# SMALL-AREA SNOW SURVEYS ON THE NORTHERN PLAINS OF NORTH DAKOTA

By Douglas G. Emerson, U.S. Geological Survey;
Thomas R. Carroll, National Weather Service;
and Harold Steppuhn, Hydrologic Consultant

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For those readers who may prefer to use the International System (SI) of metric units rather than inch-pound units, the conversion factors for the terms used in this report are given below.

| Multiply inch-pound unit | By | To obtain SI unit |
|---|---|---|
| Electron volt (eV) | 0.9997 | electron volt, international (eV) |
| Foot (ft) | 0.3048 | meter (m) |
| Inch (in.) | 2.540 | centimeter (cm) |
| Mile (mi) | 1.609 | kilometer (km) |
| Square mile ($mi^2$) | 2.590 | square kilometer ($km^2$) |

Electron volt (eV) is a unit of energy equal to the energy acquired by an electron when it passes through a potential difference of 1 volt in a vacuum. For a given form of radiation, eV is proportional to a particular wavelength.

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*ABSTRACT*

*Snow-cover data are needed for many facets of hydrology. The variation in snow cover over small areas is the focus of this study. The feasibility of using aerial surveys to obtain information on the snow water equivalent of the snow cover in order to minimize the necessity of labor intensive ground snow surveys was evaluated. A low-flying aircraft was used to measure attenuations of natural terrestrial gamma radiation by snow cover.*

*Aerial and ground snow surveys of eight 1-mile snow courses and one 4-mile snow course were used in the evaluation, with ground snow surveys used as the base to evaluate aerial data. Each of the 1-mile snow courses consisted of a single land use and all had the same terrain type (plane). The 4-mile snow course consists of a variety of land uses and the same terrain type (plane).*

*Using the aerial snow-survey technique, the snow water equivalent of the 1-mile snow courses was measured with three passes of the aircraft. Use of more than one pass did not improve the results. The mean absolute difference between the aerial- and ground-measured snow water equivalents for the 1-mile snow courses was 26 percent (0.77 inches). The aerial snow water equivalents determined for the 1-mile snow courses were used to estimate the variations in the snow water equivalents over the 4-mile snow course. The weighted mean absolute difference for the 4-mile snow course was 27 percent (0.8 inches).*

*Variations in snow water equivalents could not be verified adequately by segmenting the aerial snow-survey data because of the uniformity found in the snow cover. On the 4-mile snow course, about two-thirds of the aerial snow-survey data agreed with the ground snow-survey data within the accuracy of the aerial technique (±0.5 inch of the mean snow water equivalent).*

## INTRODUCTION

Snow-cover data in terms of water equivalents are needed by Federal, State, and local agencies, and private groups who have the responsibility of managing snow cover for maximum crop production, maintaining transportation routes, and determining runoff for flood prediction and reservoir storage. Most of these uses require information on variations in snow-cover distribution over large areas. There has always been difficulty in obtaining data on the variations in snow-cover distribution on the northern plains, and this became more evident when such data were needed for small watershed modeling. The input required to adequately model a watershed was much more detailed and at a much smaller scale than that normally available from precipitation gages. The model being used was the Precipitation Runoff Modeling System (Leavesley and others, 1983).

## Purpose and Objectives

The purpose of this study was to evaluate the feasibility of using aerial snow surveys to obtain the variations of snow cover on small selected land use/terrain type units. Aerial snow-survey techniques would be tested on relatively short snow courses (for example, 1 mi long). One objective was to determine the number of passes needed over a 1-mi snow course to get reliable data. By picking the 1-mi snow course in such a way that it contained only one land use and only one terrain type, the snow water equivalent determined for a snow course covering a particular land use and terrain type might be extrapolated to other areas in a manner similar to that used in the ground snow-survey technique. A second objective was to ascertain whether or not aerial snow-survey data could be delineated into small segments (the distance covered in 5 seconds of flying time) to determine the variations of snow water equivalent over smaller areas. If these objectives could be met, snow water equivalents for each of the land use/terrain types could be used as input to small-area watershed models. Owing to time and funding restraints, only one terrain type with several land uses was investigated.

## Snow-Cover Physics

The snow water equivalent across the northern plains of North America usually varies from one climatic area to the next, from region to region, from field to field, and between one storm and the next. The northern plains are so vast that individual cyclonic storms that produce most of the snow rarely extend across the entire area. Regional variation in snow cover results mainly from the nonuniform fall of snow. Snowfall depths are greatest near storm-path centers and least at storm-path edges. However, the magnitudes of storms and the variations in routes of storms across the plains contribute to a general increase in snow-cover uniformity as winter progresses. Water equivalents and distribution patterns of snow also are time dependent, being significantly related to frequency of storms, total seasonal snowfall, wind, and snowmelt.

Topography also has a great effect on snowfall and snow retention. The northern plains generally lack large features such as mountains that may exert regional control on snowfall. However, smaller features may have only a minor control on snowfall but a major control on local snow retention. For example, hilly and stream-dissected terrains usually have great variability in snow depths. Such variation occurs when winds sweep the hilltops and uplands bare and deposit snow in deep drifts in lowlands and sheltered sites.

Undulating terrain causes differences in snowmelt, thus affecting long-term snow retention. A south-facing hill slope receives greater radiant energy than a slope facing north, resulting in greater snow-cover ablation.

Snow tends to accumulate more uniformly on flat lands than on hilly landscapes. Snow-cover variation on generally flat terrain primarily results from aberrations and protuberances on the surface. Variation also is caused by overwinter vegetation, land use, manmade structures and other obstructions, and a phenomenon called duning.

Duning results from the transport of snow particles by near-surface turbulent air and is controlled by interactions between gravitational, eolian, and surface-bonding forces. Upward currents of the turbulent air stream, although unable to maintain the particles in suspension, permit the horizontal flow to transport the snow laterally as part of a dune moving along the surface.

Duning can result in a field covered with immobile snow dunes that are 2 to 20 in. high and spaced 6 to 100 ft apart. The dunes have irregular triangular cross sections with wide bases and small acute angles pointing upwind. Once immobile, a dune compacts quickly. Its surface hardens, becoming quite resistant to subsequent wind shear. A field covered with snow dunes presents a rather stationary irregular surface capable of trapping windblown snow transported during future storms. As each new snowfall is trapped, the snow cover on a field becomes more uniform. The final result is a field covered with snow of different age but having a uniform depth and water equivalent.

## Ground Snow-Survey Technique

A ground snow-survey technique based on stratified sampling has been very successful on the northern plains. This technique is based on the research relating snow accumulation to terrain, vegetation, and land use. Steppuhn and Dyck (1974) described stratified sampling as a trilevel design consisting of subunits (points) within areal units (snow courses) within strata (land use/terrain type classes). The technique takes into consideration that physiographic features such as terrain, vegetation, and land use are not distributed randomly. Water equivalent is defined for a particular areal unit as the mean of the sampled areal units of that particular combination of land use/terrain type. The area of interest is partitioned into a number of strata, where each stratum contains a number of areal units and each areal unit a number of subunits. Snow-cover measurements are made in a number of subunits, areal units, and strata. Application of this technique to northern plains snow cover (Lakshman, 1973, and Steppuhn, 1976) indicated a large covariance between depth and water equivalent, along with a relatively small density variance. Because the variance for snow depth is larger than that for snow density, more depth measurements than density measurements are required for a statistically valid estimate of true snow water equivalents. By using the stratified technique, the variation in snow cover over a singular climatic area can be estimated for each particular land use/terrain type (Steppuhn and Dyck, 1974).

## Aerial Snow-Survey Technique

An aerial snow-survey technique being used by the National Weather Service (Peck and others, 1980) measures the attenuation of natural terrestrial gamma radiation to determine snow water equivalent. The gamma radiation is measured from a low-flying aircraft. Gamma-radiation fluxes near the ground originate primarily from the natural potassium-40 ($^{40}K$), uranium-238 ($^{238}U$), and thallium-208 ($^{208}Tl$) radioisotopes. In a typical soil, 96 percent of the gamma radiation is emitted from the top 8 in. (Zotimov, 1968). Gamma radiation is attenuated by material lying between the source (top 8 in. of soil) and an airborne detector. The uncollided gamma radiation (gamma radiation not attenuated), which reaches the detector system, is counted. Because water in either the solid or liquid form attenuates the gamma radiation, water quantity can be calculated.

Background radiation must first be determined for the proposed snow course. Relating the aerial radiation measurement and the ground measurement of the soil moisture without snow cover gives the background radiation. Background radiation needs to be determined only once for a single snow course. The snow course can then be reflown and the attenuation of the radiation is measured and compared with the background radiation for calculating the quantity of water in the snow cover and top 8 in. of soil. Soil moisture measured at the time of the survey is subtracted from the calculated water quantity to give the snow water equivalent.

Three snow water equivalent values are calculated by measuring the attenuation of the gamma-radiation flux from the potassium spectrum (1.36-1.56 million electron volts, MeV), the thallium spectrum (2.41-2.81 MeV), and the gross-count energy spectrum (0.41-3.0 MeV). The gross-count flux consists of both discrete and continuous energy components. The potassium spectral peak is consistently the strongest in the energy spectrum and has been used successfully to measure snow water equivalent in Canada and in the United States (Glynn and Grasty, 1980, and Peck and others, 1980).

The gross-count spectrum accumulates an order of magnitude more counts than the potassium and thallium spectral peaks. Consequently, gross counts are useful when measuring the variability of snow water equivalent along a snow course or the snow cover with 6 to 10 in. of snow water equivalent.

Details of the airborne detection package used by the National Weather Service have been described by Carroll and Vadnais (1980) and Fritzsche (1979). The optimum length of an operational snow course of the National Weather Service is 5 to 15 mi. An aircraft, like the twin-engine Aero Commander[1/] of

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[1/] Use of the brand name in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

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the National Weather Service, flies at an altitude of 500 ft and continuously measures natural terrestrial gamma radiation over a path 1,000 ft wide. Consequently, radiation data collected over operational snow courses represent mean areal measurements over approximately 1 to 3 $mi^2$. The airborne technique is capable of measuring the mean snow water equivalent over an operational snow course with an accuracy of $\pm 0.5$ in. at the 68-percent confidence level (Carroll and Vadnais, 1979).

## Problems in Collecting Snow-Cover Data

Intensive ground snow surveys based on land use/terrain type as previously described were used to obtain the needed data for a watershed modeling study. Snow water equivalents were obtained for areas with about an average size of 0.02 $mi^2$. Such data proved valuable in watershed modeling. The ground snow survey provided the required data but was labor intensive and time consuming. Comparison of the survey data with precipitation-gage data showed that required variations in snow-cover distribution could not be obtained from precipitation-gage data. Since labor and time restrictions limit the number of surveys that can be made during a winter, a more expedient method is needed.

The aerial snow survey as previously described can be used to determine the mean snow water equivalent for 20 to 40 operational snow courses per day. Extensive surveys can be performed even after an early spring snowfall prior to snowmelt, providing managers and hydrologists with valuable real-time data. The aerial snow survey provides valuable data but not for those who need to know the variations in snow-cover distribution at scales smaller than those of the National Weather Service's operational snow courses.

The main concern on short snow courses is that the radiation count may cause inaccuracy because sample size is too small. For operational snow courses, radiation count periods range from 22 to 68 seconds.

## STUDY AREA AND SNOW-COVER CONDITIONS

The snow courses selected for the study are located in north-central North Dakota near the J. Clark Salyer II National Wildlife Refuge (fig. 1). The area is part of the glaciated plains of the Central Lowland and is characterized by flat topography. The land is used primarily for the production of small grain and oilseed crops.

The mean annual precipitation is about 16 in. (U.S. Environmental Data and Information Service, 1982), of which about 25 percent occurs in the form of snow. Snow normally accumulates from mid-November to mid-March and is rarely interrupted by a melt period. The mean temperatures for November, December, January, February, and March are 18.0, 17.5, 1.5, 9.0, and 21.0°F, respectively.

Eight 1-mi snow courses (ND140, ND141, ND143, ND145, ND146, ND147, ND148, and ND149; fig. 1) were selected for snow survey by aerial and ground techniques. Each of the eight 1-mi snow courses was chosen to span fields with a single terrain type (plane) and land use. A single terrain type was selected for all eight courses to eliminate the effects of terrain on the local redistribution of snow cover. The eight 1-mi snow courses include two snow courses for each land use prevalent in the study area: fallow, grain-stubble mulch, grain stubble, and sunflower stubble. The land use for ND141 and ND148 was fallow. ND141 had a negligible quantity of stubble and new growth but had a smoother surface than ND148. ND148 was completely bare of vegetation but had a very rough, cultivated surface. The land use for ND143 and ND145 was grain-stubble mulch. Both ND143 and ND145 generally appeared to have been cultivated about the same degree. The land use for ND140 and ND147 was grain stubble. Both fields had dense stands of grain stubble; however, the stubble on ND140 was cut a few inches shorter than on ND147. The land use for ND146 and ND149 was sunflower stubble. Both sunflower-stubble snow courses generally appeared to be the same with mostly standing stalks.

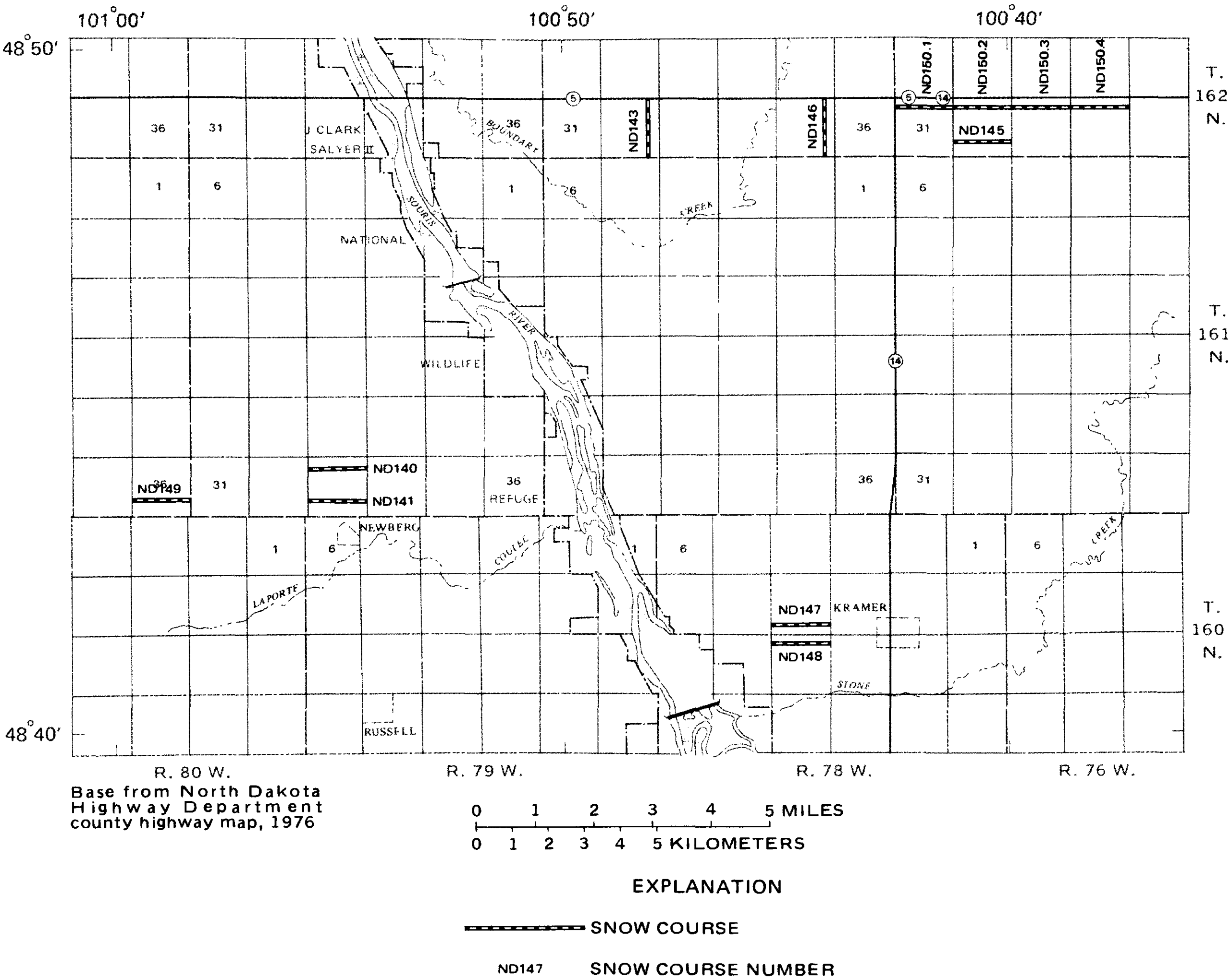


**Figure 1.—Location of Snow Courses.**

One 4-mi snow course (ND150, fig. 1) that met the same terrain-type requirements as the 1-mi snow courses but was a mixture of the previously designated land uses was selected. The land use along snow course ND150 is illustrated in figure 2. The snow course has been delineated into 1-mi segments noted as 0.1, 0.2, 0.3, and 0.4 and into fields noted by letters.

Snow-cover data were to be collected during the 1980-81 and the 1981-82 winters. No snow surveys were made during 1980-81 because the winter was very mild with very little snow cover. Snow cover during 1981-82 was adequate but, due to unusual meteorological conditions, was rather uniformly redistributed. Unprotected areas such as fallow fields were not blown free of snow, and protected areas such as tree shelterbelts were not drifted completely full of snow. Duning occurred in the fallow and grain-stubble mulch fields, resulting in entrapment of snow. Accordingly, snow cover was relatively uniform regardless of land use.

## SNOW-SURVEY DATA

### Ground Snow-Survey Data

Between 132 and 198 snow-depth measurements were made at equal intervals along each 1-mi snow course. The depth measurements were made by using a steel depth rod. Eight to 10 snow-density measurements were taken for each snow course by the standard method of gravimetric measurement using a snow tube to obtain a sample core. A Federal snow sampler or a modified form of the Adirondack snow sampler that has a 4-in. diameter core tube was used. A summary of the data for the 1-mi snow courses obtained on February 25 and 26, 1982, is listed in table 1. ND140 and ND145 each have a drainage ditch across them, so the mean snow depth for these fields was recomputed eliminating snow depths associated with the drainage ditches. The recomputed data are listed in table 1 as ND140A and ND145A. Data for ND140A and ND145A are representative values of the mean snow depth for their land uses, respectively, and these data, rather than data for ND140 and ND145, were used in evaluation of ND150.

For the 4-mi snow course (ND150), 609 snow-depth measurements were made. The summary of the data for ND150 obtained on February 25 and 26, 1982, is listed in table 2.

### Ground Soil-Moisture Survey Data

Soil-moisture samples were collected along several snow courses during the background (no snow cover) radiation survey (table 3) and also during the snow-cover surveys. Soil samples were collected at approximately equal intervals along the snow courses and were obtained from the upper 8 in. by using a spade or in the case of frozen soil by using a pick or a hatchet.

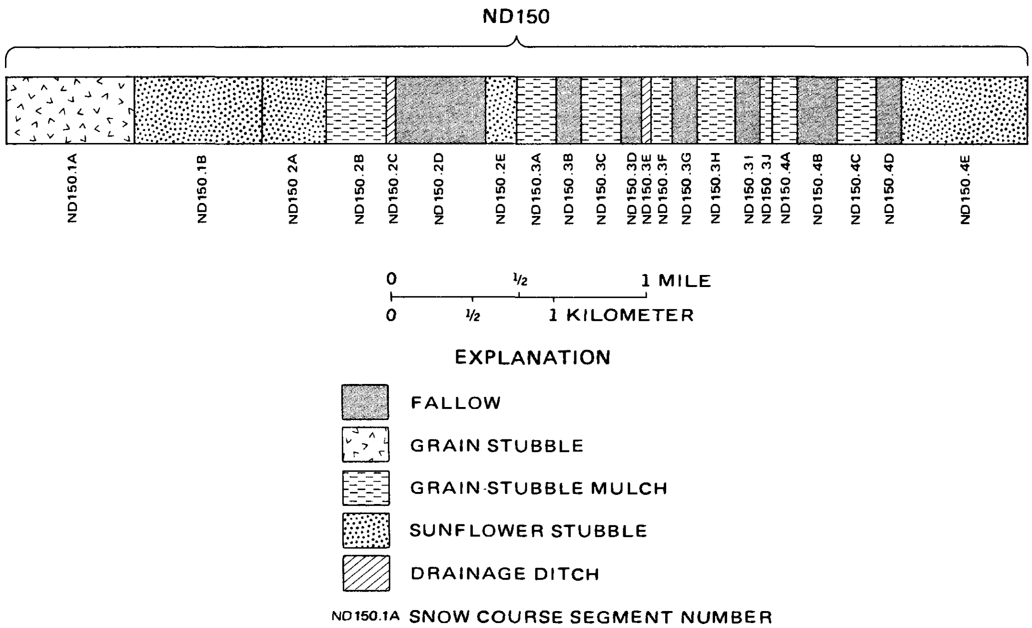


**Figure 2.—Land-use composite of ND150.**

TABLE 1.--Summary of the ground snow-survey data for the 1-mile snow courses obtained on February 25 and 26, 1982

| Snow course number | Snow depth | | | Snow density 1/ | | | Snow water equivalents, in inches | Land use |
|---|---|---|---|---|---|---|---|---|
| | Number of samples | Mean depth, in inches | Standard deviation, in inches | Number of samples | Mean density, in percent | Standard deviation, in percent | | |
| ND140 | 198 | 11.3 | 4.2 | 10 | 24.4 | 6.22 | 2.76 | Grain stubble |
| ND140A | 193 | 10.8 | 2.5 | 10 | 24.4 | 6.22 | 2.64 | Grain stubble |
| ND141 | 188 | 10.1 | 3.1 | 10 | 26.3 | 5.33 | 2.66 | Fallow |
| ND143 | 146 | 9.8 | 3.4 | 8 | 30.6 | 5.34 | 3.00 | Grain-stubble mulch |
| ND145 | 132 | 10.6 | 7.2 | 8 | 29.7 | 5.01 | 3.15 | Grain-stubble mulch |
| ND145A | 128 | 9.6 | 3.6 | 8 | 29.7 | 5.01 | 2.85 | Grain-stubble mulch |
| ND146 | 149 | 13.0 | 2.8 | 8 | 23.8 | 1.74 | 3.09 | Sunflower stubble |
| ND147 | 164 | 12.6 | 3.5 | 8 | 24.4 | 5.81 | 3.07 | Grain stubble |
| ND148 | 171 | 10.4 | 4.2 | 9 | 33.3 | 8.51 | 3.46 | Fallow |
| ND149 | 195 | 12.6 | 2.8 | 10 | 22.3 | 3.33 | 2.81 | Sunflower stubble |

1/The specific gravity of snow in percent (a dimensionless ratio) is commonly called the snow density (which, properly, would be mass per unit volume). To convert from percent to gram per cubic centimeter ($g/cm^3$, units in common use), divide by 100.

TABLE 2.--Summary of the ground snow-survey data for ND150 obtained on February 25 and 26, 1982

| Snow course segment number | Length of snow course segment, in miles | Number of samples | Snow depth | | Snow water equivalent, in inches[a] | Land use |
|---|---|---|---|---|---|---|
| | | | Mean snow depth, in inches | Standard deviation, in inches | | |
| ND150.1-A | 0.50 | 74 | 10.3 | 2.3 | 2.51 | Grain stubble |
| ND150.1-B | .50 | 99 | 15.4 | 2.0 | 3.54 | Sunflower stubble |
| ND150.1 | 1.00 | -- | [b]12.8 | -- | [b]3.03 | -- |
| ND150.2-A | .25 | 32 | 14.2 | 2.0 | 3.27 | Sunflower stubble |
| ND150.2-B | .24 | 28 | 9.4 | 2.9 | 2.84 | Grain-stubble mulch |
| ND150.2-C | .03 | 4 | 32.4 | 9.0 | [c]8.75 | Drainage ditch |
| ND150.2-D | .36 | 39 | 8.8 | 3.0 | 2.62 | Fallow |
| ND150.2-E | .12 | 20 | 14.0 | 2.6 | 3.22 | Sunflower stubble |
| ND150.2 | 1.00 | -- | [b]11.6 | -- | [b]3.09 | -- |
| ND150.3-A | .15 | 27 | 11.0 | 3.6 | 3.32 | Grain-stubble mulch |
| ND150.3-B | .10 | 19 | 8.8 | 2.2 | 2.62 | Fallow |
| ND150.3-C | .15 | 27 | 10.0 | 3.0 | 3.02 | Grain-stubble mulch |
| ND150.3-D | .09 | 17 | 5.9 | 2.5 | 1.76 | Fallow |
| ND150.3-E | .02 | 5 | 39.1 | 13.6 | [c]10.56 | Drainage ditch |
| ND150.3-F | .09 | 16 | 8.2 | 1.9 | 2.48 | Grain-stubble mulch |
| ND150.3-G | .10 | 19 | 10.0 | 2.8 | 2.98 | Fallow |
| ND150.3-H | .15 | 27 | 13.3 | 5.2 | 4.02 | Grain-stubble mulch |
| ND150.3-I | .10 | 19 | 8.4 | 2.5 | 2.50 | Fallow |
| ND150.3-J | .05 | 9 | 9.0 | 2.0 | 2.72 | Grain-stubble mulch |
| ND150.3 | 1.00 | -- | [b]10.4 | -- | [b]3.09 | -- |
| ND150.4-A | .10 | 13 | 7.2 | 2.9 | 2.17 | Grain-stubble mulch |
| ND150.4-B | .15 | 19 | 8.6 | 3.4 | 2.56 | Fallow |
| ND150.4-C | .15 | 19 | 10.4 | 2.6 | 3.14 | Grain-stubble mulch |
| ND150.4-D | .10 | 13 | 10.7 | 2.3 | 3.19 | Fallow |
| ND150.4-E | .50 | 64 | 10.8 | 3.8 | 2.48 | Sunflower stubble |
| ND150.4 | 1.00 | -- | [b]10.0 | -- | [b]2.63 | -- |
| ND150 | 4.00 | -- | [b]11.2 | -- | [b]2.96 | -- |

[a]Mean density for the particular land use (table 1) was used to compute the snow water equivalents.
[b]Mean weighted by length of snow course segment.
[c]A density of 27 percent was used to compute snow water equivalent.

TABLE 3.--Summary of soil-moisture data

| Snow course number | Date samples were collected | Number of soil-moisture samples | Mean soil moisture, in percent by weight | Standard deviation, in percent by weight |
|---|---|---|---|---|
| | | During background | | |
| ND140 | 11/07/80 | 20 | 23.8 | 4.2 |
| ND140 | 3/10/81 | 20 | 25.3 | 7.0 |
| ND140 | 11/03/81 | 20 | 15.7 | 2.3 |
| ND141 | 11/07/80 | 20 | 25.0 | 3.0 |
| ND141 | 3/10/81 | 20 | 27.0 | 8.3 |
| ND141 | 11/03/81 | 20 | 18.8 | 3.9 |
| ND143 | 11/07/80 | 20 | 30.6 | 4.8 |
| ND143 | 3/10/81 | 19 | 30.3 | 4.9 |
| ND143 | 11/02/81 | 20 | 23.4 | 3.9 |
| ND145 | 11/07/80 | 20 | 33.9 | 4.4 |
| ND145 | 3/10/81 | 20 | 41.1 | 7.6 |
| ND145 | 11/02/81 | 20 | 27.5 | 4.2 |
| ND146 | 11/03/81 | 10 | 24.0 | 1.5 |
| | | During snow cover | | |
| ND140 | 2/02/82 | 8 | 17.1 | 2.5 |
| ND141 | 2/02/82 | 8 | 20.9 | 4.8 |
| ND143 | 2/02/82 | 8 | 23.6 | 1.1 |
| ND145 | 2/03/82 | 8 | 27.2 | 3.5 |
| ND146 | 2/03/83 | 4 | 34.2 | 4.7 |
| ND147 | 2/02/82 | 8 | 22.6 | 5.7 |
| ND148 | 2/02/82 | 8 | 23.0 | 2.9 |
| ND149 | 2/02/82 | 8 | 16.5 | 2.3 |

Soil-moisture determinations for the representative soil samples were made by the oven drying method. Snow courses containing a single land use usually had a more uniform soil moisture than snow courses containing a mixture of land uses because the plant type, period of plant growth, time of harvest, and period of fallow are uniform. The more uniform the soil moisture is along a snow course, the more representative a single value of soil moisture is for that snow course. A summary of the soil-moisture data is listed in table 3. Soil-moisture measurements were not made along ND150; therefore, the mean soil moisture for each interval could not be determined. A mean soil-moisture value of 26 percent by weight (based on results from the 1-mi snow courses) was used for the entire length of the field.

## Aerial Snow-Survey Data

Each snow course was flown three times during all background and snow-cover surveys. In this way, it was possible to accumulate radiation data for a 1-mi snow course that would have radiation counts approximately equivalent to those associated with a snow course 1, 2, or 3 mi long. Results of the aerial data collection made on February 26, 1982, are given in table 4.

Count rates for the three gamma-radiation fluxes were measured for all snow courses. The potassium spectral peak was used in the analysis of the 1-mi snow courses and the gross-count energy spectrum was used in the analysis of the 4-mi snow course.

The snow water equivalent distribution over ND150 that was made on February 26, 1982, is shown in figure 3. Count rates were recorded in 5-second intervals as the aircraft flew over the snow course. The 5-second intervals are equivalent to approximately 1,200-ft intervals along the snow course. Although there is very little repetition in the measurements, the variability is well within the difference of the aerial technique.

# ANALYSIS

This study addresses variation in snow depth and water equivalent on a small scale (for example, 1 mi or shorter snow courses). A comparison of the aerial snow survey with one, two, or three passes to the ground snow survey is shown in table 5. The difference from the ground survey data (in percent of and inches from) were computed for the aerial data for each snow course. Snow courses ND140, ND145, ND146, and ND148 showed small differences ranging from -13 to +16 percent. ND141 and ND147 showed moderate differences with the largest being 34 percent. The large differences for ND149 (103 to 114 percent) could not be explained. The mean, mean of absolute value, and standard deviation of the differences are computed for the 1-mi snow courses for the various number of passes (table 5). The variations among these statistics are negligible, indicating that more than one

TABLE 4.--Summary of the aerial snow-survey data obtained on February 26, 1982

| Snow course number | One pass | Two passes | | Three passes | |
|---|---|---|---|---|---|
| | Mean snow water equivalent, in inches | Mean snow water equivalent, in inches | Range, in inches | Mean snow water equivalent, in inches | Range, in inches |
| ND140 | 3.2 | 2.8 | 2.3-3.2 | 2.9 | 2.3-3.2 |
| ND141 | 2.9 | 3.2 | 2.9-3.4 | 3.5 | 2.9-4.3 |
| ND145 | 2.9 | 2.8 | 2.6-2.9 | 3.0 | 2.6-3.5 |
| ND146 | 2.9 | 3.3 | 2.9-3.7 | 3.1 | 2.8-3.7 |
| ND147 | 4.0 | 4.1 | 4.0-4.1 | 3.9 | 3.7-4.1 |
| ND148 | 3.0 | 3.5 | 3.0-3.9 | 3.6 | 3.0-3.9 |
| ND149 | 5.7 | 6.0 | 5.7-6.3 | 5.9 | 5.6-6.3 |
| ND150 | 3.4 | 3.2 | 3.0-3.4 | 3.2 | 3.0-3.4 |

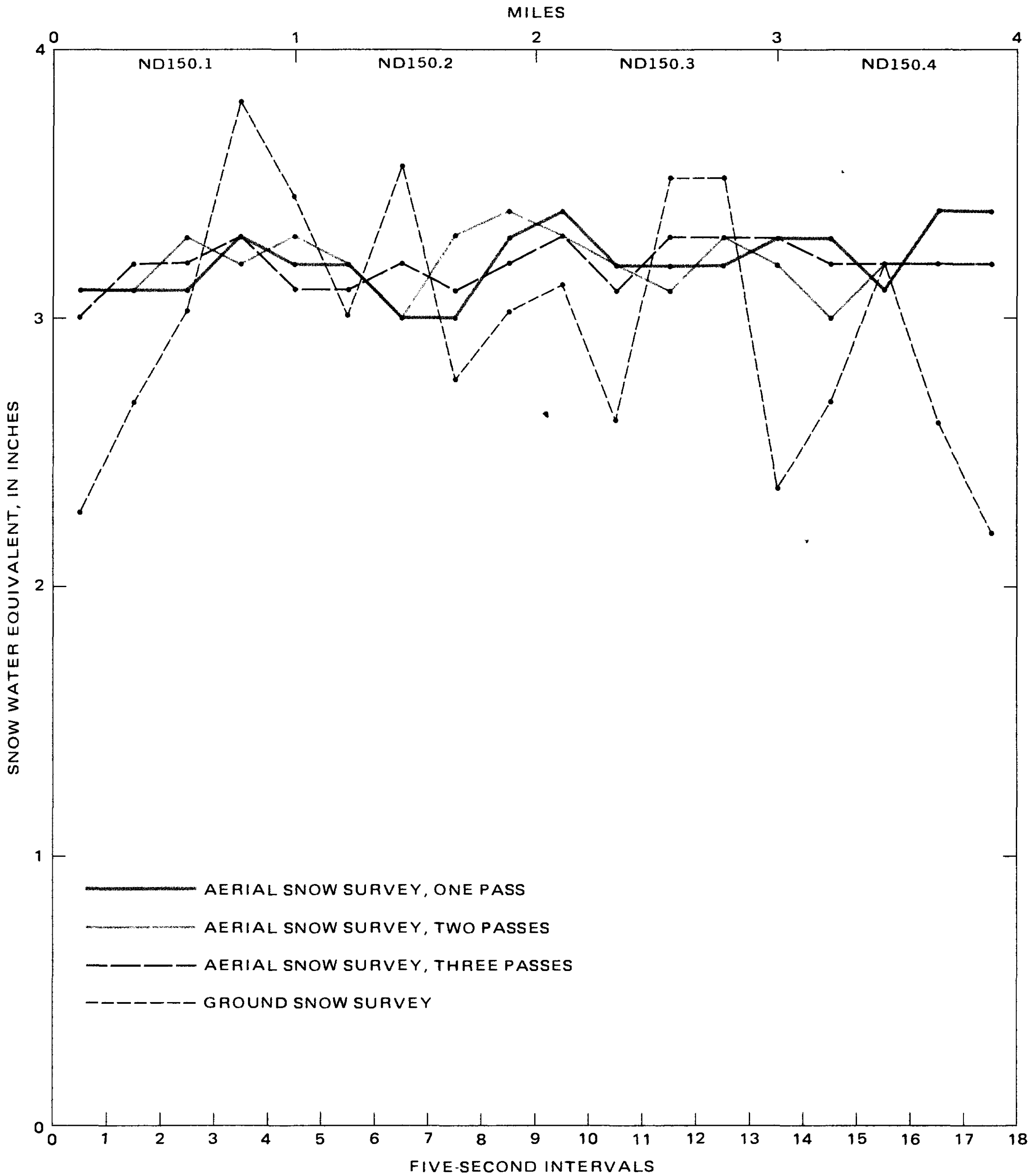


**Figure 3.—Snow water equivalents for ND150.**

TABLE 5.--Comparison of the snow water equivalents of the aerial snow survey to the ground snow survey

| Snow course number | Difference between aerial- and ground-measured snow water equivalents | | | | | |
|---|---|---|---|---|---|---|
| | One aerial pass and ground snow survey | | Two aerial passes and ground snow survey | | Three aerial passes and ground snow survey | |
| | Percent | Inches | Percent | Inches | Percent | Inches |
| ND140 | 16 | 0.44 | 1 | 0.04 | 5 | 0.14 |
| ND141 | 9 | .24 | 20 | .54 | 32 | .84 |
| ND145 | -8 | -.25 | -11 | -.35 | -5 | -.15 |
| ND146 | -6 | -.19 | 7 | .21 | 1 | .01 |
| ND147 | 30 | .93 | 34 | 1.03 | 27 | .83 |
| ND148 | -13 | -.46 | 1 | .04 | 4 | .14 |
| ND149 | 103 | 2.89 | 114 | 3.19 | 110 | 3.09 |
| Mean | 19 | .51 | 24 | .67 | 25 | .70 |
| Mean of absolute value | 26 | .77 | 27 | .77 | 26 | .74 |
| Standard deviation | 37 | 1.06 | 39 | 1.10 | 37 | 1.04 |
| ND150 | 15 | 0.44 | 8 | 0.24 | 8 | 0.24 |

pass does not improve results. The mean absolute difference in percent for one pass on the 1-mi snow courses (26 percent) is 18 percent greater than the difference in percent for ND150 (8 percent) for two and three passes (represents 8- and 12-mi long snow courses). Therefore, indications are that one pass over a 1-mi snow course gives reasonable results. If ND149 was omitted from the computation, the mean absolute difference for the 1-mi snow courses would be only 14 percent.

The mean aerial snow water equivalents determined by one pass over the 1-mi snow courses (table 4) were used to estimate the snow water equivalents for ND150, which has a mixture of land use units. The estimated values are compared with the ground snow-survey data from table 2. The results are listed in table 6. The difference for the individual snow course segments ranged from -27 to 73 percent. The mean absolute difference for ND150 weighted by the length of the snow course segments was 27 percent.

For comparison of the transferability, the snow depths for ND150 were estimated by using the mean snow depth that was determined for the 1-mi snow courses corresponding to the same land use. Drainage ditches, which can vary in size, were not evaluated in the 1-mi snow course analysis. Therefore, the depths measured for the two ditches crossing ND150 were used in the estimation of the snow depths for ND150. The estimated snow depth and its difference for ND150 are given in table 7. A comparison of the measured and estimated snow depths shows the transferability of ground stratified data within a climatic area. Snow-survey data from the 1-mi snow courses estimated the snow depths for the entire 4-mi snow course (ND150) within 2 percent. Because snow depths can be transferred successfully within a climatic area and variance of snow density is small, the snow water equivalents as well as the snow depths can be transferred.

The estimated snow water equivalents and their differences are also listed in table 7. The mean difference for snow water equivalent weighted by the length of the field segments was 2 percent. The weighted mean difference for the estimated aerial snow water equivalents was 22 percent (table 6) and is compatible with the mean absolute difference of 26 percent (table 5) of one pass over the 1-mi snow courses as would be expected.

The aerial snow-survey data were delineated into smaller segments (the distance covered in 5 seconds of flight time) and compared to the measured ground snow-survey data (fig. 3) for the 4-mi snow course. Variations in snow water equivalents could not be verified adequately by delineating the aerial data into smaller segments because of the uniformity found in the snow cover. About two-thirds of the aerial snow-survey data compares with ground snow-survey data within the accuracy of the aerial

TABLE 6.--Estimated aerial snow water equivalents for ND150

| Snow course segment number | Estimated aerial snow water equivalent, in inches | Difference between estimated aerial- and ground-measured snow water equivalents | |
|---|---|---|---|
| | | Percent | Inches |
| ND150.1-A | 3.6 | 43 | 1.1 |
| ND150.1-B | 4.3 | 23 | .8 |
| ND150.1 | [a]4.0 | [a]33<br>[b]33 | [a]1.0<br>[b]1.0 |
| ND150.2-A | 4.3 | 31 | 1.0 |
| ND150.2-B | 2.9 | 4 | .1 |
| ND150.2-C | [c]8.75 | -- | -- |
| ND150.2-D | 3.0 | 15 | .4 |
| ND150.2-E | 4.3 | 34 | 1.1 |
| ND150.2 | [a]3.6 | [a]16<br>[b]16 | [a].5<br>[b].5 |
| ND150.3-A | 2.9 | -12 | -.4 |
| ND150.3-B | 3.0 | 15 | .4 |
| ND150.3-C | 2.9 | -3 | -.1 |
| ND150.3-D | 3.0 | 68 | 1.2 |
| ND150.3-E | [c]10.56 | -- | -- |
| ND150.3-F | 2.9 | 16 | .4 |
| ND150.3-G | 3.0 | 0 | 0 |
| ND150.3-H | 2.9 | -27 | -1.1 |
| ND150.3-I | 3.0 | 20 | .5 |
| ND150.3-J | 2.9 | 7 | .2 |
| ND150.3 | [a]3.1 | [a]0<br>[b]16 | [a]0<br>[b].5 |
| ND150.4-A | 2.9 | 32 | .7 |
| ND150.4-B | 3.0 | 16 | .4 |
| ND150.4-C | 2.9 | -6 | -.2 |
| ND150.4-D | 3.0 | -6 | -.2 |
| ND150.4-E | 4.3 | 73 | 1.8 |
| ND150.4 | [a]3.6 | [a]38<br>[b]42 | [a]1.0<br>[b]1.1 |
| ND150 | [a]3.6 | [a]22<br>[b]27 | [a].6<br>[b].8 |

[a]Mean weighted by length of snow course segment.
[b]Mean of the absolute values weighted by length of snow course segment
[c]The snow water equivalent from the ground snow survey was used.

TABLE 7.--Estimated ground data for ND150

| Snow course segment number | Estimated ground snow depths, in inches | Difference between measured and estimated snow depths | | Estimated snow water equivalents, in inches a/ | Difference between measured and estimated ground snow water equivalents | |
|---|---|---|---|---|---|---|
| | | Percent | Inches | | Percent | Inches |
| ND150.1-A | 11.7 | 14 | 1.4 | 2.85 | 14 | 0.34 |
| ND150.1-B | 12.8 | -17 | -2.6 | 2.94 | -17 | -.60 |
| ND150.1 | b/12.2 | b/-5<br>c/16 | b/-.6<br>c/2.0 | b/2.90 | b/-4<br>c/16 | b/-.13<br>c/.47 |
| ND150.2-A | 12.8 | -10 | -1.4 | 2.94 | -10 | -.33 |
| ND150.2-B | 9.7 | 3 | .3 | 2.93 | 3 | .09 |
| ND150.2-C | d/32.4 | -- | -- | e/8.75 | -- | -- |
| ND150.2-D | 10.2 | 16 | 1.4 | 3.04 | 16 | .42 |
| ND150.2-E | 12.8 | -9 | -1.2 | 2.94 | -9 | -.28 |
| ND150.2 | b/11.7 | b/1<br>c/9 | b/.1<br>c/1.1 | b/3.15 | b/2<br>c/9 | b/.06<br>c/.28 |
| ND150.3-A | 9.7 | -12 | -1.3 | 2.93 | -12 | -.39 |
| ND150.3-B | 10.2 | 16 | 1.4 | 3.04 | 16 | .42 |
| ND150.3-C | 9.7 | -3 | -.3 | 2.93 | -3 | -.09 |
| ND150.3-D | 10.2 | 73 | 4.3 | 3.04 | 73 | 1.28 |
| ND150.3-E | d/39.1 | -- | -- | e/10.56 | -- | -- |
| ND150.3-F | 9.7 | 18 | 1.5 | 2.93 | 18 | .45 |
| ND150.3-G | 10.2 | 2 | .2 | 3.04 | 2 | .06 |
| ND150.3-H | 9.7 | -27 | -3.6 | 2.93 | -27 | -1.09 |
| ND150.3-I | 10.2 | 21 | 1.8 | 3.04 | 22 | .54 |
| ND150.3-J | 9.7 | 8 | .7 | 2.93 | 8 | .21 |
| ND150.3 | b/10.5 | b/1<br>c/16 | b/.1<br>c/1.7 | b/3.13 | b/1<br>c/16 | b/.04<br>c/.50 |
| ND150.4-A | 9.7 | 35 | 2.5 | 2.93 | 35 | .76 |
| ND150.4-B | 10.2 | 19 | 1.6 | 3.04 | 19 | .48 |
| ND150.4-C | 9.7 | -7 | -.7 | 2.93 | -7 | -.21 |
| ND150.4-D | 10.2 | -5 | -.5 | 3.04 | 5 | -.15 |
| ND150.4-E | 12.8 | 19 | 2.0 | 2.93 | 19 | .46 |
| ND150.4 | b/11.4 | b/13<br>c/16 | b/1.3<br>c/1.6 | b/2.96 | b/13<br>c/16 | b/.33<br>c/.43 |
| ND150 | b/11.4 | b/2<br>c/14 | b/.2<br>c/1.6 | b/3.04 | b/3<br>c/14 | b/.08<br>c/.42 |

a/Mean density for the particular land use (table 1) was used to compute the snow water equivalents.
b/Mean weighted by length of snow course segment.
c/Mean of the absolute values weighted by length of snow course segment.
d/Because the drainage ditches were not evaluated in the 1-mile snow course analysis, the snow depths which were measured were used in the prediction of the snow depths of ND150.
e/A density of 27 percent was used to compute snow water equivalent.

technique (±0.5 in. of snow water equivalent). Snow-survey data for a snow cover with more variable distribution are needed to form a confident conclusion.

## SUMMARY AND CONCLUSIONS

Ground and aerial snow surveys were used to evaluate the feasibility of obtaining the variation of snow cover on a smaller scale than the present operational snow courses (5 to 15 mi) of the National Weather Service. Eight 1-mi snow courses, each consisting of a single land use and a common terrain type, and one 4-mi snow course that consisted of a mixture of land uses and the same terrain type of plane were used in the evaluation.

One aerial snow-survey pass was found to be adequate for measuring the snow cover over the 1-mi snow courses. Additional passes did not increase measurement accuracy. The mean absolute difference between the aerial- and ground-measured snow water equivalents for the 1-mi snow courses was 26 percent (0.77 in.). An aerial measurement of one of the 1-mi snow courses with difference over 100 percent was inexplicable. If this measurement was omitted, the mean absolute difference for the 1-mi snow courses would be only 14 percent. The aerial snow water equivalents determined by one pass over the 1-mi snow courses were used to estimate the variations in the snow water equivalents over the 4-mi snow course. The weighted mean absolute difference for the 4-mi snow course was 27 percent (0.8 in.). Aerially measuring snow cover for multiple single land use units and extrapolating the data over an area to obtain the variations of snow cover appears to be feasible. Additional research with different terrain types and under different snow-cover conditions is needed to verify the approach. Variations in snow water equivalent could not be verified adequately by segmenting the aerial snow-survey data because of the uniformity found in the snow cover. About two-thirds of the aerial snow-survey data compares with the ground snow-survey data within the accuracy of the aerial technique (±0.5 in. of snow water equivalent).

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