Mean Snowpack Water Equivalent Maps and Snow Course Data Problems over Southern Ontario

by

H.L. Ferguson and B.E. Goodison

Hydrometeorology and Environmental Impact
Research Division, Atmospheric Environment
Service, Downsview, Ontario

Introduction

In 1954 the Atmospheric Environment Service (formerly the Meteorological Branch) agreed to publish, on an annual basis, snow survey data collected by various co-operating agencies in eastern Canada. Under this arrangement the collecting agencies are responsible individually for quality control of the information they provide for the publication Snow Cover Data (Atmospheric Environment Service, 1973).

During the winter of 1972-73 Environment Canada and the Department of Energy Mines and Resources conducted experimental airborne gamma radiation spectrometer surveys of snow cover over southern Ontario. The need for "ground truth" in support of these aerial surveys directed the attention of co-operating agencies to the network data available for the region and prompted the present study.

There are currently over 100 network snow courses in operation for that portion of Ontario south of a French River - North Bay - Matawa line. These are operated by 5 different agencies, of which the Ontario Ministry of Natural Resources runs the largest snow surveying program. Due to the snowbelt effects of the Great Lakes and frequent winter thaws, especially in the southern part of the region, the temporal and spatial variability of snow cover is relatively large and the flood potential of snowmelt runoff shows a similar variability.

Several questions arise in regard to network snow cover data. Can the published data be usefully analyzed and mapped on a climatological and/or synoptic basis? How would synoptic maps of snow cover compare with gamma survey results? What relationships exist between snow cover and accumulated snowfall patterns? How are these patterns related to such variables as latitude, elevation, air temperature, vegetative cover and distance from the Great Lakes? What actions could be taken by the snow cover data collection agencies to improve the usefulness of published data?

Some initial results of a study to answer these questions are presented in this paper.

General Problems of Snow Cover Measurement and Sampling

In conjunction with the gamma survey project, monthly maps of snowpack water equivalent were prepared for the period January to March, 1973. This period was one in which snowfall was below normal and mean temperature generally above normal. Five-year (1969-1973) and ten-year (1964-1973) monthly snow water equivalent maps (January to March) for mid-month means were prepared for comparative purposes using only the available published data. Although absolute values might differ over time it seemed likely that the general patterns might be persistent. However, it should be noted that the number of snow courses available for the ten-year analysis is only 25% of the 1973 total.

When using published data to produce regional maps of snow cover one must not overlook the problems associated with instrumental and network biases which undoubtedly influence spatial and temporal variations. The problem of mapping snow cover has been discussed recently by McKay and Thompson (1972). They point out that the "key issue in mapping snow data is its interpretation from the point of view of instrumental accuracy and comparability, representativeness, and sampling error". Several papers have been published which discuss instrument accuracy (for example, McKay, 1968; Freeman, 1965). The problems of representativeness and sampling are more difficult to assess.

A sampling problem exists because snow cover in any one area is, by its nature, variable. There is a tendency to avoid areas of high internal variability in favour of those areas with a more uniform cover. The publication Snow Cover Data does not provide estimates of standard error and thus one has no idea of the variability within a particular course. Related to this is the question of representativeness of the snow courses. Courses have been established by each of the co-operating agencies for a particular purpose. Often they may be in sheltered locations where above normal accumulations ensure continuity of measurement. Thus a measured value may be considered useful as a basin "index" rather than a "true" value if it correlates well with subsequent basin yield.

While bias may not be a serious problem for a particular application of the data, it does constitute a problem when one wishes to map and use absolute values for other purposes. Furthermore, the individual agencies generally recognize that a true value would be preferable to an "index".

Average Distributions of Snowpack Water Equivalent over Southern Ontario

a) Five-Year Mean Monthly Maps

Figure 1 shows the distribution of snow courses in the Southern Ontario study region. Most are sampled every two weeks, but those along the Rideau and Trent canal systems are only sampled once during the winter season.

Figure 2 is the preliminary analysis of the five-year mean snowpack water equivalent for mid-March. It is based solely on the published snow cover data for the fifty-three courses available for the 1969-1973 period.

The map shows four or five distinct "high" snowpack water equivalent areas - east of Lake Huron, above the Niagara Escarpment, east of Georgian Bay, in the Algonquin Highland region and in the Ottawa region. Isolines north of Lake Ontario are nearly parallel to the lake, with snow water equivalent increasing to the north. Two notable irregularities existed in the Rostock - Sebringville area of south-western Ontario, and in the Trenton - Stirling - Plainfield region north of Lake Ontario. Whether such absolute differences should exist in these areas is not known, and will be investigated further.

In an effort to increase the reliability of the mapped patterns, normal monthly snowfall totals (available from a large number of observing stations) were mapped. The preliminary snow water equivalent map (Fig.2) was then adjusted, taking into account the mean snowfall data, resulting in the modified analysis shown in Fig.3. Snowfall statistics were particularly useful in those areas where there was a lack of snow course data, for example north-west of Lake Simcoe, where large snowfall values are recorded. The changes introduced in the snowpack patterns north of Lake Ontario and near Georgian Bay are noteworthy. It should be pointed out that Fig.3 still takes full account of all five-year mean snow course data, but the interpolation of the pattern between stations has been improved by taking account of snowfall data.

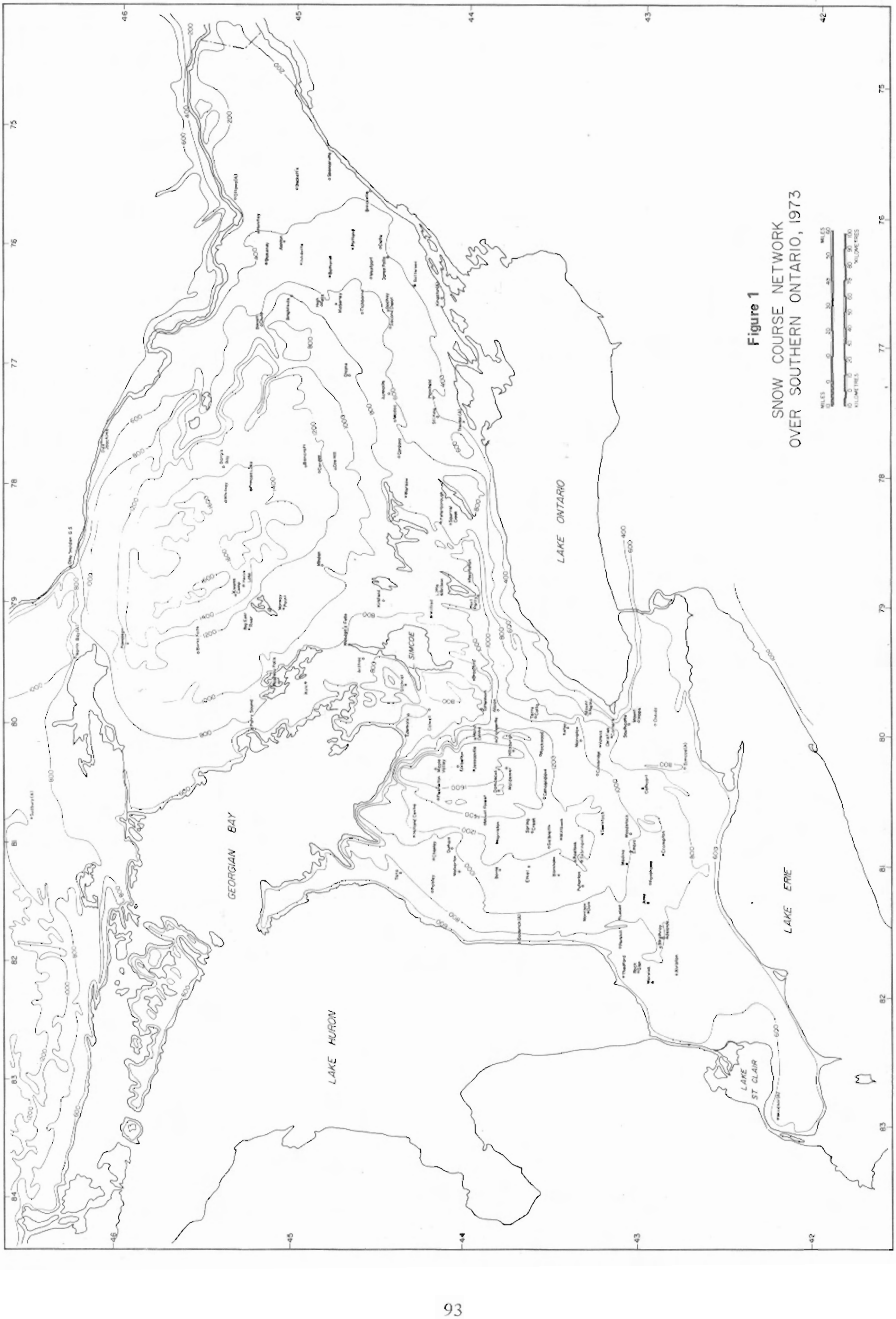

Figure 1
SNOW COURSE NETWORK
OVER SOUTHERN ONTARIO, 1973

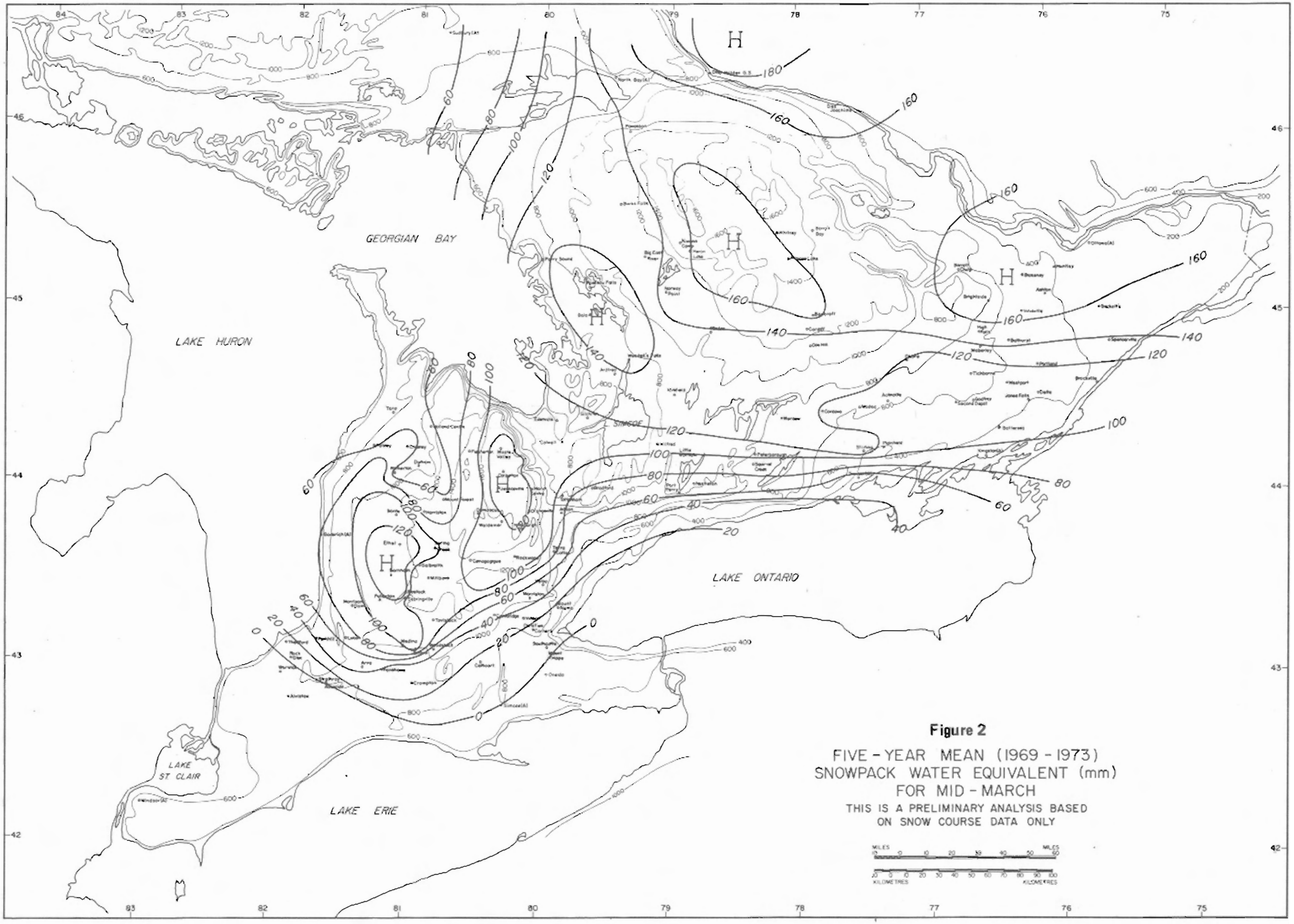

Figure 2

FIVE - YEAR MEAN (1969 - 1973)
SNOWPACK WATER EQUIVALENT (mm)
FOR MID - MARCH
THIS IS A PRELIMINARY ANALYSIS BASED
ON SNOW COURSE DATA ONLY

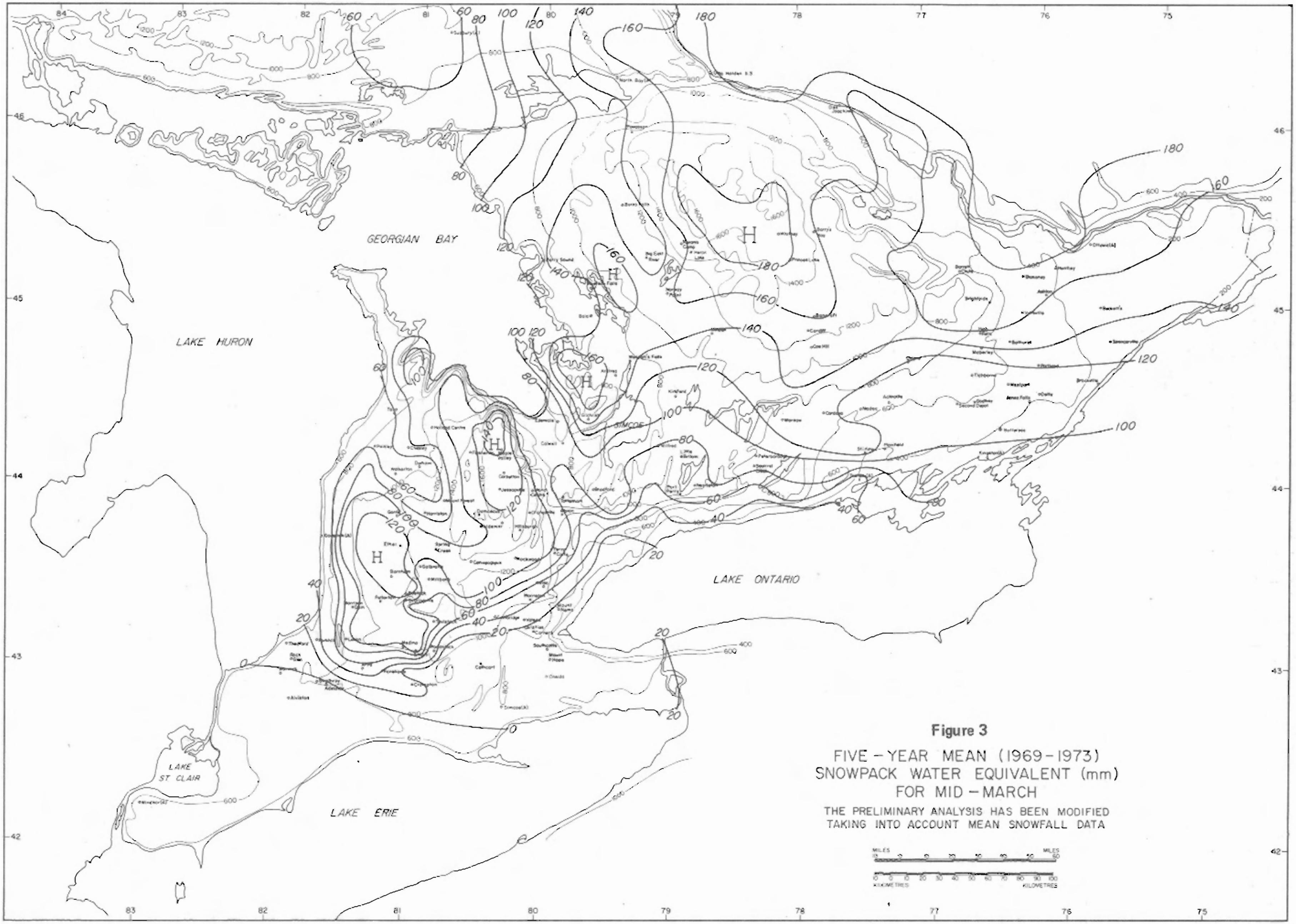

Figure 3

FIVE - YEAR MEAN (1969 - 1973) SNOWPACK WATER EQUIVALENT (mm) FOR MID - MARCH

THE PRELIMINARY ANALYSIS HAS BEEN MODIFIED TAKING INTO ACCOUNT MEAN SNOWFALL DATA

The final step (Fig.4) in the analysis of monthly patterns was to spatially smooth the distribution shown in Figure 3 using a 32km x 32km grid. This grid is shown in Figure 4 and its area corresponds to the average represented by one snow course in the study area. The mean density of the Southern Ontario snow course network is one course per 1024 square kilometres. This graphical differential analysis method tends to suppress local anomalies in the pattern. Such anomalies may occur when two courses which are relatively close together report relatively large differences in mean snowpack conditions. These anomalies are frequently due to local-scale variations in exposure and land use and should be smoothed out in regional analyses of the type we are concerned with here.

It will be noted that the main patterns of highs and lows are retained in the smoothed analysis. Also, it should be pointed out that a value interpolated at a point from Figure 4 represents the mean value over an area of $1024km^2$ around that point rather than a specific value for the point itself. Given the problems of representativeness and network density limitations, this approach seems very reasonable. For specific studies over small basins it is clear that denser networks may be needed and correspondingly smaller grids or smaller-scale analyses, taking account of local changes in exposure and land use, will have to be used.

Furthermore, the standard snow course is an average over a 275m distance, and as the study area becomes smaller, the area represented by each snow course becomes significant, so that the snow course reading in a very small basin can no longer be considered a "point value".

The above procedure was repeated for the five year mean snowpack water equivalent for mid-February (Fig.5). By comparing February and March distributions, a map showing change in snowpack water equivalent was constructed (Fig.6).

Net accumulation from mid-February to mid-March is characteristic in the highland regions of Southern Ontario while depletion zones show up along the shorelines of the Great Lakes south of 45°N. Although these distributions are constructed from spatially smoothed maps, similar results may also be determined using absolute values at individual network locations.

b) Comparison of Five-Year and Ten-Year Snowpack Water Equivalents

Table 1 presents five-year and ten-year mean snowpack water equivalents and the range over the ten-year period for the three months under study. Certain points are prominent. First, for both five and ten-year periods there are courses which consistently show an increase from February to March while the others show a decrease; this pattern of change corresponds well to the map drawn using the spatially smoothed values (Fig.6). Secondly, the ten-year means are significantly lower than the five-year means, even though the ten-year period includes data for those five years. This clearly reflects the well-known problem of achieving stability in normal values and indicates that the development of definitive normal maps requires a longer period of record than is currently available. The current mean maps, based on 5 or 10 years of record, should therefore be regarded only as reasonable estimates of long-term normal distributions.

Thirdly, the maximum and minimum snowpack water equivalents are both varied and extreme for different snow courses and for different months. By mid-March, wide extremes of range may exist for any single course, and thus wide deviations from the mean pattern may be expected in any one year. There is clearly a case to be made for examining median values (as has been done in many snow cover studies) as well as mean values, when the snowcover is intermittent, as it frequently is over Southern Ontario.

c) An Example of Data Interpretation Problems

Three snow courses of particular interest are Stirling (190m, 625ft),

TABLE 1

Comparison of 5 year (1969-1973) and 10 year (1964-1973) snowpack water equivalents (mm's) at selected locations in Southern Ontario

SNOW COURSE	LOCATION	5 YR MEAN			10 YR MEAN			MAX + MIN (10 YR PERIOD)		
		JAN	FEB	MAR	JAN	FEB	MAR	JAN	FEB	MAR
DES JOACHIMS	46°11', 77°42'	88	111	164	81	115	149	43-97	79-147	74-274
BARRETT CHUTE	45°15', 76°45'	92	149	168	65	113	127	0-127	43-218	43-272
HIGH FALLS	44°57', 76°36'	78	139	158	60	107	117	3-114	53-198	41-279
WASDELL'S FALLS	44°47', 79°18'	90	131	142	67	105	115	13-142	51-157E	46-201
STIRLING	44°16', 77°30'	100	188	123	81	141	81	61-180	64-310	0-300
PLAINFIELD	44°17', 77°21'	81	134	107	67	102	68	51-132	64-277	0-259
CORBETTON	44°10', 80°18'	101	117	125	81	92	90	25-127	36-132	0-198
WALDEMAR	43°54', 80°17'	79	110	109	64	86	76	23-122	30-127	0-163
TERRA COTTA	43°43', 79°57'	72	81	98	54	69	67	3-97	20-107	46-152
FANSHAWE	43°03', 81°11'	42	44	40	35	31	27	18-76	0-79	0-61
FULLARTON	43°24', 81°13'	106	126	111	85	94	73	30-163	0-188	0-147
GORRIE	43°55', 81°09'	105	113	105	86	85	75	36-150	0-145	0-157

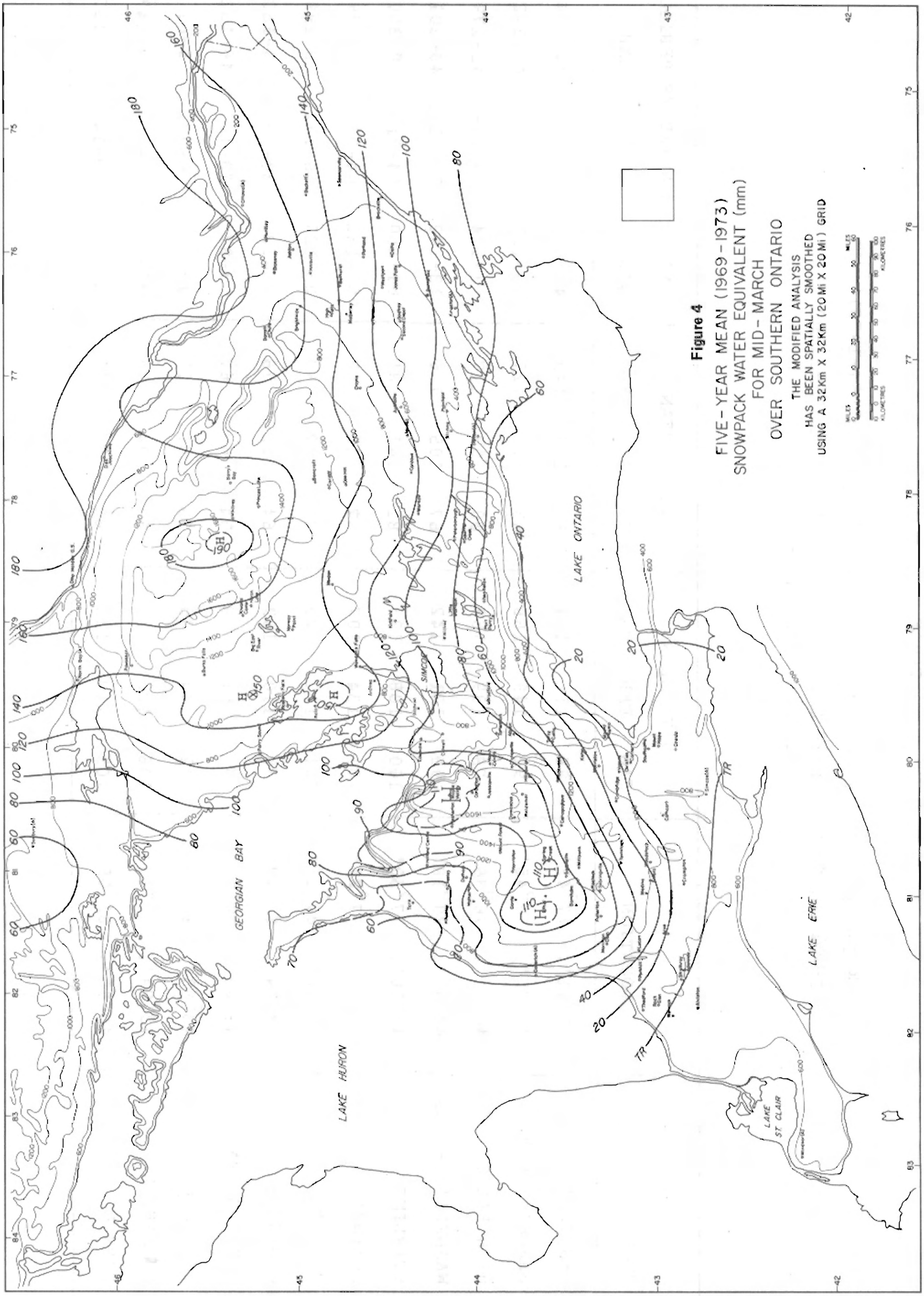

Figure 4

FIVE-YEAR MEAN (1969-1973)
SNOWPACK WATER EQUIVALENT (mm)
FOR MID-MARCH
OVER SOUTHERN ONTARIO

THE MODIFIED ANALYSIS
HAS BEEN SPATIALLY SMOOTHED
USING A 32Km X 32Km (20Mi X 20Mi) GRID

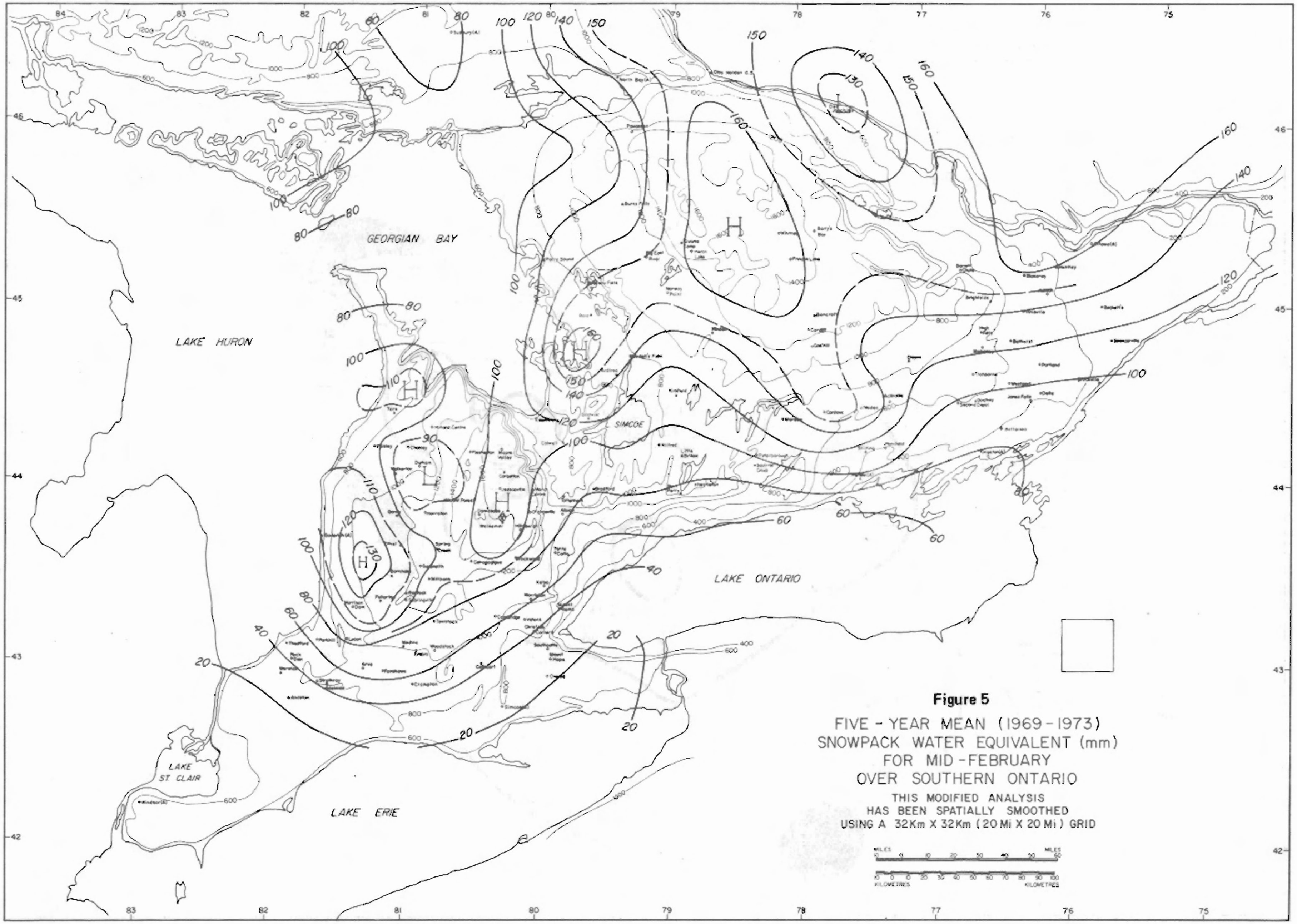

Figure 5

FIVE - YEAR MEAN (1969 - 1973)
SNOWPACK WATER EQUIVALENT (mm)
FOR MID - FEBRUARY
OVER SOUTHERN ONTARIO

THIS MODIFIED ANALYSIS
HAS BEEN SPATIALLY SMOOTHED
USING A 32Km X 32Km (20 Mi X 20 Mi) GRID

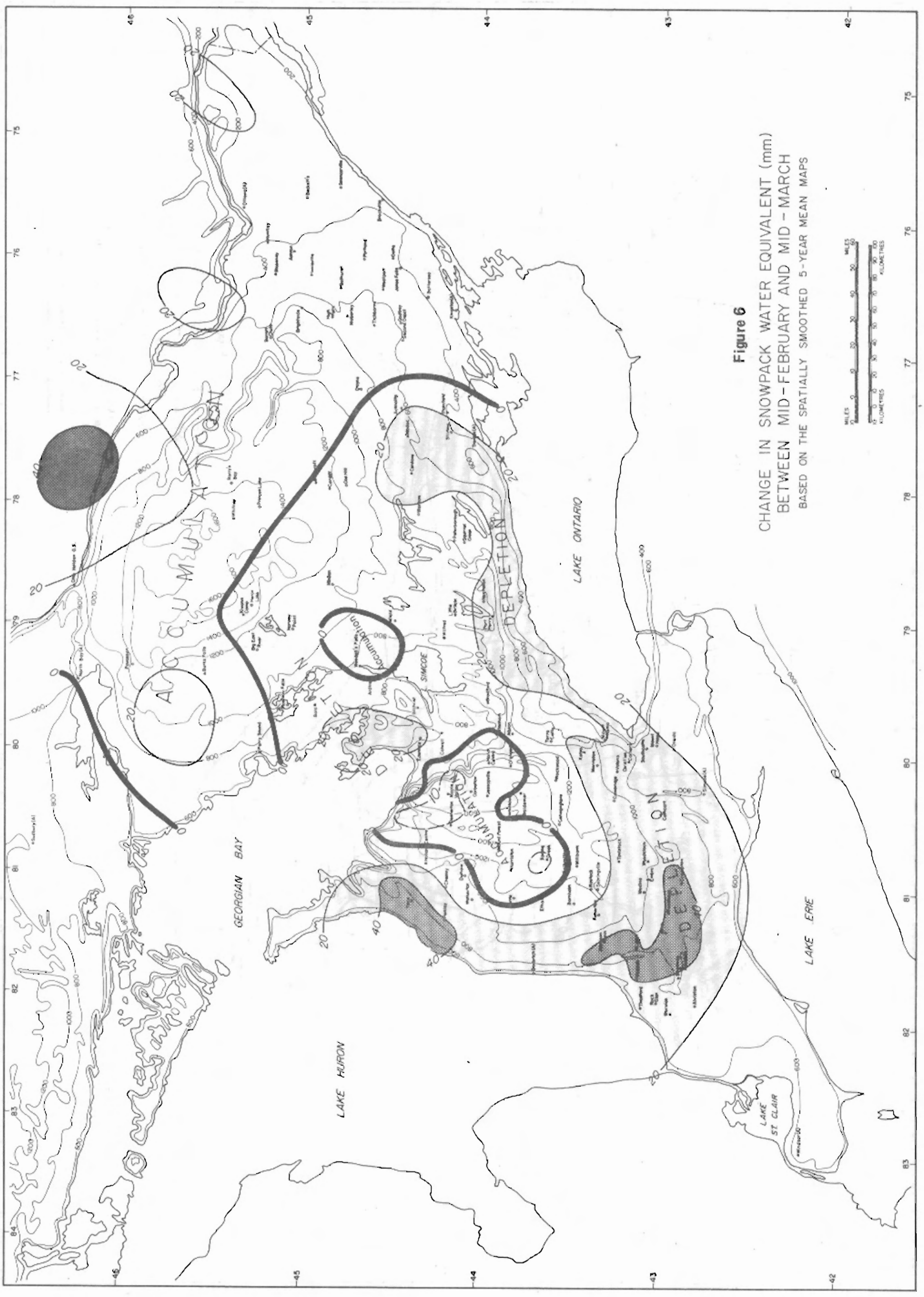

Figure 6

CHANGE IN SNOWPACK WATER EQUIVALENT (mm)
BETWEEN MID-FEBRUARY AND MID-MARCH
BASED ON THE SPATIALLY SMOOTHED 5-YEAR MEAN MAPS

Plainfield (107m, 350ft) and Trenton (81m, 266ft). Although they are located close together, Stirling indicates a consistently higher snow water equivalent than the other stations. This results in a pronounced isopleth gradient in this area. To what extent is each station representative of the general area? Are the gradients due to very localized variations in exposure and land use, or do they reflect meso-scale changes in climate?

Table 2 compares the long-term mean snowfall for Trenton and Stirling. Trenton receives more snowfall and more total precipitation. Both may receive rain during the winter period.

A more specific comparison is given in Table 3 which compares the Trenton and Stirling snow courses for 1972 and 1973. There are striking differences between 1972 and 1973 at the two stations, but in both years Stirling reported substantially more snow on the ground than Trenton. The two stations appear to represent an unusual situation in that the station reporting higher seasonal snowfall reports lower snowpack accumulations. It is possible that such an anomaly could be related to small but critical temperature variations (near $32^{o}F$), Trenton being the warmer station. It is clear that the development of regression equations relating snowpack conditions to snowfall, temperature, elevation and other variables may help to explain such apparent anomalies.

Another possible reason for such differences is vegetation irregularities. A given snow course may be located in an area having a different vegetative cover than the neighbouring snow course. Different vegetative covers may include bush, bush openings, long grass and scrub, long pasture grass, short grass, or ploughed fields. Differing exposure characteristics will significantly affect accumulation, redistribution and snowmelt characteristics. In any particular region any one or a combination of the above vegetative coverings may be "representative" of the area under consideration. While it may be possible to obtain information on regional land use or cover, there is generally no record available of the specific vegetation and exposure characteristics of individual snow courses. Therefore, it is not possible to assess the importance of these factors on the network variations, nor is it possible to interpret the snow water equivalent values in terms of regional land use and exposure features. It is felt that vegetation and exposure are critical variables and must be considered in snow course sampling and network design, yet there is little information available at present to allow adjustment of published data.

The effect of vegetation in an agricultural area may be seen in Figure 7. This photo was taken at Cold Creek Conservation Area near Bolton, Ontario on December 27, 1973. An initial rain-on-snow event and subsequent melt commenced on December 25, and ended on December 28 with the passage of a cold front. During this sequence long grass areas retained much of their snow while ploughed fields (in background of photo) and short grass areas lost much of their snow cover. Subsequent fresh snow fell on the basin and different snowpack water equivalents were obtained on the January 1 survey depending on which vegetation type was being sampled. In the Cold Creek Research Basin varying land uses and exposures are sampled in order to try to assess this problem more accurately. With no information on land use for the provincial network snow courses, one can readily see the difficulties in comparing varying water equivalent values of nearby stations.

Comparison of Gamma Survey Results and Snow Water Equivalent Maps for Southern Ontario, 1973

During the 1972-73 winter season an aerial gamma survey project was carried out over Southern Ontario. Details of the survey may be found in Loijens and Grasty (1973), Grasty, Loijens and Ferguson, (1974) and Loijens, (1974).

One of the aims of the present paper was to compare the mapped patterns of snowpack water equivalent over Southern Ontario with the gamma survey results. Figure 8 shows the distribution of snowpack water equivalent

Table 2. Comparison of long-term mean snowfall data for Trenton ($44^{\circ}07'$ N, $77^{\circ}32'$ W, 266 ft) and Stirling $44^{\circ}19'$ N, $77^{\circ}38'$ W, 455 feet)

Figures in brackets represent percentage of accumulated total precipitation which fell as snow

STATION	LONG-TERM MEAN SNOWFALL ACCUMULATED FROM DEC. 1 (cm)			
	Jan. 1	Feb. 1	Mar. 1	Apr. 1
TRENTON (266ft)	37.6 (47%)	86.9 (57%)	124.2 (58%)	149.1 (53%)
STIRLING (455ft)	32.8 (51%)	75.7 (61%)	112.0 (62%)	140.2 (59%)

TABLE 3. Comparison of Snow Cover and Snowfall Data for Trenton SC($44^{\circ}07'$N, $77^{\circ}32'$W, 266ft) and Stirling SC($44^{\circ}16'$N, $77^{\circ}30'$W, 625 feet)

Figures in brackets represent percentage of snowfall in total precipitation.

STATION	SNOWPACK WATER EQUIVALENT (mm)						SNOWFALL ACCUMULATED FROM DEC. 1 (cm)							
	1972			1973			1972				1973			
	Jan. 15	Feb. 15	Mar. 15	Jan. 15	Feb. 15	Mar. 15	Jan. 1	Feb. 1	Mar. 1	Apr. 1	Jan. 1	Feb. 1	Mar. 1	Apr. 1
TRENTON SC (266 ft)	MISG	53	99	TR	TR	TR	25.1 (28%)	75.7 (54%)	136.4 (61%)	181.6 (60%)	69.6 (53%)	82.3 (47%)	107.7 (48%)	109.2 (34%)
STIRLING SC (625 ft)	MISG	97	150	84	79	0	STATION				DISCONTINUED			

Figure 7. December 27, 1973, Cold Creek IHD Research Basin —
The Effect of Vegetation on Snow Cover in an Agricultural Area.

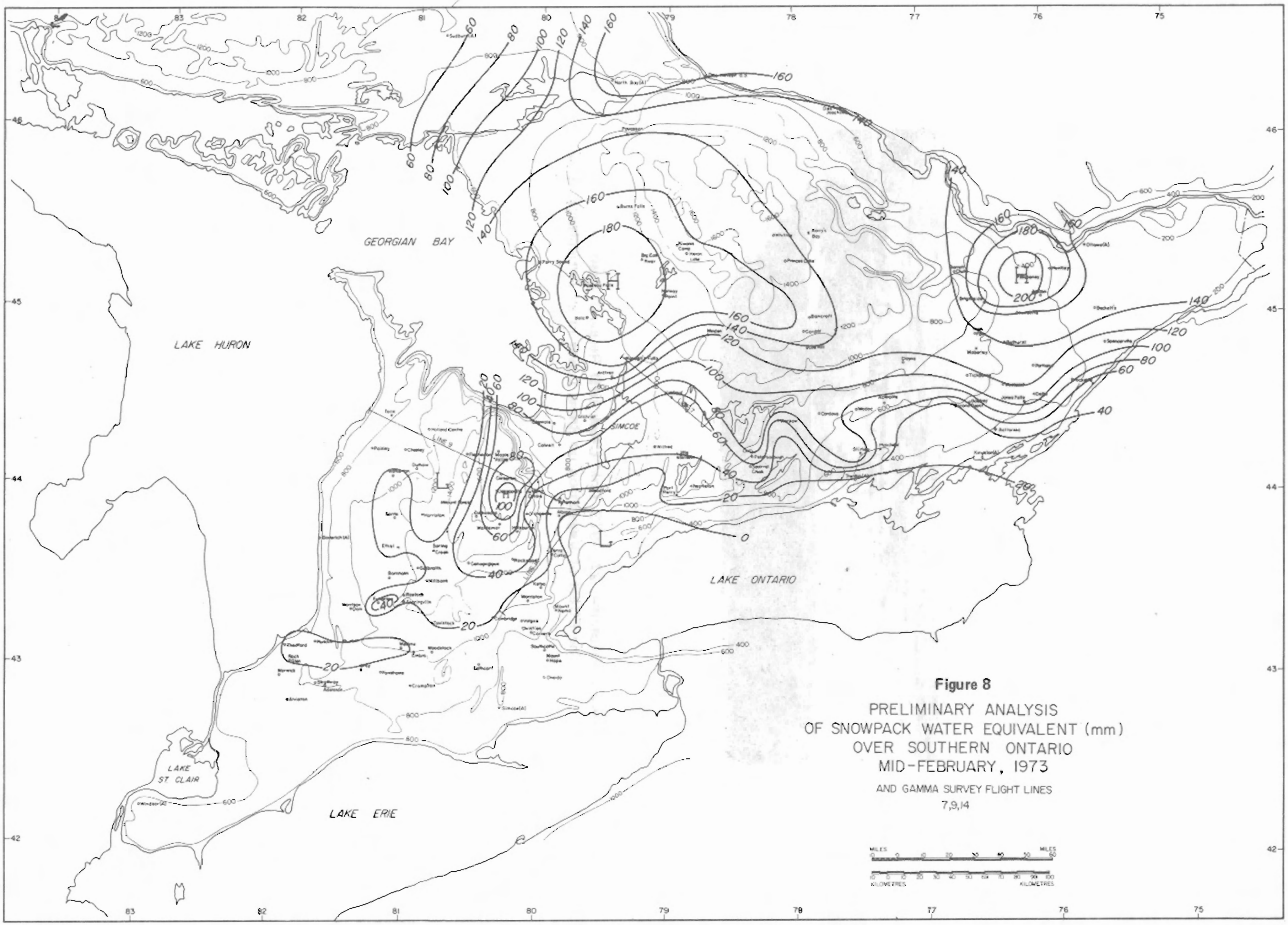

Figure 8

PRELIMINARY ANALYSIS
OF SNOWPACK WATER EQUIVALENT (mm)
OVER SOUTHERN ONTARIO
MID-FEBRUARY, 1973
AND GAMMA SURVEY FLIGHT LINES
7,9,14

over Southern Ontario for mid-February, 1973 based on surface network data. The pattern is somewhat similar to the mean five-year smoothed pattern of Figure 5, but absolute values were much less in Southwestern Ontario and along the margins of the Great Lakes. Above-normal accumulations will be noted east of Georgian Bay and near Ottawa. Naturally the 1973 survey shows more irregularities than the smoothed 1969-1973 pattern.

Superimposed on Figure 8 are three of the gamma survey lines. Figures 9, 10, and 11 compare gamma survey results along survey lines 7, 14, and 9 respectively with snowpack water equivalent totals determined from the mapped pattern of Figure 8.

Gamma flight line 7 (Figure 9) crosses an apparent gradient zone, but the aerial survey indicates generally higher snow water equivalent values than the mapped values. The snow courses on the flight track, where ground measurements were taken on the same day as the flight, differ markedly from the gamma results. It is not possible to say with certainty which method is more accurate.

Flight line 14 (Figure 10) passes over a rather non-descript zone. It transects a mapped zero line, which however is based on very little measured data. Does this zero line really exist in this area? The gamma survey suggests not, and in this case appears to provide more detail on the variations of snowpack water equivalent than is possible to determine from the map.

The most interesting comparison is along flight line 9 (Figure 11). From Lake Huron eastward, the first three snow courses report "patches of snow and ice" and a minimum value of 3mm water equivalent has been assumed to represent this reported snow cover. Probably the value is higher. At those specific points, the comparison is reasonable, but again the gamma survey appears to add information on variations in snow cover between snow courses which is not available from Figure 8 alone. Strong gradients on the Niagara Escarpment are shown both by the gamma survey and the map, but they do not correspond exactly. The gamma survey is probably more accurate in the positioning of the gradient, as the isolines could be redrawn using the same surface data to correspond more closely to the gamma survey results. From the above examples, it is clear that the gamma survey provides information where there is a lack of ground survey data, and also provides detail as to positioning of pronounced gradient zones and areas of no snow cover. However, considering the accuracy and limitations of both techniques, the methods of survey necessarily complement each other with respect to the information they provide. It seems likely that some judicious combination of mean surface data, current surface data and gamma survey data could be formulated to provide an optimum analysis of snow cover over a given region at a given time. This would make the best use of all available information.

Future Research

Due to the limited time base and gaps in the network the mean snow cover maps presented in this paper should be regarded as preliminary. Figure 12 provides an indication of variations in snow course network density relative to the average for the whole region. It should be noted that all network snow courses have been included; in some cases only one observation is taken per year, which is of limited use for monthly climatological analysis.

Work is in progress to improve the mean maps by developing regression equations for mean monthly snow cover based on snowfall, temperature, elevation and other physiographical and climatological variables. Such work should also provide insights into climatological aspects of snowpack accumulation and ablation processes and the relationships between micro - and meso-scale snow cover patterns.

When work has been completed on the climatological mean maps, they

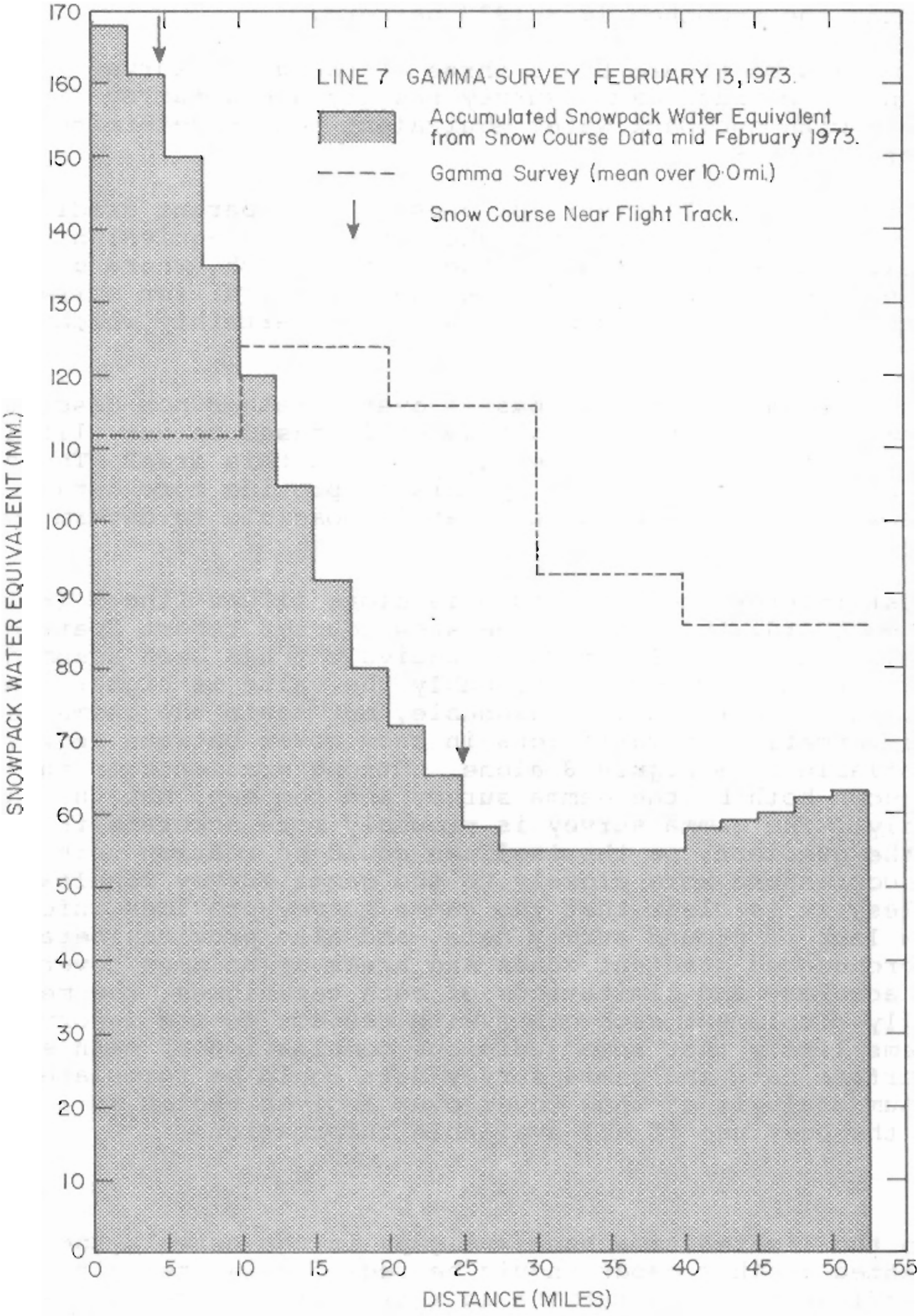
LINE 7 GAMMA SURVEY FEBRUARY 13, 1973.
Accumulated Snowpack Water Equivalent from Snow Course Data mid February 1973.
Gamma Survey (mean over 10·0 mi.)
Snow Course Near Flight Track.
SNOWPACK WATER EQUIVALENT (MM.)
170
160
150
140
130
120
110
100
90
80
70
60
50
40
30
20
10
0
0
5
10
15
20
25
30
35
40
45
50
55
DISTANCE (MILES)

Figure 9

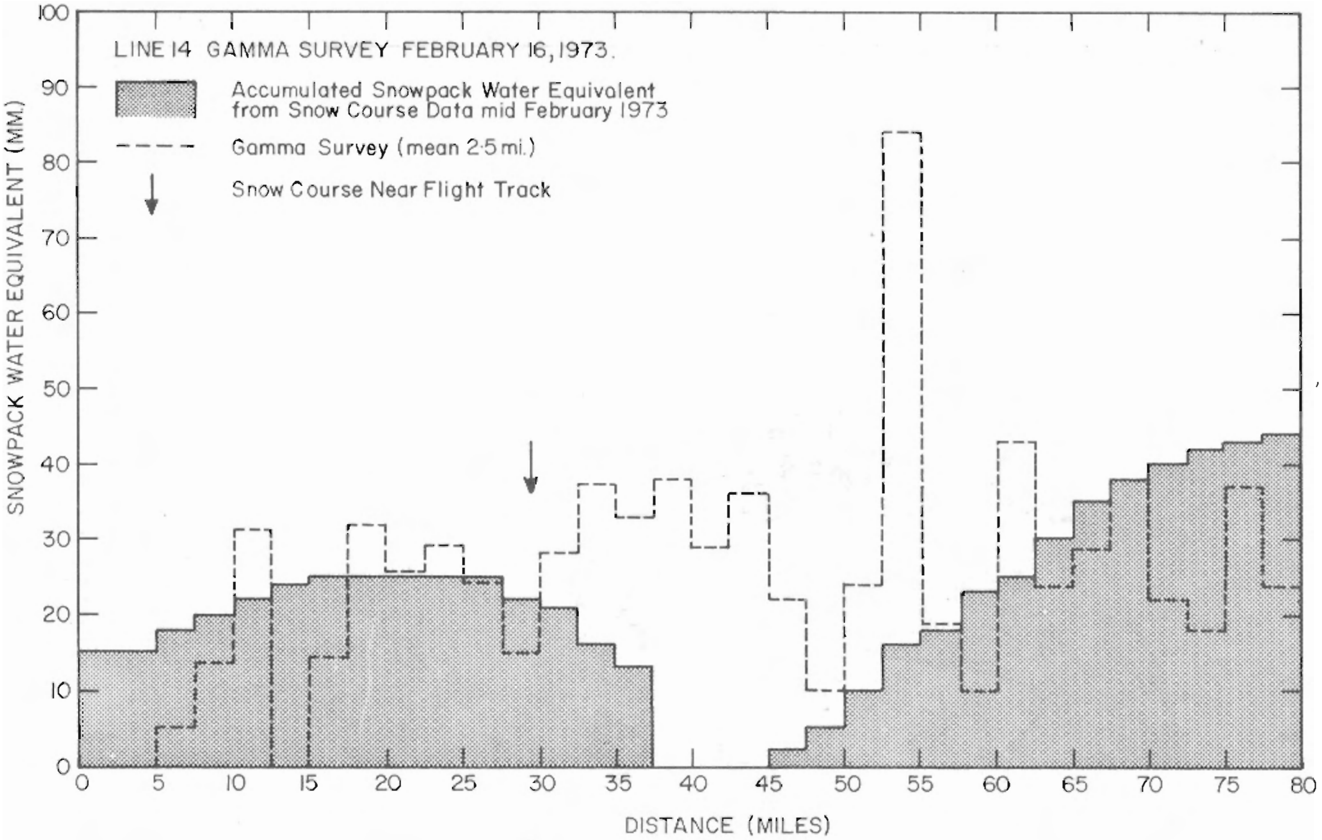

Figure 10

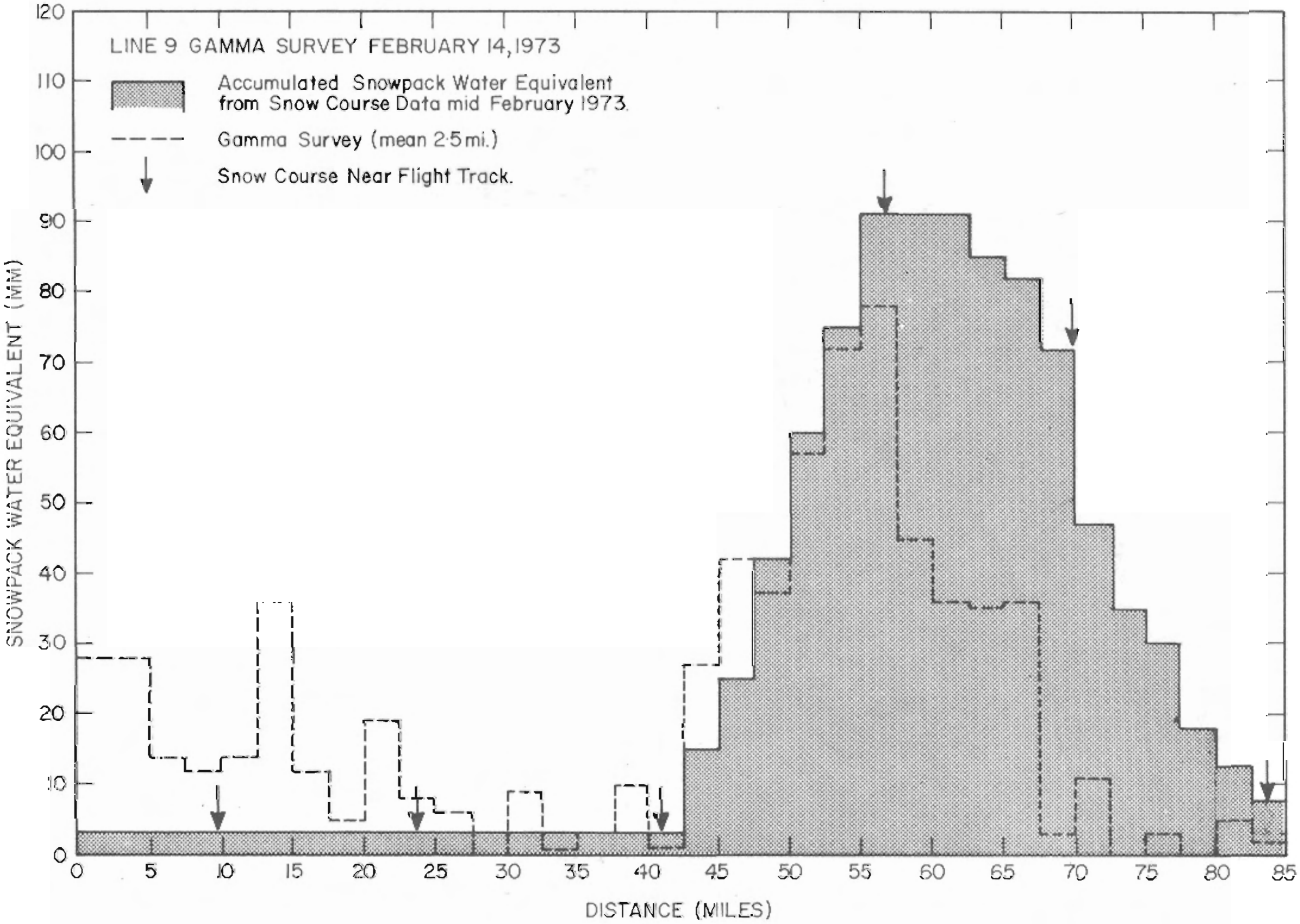

Figure 11

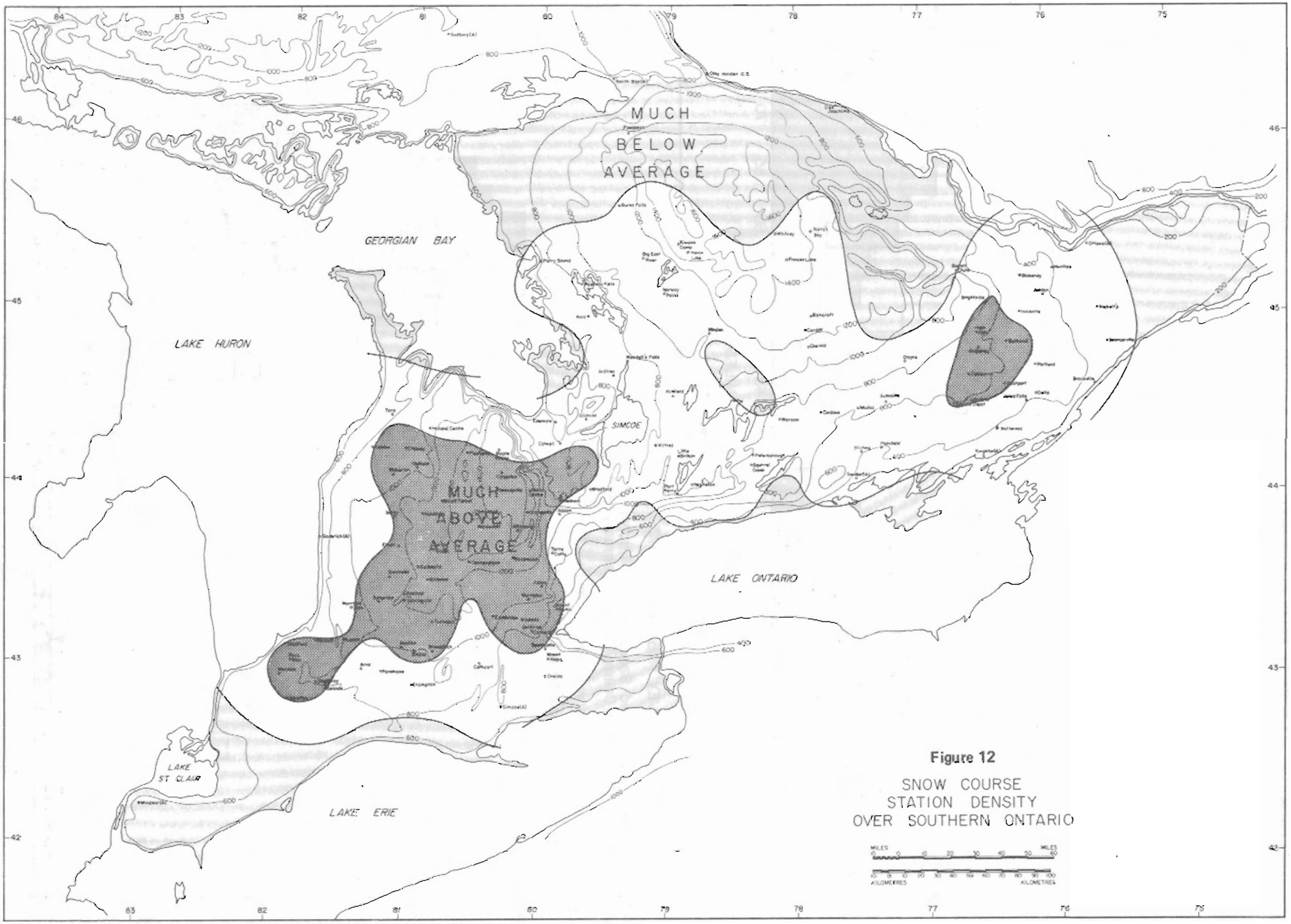

Figure 12

SNOW COURSE
STATION DENSITY
OVER SOUTHERN ONTARIO

can be used as a basis for analyzing synoptic snow cover maps for a specific date. The suggested procedure is to apply available computer interpolation programs to the observed deviations from normal, and add the resultant field to the mean to obtain the synoptic snow cover map. Techniques are available for obtaining computer maps in either grid-square or isoline formats.

Summary of Problems and Recommendations

The following are significant problems in using and interpreting published Snow Cover Data as a basis for developing climatological and synoptic maps of snow cover water equivalent over Southern Ontario:

1) Areas of sparse network density.

2) Insufficient frequency of observations at some snow courses.

3) Missing or inadequate data. The published record does not distinguish between a trace, zero snow cover and a missing observation.

4) Lack of information on the type of equipment used.

5) Errors in published locations of snow courses. (Corrections noted to date are listed in Appendix I)

6) Lack of detailed information on the vegetative cover and exposure at snow course sites.

The last problem makes it very difficult to interpret anomalies (such as very large differences between neighbouring courses) in a rational fashion.

Participating agencies should consider the following possibilities for improving the usefulness of published network snow course data:

1) There should be a review of recent published data to ensure, for example, that the names of snow courses, their locations, elevations, and other information are correct. Agencies collecting the data should routinely review and check the information and pass corrections on to the Atmospheric Environment Service.

2) A catalogue of snow course site descriptions and a sketch or photo might be compiled for reference by users of Snow Cover Data. Both a summer and a winter photo would be useful. These descriptions should be reviewed and amended by the data collection agency when:

i) The snow course is moved (even a short distance).

ii) Land use changes significantly - this may occur from year to year or over a period of years.

3) Standardization insofar as possible of observing procedures would be very useful, specifically in regard to:

i) Frequency and dates of surveys. Some agencies sample only once a year. This is not very useful for purposes of snow-pack metamorphasis studies and climatological analyses. The ideal would be to have all courses read once or twice monthly on fixed dates from November through April.

ii) Equipment. At least the type of sampler used for each observation should be identified.

iii) Design of courses; number of points, etc.

iv) Reporting of observing problems (e.g., ice which cannot be penetrated) which make the observations doubtful, either over a season or on a particular survey date.

v) Distinguishing between missing observations, zero snow cover or patchy snow cover. This is a serious problem which can be easily rectified by co-operation between the co-operating agencies and the Atmospheric Environment Service. At present the published data do not distinguish between these three cases, even if the co-operating agency does.

vi) Design and standardization of reporting forms. This would simplify tabulation, reporting and publishing of the data.

A meeting of representatives of the co-operating agencies in Southern Ontario to discuss these recommendations would be highly desirable. While we have dealt specifically with Southern Ontario, similar difficulties exist in other regions. The Eastern Snow Conference may have an interest in participating in such a meeting, since some standardization of procedures, reporting formats, etc., across Eastern Canada and the Northeastern United States would be worthwhile.

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Correction of Snow Course Locations

Station	1971-72 Published		Corrected	
Sebringville	43°42'	81°01'	43°24'	81°01'
Oneida	43°02'	80°58'	43°02'	79°57'
Cathcart	43°06' (ELEV. 875')	80°27'	43°07' (ELEV. 835')	80°27'
Tee Lake	46°46'	79°04'	46°46'	79°02'
Spencerville	44°51'	76°33'	44°51'	75°32'
Tichborne	44°14'	76°41'	44°43'	76°41'
Godfrey	44°34'	76°39'	44°34'	76°41'
Ashton	44°09'	76°04'	45°09'	76°04'
Battersea	44°25'	76°39'	44°26'	76°25'
Nestleton	49°09'	78°48'	44°09'	78°48'
Powassan (relocated Dec/71)	46°05'	79°22'	46°04'	79°25'
Barry's Bay	45°29'	77°41'	45°31'	77°54'
Bancroft (relocated Nov/73)	45°04'	77°52'	44°59'	77°58'

In addition Heron Lake at 45°25'N, 78°50'W is also listed as Huron Lake in a different basin. Huron Lake is incorrect. The basins are: Heron-Muskoka; Huron-Madawaska. The Jessopville snow course was not used in the analysis because of consistent abnormally high snow water equivalent values. This was done on the advice of the collecting agency.