured close to the true value and excluding the significant undermeasurement of 24/2/76 the mean water equivalent was within 4% of the true plot measurement. Of the four samplers used operationally by agencies in Eastern North America, the Adirondack provided the best estimate of mean water equivalent. However, if thick ice lenses are

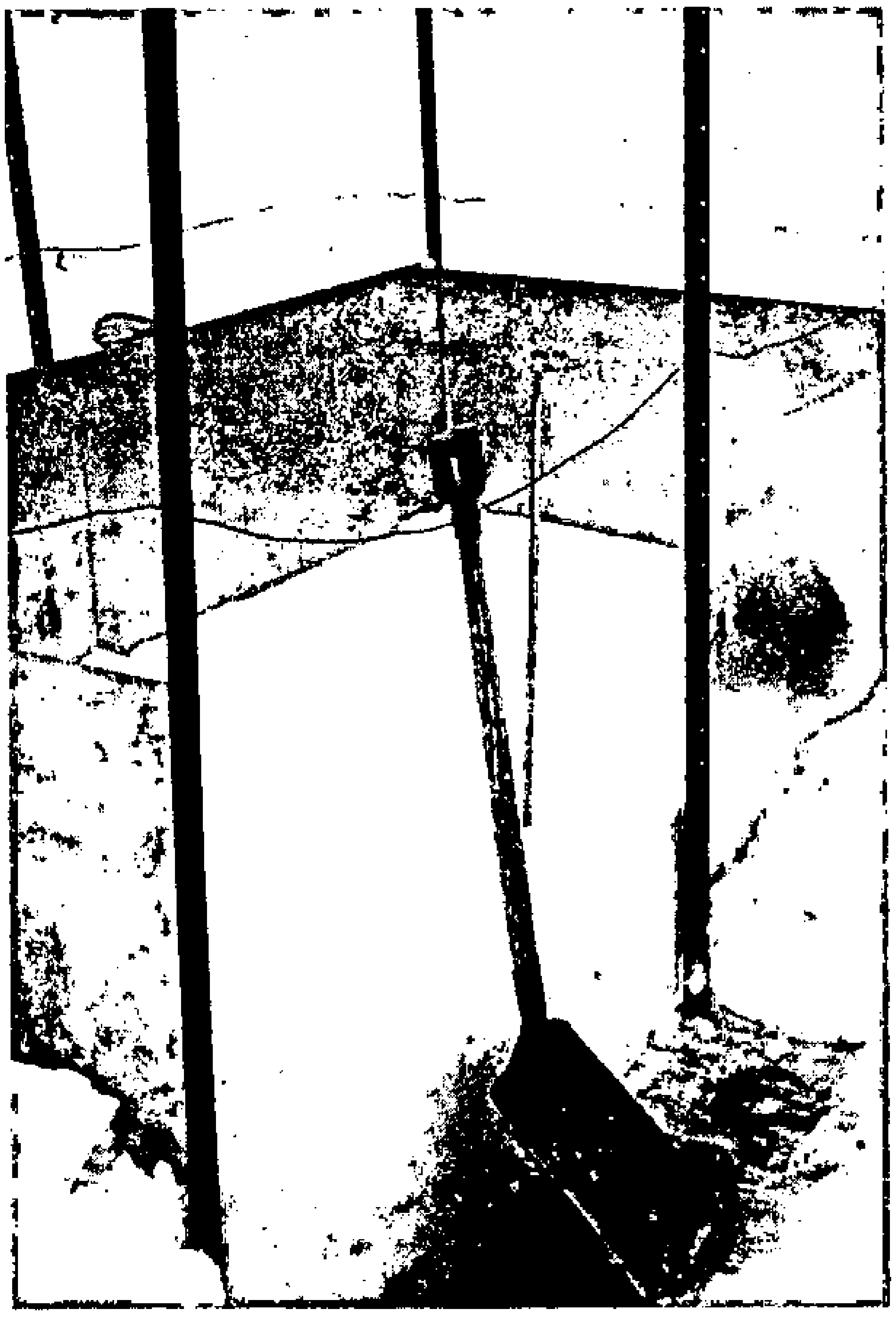


Figure 2a: Snowplot before being cleared.

Figure 2b: Snowplot being cleared.

TABLE 2
MEASURED WATER EQUIVALENT (CM) AND RATIO (%) TO TRUE AS DETERMINED FROM CLEARING STYROFOAM PLOT

Test	True (cm)	M.S.C.		Standard Federal		Federal (L-S)		Bowman		McCall		Adirondack	
		W.E. (cm)	%[a]	W.E. (cm)	%	W.E. (cm)	%	W.E. (cm)	%	W.E. (cm)	%	W.E. (cm)	%
18/12/74	1.23	1.28	+4.1	1.34	+8.9	1.38	+12.2	1.28	+4.1	1.31	+6.5	NO TEST	
20/2/75	8.47	9.09	+7.1	8.90	+4.8	9.00	+6.0	8.30	-2.2	8.60	+1.3	NO TEST	
20/3/75 m	9.51	9.32	-1.8	9.49	-0.3	10.67	+12.4	10.07	+6.1	9.32	-1.8	NO TEST	
20/3/75 t	14.01	15.80	+13.0	13.95	-0.2	14.27	+2.1	13.28	-5.0	13.56	-3.0	NO TEST	
29/12/75	1.90	1.97	+3.7	2.02	+6.3	2.03	+6.8	1.91	+0.5	1.94	+2.1	1.91	+0.5
5/1/76	5.00	5.31	+6.2	5.23	+4.6	5.54	+10.8	5.22	+4.4	4.98	-0.4	4.92	-1.6
28/1/76	6.60	7.45	+12.9	7.42	+12.4	7.82	+18.5	7.28	+10.3	6.98	+5.8	6.78	+2.7
24/2/76	14.44	14.73	+2.0	15.73	+8.9	16.47	+14.1	15.39	+6.6	14.93	+3.4	13.15	-9.1
11/3/76	18.01	19.67	+9.2	18.43	+2.3	21.30	+18.3	19.01	+5.6	17.41	-3.3	18.75	+4.1
21/1/77[b]	8.23	8.37	+1.7	8.83 (8.35)	+7.3[c] (+1.4)[d]	8.07	-2.0	7.81	-5.2	8.40	+2.1	8.21	-0.3
2/3/77	16.99	17.71	+4.2	18.89 (18.36)	+11.2[c] (+8.1)[d]	18.67	+9.9	18.58	+9.4	17.29	+1.8	17.49	+2.9
MEAN	9.49	10.06	+6.0	9.93	+4.6	10.47	+10.3	9.83	+3.5	9.52	+0.3	10.17	0.0[e]

NOTES

a. Percentage difference from true
b. 8 Samples taken by each sampler in 1977 tests
c. Sampler used for regular snow surveys
d. Cutter sharp; only used for test plot
e. For 7 tests only.

encountered an Adirondack with a bung cutter is unable to penetrate them and a complete sample will not be obtained.

The Bowman and McCall are test samplers and they are not generally used operationally. The Bowman sampler gives results similar to the standard Federal, although it does penetrate ice lenses more easily. The McCall sampler repeatedly provided the most accurate mean water equivalent, and for the entire test period it averaged within 1% of the true water equivalent and density. It showed no consistent measurement bias. This was the best sampler for penetrating ice layers and for ensuring that a solid plug was obtained.

To compare sampler performance over the entire test period, the root-mean-square error was calculated for the density measurements (see Table 3). The RMS for the McCall is half that of the next lowest one. The Federal L-S has the highest, even if the three large deviations of 1976 are excluded. Most significant is that the MSC, Adirondack, standard Federal and Bowman samplers have virtually the same RMS for the test period. Given the mean deviations and similar RMS errors, there appears to be little to choose between the MSC, standard Federal and Bowman samplers.

The samplers used in the test program were not used for regular snow surveys, yet the cutters dulled solely because of contact with snow and ice, and not with frozen soil or stones as would be common on regular snow surveys. At the end of 1976 season all the samplers were sharpened since most had dulled considerably from sampling the icy plots. The notable exception was the McCall; its cutter does not dull as quickly since the sampler

TABLE 3

CALCULATED MEAN SAMPLE DENSITY (gcm^{-3}) AND RATIO (%) TO CALCULATED TRUE DENSITY

Test	True density	M.S.C.		Standard Federal		Federal (L-S)		Bowman		McCall		Adirondack	
		ρ	%	ρ	%	ρ	%	ρ	%	ρ	%	ρ	%
18/12/74	.171	.178	+4.1	.187	+9.3	.193	+12.8	.177	+3.5	.176	+2.9	NO TEST	
20/2/75	.225	.239	+6.3	.235	+4.4	.237	+5.3	.219	-2.3	.221	-1.8	NO TEST	
20/3/75m	.408	.423	+3.6	.404	-1.0	.435	+6.6	.420	+2.9	.409	+0.2	NO TEST	
20/3/75t	.362	.380	+5.0	.356	-1.7	.387	+6.9	.349	-3.6	.344	-5.0	NO TEST	
29/12/75	.140	.142	+1.4	.147	+5.0	.149	+6.4	.141	+0.7	.145	+3.6	.143	+2.1
5/1/76	.222	.235	+5.9	.239	+7.7	.244	+9.9	.234	+5.4	.220	-0.9	.213	-3.2
28/1/76	.258	.288	+11.6	.288	+11.6	.305	+18.2	.287	+11.2	.270	+4.7	.263	+1.9
24/2/76	.378	.373	-1.3	.414	+9.5	.434	+14.8	.410	+8.5	.390	+3.2	.336	-11.1
11/3/76	.353	.391	+10.8	.358	+1.4	.424	+20.1	.378	+7.0	.339	-4.0	.364	+3.1
21/1/77[b]	.205	.208	+1.4	.220	+7.3[c]	.205	0.0	.194	-5.4	.204	-0.5	.197	-3.9
				(.210)	(+2.4)[d]								
2/3/77	.298	.312	+4.7	.339	+13.8[c]	.328	+10.1	.325	+9.1	.299	+0.3	.300	+0.7
				(.329)	(+10.4)[d]								
MEAN	.275	.288	+4.9	.288	+4.9	.304	+10.4	.285	+3.6	.274	-0.3	.259	-2.3[e]
RMS		.017		.019		.035		.019		.009		.017	

NOTES

a. Percentage difference from true
b. Samples taken by each smapler in 1977 tests
c. Sampler used for regular snow surveys
d. Cutter sharp; only used for test plot
e. For 7 tests only

is driven straight down through the snowpack rather than being turned to bring the cutter into action. In 1977, two standard Federal samplers were tested: one was sharpened, coated with silicone on the inside of the tube and was used only on the test plot; the other was sharpened at the beginning of the season, but is was dulled by use on regular snow surveys. The 1977 results indicate that a sharp cutter will give more accurate results. It is quite possible that the large errors of the Federal L-S sampler in 1976 were associated with a dull cutter. It was found that the cutters can dull very quickly and sharpening may be required more often than once per season. The Canadian MSC cutter lost its sharp edge the easiest and quickest of all the samplers. One cannot quantify the error specifically attributable to cutter sharpness, but it is strongly recommended that cutters must be kept sharp for best performance.

STATISTICAL COMPARISON OF SNOW SAMPLER RESULTS

A basic question which requires attention is whether the sampler measurements are significantly different from each other and from the "true" mean, or specifically, greater than the true mean. Standard statistical methods for hypothesis testing were used to assess these questions. In the application of any statistical hypothesis two factors dominate the outcome - how close is the sample mean to the true mean and how large is the variation about that mean, as represented by the standard error of the mean? If the standard error is very small, the means must be close together in order not to reject the null hypothesis. Conversely, the means can be relatively far apart, but if the standard error is sufficiently large, the null hypothesis will not be rejected. An example of the interval estimate of the population mean water equivalent measured by the different samplers is graphically shown in Figure 3 for the test on 11/3/76. In this example the MSC and Federal L-S samplers exhibit a mean water equivalent significantly different from the true mean. Since mean water equivalent determination may be affected by depth irregularities, mean density was ultimately used as the test parameter.

FIGURE 3
Interval Estimates of Population Mean Snow Water Equivalent Using Different Snow Samplers

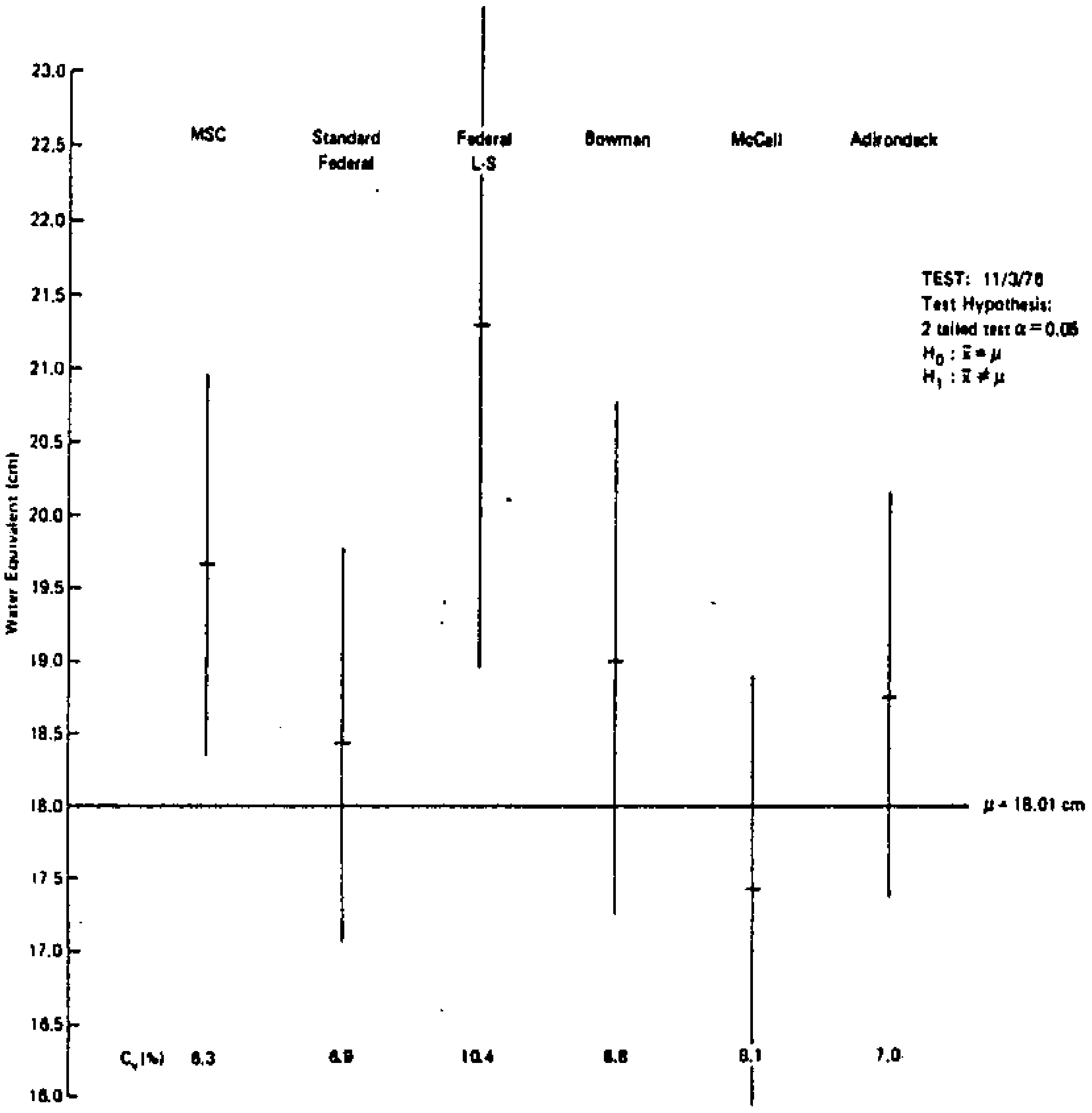


Table 4 summarizes the calculated t-value and the decision of rejection or acceptance of the null hypothesis ($\alpha = .95$) for the eleven tests. Only the McCall sampler did not have a mean density significantly different from the true mean, while the Adirondack and Bowman samplers differed signficantly from true only once. The Adirondack, like the McCall repeatedly had a sample mean close to the true mean, which makes rejection of the null hypothesis difficult. The Bowman sampler generally had a larger deviation from the true mean, but its larger standard error prevented rejection of the null hypothesis.

For the three samplers most commonly used in Canada the results were not as encouraging. The MSC, Federal and Federal L-S had a sample mean significantly different from the true mean for about half the cases, with the Federal L-S differing most often. It is interesting that the 1975-1976 tests exhibited most of the differences. There was no change in method which might have affected the results, but it is possible that the cutters were not sharp enough to sample accurately the ice layered snowpacks. It was also found that these three samplers had statistically significant differences greater than the true mean for 65%-70% of the tests. The McCall and Adirondack samplers showed no significant overmeasurement.

TABLE 4

RESULTS OF SIGNIFICANCE TESTS FOR MEAN SNOWPACK DENSITY AS MEASURED BY SNOW SAMPLER

Test	True Mean Density ($\bar{\rho}$) (gcm^{-3})	M.S.C.				Standard Federal				Federal (L-S)				Significant Ice layers or lenses
		$\bar{\rho}$	t_c[a]	Test[b] 1	Test[c] 2	$\bar{\rho}$	t_c	Test 1	Test 2	$\bar{\rho}$	t_c	Test 1	Test 2	
18/12/74	.171	.178	2.48	NS	.05	.187	4.36	.05	.01	.193	4.40	.05	.01	No
20/2/75	.225	.239	5.35	.01	.01	.236	1.20	NS	NS	.237	1.87	NS	NS	No
20/375m	.408	.423	0.76	NS	NS	.404	-0.19	NS	NS	.435	1.90	NS	NS	Yes
20/3/75t	.362	.380	2.08	NS	.05	.356	-0.46	NS	NS	.387	2.32	NS	.05	Yes
29/12/75	.140	.142	0.70	NS	NS	.147	4.12	.01	.01	.149	3.37	.05	.01	No
5/1/76	.222	.235	3.06	.05	.05	.239	3.38	.05	.01	.244	5.25	.01	.01	Yes
28/1/76	.258	.288	3.00	.05	.05	.288	2.72	.05	.05	.305	2.76	.05	.05	Variable
24/2/76	.378	.373	-0.65	NS	NS	.414	8.99	.01	.01	.434	7.00	.01	.01	Yes
11/3/76	.353	.391	3.41	.05	.01	.358	0.47	NS	NS	.424	6.20	.01	.01	Yes
21/1/77	.205	.208	0.60	NS	NS	.220	1.88[d]	NS	NS	.205	0.00	NS	NS	No
						(.210)	(1.00)[e]	(NS)	(NS)					
2/3/77	.298	.312	3.50	.01	.01	.330	5.13	.01	.01	.328	6.00	.01	.01	Variable
						(.329)	(6.20)	(.01)	(.01)					

Test	True Mean Density ($\bar{\rho}$) (gcm^{-3})	Bowman				McCall				Adirondack				Significant Ice layers or lenses
		$\bar{\rho}$	t_c	Test 1	Test 2	$\bar{\rho}$	t_c	Test 1	Test 2	$\bar{\rho}$	t_c	Test 1	Test 2	
18/12/74	.171	.177	1.21	NS	NS	.176	0.68	NS	NS	NO TEST				No
20/2/75	.225	.219	-1.01	NS	NS	.221	-1.03	NS	NS	NO TEST				No
20/375m	.408	.420	1.34	NS	NS	.409	0.11	NS	NS	NO TEST				Yes
20/3/75t	.362	.349	-0.78	NS	NS	.344	-1.10	NS	NS	NO TEST				Yes
29/12/75	.140	.141	0.34	NS	NS	.145	0.75	NS	NS	.143	1.81	NS	NS	No
5/1/76	.222	.234	1.85	NS	NS	.220	-0.31	NS	NS	.213	-1.90	NS	NS	Yes
28/1/76	.258	.287	1.94	NS	NS	.270	1.09	NS	NS	.263	0.51	NS	NS	Variable
24/2/76	.378	.385	0.94	NS	NS	.390	1.96	NS	NS	.336	-3.61	.05	NS	Yes
11/3/76	.353	.378	1.93	NS	NS	.339	-0.69	NS	NS	.364	1.72	NS	NS	Yes
21/1/77	.205	.194	-1.83	NS	NS	.204	-0.17	NS	NS	.197	-1.00	NS	NS	No
2/3/77	.298	.325	4.50	.01	.01	.299	0.20	NS	NS	.300	0.50	NS	NS	Variable

Notes:
a. Calculated t-value where $t_c = \frac{x - \mu_o}{s/\sqrt{N}}$

b. Test 1 Hypothesis, $H_o: \mu_1 = \mu_o$ $H_1: \mu_1 \neq \mu_o$ Using two tailed test
Level of Significance for rejecting null hypotheses
NS – fail to reject null boypotheses
.05 – reject null hypotheses at .05 level
.01 – reject null hypothesis at .01 level

c. Test 2 Hypothesis, $H_o: \mu_1 = \mu_o$ $H_1: \mu_1 > \mu_o$ Using one-tailed test level of significance for rejecting null hypothesis (as in Note 2)

d. Sampler used on reguler snow survey (cutter dulled)

e. Sampler only used on test plot (cutter sharp)

A statistical intercomparison of the sample means of the three samplers used operationally in Eastern Canada (MSC, Federal, Federal L-S) was carried out. The standard t-test for the difference of means of independent samples (Davis, 1973) was used as the test statistic. The null hypothesis stated that the mean of the population from which the first sample was drawn is the same as the mean of the parent population of the second sample. In this comparison of snow samples it is known that the samples were drawn from the same population. If repeated differences should occur, it suggests that one sampler performs differently from another. In only the test of 24/02/76, did the mean of the MSC differ significantly from the Federal samplers and for that of 11/03/76 did the two Federal samplers differ. In most cases, the three samplers will provide similar estimates of snowpack water equivalent and density at a "point".

In summary, the MSC, Federal and Federal L-S snow samplers provide comparable measurements, but they tend to overmeasure the true mean by a statistically significant amount. This overmeasurement averages 5%-10%. If complete snow cores are obtained by the sampler (as in this experiment), there is little difference between the MSC and standard Federal sampler.

PERFORMANCE OF DIFFERENT SNOW SAMPLERS IN SAMPLING SHALLOW SNOWPACKS

A few basically qualitative comments on the performance of each sampler are summarized below:

Canadian MSC: This sampler generally cuts a good core, but because of its larger diameter the core is often difficult to hold in the tube without the assistance of a shovel. This destroys the sampling site which is not desirable if repetitive sampling is required throughout the season. Penetration of ground ice layers is very difficult, if not impossible. The cutter dulls very easily when sampling dense snow.

Standard Federal: It is a portable, easy to handle sampler which can penetrate most ice lenses and layers, although considerable force may be required. Because of its smaller diameter, plugging or blocking of the snow core as it enters the tube may occur when dense ice lenses are encountered. The sampler generally retains the snow core very well. As with other thin walled samplers, the core may stick and adhere to the side walls under certain conditions. A baked silicone coating helps minimize this problem. The sampler is useful for sampling wide ranges of snowpack conditions.

Federal L-S: Its properties are similar to the standard Federal, but its 8-tooth cutter may break ice lenses into chunks rather than cutting a "clean" core. Blocking may result.

Bowman: The tube used in this test was the same as the Federal, but the cutter with alternating cutter and raker teeth was more effective in cutting ice lenses and ice layers on the ground than the standard 16-tooth Federal cutter.

Adirondack: This sampler's great advantage is its fiberglass construction. In particular, its slow response to a marked temperature change prevented freezing of the snow core in the tube. The bung cutter tested could not penetrate dense snowpacks or ice layers on the ground. Like the MSC sampler, snow cores can be difficult to retain.

McCall: This thick walled aluminum sampler's main disadvantage is its extra weight. The thicker aluminum wall prevents the snow core from freezing in the tube. A drop hammer is used if ice is encountered and the cutter is most effective in penetrating ice layers.

COMPARISON OF RESULTS WITH PREVIOUS STUDIES

The results of the tests are similar to those reported by Work et al. (1965) for deep mountain snowpacks and for a cold light density shallow snowpack in Alaska (see Table 5). The variability among tests and the relative performance of the standard Federal, Bowman and Adirondack samplers in the Southern Ontario tests are very similar to the results obtained for different snowpack conditions in other geographic regions.

In the deep warm snowpacks of California, Peterson and Brown (1975) found that the overmeasurement of the water equivalent was a function of the measured density (Figure 4), with the error increasing with increasing density. They stated, however that tests in shallow snowpack regions were required to define the boundary conditions of their error curve. The current tests in shallow snowpacks show that for the standard Federal and MSC samplers no definite relationship existed between density and the measurement error. What is particularly notable in Figure 4 is the scatter in measurement error associated with snowpacks which might have significant ice layers or lenses in them. In the case of the Federal sampler there is generally a decrease in the error when ice layers or lenses are encountered. It is probable that some blocking of the core entering the tube is caused by the lenses in the snowpack, but the average net effect in these tests was to counterbalance the tendency to overmeasure.

TABLE 5a

SUMMARY OF SNOW SAMPLER TESTS AT MT. HOOD, OREGON, U.S.A.

	Measured Snow Water Equivalent (mm)						
	#1 214.1	#2 275.3	#3 1077.0	#4 1310.6	#5 2169.2	#6 1325.9	#7 737.1
Snow Sampler	Per Cent Error of Snow Sampler						
Standard Federal	+9.0	+6.8	+11.8	+11.2	+10.2	+12.0	+12.3
Federal (L-S)	-	-	-	-	+ 8.0	-	-
Federal - Sharpened[a]	-	-	-	-	-	+ 4.6	+ 3.7
Bowman[b]	+1.8	-0.6	-	-	-	-	-
Rosen[c]	+3.2	+0.6	+ 5.7	+ 6.4	+ 2.9	-	-
Adirondack	+1.9	+2.8	-	-	- 0.4	-	-

Notes: a - Standard 16 tooth Federal sampler with teeth sharpened to the inside
b - Plastic tube
c - Similar to the McCall sampler, but has 8-tooth cutter

TABLE 5b

SUMMARY OF SNOW SAMPLER COMPARISONS IN ALASKA, U.S.A.

	Sampling Location, Water Equivalent (mm) and Density (g cm^{-3})					
	SCS Grounds 67.8 (.156)	Cleary Summit 78.8 (.155)	Exper. St'n 66.8 (.160)	Fort Yukon 68.6 (.151)	Chandalar 82.3 (.171)	Mean 72.9
Snow Sampler	Per Cent Error of Sampler					
Standard Federal	3.0	10.6	11.0	4.1	11.4	+ 8.2
Federal (Slotless)	7.5	9.4	10.6	7.8	13.9	+10.0
Bowman[a]	1.5	7.1	6.5	-1.5	6.2	+ 4.1
Adirondack	1.1	-3.9	4.6	-0.7	8.0	+ 1.9
CRREL	8.6	-0.6	6.1	8.1	13.3	+ 7.1

Note: a - Plastic tube used

After: Work et al. (1965)

Turcan and Loijens (1975) discussed in detail the problem of blocking and compaction in snow survey measurements and the associated errors. They argued that compression of the snow in the tube, caused by friction between the snow and the walls of the sampler, and blocking of the opening of the sampler by ice layers when it is inserted into the snowpack result in the measured density being less than the true density. During the current testing program, core lengths were recorded to test the Turcan - Loijens method, but in most tests even the individual samples had a desnity greater than the true mean.

Figure 5 is an example of the Turcan - Loijens correction procedure applied to the test 20/3/75t. The mean density for the plot was .362 g cm^{-3}, but there were several ice lenses in the snowpack. Using the Federal sampler a core up to 35% shorter than the sample depth was recorded and using the Turcan - Loijens method the true density was calculated to be .436 g cm^{-3}. The MSC sampler showed no clear relation between core length and

FIGURE 4
Snow Sampler Error
As A Function of Density

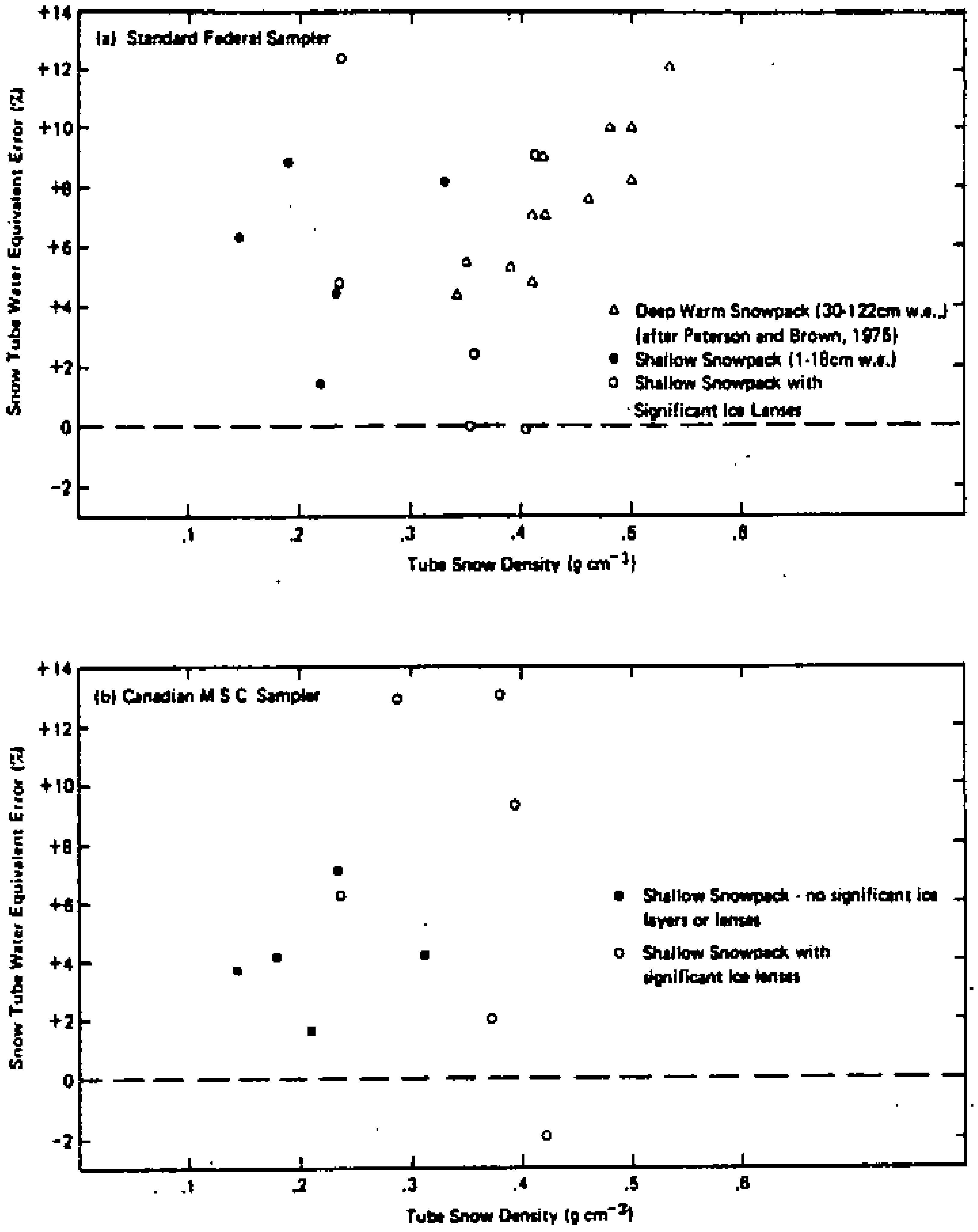
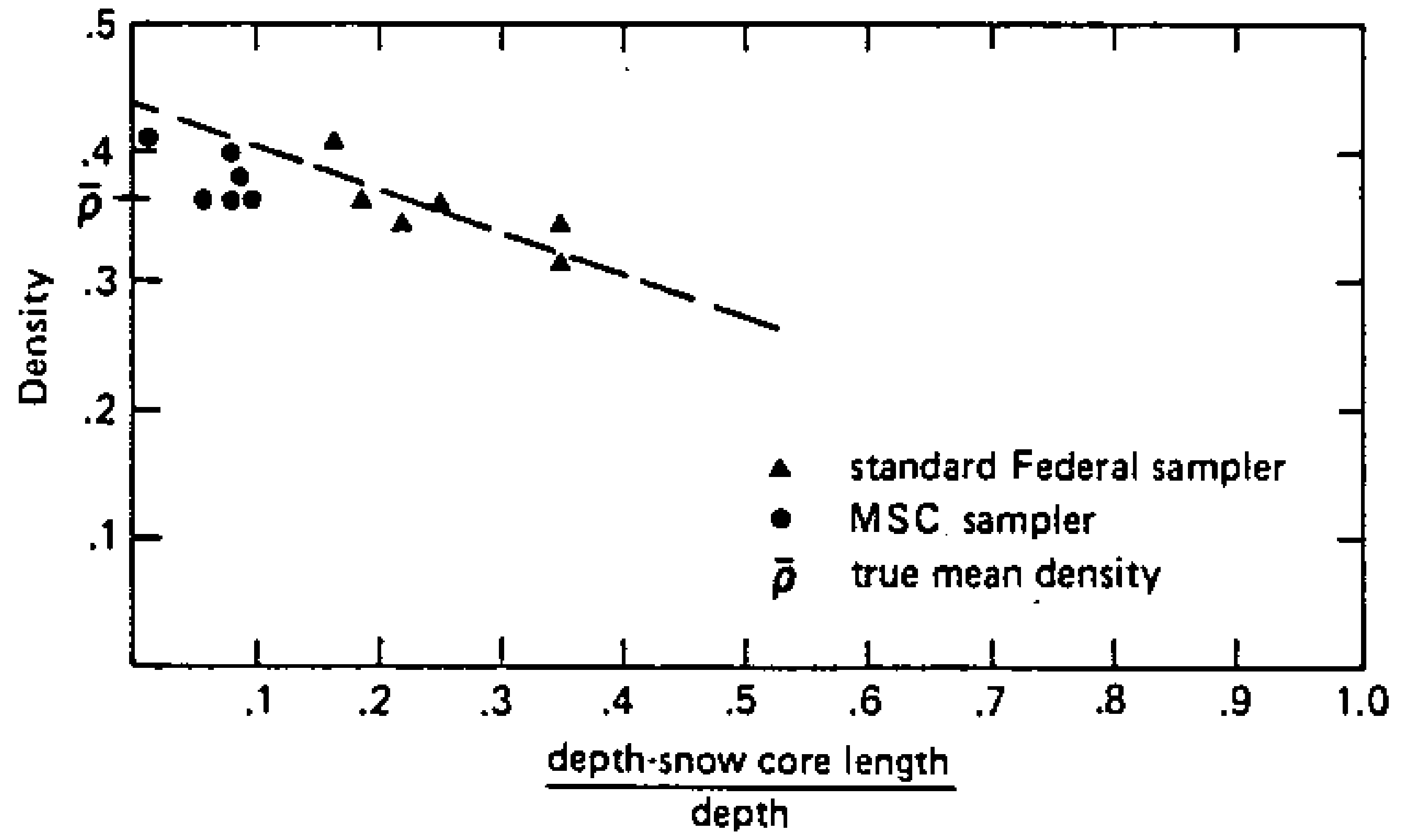


FIGURE 5
Application of the Turcan-Loijens
Correction of Measured Density



density. Certainly in this case, the correction procedure results in an erroneous "true density".

The Turcan - Loijens technique usually increases the measured density, but the sampler testing demonstrated that snow tubes generally overmeasure already and a further increase would only augment the error. However, blocking is a real problem and can result in definite undermeasurement at any point. In practice if a short core is extracted, it should be discarded and the point resampled. The method for density correction suggested by Turcan and Loijens cannot be recommended for use in Southern Ontario.

DISCUSSION

A basic point for discussion is whether one should correct snow course data for instrument errors. The tests in Southern Ontario shallow snowpacks did not confirm a definite error relationship as found by Peterson and Brown in deep warm snowpacks or as proposed by Turcan and Loijens. At best a mean average error correction might be deemed applicable. Yet it was found that density and water equivalent measurements were less variable in uniform snowpacks devoid of ice lenses or ice layers on the ground. As well, Goodison (1977) has shown that in contrast to the measurements over the snowplot (or at a point on a snow course) the statistical variation associated with measurements along snow courses was much greater than even the maximum recorded over a test snowplot. For example, for a snow course over a slightly rolling short grass field the variation in water equivalent was up to six times greater than that observed at a point. Density variations were two to three times greater along the course than those recorded on the plot. Even along a course in long pasture grass it was found that the coefficient of variation and relative standard error of the mean for depth, density and water equivalent were twice that monitored over the test plots. Thus, the siting of a snow course and the effect of topography and vegetation on snow distribution could have a far greater effect on accurate water equivalent estimates than those errors associated with each individual measurement.

There are other factors which limit the systematic correction of individual snow tube measurements in addition to the relative variability of point and areal measurements. Although snow tubes provided a generally positively biased estimate of snow water equivalent and density, the amount of overmeasurement depended largely on internal snowpack structure. A suitable correction procedure, other than reducing the observed values by a mean percentage, could not be established. As well, the condition of the snow surveying equipment, such as cutter sharpness, had an upredictable effect on the accuracy of the results. Finally, it is possible that complete snow cores are not taken every time; ice layers may not be penetrated; blocking by ice lenses may cause undermeasurement at an individual sample point. Any of these factors will tend to reduce the bias of overmeasurement found for the test plots. Most important, however, is that the standard equipment will provide comparable measurements, although they tend to overmeasure by 5%-10%.

Rather than attempting to apply mean corrections for instrument error in snow survey data, is it possible to have a sampler which will consistently measure near the true amount under a wide variety of snowpack conditions? Are the McCall and Adirondack samplers the answer? The Atmospheric Environment Service is currently re-evaluating their MSC sampler in an attempt to improve the effectiveness of its cutter when ice layers are encountered and to reduce sticking problems in the tube. Tests for the latter problem include using a clear polycarbonate tube and applying a silicone coating to thin metal tubes. At the same time there is a demand for metric equipment as both Canadian and American agencies initiate metriction programs. Currently, new metric size (10 cm^2 area) cutters are being tested in shallow and deep snowpacks. Two versions are being tested: one has a cutter 2.5 cm long; the other has one 5 cm long. Both fit on a standard Federal tube. An initial test gave encouraging results (i.e. +1-2%), but more tests are required before the results can be discussed fairly. Metrication also provides an appropriate time to initiate other cutter/tube design changes to improve the snow sampler's performance. This problem is one which should be considered in the near future and the author would appreciate receiving comments on this problem, including suggestions for possible design changes.

ACKNOWLEGMENTS

The author gratefully acknowledges the capable and very necessary assistance of Mr. J. Metcalfe and Mr. M. Malone in performing these snow sampler tests over the past few winter seasons.

REFERENCES

Bindon, H.H., 1964: Design of snow samplers for Canadian snow surveys. Proc. Eastern Snow Conference, 21st Annual Meeting, 23-28.

Bray, D.I., 1973: A report on the variability of snow water equivalent measurements at a site. Proc. Eastern Snow Conference, 30th Annual Meeting, 20-31.

Davis, J.C., 1973: Statistics and Data Analysis in Geology. John Wiley and Sons, Inc., Toronto, 550 p.

Freeman, T.G., 1965: Snow survey samplers and their accuracy. Proc. Eastern Snow Conference, 1-10.

Goodison, B.E., 1977: Snowfall and Snow Cover in Southern Ontario: Principles and Techniques of Assessment. Ph.D. Thesis, University of Toronto, Toronto, Ontario, 403 p.

Peterson, N.R. and A.J. Brown, 1975: Accuracy of snow measurements. Proceedings, Western Snow Conference, 43rd Annual Meeting, 1-5.

Turcan, J. and H.S. Loijens, 1975: Accuracy of snow survey data and errors in snow sampler measurements. Proceedings, Eastern Snow Conference, 32nd Annual Meeting, 2-11.

Work, R.A., H.J. Stockwell, T.G. Freeman and R.T. Beaumont, 1965: Accuracy of Field Snow Surveys, Western United States, including Alaska. U.S. Army, CRREL Tech. Report 163, 43 p.

Presented at CMOS, Saskatoon, June 1981

NIPHER TYPE SHIELD FOR RECORDING PRECIPITATION GAUGES: FIELD TRIALS

B.E. Goodison and J.R. Metcalfe

Atmospheric Environment Service
Downsview, Ontario

Introduction

Canadian experiments (Goodison, 1978a, 1978b; Turner and Goodison, 1977) have indicated that the MSC Nipher shielded snow gauge has a superior catch efficiency for measuring snowfall water equivalent than standard Alter-shielded recording gauges. In many areas, and of course at remote stations, recording gauges are the preferred precipitation gauge. In order to improve the performance of Alter-shielded recording gauges and to avoid the errors associated with the standard non-recording Nipher gauge, it was proposed that a larger Nipher-type shield should be constructed, scaled to fit the 20.7 cm (8 inch) diameter recording gauges. The aim was to obtain measurements from a recording gauge which would be compatible with the official MSC Nipher snow gauge measurements.

The "scaled-up" version of the MSC Nipher shield was designed by the Atmospheric Instruments Branch of AES. The shield was made of fiberglass. An elongated tube of galvanized sheet metal (diameter 20.7 cm) was affixed to the gauge to extend its orifice even with the top of the shield. Gauges were mounted at 2 m above the ground.

Test Sites

Two prototype installations were tested at the Woodbridge Research Station during 1978-79. During 1980-81 Nipher shielded recording gauges were tested at the following stations:

Woodbridge Research Station - Fischer & Porter and Universal
Resolute, NWT - Fischer & Porter
Bad Lake, Sask. - Fischer & Porter
Regina, Sask. - Fischer & Porter
Monticello, Ont. - Fischer & Porter (open and bush site)
Dorset, Ont. - Universal
Peterborough, Ont. - Universal
Dorval, P.Q. - Fischer & Porter

Preliminary Results

Early results from the Woodbridge station indicated that the recording Fischer and Porter and Universal gauges with the new Nipher shield recorded a substantially higher catch than either unshielded or Alter-shielded gauges (Table 1) but the catch was 7-15% less than the standard MSC Nipher gauge at the station.

Data from Saskatchewan for the 1979-80 winter confirmed the higher catch efficiency for recording gauges using the Nipher type shield. At Bad Lake, a Nipher shielded Fischer and Porter caught 96% of the standard MSC Nipher compared to only 37% for an Alter-shielded Fischer and Porter. This latter catch is in line with the long term average monthly catch of 35% reported by Gray et al. (1979). At Regina, the modified Fischer and Porter gauge caught 94% of the MSC Nipher. At both stations only snow events were recorded.

At Monticello, Ontario, paired Nipher and Alter shielded gauges were placed in both open and sheltered bush locations to assess the effect of siting on the large shield.

A comparison of the catch efficiencies is given in Table 2. Both gauges in the bush site caught the same, and the Nipher shielded gauge, as might be expected, did cap over in December and remained capped until cleared by hand. This would be a problem at remote stations. It appears, however, that this type of shielding is not necessary at well sheltered sites as the catch of the Alter-shielded gauged is just as good.

Data from other sites, not subject to large numbers of trace amounts of snowfall (e.g. Resolute), display similar results. At Resolute, the Nipher shielded Fischer and Porter measured more than the standard MSC Nipher. This may be the result of accumulation of trace amounts and/or blowing snow. Further analysis measurements from other gauges at this site is required to assess this difference.

Existing Problems

Problems still exist which require attention. These include:

1) the physical size of the shield which makes servicing of the Fischer and Porter and Universal gauges awkward and difficult;

2) the supporting structure which requires refinement to permit easy and accurate positioning of the shield around the orifice extension and level with the orifice;

3) determination of the best material for making the orifice extension in order to minimize snow sticking to it and not falling into the gauge;

4) determination of the extent of the potential for snow capping the gauge, even at open sites;

5) assessment of the amount of blowing snow which the gauge could catch.

Summary

Preliminary data from a variety of regions indicates the Nipher shielded recording gauges provide measurements more compatible with official MSC Nipher measurements than Alter-shielded or unshielded recording gauges. Further field trials and wind tunnel investigations are planned during 1981-82.

Acknowledgements

The Atmospheric Environment Service Instruments Branch personnel, particularly Mr. V. Turner, have been active in supporting the design and testing of this instrument. Many individuals and agencies have cooperated in the installation and operation of gauges for this project, particularly personnel from University of Saskatchewan, AES Central Region, Grand River Conservation Authority, Trent University and the Ontario Ministry of Environment.

References

Goodison, B.E., 1978a: Accuracy of Canadian snow gage measurements. Journal of Applied Meteorology, Vol. 17, No. 10, 1542-1548.

Goodison, B.E., 1978b: Canadian snow gauge measurements: accuracy, implications, alternatives, needs. Proceedings, Seventh Symposium on Applied Prairie Hydrology, Water Studies Institute, Saskatoon, May 9-11, 1978, pp. 7-15.

Gray, D.M., H. Steppuhn and F.L. Abbey, 1979: Estimating the areal snow water equivalent in the Prairie environment. Proc. Canadian Hydrology Symposium: 79, Vancouver, May 10-11, 1979, p. 302-322.

Turner, V.R. and B. Goodison, 1977: Wind tunnel evaluation of flow around snow gauges. Paper presented at the 11th Annual Canadian Meteorological Society Congress, Winnipeg, Manitoba, June 1-3, 1977.

TABLE 1

SNOW GAUGE COMPARISONS, TORONTO MET RESEARCH STATION

SNOW SEASON	MSC NIPHER	UNSHIELDED BELFORT GAUGE	ALTER SHIELDED BELFORT GAUGE	ALTER SHIELDED F&P GAUGE	NIPHER SHIELDED BELFORT GAUGE	NIPHER SHIELDED F&P GAUGE	WYOMING SHIELDED BELFORT GAUGE
1978-79	102.6 MM	54.5 MM	65.4 MM	60.8 MM	94.7 MM	86.2 MM	72.8 MM
CATCH TOTAL AS % OF MSC NIPHER	100%	53%	64%	59%	92%	84%	71%
1980-81	120.8 MM	63.7 MM	81.2 MM	N/A	112.0 MM	116.8 MM	96.0 MM
CATCH TOTAL AS % OF MSC NIPHER	100%	53%	67%		93%	97%	79%

TABLE 2

SNOW GAUGE CATCH COMPARISONS, MONTICELLO, ONT. 1980-81

DATE	RAIN GAUGE MAIN SITE	MSC NIPHER GAUGE MAIN SITE	ALTER SHIELDED F&P GAUGE MAIN SITE	NIPHER SHIELDED F&P GAUGE MAIN SITE	ALTER SHIELDED F&P GAUGE BUSH SITE	NIPHER SHIELDED F&P GAUGE BUSH SITE	WYOMING SHIELDED F&P GAUGE
DEC. 1	4.0	3.6					
2	13.8	8.2	25.4	25.4	22.9	10.2	25.4
7	9.2			7.6	10.2	10.2	7.6
8	6.0			10.2	2.5		7.6
9		3.0	5.1	2.5	5.1	2.5	
10		1.6	10.2	2.5	2.5	5.1	5.1
11		1.0		7.6			
12		7.0	7.6		7.6	5.1	10.2
13		4.4		5.1	5.1	5.1	
14		1.4			2.5	2.5	7.6
17		2.6		2.5	5.1	2.5	5.1
18		1.6	5.1	2.5			
19		1.6			2.5		
20		0.6					
21		0.2		2.5	2.5	2.5	
22		1.0					
23		3.4		2.5	5.1		7.6
24		1.4				5.1	
25		0.6				17.8	
26		0.4			2.5		
28		5.4		7.6	10.2		
29	•0.2	2.2	7.6	5.1		22.9•	10.2
JAN. 1		3.4		2.5	2.5	2.5	
2		1.0		2.5		2.5	
3		0.6			2.5		
4		0.4					
5		0.2	5.1				
6		4.6		2.5	5.1	5.1	12.7
9		0.8			2.5	2.5	
10		0.4		2.5		2.5	
13		0.3					
15		3.0			2.5		
16		0.8		2.5	2.5	2.5	
22		1.4					
23		2.0	5.1	2.5	2.5	2.5	7.6
26		1.0		2.5		2.5	
27		0.6			2.5		
28		2.4		2.5	2.5	2.5	
FEB. 1		11.4	17.8	10.2	10.2		12.7
2		0.9					5.1
3		0.6					
4		0.6		2.5		10.2	
5		0.6			2.5		
6		0.9			2.5		
7		2.0		2.5	2.5		5.1
8		0.4				2.5	
9		0.4					
SEASONAL TOTALS	33.2 + 91.9 = 125.1		89.0	118.8	129.1	129.3	129.6
CATCH TOTAL AS % OF STANDARD NIPHER		100%	71%	95%	103%	103%	[illegible]

F&P = FISCHER AND PORTER

• = GAUGE CAPPED OVER

CANADIAN SNOWFALL MEASUREMENTS: SOME IMPLICATIONS FOR THE COLLECTION AND ANALYSIS OF DATA FROM REMOTE STATIONS [1]

642-78

By

B. E. Goodison [2] and D. J. McKay [3]

Introduction

Over the past few years there has been a significant effort within the Atmospheric Environment Service (AES) to investigate the adequacy of our present methods of measuring snowfall precipitation. AES operates a national network of about 2700 weather observing stations. The MSC Nipher shielded snow gauge is the standard instrument used to measure snowfall precipitation at more than 325 stations. At stations without a snow gauge the measured ruler depth of fresh snowfall is converted to water equivalent by dividing the depth by ten. Both methods of measurement require at least daily measurements by observers. In addition AES processes data from a network of over 110 Fischer and Porter recording precipitation gauges located at sites where regular observations are not feasible. The Universal gauge is used only in a few research and experimental basins. However, with increased automation and the demand for real-time acquisition of data from remote sites, automatic recording gauges, such as the Fischer and Porter, are becoming more important in the operational observation network. One then is faced with the problem of comparing data from different sites, while using different methods of measurement.

The problem of snowfall measurement, particularly as related to snow gauge measurements, has been recognized and investigated in other Northern countries. Members of both the Western and Eastern Snow Conferences have been concerned with this problem for many years (for example: Warner, 1966; Rechard and Larson, 1971; Larson, 1972; Hamon, 1973; Larson and Peck, 1974; Rechard et. al., 1974). Canadian field investigations to evaluate the accuracy and comparability of different methods of snowfall precipitation measurements were limited. Beginning in 1973, a series of projects were conducted by personnel from both the Hydrometeorology Research Division and the Atmospheric Instruments Branch aimed at evaluating and improving the accuracy of Canadian snowfall measurement methods.

Field investigations to assess the accuracy and comparability of different snow gauges have been conducted at the Cold Creek Hydrometeorological and Woodbridge Research Stations north of Toronto. Additional studies are being carried out at Peterborough and Monticello Ontario and Resolute N.W.T. to investigate the benefits of artificial shielding of gauges. Flow visualization experiments to study the airflow around shielded and unshielded gauges were conducted in the AES wind tunnel. Finally, research and development work was being carried out concurrently on the Fischer and Porter gauge to obtain increased resolution.

This paper will briefly review the accuracy of snow gauges as determined by field studies at the Cold Creek station, with particular emphasis on the accuracy of the Fischer and Porter gauge, since it is most suited to the remote telemetry of precipitation data. Methods being developed and tested by the Atmospheric Instruments Branch to increase the resolution of the Fischer and Porter and to incorporate a built-in processing facility to correct measured gauge catch for environmental parameters will be presented.

Accuracy of Snow Gauges Used in Canada

Long term observations have shown that, even at the same site, different gauges can provide significantly different precipitation totals (Allis et al., 1963; Harris and

---

[1] Presented at the Western Snow Conference, April 18-20, 1978, Otter Rock, Oregon. Mention of trade or company names in this paper is solely for the benefit of the reader.

[2] Atmospheric Research Directorate, Atmospheric Environment Service, Downsview, Ont.

[3] Atmospheric Instruments Branch, Atmospheric Environment Service, Downsview, Ont.

Carder, 1974). Wind has been shown to be a major cause of error in precipitation gauge measurements (Weiss and Wilson, 1957; Larson and Peck, 1974; Goodison, 1977a). Basically, the catch efficiency of precipitation gauges decreases with increasing wind speed, but siting in a natural "well-protected" location will minimize the effect of wind. In practice, however, in much of Canada it is often difficult, if not impossible, to find the ideal location. Consequently, gauges are necessarily placed in exposed windy locations. Determination of the relationship between the catch of different gauges used in Canada and environmental parameters was a necessary first step before new or improved methods of measurement could be developed or evaluated.

The field procedures used to assess the accuracy and comparability of snow gauges at the Cold Creek station are presented in detail in Goodison (1977a) and summarized in Goodison (1975; 1977b). Instruments evaluated included the Fischer and Porter, Universal (Belfort), and MSC Nipher shielded snow gauges. Gauges were located at two open and two sheltered sites in order to sample a wider range of wind speeds. Shielded and unshielded pairs of gauges were located at the open sites. An Alter shielded Fischer and Porter and MSC Nipher shielded snow gauge were installed at each site. Wind speed at gauge height (2m) was measured at all sites. "Ground true" precipitation was determined by weighing the storm snowfall which accumulated on snow boards located at the two sheltered sites. To minimize the effect of measurement errors or possible biases, only storm totals with a ground true value greater than 5 mm snow water equivalent were used in the final analysis. The contents of the Nipher gauge were both weighed and poured out in order to assess retention losses. The Universal gauges were operated in the normal manner, but to overcome the course 2.54 mm incremental weighing resolution of the Fischer and Porter gauge, weighted bags were attached under the orifice in place of the bucket to catch the snow. These bags were weighed after the storm to determine the snowfall water equivalent.

An example of an initial plot of results is given in Figure 1. It summarizes the relationship between the ratio of gauge catch to ground true snowfall as a function of wind speed for the Fischer and Porter gauge. The results are differentiated by site and storm total. Data from the four sites were quite consistent with the smaller storms falling within the range of the larger ones.

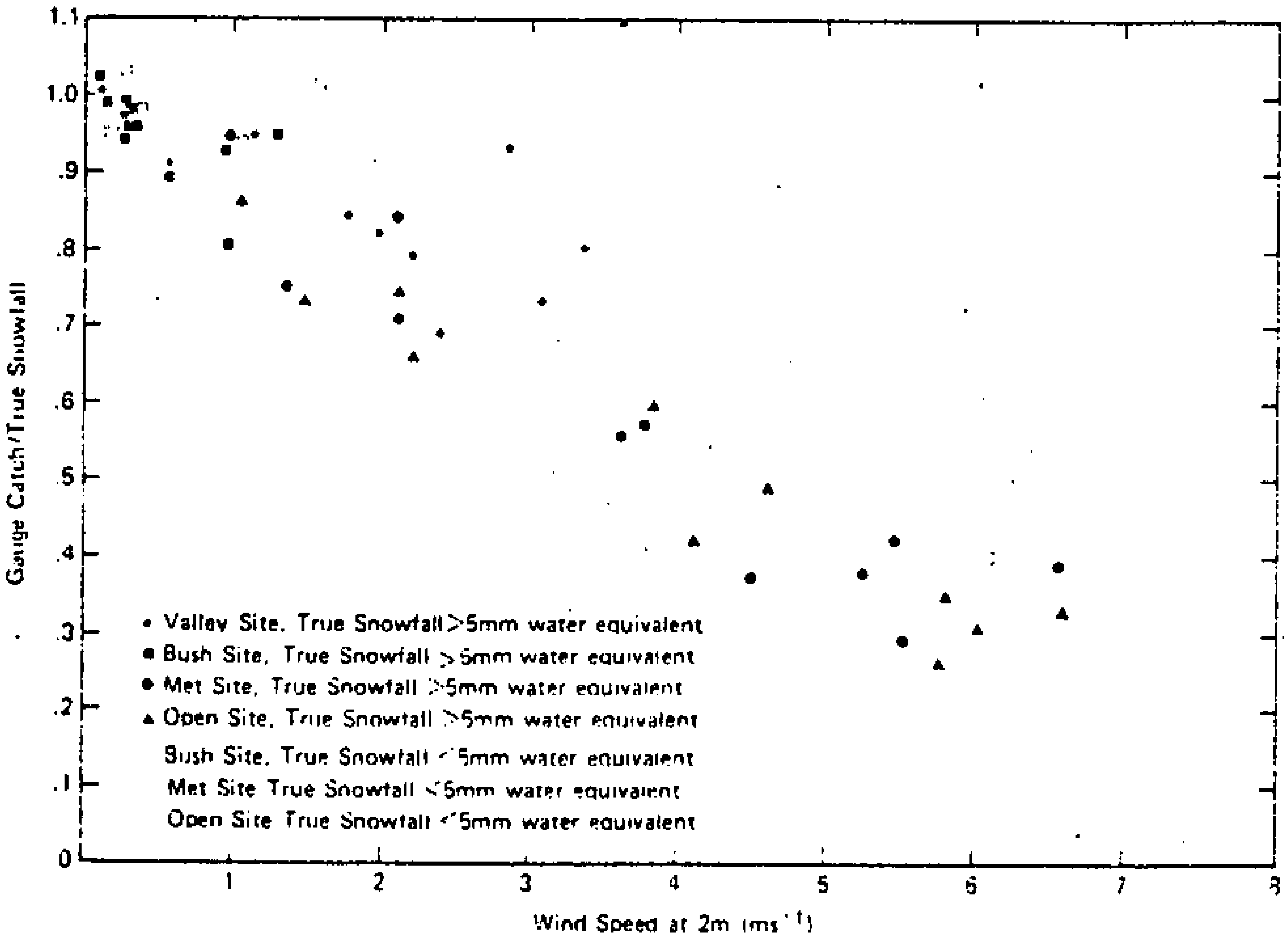


Figure 1: Observations of gauge catch versus wind speed for the Alter shielded Fischer and Porter precipitation gauge

To assess objectively the effect of environmental parameters on gauge catch, standard stepwise multiple regression procedures were used to analyze the ratio of gauge catch to ground true. Parameters assessed in the analysis included mean storm wind speed, screen air temperature, 700 mb and 850 mb temperature, and density of newly fallen snow. For all gauges tested wind speed was the dominant environmental parameter influencing gauge catch. For the Fischer and Porter and Universal gauges, screen air temperature was statistically significant secondary parameter, although in the Cold Creek tests it added only a 2% and 1% increase in the explanation of variance of the respective models. In Figure 1, the three notable deviations of valley and bush site data occurred when the mean air temperature was near or above freezing, i.e. ±1.0°C. Figure 2 shows the fitted curves of the gauge catch ratio as a function of wind speed and air temperature for the shielded Fischer and Porter gauge based on storm total greater than 5 mm. The exponential relation shown was typical for all gauges tested except the Nipher shielded gauge. For the Universal and Fischer and Porter gauges, screen air temperature was positively related to catch, i.e. the higher the temperature the higher the catch ratio. These results follow the relations suggested by previous American investigations (e.g. Hamon, 1973). For the same environmental conditions, the Fischer and Porter had a lower catch ratio than the Universal gauge.

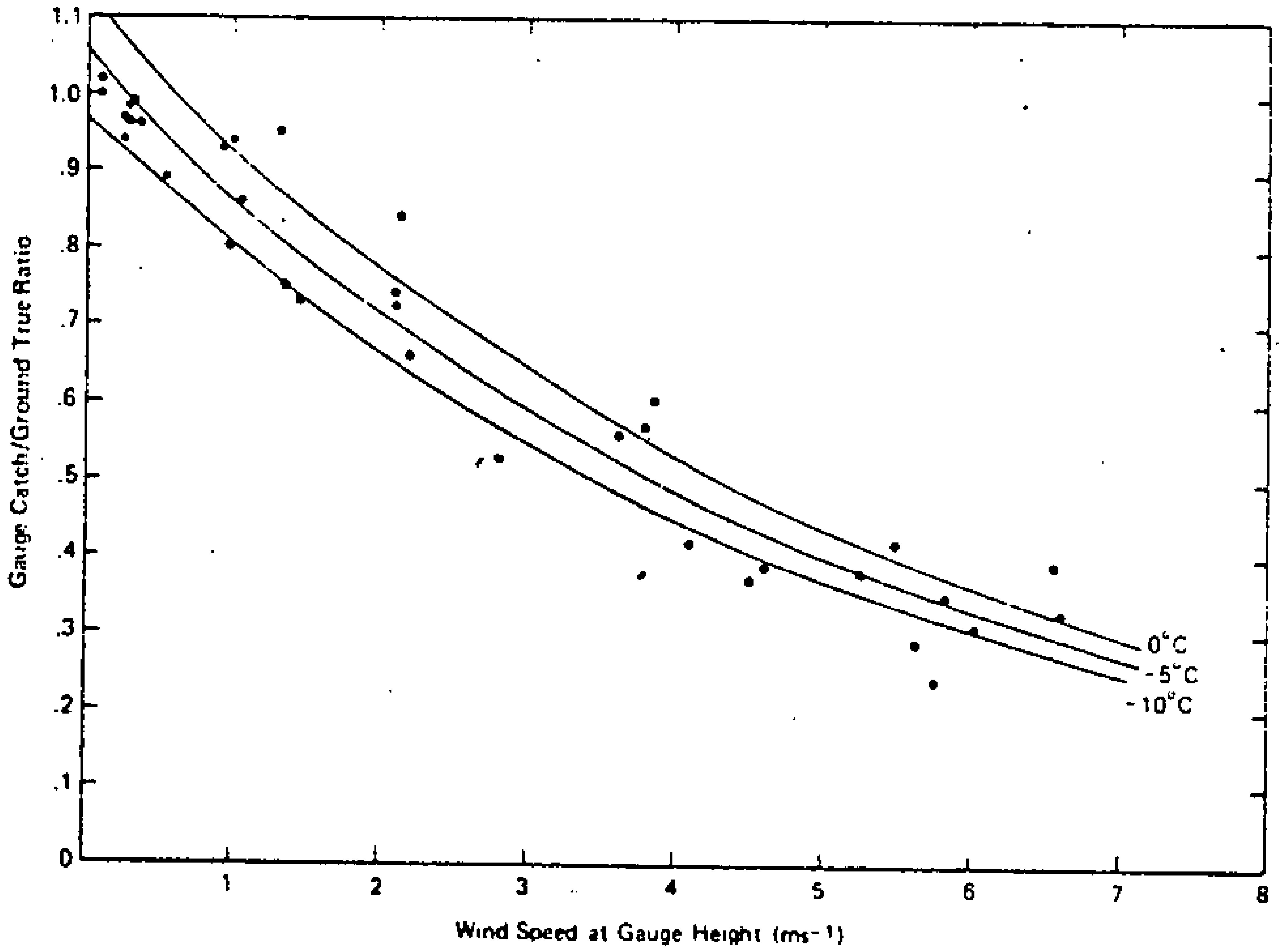


Figure 2: Gauge catch ratio as a function of wind speed and temperature for Alter shielded Fischer and Porter precipitation gauge

The results for the Canadian MSC Nipher shielded gauge were very different. Figure 3 compares the mean curves of gauge catch ratio with respect to wind speed for the three types of shielded gauges. For wind speeds up to 4 ms^{-1} the Nipher gauge overmeasured true snowfall, and for speeds up to 5.5 ms^{-1} the mean gauge catch is within 10% of true. Screen air temperature was inversely related to gauge catch, but it was not statistically significant. Instead the 700 mb temperature was a significant secondary parameter. The Nipher gauge also requires a correction for the retention of moisture in the collector when its contents are melted and poured out for measurement. The mean retention loss was 0.15 ±0.02 mm for each observation. Since the gauge is non-recording, adjustment for trace observations is also necessary. A more complete discussion of these corrections and their significance, particularly in low snowfall regions such as the Prairies and Arctic, is given in Goodison (1978).

As found by other researchers, unshielded gauges caught less than their shielded counterparts. Preliminary results for these gauges are summarized in Goodison (1977b). Of

---

particular
ed an expon
shielded an
that the su
It appears
to the meth
the gauge d

Implicati

T
cedures t
precipita
for envir
we get aw
tion to i

A
logic moc
ence to t
precipita
the estin
not neces
ficulty

correcte
Would th
hydrolog

include
tion act
areas. P

icular interest was the fact that the unshielded collector of the Nipher gauge display- n exponential decrease in catch ratio with increasing wind speed similar to other lded and unshielded gauges, but quite unlike its shielded counterpart. This suggests the superior catch ratios of the Nipher gauge are a result of the solid shield design. ppears that "undercatch" associated with Nipher gauge measurements are related as much he method of observation (i.e., the problem of trace amounts and retention losses) as gauge design (Goodison, 1978).

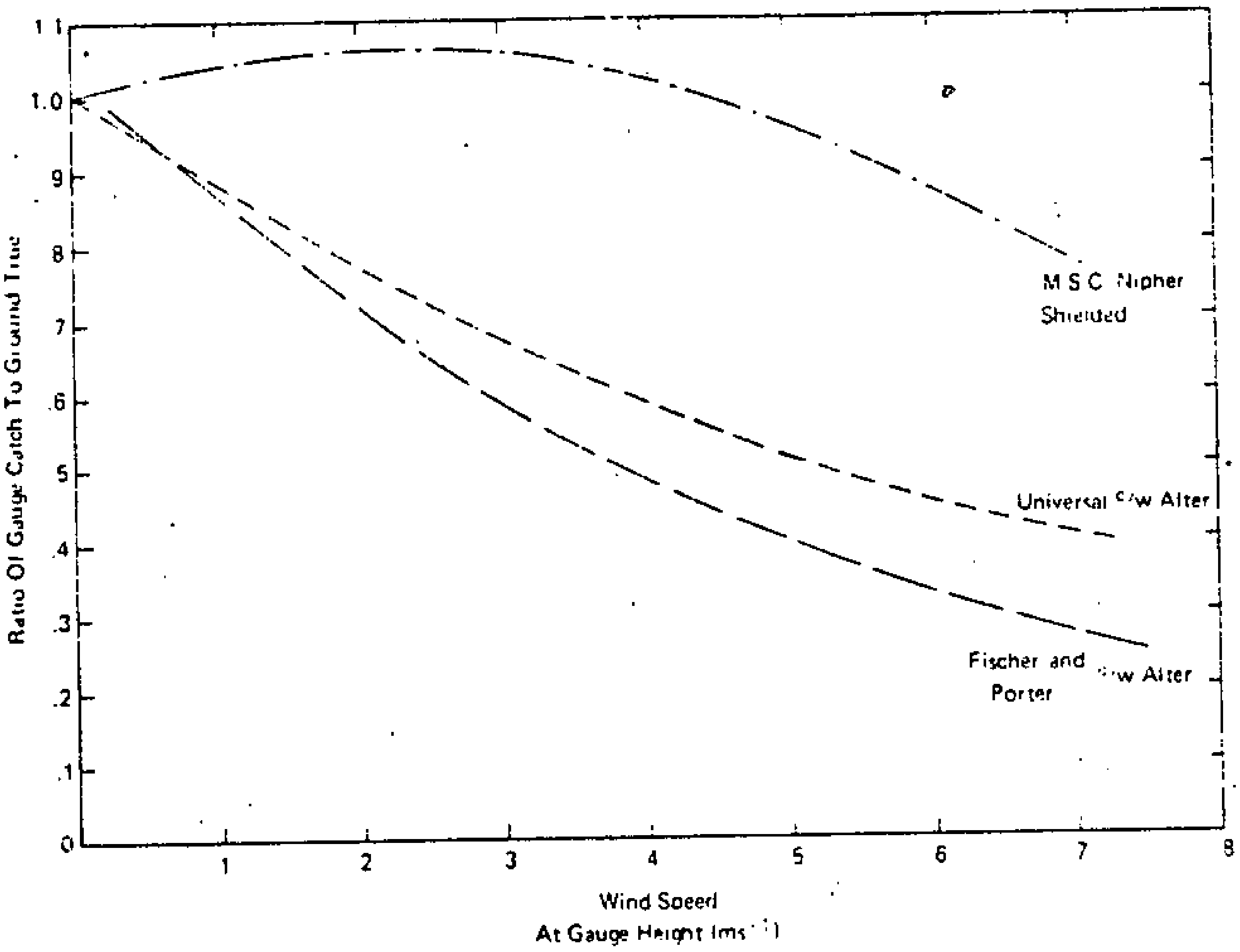


Figure 3: Gauge catch ratio as a function of wind speed for shielded precipitation gauges

lications for the Collection and Analysis of Snowfall Data

The results emphasize that each type of gauge requires individual correction pro- lures to determine true precipitation at a point. It is clear that to obtain comparable ecipitation data for either the same site or sites with different exposures, correction environmental factors, notably wind speed, is required. In 1978, is it not time that get away from using measured precipitation solely as an index and give some considera- on to its use as an absolute quantity?

At last year's Western Snow Conference there were several papers related to hydro- gic modelling which involved the use of snowfall data. Tangborn (1977, p. 39) in refer- ce to the selection of precipitation stations in basin analyses stated that: "additional ecipitation gages placed within or very near the drainage basin would likely improve e estimate of basin precipitation, It should be noted that high altitude stations are t necessarily the most representative. The reason for this is believed to be the dif- culty in catching precipitation as snow at these exposed, windy sites".

There will certainly be a problem of measurement at high altitude sites and un- rrected gauge measurements certainly will not be representative of true precipitation. uld the correction of data from such sites provide more suitable input data for our drologic models?

Keyes (1977) discussed the need for the expansion of national climatic networks to clude high elevation precipitation measuring stations to assess future weather modifica- on activities. Sites would be required upwind, within and downwind of mountain target eas. Presumably for such a study exact absolute quantities would be necessary in order to assess accurately the effect of weather modification schemes. The above results indicate that unless exposure, environmental conditions, and type of equipment are identical at all sites the measured precipitation statistics would not be comparable. Use of gauge catch correction curves would be one approach to achieving comparable snowfall data for the site.

Then there was the evaluation by Baker et al (1977) of four snow models, two of which included a "precipitation adjustment factor" and two which did not. The conclusion was that the output of all models was quite sensitive to small adjustments in air temperature and precipitation, indicating the need for accurate daily records of these parameters if the models were to be used to simulate the snow regime on a particular site. If a continuous physically-based conceptual hydrologic model is to be used effectively, comparable and accurate precipitation data must be used. A change in the method of measurement at a station will affect a time series analysis of historic data. Any areal analysis of precipitation gauge data from sites with varying exposures can provide very misleading results unless corrections for variations in gauge catch are first made.

The problem becomes even more perplexing when considering the measurement and analysis of data from remote stations and their comparability with standard network stations in say an international drainage basin such as the Columbia or Saint John. The MSC Nipher shielded snow gauge and the Alter shielded Universal gauge are the national standard gauges for snowfall precipitation measurement in Canada and the United States, respectively. The analysis of gauge catch efficiency has shown that, under similar conditions, these gauges will provide very different snowfall water equivalent totals which could cause an artificial discontinuity in the precipitation pattern at the Canada-United States border. To avoid such a discrepancy in areal analyses, the measured precipitation should first be corrected to achieve comparable data sets.

If it is necessary to expand the regional or basin network, it is only reasonable to want data which can be readily compared to the longer term network station data. One way is to use similar equipment and install it at a site with a similar exposure. In Canada this would require installation of a Nipher gauge at a relatively exposed site. Although the Nipher gauge has a superior catch efficiency compared to the other gauges, it is non-recording and must be attended daily by an observer. Consequently, it is not presently suited to situations which require measurements from remote sites.

In Canada, the alternative choice has been the use of the Fischer and Porter gauge, an instrument with characteristics suited to the collection and, if necessary, real-time transmission of precipitation data from remote stations. There is a serious problem, however. The Fischer and Porter gauge had the poorest catch efficiency for snowfall of all gauges tested. Unless the gauges were well sheltered so as to minimize the effect of wind, the measured catch should be corrected for the effect of wind speed and temperature in order to be useful. Cold Creek tests showed that a well sheltered Fischer and Porter gauge could provide acceptable uncorrected measurements, i.e. within 5-7% of true. If gauges must be located at exposured or partially sheltered sites, then a record of wind speed at gauge height is necessary to correct the measured precipitation total. This creates a problem since wind speed is not normally measured at remote stations. Given the correction curves above this requirement should be given serious consideration if accurate data are really our aim. In Canada the Fischer and Porter gauge is currently being installed at the new automatic weather stations at a unit cost of $5500. Should we not seriously ask what kind of data we will receive from this instrument? Will the data be only an indicator of when precipitation occurred? Will the data even do that?

A problem with the Fischer and Porter gauge and the application of its correction curves is its resolution of 2.54 mm. For example, for a snowfall with density of 0.08 gcm^{-3}, falling at a wind speed of 4 ms^{-1} and an air temperature of $-5^{o}C$, more than 6 cm depth would be required before the event would even be recorded on the punch tape. It might take several small storm events before the gauge even recorded that precipitation had occurred. This resolution limits the accurate application of gauge catch correction procedures as it may be difficult to accurately define when the snowfall event had occurred. An example of the application of gauge catch corrections is given in Table 1.

The results were very encouraging, especially considering the magnitude of some of the corrections; however, the constraint of the 2.54 mm resolution is evident. Correction of Fischer and Porter data from sites where many small events occurred over varying wind speeds has proven more frustrating. In heavy snowfall regions, particularly at sheltered sites, this problem is certainly less significant. In Canada, however, if the instrument is to be used at sites where in reality its use was not designed for, then improved resolution and the utilization of correction procedures may be a potential alternative.

Table 1

Calculation of True Snowfall Water Equivalent (mm)
for Individual Storms at Cold Creek, Ontario, 1972-1973

Date	Ruler	Nipher		Unshielded Universal		Alter shielded F&P	
	(ρ = .1)	Uncorr.	Corr.	Uncorr.	Corr.	Uncorr.	Corr.
29/12	12.19	11.43	11.17	5.33	13.00	5.08	12.93
27-28/01	2.29	7.52	7.44	4.32	8.38	5.08	8.25
07/02	8.64	6.73	6.51	2.03	4.19	2.54	4.54
14-15/02	1.78	4.22	5.94	1.16	4.82	2.54	6.62
20-21/02	11.69	12.44	12.15	4.70	9.45	5.08	8.41
25/02	6.60	3.86	3.78	2.03	4.08	2.54	3.29
Totals	43.19	46.20	46.99	19.57	43.92	22.86	44.04

Increasing the Resolution of the Fischer and Porter

First let us assure you that you should not run to your local dealer and buy one of the units about to be described. The purpose of the instrument system developed for this test was to satisfy a specific requirement and to verify a concept. It is the concept which will be elaborated on here.

With the advent of microprocessors it is now possible to attempt to make measurements which were at best impractical using standard analog and digital circuits. They allow such things as algorithm linearization, numerical averaging and decision making to be accomplished at the sensor level.

In the case of precipitation sensors the Atmospheric Environment Service has had an automatic weather station requirement for a precipitation sensor with a high resolution to be used as an indication of the occurence of precipitation. For summer operation a tipping bucket rain gauge with a resolution of 0.25 mm was satisfactory; however, for most of Canada using heated gauges during the winter gave totally unacceptable results for measuring snow. A weighing gauge provided acceptable totals, but available gauges do not have sufficient resolution. During our evaluations we noted that the Fischer and Porter Gauge had the potential for significantly higher resolution than allowed by its mechanical encoding disc (2.54 mm). Visual estimation of precipitation could be made to better than 0.51 mm.

By substituting a Baldwin optical absolute position encoder for the mechanical encoder we found that under laboratory conditions a resolution of 0.25 mm was easily obtainable. Outside, however, oscillations due to wind pumping were much more evident with the increased resolution, and although the damping fluid tended to minimize the magnitude of wind pumping, it did not eliminate it. It was also found that under calm wind conditions the damper could cause the gauge mechanism to stick if it was not very carefully adjusted. This tended to reduce the resolution to about 0.76 mm.

At this point in the development the microprocessor provided a possible solution. The Fischer and Porter gauge is a second order mechanical system that oscillates in a well prescribed fashion. The true weight of the accumulated precipitation could be determined by making frequent measurements of the weight (at a measuring frequency higher than the natural oscillation) over several cycles of oscillation and averaging the results. However, since the system has a sinusoidal oscillation with only a small amount of damping it is sufficient to measure the maximum and minimum indicated weight over several cycles and find the mean. These points are easy to measure because the time interval spent near the maximum and minimum points is relatively longer than at any other positions. The technique of obtaining the average weight as the mean of the maximum and minimum indicated weight, not only allows us to extract a meaningful measurement during wind pumping, it allows the possibility of obtaining a mean with twice the resolution of the individual measurement. This factor can be used to minimize digitizing errors. Figure 4 shows a simplified flow chart for the system. In the feasability stage the system was programmed on an Intel [illegible] to measure precipitation only and output the result on an LED display. While this proved that the concept was sound the microprocessor system used was not practical for operational use.

At about this stage of the investigation the results of the Canadian field experiments were becoming available. This represented a good opportunity for a joint project whereby we could combine a field test of a precipitation gauge with a built in processing facility and provide increased resolution for further snow studies.

In order to minimize the amount of development work it was decided to use commercially available equipment as much as possible. An Intel System 80/10 single board computing system was used to measure and process the precipitation gauge data, measure wind, temperature and dewpoint, and format an output message to an ASR33 Teletype machine. The analog voltage data from temperature and dewpoint sensors were measured using an Intel 723 A/D board which is designed for the 80/10 system. Non commercial design consisted of building the following:

1) the optoisolator interface between the Baldwin Shaft encoder, the wind sensor and the System 80/10 I/O ports.

2) a 2Hz crystal controlled oscillator for the real time clock.

3) Resistance to voltage converters for the temperature and dewpoint sensor.

4) Software.

Items 1) and 3) were built on an auxillary development board which fits into the System 80/10 card frame. Software was written in PLM high level language on an Intel MDS development system. This allows very rapid turn around for changes in programming that may be necessary. This is a desirable feature in an experimental system because it allows easy correction of erroneous algorithms and it allows the system to be reconfigured when necessary. For instance, since we could not get delivery of the A/D board we were able to configure the software to produce dummy temperature and dewpoint data for testing purposes.

Figure 5 shows a sample of the output from the system. A printout is produced every 10 minutes and whenever an increment of precipitation occurs. The system samples the precipitation and wind sensor approximately 1300 times per second. It determines the maximum and minimum precipitation readout during a 4 second interval and calculates the average precipitation value. This is compared to the previously calculated value to determine if precipitation has occured. Meanwhile the input from the wind sensor is accumulating the number of revolutions made by the cups. This data is updated at each 10 minute readout. Before each printout the temperature and dewpoint are read and the corrected precipitation is calculated using the algorithm based on the Cold Creek field tests. It is intended to use the dewpoint to determine when the precipitation is rain (dewpoint >0^{o}C) where no correction is made and snow (dewpoint $\leq 0^{o}$C) where the correction is calculated.

The printed output format is as follows:

DAY:HR:MN
Incremental amount of precipitation since last printout (x.01 inches).
Total accumulated precipitation (average) (x.01 inches).
Maximum indicated precipitation since last 10 minute readout (x.01 inches).
Minimum indicated precipitation since last 10 minute readout (x.01 inches).
Wind speed during last 10 minute interval (x.01 mph).
Temperature (^{o}C)
Dewpoint (^{o}C)
Corrected incremental precipitation since last printout (x.0001 inches).

```
FISCHER & PORTER PROCESSOR
DAY:HR:MIN IS 020:14:41 IF CORRECT TYPE C

020:14:41  156  156  156  156    2   99   99 *976
020:14:50    0  156  157  156  475   99   99    0
020:15:00    0  156  157  156  566   99   99    0
020:15:10    0  156  157  156  627   99   99    0
020:15:20    0  156  157  156  567   99   99    0
020:15:23    1  157  157  156  169   99   99  156
020:15:30    0  157  157  156  666   99   99    0
020:15:40    0  157  157  156  564   99   99    0
020:15:50    0  157  158  156  566   99   99    0
020:16:00    0  157  157  156  565   99   99    0
020:16:10    0  157  158  156  569   99   99    0
020:16:20    0  157  157  157  541   99   99    0
020:16:30    0  157  158  157  607   99   99    0
020:16:31    1  156  159  156   99   99   99  156
020:16:40    0  156  159  156  576   99   99    0
020:16:50    0  156  158  157  466   99   99    0
020:17:00    0  156  158  157  552   99   99    0
020:17:10    0  156  156  157  534   99   99    0
020:17:20    0  156  159  157  541   99   99    0
020:17:30    0  156  159  156  551   99   99    0
```

Figure 5

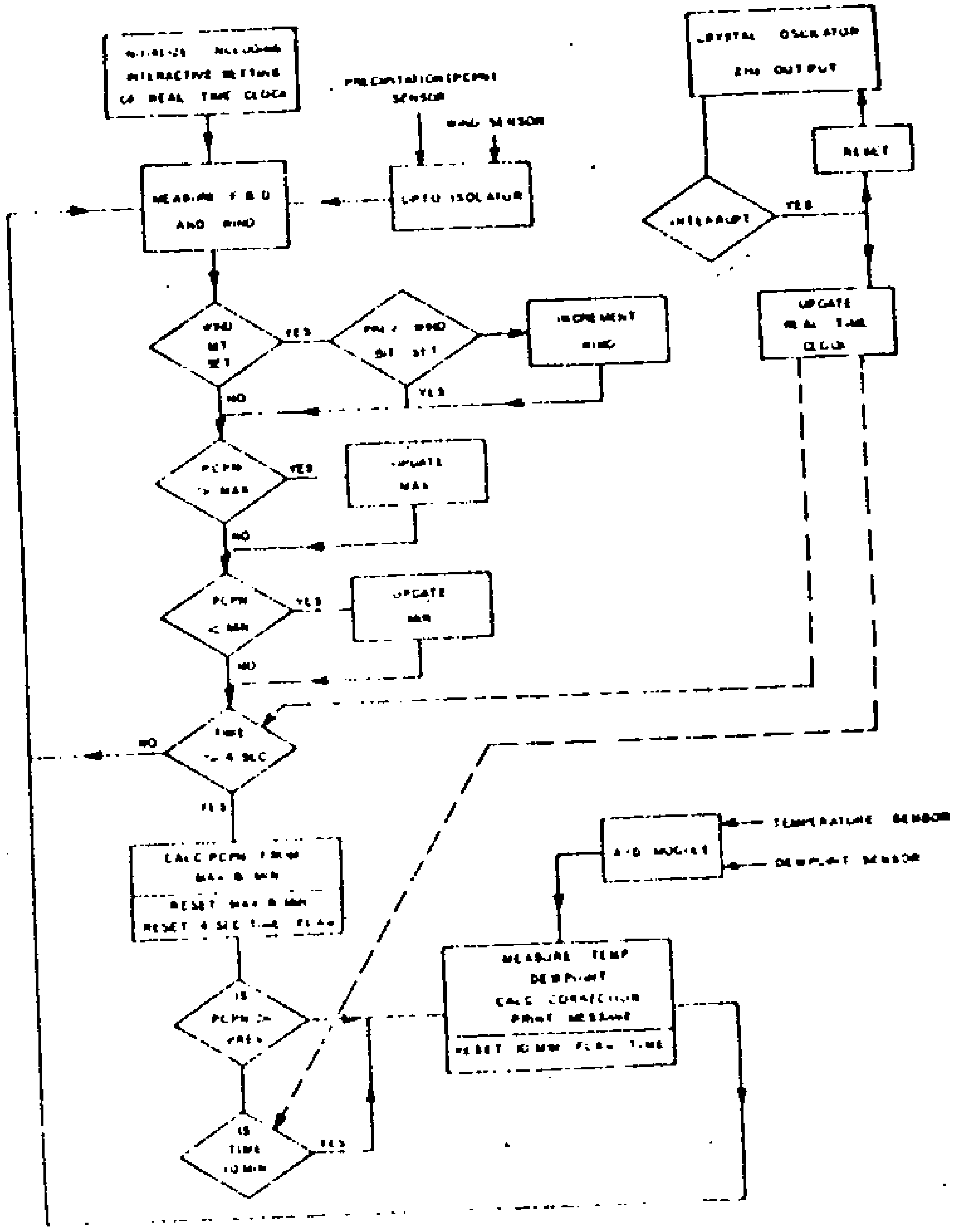


Figure 4

te: The maximum and minimum values are included in this readout to indicate the magni-
de of wind pumping. The difference of these two values was greater than 0.30 during one
orm at our headquarters site this winter.

Unfortunately the system was not installed in the field until late in the snowfall
at so that the amount of data obtained was limited. Testing will continue next year at
ich time temperature and dewpoint parameters will be included and a fuller assessment of
e utility of the system will be possible.

On the practical side, this system could hardly be considered suitable for our
twork application. The cost of the system is about $10,000, it requires 110 VAC power,
d a multiconductor cable between the sensors and the heated shelter for the System 80/10.

However, we are now developing low power, low temperature microcomputer systems
ich can be combined with a meteorological sensor or group of sensors to provide a "smart"
nsor. This "smart" sensor will be able to process the raw sensor signals, provide linear-
ation, averaging, or corrections as required (or requested under software control), pro-
de self evaluation, and enable communication of this data with a minimum of hardware. We
pe the data from this test will put us a step closer to the introduction of smart pre-
pitation gauges.

REFERENCES

Allis, J. A., B. Harris, and A. L. Sharp, 1963: A comparison of performance of five rain gauge installations. J. Geophys.Res., 68, 4723-4729.

Baker, M. B. and D. Ross Carder, 1977: Comparative evaluations of four snow models. Proc. West Snow Conf., 45, 58-62.

Goodison, B. E., 1975: Snow studies at Cold Creek; testing and evaluation of gauges used in Canada for fresh snowfall measurement. Proc. Canadian Hydrology Symposium -75, Winnipeg, Aug. 11-14, 1975, 26-35.

Goodison, B. E., 1977a: Snowfall and Snow Cover in Southern Ontario: Principles and Techniques of Assessment. Ph.D. thesis, University of Toronto, 403 pp.

Goodison, B. E., 1977b: Accuracy of Canadian snow gauge measurements. Proc. Second Conference on Hydrometeorology, AMS, Toronto, October 25-27, 1977, 220-224.

Goodison B. E., 1978: Canadian snow gauge measurements: accuracy, implications, alternatives, needs. Preprints, 7th Symposium on Applied Prairie Hydrology, Saskatoon, May 9-11, 1978, 9 pp (in press).

Hamon, W. R., 1973: Computing actual precipitation in mountainous areas. Proc. WMO-IAHS Symposium on the Distribution of Precipitation in Mountainous Areas. Volume 1, WMO No. 326, World Meteorological Organization, Geneva, 159-173.

Harris, R. E. and A. C. Carder, 1974: Rain and snow gauge comparisons, Can. J. of Earth Sciences, 11, 557-564.

Keyes, Jr. C. G., 1977: NAIWMC - Impact on hydrometeorological measurements. Proc. West Snow Conf., 45, 28-34.

Larson, L. W. and E. L. Peck, 1974: Accuracy of precipitation measurements for hydrologic modeling. Water Resources Research, 10, 857-863.

Rechard, P. A. and L. W. Larson, 1971: The use of snow fences for shielding precipitation gages. Proc. West Snow Conf., 39, 56-62.

Rechard, P. A., R. E. Brewer and A. Sullivan, 1974: Measuring snowfall, a critical parameter for snow resource management. Symp. on the Advanced Concepts and Techniques in the Study of Snow and Ice Resources. Monterey, California, December 2-6, 1973, 706-715.

Tangborn, W. V., 1977: Application of a new hydrometeorological streamflow prediction model. Proc. West Snow Conf., 45, 35-43.

Warner, O. R., 1966: Precipitation gages - types, methods and uses. Proc. West Snow Conf., 34, 78-81.

Weiss, L. L. and W. T. Wilson, 1957: Precipitation gage shields. I.A.S.H. General Assembly of Toronto, Vol. I, Pub No. 43, IAHS, Gentbrugge 462-484.

#76

ABSTRACT

METRICATION OF MANUAL SNOW SAMPLING EQUIPMENT

by

WESTERN SNOW CONFERENCE METRICATION COMMITTEE:
Phillip E. Farnes, Ned R. Peterson, Barry E. Goodison, and Robert P. Richards[1]

The Western Snow Conference Metrication Committee, after four years of field testing, is presenting its proposal and design of metric snow sampling equipment.

The snow sampler for the deeper western snowpacks has approximately 10.5 cm^2 cutter area while the sampler for the more shallow snowpacks (up to 1 m depth) has approximately 30 cm^2 cutter area.

Extensive field tests show comparisons between ground truth, the federal snow sampler, the metric snow sampler and other snow samplers. Also included are drawings and specifications for the new metric snow samplers. A method for adjusting back records collected using the present samplers so they will be compatible with the metric samplers is presented. A method for converting present sampling equipment into a metric sampler is proposed.

The data obtained by the metrication committee includes extensive field measurements using controlled sampling procedures in the snowpacks of eastern Canada, western Canada, the Sierra Mountains in California and the Rocky Mountains in Montana.

---

[1] Phillip E. Farnes, Soil Conservation Service, Bozeman, Montana
Barry E. Goodison, Atmospheric Environment Service, Downsview, Ontario
Ned R. Peterson, Department of Water Resources, Sacramento, California
Robert P. Richards, Ministry of the Environment, Victoria, British Columbia

Presented at the 50th Annual Western Snow Conference in Reno, Nevada
April 20-23, 1982

Table II. Data obtained prior to Metrication Committee 1964-1978.

---> All SWE in mm

Location	No.	Date	Std. Fed. Depth (cm)	Standard Federal	1978 Metric (short)	Long Metric (78)	BUNG	Broken Tooth Fed.	Pit or Template	Profile Gage	McCall	Adirondack	Utah	MSC	Bowman	Rosen	L&S	CRREL 500 cm^2 Tubes
Inside Dia mm		Note: Prior to		37.7	35.7	35.7	37.7	37.7	---	---	37.7	67.4	37.7	70.5	37.7	37.7	37.7	58.1
AREA cm^2		1979 depths are		11.2	10.0	10.0	11.2	11.2			11.2	35.7	11.2	39.1	11.2	11.2	11.2	26.5
SHARP or BLUNT		from Federal		Blunt	Sharp	Sharp	Sharp	Blunt	---	---	SHARP	SHARP	SHARP	SHARP	SHARP	BLUNT	BLUNT	SHARP
No Teeth		sampler.		16	16	16	0	15	---	---	16	0	32	16	16	8	8	0
Tubing Material				Alum.	Alum.	Alum.	Alum.	Alum.	---	---	Alum.	Fiberglass	Steel	Alum.	Plastic	Alum.	Alum.	Stain. Steel
Mount Hood, OR	64-OR-1	11/19/63	93	232					214			218			210	221		
Mount Hood, OR	64-OR-2	12/2/63	84	294					276			283			274	277		
Mount Hood, OR	64-OR-3	2/3/64	361	1201					1077							1138		
Mount Hood, OR	64-OR-4	2/24/64	371	1458					1311							1394		
Mount Hood, OR	64-OR-5	5/12/64	498	2390					2169			2159				2233	2342	
Mount Hood, OR	64-OR-6	7/8/64	155	991			892		843									
SCS Grounds, AK	64-AK-1	3/10/64	43	70					68			69			69			74
Cleary Summit, AK	64-AK-2	3/11/64	51	87					79			76			84			78
Exp. Farm, AK	64-AK-3	3/12/64	41	74					67			70			71			71
Fort Yukon, AK	64-AK-4	3/16/64	46	71					69			68			68			74
Arctic Village, AK	64-AK-5	3/17/64	56	99					86			84			88			96
Venetie, AK	64-AK-6	3/17/64	36	61					56			54			57			62
Chandalar Lake, AK	64-AK-7	3/18/64	48	92					82			89			87			93
Lick Creek, MT	64-MT-1	5/7/64	108	428			401		399									
Lick Creek, MT	64-MT-2	5/7/64	109	440			403											
Lick Creek, MT	64-MT-3	5/15/64	81	374			346											
Lick Creek, MT	64-MT-4	5/19/64	51	247			226											
Lick Creek, MT	64-MT-5	5/21/64	33	151			142											
Lick Creek, MT	64-MT-6	5/23/64	25	101			90											
Lick Creek, MT	64-MT-7	5/25/64	8	30			26											
Alpha, CA	66-CA-1	2/17/66	217	759					722									
Alpha, CA	66-CA-2	3/15/66	173	719					688									
Alpha, CA	66-CA-3	4/13/66	137	589					551									
Alpha, CA	66-CA-4	5/2/66	78	419					376									
Alpha, CA	67-CA-1	2/17/67	100	343					330									
Alpha, CA	67-CA-2	4/11/67	204	795					754									
Alpha, CA	67-CA-3	5/2/67	247	1016					932									
Alpha, CA	67-CA-4	5/11/67	169	843					767									
Alpha, CA	68-CA-1	4/12/68	95	478					442									
Alpha, CA	70-CA-1	4/16/70	121	493					460									
Alpha, CA	71-CA-1	NA	134	310					310									
Alpha, CA	74-CA-1	NA	168	841					765									
Luther Marsh, ONT	74-ON-1	12/18/74	7	13					12		13			13	13		14	
Luther Marsh, ONT	75-ON-1	2/20/75	37	89					85		86			91	83		90	
Luther Marsh, ONT	75-ON-2	3/20/75	23	95					95		93			93	101		107	
Luther Marsh, ONT	75-ON-3	3/20/75	39	140					140		136			158	133		143	
Big Sky Plowed, MT	75-MT-1	2/6/75	190	737						696								
Big Sky Exposed, MT	75-MT-2	2/6/75	105	279						269								
Big Sky Shaded, MT	75-MT-3	2/6/75	119	381						290								
Five Bull, MT	75-MT-4	3/15/75	62	203						150								
Trinkus Lake, MT	75-MT-5	3/15/75	272	1054						1059								
Upper Holland Lake, MT	75-MT-6	3/15/75	190	737						643								
Badger Pass, MT	75-MT-7	3/16/75	282	1219						1102								
Blue Lake, MT	75-MT-8	3/16/75	198	864						714								
Spotted Bear Mtn., MT	75-MT-9	3/16/75	114	356						348								
Badger Pass, MT	75-MT-10	4/6/75	241	1067						894								
Blue Lake, MT	75-MT-11	4/6/75	161	483						488								
Gunsight Lake, MT	75-MT-12	4/6/75	229	940						803								
Spotted Bear Mtn., MT	75-MT-13	4/6/75	122	381						378								
Trinkus Lake, MT	75-MT-14	4/6/75	190	635						635								
Twin Creeks, MT	75-MT-15	4/6/75	104	381						295								
Upper Holland Lake, MT	75-MT-16	4/6/75	224	864						767								
Badger Pass, MT	75-MT-17	5/15/75	213	1092						950								
Blue Lake, MT	75-MT-18	5/15/75	193	1016						942								
Gunsight Lake, MT	75-MT-19	5/15/75	173	1029						859								
Spotted Bear Mtn., MT	75-MT-20	5/15/75	57	279						221								
Trinkus Lake, MT	75-MT-21	5/15/75	224	1143						1072								
Upper Holland Lake, MT	75-MT-22	5/15/75	168	914						775								
Badger Pass, MT	75-MT-23	5/31/75	272	1511						1308								
Blue Lake, MT	75-MT-24	5/31/75	113	635						518								
Gunsight Lake, MT	75-MT-25	5/31/75	163	1080						864								
Trinkus Lake, MT	75-MT-26	5/31/75	117	533						645								
Upper Holland Lake, MT	75-MT-27	5/31/75	115	686						645								
Fisher Creek, MT	75-MT-28	6/27/75	175	914						777								
White Mill, MT	75-MT-29	6/27/75	117	635						528								

TABLE I

APPROXIMATE OVERMEASUREMENT OF SNOW WATER EQUIVALENT FOR VARIOUS SNOW SAMPLERS IN PERCENT

TYPE	CUTTER AREA, cm²	OVERMEASUREMENT
Glacier	81.9	0
Standard Federal	11.2	9
Sharpended Federal	11.2	5
78 Short Metric	10.0	6
78 Long Metric	10.0	3
79 Metric	9.9	6½
80 Metric	10.0	3½
81 Metric	10.4	4
ESC-30	29.8	0
Broken-tooth Federal	11.2	10½
BUNG	11.2	3
McCall	11.2	3½
Adirondack	35.7	1
CRREL Sampler	20.4	0
CRREL Tubes (500 cm³)		6½ (shallow snow)
Aluminum Tubing	77.1	0
ESC-50	49.6	0
PVC Tubing	20.9	0
ESC-40	40.5	0
Rosen	11.2	3
Bowman	11.2	4
L&S	11.2	10
MSC	39.1	6½

Table II. (Continued)

---> All SWE in mm

Location	No.	Date	Std. Fed. Depth (cm)	Standard Federal	1978 Metric (short)	Long Metric (78)	BUNG	Broken Tooth Fed.	Pit or Template	Profile Gage	McCall	Adirondack	Utah	MSC	Bowman	Rosen	L&S	CRREL 500 cm² Tubes
Cooke Station, MT	76-MT-1	12/29/75	122	368						360								
Fisher Creek, MT	76-MT-2	12/29/75	188	648						588								
Cooke Station, MT	76-MT-3	12/29/75	112	419						348								
White Mill, MT	76-MT-4	12/29/75	168	559						494								
NE Entrance, MT	76-MT-5	12/29/75	62	165						157								
NOTE: PROFILE GAGE MODIFIED IN JANUARY 1976																		
Gunsight Lake, MT	76-MT-16	2/29/76	269	889						892								
Spotted Bear Mtn., MT	76-MT-17	2/29/76	107	305						297								
Trinkus Lake, MT	76-MT-18	2/29/76	165	508						495								
Badger Pass, MT	76-MT-19	3/3/76	300	1118						1044								
Blue Lake, MT	76-MT-20	3/3/76	218	711						701								
Twin Creeks, MT	76-MT-21	3/3/76	117	305						318								
Upper Holland Lake, MT	76-MT-22	3/4/76	193	635						594								
Trinkus Lake, MT	76-MT-23	3/31/76	199	762						767								
Twin Creeks, MT	76-MT-24	3/31/76	102	356						361								
Trinkus Lake, MT	76-MT-25	5/2/76	114	533						455								
Cold Creek, ONT	76-ON-1	12/29/75	14	20					19		19	19		20	19		20	
Luther Marsh, ONT	76-ON-2	1/5/76	23	52					50		50	49		53	52		55	
Luther Marsh, ONT	76-ON-3	1/28/76	26	74					66		70	68		75	73		78	
Luther Marsh, ONT	76-ON-4	2/24/76	38	157					144		149	132		147	154		165	
Luther Marsh, ONT	76-ON-5	3/11/76	51	184					180		174	188		197	190		213	
Luther Marsh, ONT	77-ON-1	1/21/77	40	88					82		84	82		84	78		81	
Luther Marsh, ONT	77-ON-2	3/2/77	57	189					170		173	175		177	186		187	
Alpha, CA	77-CA-1	4/15/77	52	188	190	188												
Short Creek, MT	77-MT-1	3/15/77	58	117	99	107	102											
Darkhorse Lake, MT	77-MT-2	3/16/77	122	340	315	325	320											
Bloody Dick, MT	77-MT-3	3/16/77	58	122	109	122	109											
Lick Creek, MT	77-MT-4	3/22/77	122	353	325	328	325			320								
Bridger Bowl, MT	77-MT-5	3/30/77	190	594	569	564	569											
Shower Falls, MT	77-MT-6	3/28/77	203	617	587	584	587											
Maynard Creek, MT	78-MT-1	12/1/77	48	93	89	84	89											
Copper Bottom, MT	78-MT-2	12/16/77	56	174	166													
Fisher Creek, MT	78-MT-3	12/27/77	213	640	599													
White Mill, MT	78-MT-4	12/27/77	185	533	508													
Cooke Station, MT	78-MT-5	12/27/77	150	401	384													
Lick Creek, MT	78-MT-6	12/28/77	58	132	119					122			122					
Bridger Bowl, MT	78-MT-7	12/29/77	142	444	406													
Lick Creek Divide, MT	78-MT-8	1/25/78	81	189	171	169	175			163								
Cooke Station, MT	78-MT-9	1/27/78	183	544	528													
White Mill, MT	78-MT-10	1/27/78	201	650	627													
Fisher Creek, MT	78-MT-11	1/27/78	262	833	808													
Bridger Bowl, MT	78-MT-12	1/31/78	213	655	630													
Crystal Lake, MT	78-MT-13	2/24/78	145	442	424													
Arch Falls, MT	78-MT-14	2/27/78	109	302	287													
Little Park, MT	78-MT-15	3/1/78	152	485	465													
Northeast Entrance, MT	78-MT-16	3/14/78	107	368	348	358	351			319								
Northeast Entrance, MT	78-MT-17	3/14/78	122	387						336								
Lick Creek, MT	78-MT-18	3/29/78	71	300	274	259	274											
Hood Meadow, MT	78-MT-19	3/29/78	86	318	310													
Shower Falls, MT	78-MT-20	3/29/78	206	798	759	759	777											
Bridger Bowl, MT	78-MT-21	3/30/78	183	813	744													
Tepee Creek, MT	78-MT-22	3/31/78	127	462	439													
Bridger Bowl, MT	78-MT-23	4/26/78	190	925	846													
Devils Slide, MT	78-MT-24	4/27/78	208	851	810	803	815											
Beartooth, MT	78-MT-25	5/10/78	249	1151	1075	1084	1072											
Cooke Pass, MT	78-MT-26	5/10/78	168	902	849	869	884			742								
Star Lake, MT	78-MT-27	5/11/78	312	1453	1369	1346	1374											
White Mill, MT	78-MT-28	5/11/78	227	1035						924								
Spur Park, MT	78-MT-29	5/12/78	178	820	796	793	759											
Shower Falls, MT	78-MT-30	5/16/78	201	919	858	830	853											
Goose Lake, MT	78-MT-31	5/30/78	323	1727	1611	1600	1671											
Mt. St. Anne, BC	78-BC-1	1/11/78	205	636	600	596	599	530			604							
Mission Creek, BC	78-BC-2	1/8/78	118	336	316	335	320	335			308							
Blackwall, BC	78-BC-3	1/7/78	172	543	516	508	517	524			515							
Luther Marsh, ONT	78-ON-1	1/19/78	41	111	111	112			110		108	113		120				115
Luther Marsh, ONT	78-ON-2	2/17/78	51	165	164	162			147		151	150		149				163
Luther Marsh, ONT	78-ON-3	3/16/78	43	125	137	130			145		114	144		150				138
Peterborough, ONT	78-ON-4	2/27/78	37	111	116	110			103					112				
Alpha, CA	78-CA-1	4/14/78	239	1016	1003	1013												

Table III. Data obtained by the Metrication Committee 1979-1981.

----> All SWE in mm

Location	No.	Date	Glacier Depth (cm)	Glacier Density	Glacier	Standard Federal	Sharpened Federal	1978 Metric (short)	1979 Metric	1980 Metric	1981 Metric	Broken Tooth Fed.	Pit or Template	Profile Gage	McCall	Adirondack	CRREL	Alum. Tubing	ESC 50 Fiberglass	ESC 50 Plastic	PVC Tubing	Utah	ESC 40	ESC 30	MSC
THE FOLLOWING DATA WERE OBTAINED USING CONTROL DESIGNED AND MANUFACTURED EQUIPMENT.																									
Maynard Creek S, MT	79-MT-1	1/30/79	99	28	275	275	277		297																
Maynard Creek N, MT	79-MT-2	1/30/79	95	25	236	264	249		265																
New World W, MT	79-MT-3	1/31/79	90	22	199	236	208		226																
New World E, MT	79-MT-4	1/31/79	90	24	212	250	215		250																
New World N, MT	79-MT-5	1/31/79	86	22	189	229	209		214																
Lower New World E, MT	79-MT-6	1/31/79	99	23	232	244	244		262																
Lower New World W, MT	79-MT-7	1/31/79	100	23	227	251	242		270																
Porcupine S, MT	79-MT-8	2/21/79	93	26	241	282	263	262	258																
Porcupine W, MT	79-MT-9	2/21/79	91	25	223	243	232	231	247																
Lower New World SE, MT	79-MT-10	2/26/79	139	29	400	460	459	462	454																
Lower New World SW, MT	79-MT-11	2/26/79	133	28	376	425	431	426	432																
Twenty-one Mile W, MT	79-MT-12	3/9/79	145	26	379	428	408	403	417																
Twenty-one Mile SW, MT	79-MT-13	3/9/79	141	26	360	414	392	396	404																
Twenty-one Mile SE, MT	79-MT-14	3/9/79	146	26	375	431	411	408	414																
Star Lake NW, MT	79-MT-15	3/21/79	254	35	885	986	993	993	1005																
Star Lake S, MT	79-MT-16	3/21/79	252	35	871	984	966	972	970																
Fisher Creek S, MT	79-MT-17	3/22/79	249	36	893	983	959	978	960																
Fisher Creek N, MT	79-MT-18	3/22/79	248	36	992	988	973	989	968																
Cooke Station W, MT	79-MT-19	3/22/79	186	33	616	678	693	692	693																
Cooke Station E, MT	79-MT-20	3/22/79	195	34	667	725	725	737	739																
White Mill S, MT	79-MT-21	3/22/79	211	34	715	818	809	839	817																
White Mill N, MT	79-MT-22	3/22/79	208	34	703	798	793	826	805																
Lick Creek N, MT	79-MT-23	4/26/79	79	37	295	291	284	256	264																
Lick Creek S, MT	79-MT-24	4/26/79	81	35	281	296	285	263	276																
Shower Falls W, MT	79-MT-25	4/27/79	196	36	704	778	741	748	740					725											
Shower Falls E, MT	79-MT-26	4/27/79	195	34	671	757	731	733	739					701											
Clark Fork W, MT	79-MT-27	5/15/79	110	43	472	566	560	544	525																
Clark Fork E, MT	79-MT-28	5/15/79	113	47	531	593	571	558	543																
Fisher Creek NW, MT	79-MT-29	5/16/79	209	41	867	956	932	935	920																
Fisher Creek S, MT	79-MT-30	5/16/79	213	42	892	998	974	989	943																
Star Lake N, MT	79-MT-31	5/29/79	214	42	892	987	958	1004	942						924										
Star Lake SW, MT	79-MT-32	5/29/79	204	42	850	928	903	943	901						889										
White Mill W, MT	79-MT-33	5/30/79	126	40	500	568	569	551	565						551			495							
White Mill E, MT	79-MT-34	5/30/79	137	41	555	629	622	606	613					581	567			560							
Cooke Station W, MT	79-MT-35	5/30/79	99	39	390	456	440	449	425					411	412			391							
Cooke Station E, MT	79-MT-36	5/30/79	89	40	356	398	403	401	382						365			368							
Spaulding, CA	79-CA-1	2/28/79	206	32	655	660	641		626																
Alpha, CA	79-CA-2	3/15/79	211	34	713	761	721	734	721																
Spaulding, CA	79-CA-3	3/16/79	168	40	664	680	651	664	684																
Spaulding, CA	79-CA-4	4/2/79	146	45	651	693	676	685	666																
Alpha, CA	79-CA-5	4/4/79	196	36	709	771	731	736	742																
Alpha, CA	79-CA-6	5/2/79	152	46	692	731	742	719	739																
Forbidden Plateau, BC	79-BC-1	2/9/79	153	26	390	413	402		394																
Whistler Mtn, BC	79-BC-2	2/20/79	133	23	307	335	319		314			335													
Blackwall Pk, BC	79-BC-3	2/21/79	169	26	442	487	467		489			448													
New Copper Mtn, BC	79-BC-4	2/22/79	58	21	119	104	104		117			120													
Newcastle Ridge, BC	79-BC-5	3/9/79	319	38	1207	1315	1241		1294			1339													
Whistler Mtn, BC	79-BC-6	3/13/79	103	35	365	399	386		396			394													
Blackwall Pk, BC	79-BC-7	3/14/79	162	31	505	555	532		545			567													
New Copper Mtn, BC	79-BC-8	3/14/79	37	27	100	96	96		88			94													
Newcastle Ridge, BC	79-BC-9	4/19/79	332	45	1493	1630	1572		1612			1674													
Newcastle Ridge, BC	79-BC-10	4/19/79	330	42	1388	1550	1478		1498			1559													
Whistler Mtn, BC	79-BC-11	4/21/79	130	33	434	476	454		483			485													
Whistler Mtn, BC	79-BC-12	4/21/79	122	32	396	442	411		458			473													
Blackwall, BC	79-BC-13	4/23/79	156	34	534	587	564		580			591													
Blackwall, BC	79-BC-14	4/23/79	162	34	543	620	596		606			623													
Newcastle Ridge, BC	79-BC-15	5/7/79	1996	49	976	1108	1057	1045	1102			1122													
Newcastle Ridge, BC	79-BC-16	5/7/79	2259	52	1167	1271	1216	1181	1239			1306													
Ottawa, ONT	79-ON-1	2/1/79	45	35	157	146	144		162							141									142
Cold Creek #1, ONT	79-ON-2	2/16/79	27	21	57	68	67		68							56									61
Cold Creek #2, ONT	79-ON-3	2/16/79	28	22	61	64	60		70							53									55
Monticello, ONT	79-ON-4	2/20/79	95	29	278	310	302		303							283									298
Monticello #1, ONT	79-ON-5	3/8/79	37	34	124	121	122		124							125									125
Monticello #2, ONT	79-ON-6	3/8/79	26	36	93	97	93		92							93									97
Peterborough, ONT	79-ON-7	3/19/79	29	43	124	138	128		126							114									136
Ottawa, ONT	79-ON-8	3/21/79	36	49	175	169	164		158							158									174

Table III. (Continued)

---> All SWE in mm

Location	No.	Date	Glacier Depth (cm)	Glacier Density	Glacier	Standard Federal	Sharpened Federal	1978 Metric (short)	1979 Metric	1980 Metric	1981 Metric	Broken Tooth Fed.	Pit or Template	Profile Gage	McCall	Adirondack	CRREL	Alum Tubing	ESC 50 Fiberglass	ESC 50 Plastic	PVC Tubing	Utah	ESC 40	ESC 30	MSC
Blackwall, BC	81-BC-1	2/26/81	165	26	438	485	461		461	450	452														
Newcastle Ridge, BC	81-BC-2	3/3/81	80	29	231	204	206		207	201	195														
Ottawa, ONT	81-ON-1	2/10/81	43	35	152	147	152				142					141									
New World W, MT	81-MT-1	1/29/81	43	20	89	97	92	96			91												94		
New World E, MT	81-MT-2	1/29/81	42	20	86	93	89	91			87												88		
Lower New World W, MT	81-MT-3	1/29/81	28	15	41	43	40	38			41												38		
Lower New World E, MT	81-MT-4	1/29/81	28	15	42	41	40	42			39												37		
Lick Creek W, MT	81-MT-5	3/12/81	81	28	226	243	240	251			236												220	221	
Lick Creek E, MT	81-MT-6	3/12/81	83	28	230	249	246	247			241												229	230	
Skylark Trail N, MT	81-MT-7	3/25/81	115	33	376	386	384	397			389												372	386	
Skylark Trail S, MT	81-MT-8	3/25/81	112	32	359	379	375	383			368												356	369	
Palace Butte NW, MT	81-MT-9	3/30/81	48	27	131	144	144	157			146												122	126	
Palace Butte NE, MT	81-MT-10	3/30/81	47	27	127	141	141	153			142												119	123	
Palace Butte SW, MT	81-MT-11	3/30/81	52	28	146	163	152	158			160												127	125	
Palace Butte SE, MT	81-MT-12	3/30/81	52	26	138	163	152	158			160												127	125	
Lick Creek W, MT	81-MT-13	3/30/81	55	30	167	187	164	181			178												184	165	
Lick Creek E, MT	81-MT-14	3/30/81	52	32	165	170	153	170			153												174	160	
Shower Falls W, MT	81-MT-15	3/31/81	179	24	432	471	458	425			450												430	428	
Shower Falls E, MT	81-MT-16	3/31/81	183	24	441	475	468	425			453												452	446	
Arch Falls N, MT	81-MT-17	3/31/81	117	26	301	304	314	282			293												288	285	
Arch Falls SE, MT	81-MT-18	3/31/81	120	27	330	319	312	294			298												302	304	
Cooke City E, MT	81-MT-19	4/8/81	111	27	303	326	331	319			318												304	287	
Cooke City W, MT	81-MT-20	4/8/81	105	27	276	299	287	293			291												273	286	
Jardine E, MT	81-MT-21	4/9/81	53	25	135	135	130	137			136												132	138	
Jardine W, MT	81-MT-22	4/9/81	55	25	136	142	133	138			146												135	147	
Black Bear E, MT	81-MT-23	4/22/81	162	41	666	675	664	673			657												680	677	
Black Bear W, MT	81-MT-24	4/22/81	159	40	640	677	652	654			646												627	627	
Whiskey Creek E, MT	81-MT-25	4/23/81	37	36	132	153	142	143			142												130	138	
Whiskey Creek W, MT	81-MT-26	4/23/81	36	36	132	149	141	137			141												126	130	
Fisher Creek N, MT	81-MT-27	5/11/81	185	34	619	670	664	698			655												642	639	
Fisher Creek S, MT	81-MT-28	5/11/81	178	35	617	642	633	652			613												614	618	
Cooke Pass N, MT	81-MT-29	5/12/81	65	38	246	250	239	242			231												244	239	
Cooke Pass S, MT	81-MT-30	5/12/81	70	38	265	279	265	263			255												265	257	
Cooke Station N, MT	81-MT-31	5/12/81	110	32	356	376	357	381			365												361	357	
Cooke Station S, MT	81-MT-32	5/12/81	109	32	348	385	368	390			384												365	362	
Luther Marsh, ONT	82-ON-1	1/8/82	22	22	48	49					48													48	48
Luther Marsh, ONT	82-ON-2	1/8/82	20	19	38	42					36													40	38
Peterborough, ONT	82-ON-3	1/13/82	23	20	47	52					49													46	46
Dorset, ONT	82-ON-4	1/22/82	48	22	104	114					112													106	103
Dorset, ONT	82-ON-5	1/22/82	51	23	118	125					118													108	110
Peterborough, ONT	82-ON-6	2/8/82	60	21	127	134					124													127	131
Peterborough, ONT	82-ON-7	2/8/82	58	22	129	131					120													123	128
Luther Marsh, ONT	82-ON-8	2/10/82	55	22	120	114					114													118	124
Battle Ridge S, MT	82-MT-1	12/29/81	68	22	147	140	136	135			127												145	141	
Battle Ridge N, MT	82-MT-2	12/29/81	66	20	133	146	128	131			124												153	145	
Battle Ridge W, MT	82-MT-3	12/29/81	38	19	74	66	66	57			64												62	62	
Battle Ridge E, MT	82-MT-4	12/29/81	35	19	65	63	64	55			59												65	59	
Shower Falls N, MT	82-MT-5	1/26/82	171	26	450	503	496	508			484												445	447	
Shower Falls S, MT	82-MT-6	1/26/82	172	26	451	522	501	510			487												457	450	
Shower Falls E, MT	82-MT-7	3/29/82	269	28	744	805	788	815			830														
Shower Falls W, MT	82-MT-8	3/29/82	264	28	734	831	805	821			824														
Lick Creek N, MT	82-MT-9	3/30/82	115	25	282	321	308	305	1		303														
Lick Creek S, MT	82-MT-10	3/30/82	118	26	310	337	323	330			322														
Alpha, CA	82-CA-1	2/2/82	212	31	649	698	685		683	664	677														
Alpha, CA	82-CA-2	2/19/82	173	39	677	734	691		683	694	680														
Alpha, CA	82-CA-3	2/25/82	157	39	620	647	625		623	621	626														
Alpha, CA	82-CA-4	3/15/82	206	36	742	803	760		785	806	781														

Table III. (Continued)

---> All SWE in mm

Location	No.	Date	Glacier Depth (cm)	Glacier Density	Glacier	Standard Federal	Sharpened Federal	1978 Metric (short)	1979 Metric	1980 Metric	1981 Metric	Broken Tooth Fed.	Pit or Template	Profile Gage	McCall	Adirondack	CRREL	Alum. Tubing	ESC 50 Fiberglass	ESC 50 Plastic	PVC Tubing	Utah	ESC 40	ESC 30	MSC
Porcupine S, MT	80-MT-1	2/1/80	44	22	95	97	89	106		87								95							
Porcupine N, MT	80-MT-2	2/1/80	44	22	96	97	89	106		87								95							
Tepee Creek W, MT	80-MT-3	2/14/80	82	22	181	203	178	188		186								177							
Tepee Creek E, MT	80-MT-4	2/14/80	79	21	165	193	171	184		182								171							
New World W, MT	80-MT-5	2/26/80	104	24	250	268	275	259		257															
New World E, MT	80-MT-6	2/26/80	104	24	248	270	275	263		262															
New World Gulch W, MT	80-MT-7	2/26/80	118	24	290	320	318	309		306															
New World Gulch E, MT	80-MT-8	2/26/80	115	24	273	311	303	294		288															
Bridger Bowl W, MT	80-MT-9	2/28/80	128	30	379	404	395	402		391															
Bridger Bowl E, MT	80-MT-10	2/28/80	120	28	337	367	378	375		356															
Sacajawea SC W, MT	80-MT-11	3/14/80	151	28	428	471	459	473		459															
Sacajawea SC E, MT	80-MT-12	3/14/80	149	28	414	469	456	477		461															
Sacajawea W, MT	80-MT-13	3/14/80	128	24	310	342	329	347		328															
Sacajawea E, MT	80-MT-14	3/14/80	140	26	359	397	383	389		387															
Maynard Cr. S, MT	80-MT-15	4/11/80	147	33	489											476	491		478						
Maynard Cr. N, MT	80-MT-16	4/11/80	144	34	489	530	503	521		507						482	477		491						
Battle Ridge S, MT	80-MT-17	4/11/80	84	32	272	271	269	253		256						267	252		273	286					
Battle Ridge N, MT	80-MT-18	4/11/80	86	32	277	273	270	258		260						278	284		267	286					
Star Lake E, MT	80-MT-19	4/22/80	208	38	790	868	838	852		836					819					780	778				
Star Lake W, MT	80-MT-20	4/22/80	219	39	846	922	886	899		891					883					853	857				
Star Lake C, MT	80-MT-21	4/22/80	214	39	830	907	861	869		867					863					826	825				
White Mill E, MT	80-MT-22	4/23/80	162	38	618	673	641	668		642					655					615	622				
White Mill W, MT	80-MT-23	4/23/80	165	38	630	687	654	686		653					658					625	634				
NE Entrance E, MT	80-MT-24	4/23/80	55	37	202	204	192	191		184										184	194				
NE Entrance W, MT	80-MT-25	4/23/80	51	38	197	194	183	182		183										180	182				
Hyalite Creek W, MT	80-MT-26	4/28/80	80	34	271	284	282	290		274					264					274	271	274			
Hyalite Creek E, MT	80-MT-27	4/28/80	84	33	278	306	300	300		286					283					278	281	286			
Window Rock N, MT	80-MT-28	4/28/80	57	36	206	230	209	190		214					187					206	187	191			
Window Rock S, MT	80-MT-29	4/28/80	61	34	206	230	225	207		222					200					216	225	207			
Arch Falls W, MT	80-MT-30	4/29/80	92	35	322	350	324	369		340										331	326	348			
Arch Falls E, MT	80-MT-31	4/29/80	98	35	344	376	340	387		364										351	349	373			
Spaulding, CA	80-CA-1	1/2/80	55	39	215	227	214	221	217																
Alpha, CA	80-CA-2	1/4/80	138	32	435	477	452	463	478																
Darrington, CA	80-CA-3	1/30/80	161	35	567	609	565	632	595	545															
Alpha, CA	80-CA-4	1/31/80	183	37	652	731	708	690	720	702															
Alpha, CA	80-CA-5	2/14/80	175	38	673	751	688	728	690	657			660												
Spaulding, CA	80-CA-6	2/27/80	56	43	242	254	253	253	242	247															
Alpha, CA	80-CA-7	2/28/80	272	35	957	1071	998	1001	1016	1046															
Alpha, CA	80-CA-8	3/13/80	279	39	1090	1168	1163	1152	1112	1096															
Darrington, CA	80-CA-9	3/26/80	235	40	950	1072	983	976	1016	968															
Alpha, CA	80-CA-10	3/27/80	269	42	1134	1225	1184	1185	1191	1181															
Alpha, CA	80-CA-11	5/1/80	172	46	792	914	892		830	875			803												
Blackwall, BC	80-BC-1	2/12/80	154	30	456	535	507		516	508															
Blackwall, BC	80-BC-2	2/12/80	156	29	454	493	477		478	471															
New Copper, BC	80-BC-3	2/13/80	43	25	107	94	90		90	94															
New Copper, BC	80-BC-4	2/13/80	44	23	99	94	90		90	91															
Whistler, BC	80-BC-5	2/14/80	121	29	338	397	387		405	381															
Whistler, BC	80-BC-6	2/14/80	120	28	339	388	385		427	348															
Newcastle Ridge, BC	80-BC-7	2/15/80	231	40	916	1029	965		998	965															
Newcastle Ridge, BC	80-BC-8	2/15/80	228	39	888	1037	972		994	949															
Newcastle Ridge, BC	80-BC-9	2/20/80	224	39	875	955	916		927	893															
Blackwall, BC	80-BC-10	2/28/80	145	31	456	518	518		508	495															
New Copper, BC	80-BC-11	2/29/80	38	28	106	96	97		94	94															
Whistler, BC	80-BC-12	3/2/80	125	33	410	449	444		438	445															
Blackwall, BC	80-BC-13	3/18/80	200	32	631	728	704		733	706															
Blackwall, BC	80-BC-14	3/18/80	200	32	642	724	702		718	691															
McBride, BC	80-BC-15	3/21/80	125	25	314	348	351		354	335															
McBride, BC	80-BC-16	3/21/80	125	25	318	354	353		340	327															
Whistler, BC	80-BC-17	3/25/80	125	30	373	412	387		394	398															
Whistler, BC	80-BC-18	3/25/80	125	32	403	387	373		398	388															
Alpha, CA	81-CA-1	2/4/81	109	24	263	279	267		275	269	273														
Alpha, CA	81-CA-2	2/17/81	86	34	293	304	291		283	287	290														
Alpha, CA	81-CA-3	3/3/81	99	37	363	409	376		378	378	369														
Alpha, CA	81-CA-4	3/18/81	90	39	355	373	358		357	351	358													353	
Alpha, CA	81-CA-5	4/3/81	157	37	576	582	568		586	576	578													563	
Alpha, CA	81-CA-6	4/16/81	96	43	409	451	444		441	416	420													400	

Table IV. Data obtained by others using some equipment similar to Metrication Committee 1977-1982.

---> All SWE in mm

Location	No.	Date	Glacier Depth (cm)	Glacier Density	Glacier	Standard Federal	Sharpened Federal	1978 Metric (short)	Long Metric (78)	1979 Metric	1980 Metric	1981 Metric	Pit or Template	Rosen
DATA OBTAINED BY OTHERS USING SOME EQUIPMENT AND PROCEDURES COMPARABLE TO BUT NOT NECESSARILY UNDER THE SAME CONDITIONS USED BY THE METRICATION COMMITTEE.														
Trinity Mtn, ID	77-ID-1	3/25/77	86			187							192	
Trinity Mtn, ID	77-ID-2	4/8/77	56			210		189	198					184
Trinity Mtn, ID	77-ID-3	4/12/77	46			173		160	164				155	146
Trinity Mtn, ID	77-ID-4	4/20/77	91			462		452	433					438
Trinity Mtn, ID	77-ID-5	4/21/77	91			469		423	457					448
Trinity Mtn, ID	77-ID-6	4/26/77	76			395		375	372					363
Graham Station, ID	78-ID-1	3/26/78	116			521							448	
Graham Station RSG, ID	78-ID-2	3/26/78	132			539							505	
Mores Creek, ID	78-ID-3	5/2/78	193			928							870	
Mores Creek RSG, ID	78-ID-4	5/2/78	223			940							858	
Trinity Mtn, ID	78-ID-5	5/28/78	188			1014							888	
Trinity Mtn RSG, ID	78-ID-6	5/28/78	205			1031							917	
Graham Station, ID	79-ID-1	1/27/79	74	22	166	192	167			182				
Graham SNOTEL, ID	79-ID-2	1/27/79	74			270							247	
Graham CA, ID	79-ID-3	1/27/79	79			282							276	
Graham RSG, ID	79-ID-4	1/27/79	70			264							249	
Trinity Mtn #1, ID	79-ID-5	3/7/79	205	31	640	692	692			666				
Trinity Mtn #2, ID	79-ID-6	3/8/79	201	31	618	685	688			670				
Trinity Mtn #3, ID	79-ID-7	3/8/79	195	32	618	692	676			665				
Trinity 8X10 CA, ID	79-ID-8	3/8/79	109			565							497	
Trinity 4X5 CA, ID	79-ID-9	3/8/79	106			533							475	
Trinity SNOTEL, ID	79-ID-10	3/8/79	115			570							513	
Trinity Hypalon, ID	79-ID-11	3/8/79	105			524							467	
Trinity RSG, ID	79-ID-12	3/8/79	120			607							504	
Columbine, CO	79-CO-1	3/20/79	188	34	632	722				670				
Columbine #1, CO	80-CO-1	2/14/80	140	30	422	439	415				430			
Columbine #2, CO	80-CO-2	2/14/80	140	29	406	432	429				448			
Willow Creek, CO	80-CO-3	3/26/80	142	28	393	419								
Columbine, CO	80-CO-4	3/26/80	201	32	648	755								
Tower, CO	80-CO-5	3/27/80	384	34	1306	1388								
Columbine, CO	80-CO-6	4/23/80	162	40	649	701								
Columbine 4P, CO	81-CO-1	3/26/81	94	27	254	278							249	
Columbine 3P, CO	81-CO-2	3/26/81	92	28	262	265							258	
Columbine LP, CO	81-CO-3	3/26/81	95	29	275	288								
Columbine NP, CO	81-CO-4	3/26/81	94	29	270	268	291							
Columbine HYP, CO	81-CO-5	3/27/81	102	30	302	325								
Columbine Trees, CO	81-CO-6	3/27/81	87	25	216	256								

NOTE: WHERE NO VALUES ARE SHOWN FOR GLACIER DENSITY AND GLACIER SWE, THE DEPTH IS FROM THE STANDARD FEDERAL SAMPLER.

DRAFT

SPECIFICATIONS FOR WSC METRIC SNOW SAMPLER

General

The WSC metric snow sampler shall conform with the attached drawing entitled "WSC Metric Snow Sampler."

Tubes

The tubes shall be fabricated from 44 mm (44.4 mm OD) 6061-T6, 18 STUBs gauge Alcoa or 17 ST Alcan aluminum or equivalent. Each tube section shall represent 75 cm snow depth. Markings are to be stamped on the tube every centimeter with zero measured from the cutter teeth. Numerals shall be stamped every fifth increment to represent depths of 5, 10, 15, 20, etc., through 75 for the first section and 80, 85, etc., for the second tube, etc.

All tubes will have baked-on silicone release agent Dow Corning 1-2531 resin or equivalent after they are completed.

Slots on the snow tubes will be 3.4 mm X 8 mm on alternate sides of the stamped numerals and increments with no overlays. The first tube section will have a slot starting at increment 11 and extended to increment 19; the next slot will be on the opposite side of depth markings and extend from 19 to 27, etc., with the uppermost slot on the first tube extending from 59 to 67. The second tube will have 8-cm-long slots beginning at 79 and ending at 143. The third tube wil begin at 154 and end at 218, etc.

Cutter

The cutter shall be milled 4130 aircraft moly or cast 17-4 stainless alloy, heat treated and ground to 36.7 mm inside diameter. The cutter shall have 16 teeth with lands approximately 2 mm width and grooves approximately 5 mm width. The teeth shall have a slope angle of 7 degrees and shall be 30 mm in length. The inside lip that is ground to 36.7 mm shall extend 15 mm from the point of the teeth. All leading surfaces of the teeth will be sharpened to the inside.

Couplings

The male and female couplings shall have a shrink fit on the tubing and have smooth surface inside the tube when screwed together. Threads are to be modified Acme with three threads per centimeter.

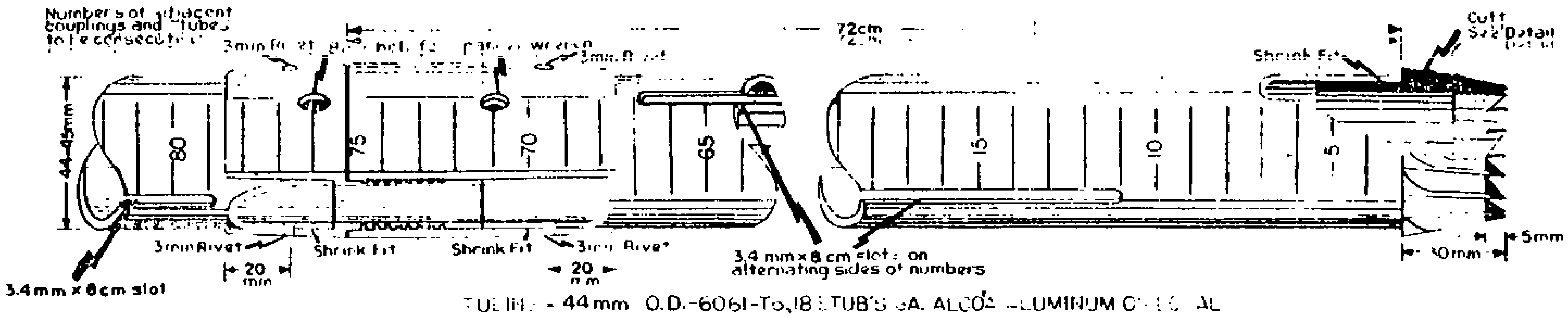
Thread Protector

The thread protector will be similar to the male coupling except that it shall not be tapered. The outside section will be knurled. A hole will be drilled for the spanner wrench. It will be constructed so as to fit in the top of any tube section.

Spanner Wrench

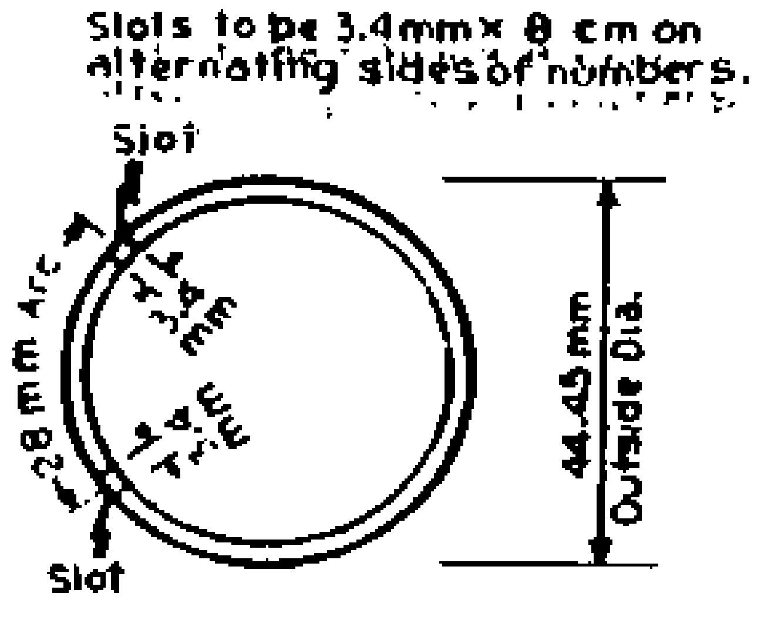
The spanner wrench will be constructed from light-weight steel stock and be bent so as to fit smoothly around the couplings and secure each tube section so any stuck or frozen threads can be released with moderate pressure. Two spanner wrenches are required for each sampler.

2/82

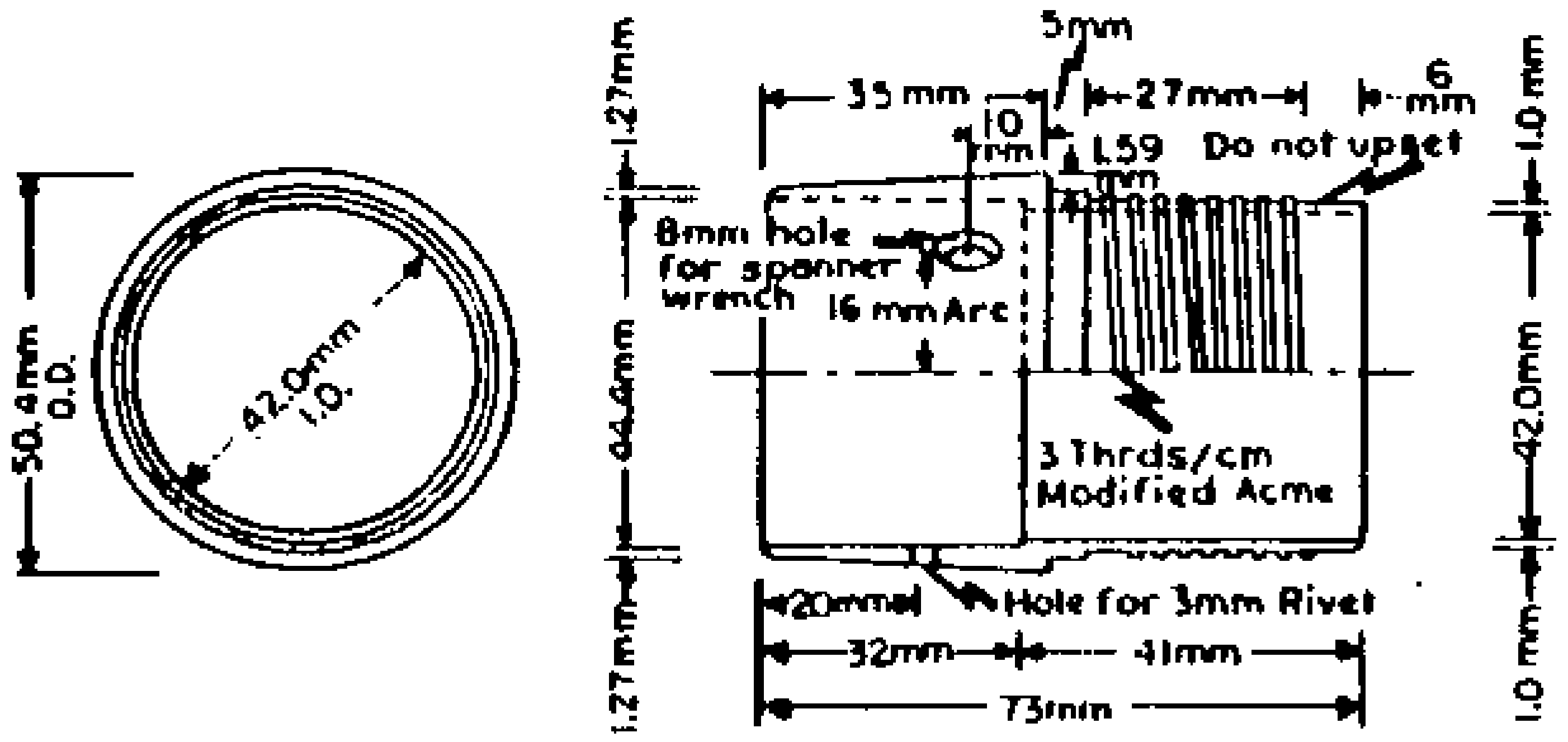


TUBING - 44mm O.D.-6061-T6,18 STUBS GA. ALCOA ALUMINUM OR EQUAL

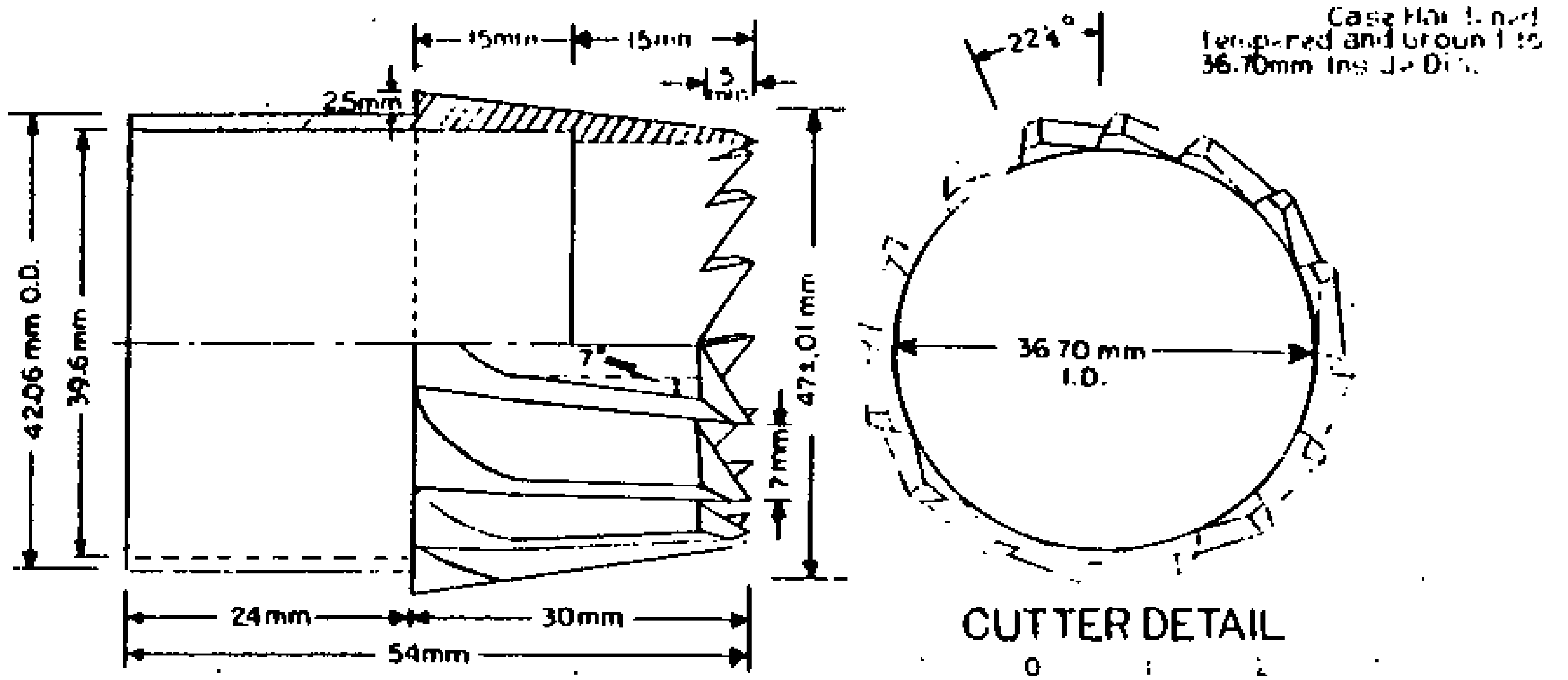
TUBE, COUPLING AND CUTTER ASSEMBLY



TUBE
CROSS SECTION



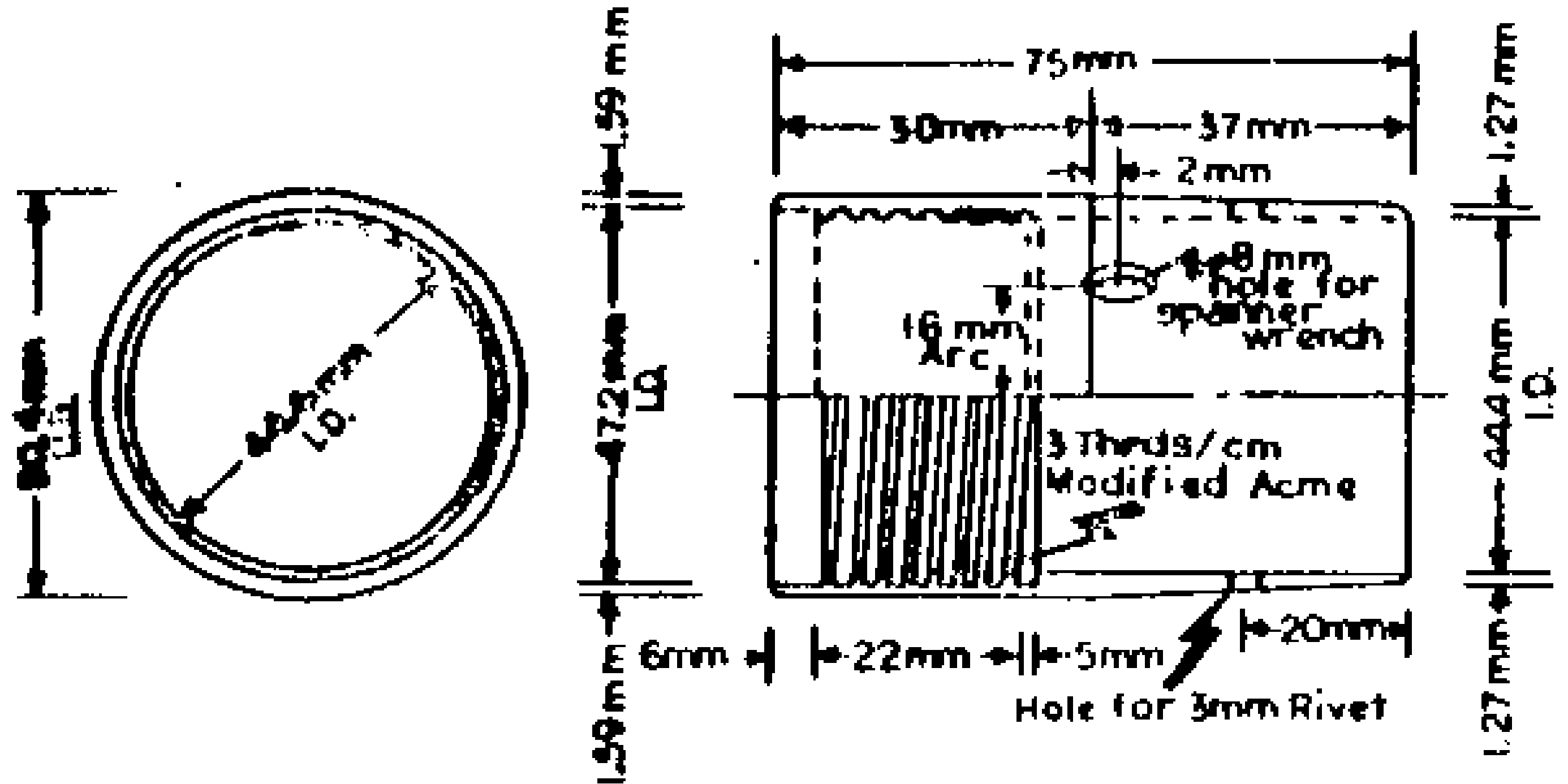
MALE COUPLING
ALCOA ALUMINUM 6061 - T6 OR EQUAL



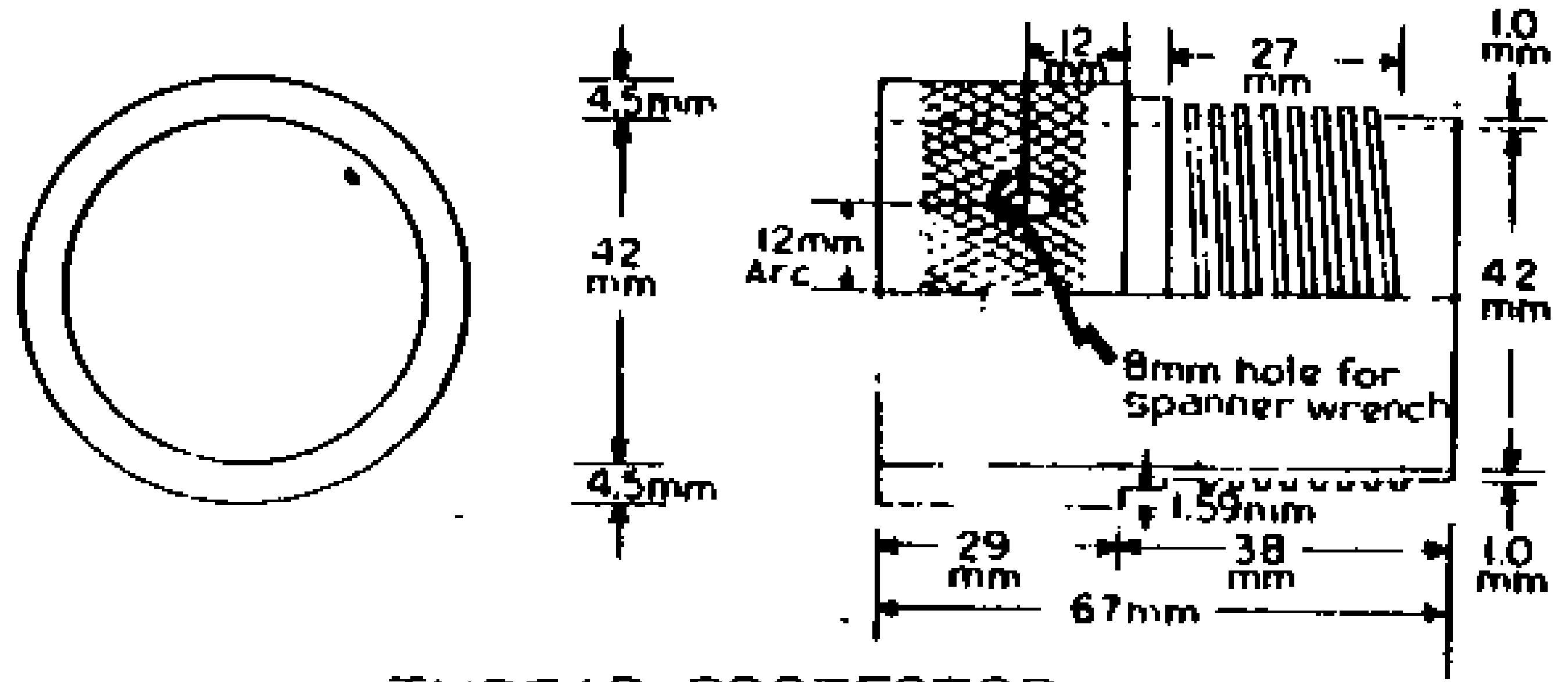
Cutter to be made in one piece

CUTTER DETAIL

0 1 2
SCALE IN CENTIMETERS

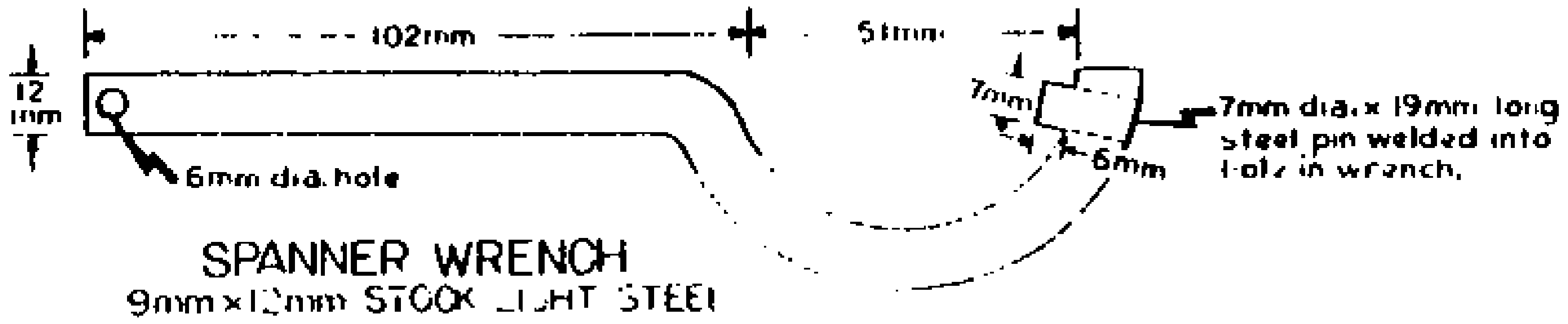


FEMALE COUPLING
ALCOA ALUMINUM 6061 -T6 OR EQUAL



THREAD PROTECTOR
ALCOA ALUMINUM 6061-T6 OR EQUAL

PRELIMINARY DRAFT
SUBJECT TO REVISION



SPANNER WRENCH
9mm x 12mm STOCK LIGHT STEEL

January 1982
3 2 1 0 1 2 3 4 5
Scale in centimeters

FIGURE WSC METRIC SNOW SAMPLER

DRAFT

SPECIFICATIONS FOR METRIC WEIGHING SCALE FOR WSC METRIC SNOW SAMPLER

General

The weighing scale and cradle shall conform with attached drawing entitled "Metric Scale for WSC Metric Snow Sampler." It shall be constructed of 6061-T6 Alcoa aluminum or equivalent. The scale spring shall be a close-wound extension coil spring with an outside diameter of 19.8 mm. The spring material shall be self-tempering steel spring wire 1.63 mm in diameter. All stamped numerals and numbers will be in black.

4 Meter Capacity Scale (for snow depths up to 4 meters)

The inner cylinder shall be calibrated on one side in increments equivalent to two centimeters. The scale shall be such that the increments will be from 0 to 340 and weigh 3,795 grams over 283.3 mm distance on the inner cylinder. Each increment shall be stamped at intervals of approximately 1.667 mm and be equal to a weight increment of approximately 22.32 grams. Beginning with zero at the bottom of the inner cylinder, each fifth increment shall be stamped with the numerals 10, 20, 30, 40, etc., through 340. Along the scale increments opposite to the numerals, the cylinder shall be stamped "cm water with WSC snow sampler." Each outer cylinder shall have the capacity stamped on it; i.e., "CAPACITY = 4 METERS."

The scale spring shall be 190.5 mm long and shall be pre-tensioned for 1,250 grams such that the weight of a 1.5-meter (2 sections) snow sampling tube (empty) will read slightly greater than zero on the scale. Scales shall be accurate to 15 grams over the full span of the scale.

6 Meter Capacity Scale (for snow depths between 4 and 6 meters)

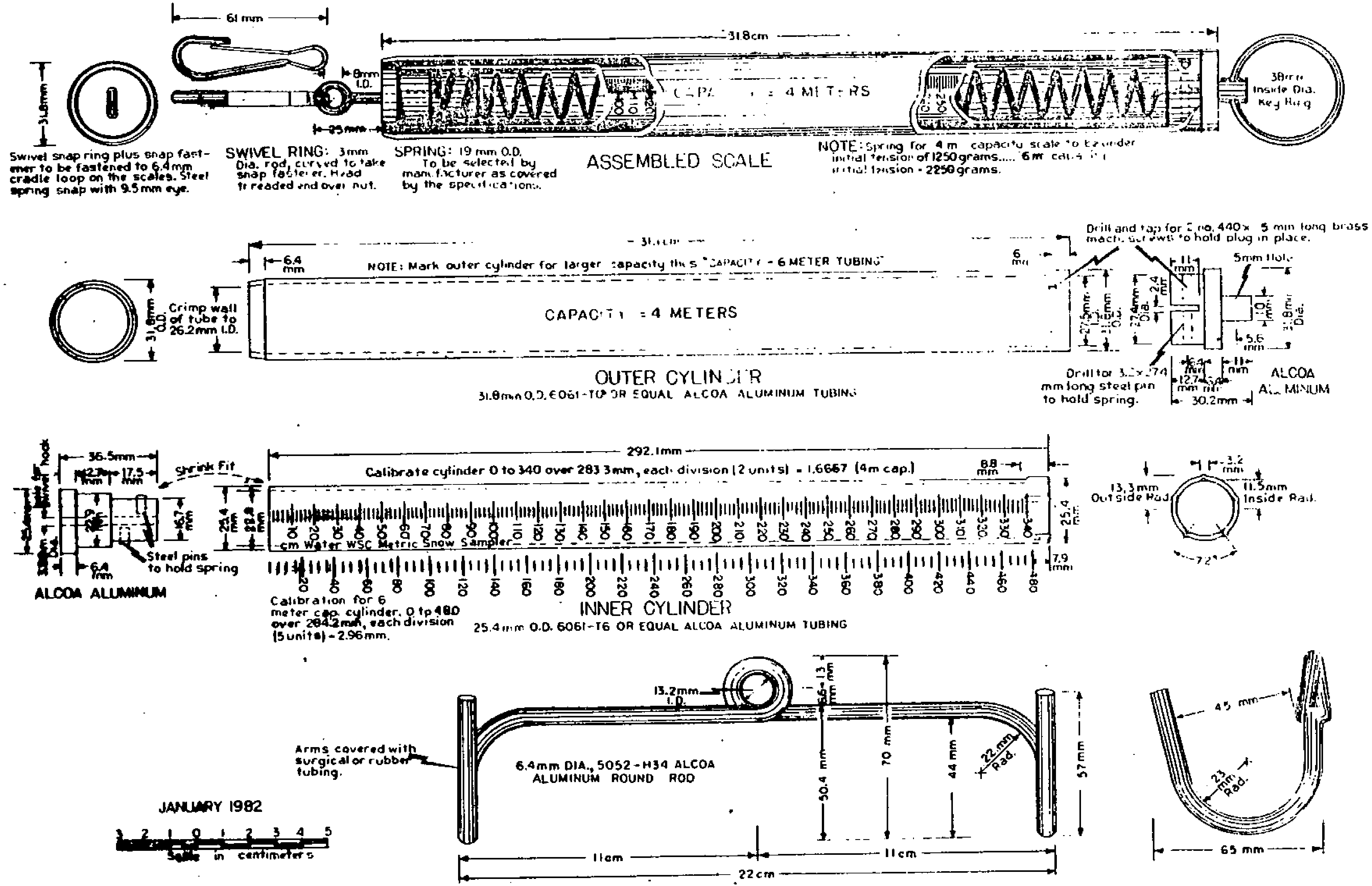
The inner cylinder shall be calibrated on one side in increments equivalent to five centimeters. The scale shall be such that the increments will be from 0 to 480 and weigh 5,357 grams over 284.2 mm distance on the inner cylinder. Each increment shall be stamped at intervals of approximately 2.96 mm and be equal to a weight increment of approximately 55.75 grams. Beginning with zero at the bottom of the inner cylinder, each fourth increment shall be stamped with the numerals 20, 40, 60, 80, etc., through to 480. Along the scale increments opposite the numerals, the cylinder shall be stamped "cm water with WSC snow sampler." Each outer cylinder shall have the capacity stamped on it; i.e., "CAPACITY = 6 METERS."

The scale spring shall be 139.7 mm long and shall be pre-tensioned for 2,250 grams such that the weight of a 3-meter (4 sections) snow sampling tube (empty) will read slightly greater than zero on the scale. Scales shall be accurate to 15 grams over the full span of the scale.

Cradle

Surgical rubber or rubber tubing shall cover the arms of the cradle to prevent the snow sampling tube from slipping in the cradle. The cradle shall be attached to the scale assembly by a swivel snap and swivel ring.

2/82



PRELIMINARY DRAFT
SUBJECT TO REVISION

FIGURE METRIC SCALE FOR WSC METRIC SNOW SAMPLER

DRAFT

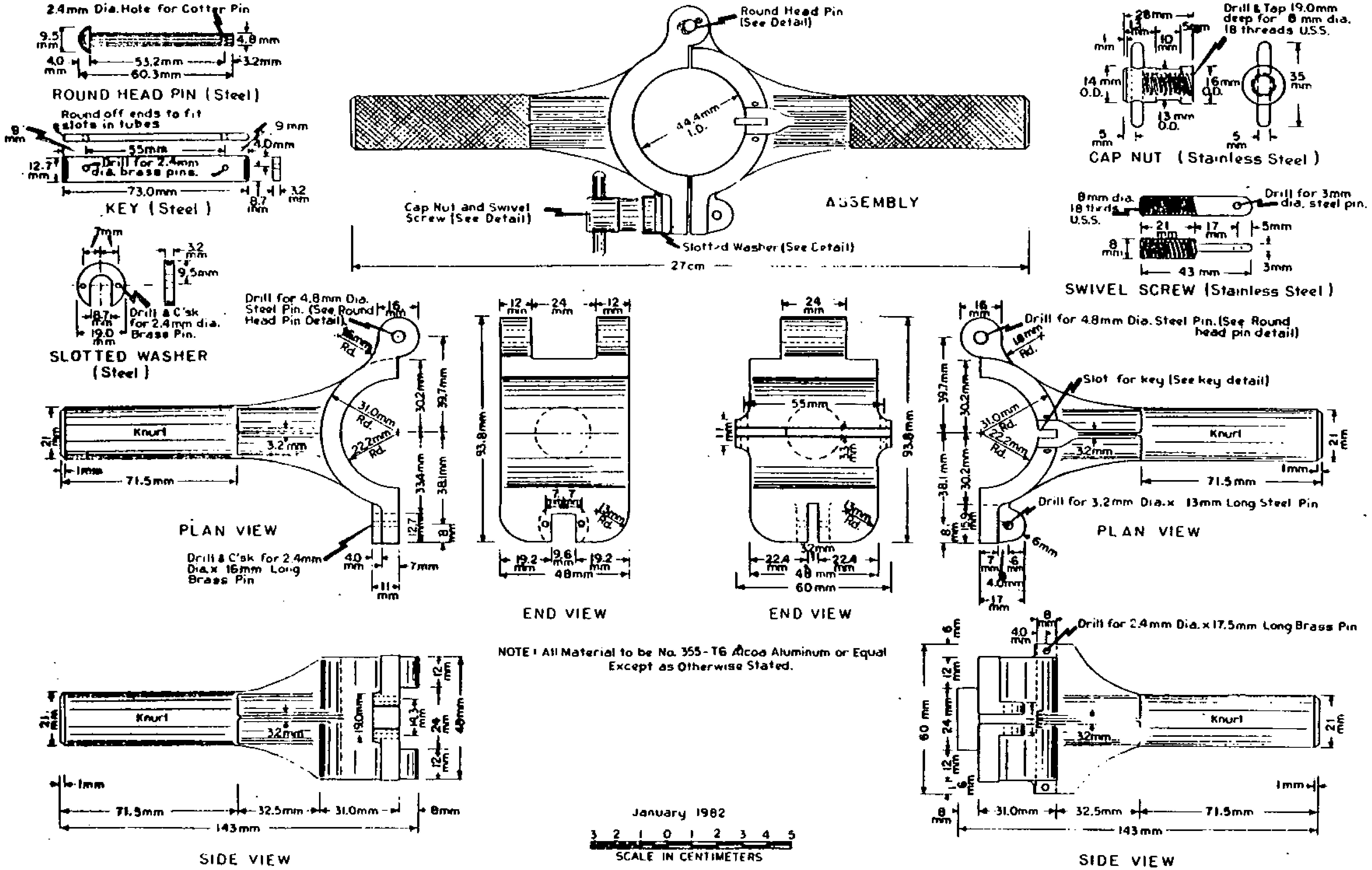
SPECIFICATIONS FOR DRIVING WRENCH FOR WSC METRIC SNOW SAMPLER

General

The driving wrench shall conform with the attached drawing entitled "Aluminum Driving Wrench for WSC Metric Snow Sampler." It shall be constructed of 355-T6 Alcoa aluminum or equivalent. The driving wrench shall be such that the key fits in the slots on the WSC metric snow sampler and the wrench fastens securely around the snow sampler tube and does not slip on the tube when a weight of 500 kilograms is applied to the wrench with the snow tube in a vertical position. The wrench shall be easy to attach to the snow tube and easy to remove.

Exception: A driving wrench constructed from reinforced nylon or other material would be acceptable provided the strength requirements specified above are met or exceeded.

2/82



NOTE: All Material to be No. 355-T6 Alcoa Aluminum or Equal Except as Otherwise Stated.

January 1982

PRELIMINARY DRAFT
SUBJECT TO REVISION

FIGURE ALUMINUM DRIVING WRENCH FOR WSC METRIC SNOW SAMPLER

DRAFT

SPECIFICATIONS FOR ESC-30 METRIC SNOW SAMPLER

General

The ESC-30 metric snow sampler shall conform with the attached drawing entitled "ESC-30 Metric Snow Sampler."

Tube

Clear plastic tube with ID of 69.85 mm and OD of 76.2 mm TENITE-BUTYRATE 516E-MH, or equivalent, with a length of 121.5 cm will be used for the tube. Markings are to be stamped or routed on the tube every centimeter with zero measured from the cutter teeth. Numerals shall be stamped or routed every fifth increment to represent depths of 5, 10, 15, 20, etc., through 120. All markings and numerals will be in black. Overall length of tube from cutter teeth to top of driving handle will be 126 cm. The driving handle collar shall be secured to the sampling tube near the end of the tube and will serve as a protector for the end of the plastic tube. The driving handles may be either permanently secured to the collar or they may be removable. The end of the tube will be threaded to accept the 1 square thread/cm on the cutter.

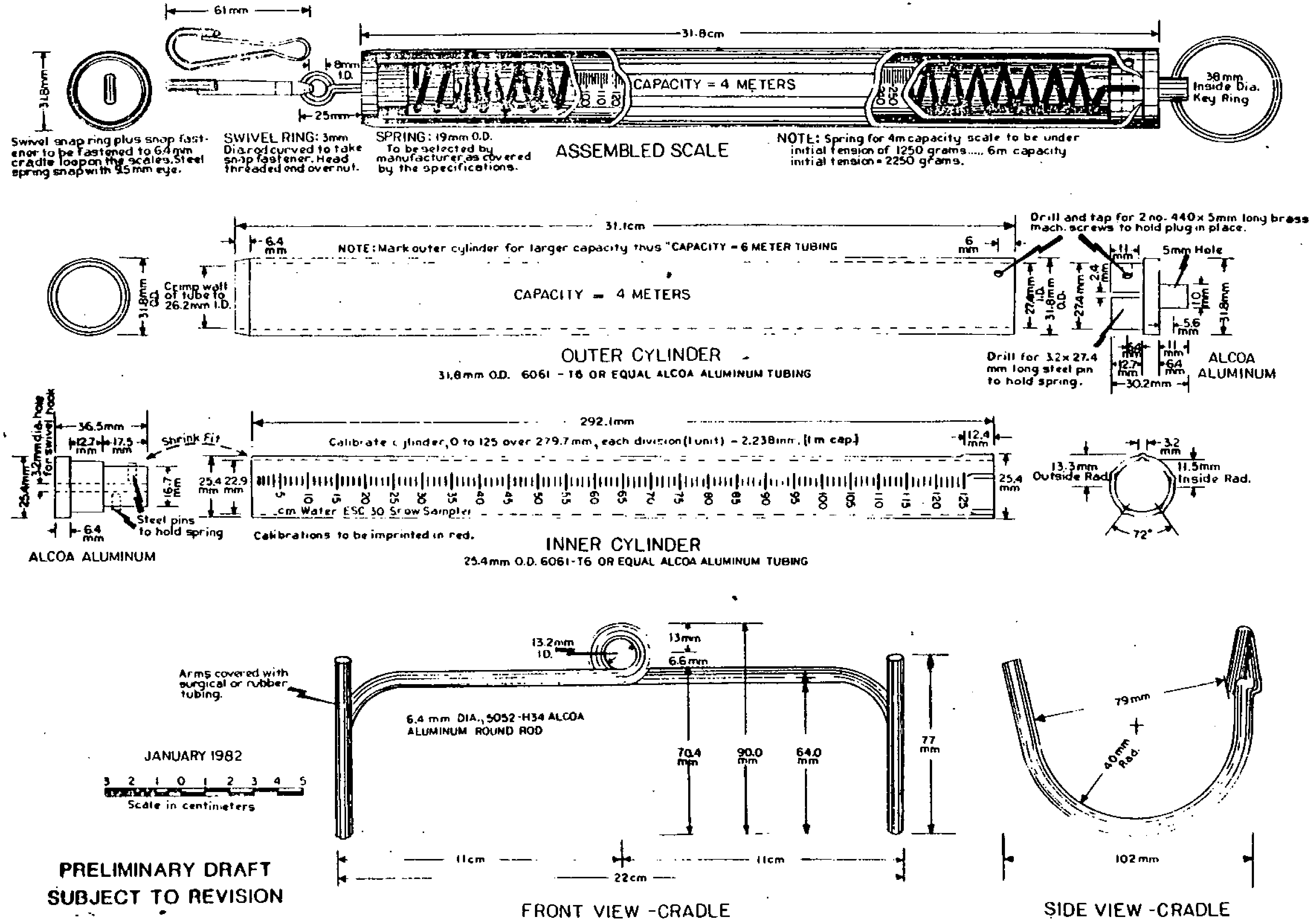
Cutter

The cutter shall be milled 4130 aircraft moly or cast 17-4 stainless alloy, heat treated and ground to 61.80 mm. The cutter shall have 16 teeth with lands approximately 2 mm width and grooves approximately 10 mm width. The teeth shall have a slope angle of 7 degrees and shall be 40 mm in length. The inside lip that is ground to 61.80 mm shall extend 15 mm from the point of the teeth. All leading surfaces of the teeth will be sharpened to the inside. The threads on the cutter will be square, 1 thread/cm.

2/82

PRELIMINARY DRAFT
SUBJECT TO REVISION

FIGURE ESC 30 METRIC SNOW SAMPLER



JANUARY 1982

PRELIMINARY DRAFT
SUBJECT TO REVISION

FIGURE METRIC SCALE FOR ESC 30 METRIC SNOW SAMPLER

DRAFT

SPECIFICATIONS FOR METRIC WEIGHING SCALE FOR ESC-30 METRIC SNOW SAMPLER

General

The weighing scale and cradle shall conform with attached drawing entitled "Metric Scale for ESC-30 Metric Snow Sampler." It shall be constructed of 6061-T6 Alcoa aluminum or equivalent. The scale spring shall be a close-wound extension coil spring with an outside diameter of 19.8 mm. The spring material shall be self-tempering steel spring wire 1.63 mm in diameter. All stamped numerals and numbers will be in red.

1 Meter Capacity Scale

The inner cylinder shall be calibrated on one side in increments equivalent to one centimeter. The scale shall be such that the increments will be from 0 to 125 and weigh 3,747 grams over 279.7 mm distance on the inner cylinder. Each increment shall be stamped at intervals of approximately 2.238 mm and be equal to a weight increment of approximately 29.976 grams. Beginning with zero at the bottom of the inner cylinder, each fifth increment shall be stamped with the numerals 5, 10, 15, 20, etc., through 125. Along the scale increments opposite to the numerals, the cylinder shall be stamped "cm water with ESC-30 snow sampler." Each outer cylinder shall have the capacity stamped on it; i.e., "CAPACITY = 1 METER."

The scale spring shall be 190.5 mm long and shall be pre-tensioned for 1,250 grams such that the empty weight of the ESC-30 snow sampling tube will read slightly greater than zero on the scale.

Cradle

Surgical rubber or rubber tubing shall cover the arms of the cradle to prevent the snow sampling tube from slipping in the cradle. The cradle shall be attached to the scale assembly by a swivel snap and swivel ring.

2/82

Reprinted from Preprint Volume: Fifth Symposium on Meteorological Observations and Instrumentation, April 11-15, 1983, Toronto, Ont., Canada. Published by the American Meteorological Society, Boston, Mass.

3.1

A NIPHER-TYPE SHIELD FOR RECORDING PRECIPITATION GAUGES

B.E. Goodison, V.R. Turner and J.R. Metcalfe

Atmospheric Environment Service
Downsview, Ontario

1. INTRODUCTION

The Atmospheric Environment Service has been involved for several years in assessing Canadian snowfall and snowcover measurement techniques. Considerable effort has been expended on assessing the accuracy and performance of snow gauges used by agencies throughout the country. Earlier field tests (Goodison 1978a) and wind tunnel flow visualization experiments (Turner and Goodison, 1977) have indicated that the Canadian MSC Nipher shielded snow gauge had a superior catch efficiency for measuring snowfall water equivalent than an unshielded or Alter shielded Universal Belfort or Fischer & Porter recording precipitation gauge. However, the MSC Nipher snow gauge is non-recording, and it is only used at manned stations. Another problem is that in low snowfall regions, such as the Arctic and Prairies, over 80% of all winter observations of precipitation measured with the Nipher can be trace amounts (Goodison, 1978b), and these are given a total accumulation of zero.

Given the limitations of the MSC Nipher and Alter shielded recording gauges, and realizing that most new precipitation stations in these regions would likely be recording gauges at "remote" sites, it was proposed that a larger Nipher-type shield should be constructed, scaled to fit the 20.7 cm (8 inch) diameter recording gauges. The aim was to develop a shield which would not only provide more accurate recording gauge measurements of snowfall, but also would provide data which would be directly compatible with measurements from the official MSC Nipher snow gauge.

Field tests were initiated during the winter of 1978-79 at the AES Toronto Met Research Station and were expanded to other sites across the country during following years. A wind tunnel study of the flow over the large Nipher shield was subsequently conducted to help to evaluate the field results.

2. DESCRIPTION OF THE SHIELD

The original design by the Data Acquisition Services Branch of AES for the Nipher-type shield was based on "scaling-up" the standard MSC Nipher shield, i.e. it was scaled to shield a 20.7 cm (8 inch) diameter orifice instead of a 12.7 cm (5 inch) collector. A wooden mould was carefully constructed from which fibreglass shields (general purpose polyester resin, chopped strand fibreglass reinforced, with glass loading of approximately 20-30%) were manufactured. An elongated tube of galvanized sheet metal (inside diameter, 20.7 cm) was affixed to the precipitation gauge to extend its orifice even with the top of the shield. The fibreglass shield, which was 71 cm high, sat in a ring which was supported by three 2.5 cm aluminum posts fixed to a base. The entire structure was then guyed from the support ring to ground anchors. The shield was adapted to fit either the Fischer & Porter or Universal Belfort recording precipitation gauges.

The absolute physical size of the shield and its support structure caused some problems. Primarily, it was difficult to accurately position the shield around the orifice extension and to level and centre the orifice inside the shield. Servicing of the precipitation gauge under the shield was awkward, particularly for one person, as the shield had to be removed each time.

Wind tunnel tests conducted subsequently, showed that the shield could be shortened by 30 cm without changing the flow pattern over the orifice. This resulted in a lighter, easier to handle shield. By making the shield shorter, the original support structure could be eliminated, the orifice extension shortened and the shield could be fixed directly to the orifice extension, thus ensuring an even spacing between the extension and the shield. This also allowed one to level both the gauge and the shield as a single unit. The shield and orifice extension are now completely supported by the precipitation gauge, thus allowing free access for gauge servicing.

A problem with all snow gauges is the sticking of snow to the orifice. The problem may be compounded for unattended recording precipitation gauges, as the snow can build up with time until the gauge "caps" over. In order to inhibit snow sticking to the orifice extension of the large Nipher-type shield the extension has been teflon coated.

3. WIND TUNNEL STUDY

The wind tunnel tests were undertaken for two reasons:

(1) to ascertain whether there is any difference in the flow pattern around a standard MSC Nipher shielded snow gauge and a Fischer & Porter gauge equipped with a large Nipher type shield, and;

(2) to predict whether a truncated version of the large Nipher shield could be used on field installations without adversely affecting the flow regime.

Each shield/gauge combination (standard shield, scaled-up shield and truncated shield) was tested in the tunnel at an air flow of approximately 3.5 m/s. The large Nipher shield and Fischer & Porter gauge were also tested at wind speeds of 1.45 and 5.02 m/s to examine the flow pattern associated with faster and slower wind speeds.

Usual wind tunnel methods were used for the tests. Wind speed measurements were made using pitot tubes and a sensitive micromanometer. To keep the relative sizes between shields and pitot tubes, a larger pitot tube was used to test the larger shield. In order to avoid distortion of the flow over the large shield resulting from the proximity of the tunnel roof, the Fischer & Porter gauge itself could not be mounted in the tunnel. Instead, a mock-up of the upper portion of the gauge with the orifice extension fitted to it was used. This arrangement is considered to have simulated adequately the essential mechanical features affecting the flow. Measurements were made in the vertical plane, which included the tunnel axis and the vertical axis of the shield.

Results of the tests are presented in Figures 1 to 5. The diagrams show the isopleths of constant wind speed ratio: i.e., measured speed divided by the undisturbed speed measured on the tunnel axis. Each diagram is based on approximately one hundred measurements at points chosen to reveal the salient features of the flow. The origin of axes for length measurements is taken as the leading edge of the shield. On the diagrams the gauge orifice is represented by hatching, while the extended solid line at the same height represents the top of the shield.

Our study shows that, while details of the flow pattern differ slightly from shield to shield, the main features of the flow are essentially the same for each gauge/shield combination. They suggest that truncating the large Nipher shield to make it easier for field handling will have little affect on the flow pattern over the gauge. Thus, the catch should be unaffected by this change. The tests at different wind speeds reveal very little change in the flow pattern for different wind speeds. On the basis of these tests one would expect that a recording gauge shielded by this large Nipher type shield should exhibit catch characteristics similar to the standard MSC Nipher snow gauge.

4. FIELD RESULTS

Two prototype installations were tested at the Toronto Met Research Station during 1978-79. Initial results (Table 1) indicated that the catch efficiency of Fischer & Porter and

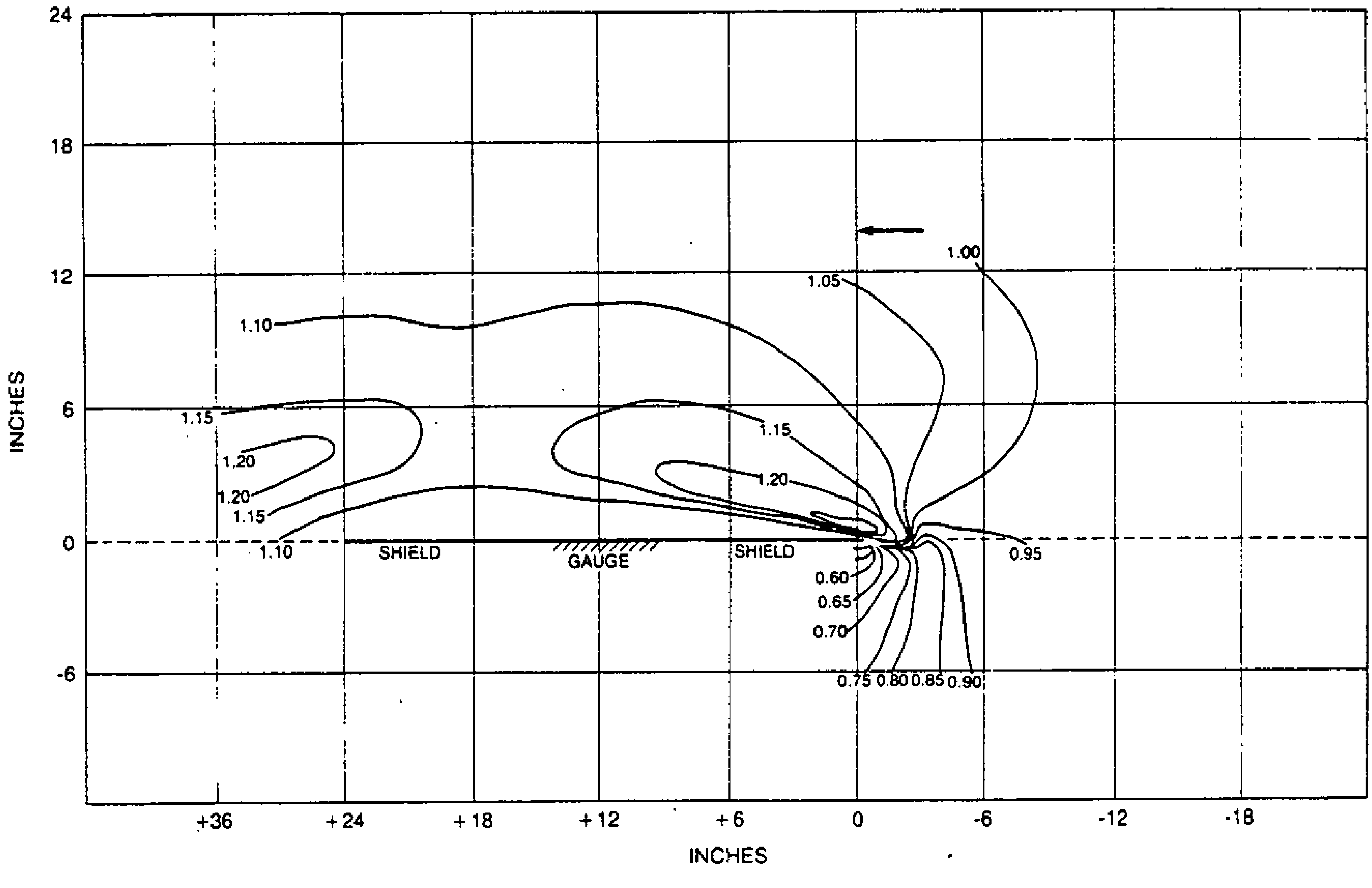


Figure 1: Wind Speed Ratio Contours - Standard Nipher Shielded Gauge . Wind Speed 3.50 m/s

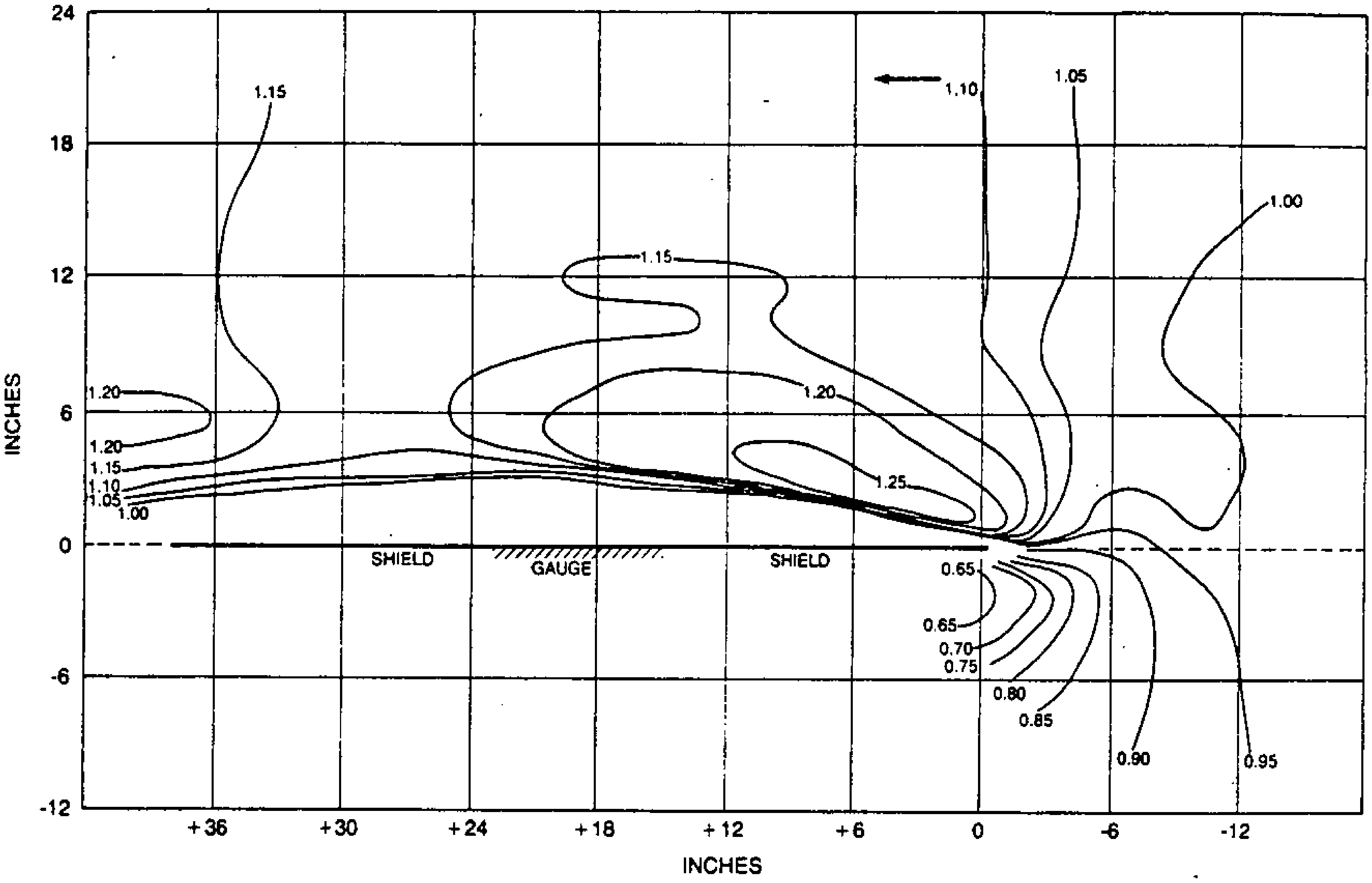


Figure 2: Wind Speed Ratio Contours - Large Nipher Shielded Fischer and Porter Gauge Wind Speed 3.62 m/s

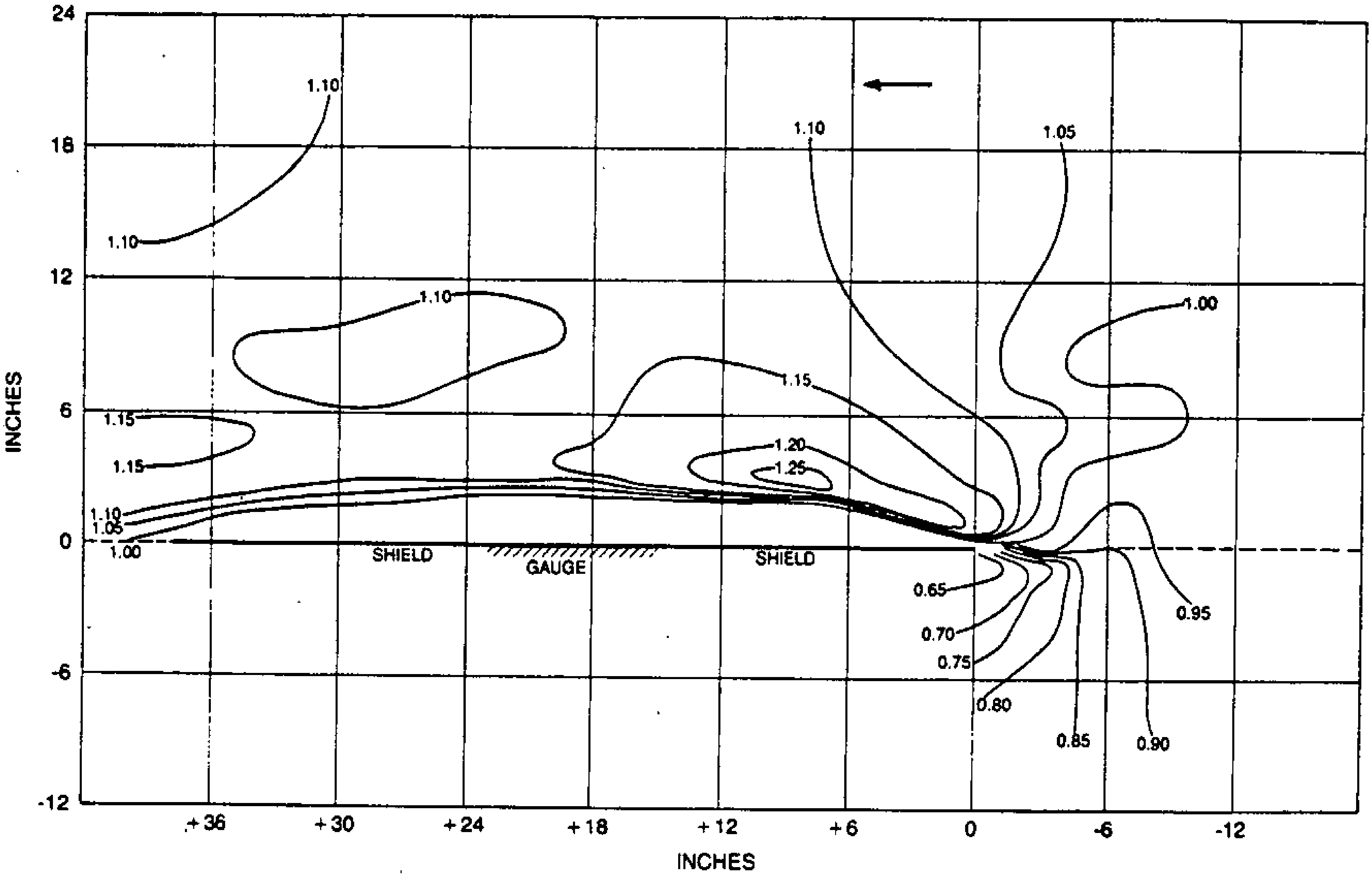


Figure 3: Wind Speed Ratio Contours - Truncated Nipher Shielded Fischer and Porter Gauge Wind Speed 3.47 m/s

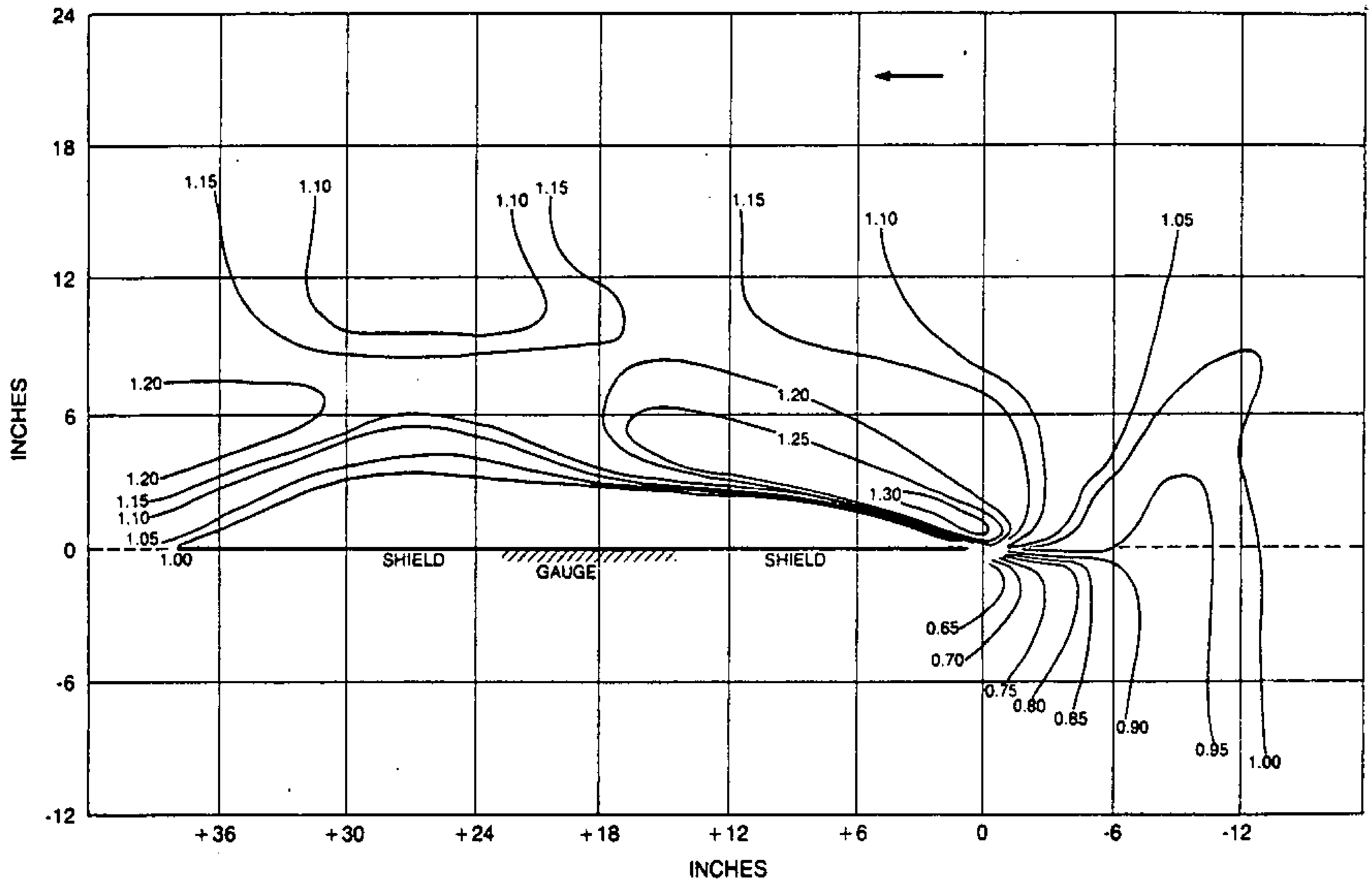


Figure 4: Wind Speed Ratio Contours - Large Nipher Shielded Fischer and Porter Gauge Wind Speed 1.45 m/s

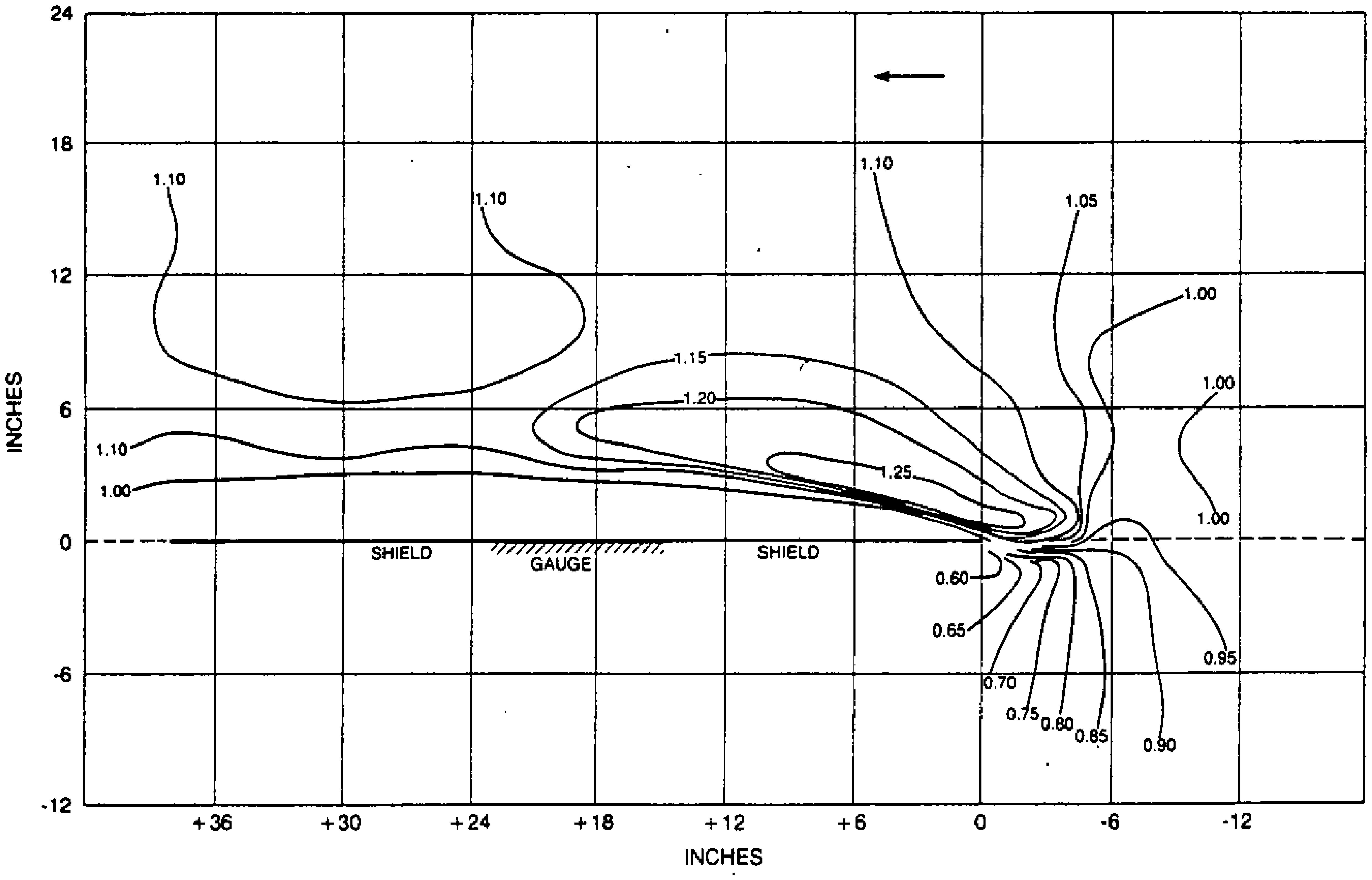


Figure 5: Wind Speed Ratio Contours - Large Nipher Shielded Fischer and Porter Gauge Wind Speed 5.02 m/s

Universal recording gauges could be significantly improved by using the large Nipher type shield and that additional field testing was warranted. Additional prototype shields were manufactured and fitted to Fischer & Porter and Universal recording gauges in the manner described above. They were installed at eight additional sites in various climatic regimes in time for the 1980-81 winter season. A variety of local siting conditions were chosen to assess the gauge's performance.

For the purpose of this study, none of the gauge measurements was corrected for undercatch due to wind or for trace amounts. The MSC Nipher shielded snow gauge is used as the standard against which the other measurements are compared since it is the "official" Canadian snow gauge.

Table 1 summarizes the seasonal totals for gauges located at the Toronto Met Research Station. The unshielded and Alter shielded gauges recorded the lowest totals, (generally, 50-65% of the MSC Nipher), but this is in line with previous results (Goodison, 1978a). The Belfort and Fischer & Porter gauges shielded with the large Nipher-type shield recorded about 90% of the MSC Nipher total. Determination of a specific reason for this consistent undermeasurement has not yet been determined. Although this site is flat and very exposed, blowing snow is generally not a problem.

At Monticello, Ontario, paired Nipher and Alter shielded Fischer & Porter gauges were placed in both open and sheltered bush locations to assess the effect of siting on the performance of the large Nipher shield. At the open site the results were similar to those reported for the Toronto Met Research Station. However, the Nipher shielded Fischer & Porter gauge located in the small opening in the bush capped over early in the winter and it recorded no accumulation until it was cleared by hand. This would be a potential problem at remote sites. It appears, however, that this type of shielding is not necessary at well sheltered sites as the catch of the Alter shielded gauge at this site was comparable with that of the standard MSC Nipher snow gauge at the open site.

Data from test sites in Saskatchewan also confirm the higher catch efficiency for recording gauges using the Nipher-type shield. At Bad Lake, Saskatchewan, winter season precipitation totals from the standard MSC Nipher snow gauge and a Nipher shielded Fischer & Porter gauge are within 5% of each other. The Alter shielded Fischer & Porter caught 35-40% of the standard MSC Nipher, which is comparable with the long term average monthly catch of 35% reported by Gray et al. (1979). Table 2 summarizes the measurements from Regina for the last three winters, and the results are similar to those from Bad Lake. Jones (1982) has conducted additional analysis of the 1981-82 data, particularly with respect to wind speed and direction and snow course measurements. He concluded that the Nipher shielded gauges consistently demonstrated a superior catch efficiency to Alter shielded or Wyoming shielded gauges. Jones (1982) also noted that the Nipher shielded Fischer & Porter recording gauge, which was mounted at 2 m, appeared to be less susceptible to the problem of catching blowing snow than the standard MSC Nipher snow gauge.

5. SUMMARY AND CONCLUSIONS

Initial field data indicate that the large Nipher-type shield can be used with recording gauges to provide measurements which are compatible with the official Canadian MSC Nipher snow gauge. Wind tunnel experiments suggest that this in fact should be the case. The Nipher-type shield improves gauge catch compared to unshielded and Alter-shielded gauges. There is little maintenance required and the new design will allow easy servicing of the gauge. However, snow can build up on the shield, even at open sites when the wind speed is low, and the gauge can cap over at sheltered sites. The design of the Nipher shield makes the gauge susceptible to catching blowing snow if it is mounted too close to the ground.

Modifications to the shield and support system, outlined earlier in the paper, were completed during the summer of 1982 and all

TABLE 1

SEASONAL SNOW GAUGE MEASUREMENTS, TORONTO MET RESEARCH STATION*

SNOW SEASON	MSC NIPHER	UNSHIELDED BELFORT GAUGE	ALTER SHIELDED BELFORT GAUGE	NIPHER SHIELDED BELFORT GAUGE	WYOMING SHIELDED BELFORT GAUGE	ALTER SHIELDED F&P GAUGE	NIPHER SHIELDED F&P GAUGE
1977-78	82.0 mm				56.1 mm		
CATCH TOTAL AS % OF MSC NIPHER	100%				68%		
1978-79	102.6 mm	54.5 mm	65.4 mm	94.7 mm	72.8 mm	60.8 mm	86.2 mm
CATCH TOTAL AS % of MSC NIPHER	100%	53%	64%	92%	71%	59%	84%
1980-81	120.8 mm	63.7 mm	81.2 mm	112.0 mm	96.0 mm	73.7 mm	116.8 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	53%	67%	93%	79%	61%	97%
1981-82	76.4 mm	36.8 mm	46.5 mm	U/S	62.5 mm	U/S	68.6 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	48%	61%		82%		89%

* NONE OF THE DATA HAS BEEN CORRECTED FOR UNDERCATCH DUE TO WIND, TRACE AMOUNTS OR RETENTION (WHERE APPLICABLE); ALL TOTALS INCLUDE RAINFALL WHERE APPLICABLE.

TABLE 2
SNOW GAUGE COMPARISONS, REGINA, SASKATCHEWAN*

SNOWFALL SEASON	MSC NIPHER SHIELDED GAUGE**	NIPHER SHIELDED FISCHER & PORTER GAUGE
JANUARY 18 TO MARCH 17, 1980	35.1 mm	33.0 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	94%
OCTOBER 24, 1980 TO MARCH 23, 1981	38.2 mm	40.6 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	106%
NOVEMBER 27, 1981 TO APRIL 19, 1982	96.5 mm	99.1 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	103%

* OPERATED BY PERSONNEL FROM AES CENTRAL REGION, SCIENTIFIC SERVICES DIVISION

** READ EVERY 24 HOURS

gauges have been re-installed for final testing during the next year. Assessment of the shield's performance for measuring rainfall is yet to be completed.

6. ACKNOWLEDGEMENTS

Many individuals and agencies have cooperated in the installation and operation of gauges for this project, particularly personnel from the University of Saskatchewan, Trent University, Grand River Conservation Authority, Ontario Ministry of Environment, and AES Central and Quebec Regions.

7. REFERENCES

Goodison, B.E., 1978a: Accuracy of Canadian Snow Gage Measurements. Journal of Applied Meteorology, Vol. 17, No. 10, 1542-1548.

Goodison, B.E., 1978b: Canadian Snow Gauge Measurements: Accuracy, Implications, Alternatives, Needs. Proceedings, Seventh Symposium on Applied Prairie Hydrology, Water Studies Institute, Saskatoon, May 9-11, 1978, pp. 7-15.

Gray, D.M., H. Steppuhn and F.L. Abbey, 1979: Estimating the Areal Snow Water Equivalent in the Prairie Environment. Proc. Canadian Hydrology Symposium: 79, Vancouver, May 10-11, 1979, p. 302-322.

Jones, K.H., 1982: A Comparison of Various Snow Gauges on the Canadian Prairies for the Winter 1981-82. Atmospheric Environment Service, Report No. CSS-R82-01, Regina, Saskatchewan, 16 pp.

Turner, V.R. and B. Goodison, 1977: Wind Tunnel Evaluation of Flow Around Snow Gauges. Paper presented at the 11th Annual Canadian Meteorological Society Congress, Winnipeg, Manitoba, June 1-3, 1977.

Proc Western Snow Conf 1984

AN INEXPENSIVE REMOTE SNOW-DEPTH GAUGE: AN ASSESSMENT

by

Barry E. Goodison[1], Bob Wilson[2], Ken Wu[2], and John Metcalfe[1]

Introduction

Snow depth on the ground is routinely measured at approximately 270 principal meteorological observing stations in Canada at 1200 GMT daily. Since about 1980, 2300 Canadian climatological stations have been asked to record daily snow depth as a standard observation. Before that time, only snow depth on the last day of the month was recorded at climatological stations. Snow depth information is valuable in many hydrological, agricultural and forestry applications and is often a substitute for snow water equivalent data when such data are unavailable.

Snow depth measurements are made manually with a snow ruler. The total depth of snow on the ground at the time of the observation is determined (in whole centimetres) by making a series of measurements and taking the average. The observer must use his expertise and judgement in obtaining a representative areal measurement at the station. Presently there are over 70 automatic meteorological stations in Canada and with the trend toward increased automation, the snow depth measurement may be lost. The need exists, therefore, for a reliable, low cost automatic snow depth sensor, which can be used on future unmanned meteorological/hydrometeorological stations. One potential method for measuring snow depth is the use of ultrasonic wave reflection in air (Caillet et al, 1979; and Gubler, 1981).

The Hydrometeorology Division and the Data Acquisition Services Branch of the Atmospheric Environment Service (AES) have been co-operating on the development of such a sensor which could be used at either manned or remote stations. Development began in 1982, with a proof of principle unit being tested during the winter of 1982-83. Two additional units were built and deployed for testing during the 1983-84 winter.

System Description

A commercially available ultrasonic ranging kit from Polaroid Corp. provides an economical means of accurately measuring target distance in terms of time to target. An on-board crystal oscillator provides a time base pulse train which is activated on a measurement request command from an external device such as a data logger or data collection platform (DCP). Once the pulse train is enabled it up-counts designated registers until a target echo is received. This immediately disables the time base pulse train. The numbers memorized in the counter can now be multiplied by the precise oscillator pulse period to give an accurate round trip time from transducer to target and return. Dividing by two gives the required time to target. The target distance is determined by multiplying the time by the velocity of sound in air at a known reference temperature. The calculated target distance is then subtracted from the actual measured distance between the sensor and a reference target (i.e. the ground at the site). Since the velocity of sound in air is highly temperature dependant, a correction must be applied to adjust the velocity for ambient air temperature. Measurement data are then formatted for transmission to an appropriate peripheral for display and/or archive. Figure 1 provides an overview of the Ultrasonic Snow-Depth gauge system.

Technical Aspects

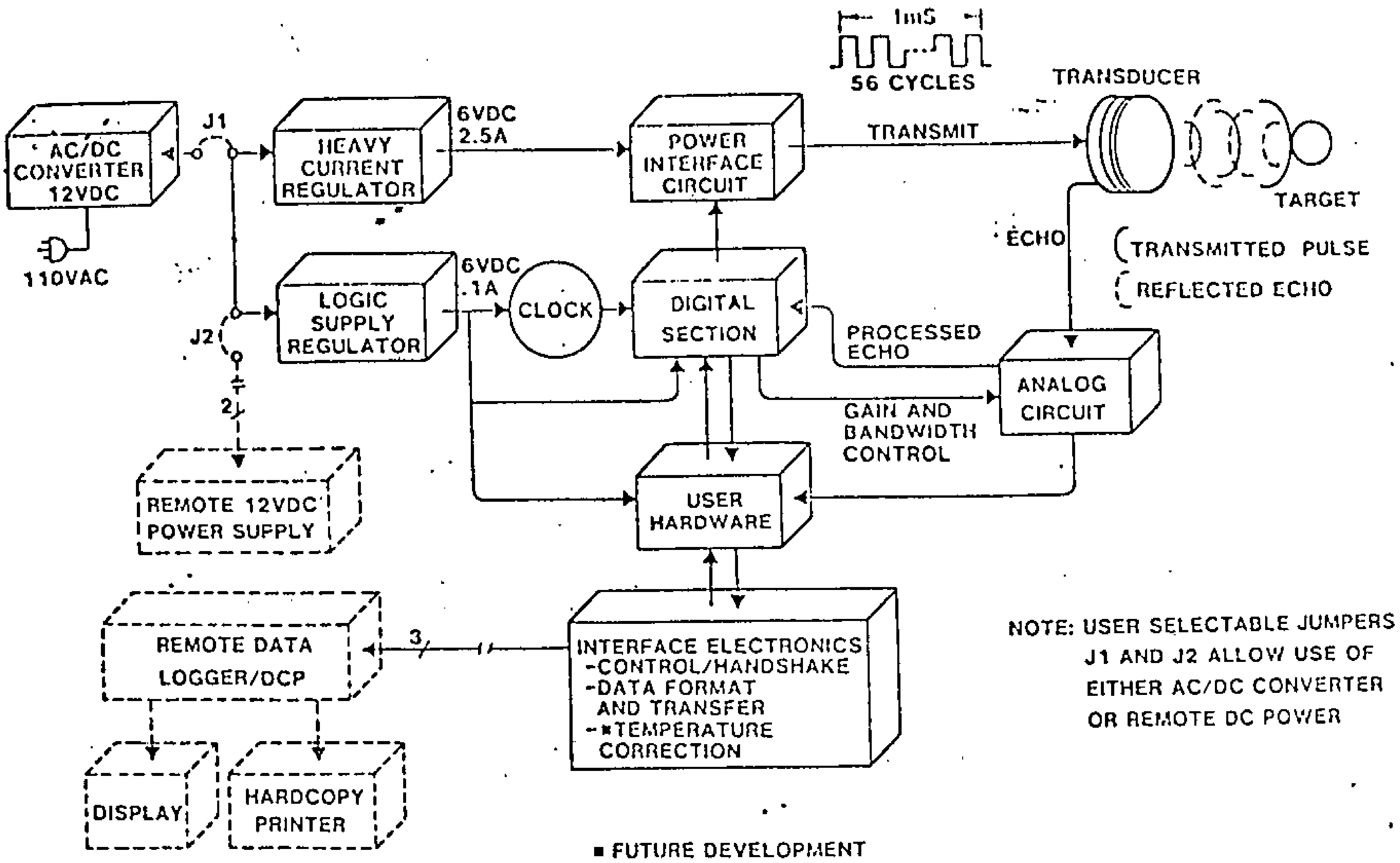
The Polaroid Ultrasonic Ranging Kits were modified to facilitate remote 'poll' or measurement requests and subsequent data transfers. The kits were also changed from battery pack power supplies to regulated DC power by the use of either an AC/DC converter at the sensor, or a remotely located raw DC supply.

---

[1] Hydrometeorology Division, Atmospheric Environment Service

[2] Measurement Technology Section, Atmospheric Environment Service

FIGURE 1- ULTRASONIC SNOW-DEPTH GAUGE



NOTE: USER SELECTABLE JUMPERS J1 AND J2 ALLOW USE OF EITHER AC/DC CONVERTER OR REMOTE DC POWER

* FUTURE DEVELOPMENT

A measurement sequence begins with the remote data logger generating a 'poll' request by raising the appropriate signal line to + 6 VDC. Internal electronics then enables the transmitter power, and synchronizes the receiver and timing logic. The transmission burst has a duration of 1 ms and is a 'chirp' of 56 cycles beginning at 60 kHz and ending at 50 kHz. Power consumption during the 1 ms transmit burst is 2.5 amperes and drops back to 100 milliamperes nominal current. At the beginning of a transmission, control logic gates the base oscillator pulse train onto the transmission line and the received 'target' echo disables the pulse train. The remote data logger counts the pulse train, converts it from binary into BCD, formats the data for transmission and sends it out for display and/or archive. Temperature corrections to the velocity of sound in air were applied to the raw data in a non-real time mode to facilitate the collection and use of temperature data from existing in-situ sensors at the sites. Calculation of actual snow depth on the ground is then determined by:

$$D = H - \frac{NtV_2}{2}\sqrt{\frac{T_1}{T_2}}$$

where: D = snow depth (cm)
H = sensor to ground baseline height (cm)
N = number of pulses counted during round trip time interval
t = oscillator period
V_2 = speed of sound in air, which is 342 m/s at 291 °K
T_1 = site temperature in °K at the time of measurement
T_2 = reference temperature, which is 291 °K

Results

A prototype snow depth measurement system was assembled and tested in the laboratory in 1982. The unit was set up to measure a fixed distance to an unobstructed solid surface every five minutes for a period of two weeks. Agreement between the sensor measurement and a ruler measurement was within ±1 cm for the entire period. The sensor was then taken to a cold chamber for testing to -40°C for a twenty-four hour period. The transducer survived this test and the sensor stability was within ±1 cm over the temperature range of +25°C to -40°C.

The sensor was deployed at AES headquarters in Toronto at the beginning of the 1982-83 winter season. The sensor was mounted 309 cm above the ground. Snowfall that year was light, providing very little data for comparison studies. Survivability of the sensor in a hostile environment, and stability of the electronics during extremes in temperature, were established during this season. During the 1983-84 season automatic data logging of sensor measurements provided a data base of approximately twenty thousand measurements. Analysis of these measurements indicates degraded sensor performance during periods of moderate to heavy snowfall. It is suspected that signal attenuation is causing problems for the echo detection circuitry during these periods. A maximum error of 12 cm was noted with most ambiguity being of the order of 6-8 cm. In no circumstance did the sensor fail to receive an echo during a measurement sequence. As well, some twenty-five comparisons of manual ruler measurements and sensor measurements were made. These results are shown in Figure 2. The sensor tended to undermeasure by approximately 2 cm.

In November 1983 another prototype system was installed at a climatological station located at Dorset, Ontario. The sensor was mounted about 1.3 m above the ground surface. A digital readout from the sensor was provided in a nearby instrument shelter. An observer took manual readings twice per day from three snow rulers fixed in the ground. The rulers were mounted in the ground around the sensor's field of view at the beginning of the season so that depth measurements could be made even if an ice layer or hard crust should form in the pack. Since the speed of sound varies with temperature, the screen temperature at the time of each observation was used to compute the corrected distance to the snowpack.

Initial results from this site (Figure 3) indicate that the ultrasonic sensor undermeasures the ruler observation by about 6 cm, with individual observations differing by up to 13 cm. Snow does build up at the ruler and this often results in an overmeasurement of up to 3 cm in snow depth by the observer. This was a sheltered site so snow scouring was not a problem. The Polaroid Ultrasonic Ranging Unit performed satisfactorily outside in ambient temperatures which ranged from +10°C to -40°C. It was also noted that rime icing or frost did not appear to build up on the sensor and had no effect on its operation. Results also indicate that the difference between the ruler and sensor measurement is not directly related to air temperature at the height of the sensor or to accumulated snow depth (maximum <1 m).

Summary

The ultrasonic snow depth sensor consistently undermeasures the actual snow depth. The causes of this bias are still under investigation. The surface of the snow and its structure (i.e. loose powder vs. hard packed crust) could have an effect. The sound wave may penetrate the surface before being reflected back toward the sensor. Signal scattering under certain atmospheric conditions is certainly a problem with most acoustic devices and could significantly reduce sensor accuracy. A strong temperature inversion near the snow surface will significantly affect the calculation of snow depth. The temperature gradient between the sensor and the snow surface could be as much as 10°C. These effects will require further evaluation.

It appears that this type of sensor offers a viable method of automatically measuring snow depth at an observing station. Planned development proposes that a microprocessor and temperature sensor be built into the gauge system to allow real-time temperature corrections for the speed of sound and also to provide some data processing capability to enhance the sensor's performance. The microprocessor could offer a high degree of flexibility in terms of formatting data and subsequent transmission to remote devices such as data loggers and DCP's. It is hoped that further refinement of the sensor/microprocessor system will ultimately produce an effective means of measuring snow depth at a remote station.

REFERENCES

Caillet, A., F. G. D'Aillon and I. Zawadzki, 1979: An ultrasound low power sonar for snow thickness measurements. Proc. Eastern Snow Conference, 36th annual meeting, Alexandria Bay, N.Y., June 7-8, 1979, p 108-116.

Gubler, H., 1981: An inexpensive remote snow depth gauge based on ultrasonic wave reflection from the snow surface. J. Glaciology, Vol. 27, No. 95, 1981, 157-163.

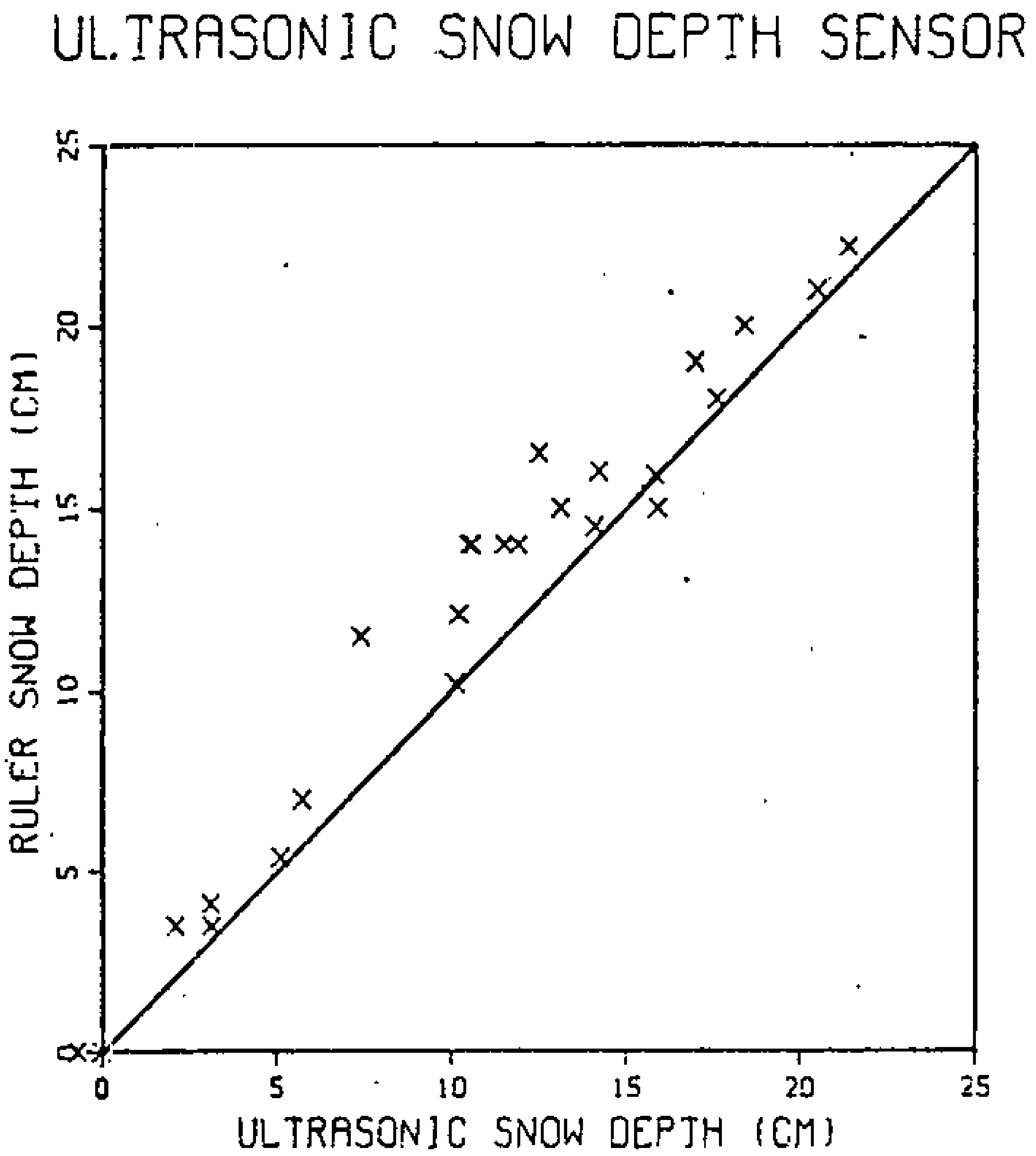


FIGURE 2: COMPARISON OF SNOW DEPTH MEASUREMENTS FROM THE ULTRASONIC SENSOR AND OBSERVED RULER MEASUREMENTS AT TORONTO, ONT.

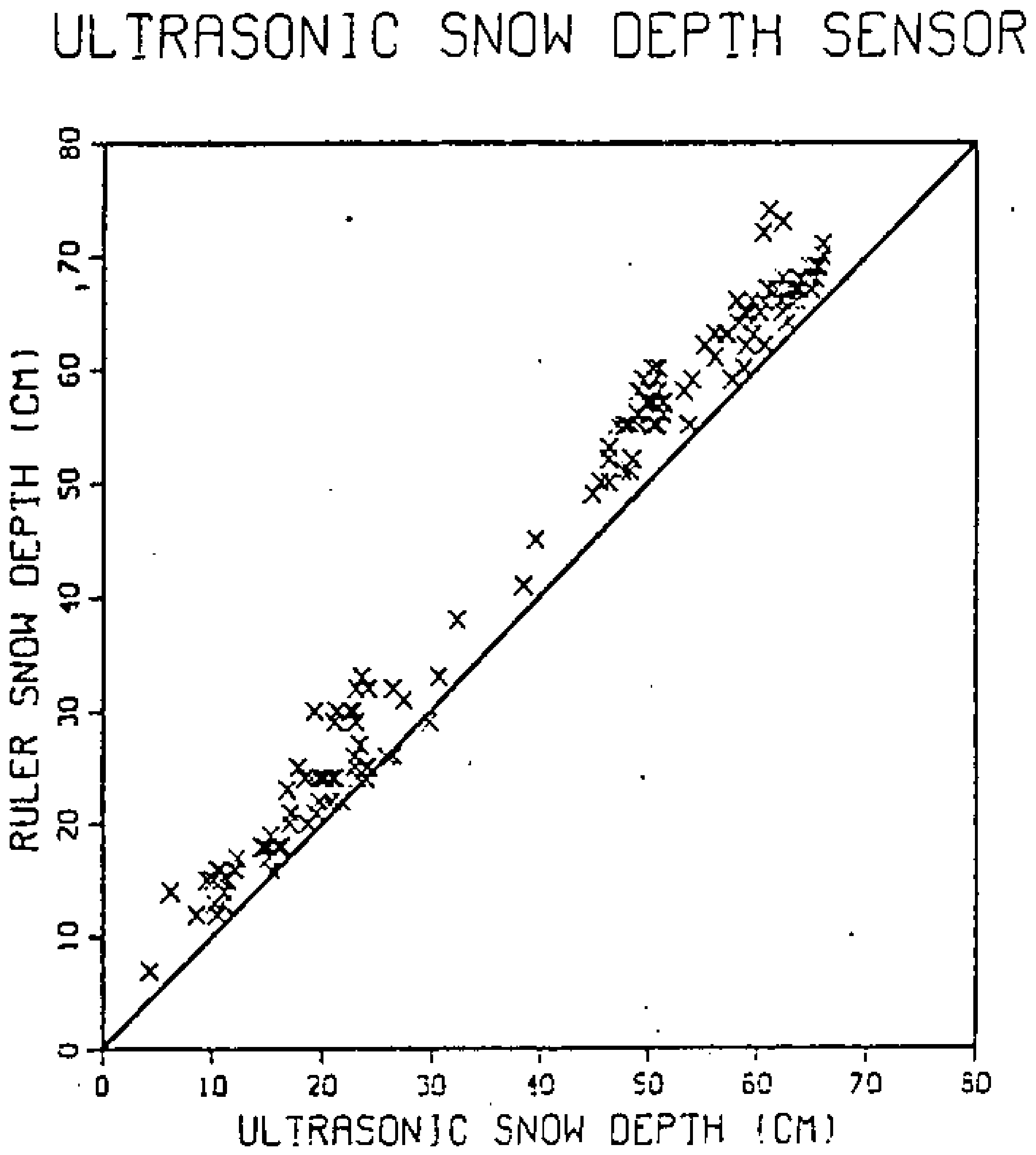


FIGURE 3: COMPARISON OF SNOW DEPTH MEASUREMENTS FROM THE ULTRASONIC SENSOR AND OBSERVED RULER MEASUREMENTS AT DORSET, ONT.

1981

An Experiment to Measure Fresh Snowfall Water Equivalent at Canadian Climate Stations

B.E. Goodison and J.R. Metcalfe

Atmospheric Environment Service
Downsview, Ontario

Currently, at more than 85% of the Atmospheric Environment Service's observing stations, precipitation in the form of snow is estimated from snow depth measurements assuming the density of fresh snow is 100 kg/m^{-3}. This is a convenient, but not necessarily, an accurate estimate of the fresh snowfall water equivalent.

There is an ever increasing demand, particularly from the water resource sector, for accurate winter precipitation data for use in engineering design or environmental assessment investigation. Studies in many regions of Canada depend on the climatological station data and are consequently limited to analyses of snowfall and the estimated water equivalent. The density of fresh snowfall even at one station will be characterized by large inter- and intra-storm variations in actual density (Potter, 1965; Goodison, 1977; O'Neill and MacNeil, 1977). Depending on the region of the country and the associated snowfall characteristics, density may vary considerably from the 10:1 depth to water equivalent ratio used throughout Canada. To get away from universal application of this ratio, however, a rational assessment of density variations throughout the country was necessary. It was proposed, therefore, to measure fresh snowfall water equivalent at selected stations. From these measurements, regional densities of snowfall might be determined and the need for an alternative method of determining snowfall precipitation at climatological stations could be assessed.

In 1979 an experiment was initiated at over 20 observing stations of the Atmospheric Environment Service to test the use of the Type B rain gauge as a "cookie-cutter" snow sampler. This was both a convenient and inexpensive method to measure the fresh snowfall water equivalent. The rain gauge orifice was used as the sampler for depths up to 4 cm and the base of the gauge for greater depths. Samples were taken on a snowboard and a shovel or spatula was used to slide under the sample to hold the snow in place while the gauge was inverted. The snow sample was then melted and the water equivalent read directly as for rainfall.

Table 1 summarizes the 1979-80 results. The density, determined from snowboard depth and water equivalent measurements, varied widely from region to region and even station to station across the country. It was also apparent that for the period of observation the average measured density was generally less than the 100 kg/m^{3} value currently being used. Observers' comments indicated that drifting or blowing snow and mixed precipitation (rain and snow mixed) were the main problems in accurately measuring snow on the snowboard. The ratio of snowboard to ruler in column (6), Table 1, gives an indication of this problem at each station. Low ratios indicate stations where this was a problem.

An attempt was made to reduce the effect of drifting and melting on the snowboards during the 1980-81 winter season by covering them with felt. Initial results (Table 2) are inconclusive on the usefulness of the felt, particularly since observers' comments on the past season's experience have not yet been received. The 1980-81 results which are available do indicate surprisingly consistent average densities for individual stations for the two years. Variations within AES Regions is not surprising because of the different snow regimes which may exist.

The method of observation, that is, use of the Type B rain gauge as a "cookie-cutter", seems to provide a reasonable method of measuring fresh snowfall water equivalent at selected stations. The method was not conceived as an observational procedure to be used at every climate station in Canada and use of the method at selected stations to determine regional densities is perhaps a more feasible approach. The technique itself

---

Proceedings of the Eastern Snow Conference, 38th Annual Meeting, Syracuse, N.Y., June 4-5, 1981

may not be useful at certain stations because of drifting snow or large numbers of rain-on-snow events. Drifting snow is a concern in the determination of snowfall precipitation using this method, but that problem currently exists with our ruler measurements. In the method tested, perhaps more than one sample should be taken to help reduce sampling errors. This, however, increases the observer's workload. Some observers expressed concern about the length of time required to carry out this type of program as compared to making a ruler measurement. This has to be considered as the vast majority of climatological station observations are taken by volunteer observers. The time to take the observation and melt the sample is a factor when considering the applicability of the method.

Detailed analyses of data collected to this time will be carried out to assess inter-storm variability at stations, compare measurements with Nipher gauge data, finalize annual statistics and compare the results with data from synoptic stations collected earlier using different techniques (e.g. Potter, 1965). The study will be terminated at some stations and perhaps extended to some other climate stations. Operational use of the method has not been considered at this time.

Acknowledgements

This study would not have been possible without the cooperation of the Regional Observational Services Divisions of the Atmospheric Environment Service, AES Field Services Directorate and the many observers at the stations where the studies were conducted.

References

Potter, J.G., 1965: "Water Content of Freshly Fallen Snow". Canada Dept. of Transport, Meteorological Branch, CIR-4232, TEC-569, 12 pp.

MacNeil, C.F. and O'Neill, A.D.J., 1977: "Measurements of the Water Equivalent of Freshly Fallen Snow in Canada's Atlantic Provinces". Proceedings, Thirty-Fourth Annual Eastern Snow Conference, Belleville, Feb. 3-4, 1977, p. 118-129.

Goodison, B.E., 1977: "Snowfall and Snow Cover in Southern Ontario: Principles and Techniques of Assessment". Ph.D. Thesis, University of Toronto, 403 pp.

Table 1: Snowfall Water Equivalent Measurements at Selected Atmospheric Environment Service Stations, 1979-80

	Depth Measurement		Water Equivalent			Ratios		
	MSC Ruler (cm) (1)	Snowboard (S.B.) (cm) (2)	Ruler (10:1) (mm) (3)	Nipher Gauge (mm) (4)	Type "B" Rain Gauge (mm) (5)	S.B. / MSC Ruler (6)	Nipher / MSC Ruler (7)	Type "B" / S.B. (8)
ATLANTIC REGION								
Shelburne, N.S.	106.0	66.2	106.0	101.0	61.6	.62	.095	.093
Royal Road, N.B.	58.2	55.4	58.2	101.4	91.2	.94	.174	.165
Churchill Falls, Nfld and Lab.	361.0	84.0	361.0	336.2	75.6	.23	.093	.090
Burgeo, Nfld	219.6	90.7	219.6	208.1	96.9	.41	.095	.107
QUEBEC REGION								
La Pocatiere	70.2	15.1	70.2	68.6	16.3	.22	.098	.108
Ste Agathe Des Monts	75.5	31.9	75.5	68.2	30.2	.42	.090	.095
Maniwaki	31.8	31.8	31.8	29.3	29.1	1.00	.092	.092
ONTARIO REGION								
Kemptville	No Data							
Pinery	88.0	87.0	88.0	n/a	67.4	.99		.077
Monticello	91.7	91.7	91.7	62.9	77.9	1.00	.069	.085
Powassan	128.3	128.3	128.3	n/a	136.7	1.00		.107
CENTRAL REGION								
Rawson Lake	26.5	32.6	26.5	27.0	30.3	1.23	.102	.093
Lloydminster	78.6	80.4	78.6	n/a	57.4	1.02		.071
Wynyard	45.9	17.7	45.9	44.3	18.1	.39	.097	.102
WESTERN REGION								
Jasper	No Data							
Fort Reliance	33.5	30.1	33.5	19.8	21.3	.90	.059	.071
PACIFIC REGION								
Blue River	287.6	287.6	287.6	231.7	232.4	1.00	.081	.081
Dease Lake	78.4	78.4	78.4	53.6	55.3	1.00	.068	.071
Hope	56.5	26.6	56.5	44.4	27.6	.47	.079	.104

Table 2: Snowfall Water Equivalent Measurements at Selected Atmospheric Environment Service Stations, 1980-81

	Depth Measurement		Water Equivalent			Ratios		
	MSC Ruler (cm) (1)	Snowboard (S.B.) (cm) (2)	Ruler (10:1) (mm) (3)	Nipher Gauge (mm) (4)	Type "B" Rain Gauge (mm) (5)	S.B. / MSC Ruler (6)	Nipher / MSC Ruler (7)	Type "B" / S.B. (8)
ATLANTIC REGION								
Shelburne, N.S.	152.6	59.3	152.6	127.2	52.0	.39	.083	.088
Royal Road, N.B.	207.3	197.6	207.3	182.9	183.6	.95	.088	.093
Churchill Falls, Nfld and Lab.	177.4	75.6	177.4	167.8	67.8	.43	.095	.090
Burgeo, Nfld	123.3	57.8	123.3	103.5	47.3	.47	.084	.082
QUEBEC REGION								
La Pocatiere	*NOT ENOUGH DATA*							
Ste Agathe Des Monts	34.4	24.4	34.4	33.2	25.0	.71	.097	.102
Maniwaki	145.5	145.5	145.5	154.0	137.3	1.00	1.06	.094
ONTARIO REGION								
Pinery	81.4	81.4	81.4	n/a	63.2	1.00		.078
Monticello	160.6	155.2	160.6	122.5	134.5	.97	.076	.087
Powassan	114.6	114.6	114.6	n/a	108.9	1.00		.095
CENTRAL REGION								
Rawson Lake	74.1	73.9	74.1	64.6	63.7	1.00	.087	.086
Lloydminster	81.0	81.0	81.0	n/a	78.3	1.00		.097
Wynyard	47.2	30.4	47.2	47.2	26.3	.64	1.00	.087
Rock Point	39.1	38.9	39.1	n/a	35.5	.99		.091
WESTERN REGION								
Jasper	40.5	40.5	40.5	30.5	30.6	1.00	.075	.076
Fort Reliance	50.1	50.4	50.1	34.4	35.3	1.00	.069	.070
PACIFIC REGION								
Dease Lake	115.7	115.7	115.7	94.7	96.8	1.00	.082	.084
Hope	*NOT ENOUGH DATA*							

Eastern Snow Conf, 1980.

AES NIPHER SHIELDS FOR RECORDING PRECIPITATION GAUGES:

AN ASSESSMENT

B.E. Goodison and J.R. Metcalfe

Atmospheric Environment Service
Downsview, Ontario

Previous field tests (Goodison, 1978a) and wind tunnel flow visualization experiments (Turner and Goodison, 1977) have indicated that the MSC Nipher shielded snow gauge has a superior catch efficiency for measuring snowfall water equivalent compared to standard Alter-shielded recording gauges. However, in low snowfall regions, such as the Arctic and Prairies, the MSC Nipher gauge has been found to be less efficient because retention losses and trace amounts were not being accumulated (Goodison, 1978b). A recording gauge would be more desirable for operation in such regions. In order to improve the performance of Alter-shielded recording gauges and to avoid the errors associated with the standard non-recording Nipher gauge, it was proposed that a larger Nipher-type shield should be constructed, scaled to fit the 20.7 cm (8 inch) diameter recording gauges. The aim was to obtain measurements from a recording gauge which would be comparable to the official MSC Nipher snow gauge measurements.

The "scaled-up" version of the MSC Nipher shield was designed by the Atmospheric Instruments Branch of AES. The shield was made of fiberglass. An elongated tube of galvanized sheet metal (diameter 20.7 cm) was affixed to the gauge to extend its orifice even with the top of the shield. Gauges were mounted at 2 m above the ground. Two prototype shields were installed on Fischer and Porter and Universal Belfort recording gauges at the Toronto Meteorological Research Station in January 1979 (Figure 1). Measurements obtained during the snow season are summarized by event in Table 1. The recording gauges with the new Nipher shield recorded a substantially higher catch than Alter-shielded, unshielded, or Wyoming shielded gauges, but the catch was still 7-15% less than the standard MSC Nipher gauge at the station.

Additional shields were built and installed for testing on gauges located in different snowfall environments during the 1979-80 winter season. Either Fischer and Porter or Universal gauges were installed at: Resolute, N.W.T.: Bad Lake, Saskatchewan; Regina, Saskatchewan; Monticello, Ontario; Dorset, Ontario; and Peterborough, Ontario. Different climatic regimes and a variety of local siting conditions were specifically chosen. Unfortunately, low snowfall and higher than normal rainfall were characteristic of many of the stations, particularly those in Ontario.

Data from Saskatchewan for the 1979-80 winter confirmed the higher catch efficiency for recording gauges using the Nipher type shield. At Bad Lake, a Nipher shielded Fischer and Porter caught 96% of the standard MSC Nipher compared to only 37% for an Alter-shielded Fischer and Porter (see Table 2). This latter catch is in line with the long term average monthly catch of 35% reported by Gray et al. (1979). At Regina, the modified Fischer and Porter gauge caught 94% of the MSC Nipher. At both stations only snow events were recorded. Very few trace amounts of precipitation were recorded at either station during the winter.

At Monticello, Ontario, paired Nipher and Alter shielded gauges were placed in both open and sheltered bush locations to assess the effect of siting on the large shield. For the period of operation, the two Nipher shielded gauges accumulated about 20% more than the MSC Nipher gauge. Reasons for this are not known at this time, but because of the size of the shield, snow may have rested on it during periods of light wind and have been blown in later. At this site (as well as at Muskoka and Peterborough) it was observed that during freezing rain events, precipitation was often recorded after the actual time of the event, presumably because of freezing on the orifice extension. Wet snow could also stick to the extension and it would only be recorded later after melting or falling into the catch bucket. Occasional undercatch by the Nipher shielded recording gauges during rain events was observed at some stations. The efficiency of this gauge configuration for measuring rainfall will be tested during the summer months.

Initial results indicate that further testing of this type of shielding is warranted. At this stage there are still problems in design which limit easy operational use of the shield. Its physical size alone makes servicing of both the Fischer and Porter and Universal gauges awkward and difficult. It is hoped that further wind tunnel tests will allow the shield to be shortened to provide a more compact operational unit.

ACKNOWLEDGEMENTS

The Atmospheric Environment Service Instruments Branch personnel, particularly Mr. V. Turner, have been active in supporting the design and testing of this instrument. Many individuals and agencies have cooperated in the installation and operation of gauges for this project, particularly personnel from University of Saskatchewan, AES Central Region, Grand River Conservation Authority, Trent University and the Ontario Ministry of Environment.

REFERENCES

Goodison, B.E., 1978a: Accuracy of Canadian snow gage measurements. Journal of Applied Meteorology, Vol. 17, No. 10, 1542-1548.

Goodison, B.E., 1978b: Canadian snow gauge measurements: accuracy, implications, alternatives, needs. Proceedings, Seventh Symposium on Applied Prairie Hydrology, Water Studies Institute, Saskatoon, May 9-11, 1978, pp. 7-15.

Gray, D.M., H. Steppuhn and F.L. Abbey, 1979: Estimating the areal snow water equivalent in the Prairie environment. Proc. Canadian Hydrology Symposium: 79, Vancouver, May 10-11, 1979, p. 302-322.

Turner, V.R. and B. Goodison, 1977: Wind tunnel evaluation of flow around snow gauges. Paper presented at the 11th Annual Canadian Meteorological Society Congress, Winnipe Manitoba, June 1-3, 1977.

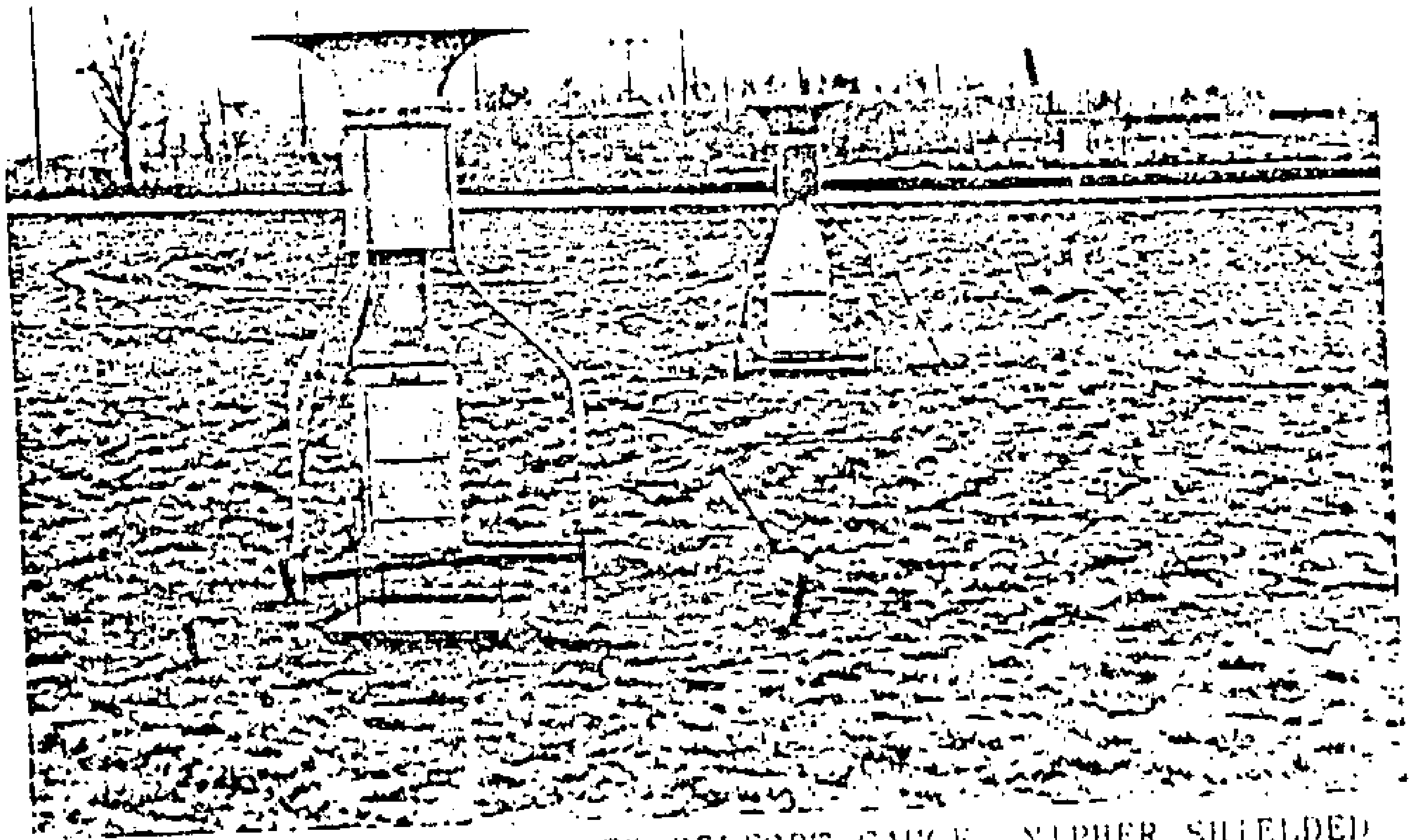


FIGURE 1: NIPHER SHIELDED BELFORT GAUGE, NIPHER SHIELDED FISCHER-PORTER GAUGE AND MSC NIPHER SHIELDED SNOW GAUGE AT TORONTO MET. RESEARCH STATION

TABLE 1

TESTING OF MSC NIPHER SHIELDS FOR RECORDING PRECIPITATION GAUGE
1978-79 SNOW SEASON

PRECIPITATION	WYOMING SHIELDED BELFORT GAUGE (mm)	NIPHER SHIELDED F-P*	NIPHER SHIELDED BELFORT (mm)	ALTER SHIELDED F-P	ALTER SHIELDED BELFORT (mm)	UNSHIELDED BELFORT (mm)	MSC NIPHER
Jan. 13, 14/79 (snow & rain)	18.3	20.3	21.6	12.7	13.5	11.2	21.8
Jan. 17/79	7.1	7.6	8.9	2.5	4.6	1.5	9.1
Jan. 20,21/79	5.6	5.1	7.1	2.5	3.8	2.0	7.6
Jan. 24,25/79 (snow & rain)	21.8	30.5	36.3	22.9	25.4	24.6	[illegible]
Feb. 4/79	2.0	2.5	2.5	2.5	2.0	1.5	4.6
Feb. 7,8/79	3.0	2.5	3.6	2.5	2.0	1.0	3.8
Feb. 16/79	1.3	2.5	[illegible]	NIL	0.8	0.3	[illegible]
Feb. 21/79 (rain)	1.0	2.5	1.0	2.5	0.8	0.5	1.3
Feb. 23,24/79 (rain)	8.9	7.6	6.9	10.2	10.2	9.9	10.9
Feb. 26/79	3.8	5.1	5.3	2.5	2.3	1.0	8.1
TOTALS	72.8	86.2	94.7	60.8	65.4	54.5	101.4
CATCH TOTAL AS % OF MSC NIPHER	72%	85%	93%	60%	65%	54%	

* F-P FISCHER-PORTER PRECIPITATION GAUGE

TABLE 2

SNOW GAUGE CATCH COMPARISONS, BAD LAKE, SASK.
1980

MONTH	FISCHER-PORTER ALTER SHIELDED	FISCHER-PORTER NIPHER SHIELDED	MSC NIPHER SHIELDED SNOW GAUGE
FEBRUARY	2.5 mm	10.2 mm	12.8 mm
MARCH	5.1 mm	5.1 mm	6.2 mm
APRIL	5.1 mm	17.8 mm	15.6 mm
TOTAL	12.7 mm	33.1 mm	34.6 mm
CATCH TOTAL AS % OF STANDARD NIPHER	37%	96%	

Reprinted from JOURNAL OF APPLIED METEOROLOGY, Vol. 17, No. 10, October 1978
American Meteorological Society
Printed in U.S.A.

Accuracy of Canadian Snow Gage Measurements

BARRY E. GOODISON

Accuracy of Canadian Snow Gage Measurements[1]

BARRY E. GOODISON

Atmospheric Environment Service, Downsview, Ontario, Canada M3H 5T4

(Manuscript received 16 December 1977, in final form 18 June 1978)

ABSTRACT

Field investigation to assess the accuracy and comparability of precipitation gage measurements of snowfall in Canada was initiated in 1973. The MSC Nipher shielded snow gage (Canadian standard gage), the Universal (Belfort) precipitation gage, and the Fischer and Porter precipitation gage were tested at open and sheltered sites. Shielded and unshielded pairs of gages were compared at an open site. Gage catch was related to "ground true" snowfall water equivalent as measured on snow boards in a sheltered site.

Each gage tested had unique performance characteristics. Curves of gage catch to ground true as a function of wind speed are given. The catch ratio of the Universal gage is higher than the Fischer and Porter for similar shielding and environmental conditions. The MSC Nipher shielded gage exhibits a superior catch efficiency. At lower wind speeds this gage can overcatch. For winds up to 5.5 m s^{-1} the catch of the Nipher gage is within 10% of true. A mean correction of 0.15 mm for retention loss is required for this non-recording gage. Reasons for the efficiency of this gage are suggested.

Users of gage measurements of snowfall water equivalent in Canada must consider the method of measurement before analyzing or correcting snowfall data.

1. Introduction

In Canada during the last 10 years, there has been an emphasis on modeling the hydrologic cycle on a basin, a region or a national scale. A common conclusion from several of the water balance studies (e.g., Findlay, 1969; Hare and Hay, 1971; den Hartog and Ferguson, 1975) was the apparent undermeasurement of precipitation, particularly snowfall. The accuracy of the areal estimate used in these studies is a function of the accuracy of both the actual point measurement and the method of areal interpolation. The latter may be improved by expanding the precipitation gage network, but this often necessitates the use of different equipment located at sites with varying exposures to measure snowfall precipitation. Ideally, each point measurement should provide a true snowfall total, but this is not the case. Environmental and physical parameters such as wind speed, air temperature, site exposure and gage configuration interact to cause the point measurement to deviate from the true value.

The problem of snowfall measurement has been recognized and investigated in other northern countries. Studies in the Soviet Union (Struzer, 1965, 1969; Bogdanova, 1968; Kuzmin, 1975) and the United States (Larson, 1972; Hamon, 1973; Larson and Peck, 1974; Rechard *et al.*, 1974) were initiated to define the accuracy of their standard snowfall measurements and to investigate and develop improved methods of measurement. This latter step can only proceed after investigation of the former. In Canada, there has been limited field investigation to evaluate the accuracy and comparability of different methods of measuring snowfall water equivalent, particularly those involving precipitation gages.

Ferguson and Pollock (1971) and Harris and Carder (1974) reported discrepancies in snowfall totals obtained using different methods of measurement at the same station. To investigate the problem in detail, a research program to study the methods of snowfall measurement used in Canada was initiated in 1973 at the Cold Creek Hydrometeorological Research Station, 35 km northwest of Toronto, near Bolton, Ontario. One of the aims of the program was to compare the catch of different gages used in Canada and to relate the catch to environmental parameters in order to estimate true snowfall.

In 1974, the World Meteorological Organization (Commission for Instruments and Methods of Observation (CIMO) Working Group on the Measurement of Precipitation, Evaporation and Soil Moisture) initiated a program to evaluate and test techniques for the measurement of snowfall using precipitation gages. Their recommendations on equipment and methods of comparison were incorporated into the Cold Creek study wherever possible.

2. Experimental methods and observations

The basic methods and preliminary observations of the Cold Creek study were reported by Goodison (1975); complete results and methods are given in

---

[1] Presented at the Second Conference on Hydrometeorology, 25–27 October 1977, Toronto, Ontario, Canada.

0021-8952/78/1542-1548$0.500

Goodison (1977). Three of the precipitation gages evaluated were the Canadian MSC Nipher shielded snow gage, the Universal (Belfort) recording precipitation gage, and the Fischer and Porter recording precipitation gage. All three are in operational use throughout Canada. The snow collector of the Nipher shielded snow gage is a hollow metal cylinder, 56 cm long and 12.7 cm in diameter. It is surrounded by a solid shield having the shape of an inverted bell. It is non-recording and requires at least daily observation; snow caught by the gage is melted and the snow water equivalent is measured with a special glass graduate. In this study, the contents of the collector were also weighed in order to assess potential retention losses. The Universal and the Fischer and Porter gages are standard weighing-type recording gages. In the latter, each snowfall event was collected and weighed separately, since the standard recording system had too coarse of a resolution (2.54 mm) for this study. Both the Universal and the Fischer and Porter were shielded with a free-swinging Alter shield. All gages were mounted with the orifice at a height of 2 m.

Four measurement sites were established—two open and two sheltered. Using the subjective classification of exposure proposed by Brown and Peck (1962) the former two would be classed as windy and the latter two as well-protected and protected. An MSC Nipher shielded snow gage and a shielded Fischer and Porter precipitation gage were installed at each site. Shielded and unshielded pairs of the Nipher, the Fischer and Porter and the Universal gages were located at an open site. Totalizing anemometers were used to measure wind speed at gage height at all four sites while wind velocity was recorded continuously at 2 and 10 m at one of the open sites. Mean storm wind speed was determined from the wind run totals at each site.

"Ground true" precipitation was determined by measuring the storm snowfall which accumulated on snow boards (929 cm^2) located at the two sheltered sites. The snow was "cut" perpendicular to the surface along all four sides of the board; the entire amount on the board was cleared into a bag which was then weighed indoors on a precision balance. Snow drifting on or off of the boards was not a problem at the sheltered sites.

Before each storm all snow boards were cleared and placed level with the snow surface. All equipment was prepared so that if hourly observations were not made during the event, at least storm totals would be recorded. For selected storms, regular hourly measurements of mass accumulation on the snow boards and in the Nipher gage, wind run, air temperature, relative humidity and crystal size and shape were made. Only storm totals were recorded with the Fischer and Porter gage. Crystal parameters displayed large intra-storm variation and had limited immediate application to the analysis of gage catch of individual storm totals. For events when only storm totals were recorded, all gages were emptied, boards cleared and totalizing anemometers read as soon as possible after the cessation of snowfall. No information on crystal size and shape was available for these storms.

Errors in the observations may be caused by incorrect depth measurements on the snow board, incorrect weighing of snow samples, adhesion of water droplets in the Nipher collector, evaporation of gage contents, blowout of snow from gage collectors, instrument bias caused by tilting of a gage or shield during the winter and bias in the siting of the gages. The latter two sources of error, if they existed, would vary by storm, and in particular, by wind velocity. If any obvious error in measurement was detected, the results were discarded. To minimize the effect of any measurement error or bias, only storms with a ground true measurement of greater than 5 mm snow water equivalent were used in the final analysis.

Data from the sheltered and open sites provided observations over a wide range of wind speed. Data from only an open site would provide few observations at low wind speeds. The maximum mean storm wind speed sampled was 6.6 m s^{-1}, although a peak mean hourly speed of 7.6 m s^{-1} was measured. In this region of southern Ontario, most snow fell at speeds between 2 and 6 m s^{-1}.

Mean screen air temperature and relative humidity were continuously recorded at the Research Station. Mean storm air temperatures between +1.0 and −18.5°C were observed, but most storms occurred when temperatures were between −3 and −8°C. The 700 and 850 mb temperatures for storm periods were determined from synoptic charts.

3. Results

Standard stepwise multiple regression procedures were used to analyze the ratio of gage catch to ground true (gage catch ratio) with respect to wind speed, screen air temperature, 850 and 700 mb temperature and snow density. Power terms of these parameters were also tested for significance. For all gages tested, wind speed was the dominant parameter, although air temperature provided additional explanation of variance. Snow density was never a significant parameter.

Fig. 1 and 2 show the gage catch ratio curves as a function of wind speed for the shielded Fischer and Porter and Universal gages, respectively. Individual observations of storm precipitation (true >5 mm) are given. The curves are the best-fit curves for the observations shown. The exponential relation between gage catch ratio and wind speed, not only gave the best fit ($r^2=0.92$ and 0.96, respectively), but also followed the relation suggested by American investigations of the Universal gage (e.g., Hamon, 1973; Brewer, 1973). The Fischer and Porter gage displayed more scatter in the results and had a lower catch ratio at equivalent

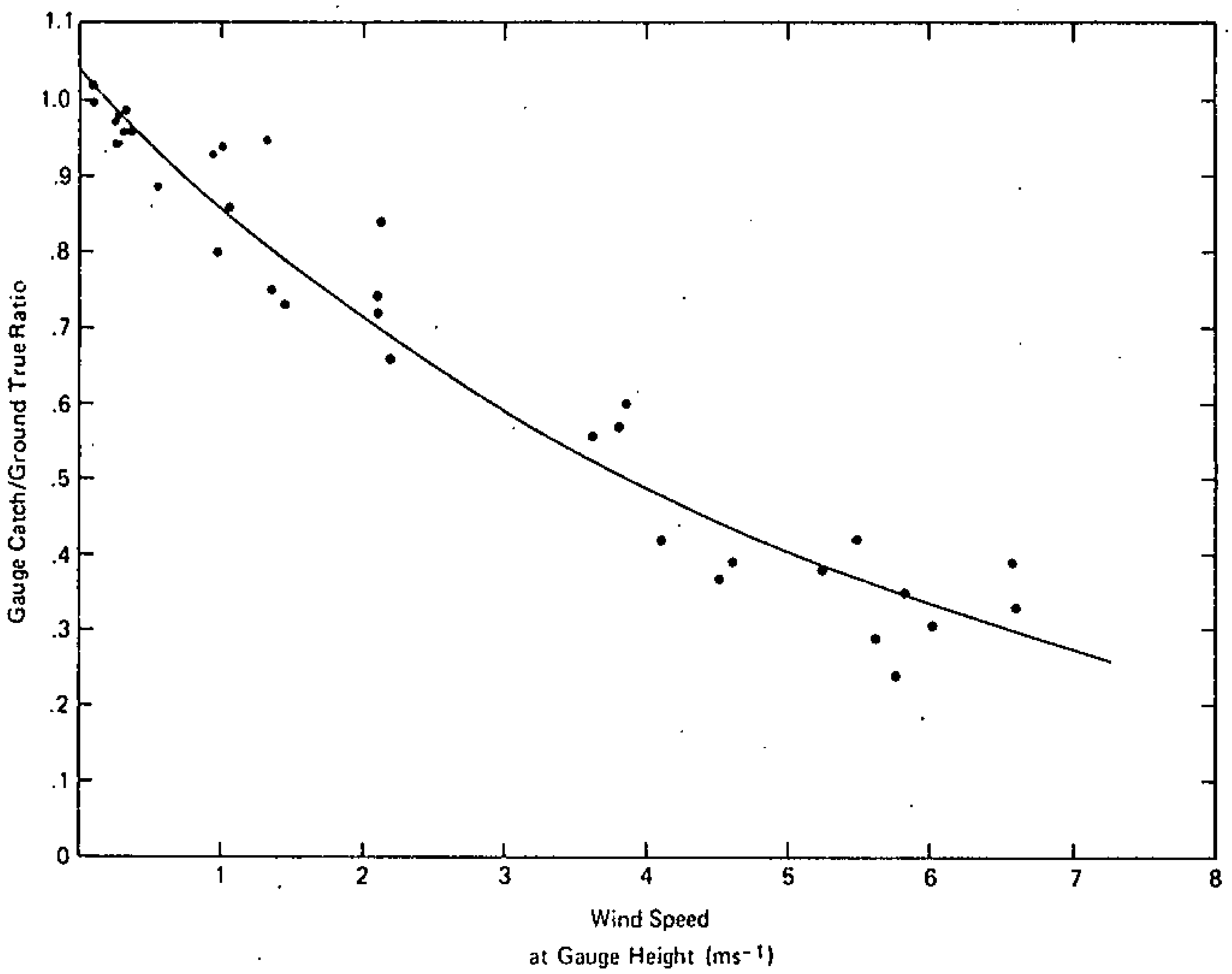


FIG. 1. Gage catch ratio as a function of wind speed for Alter-shielded Fischer and Porter precipitation gage.

wind speeds than the Universal gage. For both gages, screen air temperature was of secondary importance and in this study contributed only an additional 2% and 1% variance explanation to the respective gage catch models. The curves shown correspond to a mean temperature of about −5°C.

The results for the Canadian MSC Nipher shielded snow gage were very different from those for the other

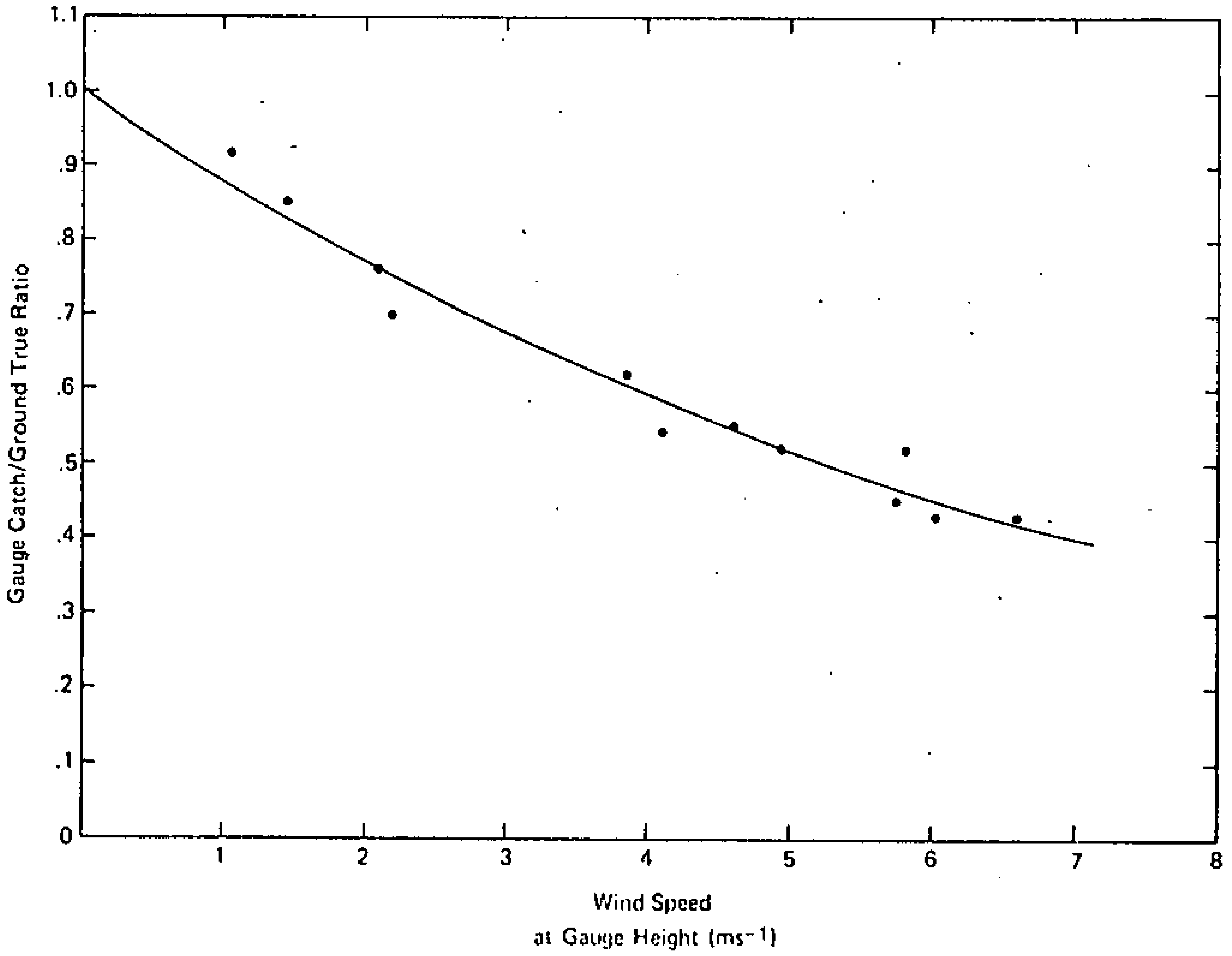


FIG. 2. Gage catch ratio as a function of wind speed for Alter-shielded Universal precipitation gage.

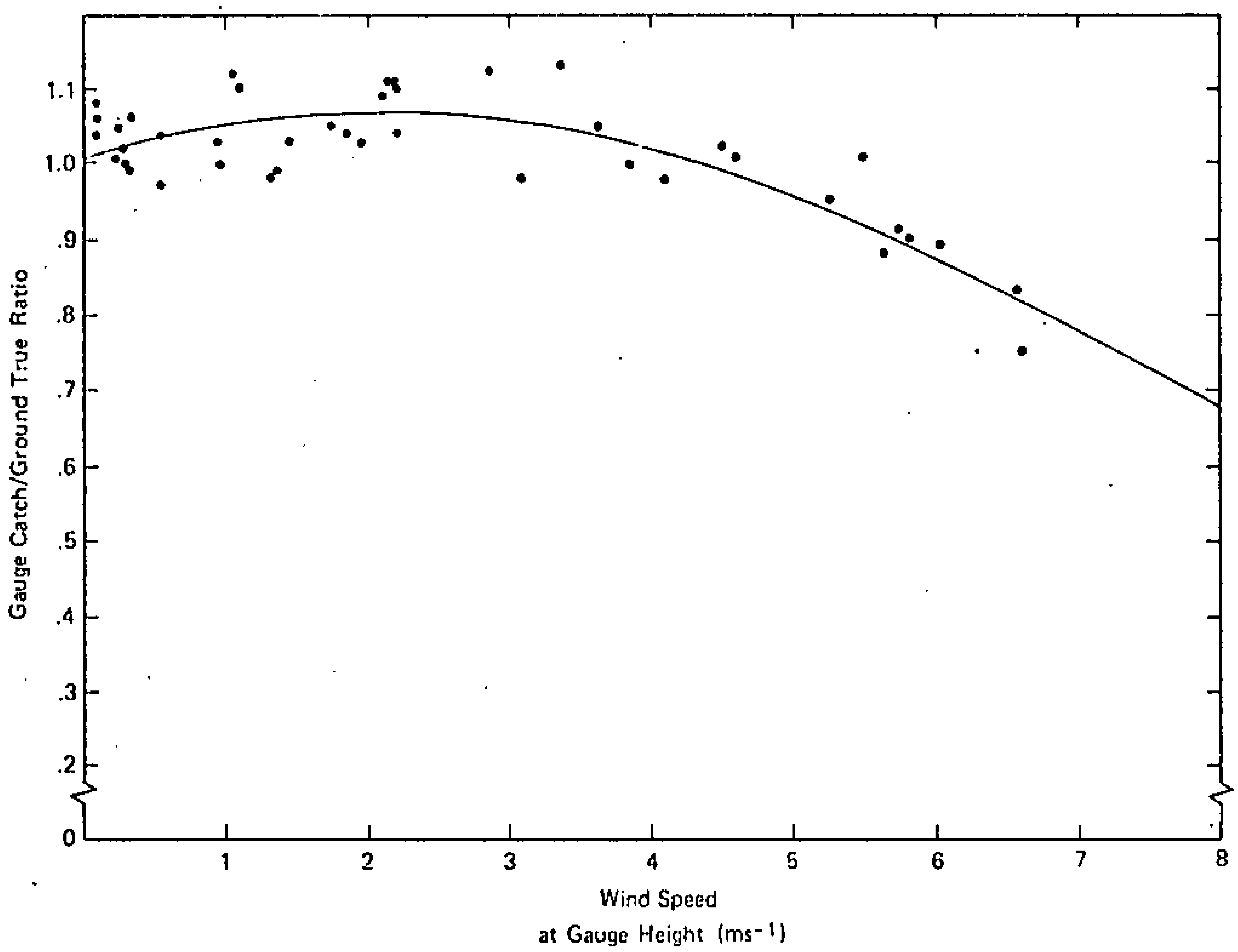


Fig. 3. Gage catch ratio as a function of wind speed for Canadian MSC Nipher shielded snow gage.

gages tested, either shielded or unshielded. Fig. 3 shows the relation between wind speed and gage catch ratio for snowfall events greater than 5 mm true water equivalent. For this gage, the best-fit curve has a wind and wind squared term which together explain 76% of the variance in the gage catch ratio. For wind speeds up to 4 m s^{-1} the Nipher gage generally overmeasures true snowfall, and for speeds up to 5.5 m s^{-1} the mean gage catch is within 10% of true. The 700 mb temperature was also a statistically

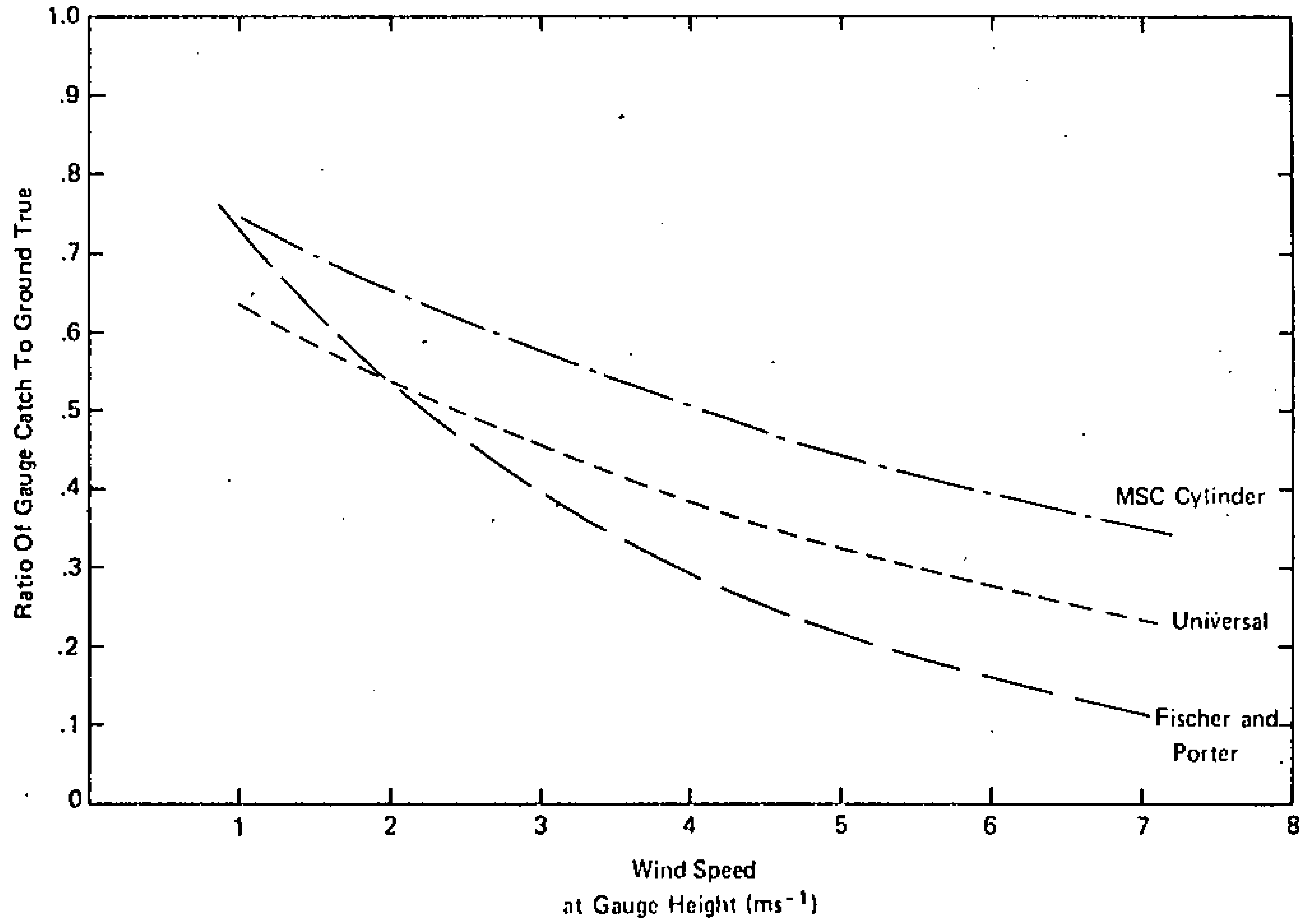


Fig. 4. Gage catch ratio as a function of wind speed for unshielded snow gages.

significant predictor parameter in the model, explaining an additional 7% of the variance in the catch ratio. It is directly proportional to the predicted gage catch ratio. The curve given in Fig. 3 corresponds to a 700 mb temperature of about −10°C. Operational use of the 700 mb temperature as a predictor parameter is limited, however, since it currently is not an easily available value for all gage locations.

The relation between gage catch ratio and mean storm wind speed for the three unshielded snow gages is summarized in Fig. 4. As would be expected, the unshielded gages had lower gage catch ratios than their shielded counterparts. Additional observations at lower wind speeds are required to finalize the relationship for the unshielded gages.

Because of the somewhat limited temperature range sampled in this study, additional data are required to finalize relationships with temperature. The initial data indicate that gage catch is directly related to screen air temperature for all gages, except the Nipher shielded gage for which it is inversely related. This gage was the only one to exhibit a significant statistical relationship with upper air temperatures.

4. Discussion

Many factors affect the catch of a precipitation gage including wind speed, fall velocity of the precipitation particles, air temperature and gage configuration. The results from the Cold Creek study indicate that there is not a universal correction curve applicable to all precipitation gages for all storm conditions. One location, such as Cold Creek, cannot provide a complete range of storm conditions which would be typical of most snowfall regions; yet, it does provide a basic assessment of the performance of the different gages in southern Ontario and adjacent regions.

Each gage tested had unique performance characteristics. The catch ratio of the Universal gage is higher than the Fischer and Porter for similar shielding and environmental conditions. Although both have 20 cm diameter orifices, their general shape and size are very different. The cone shape of the Fischer and Porter gage can induce an airflow up the side of the gage and over the orifice. This updraft would increase turbulence over the orifice and inhibit the fall of snowflakes into the gage. Shielding of the gages did increase gage catch. The Alter shield was similarly effective in increasing the catch of both gages. At 5 m s^{-1}, the Alter-shielded Fischer and Porter and Universal gages caught 40 and 51% of ground true precipitation, respectively, while their unshielded counterparts caught only 21 and 32%, respectively. Both of these shielded and unshielded pairs of gages exhibited a decreasing catch ratio with increasing wind speed.

The form of the relation between the gage catch ratio and environmental parameters is similar to that reported by Hamon (1973) and Larson and Peck (1974), although there was no clear differentiation of the gage types used in these studies. The gage catch ratios recorded at Cold Creek are lower than those reported by Larson and Peck (1974). One of the possible reasons for the difference is the use of snow

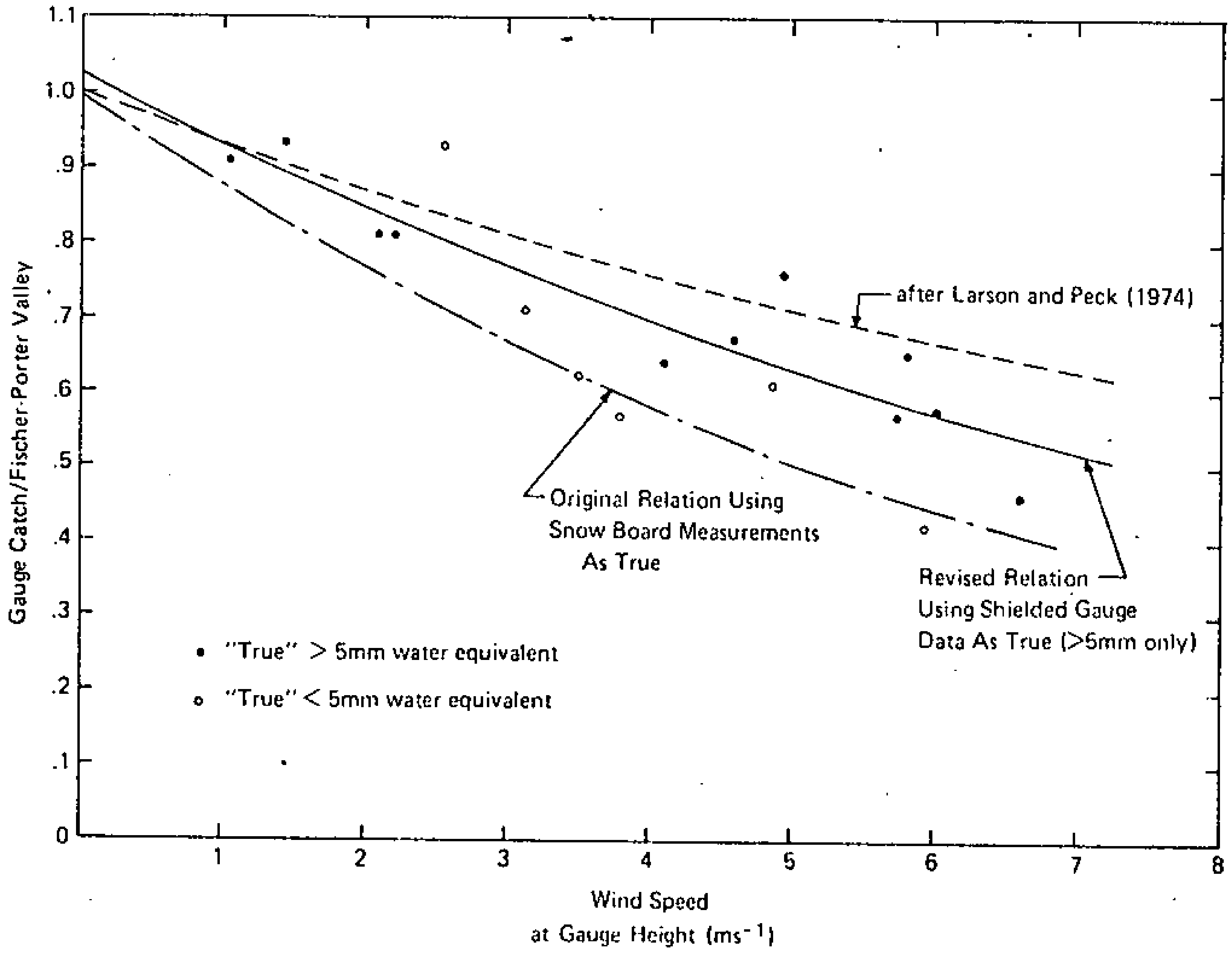


FIG. 5. Comparison of gage catch ratio relations for different methods of determining actual snowfall.

boards, rather than a gage, in a sheltered location to measure actual snowfall. Fig. 5 illustrates the effect of using the catch of a shielded Fischer and Porter gage located at the protected site as true. The net effect is to increase the scatter in the calculated ratios as well as to increase the absolute value of the ratios. If the gage in the sheltered site, i.e., the standard for measuring true snowfall, is at all affected by wind, its recorded storm total will be less than true. The amount measured by this gage will vary from the actual snowfall depending on the wind speed at the sheltered site and other storm characteristics. In this type of field investigation there remains a need to outline or define a universal standard for determining true snowfall.

The results for the Canadian MSC Nipher shielded snow gage shed a different view on the discussion of gage "undercatch." The unshielded collector displayed a gage catch curve similar to that of the other unshielded gages, but addition of the one-piece Nipher shield produced a completely different relation from that which would have been expected if an Alter shield had been used. The improved efficiency of this gage is directly attributable to the solid shield. In summary, reasons for the efficiency of the gage and the overcatch at lower wind speeds are as follows: an effective shield design which minimizes turbulence over the gage; the relatively small surface area exposed to the wind compared to other gages; hard snow particles bouncing off the rim and into the collector; and snow accumulation on the rim at low wind speeds, some of which can be subsequently blown into the collector by a gust of wind (Goodison, 1977). The latter two factors tend to increase the scatter of the ratios for the Nipher at any given wind speed, while the basic form of the relation is primarily dependent on the first two factors.

More factors affect the catch of the Nipher gage than the other gages. The significance of 700 mb temperature is interpreted as the influence of crystal type and size on gage catch. Further definition of the importance of this parameter is required. The relation between screen air temperature and gage catch is the opposite of all other gages, including the shielded collector of the Nipher gage, as warm air temperatures are associated with lower catch ratios. At temperatures near 0°C, wet snow has been observed to build up on the snow collector and during such conditions it is often difficult to determine what should be included in the measurement. A limited number of observations during such events indicate that the gage catch ratio is about 0.15 lower than the mean curve given in Fig. 3.

One additional correction is necessary with Nipher gage measurements. The Nipher gage is not a recording weighing gage; its contents are melted and measured as water equivalent. Because of adhesion of the water droplets to the side of the collector, the poured out total will be less than the actual catch. This retention loss averaged 0.15 ± 0.02 mm. If the Nipher gage is emptied frequently, the retention loss could become a significant total. Adjustment for the mean retention loss is made before correcting the gage catch for the effect of other environmental parameters.

5. Implications of results

The above results indicate that each of the gages tested require unique correctional procedures to determine true precipitation. Users of Canadian snow gage data should be aware of the type of gage used and the local site conditions so that appropriate adjustments may be undertaken. If the gages are well sheltered, so that the influence of wind is minimized, a correction of the measured catch may not be required. Conversely, if gages are located at an open or partially sheltered site, a record of wind speed at gage height is necessary to correct the measured precipitation total.

Although the Nipher gage has a superior catch efficiency compared to the other gages, it must be attended daily by an observer. Conversely, an Alter-shielded Fischer and Porter gage has a relatively poor catch efficiency for snowfall, but it is more suited for use in research and experimental basins or at long-term remote observing stations. Wind speed, however, is not normally measured at these stations, so siting of the gage to minimize the adverse effect of wind becomes critical. Areal analysis of precipitation gage data from sites with varying exposures can provide very misleading results unless corrections for variations in gage catch are made first.

These results demonstrate the need for careful consideration of the different characteristics of precipitation gages used in research and climatic studies throughout Canada. A blanket statement on gage undercatch indeed may not be appropriate. The correction curves presented in this paper should not be viewed as universal curves applicable in all regions of Canada. It is hoped, however, that similar studies will be carried out in other climatic regions of Canada. The results from this study can then provide a basis of comparison for such regional studies and for other experiments in snowfall measurement proposed by other countries.

Acknowledgments. The capable assistance of M. E. Malone and J. R. Metcalfe in helping perform the field experiments and the cooperation of personnel from the Metropolitan Toronto and Region Conservation Authority, Cold Creek Conservation Area, are gratefully acknowledged. The author also wishes to express sincere thanks to Mr. H. L. Ferguson and Dr. F. K. Hare for their comments and support in this project.

REFERENCES

Bogdanova, E. G., 1968: Estimate of the reliability of the characteristics of the shortage in solid precipitation due to wind. *Soviet Hydrology*, No. 2, 139–146.

Brewer, R. E., 1973: Measurement of solid precipitation under windy conditions. M.Sc. thesis, University of Wyoming, 140 pp.

Brown, M. J., and E. L. Peck, 1962: Reliability of precipitation measurements as related to exposure. *J. Appl. Meteor.*, 1, 203–207.

den Hartog, G., and H. L. Ferguson, 1975: National water balance maps of evapotranspiration and precipitation. *Proc. Canadian Hydrol. Symposium-75*, Winnipeg, Assoc. Comm. Hydrology, Nat. Res. Council of Canada, 511–525.

Ferguson, H. L., and D. M. Pollock, 1971: Estimating snowpack accumulation for runoff prediction. Runoff from Snow and Ice, *Proc. 8th Canadian Hydrology Symp.*, Quebec City, Subcomm. Hydrology, Assoc. Comm. Geodesy and Geophys., Nat. Res. Council of Canada, 7–28.

Findlay, B. F., 1969: Precipitation in Northern Quebec and Labrador: An evaluation of measurement techniques. *Arctic*, 22, 140–150.

Goodison, B. E., 1975: Snow studies at Cold Creek: Testing and evaluation of gauges used in Canada for fresh snowfall measurement. *Proc. Can. Hydrol. Symp.-75*, Winnipeg, Assoc. Comm. Hydrology, Nat. Res. Council of Canada, 26–35.

——, 1977: Snowfall and snow cover in southern Ontario: Principles and techniques of assessment. Ph.D. thesis, University of Toronto, 403, pp.

Hamon, W. R., 1973: Computing actual precipitation in mountainous areas. *Proc. WMO-IAHS Symp. on the Distribution of Precipitation in Mountainous Areas*, Vol. 1, WMO No. 326, 159–173.

Hare, F. K., and J. E. Hay, 1971: Anomalies in the large-scale annual water balance over northern North America. *Can. Geogr.*, 15, 79–94.

Harris, R. E., and A. C. Carder, 1974: Rain and snow gauge comparisons. *Can. J. Earth Sci.*, 11, 557–564.

Kuzmin, P. P., 1975: Development of a reference precipitation gauge for the measurement of snow. Unpublished written communication with the Chairman of the WMO CIMO WG on Measurement of Precipitation, Evaporation and Soil Moisture, Geneva.

Larson, L. W., 1972: Approaches to measuring "true" snowfall. *Proc. 29th Annual Eastern Snow Conf.*, Oswego, 65–76.

——, and E. L. Peck, 1974: Accuracy of precipitation measurements for hydrologic modeling. *Water Resour. Res.*, **10**, 857–863.

Rechard, P. A., R. E. Brewer and A. Sullivan, 1974: Measuring snowfall, a critical factor for snow resource management. *Proc. Symp. Advanced Concepts and Techniques in the Study of Snow and Ice Resources*, Monterey, U.S. Nat. Acad. Sci., 703–715.

Struzer, L. R., 1965: Principal shortcomings of methods of measuring atmospheric precipitation and means of improving them. *Soviet Hydrology*, No. 1, 21–35.

——, 1969: Methods of measuring the corrected values of solid atmospheric precipitation. *Soviet Hydrology*, No. 6, 560–565.

WATER RESOURCES RESEARCH, VOL. 17, NO. 4, PAGES 893-900, AUGUST 1981

Compatibility of Canadian Snowfall and Snow Cover Data

B. E. GOODISON

Atmospheric Environment Service, Downsview, Ontario, Canada

The accuracy and compatibility of Canadian snowfall and snow survey data were investigated in the Cold Creek research basin in southern Ontario. Problems in obtaining compatible point measurements of snowfall precipitation from gauge and ruler measurements are discussed. However, it is shown that correction of gauge measurements (MSC Nipher, Universal, Fischer and Porter) of snowfall water equivalent for catch variations caused by environmental factors, notably wind speed, results in compatible storm or seasonal totals. Accurate statistics of basin snow cover were determined from snow courses specifically sited in relation to basin land use. At the time of peak accumulation, which might occur at any time during the winter, there was a statistically significant difference in snow cover between land use categories. Mean basin snow cover was calculated by weighting the snow survey measurements in proportion to basin land use. The need to consider the effect of changing land use on snow course measurements is demonstrated. Results show that as an alternative to direct snow survey measurements, accumulated precipitation may be used to estimate snow cover up to peak accumulation. Net snow cover determined from accumulated corrected gauge data less short-term melt losses and snow evaporation was within the confidence limits of the basin mean snow cover measured during the winter. Compatible results are only achieved when precipitation measurements are corrected for gauge catch variations and snow survey data are representative of basin land use.

INTRODUCTION

Most Canadian snowfall and snow cover data are collected in support of hydrometeorological operations and research. In most instances they involve basic, routine, or what some might call simple measurements. Many hydrological models, particularly those including snowmelt runoff, have evolved using this data base. A necessary initial assumption in these models was that the snow data were essentially compatible and correct. However, there is reason to question not only the accuracy and representativeness of the data but also the compatibility of the snowfall and snow cover statistics [*Adams et al.*, 1966; *Dyck*, 1969; *Provart*, 1970; *Goodison*, 1977].

The difficulties in snow measurement have been recognized in other northern countries. For example, studies in the USSR and USA were initiated to define the accuracy of their standard snowfall–snow cover measurements and to investigate and develop improved methods of measurement. This latter aim can be achieved only after investigation of the former. The successful development, assessment, and integration of new techniques, such as those involving the acquisition of snow measurements by remote sensors, can only be accomplished through comparison with existing methods. Knowledge of the accuracy and compatibility of snow data is fundamental if there is to be effective expansion of automatic snow sensor data in water supply forecasting techniques and if various models, particularly physically based ones, are to be transferred effectively from region to region or from country to country.

The monitoring of potential flood conditions in many regions requires continuous assessment of snowpack water equivalent. In an area such as southern Ontario, where winter ablation and winter rain may interrupt the continuous development of a snowpack, spatial and temporal variations of snow cover generally exclude the use of a single spring snow survey to measure the maximum snow accumulation. Instead, the preparation of runoff forecasts relies on twice monthly snow surveys and daily precipitation measurements. Operationally, snow data have tended to be used as an index of potential flood conditions rather than as an input to a physically based snowmelt model. However, to model basin snow ablation processes through the winter and spring, an accurate assessment of snow accumulation is necessary. An effective blend of snow survey and precipitation data must occur if the resulting forecasts are to be useful and accurate. Consequently, one of the aims of the research carried out in the Cold Creek Basin (60 km^2; 40 km northwest of Toronto, Ontario) was to conduct a rational analysis of the accuracy and compatibility of Canadian snowfall and snow survey data.

ACCURACY AND COMPATIBILITY OF SNOWFALL MEASUREMENTS

The calculation of basin precipitation in the form of snow still relies on point measurements as the basic input data. However, as shown in Table 1, there can be a problem in obtaining compatible measurements either when using different methods of measurement at a single site or when using similar equipment at different sites with varying exposures. The problem is compounded when areal snowfall totals are calculated from data collected by different measurement methods at variously exposed sites over the basin. Which of the measured totals is the most nearly correct?

Field studies to investigate this problem in greater detail were initiated at the Hydrometeorological Research Station in 1973. The locations of this station and other hydrometeorological stations and snow courses in the Cold Creek Basin are shown in Figure 1. Gauges evaluated included the Fischer and Porter, Universal-Belfort (USA), Tretyakov (USSR), and MSC Nipher shielded snow gauge (Canada). One of the aims of the study was to establish a functional relationship between gauge catch and environmental parameters, such as wind speed and temperature, which could be used to estimate actual snowfall or 'ground true' precipitation.

Complete details on the basic method of observation, associated errors, and results are presented by *Goodison* [1977] and summarized by *Goodison* [1978*a*]. Figure 2 summarizes the best fit relationships of the ratio of gauge catch to ground true (determined from storm snowfall accumulation on snow boards at a sheltered site) with respect to wind speed for four

Paper number 1W0205.
0043-1397/81/001W-0205$01.00

TABLE 1. Precipitation Measurements at the Cold Creek Hydrometeorological Station and at Selected Sites in Cold Creek Basin, 1972–1973

			Total Precipitation,[a] mm		
Gauge Installation	Site	Exposure	Dec. 1972	Jan. 1973	Feb. 1973
MSC Nipher shielded	HRS	open	97.35	26.43	46.36
Unshielded Universal	HRS	open	61.97	20.20	26.94
Fischer and Porter with Alter shield	HRS	open	...	20.32	30.48
Unshielded Fischer and Porter	HRS	open	...	...	25.40
Ruler Estimate based on 10:1 ratio	CCS	partially sheltered by barn	98.02	27.43	48.02
Unshielded Universal	MW	open	59.45	21.46	24.89
Unshielded Universal	CCL	sheltered	88.27	31.62	40.64
Universal with Alter shield	BF	partially sheltered	79.50	20.70	33.28

HRS, Hydrometeorological Research Station; CCS, Cold Creek Climate Station; MW, Mt. Wolf; CCL, same as snow course; BF, Bolton Farm.

[a] Snow and rain.

types of shielded gauges. Wind speed was the dominant environmental parameter affecting gauge catch, although air temperature provided additional explanation of variance. The relationships for the Universal, Tretyakov, and Fischer and Porter gauges follow the basic trend of decreasing catch efficiency with increasing wind speed, as reported by *Hamon* [1973] and *Larson and Peck* [1974]. In all field tests the Alter shielded and unshielded Fischer and Porter gauges measured

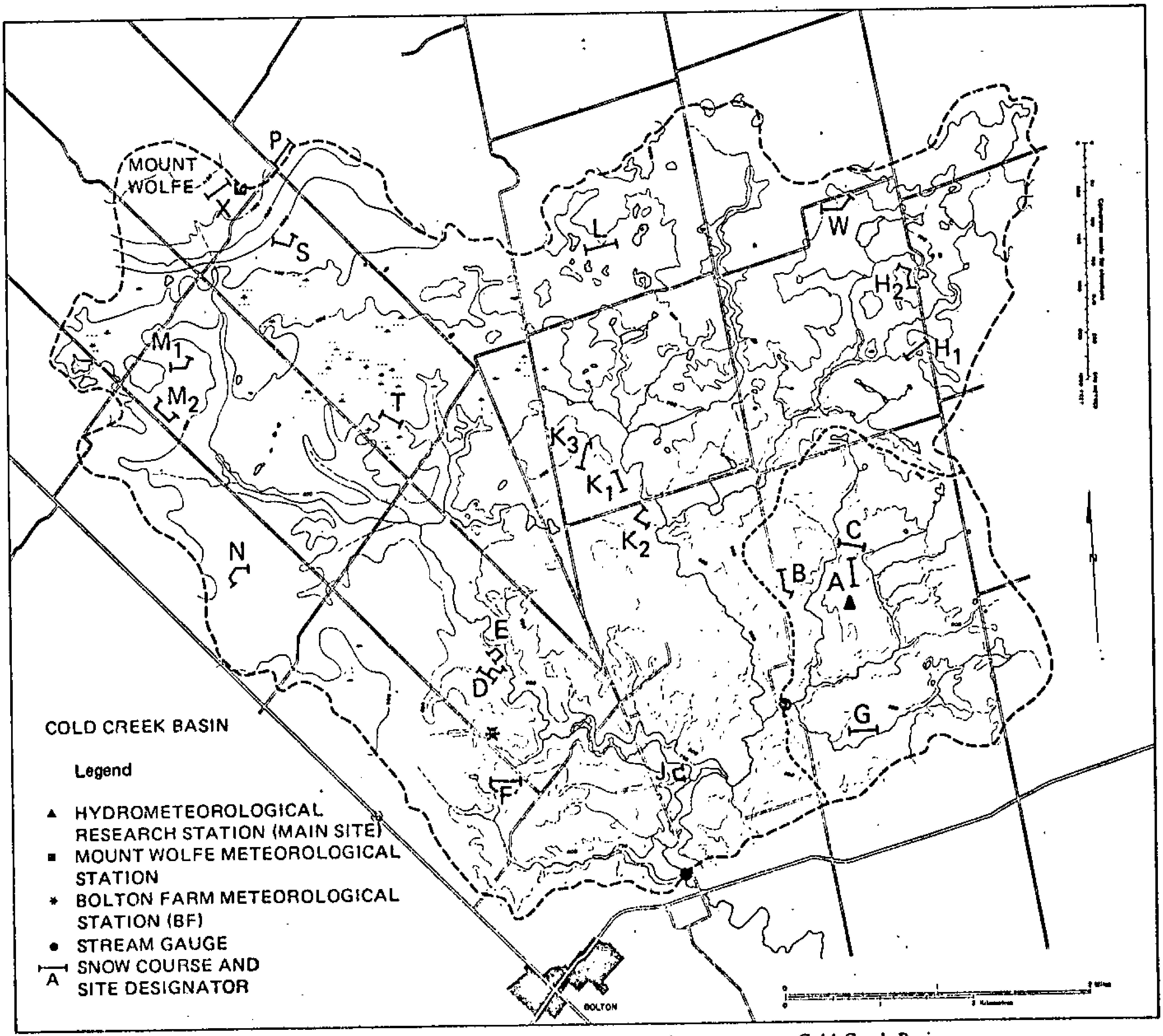


Fig. 1. Locations of hydrometeorological stations and snow courses, Cold Creek Basin.

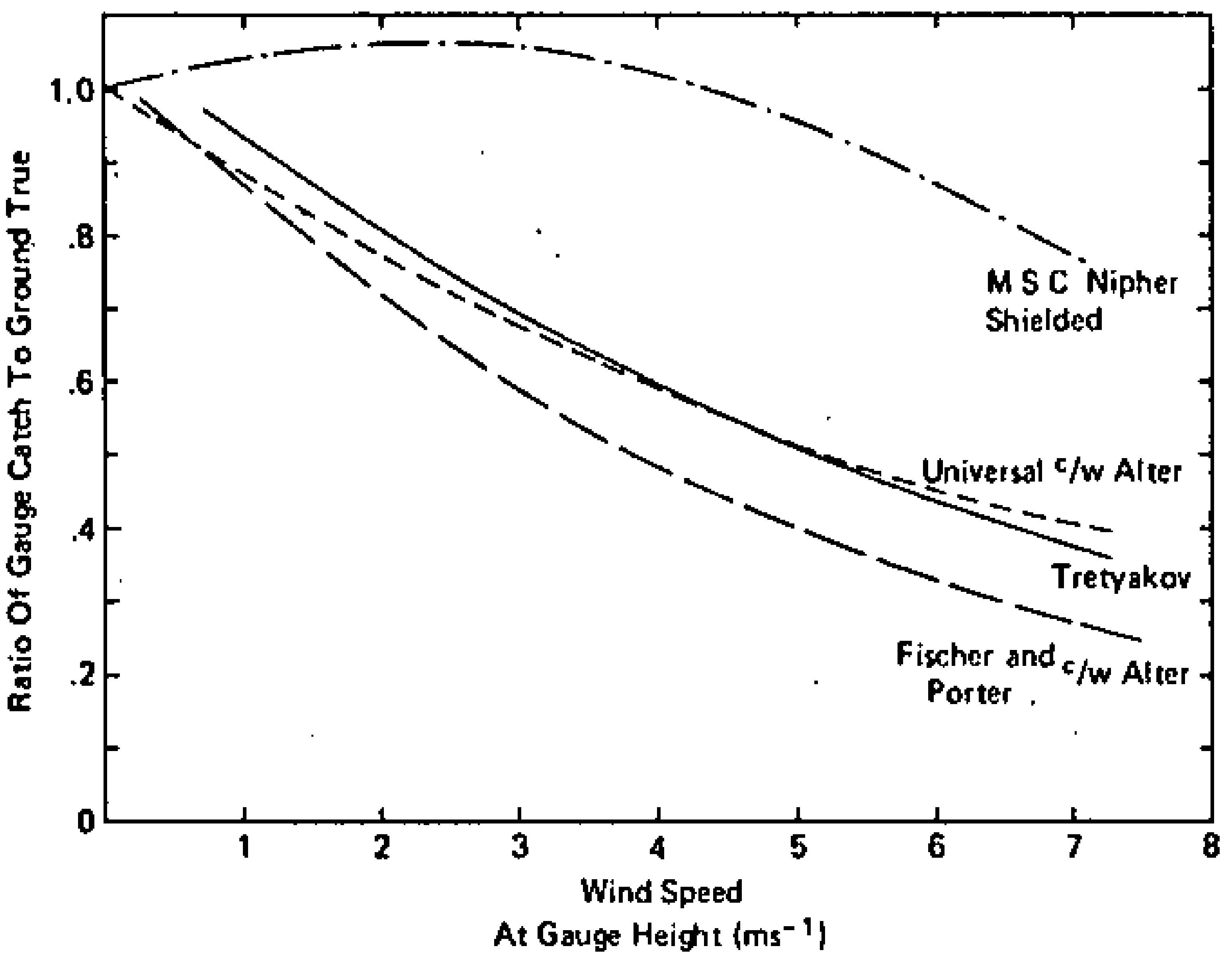


Fig. 2. Mean gauge catch ratio as a function of wind speed for shielded snow gauges.

less than the respective Universal gauges. This relationship was also reflected in the measured seasonal snowfall totals (see Table 1). A discussion of the results for the Fischer and Porter gauge and of the implications for the collection and use of these data is provided by *Goodison and McKay* [1978].

The catch for the Canadian MSC Nipher shielded snow gauge was markedly different from the other gauges tested, since for wind speeds up to 5.5 m s^{-1} the mean gauge catch was within 10% of ground true. In sheltered sites, snow capping and the buildup of wet snow can be a problem. Because the gauge is nonrecording and the contents are melted and poured into a graduate for measurement, adjustment for moisture retained in the Nipher collector (determined to be 0.15 ± 0.02 mm) and for trace amounts is necessary. A more complete discussion of the results for the Nipher gauge and their significance, particularly in low-snowfall regions, such as the Prairies and the Arctic, is given by *Goodison* [1978*b*].

The results emphasize that each type of gauge requires its own correction procedure to determine 'true' snowfall precipitation at a point. To obtain compatible precipitation data for either the same site or sites with different exposures, correction of the measured total for the effect of environmental factors, particularly wind speed, is required.

Table 2 illustrates the positive effect of correcting the 1972–1973 winter snowfall precipitation measurements which were collected prior to the testing program. At the Research Station the corrected totals increased significantly for the Fischer and Porter and Universal gauges but only slightly for the Nipher gauge. A comparison of the measured Nipher total at the Research Station and the unshielded Universal gauge at Mt. Wolfe (7 km to the north) would suggest that a significant areal variation in snowfall exists. However, the corrected gauge data indicate that the areal variation between the two sites, which are located at extreme ends of the basin, is actually small and within the errors of measurement and correction.

Tables 1 and 2 also include snowfall water equivalent totals calculated from ruler depth measurements, using a mean density of 100 kg m^{-3}. These totals compare favorably with the Nipher totals. In addition, a comparison of the average snowfall water equivalent for 23 snowfall events over a 3-year period showed the ruler estimate to differ by only 1% from that measured on snow boards. However, as for the 1972–1973 data, the mean error (rms) on a storm by storm basis was ±30%.

Ruler estimates will be in error in regions where the particular snowfall regime is characterized by snow with a mean density somewhat different from 100 kg m^{-3} (e.g., lake effect snowfall). The error when ruler estimates are used depends not only on the magnitude of the deviation of the true storm density from 100 kg m^{-3} (observed in this study to range from 50 to 205 km m^{-3} with wide intrastorm variation) but also on the site where the measurements are made, the representativeness of the depth measurements, and the time of the observation during the storm [*Goodison*, 1977]. Unlike gauge measurements, there is a large subjective element involved in obtaining representative depth measurements, and this makes

TABLE 2. Calculation of True Snowfall Water Equivalent, at Cold Creek Hydrometeorological Research Station and Mt. Wolfe for Individual Storms, Winter 1972–1973

				Nipher Gauge, mm		Unshielded Universal, mm		Alter-Shielded Fischer and Porter, mm		Mt. Wolfe Unshielded Universal, mm	
Date	Wind Speed, m s^{-1}	Temperature, °C	Ruler, mm	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected	Uncorrected	Corrected
December											
8	1.4	−3.6	5.33	6.23	6.17	3.30	5.35	···	···	3.56	5.77
10	2.6	−3.1	4.06	3.05	3.18	1.27	2.46	···	···	1.28	2.47
15	3.1	−5.4	18.29	16.26	15.97	7.11	16.13	···	···	8.13	18.44
16	6.0	−8.1	10.16	9.45	10.97	2.54	10.11	···	···	2.29	9.11
29	3.6	−5.0	12.19	11.43	11.17	5.33	13.00	5.08	12.93	4.57	11.15
January											
14	1.7	−2.1	2.03	1.27	1.35	0.64	1.05	0.76	1.00	0.25	0.41
27–28	2.3/3.3	−0.5/−3.2	2.29	7.52	7.44	4.32	8.38	5.08	8.25	6.35	12.55
February											
7	3.3	−0.8	8.64	6.73	6.51	2.03	4.19	2.54	4.54	2.54	5.24
14–15	5.3/7.6	−6.2/−3.5	1.78	4.22	5.94	1.16	4.82	2.54	6.62	1.27	5.82
20–21	2.5/3.2	+0.2/−5.5	11.69	12.44	12.15	4.70	9.45	5.08	8.41	4.32	9.29
25	1.6	−10.1	6.60	3.86	3.78	2.03	4.08	2.54	3.29	1.91	3.84
Totals											
Dec. 8 to Feb. 25			83.06	82.46	84.63	34.43	79.02	···	···	36.47	84.09
Dec. 29 to Feb. 25			45.22	47.47	48.34	20.21	44.97	23.62	45.04	21.21	48.30

correction of ruler estimates of water equivalent for density variations difficult.

If models of snow accumulation and ablation are to be successful, accurate daily records of precipitation are required to simulate the snow regime at a site. It is necessary, therefore, that users of Canadian snowfall precipitation data make themselves aware of the type of measurement method used or the type of snow gauge used and the shielding, and the local site conditions. Only then can one carry out a rational assessment of the accuracy of the data and decide whether to correct snow gauge measurements to provide compatible point data suitable for use in areal analyses and model simulations. The question then remains whether the corrected accumulated snowfall precipitation is compatible with the standard operational tool—the snow survey.

ACCURATE DETERMINATION OF SNOW COVER

Snow Survey Network

The most suitable sampling scheme for the analysis of snow cover must be related to the climatic and landscape characteristics of the region. The final distribution of snow cover over a basin depends not only on the initial variation in snowfall but also on the ability of different surfaces to catch and retain snow, the meteorological conditions which prevailed during the accumulation period (e.g., the frequency and duration of blowing and drifting snow), the temperature during ablation periods, and the snowiness of the winter. Various survey schemes which consider these factors have been discussed by *Vershinina* [1972], *Dickinson and Whiteley* [1972], *Steppuhn and Dyck* [1974], *Adams* [1976], and *Goodison* [1977]. All of these studies were concerned with obtaining accurate areal estimates of snow cover rather than just an index of potential flood conditions.

Because of the local landscape and climatic conditions of this region of southern Ontario, the most effective sampling method to meet the needs of the study was a standard fixed point snow course network established with consideration of local terrain and land use variations. The large number of small (4–20 ha) individually fenced fields with differing land use (mixed farming) limits the effective operation of continuous traverses of landscape units such as those used by *Steppuhn* [1976] for Prairie regions. In addition, since a single spring snow survey could not be relied on to provide data on the peak snow accumulation and random traverses would not provide the consistency for the intraannual or interannual comparison of data, regular snow survey measurements during the winter were required to monitor changes in the snowpack.

Reconnaissance snow courses in 1970–1971 indicated that a distinct difference existed between winter land use types and snow cover properties. In 1971–1972 a network of 16 snow courses (most were standard 10-point courses) was established. Snow course sites were objectively selected so that there was a relatively even areal representation throughout the basin and a distribution approximating both the hypsometry and land use of the basin. Land use data were based initially on the national ARDA (Agriculture and Rehabilitation Act, Canada Land Inventory) land classification system and were updated with a detailed field by field winter land use survey in 1973. Three courses (long grass, short grass, and mixed forest) were established as control courses near the Research Station. More detail on network design and site selection is given by *Goodison* [1977]. Unlike most operational snow courses, all landscape types, not just those areas with maximum accumulation, were sampled.

The final land use stratification and relative basin coverage for each type were as follows: forest, 12%; long pasture grass, 39%; medium hay or grain stubble, 10%; short grass, 18%; and ploughed, 21%. Fields of any land use type which were sheltered by forest exhibited snow cover characteristics similar to those of the long grass sites, and a 4% increase in this category was made to allow for this. Individual fields in the basin might change their land use from season to season, but the relative distribution of land use remained quite stable over the 1970–1976 period. Land use of each snow course was recorded annually.

Snow Cover-Vegetation Relationships

Snow cover over the Cold Creek Basin displayed considerable spatial and temporal variability both within and between winter seasons. *Goodison* [1977] found that during the 1971–1977 period, large interannual variations in depth, density, and water equivalent were common on any snow course at the time of peak accumulation, which could occur at any time from January to April. In a single year the date of peak accumulation may vary for different land uses, although the expected variability (as expressed by the coefficient of variation) for each land cover type was quite consistent, indicating that the standard fixed point snow course which is regularly measured can provide data whose means and error variances are consistent over time.

Differences in snow cover among land use types increased as the season progressed, reflecting the ability of different vegetation zones to repeatedly accumulate and retain snow in a specific manner. The maximum difference in snow cover among categories generally occurred at the time of peak accumulation, resulting in a distribution of snow cover such as that shown in Figure 3. The probability distribution for depth is based on data from all points on the 16 snow courses and from additional depth measurements (five between each survey point) made along each course. The means and confidence limits for the depth, density, and water equivalent at only the snow course points representing each land cover type are tabulated separately in Figure 3. An analysis of variance indicated that a statistically significant difference in mean snow cover properties existed between land use categories. This also occurred at peak accumulation in other years.

Several points characteristic of the snow cover emerge. The open areas of short grass or ploughed fields have the highest density, lowest snow water equivalent, and lowest depth of the different land use types. Being susceptible to redistribution by the wind, snow accumulation on these courses reflects the influence of local terrain, resulting in the most variable snow cover. The snow cover in the more protective vegetation classes and in the sheltered fields not only displays steadily increasing depth but also more normal and less variable snow depth distributions. The increase in mean depth and the change in the depth distribution from the exposed smooth surfaces to the more protective land covers are clearly illustrated.

The distributions suggest that additional subdivisions by terrain might be beneficial for the open grass and ploughed sites. Variations which could be related to terrain were investigated and reported in detail by *Goodison* [1977]. Basically, it was found that the effect of terrain on local snow cover depended first on the local land use, which influenced

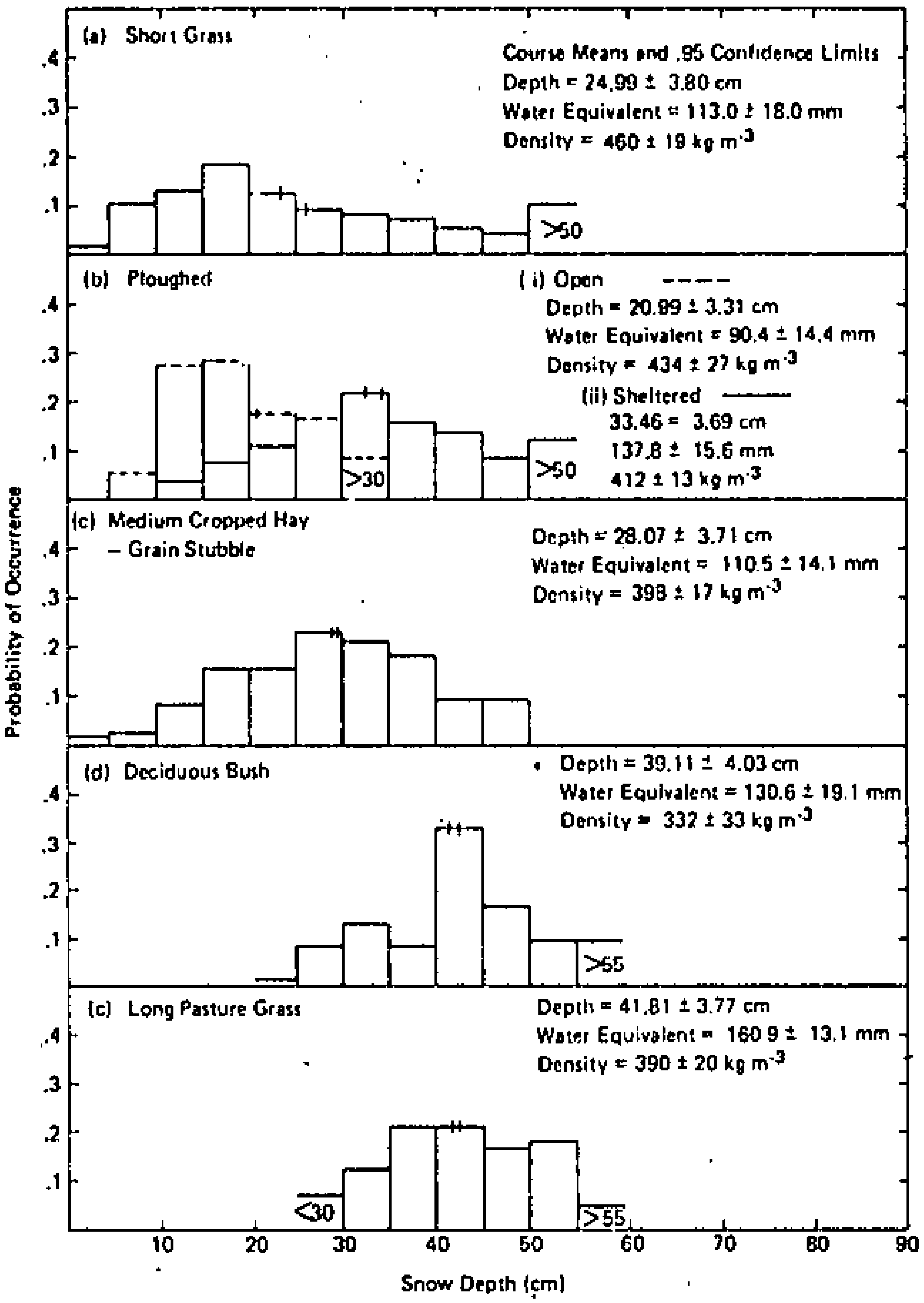


Fig. 3. Probability distribution of snow depth by land use type, March 26–29, 1972.

the amount of snow accumulation. Terrain irregularities, when significant, increased the error variance of the snow cover properties. Since slopes in the basin were irregular and generally short, stratification of individual Cold Creek snow courses by terrain was impractical, although the snow courses were established with consideration of local terrain variations.

The variability (as described by the coefficient of variation) associated with mean snow cover properties also exhibits a definite relation with land use. Figure 4 compares the seasonal variability for categories of long grass, short grass, and deciduous bush. As might be expected, the open short grass courses had the greatest variability of snow depth throughout the season, yet all four courses, located at different sites throughout the basin, displayed similar variability. The variation in snow depth for long grass and deciduous bush is lower and more consistent throughout the season. In the case of these two land classes, wind redistribution of snow and the influence of terrain are minimized by the increased protection afforded by the land cover. Increased variability during snowmelt events (January and April) was common on all courses.

An important consideration in the determination of areal snow cover which is often overlooked is the effect of a change in land use on a particular snow course. Snow courses are installed with the intention of repeatedly sampling the same points over time. Generally, agencies try to avoid areas where there will be annual changes in land use, but this can be difficult. If the land cover should change, one may move the snow course (this is, in fact, rarely done) or leave it and monitor the snow cover as in previous years. However, this will result in snow cover data which are not compatible with previous surveys.

The effect of a change in land use on snow course data is shown in Figure 5. Course CCX was established over a level ploughed field to compare with CCP, a neighbouring course over long pasture grass. Course CCP was on a ploughed field 6 km to the south and at an elevation 80 m lower (Figure 1). In 1973–1974 the two ploughed fields have virtually identical mean snow water equivalents, and except for the first survey they were significantly different (statistically) from that of long pasture grass. For similar landscape units there was no significant difference directly attributable to elevation differences, yet for courses at similar elevation and location, land use caused a large and statistically significant difference in snow water equivalent.

In the 1975–1976 season, CCX was covered by wheat stubble, resulting in a water equivalent greater than that determined for the ploughed field but less than that determined for long grass. This would be expected given the discussion above. During 1976–1977 the adjacent courses CCX and CCP had the same land use, while CCF was still ploughed. The latter had a water equivalent significantly less than that of the other two. Over the three winters the characteristics of snowpack development were drastically transformed for CCX solely because of changes in land use. When these changes are known, snow accumulation for this course can be rationally compared with that from other courses, and differences in the annual statistics can be accounted for. If the change is not known, faulty analyses of spatial and temporal variability of snow cover would result.

The importance of land use stratification for the accurate assessment of mean basin snow cover is evident. Standard snow courses measured regularly throughout the winter can provide the data for the calculation. The best method to determine mean snow water equivalent, depth, or density is to weight the measured parameters according to the proportion of the basin covered by each land use type. The associated error statistics are weighted by the square of the proportional area. The mean and standard error of each land use can be calculated by combining the observations from each course measured in that unit on a particular survey date. This can be achieved by calculating the mean snow cover for each land use from the individual snow course means, which are weighted by the number of observations in each. The same proce-

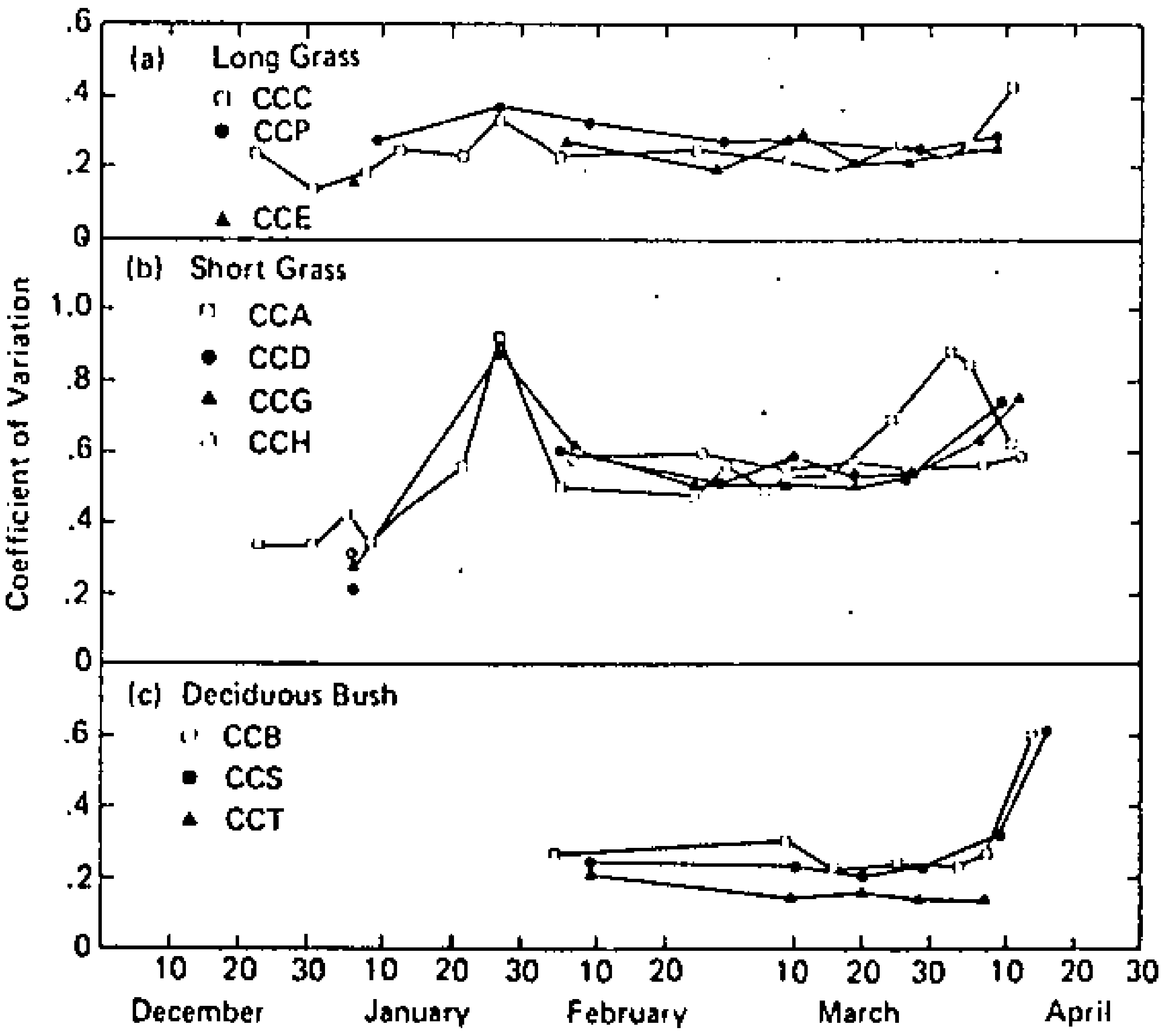


Fig. 4. Snow depth variation with different vegetation types, 1971–1972.

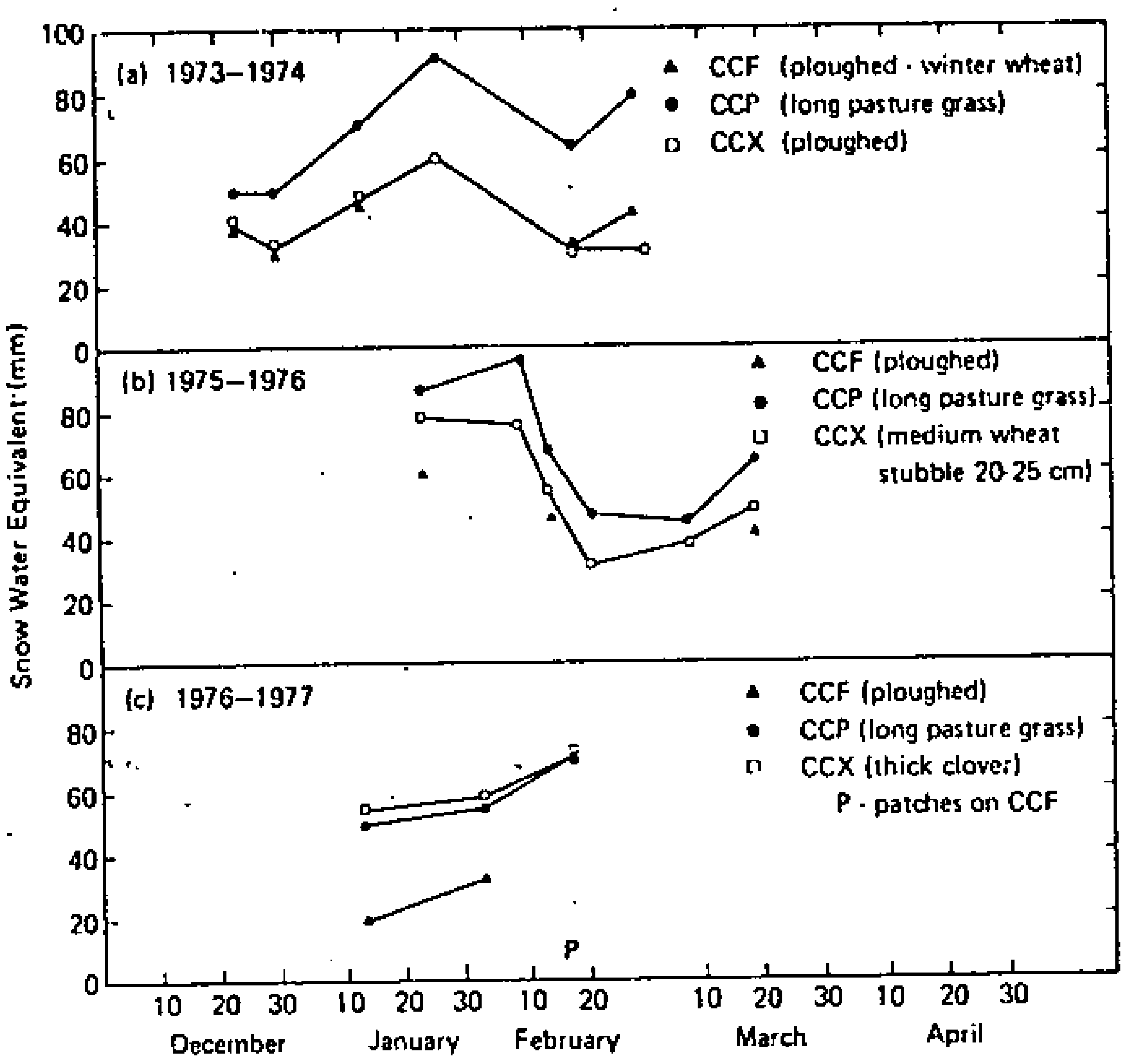


Fig. 5. Variations in snow water equivalent as related to annual changes in land use.

dure can be used to calculate the mean change in snow water equivalent between selected survey periods.

MASS BALANCE OF THE SNOWPACK: COMPARISON OF MEASURED AND CALCULATED SNOWPACK ACCUMULATION

The previous discussion has shown that accurate determination of basin snowfall and snow cover water equivalent can be difficult in southern Ontario. Since effective monitoring and evaluation of current and future hydrological conditions in the region requires use of both data sets, the inevitable question is whether correction of field measurements can provide snowfall and snow cover statistics which are in fact compatible.

The mass balance of the snowpack in the basin is of course a function of precipitation (rain and snow) minus any snowmelt and evaporation/sublimation losses. The mass balance at a point in time and the change over time can be calculated by measuring or estimating each of these components individually, or they can be determined from snow survey measurements weighted by land use. To compare the calculated and measured totals, snowmelt and evaporation losses must be considered.

A snowmelt index plot was installed to monitor 'point' snowmelt losses from an open environment during accumulation periods. The plot was a 6-m^2 area from which all runoff was measured. Details of its construction and use are given by *Goodison* [1977]. For short-term melt events during the accumulation period, snowmelt plot losses compared favorably with the loss calculated by using the degree-day index commonly used for southern Ontario, i.e., 0.91 mm/degree-day of maximum temperature greater than 0°C [*Bruce and Clark*, 1966]. The degree-day approach was used to estimate melt losses when melt plot data were missing.

Although rates of snow evaporation generally are considered to be small and within the error limits of other measurements, their cumulative total may be significant, and thus evaporation cannot be excluded in the mass balance computation. Snow evaporation was computed following the method tested by *Williams* [1958] at an Ottawa site, whereby the evaporation rate E(kg m^{-2} s^{-1}) is calculated as $E = 0.183 \times 10^{-5} \rho U_{10}(e - e_s)$, ρ being the mean air density (kg m^{-3}), U_{10} the mean wind speed at 10 m (m s^{-1}), e the vapor pressure of air (mbar), and e_s the saturated vapor pressure over ice at the mean snow surface temperature (mbar).

Evaporation/sublimination losses from cylinders were measured for selected periods to assess the applicability of the calculation procedure [*Goodison*, 1977]. A mean calculated evaporation rate for the test periods of 0.12×10^{-4} kg m^{-2} s^{-1} compared well with the mean measured rate of 0.13×10^{-4} kg m^{-2} s^{-1}. Subsequent comparison with measurements for March 17 and 19, 1976 [*McKay and Thurtell*, 1978], using the eddy correlation technique showed the calculated and measured evaporation losses to be within 10%, further supporting the above method of computing evaporation.

An analysis of the measured and calculated change in the mass balance of the snowpack is one approach of assessing the compatibility of accumulated precipitation and snowpack measurements. Table 3 compares measured and calculated change in snowpack water equivalent for individual accumulation periods in 1975 and 1976. The effect of using different

TABLE 3. Measured and Calculated Change in Snowpack Water Equivalent, Cold Creek Basin

					Precipitation[c]/Net Accumulation[d]				
Period	Change in Snow Cover Water Equivalent,[a] mm	Snowmelt (Index-Plot), mm	Stream Runoff,[b] mm	Evaporation, mm	Nipher Corrected,[e] mm	Nipher Corrected,[f] mm	Universal Uncorrected, mm	Universal Corrected, mm	Ruler, mm
Feb. 7–15, 1975	4.24 ± 2.74	nil	nil	1.01	4.54/3.53	4.48/3.47	3.30/2.29	4.28/3.27	8.13/7.12
March 4–14, 1975	10.23 ± 4.48	9.87[g]	5.53	3.64	24.56/10.05	22.17/8.66	11.05/2.46	22.43/8.82	18.80/4.29
Dec. 16–23, 1975	10.83 ± 1.72	nil	nil	0.54	10.21/9.67	11.35/10.81	6.35/5.81	11.89/11.35	11.18/10.64
Dec. 23, 1975 to Jan. 25, 1976	46.54 ± 8.96	7.74	1.45	8.41	61.25/45.10	61.46/45.31	35.76/19.61	57.83/41.68	62.49/46.34
Jan. 25, 1976 to Feb. 6, 1976	−0.45 ± 8.13	16.36	0.52	3.42	20.52/0.74	20.73/0.95	14.44/−5.34	21.03/1.25	11.70/−8.08

[a] Snow survey measurements weighted by land use.
[b] East Tributary; base-flow excluded.
[c] Including liquid precipitation (if any).
[d] Precipitation minus snowmelt minus evaporation.
[e] Using daily mean wind speed.
[f] Using storm mean wind speed.
[g] Degree-day ($0.91\ (T_{max})$) calculation.

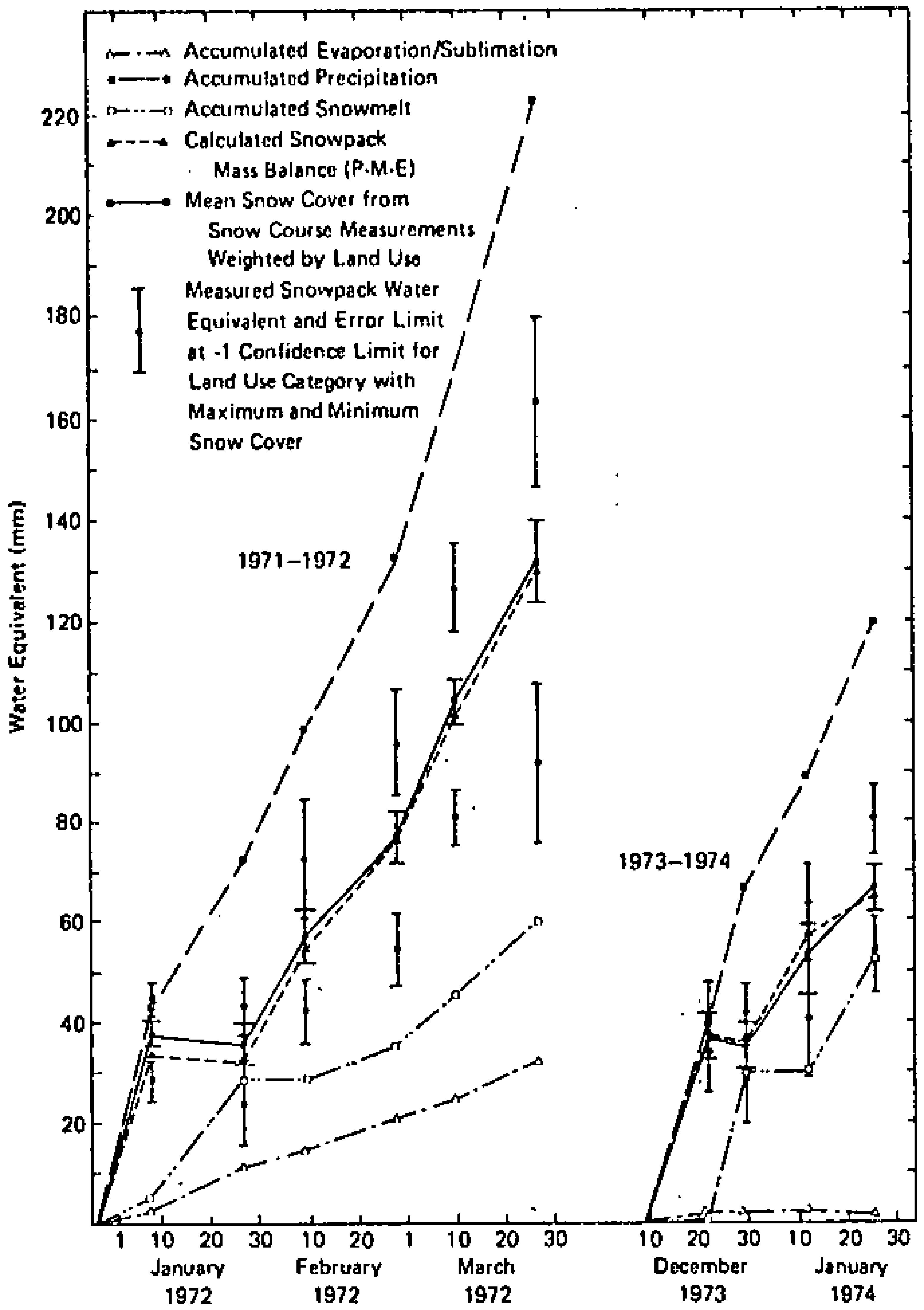


Fig. 6. Calculated and measured snowpack mass balance, Cold Creek Basin, 1971–1972 and 1973–1974.

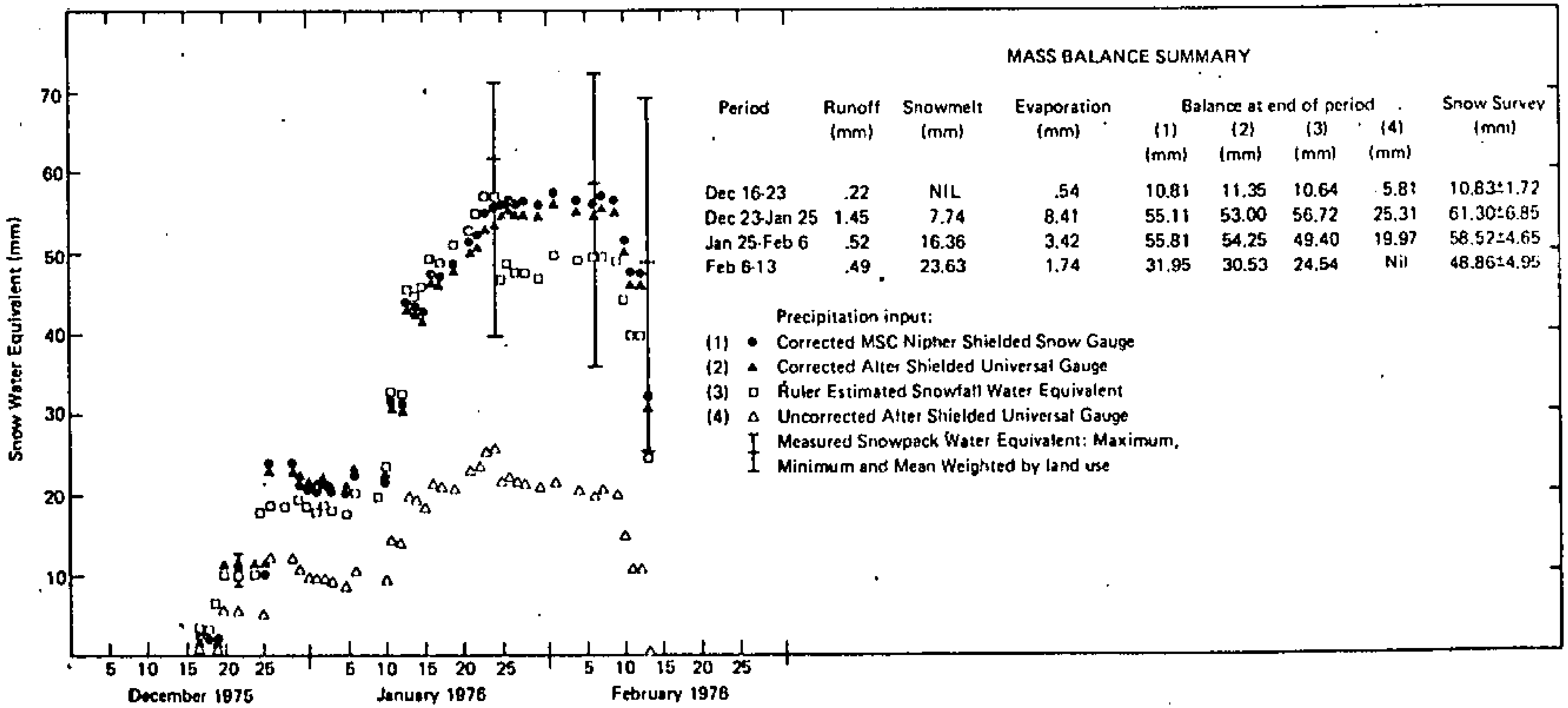
methods of precipitation measurement in the mass balance calculation was assessed. The change in snowpack water equivalent for the basin was determined from successive snow course measurements weighted by land use, as noted previously.

In all cases the corrected Nipher gauge and corrected Universal guage calcuations of net accumulation were within the error limits of the change in snowpack determined by snow survey measurement. However, there is considerable disagreement when uncorrected Universal gauge measurements are used. For the three periods of greatest change, the net accumulation is below the lower error limit of measured snowpack change. The results obtained when ruler measurements were used, are erratic, but such variability could be expected, as discussed above.

Comparison of the measured and calculated accumulation up to the time of peak snow cover is another method of assessing compatibility of the snow data. Figure 6 compares the net accumulation of measured and calculated showpack water equivalent for 1971–1972 and 1973–1974. The accumulated totals of precipitation (Nipher gauge), snowmelt (1971–1972, degree-day method; 1973–1974, snowmelt plot), and evaporation are also shown. The mean snow cover and its error limit are given for the land uses with the maximum and minimum snow cover. Development of a distinct stratification of snow cover in relation to land use is evident in both years. It is clearly shown that during both accumulation periods the mass balance calculated by using corrected Nipher gauge data is compatible with that determined from a land use stratified system of snow course measurements. An accurate estimate of snow cover would not be obtained from snow courses which sampled only one type of land use.

Figure 7 shows the results for 1975–1976 when four different estimates of precipitation were available for the calculation of the daily mass balance. The corrected Nipher and Universal gauge data are compatible with the snow cover estimate (determined from a reduced network of seven snow courses), except on the date of the final survey. This is because the snowmelt plot recorded a large loss on February 13, but the snow courses had not yet shown a decrease in snowpack water equivalent. This was the beginning of the major ablation period of the season.

The variability of the ruler estimates is again evident. The inaccuracy and noncompatibility of uncorrected gauge data with snow survey measurements are clearly shown. In fact, the daily mass balance calculated by using uncorrected Universal guage data is even less than the mean measured snowpack water equivalent for the land use with the minimum snow cover. The benefits gained from using compatible data in the analysis of basin snow cover are very evident.



MASS BALANCE SUMMARY

Period	Runoff (mm)	Snowmelt (mm)	Evaporation (mm)	Balance at end of period (1) (mm)	(2) (mm)	(3) (mm)	(4) (mm)	Snow Survey (mm)
Dec 16-23	.22	NIL	.54	10.81	11.35	10.64	5.81	10.83±1.72
Dec 23-Jan 25	1.45	7.74	8.41	55.11	53.00	56.72	25.31	61.30±6.85
Jan 25-Feb 6	.52	16.36	3.42	55.81	54.25	49.40	19.97	58.52±4.65
Feb 6-13	.49	23.63	1.74	31.95	30.53	24.54	Nil	48.86±4.95

Precipitation input:
(1) ● Corrected MSC Nipher Shielded Snow Gauge
(2) ▲ Corrected Alter Shielded Universal Gauge
(3) □ Ruler Estimated Snowfall Water Equivalent
(4) △ Uncorrected Alter Shielded Universal Gauge
I Measured Snowpack Water Equivalent: Maximum, Minimum and Mean Weighted by land use

Fig. 7. Comparison of measured and calculated snow cover water equivalent, Cold Creek Basin, 1975–1976.

SUMMARY

With an increasing emphasis on the development and use of snow cover runoff models, it is imperative that the hydrologist be aware of the accuracy and compatibility of his basic data. For any study using snowfall precipitation data one must be aware of the method of observation, the specific type of equipment, and the local site conditions. Analyses of data from different sites and different equipment can only be successful if the input data are compatible. It has been shown that corrected gauge measurements of snowfall can provide accurate and compatible data in a meaningful form suitable for further analyses. Because of inconsistent results, ruler estimates of snowfall precipitation are not recommended for use in short-term hydrometeorological analyses. The basic principle of acquiring compatible snowfall precipitation data applies not only to basin research but also to data from national and international networks.

Accurate basin snow cover estimates of depth, density, and water equivalent can be obtained from a snow course network specifically designed to represent local landscape characteristics. In a region where rapid temporal and spatial changes in the snow cover are common, a snow course with fixed sampling points provides regular, compatible, and repeatable measurements throughout the winter. Sampling of only one type of land use results in a biased estimate useful only as an index of basin snow cover. If the aim is to develop accurate and physically meaningful hydrological models, the use of indices and optimized parameters must be minimized.

Finally, the results from Cold Creek Basin demonstrate that snowpack accumulation can be determined not only from snow survey data adjusted for land cover characteristics but also from a simple mass balance model which uses corrected precipitation data. This ultimate compatibility of snowfall and snow cover measurements is an important result for snow science research in this region. Effective areal analyses can only be successful if the siting, equipment, and method of observation of both snowfall and snow cover are known. Only then can one determine if the data are compatible. *Provart* [1970] could not fully assess his snow ablation model because of uncertainties about the accuracy of his measured input (precipitation) and measured output (snowpack water equivalent). Such uncertainties can now be minimized by employing the analytical techniques outlined above, thus allowing one to concentrate on evaluating the model itself. The use of accurate and compatible snowfall and snow cover measurements is surely an aim to which all hydrologists or hydrometeorologists should strive.

Acknowledgments. The author is most grateful to H. L. Ferguson (Atmospheric Environment Service) and F. K. Hare (University of Toronto) for their encouragement, comments, and support throughout this study. The study would not have been possible without the cooperation of many persons, but especially, the author wishes to acknowledge J. Metcalfe and M. Malone for their initiative, interest, and capable support in all phases of the snowfall-snowpack program.

REFERENCES

Adams, W. P., Areal differentiation of snow cover in East Central Ontario, *Water Resour. Res., 12,* 1226-1234, 1976.

Adams, W. P., W. R. Cowan, B. F. Findlay, J. S. Gardner, and R. J. Rogerson, Snowfall and snow cover at Knob Lake, central Labrador-Ungava, Hydrological Studies in Labrador-Ungava, *McGill Sub-Arct. Res. Pap. 22,* pp. 114-140, McGill Univ., Montreal, Que., Can., 1966.

Bruce, J. P., and R. H. Clark, *Introduction to Hydrometeorology,* 319 pp., Pergamon, New York, 1966.

Dickinson, W. T., and H. R. Whiteley, A sampling scheme for shallow snowpacks, *Int. Ass. Hydrol. Sci. Bull., 17,* 247-258, 1972.

Dyck, G. E., Comparison of snow measurements, B.Sc. thesis, 41 pp, Univ. of Sask., Saskatoon, Sask., Can., 1969.

Goodison, B. E., Snowfall and snow cover in southern Ontario: Principles and techniques of assessment, Ph.D. thesis, 403 pp, Univ. of Toronto, Toronto, Ont., Can., 1977.

Goodison, B. E., Accuracy of Canadian snow gage measurements, *J. Appl. Meteorl., 17,* 1542-1548, 1978*a*.

Goodison, B. E., Canadian snow gauge measurements: Accuracy, implications, alternatives, needs, in *Proceedings of the Seventh Symposium on Applied Prairie Hydrology, May 9-11, 1978,* pp. 7-15, Water Studies Institute, Saskatoon, Sask., Can., 1978*b*.

Goodison, B. E., and D. J. McKay, Canadian snowfall measurements: Some implications for the collection and analysis of data from remote stations, *Proc. West. Snow Conf., 46,* 48-57, 1978.

Hamon, W. R., Computing actual precipitation in mountainous areas, Proceedings of the WMO-IAHS Symposium on the Distribution of Precipitation in Mountainous Areas, vol. 1, *WMO Publ. 326,* pp. 159-172, World Meteorol. Organ., Geneva, 1973.

Larson, L. W., and E. L. Peck, Accuracy of precipitation measurements for hydrologic modeling, *Water Resour. Res., 10,* 857-863, 1974.

McKay, D. C., and G. W. Thurtell, Measurements of the energy fluxes involved in the energy budget of a snow cover, *J. Appl. Meteorl., 17,* 339-349, 1978.

Provart, M., An analytical model for snow ablation, M.Sc. thesis, 204 pp, Univ. of Guelph, Guelph, Ont., Can., 1970.

Steppuhn, H., Areal water equivalents for prairie snowcovers by centralized sampling, *Proc. West. Snow Conf., 44,* 63-68, 1976.

Steppuhn, H., and G. E. Dyck, Estimating true basin snowcover, in *Advanced Concepts and Techniques in the Study of Snow and Ice Resources,* pp. 314-324, National Academy of Sciences, Washington, D. C., 1974.

Vershinina, L. K., Ratios between the water equivalents of snow in the field, forest, and ravine-gully network in river basins, *Sov. Hydrol.,* no. 5, 421-438, 1972.

Williams, G. P., Evaporation from snow covers in Eastern Canada, *Proc. East. Snow Conf., 15,* 18-30, 1958.

(Received August 21, 1979;
revised December 12, 1980;
accepted January 15, 1981.)

Abstract

CANADIAN SNOW GAUGE EXPERIMENT: RECENT RESULTS

by

B.E. Goodison and J.R. Metcalfe

For several years the Hydrometeorology Division of the Atmospheric Environment Service has been conducting field tests on the accuracy and performance of various types of snow gauge installations used throughout Canada. This paper reviews results on the performance of two types of shielding for recording gauges - the Wyoming shield and a large Nipher-type shield now under test by the AES. The advantages and disadvantages of each type of shield are reviewed. Seasonal totals show that on the average the large Nipher-type shield undercatches the standard MSC Nipher snow gauge by less than 10%, while the Wyoming shielded gauge undercatches it by about 25%. Alter-shielded recording gauges generally measure about 60% of the snowfall measured using the MSC Nipher shielded snow gauge. Inconsistencies in the daily measurements from some recording gauges were observed and these must be understood before the gauges can be operated successfully at automatic stations in Canada.

KEYWORDS: SNOW GAUGE MEASUREMENT; WYOMING SHIELD; NIPHER SHIELD

RECENT RESULTS

By

B.E. Goodison 1/ and J.R. Metcalfe 1/

INTRODUCTION

The Atmospheric Environment Service has been involved for several years in assessing the accuracy and performance of snow gauges used in Canada. Goodison (1978a; 1978b) and Goodison and McKay (1978) reported on field tests which showed that the Canadian MSC Nipher shielded snow gauge had a generally superior catch efficiency, with respect to wind speed, compared to unshielded or Alter-shielded Universal Belfort and Fischer and Porter gauges. However, the Nipher gauge is non-recording and it is only used at manned stations. Measurements from this gauge may require correction for trace amounts of snowfall which are not accumulated between observations, and in Arctic and Prairie regions, over 80% of all winter observations of precipitation may be trace amounts (Goodison, 1978b). Given these limitations, and realizing that most new precipitation stations in these regions would likely be recording gauges located at remote sites, an assessment of alternative methods of artificial shielding of gauges to improve catch efficiency was warranted. This paper reviews the performance of two types of shielding for recording gauges - the Wyoming shield and a large prototype Nipher-type shield.

INSTALLATIONS AND OBSERVATIONS

Based on results reported by Rechard et al. (1974), Wyoming shielded recording gauges were installed at selected sites in Canada in order to assess their performance. Installations at Regina (Cork, 1978; Dublin, 1979) and the Toronto Meteorological Research Station used the basic design proposed by the Wyoming Water Resource Institute researchers. At the Toronto site, an "Arctic version" Wyoming shield was constructed which used lightweight nylon snowfencing instead of wood and had no Alter shield around the gauge. There was no difference in gauge catch between the two shields, so the "Arctic version" was used for subsequent installations at Resolute Bay, N.W.T. and at Monticello and Peterborough, Ontario. Data are available since 1977-78, except for periods of gauge malfunction.

As a possible alternative to the Wyoming shield and in an effort to obtain recording gauge measurements which would be compatible with the standard Nipher snow gauge, a Nipher-type fiberglass shield was designed by the Data Acquisition Services Division of AES to fit 20.7 cm (8 inch) diameter recording gauges. Goodison and Metcalfe (1980) provide additional details on the gauge and initial results. Prototype shields were fitted to Fischer and Porter and Universal recording gauges and installed at eight sites in various climatic regimes. A variety of local siting conditions were chosen to assess the gauge's performance, and where possible, the gauges were co-located with Wyoming shielded gauges. Initial testing began during the 1978-79 winter season.

Modifications to the original design of the Nipher-type shield were found to be necessary and changes are now in progress. The physical size of the shield made servicing of the gauge awkward and difficult. Wind tunnel tests showed that the shield could be shortened by 30 cm without changing the air flow pattern over the orifice, so this change has been initiated. The support structure for the shield has been refined to permit easy and accurate positioning of the shield around the orifice extension and the need for support bars has been eliminated.

RESULTS

In this initial comparison, none of the gauge measurements was corrected for undercatch due to wind or trace amounts. The MSC Nipher shielded snow gauge is used as

---

Presented at the Western Snow Conference, April 20-23, 1982, Reno, Nevada

1/ Hydrometeorology Division, Atmospheric Environment Service, 4905 Dufferin Street, Downsview, Ontario, Canada M3H 5T4

Canadian snow gauge.

Table 1 summarizes the seasonal totals for gauges located at the Toronto Meteorological Research Station. The unshielded and Alter shielded gauges recorded the lowest totals, (generally, 50-65% of the Nipher), but this is in line with previous results (Goodison, 1978a). The Wyoming shielded Belfort gauge measured from 70-80% of the MSC Nipher, but it is not known why the catch has progressively increased each year. Finally, the gauges shielded with the large Nipher-type shield recorded approximately 90% of the MSC Nipher total. This site is flat and very exposed, but blowing snow is not a common problem. For conditions encountered at this station both the Wyoming and large Nipher-type shields are more effective than no shield or the Alter shield.

TABLE 1

SEASONAL SNOW GAUGE MEASUREMENTS, TORONTO MET RESEARCH STATION*

SNOW SEASON	MSC NIPHER	UNSHIELDED BELFORT GAUGE	ALTER SHIELDED BELFORT GAUGE	NIPHER SHIELDED BELFORT GAUGE	WYOMING SHIELDED BELFORT GAUGE	ALTER SHIELDED F&P GAUGE	NIPHER SHIELDED F&P GAUGE
1977-78	82.0 mm				56.1 mm		
CATCH TOTAL AS % OF MSC NIPHER	100%				68%		
1978-79	102.6 mm	54.5 mm	65.4 mm	94.7 mm	72.8 mm	60.8 mm	86.2 mm
CATCH TOTAL AS % of MSC NIPHER	100%	53%	64%	92%	71%	59%	84%
1980-81	120.8 mm	63.7 mm	81.2 mm	112.0 mm	96.0 mm	73.7 mm	116.8 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	53%	67%	93%	79%	61%	97%
1981-82	76.4 mm	36.8 mm	46.5 mm	U/S	62.5 mm	U/S	68.6 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	48%	61%		82%		89%

* NONE OF THE DATA HAS BEEN CORRECTED FOR UNDERCATCH DUE TO WIND, TRACE AMOUNTS OR RETENTION (WHERE APPLICABLE); ALL TOTALS INCLUDE RAINFALL WHERE APPLICABLE.

Table 2 provides a summary of the measurements made at Regina Airport during the last three winters. The test site is very exposed and well away from the airport buildings. The seasonal total for the Wyoming shielded gauge is more variable and less than that of the Nipher shielded Fischer and Porter gauge, with the latter measuring within 5% of the standard Nipher shielded gauge located at the test site. Although seasonal totals for the two Nipher shielded gauges compare well, the Fischer-Porter gauge was equipped to record in only increments of 2.54 mm. Thus, the timing of precipitation events, particularly small ones, could not always be determined. As the average catch efficiency of a gauge decreases, this becomes an even greater problem in these low snowfall regions.

Results from Resolute Bay, N.W.T. are summarized in Table 3. The two shielded gauges caught more than the standard Nipher gauge. Malfunction of the Wyoming shielded gauge has precluded complete analysis during the past two years. The two factors causing recording gauges to measure higher amounts are their accumulation of trace amounts and of blowing snow. Why the Nipher shielded recording gauge should measure an amount so much greater than the standard Nipher has not been determined. In both years, a sudden increase caused by something falling into the gauge (presumably snow stuck to the orifice extension) has occurred in the Nipher shielded Fischer and Porter. An assessment of whether this accumulation is real or not must be made.

The problems caused by blowing snow and snow collecting around the orifice and then falling into the gauge is also evident from data collected at different sites at Monticello, Ontario during January 1982 (Table 4). These data are given as they were recorded by each gauge, with no "quality control" applied. There are differences in timing between the gauges because they record only increments of 2.54 mm and because each has a different catch efficiency. There are other days when totals are difficult to rationalize. For example, the measurement of 50.8 mm by the Wyoming shielded gauge on January 10-11 is significantly greater than the other gauges. Was this a result of

SNOW GAUGE COMPARISONS, REGINA, SASKATCHEWAN*

SNOWFALL SEASON	MSC NIPHER SHIELDED GAUGE**	NIPHER SHIELDED FISCHER & PORTER GAUGE	WYOMING SHIELDED BELFORT GAUGE
JANUARY 18 TO MARCH 17, 1980	35.1 mm	33.0 mm	23.6 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	94%	67%
OCTOBER 24, 1980 TO MARCH 23, 1981	38.2 mm	40.6 mm	33.3 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	106%	87%
NOVEMBER 16, 1981 TO APRIL 6, 1982	109.2 mm	104.1 mm	81.5 mm
CATCH TOTAL AS % OF MSC NIPHER	100%	95%	75%

* OPERATED BY PERSONNEL FROM AES CENTRAL REGION, SCIENTIFIC SERVICES DIVISION
** READ EVERY 24 HOURS

TABLE 3
SNOW GAUGE COMPARISONS, RESOLUTE BAY, NWT

SNOW SEASON	MSC NIPHER (mm)	WYOMING BELFORT GAUGE (mm)	NIPHER SHIELDED F&P GAUGE (mm)
1977-78	116.3	135.5	N/A
1978-79	69.6	93.9	N/A
1979-80	67.7	82.2	N/A
1980-81	62.6	U/S	114.3
1981-82	34.2	U/S	121.9

blowing snow? A similar problem occurred with the Nipher shielded Fischer and Porter gauge on January 23. The reasons for such inconsistencies in the recorded gauge data must be understood before the gauges can be operated successfully at automatic stations in Canada. A Nipher shielded recording gauge was also located in a small opening in the bush, but it capped over early in the winter and no accumulation was recorded. This type of shield is susceptible to capping at a sheltered site.

SUMMARY

Results from the Canadian test sites indicate that a Nipher shielded recording gauge will undercatch the standard MSC Nipher snow gauge by less than 10%, while a Wyoming shielded gauge will undercatch it by about 25%. A summary of the advantages and disadvantages of each shield is possible. The Wyoming shield provides improved gauge catch compared to unshielded or alter shielded gauges. However, its physical size can be a constraint at some locations and its installation is more time consuming and difficult. Annual inspection and maintenance of the shield is required, the extent of which depends largely on the local environment. The shield in Resolute is in excellent condition compared to installations at southern Ontario stations. It can be difficult to service the gauge.

The Nipher-type shield improves gauge catch compared to unshielded, Alter-shielded and Wyoming shielded installations. There is little maintenance required and the new design will allow easy servicing of the gauge. However, snow can build up on the shield even at open sites and the gauge can cap over at sheltered sites. A gauge with this type of shield appears to be more susceptible to catching blowing snow. Finally, manufacture of the shield does require a mould.

TABLE 4

COMPARISON OF SNOW GAUGE MEASUREMENTS (mm), MONTICELLO, ONTARIO
JANUARY 1982

	RAIN GAUGE MAIN SITE	MSC NIPHER GAUGE MAIN SITE	SNOWBOARD MAIN SITE	ALTER SHIELDED F&P GAUGE MAIN SITE	NIPHER SHIELDED F&P GAUGE MAIN SITE	ALTER SHIELDED F&P GAUGE BUSH SITE	WYOMING SHIELDED F&P GAUGE
1	1.8	5.4 Blowing Snow	6.0	7.6	7.6		
2			0.4				
3	Trace						
4	13.8			22.9	25.4	12.7	15.2
5		7.0 Blowing Snow	7.0		5.1	2.5	2.5
6		1.4	1.4		7.6		
7		1.0	0.6				
8		1.8 Blowing Snow	1.4			2.5	5.1
9		2.4	1.8				
10		1.2	1.0	5.1	7.6	2.5	10.2
11		8.0 Blowing Snow	6.2	7.6	12.7	5.1	40.6
12		0.2	0.2		7.6		5.1
13		5.2	4.4		7.6	5.1	
14		1.0	0.6		2.5		2.5
15		Trace					2.5
16		2.6 Blowing Snow	2.6		5.1	5.1	5.1
17		0.8	1.0		2.5		5.1
18		0.2	0.2				
19					5.1		2.5
20		0.8	0.6				
21		1.8	1.8			2.5	
22		Trace					
23	0.5	7.0 Blowing Snow	6.3	30.5	27.9	17.8	17.8
24		0.8	0.8		7.6		2.5
25		2.0	2.8		2.5		
26		0.2	0.2				
27							
28		1.0	0.8			2.5	2.5
29							
30		7.2	7.6			5.1	
31		8.0	9.0	10.2	15.2	10.2	5.1
TOTALS	15.1	+ 67.0 = 82.1 mm	64.7 mm	83.9 mm	149.6 mm	73.6 mm	124.3 mm

One more year of testing of the shields is planned, with particular emphasis being placed on the performance of the modified large Nipher-type shield.

REFERENCES

Cork, H.F., 1978: Wyoming-Shielded Storage Gauge, Regina, 1977 and 1978. Prairie Hydrometeorological Centre Report No. 29, Atmospheric Environment Service, Regina, 18 pp.

Dublin, J., 1979: Wyoming-Shielded Storage Gauge, Regina. Prairie Hydrometeorological Centre Report No. 35, Atmospheric Environment Service, Regina, 8 pp.

Goodison, B.E. and J.R. Metcalfe, 1980: AES Nipher Shields for Recording Precipitation Gauges: An Assessment. Proceedings, 37th Annual Eastern Snow Conference, Peterborough, Ontario, June 5-6, 196-198.

Goodison, B.E., 1978a: Accuracy of Canadian Snow Gage Measurements. Journal of Applied Meteorology, Vol. 17, No. 10, 1542-1548.

Goodison, B.E., 1978b: Canadian Snow Gauge Measurements: Accuracy, Implications, Alternatives, Needs. Proceedings, Seventh Symposium on Applied Prairie Hydrology, Water Studies Institute, Saskatoon, May 9-11, 1978, 7-15.

Goodison, B.E. and D.J. McKay, 1978: Canadian Snowfall Measurements: Some Implications for the Collection and Analysis of Data from Remote Stations. Proc. Western Snow Conference, 46, 48-57.

Rechard, P.A., R.E. Brewer and A. Sullivan, 1974: Measuring Snowfall, A Critical Factor for Snow Resource Management. Advanced Concepts and Techniques in the Study of Snow and Ice Resources. U.S. Nat. Acad. Sci., Washington, 706-715.

5th Northern Research Basin, Workshop, Vierumaki, Finland
March 1984

New Canadian Instrumentation for Improved Snowfall and Snow Cover Measurements in Northern Environments

Barry E. Goodison
Hydrometeorology Division
Atmospheric Environment Service
Downsview, Ontario, Canada
M3H 5T4

INTRODUCTION

During the past few years there has been a continued effort to improve snowfall and snowcover measurements in Canada. In the case of the former, improved shielding of recording precipitation gauges and the initiation of development of an automatic snow depth sensor, both aimed at use at automatic remote stations, are promising improvements. As for snow cover measurement the Atmospheric Environment Service is in the process of implementing the new snow sampler designs recently recommended by the Western Snow Conference Metrication Committee. These three developments will be briefly reviewed in this paper. All are expected to affect future network design and operations of the Atmospheric Environment Service.

A Nipher-Type Shield for Recording Precipitation Gauges

Considerable effort has been expended on assessing the accuracy and performance of snow gauges used by agencies through out Canada. Earlier field tests (Goodison 1978a) and wind tunnel flow visualization experiments (Turner and Goodison, 1977) have indicated that the Canadian MSC Nipher shielded snow gauge has a superior catch efficiency for measuring snowfall water equivalent than an unshielded or Alter shielded Universal Belfort or Fischer & Porter recording precipitation gauge. However, the MSC Nipher snow gauge is non-recording, and it is only used at manned stations. Another problem is that in low snowfall regions, such as the Arctic and Prairies, over 80% of all winter observations of precipitation measured with the Nipher can be trace amounts (Goodison, 1978a), and these are given a total accumulation of zero.

Given the limitations of the MSC Nipher shielded snow gauge and Alter shielded recording gauges, and realizing that most new precipitation stations in these regions would likely be recording gauges at automatic stations at "remote" sites, it was proposed that a larger Nipher-type shield should be constructed, based on scaling-up the standard MSC Nipher shield, scaled to fit the 20.7 cm (8 inch) diameter recording gauges. The aim was to develop a shield which would not only provide more accurate recording gauge measurements of snowfall, but also would provide data which would be directly compatible with measurements from the official MSC Nipher snow gauge.

Using a wooden mould, fibreglass shields (general purpose polyester resin, chopped strand fibreglass reinforced, with glass loading of approximately 20-30%) were manufactured. An elongated tube of galvanized sheet metal (inside diameter, 20.7 cm) was affixed to the precipitation gauge to extend its orifice even with the top of the shield. The initial design had the fibreglass shield, which was 71 cm high, in a ring which was supported by three 2.5 cm aluminum posts fixed to a base. The entire structure was then guyed from the support ring to ground anchors. The shield was adapted to fit either the Fischer & Porter or Universal Belfort recording precipitation gauges.

The absolute physical size of the shield and its support structure caused some problems. Primarily, it was difficult to accurately position the shield around the orifice extension and to level and centre the orifice inside the shield. Servicing of the precipitation gauge under the shield was awkward, particularly for one person, as the shield had to be removed each time.

Wind tunnel tests conducted subsequently, showed that the shield could be shortened by 30 cm without changing the flow pattern over the orifice. This resulted in a lighter, easier to handle shield. By making the shield shorter, the original support structure could be eliminated, the orifice extension shortened and the shield could be fixed directly to the orifice extension, thus ensuring an even spacing between the extension and the shield. This also allowed one to level both the gauge and the shield as a single unit. The shield and orifice extension are now completely supported by the precipitation gauge, thus allowing free access for gauge servicing. Also, the orifice extension was teflon coated on the inside to inhibit snow sticking to it and causing capping of the orifice.

Wind tunnel tests of the large shield were undertaken for two reasons:

1) to ascertain whether there was any difference in the flow pattern around a standard MSC Nipher shielded snow gauge and a Fischer & Porter gauge equipped with a large Nipher type shield, and;

2) to predict whether a truncated version of the large Nipher shield could be used on field installations without adversely affecting the flow regime.

Each shield/gauge combination (standard shield, scaled-up shield and truncated shield) was tested in the tunnel at an air flow of approximately 3.5 m/s. The large Nipher shield and Fischer & Porter gauge were also tested at wind speeds of 1.45 and 5.02 m/s to examine the flow pattern associated with faster and slower wind speeds.

On the basis of these tests one would expect that a recording gauge shielded by this large Nipher type shield should exhibit catch characteristics similar to the standard MSC Nipher snow gauge. More complete information on the tests is given in Goodison et al., (1983).

Field results of the new shield have been most encouraging. Prototype shields were manufactured and fitted to Fischer & Porter and Universal recording gauges in the manner described above. Gauges were installed at eight sites in various climate regimes across Canada. A variety of local siting conditions were chosen to assess the gauge's performance.

For the purpose of this study, none of the gauge measurements was corrected for undercatch due to wind or for trace amounts. The MSC Nipher shielded snow gauge is used as the standard against which the other measurements are compared since it is the "official" Canadian snow gauge.

Table 1 summarizes the seasonal totals for gauges located at the Toronto Met Research Station. The unshielded and Alter shielded gauges recorded the lowest totals (generally, 50-65% of the MSC Nipher), but this is in line with previous results (Goodison, 1978a). The Belfort and Fischer & Porter gauges shielded with the large Nipher-type shield recorded about 90% of the MSC Nipher total.

At Monticello, Ontario paired Nipher and Alter shielded Fischer & Porter gauges were placed in both open and sheltered bush locations to assess the effect of siting on the performance of the large Nipher shield. At the open site the results were similar to those reported for the Toronto Met Research Station. However, the Nipher shielded Fischer & Porter gauge located in the small opening in the bush capped over early in the winter and it recorded no accumulation until it was cleared by hand. This would be a potential problem at remote sites. However, this type of shielding is not necessary at well sheltered sites as the catch of Alter shield gauge at this site was comparable with that of the standard MSC Nipher snow gauge at the open site.

Data from test sites in Saskatchewan also confirm the higher catch efficiency for recording gauges using the Nipher-type shield. At Bad Lake, Saskatchewan, winter season precipitation totals from the standard MSC Nipher snow gauge and a Nipher shielded Fischer & Porter gauge are within 5% of each other. The Alter shielded Fischer & Porter caught 35-40% of the standard MSC Nipher, which is comparable with the long term average monthly catch of 35% reported by Gray et al., (1979). Table 2 summarizes the measurements from Regina for the last three winters, and the results are similar to those from Bad Lake. Jones (1982) has conducted additional analysis of the 1981-82 data, particularly with respect to wind speed and direction and snow course measurements.

Initial field data indicate that the large Nipher-type shield can be used with recording gauges to provide measurements which are compatible with the official Canadian MSC Nipher snow gauge. The Nipher-type shield improves gauge catch compared to unshielded and Alter-shield gauges. There is little maintenance required and the new design will allow easy servicing of the gauge. However, snow can build up on the shield, even at open sites when the wind speed is low, and the gauge can cap over at sheltered sites. The design of the Nipher shield makes the gauge susceptible to catching blowing snow if it is mounted too close to the ground.

Table 1

Seasonal Snow Gauge Measurements, Toronto Met Research Station*

Snow Season	MSC Nipher	Unshielded Belfort Gauge	Alter Shielded Belfort Gauge	Nipher Shielded Belfort Gauge	Wyoming Shielded Belfort Gauge	Alter Shielded F&P Gauge	Nipher Shielded F&P Gauge
1977-78	82.0 mm				56.1 mm		
Catch Total as % of MSC Nipher	100%				68%		
1978-79	102.6 mm	54.5 mm	65.4 mm	94.7 mm	72.8 mm	60.8 mm	86.2 mm
Catch Total as % of MSC Nipher	100%	53%	64%	92%	71%	59%	84%
1980-81	120.8 mm	63.7 mm	81.2 mm	112.0 mm	96.0 mm	73.7 mm	116.8 mm
Catch Total as % of MSC Nipher	100%	53%	67%	93%	79%	61%	97%
1981-82	76.4 mm	36.8 mm	46.5 mm	U/S	62.5 mm	U/S	68.6 mm
Catch Total as % of MSC Nipher	100%	48%	61%		82%		89%

* None of the data has been corrected for undercatch due to wind, trace amounts or retention (where applicable); all totals include rainfall where applicable.

Table 2

Snow Gauge Comparisons, Regina, Saskatchewan*

Snowfall Season	MSC Nipher Shielded Gauge**	Nipher Shielded Fischer & Porter Gauge
January 18 to March 17, 1980	35.1 mm	33.0 mm
Catch Total as % of MSC Nipher	100%	94%
October 24, 1980 to March 23, 1981	38.2 mm	40.6 mm
Catch Total as % of MSC Nipher	100%	106%
November 27, 1981 to April 19, 1982	96.6 mm	99.1 mm
Catch Total as % of MSC Nipher	100%	108%

* Operated by personnel from AES Central Region, Scientific Services Division

** Read every 24 hours

Automatic Snow Depth Sensor

Snow depth on the ground is routinely measured at all synoptic and principal observing stations in Canada at 1200 Z, and since about 1980, all climatological stations have been asked to record daily snow depth as a standard observation. Before that time, only snow depth on the last day of the month was recorded at the climatological stations. Snow depth information is valuable in many hydrological, agricultural and forestry applications; it is often a substitute for snow water equivalent data when such data are unvailable. Snow depth measurements are made manually with a snow ruler. The observer uses his expertise and judgment in obtaining a representative areal measurement at the station. As stations are automated or new automatic stations are opened at remote locations, the snow depth measurement will be lost. There is a need, therefore, for an inexpensive automatic snow depth sensor, which can be used on future automatic hydrometeorological stations.

The Hydrometeorology Division and the Data Acquisition Services Branch of the Atmospheric Environment Service have been co-operating on the development of an inexpensive automatic snow-depth gauge which could be used at either manned or remote stations. Development began in 1982, with the first unit being tested during the winter of 1982-83. Two additional units were built and deployed for testing during the 1983-84 winter.

The basis of the method for measuring snow depth is the use of ultrasonic wave reflection. A micro-processor based system, which incorporates a commercially available, inexpensive Polaroid Ultrasonic Ranging Unit, is in the process of being developed and tested as a potential primary sensor for use on automatic hydrometeorological stations. The microprocessor measures the time interval between a transmitted "chirp" and the received echo, converts this into a snow depth measurement and, with appropriate programming and interfacing, can format the data for transmission to a variety of local or remote devices, including data collection platforms (DCP's). Signal processing capabilities of the microprocessor can be used to apply temperature corrections for the speed of sound, a correction which must be made to determine true snow depth. More information on this system is provided in Goodison et al. (1984).

Initial results from the Dorset test site in Ontario are given in Figure 1. The sensor was mounted about 1.3 m above the ground surface. A digital readout from the sensor of the computed snow depth was provided in a nearby instrument shelter. An observer took manual readings twice per day from three snow rulers fixed in the ground. The rulers were mounted in the ground around the sensor's field of view at the beginning of the season so that depth measurements could be made even if an ice layer or hard crust should form in the pack. The temperature at the time of each observation was required to compute the correct distance to the snowpack, since the speed of sound varies with temperature. This correction will be incorporated into the microprocessor system in future models.

Initial results from this site indicate that the ultrasonic sensor undermeasures the ruler observation by about 6 cm, with individual observations differing by up to 13 cm. The causes of this bias are still under investigation. One factor is known; snow does build up at the ruler and the observer overmeasures the snow depth by up to 3 cm. This was a sheltered site, so snow scouring was not a problem. The surface of the snow and its structure, (i.e. loose powder vs. hard pack crust) could have an effect. Does the sound wave penetrate the surface before reflecting back toward the sensor? Is some of the signal scattered rather than all of it being reflected back? Does a strong temperature inversion near the snow surface significantly affect the calculation of snow depth? The temperature gradient between the sensor the snow surface could be up to 10°C. This effect will need further evaluation. It appears, however, that the difference between the ruler and sensor measurement is not directly related to air temperature at the height of the sensor. Evaluation of data collected later this winter will continue in an effort to assess fully these differences.

It seems that this type of sensor offers a viable method of automatically measuring snow depth at an observing station. It is hoped that further refinement of the sensor/microprocessor system will ultimately produce an effective means of measuring snow depth at a remote station.

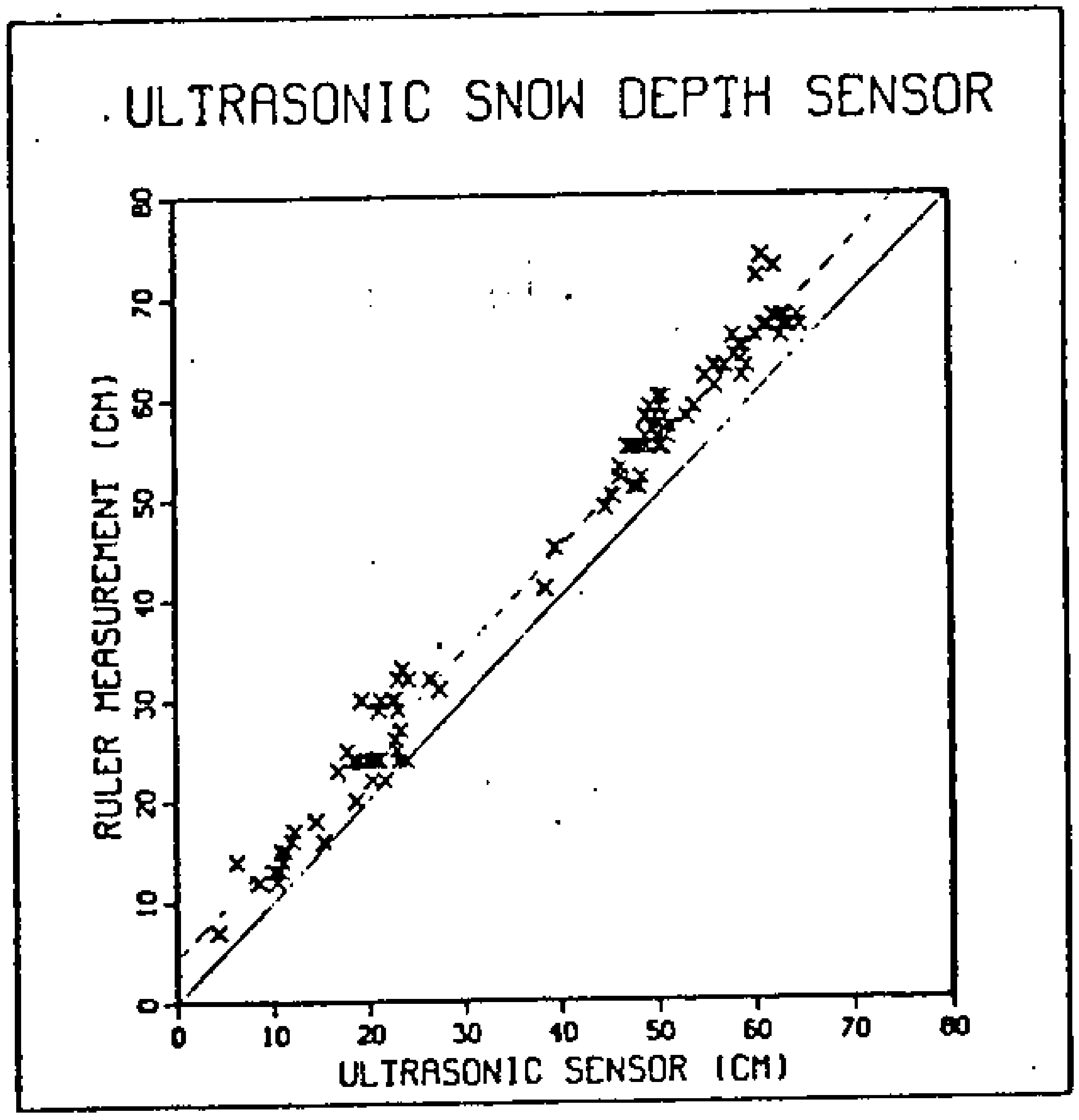


Figure 1: Comparison of Snow Depth Measurements from the Ultrasonic Sensor and Observed Ruler Measurements.

Metrication of North American Snow Sampling Equipment

The Western Snow Conference established a metrication committee in July 1978 to review, test and recommend equipment and procedures for the metrication of snow surveys and manual snow sampling equipment. In 1982, at the joint meeting of the Western and Eastern Snow Conferences the results of four years of testing were presented, and recommendations on metrication were presented. (Farnes et al., 1982).

A final report on the topic (Farnes et al., 1983) was prepared by the committee in which field tests, methods, and results are fully documented. Design recommendations, specifications and drawings are included in the report, as well as a proposal for converting equipment and historic data records.

Test procedures and initial results were given in Farnes et al. (1980). These results showed that small diameter cutters (i.e. areas of 10-12 cm^2) overmeasured by up to 10% while larger diameter samplers measured closer to true. Table 3 summarizes the overmeasurement of snow water equivalent for various snow samplers.

Figure 2 shows snow water equivalent for the Glacier snow sampler (reference sampler) compared to the standard Federal snow sampler, which is the sampler used in deep snowpacks in North America. The Federal sampler overmeasures by about 9% for all water equivalents tested. As a result of tests, the WSC Committee proposed a WSC metric snow sampler, with cutter area of approximately 10.6 cm^2 and with scales that read in true weight, i.e. 1 gram weight equals 1 mm water equivalent. Results of tests with the metric sampler are shown in Figure 3.

A new sampler for shallow snowpacks is also proposed - the ESC-30 metric snow sampler. It has a cutter area of 30 cm^2 and uses clear plastic as the tubing material. For snow depths less than 1 metre it shows no significant overmeasurement (Figure 4).

Three phases could be used in the conversion to metric units. First, a soft conversion would be applied to data obtained with existing equipment. The Atmospheric Environment Service started doing this in the winter of 1978-79. Secondly existing equipment can be modified by changing the markings on the tube and scale to metric units and changing the cutter on the standard Federal sampler with the new metric design. Finally, modified equipment would be replaced with newer equipment.

The Atmospheric Environment Service has initiated the changeover of its equipment. New small diameter metric samplers have been requisitioned, although the old Federal cutter is still being used. It will be changed when other snow survey agencies change their cutters. Design specifications for the new ESC-30 sampler have been completed and will be ordered shortly. It is expected that other operational agencies will follow as resources permit.

It is impossible to give a complete outline of the metrication plans in this paper. It is hoped, however, that standardization of equipment will gradually result, thus facilitating a more ready exchange of data between agencies.

TABLE 3

OVERMEASUREMENT OF SNOW WATER EQUIVALENT AND CORRECTION FACTOR FOR VARIOUS SNOW SAMPLERS

TYPE	CUTTER AREA, cm²	OVERMEASUREMENT (Percent)	CORRECTION FACTOR 1/
Glacier (used as Ground Truth)	81.9	0	1.00
Standard Federal	11.2	10.0	.91
Sharpened Federal	11.2	6.2	.94
1978 Metric (short)	10.0	7.6	.93
1978 Metric (long)	10.0	4.0	.96
1979 Metric	10.0	7.6	.93
1980 Metric	10.0	4.5	.96
1981 Metric	10.4	3.8	.96
ESC-30	30.0	-0.3	1.00
Aluminum Tubing	77.1	0.6	.99
ESC-50	50.0	-0.1	1.00
PVC Tubing	20.9	0.0	1.00
ESC-40	40.0	0.2	1.00
Broken-tooth Federal	11.2	12.1	.89
BUNG	11.2	4.7	.96
McCall	11.2	4.5	.96
Adirondack	35.7	-0.2	1.00
CRREL Tubes (Volume = 500 cm³)		7.1 2/	.93
Rosen	11.2	4.1	.96
Bowman	11.2	4.6	.96
Leopold and Stevens	11.2	8.2	.92
MSC	39.1	7.0	.93
Utah	11.2	5.6	.95

1/To obtain true SWE with various samplers, multiply measured SWE by the correction factor.

2/All tests in shallow snow in Alaska

BASED ON DATA OBTAINED BY METRICATION COMMITTEE AND OTHER STUDIES OF SNOW SAMPLER ACCURACY. COMPARISONS MADE WITH GLACIER SAMPLER WHEN DATA AVAILABLE; OTHERWISE, COMPARISONS MADE WITH STANDARD FEDERAL OR COMBINATION OF GLACIER AND STANDARD FEDERAL.

It is impossible to give a complete outline of the metrication plans in this paper. It is hoped, however, that standardization of equipment will gradually result, thus facilitating a more ready exchange of data between agencies.

TABLE 3

OVERMEASUREMENT OF SNOW WATER EQUIVALENT AND CORRECTION FACTOR FOR VARIOUS SNOW SAMPLERS

TYPE	CUTTER AREA, cm^2	OVERMEASUREMENT (Percent)	CORRECTION FACTOR 1/
Glacier (used as Ground Truth)	81.9	0	1.00
Standard Federal	11.2	10.0	.91
Sharpened Federal	11.2	6.2	.94
1978 Metric (short)	10.0	7.6	.93
1978 Metric (long)	10.0	4.0	.96
1979 Metric	10.0	7.6	.93
1980 Metric	10.0	4.5	.96
1981 Metric	10.4	3.8	.96
ESC-30	30.0	-0.3	1.00
Aluminum Tubing	77.1	0.6	.99
ESC-50	50.0	-0.1	1.00
PVC Tubing	20.9	0.0	1.00
ESC-40	40.0	0.2	1.00
Broken-tooth Federal	11.2	12.1	.89
BUNG	11.2	4.7	.96
McCall	11.2	4.5	.96
Adirondack	35.7	-0.2 2/	1.00
CRREL Tubes (Volume = 500 cm^3)		7.1	.93
Rosen	11.2	4.1	.96
Bowman	11.2	4.6	.96
Leopold and Stevens	11.2	8.2	.92
MSC	39.1	7.0	.93
Utah	11.2	5.6	.95

1/To obtain true SWE with various samplers, multiply measured SWE by the correction factor.

2/All tests in shallow snow in Alaska

BASED ON DATA OBTAINED BY METRICATION COMMITTEE AND OTHER STUDIES OF SNOW SAMPLER ACCURACY. COMPARISONS MADE WITH GLACIER SAMPLER WHEN DATA AVAILABLE; OTHERWISE, COMPARISONS MADE WITH STANDARD FEDERAL OR COMBINATION OF GLACIER AND STANDARD FEDERAL.

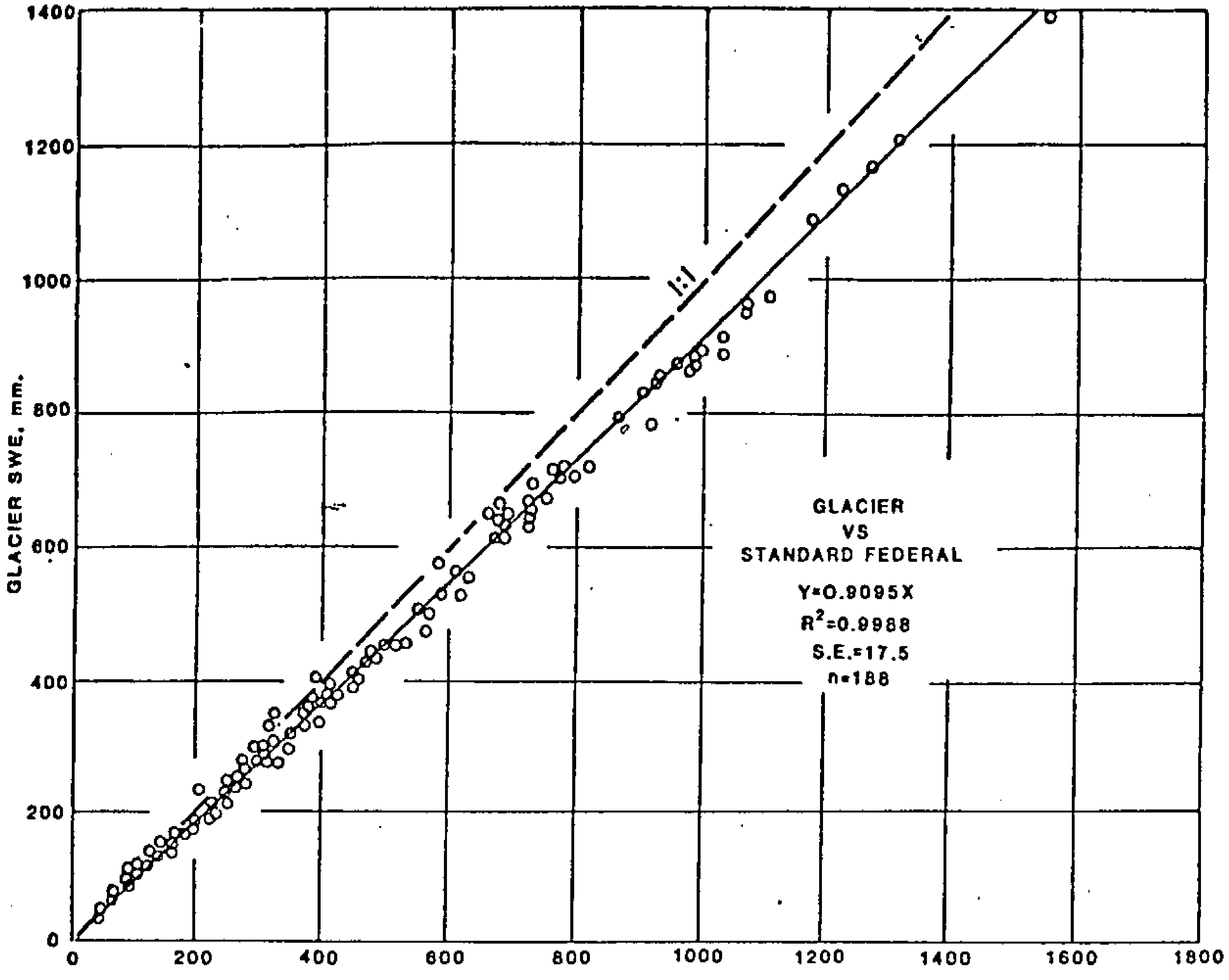


FIGURE 2. Snow water equivalent (SWE) for the Glacier snow sampler compared to the standard Federal snow sampler.

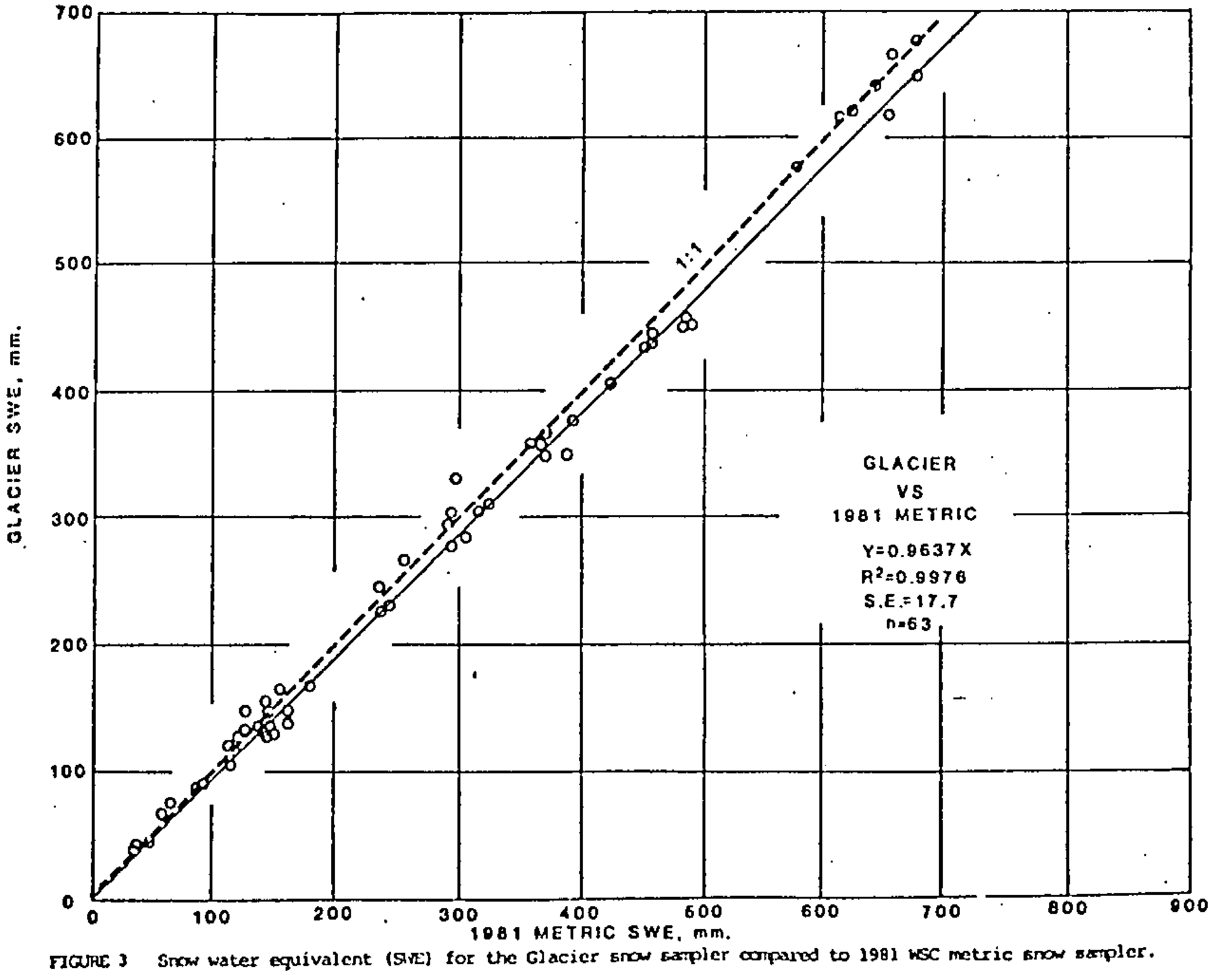


FIGURE 3 Snow water equivalent (SWE) for the Glacier snow sampler compared to 1981 WSC metric snow sampler.

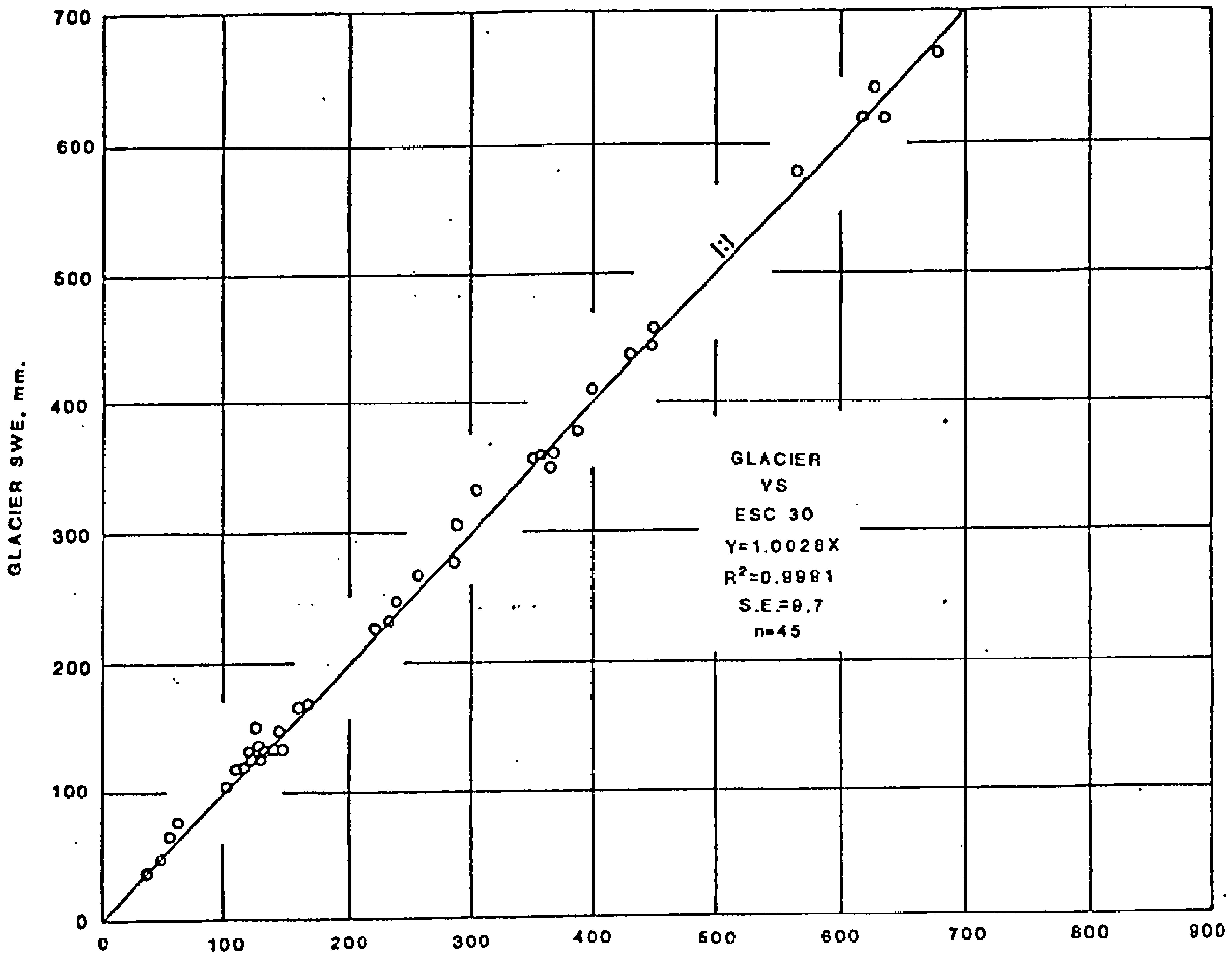


FIGURE 4 Snow water equivalent (SWE) for the Glacier snow sampler compared to the ESC 30 snow sampler.

References

Farnes, P.E., B.E. Goodison, N.R. Peterson, R.P. Richards, 1983. Final Report, Metrication of Manual Snow Sampling Equipment. Western Snow Conference, Spokane, Washington, 106 pp.

Farnes, P.E., B.E. Goodison, N.R. Peterson, R.P. Richards, 1982. Metrication of Manual Snow Sampling Equipment by Western Snow Conference Metrication Committee, Proc. Western Snow Conference. Reno, Nevada, pp. 120-132.

Farnes, P.E., B.E. Goodison, N.R. Peterson and R.P. Richards, 1980: Proposed Metric Snow Samplers by Western Snow Conference Metrication Committee, Proc. Western Snow Conference, Laramie, Wyoming, pp. 107-119.

Goodison, B.E., 1978a: Accuracy of Canadian Snow Gauge Measurements. Journal of Applied Meteorology, Vol. 17, No. 10, 1542-1548.

Goodison, B.E., 1978b: Canadian Snow Gauge Measurements: Accuracy, Implications, Alternatives, Needs. Proceedings, Seventh Symposium on Applied Prairie Hydrology, Water Studies Institute, Saskatoon, Saskatchewan, May 9-11, 1978, pp. 7-15.

Goodison, B.E., V.R. Turner, and J.R. Metcalfe, 1983: A Nipher-type shield for recording precipitation gauges. Proc. 5th AMS Symposium on Meteorological Observations and Instrumentation, April 11-15, 1983. Toronto, pp. 21-26.

Goodison Barry E., Bob Wilson, Ken Wu, John Metcalfe, 1984: An Inexpensive Remote Snow-Depth Gauge: An Assessment. Paper to be presented at 1984 Western Snow Conference, Sun Valley, Idaho, USA, April 17-19, 1984.

Gray, D.M., H. Steppuhn and F.L. Abbey, 1979: Estimating the Areal Snow Water Equivalent in the Prairie Environment. Proc. Canadian Hydrology Symposium: 79, Vancouver, May 10-11, 1979, pp. 302-322.

Jones, K.H., 1982: A Comparison of Various Snow Gauges on the Canadian Prairies for the Winter 1981-82. Atmospheric Environment Service, Report No. CSS-R82-01, Regina, Saskatchewan, 16 pp.

Turner, V.R., and B. Goodison, 1977: Wind Tunnel Evaluation of Flow Around Snow Gauges. Paper presented at the 11th Annual Canadian Meteorological Society Congress, Winnipeg, Manitoba, June 1-3, 1977.