~~Bull 4/1~~

~~O.W.R.C.~~
~~Water Resources~~
~~Climatic Series~~

Water management in Ontario

Ontario
Water Resources
Commission

Water Resources
Bulletin 4-1
Climatic series

Ont
Environ
Water res

SNOW SURVEY REPORT

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN 1968—1969

IHD 1965 INTERNATIONAL HYDROLOGIC DECADE CANADA
CANADA DÉCENNIE HYDROLOGIQUE INTERNATIONALE 1974 DHI

WATER RESOURCES
BULLETIN 4-1
Climatic series

SNOW SURVEY REPORT

EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN

1968—1969

By
L.A. Logan

ONTARIO WATER RESOURCES COMMISSION

DIVISION OF WATER RESOURCES

TORONTO ONTARIO

1971

TABLE OF CONTENTS

ACKNOWLEDGEMENT

The snow survey program is being carried out as part of the hydrologic studies being undertaken by the River Basin Research Branch of the Division of Water Resources.

Mr. D. Puccini, Engineer, established the snow survey network; collection of data and the preparation of a preliminary draft snow survey report was carried out by Mr. A. Sweetman, Engineer, with the assistance of Mr. D. Donohue, Technician of the River Basin Research Branch.

ABSTRACT

Snow-cover investigation in the East and Middle Oakville creeks drainage basin is one of several phases of hydrologic studies being carried out by the Division of Water Resources, Ontario Water Resources Commission, as part of its International Hydrological Decade representative basin program. The snow survey data collection program, initiated in the winter season of 1968-1969, forms part of a precursory study for arriving at acceptable hydrologic parameters for use in evaluating general water balances in the basin. The established sampling network facilitated the collection of an adequate quantity of data, for use in estimating basin snowpack index water equivalents and the extent of snow cover in the specific areas. The gravimetric method of sampling employed provides the measurements of snow depth, core length and weight measurement of equivalent depth of melt water. Statistical evaluation of the data established the accuracy and reliability of the sampling, the acceptable quality of the data and the adequacy of the designed network. Further reliability and consistency of the data were ascertained through a simple linear regression, with verification that under the prevailing conditions of the investigation, the gravimetric technique was adequate for providing sample estimates of the snowpack water equivalents. The adequacy of the sampling network was substantiated by the comparison of estimates of the basin snowpack indices determined by different methods of data evaluation.

SNOW SURVEY REPORT
EAST AND MIDDLE OAKVILLE CREEKS DRAINAGE BASIN
1968-1969

INTRODUCTION

The Ontario Water Resources Commission initiated the study of winter precipitation and snow cover in the East and Middle Oakville creeks International Hydrological Decade (I.H.D.) representative drainage basin in the winter of 1968. The drainage basin, located in southern Ontario, covers an area of 76 square miles. Its boundaries extend approximately between 79° 45'W and 80° 0'W longitude and 43° 20'N and 43° 38'N latitude. The topography has moderate slopes, with increased surface undulations in the most elevated areas. The elevation ranges from 1,200 feet above sea level at the main stream source to 600 feet above sea level at the lowest streamflow gauging station. Approximately 28 per cent of the drainage area is enclosed between elevation 800 feet and 1,200 feet above sea level. The vegetative covers are predominantly crops and pastures, with sparse distribution of improved and unimproved forested areas.

Snow accumulation and complete areal snow cover are normal events in the basin for three to five months of the year. From the condition of the snowpack (accumulated snow), a measure of the winter precipitation amounts in the basin can be estimated.

An approach towards providing estimates of the basin snowpack conditions at a given time is by way of snow survey investigations. Snow surveys are normally carried out by way of data collection from a sampling network comprised of a number of snow courses. The gravimetric method, which entails weight measurements of core samples from the snowpack, is one of several sampling techniques employed for obtaining the data necessary for evaluating the basin snowpack condition. This sampling technique provides an estimate of the areal extent of the basin snow cover, an indication of the trend of snow accumulation and depletion, and an index of the basin runoff potential from snowmelt.

This report deals with preliminary analyses for the evaluation of the data collected from the first of a series of seasonal snow survey investigations. Subsequently, the data will be used in analyses of runoff and water balances in the basin.

OBJECTIVES

The basic objectives which characterize the snow survey investigation may be summarized as follows:

1. To determine the point values of the snowpack depth, water equivalent, core length, and density for all the selected snow courses in the drainage basin.
2. To determine the uniformity of snow cover on each snow course and the adequacy of representation of the basin snow cover in the designated areas.
3. To evaluate the comparative reliability and quality of the individual point measurements, as well as the relative reliability of the data between the snow courses.
4. To determine and establish, by a practicable and reliable method, satisfactory precipitation storage estimates or hydrologic input indices for the drainage basin for the winter precipitation period.

BASIC CONCEPTS

The density of snow may be defined as the ratio between the volume of melt water from a given sample of snow and the initial volume of the sample (7)*. For a given snowpack, the density is known to vary widely with time, to vary directly with depth and stratification of the pack, and to exhibit areal variability within a region of snow accumulation (1, 4, 5, 9, 14).

The gravimetric method of sampling attempts to provide direct estimates of an index of the water stored in the snowpack. From a number of point measurements of snow depth and water equivalent (equivalent depth of melt water, as determined from the weight of the sample), an integrated average of the snowpack water equivalent and density may be determined (4, 5, 7).

By operating with the above-mentioned basic relationship between the snowpack indices (depth, water equivalent and density) and with the support of a number of apparent assumptions, the quality and reliability of the data collected may be evaluated analytically.

---

* References in Bibliography

Assumptions

Snow deposition on a drainage basin is known to be heterogeneous in distribution (5, 13) . It is, therefore, necessary to be aware of the limitations of the method of sampling employed. The successful use of the gravimetric method in this investigation is subject to a number of limitations. The main purpose for the summarized assumptions given below is to facilitate meaningful and rational physical interpretations of the analysed data. The following are assumed:

1. The selected sampling network provides a sufficient number of samples for reliable estimates of the basin snowpack indices.
2. The large-scale effects of the regional orographic factors (elevation, exposure, rise and orientation) with respect to storm experiences in the basin are general for all locations.
3. The nature of snow deposition and distribution at a selected site is influenced entirely by the combined effects of the local terrain parameters or environmental factors, such as vegetation, ground slopes, aspects and degree of protection from the wind.

4. The average density of the snowpack determined from the simultaneous point measurements of depth and water equivalent, on a particular date, represents a constant for the basin at that time period.
5. The point measurements taken from the snowpack on a particular survey represent a statistical sample drawn at random from a normal finite population.

Statistical Procedures

Statistical procedures can be used to evaluate the accuracy and limitations of the point measurements and the reliability and quality of the data for use in obtaining basin snowpack index water equivalents.

By accepting the assumption of normality and randomness of a sample, bias introduced into the data by selective sampling is neglected; hence, the sampling errors and variations of a sample may be determined by application of standard statistical equations (6, 8, 11) of the forms:

$$\bar{X} = \frac{\sum_{i=1}^{N} X_i}{N}, \qquad \ldots (1)$$

$$S = \left[\frac{\sum_{i=1}^{N} (X_i - \bar{X})^2}{N-1}\right]^{\frac{1}{2}}, \qquad \ldots (2)$$

$$C = \frac{S}{\bar{X}}, \qquad \ldots (3)$$

$$S_{\bar{X}} = \frac{S}{\sqrt{N}}, \qquad \ldots (4)$$

where: $\bar{X}$ = sample average;

X_i = i^{th} point measurement;

S = standard deviation;

N = number of observations;

C = coefficient of variation;

$S_{\bar{X}}$ = standard error of average;

i = 1, 2, 3 ... , N observations.

The errors associated with each sample average may be determined and examined from confidence limits specified by given probability levels. The confidence interval for the population average, μ, for depth or water equivalent, may be determined from the general expression:

$$\mu = \bar{X} \pm t_{0.05} S_{\bar{X}} \quad , \qquad \ldots (5)$$

where $t_{0.05}$# is the value of the standard normal deviate at the five per cent probability level for (N-1) degrees of freedom (6, 8, 11, 12) .

By operating with the stated assumption that the average density of the snowpack is a constant at a specific time, tests for consistency and reliability of the data can be carried out by an examination of the statistical association between the measured depths and water equivalents. These tests can be applied to data collected on a particular date from a snowpack of a given areal extent. The statistical association between the two variables was derived from a developed empirical function based on an assumed linear regression (8, 11, 12) . Water equivalent, W, is the dependent variable and depth, D, the applied independent variable. By using the least-square technique with the added assumption that the origin of the line is at the point of averages (11, 12) , the derived function is of the form:

$$W_c = A + bD \quad , \qquad \ldots (6)$$

in which

Standard table of 't'-distribution.

$$b = \frac{\sum_{i=1}^{N} (W_i - \bar{W})(D_i - \bar{D})}{\sum_{i=1}^{N} (D_i - D)^2} \qquad \ldots (6a)$$

and

$$A = \bar{W} - b\bar{D}, \qquad \ldots (6b)$$

where W_c is the predicted estimate of the water equivalent, b the regression coefficient (an estimate of the defined constant density), A the intercept on the ordinate. In the case of the regression treatment, the least-square derivation for the empirical function obviates the assumption of a type of distribution or randomness of the data.

The regression is distributed with a residual variance estimated by:

$$S_e^2 = \frac{\sum_{i=1}^{N} (W_i - Wc)^2}{N-2}, \qquad \ldots (7)$$

where S_e is the standard error of estimate.

The corresponding variance associated with the regression coefficient may be estimated by:

$$S_b^2 = \frac{S_e^2}{\sum_{i=1}^{N} (D_i - \bar{D})^2}, \qquad \ldots (8)$$

where S_b is the standard error of the regression coefficient.

Due to practical knowledge of the nature of the variables, the line of regression may be forced through the origin, that is, for $D = 0$, $W = 0$. Equation (6b) gives an estimate of this condition for the population with estimated variance:

$$S_A^2 = S_e^2 \left[\frac{1}{N} + \frac{\bar{D}^2}{\sum_{i=1}^{N} (D_i - \bar{D})^2} \right] , \quad \dots (9)$$

where S_A is the standard error of the intercept.

The practical significance of the regression may be determined by the coefficient of determination:

$$r^2 = 1 - \frac{S_e^2}{S_W^2} , \quad .25 \leqslant r^2 \leqslant 1.0 , \qquad \dots (10)$$

where r is the coefficient of correlation and S_W is the standard deviation of the water equivalent. Equation (10) indicates that if the computed value of r^2 is greater than or equal to .25 then the regression may be regarded as practically significant (11, 12) .

A test of linearity of the regression, based on the 'F'-distribution, is given by the general form:

$$F = \frac{S_R^2 / 1}{S_e^2 / (N-2)} , \quad P(F(1, N-2) > F') \leqslant .05, \qquad \dots (11)$$

where $S_R^2 = S_W^2 - S_e^2$ is the variance accounted for by the regression. Equation (11) indicates that the linear regression may be regarded as significant if the computed F-value is greater than or equal to the corresponding F-value (F') determined from a standard table of 'F'-distribution (8, 11) for the defined degrees of freedom (1, N-2) at a given probability level ($P = .05$).

The confidence interval on the population regression coefficient, β, may be obtained by replacing μ, $\overline{X}$, and $S_{\overline{X}}$ in equation (5) by β, b, and S_b, respectively; similarly for the population intercept, α, the confidence interval may be obtained by replacing μ, $\overline{X}$, and $S_{\overline{X}}$ by α, A and S_A, respectively. The value of the standard normal deviate remains at $t_{0.05}$, in this case for (N-2) degrees of freedom.

FIELD INVESTIGATION

With the aid of a topographic map of the basin, a desirable number of snow courses were selected by way of an elimination process through field surveys and site investigations. The implementation of a designed sampling program facilitated the collection of a desirable quantity of data which were necessary for the network evaluation. The sampling equipment employed were the conventional tube-type snow samplers (2, 3, 7, 10).

Snow Survey Network

The survey network consists of eight snow courses. The basic criteria for selecting these snow courses were basin topography and vegetative cover. The unique location of the drainage basin within a larger geographic region and the relatively graded, uniform topography supported the acceptance of the assumption of the large-scale effect of the regional orographic factors with respect to storm experiences in the basin. Operating with the above-mentioned criteria and assumption, eight snow courses were selected throughout the range of topography and major types of vegetation in the basin. The locations of the selected sites are shown on Map 1 of Appendix I.

The selection of the individual sites for each snow course was directed by accepted guidelines (3, 5, 10), including conditions such as well-sheltered area, well-drained site on clean litter or soil free from stumps or debris, uncultivated, and a readily accessible location. A standard snow course consists of ten sampling points with spacing of 100 feet in a straight line. Changes in local ground slopes and limited property boundaries necessitated some modifications in layout at a few sites. Figures 1 to 8 of Appendix I are diagrammatic sketches of the individual site layouts.

The network density was approximately one snow course per 9.5 square miles.

Snow-Sampling Equipment

Two types of snow-samplers were employed, the Mount Rose sampler and the MSC Type-I sampler. Each sampler consists of a duralumin tube, with a saw-toothed cutter as an integral attachment at one end. The toothed cutter allows for easy insertion of the tube into the snowpack. Each tube has graduation in inches on the outer surface which provides for depth measurement to the nearest 0.1 inch. The unit length of each Mount Rose sampler tube is 42 inches with an inside diameter of 1.485 inches. The length of the MSC Type-I sampler tube is 43 inches with an inside diameter of 2.785 inches.

A tubular extensible spring balance was provided with the samplers for obtaining a direct estimate of the equivalent depth of melt water in each sampled core by weighing. The balance has two separate scale calibrations, one for each sampler. Unit calibrations, weight = 1.0 ounce, for the Mount Rose sampler and weight = 3.5 ounces for the MSC Type-I sampler, are equivalent to a snowpack water equivalent of 1.0 inch. The Mount Rose sampler was recommended for sampling in a very deep powdery snowpack, while the MSC Type-I was recommended for sampling in shallow and less powdery snow (3) .

Other accessories were a wire cradle for suspending the tube on the balance, a turning and driving wrench for operating the sampler, spanner wrenches for assembling tube units of the Mount Rose sampler, cleaning tools and carrying cases.

Data Collection

Prior to the expected winter precipitation period, each selected snow course was prepared for observation. Preparations involved checking and staking the designed layout and clearing tall grasses and debris from within a radius of five to ten feet of each staked point.

It was planned to commence snow surveys when snow had accumulated to an estimated depth of two inches in the basin, but the first major snowfall occurred in early January, 1969, with an accumulation of greater than twelve inches. Snow surveys commenced immediately after this major storm event. Subsequent surveys were done at least once every two weeks.

Point measurements obtained at each of the ten sampling points on each snow course were: snowpack depth, water equivalent and core length. Each core sample was obtained by inserting the tube sampler into the snowpack, held normal to the ground slope and driven to the full extent of the snowpack depth. Table 1 of Appendix I shows a compiled, sample, snow survey data report sheet. Notes were made on the visual appearance of average conditions of the snowpack (e.g. presence or absence of crust and ice layers) and of the soil condition beneath the snowpack (e.g. frozen or moist). A summary of the data collected is given in Table 2 of Appendix I. These are averages of the respective ten-point observations, with the corresponding average snow density on each snow course.

During the initial survey, the Mount Rose sampler was employed for sampling in the deep powdery snow; the MSC Type-I sampler was employed during all subsequent surveys. Observational errors were kept at a minimum by strict adherence to the measurement procedures. Special efforts were made to minimize the wind effect on the spring balance during the weighing operations.

SNOW COURSE EVALUATION

The snow courses were compared and evaluated on the basis of the variability in accumulation. The variations about the average snowpack indices were determined statistically and used as measures of the snow cover uniformity on the respective snow course. A good to near excellent snow course would have the least variation about each sample average snowpack index.

The standard deviation and coefficient of variation were computed for each sample size by applying the standard equations (1) to (3) on page 7. Tables 1, 2, 3 and 4 of Appendix II show the computed averages and respective deviations for snow depth, water equivalent, core length, and density on each snow course. The analysis was done for each survey for the period of snowfall. The effects of the local terrain parameters on snow deposition appeared to be more appreciable during the accumulation period. It is believed that the terrain parameters impart similar effects to precipitation experiences, snow as well as rain, in the basin. These effects on snowfall are the more pronounced during the snow accumulation period. On the other hand during the major snowmelt period, the expected differences in melt rates on different areas of the basin would introduce variations in the data not accounted for by the effect of terrain parameters on snow deposition. The data from this melt period were therefore omitted from this analysis.

Single-Index Ranking

Field experiences gained in sampling the snowpack showed that the possible observational errors associated with the measuring of the snowpack indices were the least for snow depth. Consequently, for practical purposes, snow depths were regarded as the most accurately measured values. This condition therefore qualifies depth as the most suitable, single index for use in comparing snow cover variability within and between courses. The variability was assessed by an examination of the series of coefficients of variation of depth. Table 5 of Appendix II shows the snow courses ranked according to the increasing order of magnitude of the variation coefficients. The table was derived by summing the ranks of each snow course for the four survey periods; the group totals were then re-ranked to give the most uniform course (highest rank 1) and the least uniform course (lowest rank 8). An examination of the results showed that snow course number 8 acquires the highest rank and snow course number 4 acquires the lowest rank, indicating that the snow cover was the most uniform in depth on snow course number 8, and least uniform in depth on snow course number 4 for the specified accumulation period. This deduction compares reasonably with field observations; that is, snow course number 8 satisfied most of the basic selection requirements for a good snow course, whereas snow course number 4 was noticeably the least sheltered. Snow courses number 2, 5, and 6 had comparable uniform depth of snow cover, and courses number 1, 3, and 7 had fair to poor coverage.

Multiple-Indices Ranking

In order to test further the degree of variability summarized by Table 5 of Appendix II, a multiple ranking procedure was carried out for all the snowpack indices. Table 6 of Appendix II gives a summary of the multiple ranking. The indices for water equivalent, core length, and density were ranked similarly to depth (Table 5 of Appendix II). The grouped totals for each index were summed and the grand totals were then re-ranked. The result did not differ significantly from that of the single-index ranking. An examination of the results showed that the depth of snow cover on snow course number 4 was undoubtedly the least uniform. Using both forms of ranking, the same snow courses can be divided into two major groups. The first group, snow courses number 1, 2, 5, 6 and 8 can be regarded as the more representative of the basin cover. These courses were located in the areas of ideal orientation and exposure to all forms of precipitation. The second group, snow courses number 3, 4, and 7 were less representative, consisting of courses that were the least sheltered and thereby were subjecting the snow cover to substantial amounts of wind drift.

SNOW DEPTH AND WATER EQUIVALENT

For the purpose of a group evaluation of the data, all of the point measurements from a particular survey were grouped in one sample analysis, excluding data from courses with poor measurements ($<$ 50 per cent snow covered). A simple computer program*, based on equations (1) to (11) of pages 7 to 10, was utilized to perform the statistical analysis. The results of the analysis facilitated an examination for the areal variations inherent in the snow cover distribution on the drainage basin and the degrees of confidence and accuracy placed on the data for use in obtaining overall averages of the basin snowpack condition. The empirical relationships determined were examined for their practical and statistical significance as a basis for establishing data reliability and consistency.

Areal Variability

The sampling errors and variability of the snowpack condition in the drainage basin were determined from each group of data, analysed by equations (1) to (4). Tables 1 and 2 of Appendix III summarize the results

---

* QUIKTRAN System - IBM Digital Computer

of the analyses.

The coefficients of variation of depth (Table 1 of Appendix III) indicated a progressive increase in values from .209 for the initial survey, to .957 for the survey on February 26, 1969. Similarly, for the water equivalent, the coefficient of variation (Table 2 of Appendix III) ranges from .139 to 1.014 for the same respective time period.

The extent to which a measure of confidence could be placed on the data, with such large variations, was determined from equation (5); that is, equation (5) gives a measure of the confidence limit or interval associated with each estimate of the basin average depth or water equivalent. For example, applied to Table 2 of Appendix III, the confidence interval on the population average water equivalent for the initial survey period, would be given by $2.8 \pm .043\ t_{0.05}$ inches and for the final survey, would be given by $2.7 \pm .313\ t_{0.05}$ inches, where $t_{0.05} = 1.99$ for (N-2) degrees of freedom. For the case of the average snow depth (Table 1 of Appendix III), the range of confidence interval on the population average would be $12.7 \pm .6$ inches to 7.4 ± 1.8 inches for the initial and final survey period, respectively. A further examination of the results showed that the errors associated with the respective estimates of the snowpack averages for the basin were less than 15 per cent at the 95 per cent confidence level for the major snow accumulation period (January 2 to 15, 1969).

The general trend of a decrease in accuracy of the estimates of the snowpack condition, shown in the results, was attributed to the break-up of the pattern of distribution of minor snow storms, to the dominant effects of wind drifts on exposed accumulations and to varying rates and stages of the snow metamorphosis on the basin.

An attempt was made to examine the effect on the accuracy of the estimates of the snowpack condition by a 50 per cent reduction in the sampling network. Four snow courses, number 1, 2, 6, and 8, with the most uniform snow cover were selected from Table 6 of Appendix II. A similar statistical analysis, as outlined previously (equations (1) to (4)), was carried out for this group of data. Tables 3 and 4 of Appendix III show the selected results. A cursory examination of the results showed that the reduction of the number of snow courses (guided by the ranked evaluation) gave an increase in the values of the estimate of the basin average water equivalents and an appreciable reduction in areal variation; however, a careful examination of the results, as outlined in the previous paragraphs, showed that the accuracy of the estimates (within 15 per cent at the 95 per cent confidence level) was confined to the same major snow accumulation period.

Empirical Relationship

The computation of the average snowpack density from a sample of measured depths and water equivalents was based on a direct relationship between the two variables; that is, an implicitly assumed linear regression with the line forced through the origin was utilized in the computations. As this implicit relationship was accepted for use in computing average snowpack density from the data of each snow course, it was extended to the computation of the basin snowpack integrated average density, from the combined data from all courses, on a particular survey. Subsequently, the knowledge of this implicit and accepted relationship was utilized to examine and evaluate the reliability of the point measurements and the quality and reliability of the grouped data among the snow courses. If a set of data was reliable and consistent in measurements, the empirical relationship derived (equation (6)) would be reliable and significant (equations (5) and (7) to (11)).

The results of the regression analyses, based on equations (6) to (11), carried out on the different groups of data, are summarized in Tables 5 and 6 of Appendix III. An examination of the results (Table 5 of Appendix III), showed that each coefficient of determination was equal to or greater than the accepted values of $r^2 = .25$; hence, the regressions were of practical significance. The computer F-values (equation (11)) employed for the test of linearity of the regressions, showed that each F-value was highly significant, indicating that the variations in the estimated water equivalents could be explained nearly entirely by the regression. With the appropriate application of equation (5), explained on page 11, the confidence limit on the regression coefficients can be determined; applied to the results (Table 5 of Appendix III), the confidence interval on the population regression coefficient can be shown to range from $.21 \pm .040$ to $.33 \pm .030$ from the second to the final survey period, respectively. The initial survey gave the most sensitive regression coefficient, of value $.07 \pm .028$. These confidence limits gave a measure of the accuracy of the slope of the regression lines.

From practical knowledge, the origin should be a point on the line of regression; however, because of errors in measurements, the intercept (equation (6b)) may not be equal to zero. The confidence limit on the intercept gave a measure of the departure of the regression line from the origin. These confidence intervals of the intercepts (equation (5)), appropriately applied to Table 5 of Appendix III, may be shown to range about the origin, with values from .32 ± .58 inch on January 15, 1969, to .19 ± .28 inch on March 14, 1969. Alternatively, the confidence level on the intercept may be determined indirectly from computed t-values; that is, the ratio between the respective intercept, A, of a regression and its standard error, S_A. When $t = {}^{A}/S_A$ was computed from Table 5 of Appendix III, it was seen that the results from only the first and third survey period gave a t-value that was respectively greater than $t_{0.05} = 1.99$, indicating that the intercepts of the regression from the other survey periods were not significant at the 95 per cent confidence level. In the case of the regression coefficients, the corresponding t-value ($t = {}^{b}/S_b$), when computed from Table 5 of Appendix III, was found to be much greater than $t_{0.05} = 1.99$ for all survey periods, indicating, therefore, that the coefficients of regression for the respective regressions were in each case very significant.

By operating with the knowledge of the above interpretations, regression analyses for the regression line forced through the origin, O(0,0), were carried out for the same set of snow data. Table 7 of Appendix III summarizes the results. The regression coefficients were measures of the average densities of the snowpack. The product of the respective standard error S_b and the value of $t_{0.05}$ gave a measure of the error associated with each coefficient at the 95 per cent confidence level. If appropriately applied, the confidence interval (equation (5)) on the population regression coefficients (Table 7 of Appendix III) gave, for example, values of $.22 \pm .032$ and $.36 \pm .046$ for the initial and final survey period, respectively. Similarly, the t-value, when computed for the respective coefficients, was, in each case, greater than $t_{0.05} = 1.99$; that is, the coefficients were all significant.

Similar regression analyses, as outlined and discussed for the total survey data, were performed on the data from the four most uniform snow courses (number 1, 2, 6, and 8). The results of the analyses are summarized in Tables 6 and 8 of Appendix III. The results followed parallel deductions to those of Tables 5 and 7 of Appendix III, but showed appreciable increases in the ranges of the confidence intervals on the intercepts about the origin, with values from .82 ± .98 inch on January 27, 1969, to .82 ± 1.72 inches on March 14, 1969, (equation (5), appropriately applied to Table 6 of Appendix III). Similarly, the t-values, when computed, indicated that the value of the intercept was significant only for the initial two survey periods.

The general indication was that the regression equation (6) of page 8, with the regression line forced through the origin, could be applied for the analysis of the data, thereby supporting reliability and consistency in the point measurements; that is, based on the validity of the implicit relationship between snow depth and water equivalent, the compiled data were of acceptable quality and accuracy for use in obtaining estimates of the basin snowpack water equivalents. It appeared, however, that a necessary requirement for practical application of the regression O(0,0) was an appreciable amount of snow accumulation, plus a time lapse to allow for destructive and constructive snow metamorphosis (initial settling of the pack, loss of shape of the original snow crystals and increases in grain size).

PRECIPITATION (SNOW) STORAGE ESTIMATES

The estimation of the winter precipitation storage in the snowpack was a necessary procedure for obtaining the input index required for use in the hydrologic calibration of the basin. The direct or indirect measurement of the snow water equivalent provides for estimating the water stored in the pack at a specific time, or for the change in storage between time periods.

An attempt was made to use different methods of integrating the individual point measurements of the snowpack into basin indices for a quantitative measure of depth of water on the basin. The different methods were applied mainly for the purpose of comparing the estimates determined by weighted average methods to those estimates determined by a simple arithmetic procedure.

Arithmetic Method

The statistical analysis of snow depth and water equivalent data showed that the errors and variabilities associated with the averages for the basin during the initial periods of snow accumulation were acceptable. The snow courses were distributed throughout the range of the basin elevation, thereby supporting the expectation of satisfactory indices of basin snowpack condition, if estimated by simple arithmetic averages. Table 3 of Appendix IV summarizes the results, showing the precipitation storage in the snowpack in terms of estimates of average water equivalent or snow depth of given average density, for several survey periods during the season.

All of the measured data from each snow course per survey period were included in the computation, including estimates of data from courses with less than 50 per cent of snow cover.

Thiessen Method

The Thiessen method was accepted as applicable for estimating the basin snowpack indices, because of the assumptions with regard to large-scale effects of meteorological conditions on the basin and that the effects of the local terrain parameters on minor storm distributions and snow cover variability on the basin were to be neglected. Outlined on Map 1 of Appendix I are the snow course locations and the polygon-area distributions. The areas enclosed by each polygon were planimetered on a topographic map of scale 1 inch = 1 mile. The per cent areal distributions from Table 1 of Appendix IV were applied to weight the data for the respective snow courses to determine estimates of the winter precipitation storage. The results are summarized in Table 4 of Appendix IV, in terms of the basin snowpack indices for several survey periods. The estimates for snow depth were less than the arithmetic average estimates, but in general, there were no significant or appreciable differences between the estimates of either method.

Area-Elevation Method

The snow courses were placed into zonal areas based on 100-foot rises in basin elevation from a lower elevation of 600 feet. The area-elevation distribution was developed by planimetering the areas enclosed by each elevation from a basin topographic map of scale 1 inch = 1 mile. It was assumed that the snow accumulation in a respective zonal area was approximately equal. Table 2 of Appendix III shows the area-elevation and zonal area distributions. The zonal area distribution factors were applied to weight the average snowpack indices on the respective snow course or group of snow courses within the zonal area. Table 5 of Appendix III shows a summary of the weighted averages of the basin precipitation storage in the snowpack for several survey periods. An examination of the results and a comparison with the estimates of the previous methods showed that there were no significant differences between the different estimates.

Isohyetal Method

A series of isohyetal maps were developed for the basin snowpack depth for the survey periods, as shown in Figures 1 to 6 of Appendix IV. Each map was developed independently from the snow course average values by isoline interpolation. Isohyet interval values used were at least twice the standard error of the respective average snow depth for the basin. By imposing this limit on the isohyet intervals, the interpolation was restricted to the same degree of errors associated with the sampling. The respective empirical relationship for the regression line forced through the origin (for the regression O(0,0)), between depth and water equivalent, with the associated standard errors, is shown on each depth isohyetal map for the periods of major snowfall (January 2 to February 5, 1969).

These maps facilitate a qualitative or visual interpretation of areal distribution of snow cover in the basin and the changes that occurred between surveys. Each map was analysed for area-isohyet distribution. The area enclosed between the isohyet intervals was planimetered on a topographic map of scale .5 inch = 1 mile and used to weight the respective average isohyet value, to determine ultimately the basin index weighted average value. Table 6 of Appendix IV summarizes the area-isohyet distribution of snow depth and the respective basin index. The results show no significant differences from the basin indices derived by the previous methods, thereby indicating that the snow courses were adequately distributed for use in estimating snow accumulation throughout the basin.

CONCLUSIONS

Various observations, analyses and interpretations of the snow survey data contributed to the following summarized conclusions:

1. A substantial amount of seasonal snow accumulation on the basin facilitated the collection of an adequate number of samples for a meaningful analysis.

2. Intra-season freeze and thaw cycles created difficulties in obtaining ideal core samples, thereby reducing the desirable accuracy of point measurements.

3. Evaluation of the data by statistical analysis facilitated the identification of the snow courses with poor or doubtful measurements. More uniform distribution of snow cover and acceptable representation were achieved from five snow course locations (snow courses number 1, 2, 5, 6, and 8).

4. The major period of snow accumulation provided adequate data for the determination of estimates of winter precipitation amounts for a degree of accuracy within 15 per cent at the 95 per cent confidence level.

5. The quality of the data was ascertained through a simple linear regression, which verified that

practical estimates of the snowpack water equivalent could be derived from the measured snow depth of a given average density. Although the computed regressions were good prediction equations, they were, however, specific to the basin snowpack conditions of the winter season of 1968-1969.

6. Reliable estimates of indices of the basin snowpack condition could be derived from a 50 per cent reduction in the evaluated sampling network.

7. Determination of estimates of the precipitation storage in the basin snowpack, for specific time periods, by several methods, showed no significant difference between the respective estimates. This indicated that the areal distribution of the snow courses throughout the basin was adequate and that their evaluation was limited mainly by the quality of the data. The arithmetic averages were desirable for easy computation of large volumes of data. The area-elevation and isohyetal method estimates were desirable for quantitative interpretation of the snow cover areal distribution and for the comparison of changes in the areal snow cover and snowpack conditions between certain time intervals.

8. The pattern of the basin snow cover distribution and time trends in accumulation and depletion

showed that the snowpack depth and water equivalent increased with increased basin elevation. Major snow storms tended to be more uniform and proportionally distributed on the basin. On the other hand, minor snow storm distributions were affected by local terrain parameters, thereby increasing the areal variability of snow cover on the basin.

RECOMMENDATIONS

1. The existing density of the sampling network should be maintained in order to ensure that the degree of representiveness of snow cover evaluated is sufficiently reproducible over a number of seasons.

2. Due to the poor quality of the data obtained from snow course number 4, an alternative location should be investigated.

3. Upon establishing an acceptable degree of reproducibility in the snow cover on the basin from the existing network, a sampling network of at least five snow courses should be maintained. A minimum of ten sampling points per course should be maintained in order to ensure representative statistical samples.

4. The frequency of the snow survey period should be increased to once per week during the period of significant freeze-thaw cycles.

BIBLIOGRAPHY

1. Adams, W. and Rogerson, R. - 1968

   "Snowfall and Snowcover at Knob Lake, Central Labrador, Ungava.", Proceedings of the 25th Annual Meeting of the Eastern Snow Conference, pp. 110-139.

2. Beaumont, R. and Work, R. - 1963

   "Snow Sampling Results with Differing Snow Samplers", Proceedings of the 20th Annual Meeting of the Eastern Snow Conference, pp. 185-191.

3. Canada Department of Transport, Meteorological Branch

   - 1961 - "A Guide to the Selection of Snow Survey Courses", Cir. 3566, OBS-305.
   - 1961 - "The Mount Rose Sampler", Cir. 3572, INS.-105.
   - 1964 - "Instruction to Snow Surveyors", Cir. 4113, OBS-329.

4. Chow, V.T. - 1964

   "Handbook of Hydrology", McGraw-Hill Book Co. Inc., New York.

5. U. S. Army Corps of Engineers - 1959

   "Snow Hydrology", OTS-U.S. Department of Commerce, PB. 151-660.

6. Fisher, R. - 1958

   "Statistical Methods for Research Workers", Hafner Publishing Co. Inc., New York.

7. Linsley, R. et al, - 1949

"Applied Hydrology", McGraw-Hill Book Co. Inc., New York.

8. Mode, E. - 1961

"Elements of Statistics", Prentice-Hall Inc., New Jersey.

9. Nicholas, L. - 1963

"Snow Survey Record", Proceedings of the 20th Annual Meeting of the Eastern Snow Conference, pp. 198-209.

10. Puccini, D. - 1967

"Snow Survey Report - Wilmot Creek Basin", 1966-1967, OWRC Preliminary Data Report No. 67-1.

11. Snedecor, G. and Cochran, W. - 1968

"Statistical Methods", Iowa State University, Press, Iowa.

12. Thom, H. - 1966

"Some Methods of Climatological Analysis", WMO-No. 199, TP. 103, Technical Note No. 81.

13. Wilson, J. - 1966

"Determination and Uses of Best Individual Sampling Points On Individual Snow Courses", Proceedings on the 34th Annual Meeting of the Western Snow Conference, pp. 82-86.

14. _____ Secretariat of the Canadian National Committee for IHD - 1966

"Guidelines for Research Basin Studies," Proceedings of the National Workshop Seminar on Research Basin Studies, Canadian National Committee for IHD.

APPENDICES-DATA SUMMARIES AND RESULTS OF ANALYSES

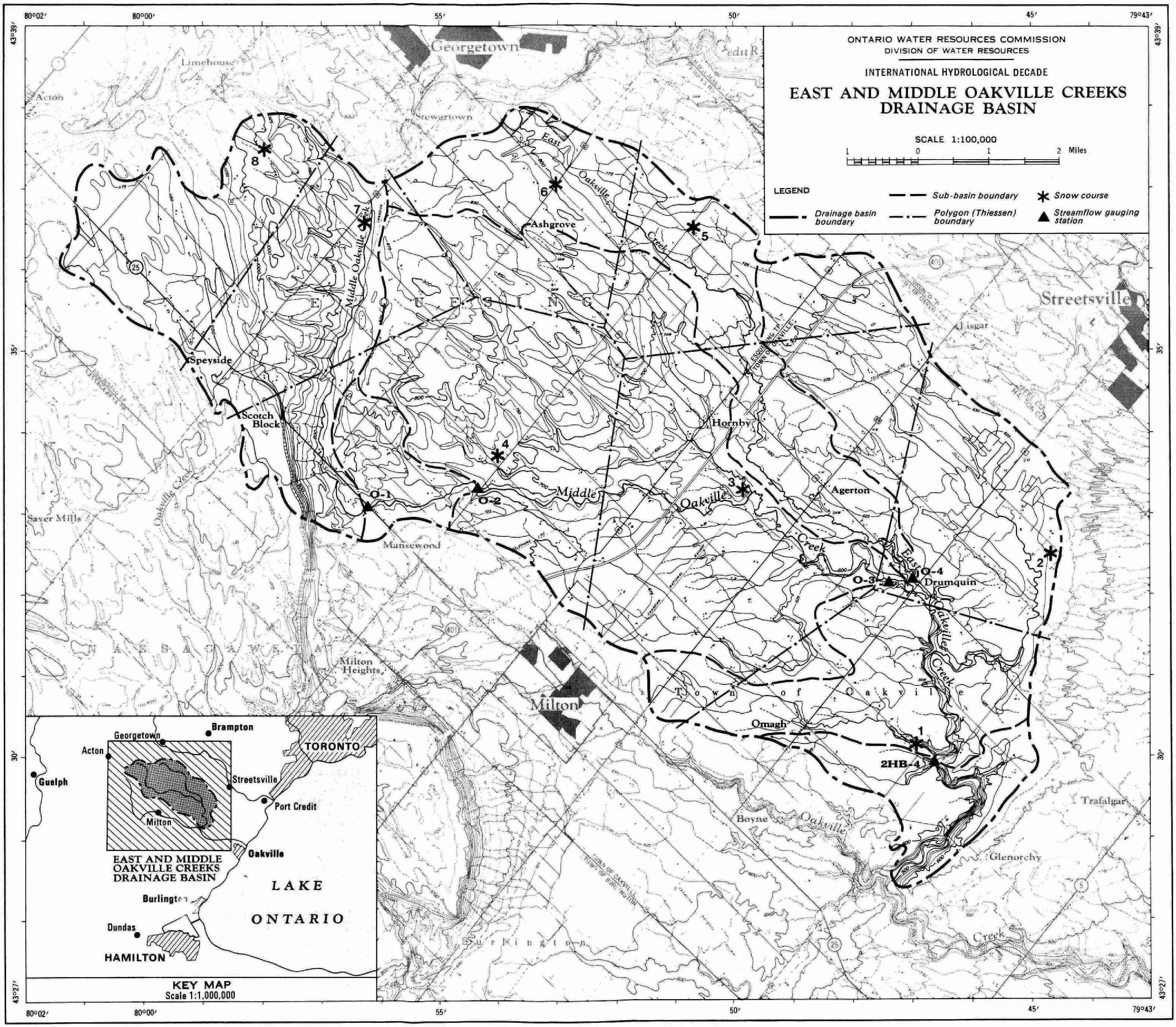
Appendix I

Map 1

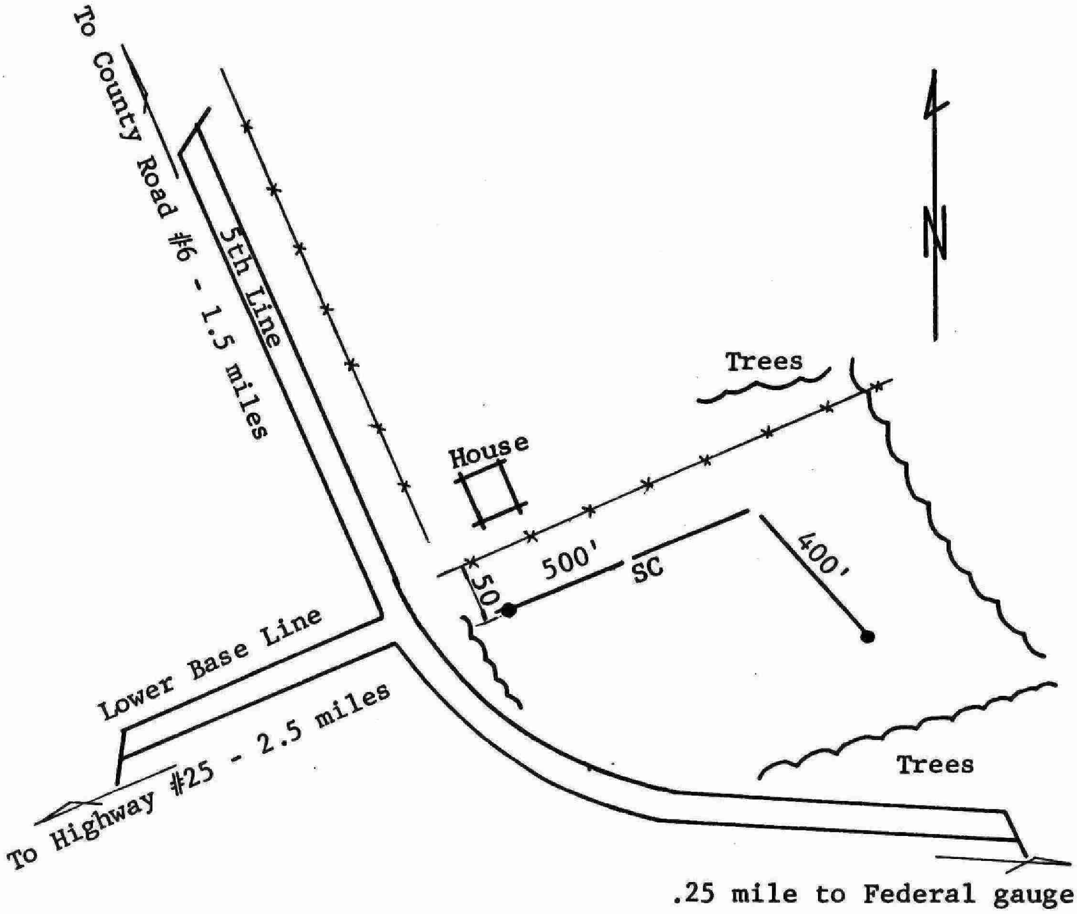
Figures 1 to 8

Table 1

Table 2



Map 1. Snow course locations.



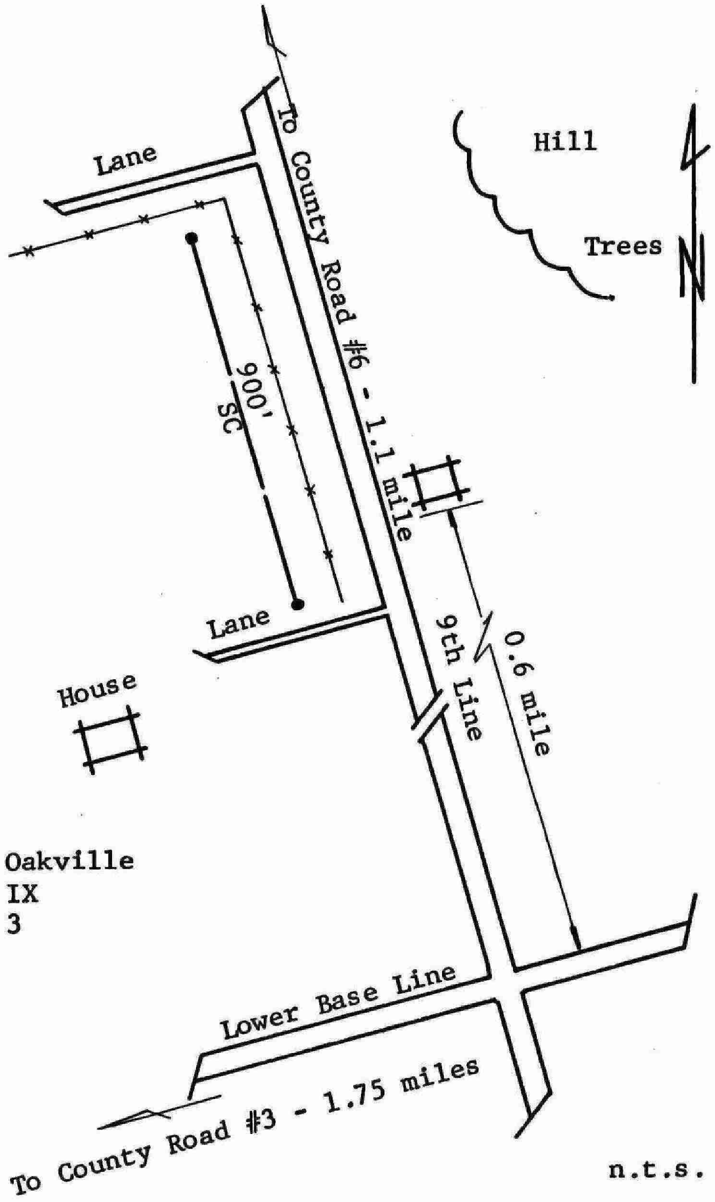
Township: Oakville
Concession: VI
Lot: 1

n.t.s.

Figure 1

Diagrammatic Sketch of Snow Course Layout: OSC-1

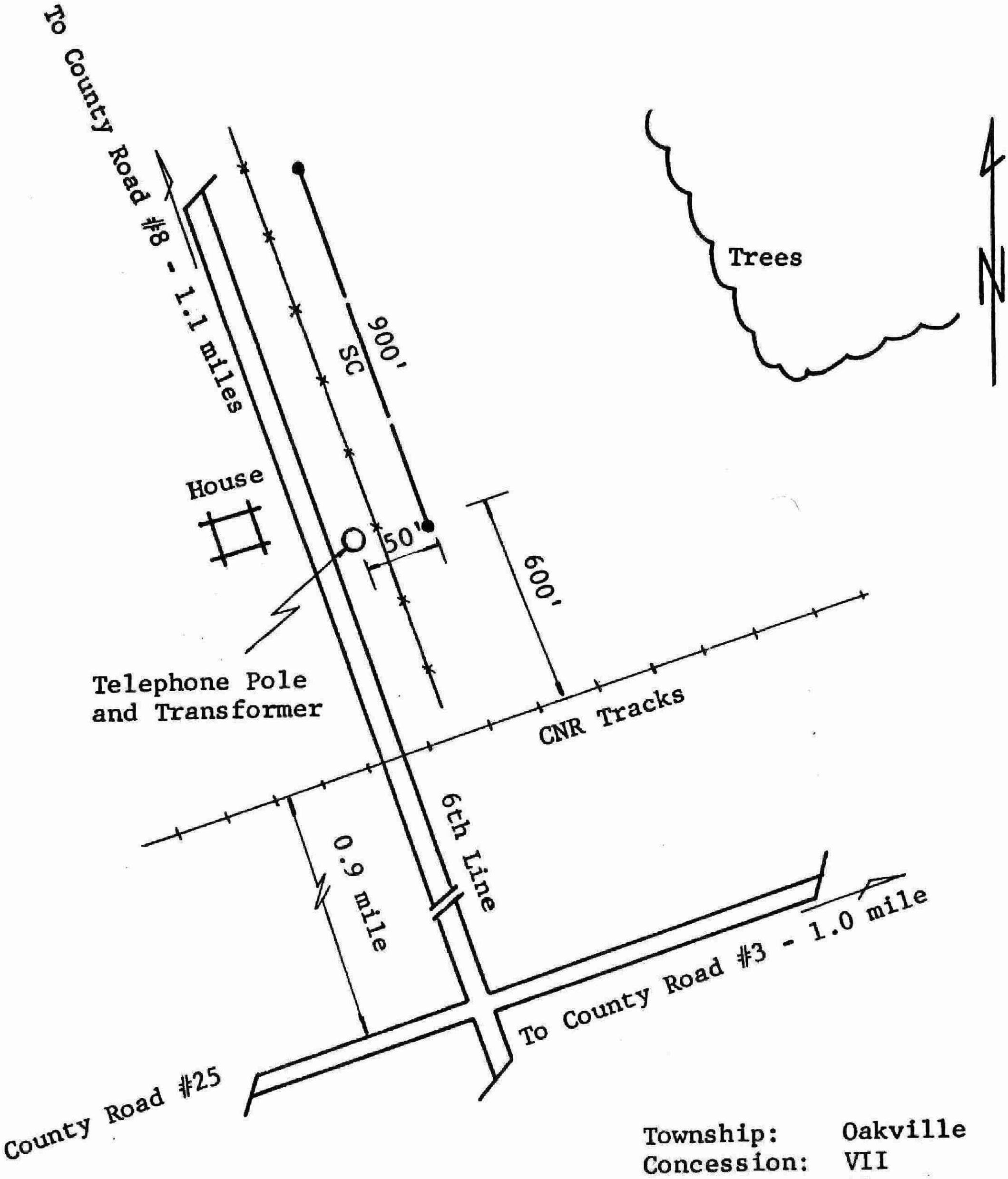
SC = Snow Course
n.t.s. = not to scale



Township: Oakville
Concession: IX
Lot: 3

Figure 2

Diagrammatic Sketch of Snow Course Layout: OSC-2



Township: Oakville
Concession: VII
Lot: 13

n.t.s.

Figure 3

Diagrammatic Sketch of Snow Course Layout: OSC-3

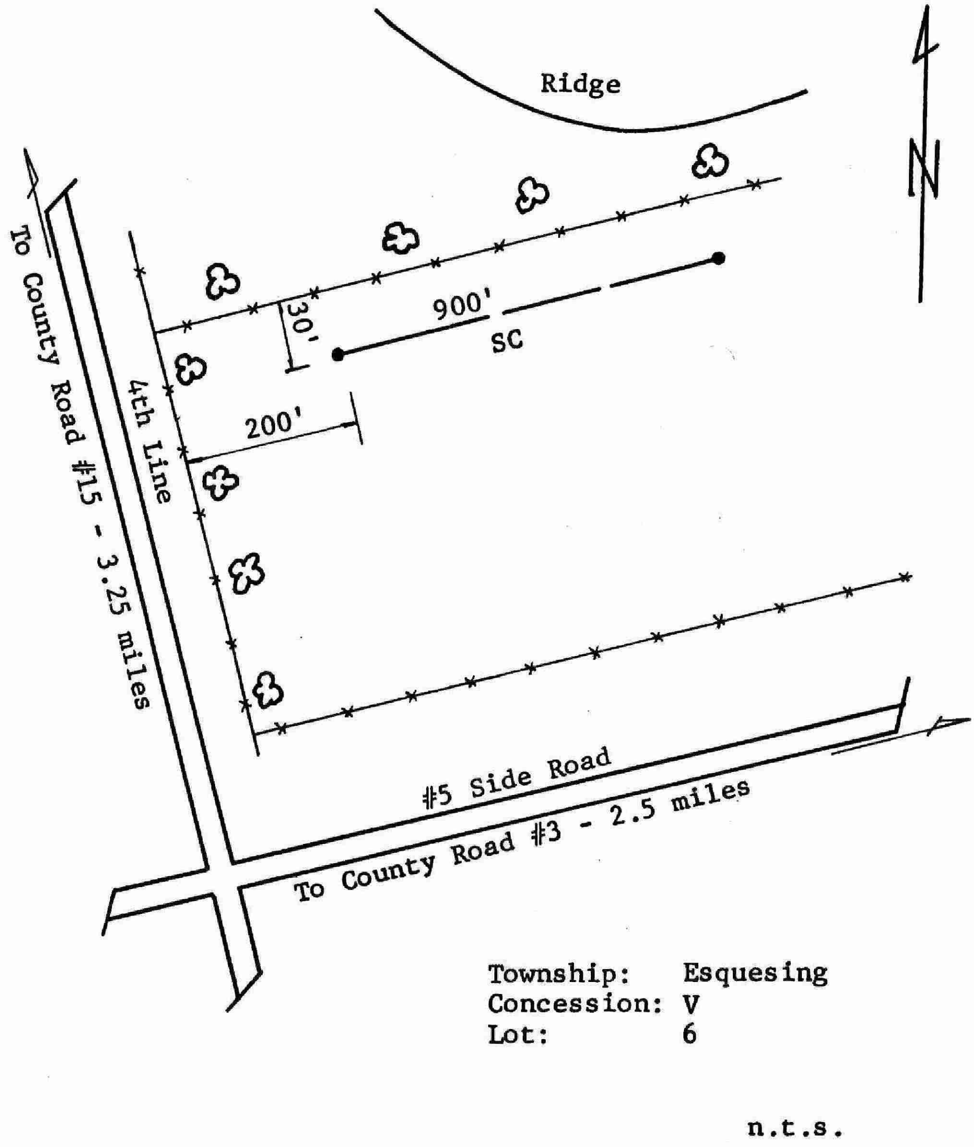


Figure 4

Diagrammatic Sketch of Snow Course Layout: OSC-4

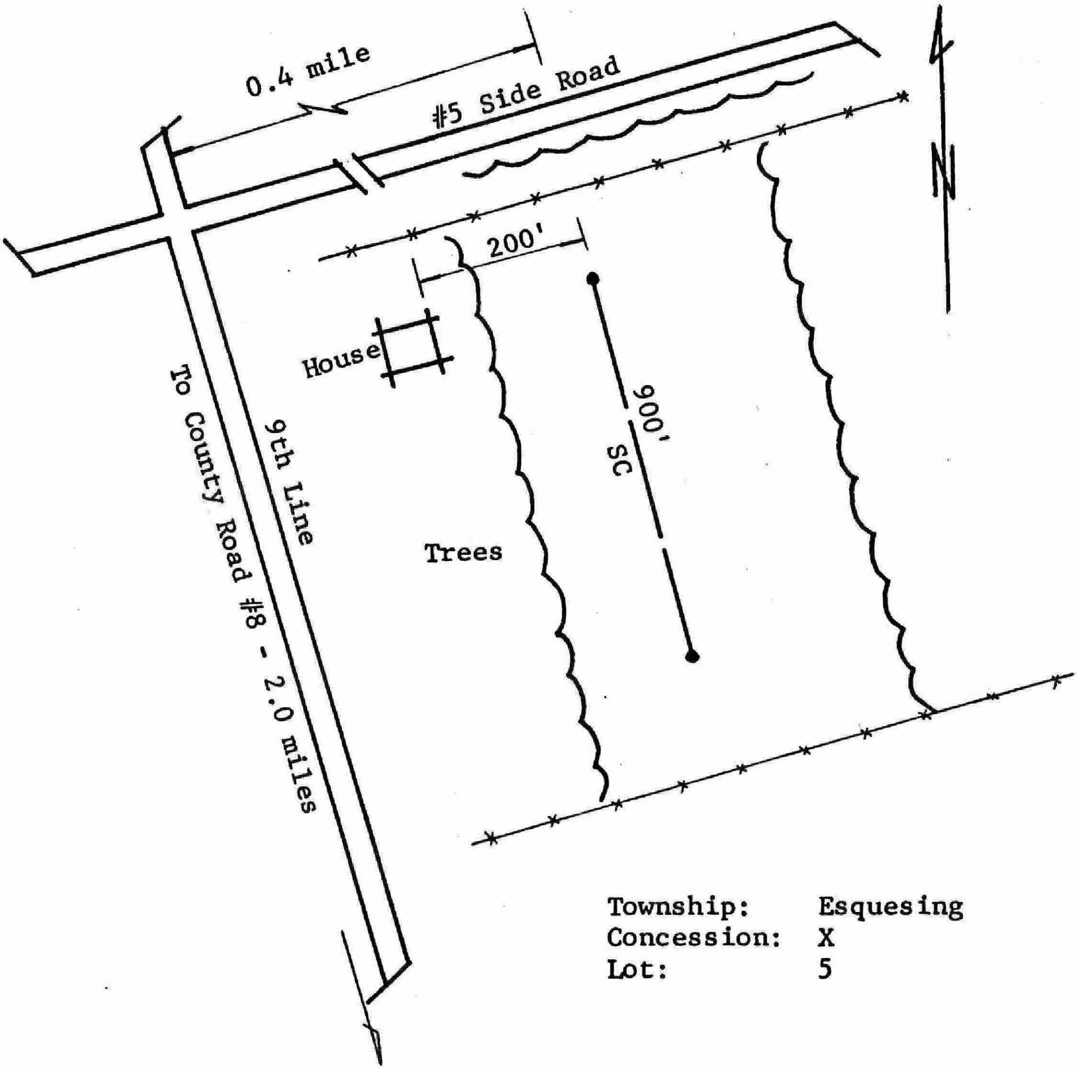
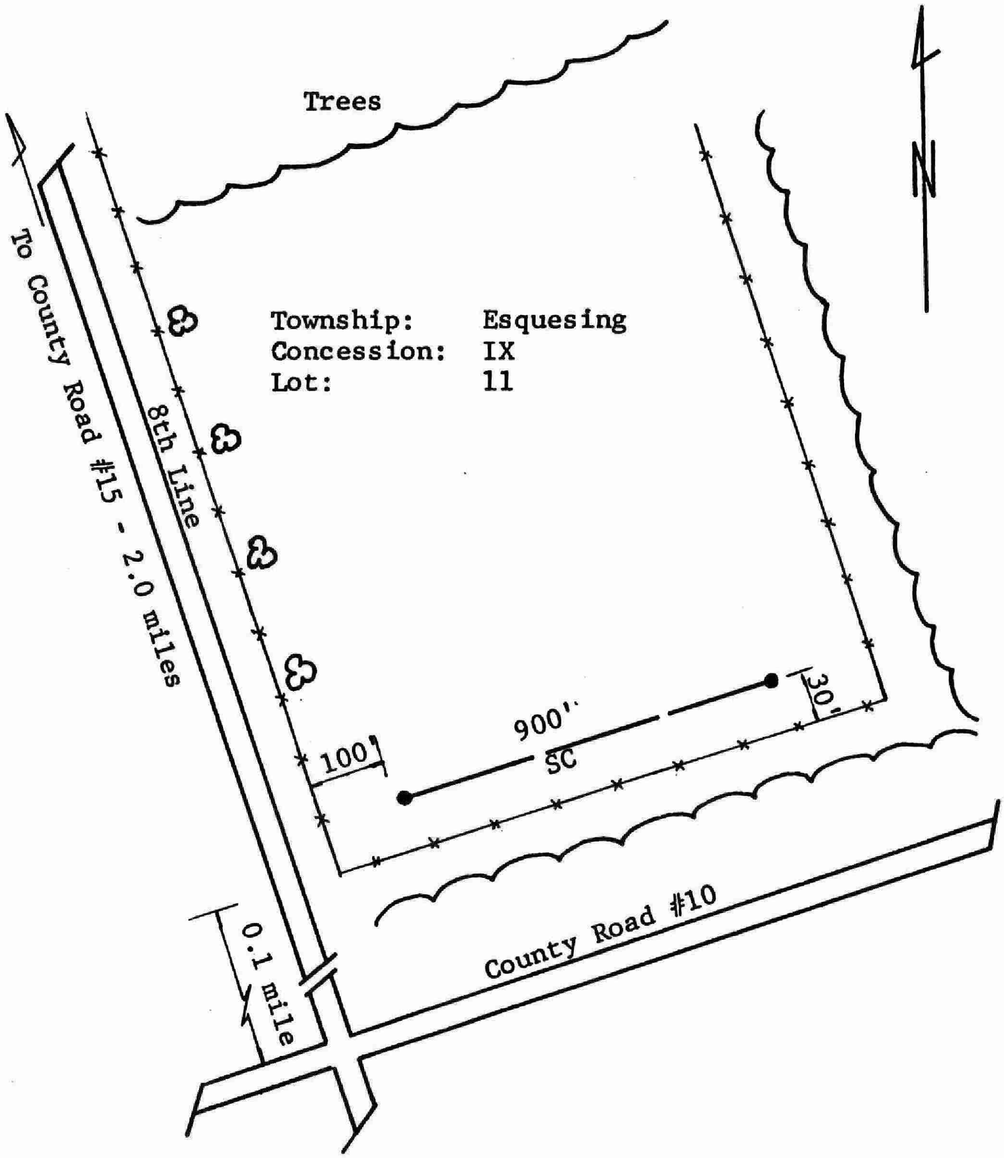


Figure 5

Diagrammatic Sketch of Snow Course Layout: OSC-5



n.t.s.

Figure 6

Diagrammatic Sketch of Snow Course Layout: OSC-6

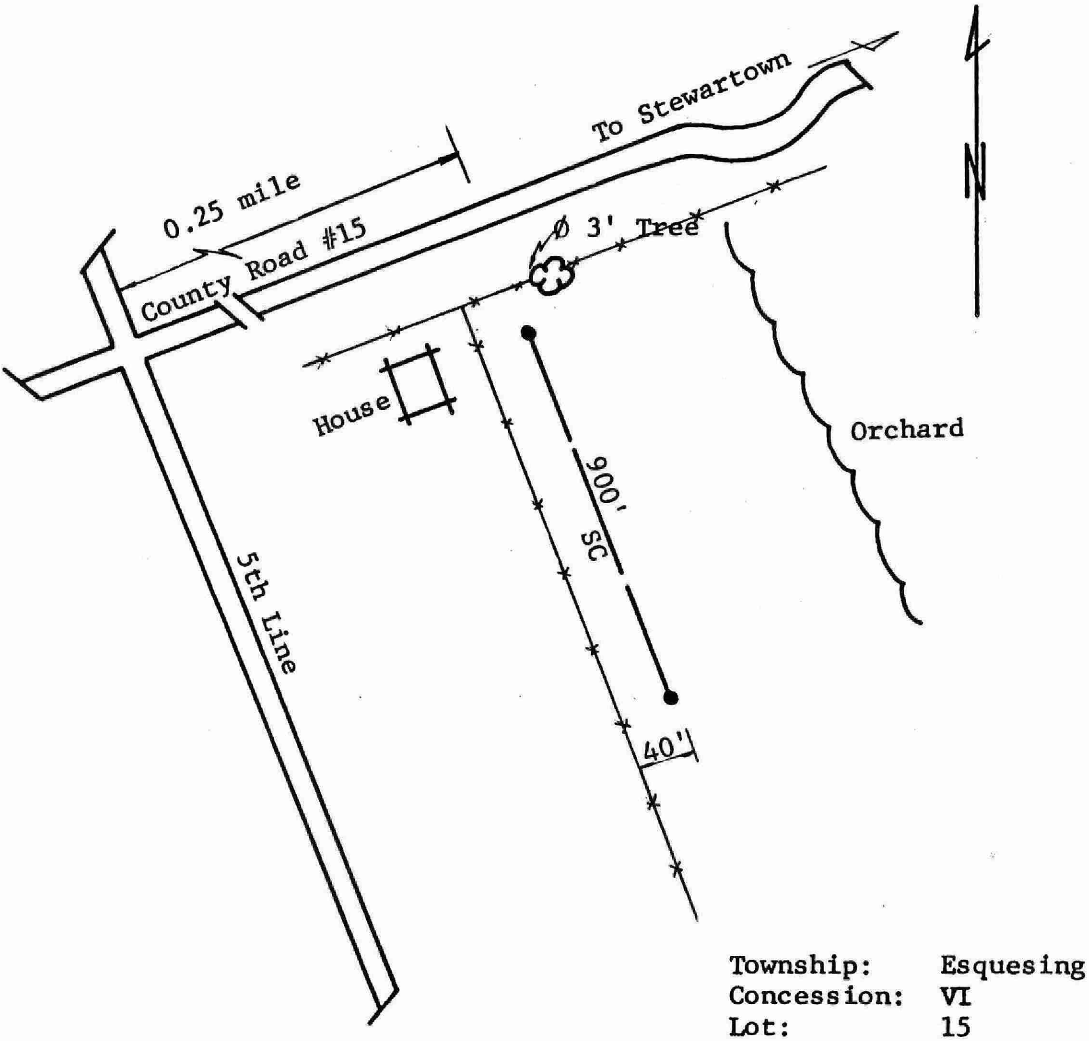
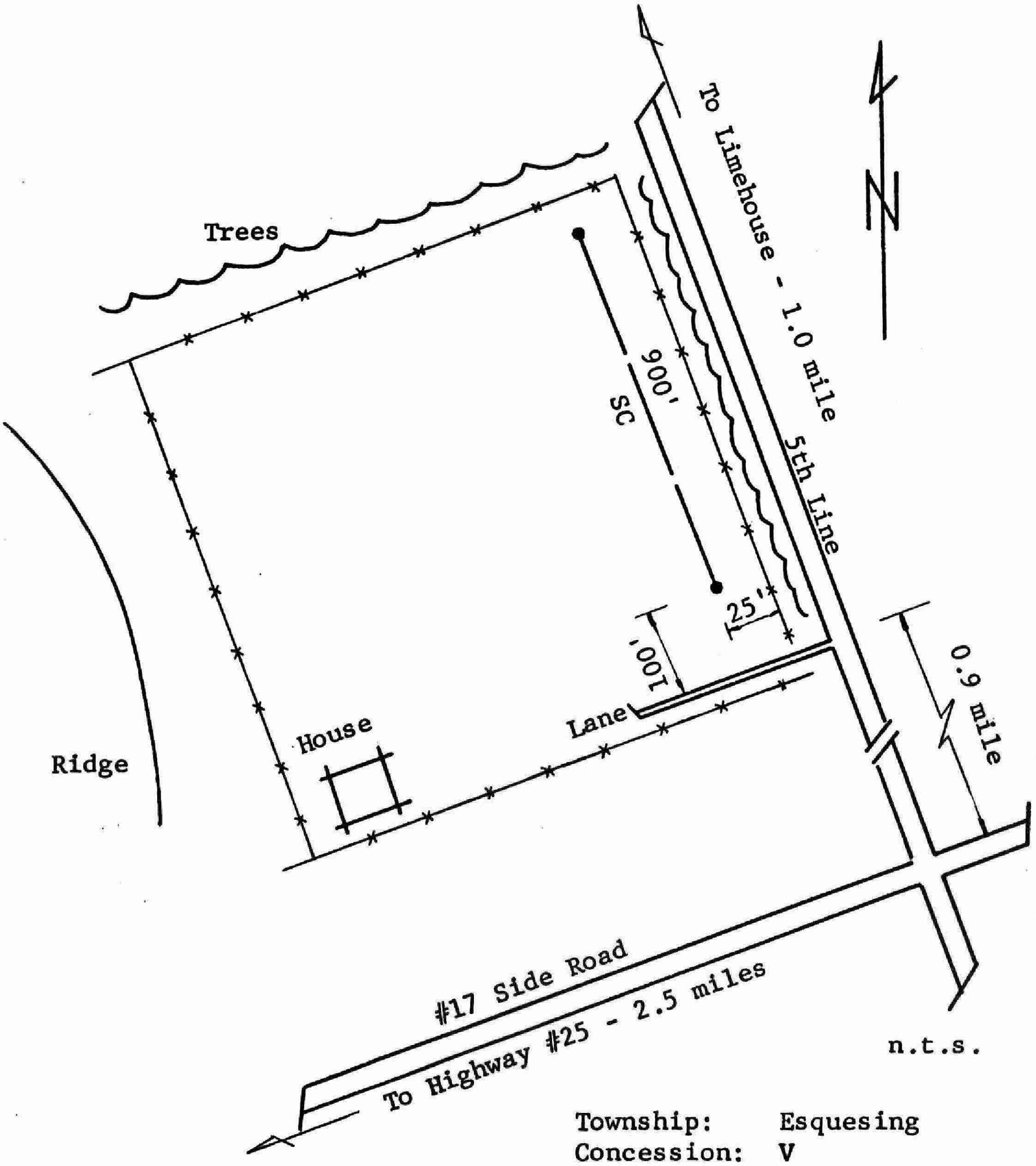


Figure 7

Diagrammatic Sketch of Snow Course Layout: OSC-7



Township: Esquesing
Concession: V
Lot: 20

Figure 8

Diagrammatic Sketch of Snow Course Layout: OSC-8

Table 1

RIVER BASIN RESEARCH BRANCH

SNOW SURVEY REPORT

Basin: Oakville Creek Station: OSC-8

Date: February 5, 1969 Time: 3:00 - 3:30 Temp: 17°

Observer: A. Sweetman & M. Long

1. Sample Number	2. Snow Depth	3. Length of Core	4. Weight of tube	5. Weight of tube & snow	6. Water Equivalent	7. Density
1	14.7	12.7	4.3	8.3	4.0	.27
2	16.5	14.0	4.3	9.4	5.1	.31
3	14.0	11.0	4.3	7.7	3.4	.24
4	12.0	9.6	4.3	6.6	2.3	.19
5	16.1	14.4	4.3	8.7	4.4	.27
6	19.3	15.3	4.3	8.3	4.0	.21
7	17.8	14.8	4.3	8.6	4.3	.24
8	17.8	17.8	4.3	10.3	6.0	.34
9	20.5	14.7	4.3	9.3	5.0	.24
10	21.0	15.0	4.3	8.5	4.2	.20
TOTAL	169.7	139.3	43.0	85.7	42.7	2.51
MEAN	17.0	13.9	4.3	8.6	4.3	.25

Crust: hard Soil Conditions: frozen Ice Layers:

COMMENTS: - snow is on grass layer

- used MSC Type-1 sampler

Table 2

Summary of Snow Survey Data

Snow Course	Date	Snow Depth (inches)	Water Equivalent (inches)	Density
OSC-1	2-1-69	12.6	2.7	.22
	15-1-69	11.1	2.8	.25
	27-1-69	4.9	1.6	.31
	5-2-69	3.9	0.4	.11
	26-2-69	-	0.1 e	-
	14-3-69	0.0	0.0	0.00
	24-3-69	0.0	0.0	0.00
OSC-2	2-1-69	12.2	2.5	.20
	15-1-69	17.3	3.9	.23
	27-1-69	9.1	3.2	.35
	5-2-69	10.4	2.7	.26
	26-2-69	5.5	1.5	.26
	14-3-69	0.9	0.3	.34
	24-3-69	0.0	0.0	0.00
OSC-3	2-1-69	11.5	2.5	.22
	15-1-69	10.4	2.2	.21
	27-1-69	5.3	1.6	.31
	5-2-69	4.9	1.0	.20
	26-2-69	1.7	0.4	.23
	14-3-69	-	0.2 e	-
	24-3-69	0.0	0.0	0.00
OSC-4	2-1-69	11.9	2.9	.25
	15-1-69	14.5	3.8	.26
	27-1-69	6.7	2.4	.35
	5-2-69	5.5	1.8	.26
	26-2-69	3.1	0.9	.17
	14-3-69	3.7	1.4	.37
	24-3-69	0.0	0.0	0.00

Table 2 (cont'd)

Snow Course	Date	Snow Depth (inches)	Water Equivalent (inches)	Density
OSC-5	2-1-69	10.8	2.7	.25
	15-1-69	12.7	3.0	.23
	27-1-69	7.0	2.1	.30
	5-2-69	5.1	1.4	.27
	26-2-69	2.0	0.4	.18
	14-3-69	0.8	0.2	.19
	24-3-69	0.0	0.0	0.00
OSC-6	2-1-69	11.0	2.8	.26
	15-1-69	15.3	4.3	.28
	28-1-69	9.8	3.4	.34
	5-2-69	9.6	3.4	.35
	26-2-69	6.4	2.0	.31
	14-3-69	7.5	3.1	.42
	24-3-69	0.0	0.0	0.00
OSC-7	2-1-69	13.8	2.9	.21
	15-1-69	13.0	2.8	.21
	28-1-69	8.9	2.2	.26
	5-2-69	7.2	1.4	.20
	26-2-69	4.6	1.0	.21
	14-3-69	3.5	1.3	.38
	24-3-69	0.0	0.0	0.00
OSC-8	2-1-69	18.2	3.0	.17
	15-1-69	20.5	3.9	.20
	28-1-69	13.9	3.3	.24
	5-2-69	17.0	4.3	.25
	26-2-69	16.4	4.1	.26
	14-3-69	14.9	4.9	.33
	24-3-69	0.0	0.0	0.00

e - estimated

Appendix II

Page

Table 1

Table 2

Table 3

Table 4

Table 5

Table 6

Table 1

Average, Standard Deviation and Coefficient of Variation of Snowpack Depth By Snow Courses for the Period of Snow Accumulation

Survey Period (Date)	Snow Course (OSC-)	Average Depth, $\bar{D}$, (in.)	Standard Deviation S_D (in.)	Coefficient of Variation C_D
2.1.69	1	12.6	1.35	.108
	2	12.2	1.82	.149
	3	11.5	.81	.071
	4	11.9	2.57	.216
	5	10.8	.70	.065
	6	11.0	1.14	.103
	7	13.8	1.02	.074
	8	18.2	1.74	.096
15.1.69	1	11.1	1.45	.131
	2	17.3	2.67	.152
	3	10.4	2.17	.209
	4	14.5	4.34	.300
	5	12.7	1.84	.145
	6	15.3	2.68	.175
	7	13.0	3.05	.234
	8	20.5	3.22	.158
27.1.69	1	4.9	1.67	.341
	2	9.1	1.81	.199
	3	5.3	1.41	.276
	4	6.7	2.62	.392
	5	7.0	1.81	.259
	6	9.8	2.21	.226
	7	8.9	1.69	.190
	8	13.9	1.14	.082

Table 1 (cont'd)

Survey Period (Date)	Snow Course (OSC-)	Average Depth, $\overline{D}$, (in.)	Standard Deviation, S_D, (in.)	Coefficient of Variation, C_D
5.2.69	1	3.9	1.11	.285
	2	10.4	2.45	.236
	3	4.9	1.86	.380
	4	5.5	4.15	.755
	5	5.1	2.23	.436
	6	9.6	2.29	.237
	7	7.2	2.96	.413
	8	17.0	2.89	.169

Table 2

Average, Standard Deviation and Coefficient of Variation of Snowpack Water Equivalent By Snow Courses for the Period of Snow Accumulation

Survey Period (Date)	Snow Course (OSC-)	Average Water Equivalent $\overline{W}$ (in.)	Standard Deviation S_W (in.)	Coefficient of Variation C_W
2.1.69	1	2.7	.13	.048
	2	2.5	.36	.144
	3	2.5	.29	.116
	4	2.9	.51	.175
	5	2.7	.37	.137
	6	2.8	.27	.097
	7	2.9	.41	.141
	8	3.0	.38	.127
15.1.69	1	2.8	.49	.175
	2	3.9	.88	.225
	3	2.2	.62	.282
	4	3.8	1.54	.405
	5	3.0	.68	.227
	6	4.3	.81	.188
	7	2.8	.76	.271
	8	3.9	1.14	.292
27.1.69	1	1.6	.61	.381
	2	3.2	.76	.237
	3	1.6	.59	.369
	4	2.4	1.19	.495
	5	2.1	.82	.390
	6	3.4	1.20	.354
	7	2.2	.67	.305
	8	3.3	.87	.263

Table 2 (cont'd)

Survey Period (Date)	Snow Course (OSC-)	Average Water Equivalent $\overline{W}$ (in.)	Standard Deviation S_W (in.)	Coefficient of Variation C_W
5.2.69	1	.4	.14	.350
	2	2.7	1.14	.415
	3	1.0	.50	.500
	4	1.8	1.32	.745
	5	3.4	.79	.565
	6	3.4	.96	.283
	7	1.4	.87	.620
	8	4.3	1.01	.236

Table 3

Average, Standard Deviation and Coefficient of Variation of Snowpack Core Length By Snow Courses for the Period of Snow Accumulation

Survey Period (Date)	Snow Course (OSC-)	Average Core Length $\overline{L}$ (in.)	Standard Deviation S_L (in.)	Coefficient of Variation C_L
2.1.69	1	8.9	.69	.078
	2	8.8	1.23	.140
	3	7.6	.97	.128
	4	8.8	2.47	.281
	5	8.3	1.08	.130
	6	9.3	1.16	.125
	7	9.8	1.83	.187
	8	10.3	1.66	.161
15.1.69	1	9.7	1.51	.156
	2	14.1	3.01	.214
	3	7.5	2.48	.331
	4	12.9	5.30	.411
	5	11.0	1.92	.175
	6	14.1	2.45	.174
	7	10.2	2.74	.268
	8	14.4	3.54	.246
27.1.69	1	4.4	1.29	.294
	2	8.3	1.76	.213
	3	4.6	.89	.194
	4	6.1	2.62	.430
	5	6.6	1.81	.275
	6	9.4	2.21	.236
	7	7.4	1.32	.178
	8	9.7	2.81	.290

Table 3 (cont'd)

Survey Period (Date)	Snow Course (OSC-)	Average Core Length $\overline{L}$ (in.)	Standard Deviation S_L (in.)	Coefficient of Variation C_L
5.1.69	1	3.7	.92	.248
	2	9.4	2.36	.252
	3	4.5	1.62	.360
	4	5.2	3.90	.750
	5	4.9	2.13	.435
	6	9.2	2.44	.265
	7	6.2	2.04	.329
	8	13.9	2.32	.169

Table 4

Average, Standard Deviation and Coefficient of Variation of Snowpack Density by Snow Courses for the Period of Snow Accumulation

Survey Period (Date)	Snow Course (OSC-)	Average Denisty $\bar{d}$ (in.)	Standard Deviation S_d (in.)	Coefficient of Variation C_d
2.1.69	1	.22	.022	.100
	2	.20	.017	.085
	3	.22	.020	.091
	4	.25	.014	.056
	5	.25	.030	.120
	6	.26	.014	.054
	7	.21	.028	.134
	8	.17	.026	.153
15.1.69	1	.25	.037	.148
	2	.23	.032	.139
	3	.21	.035	.167
	4	.26	.036	.138
	5	.23	.030	.131
	6	.28	.014	.050
	7	.21	.014	.067
	8	.20	.056	.280
27.1.69	1	.31	.047	.151
	2	.35	.056	.160
	3	.31	.063	.204
	4	.35	.041	.117
	5	.30	.046	.153
	6	.34	.057	.168
	7	.26	.096	.370
	8	.24	.061	.254

Table 4 (cont'd)

Survey Period (Date)	Snow Course (OSC-)	Average Density $\bar{d}$ (in.)	Standard Deviation S_d (in.)	Coefficient of Variation C_d
5.2.69	1	.12	.098	.815
	2	.27	.081	.300
	3	.20	.039	.195
	4	.26	.119	.457
	5	.27	.094	.347
	6	.35	.059	.169
	7	.20	.064	.320
	8	.25	.023	.092

Table 5

Ranked Snow Courses by Coefficient of Variation, C_D, of Snowpack Depth for the Period of Snow Accumulation

ACCUMULATION PERIOD - STATISTICAL PARAMETERS -										
DATE	2.1.69		15.1.69		27.1.69		5.2.69			
Snow Course OSC-	C_D	Rank (k)	C_D	Rank (k)	C_D	Rank (k)	C_D	Rank (k)	Total Rank (Σ k)	Group Rank (K)
1	.108	6	.131	1	.341	7	.285	4	18	5½
2	.149	7	.152	3	.199	3	.236	2	15	2½
3	.071	2	.209	6	.276	6	.380	5	19	7
4	.216	8	.300	8	.392	8	.755	8	32	8
5	.065	1	.145	2	.259	5	.436	7	15	2½
6	.103	5	.175	5	.226	4	.237	3	17	4
7	.074	3	.234	7	.190	2	.413	6	18	5½
8	.096	4	.158	4	.082	1	.169	1	10	1

Table 6

Summary of Ranked (Multiple) Snow Courses by Coefficient of Variations of Snowpack Depth, Water Equivalent, Core Length and Density for the Period of Snow Accumulation

Snow Course OSC-	GROUP RANK K								Total Group Rank (ΣK)	Multiple Rank (R)
	Depth		Water Equivalent		Core Length		Density			
	Σk	K	Σk	K	Σk	K	Σk	K		
1	18	5½	11	2	11	1	21	6	14½	3
2	15	2½	15	4	15	3	16	3	12½	2
3	19	7	19	5	18	4½	20	5	21½	6
4	32	8	32	8	32	8	14	2	26	8
5	15	2½	22	7	19	6½	18	4	20	5
6	17	4	10	1	12	2	9	1	8	1
7	18	5½	21	6	19	6½	22	7	25	7
8	10	1	14	3	18	4½	24	8	16½	4

Appendix III

Table 1

Standard Deviations and Variations of Basin Snowpack Measured Depths by Survey Periods

Survey Period (Date)	Average Depth, $\bar{D}$ (in.)	Standard Deviation, S_D (in.)	Standard Error of Average Depth, $S_{\bar{D}}$ (in.)	Coefficient of Variation, C_D
2.1.69	12.7	2.64	.295	.209
15.1.69	14.4	4.13	.461	.288
27.1.69	8.1	3.29	.368	.404
5.2.69	8.0	4.77	.533	.599
†26.2.69	5.7	5.43	.650	.957
*14.3.69	7.4	5.71	.903	.774

---

† OSC-1 excluded)
) 0 or $<$ 50% snow cover
* OSC-1, 2, 3, and 5 excluded)

Table 2

Standard Deviations and Variations of Basin Snowpack Measured Water Equivalents by Survey Periods

Survey Period (Date)	Average Water Equivalent, $\overline{W}$ (in.)	Standard Deviation, S_W (in.)	Standard Error of Average Water Equivalent, $S_{\overline{W}}$ (in.)	Coefficient of Variation C_W
2.1.69	2.8	.38	.043	.139
15.1.69	3.3	1.12	.125	.335
27.1.69	2.5	1.08	.121	.434
5.2.69	2.1	1.51	.169	.735
†26.2.69	1.5	1.49	.178	1.014
*14.3.69	2.7	1.98	.313	.745

---

† OSC-1 excluded)
) 0 or $<$ 50% snow cover
* OSC-1, 2, 3 and 5 excluded)

Table 3

Standard Deviations and Variations of Basin Snowpack Measured Depths for the Most Uniform Snow Courses (OSC-1, 2, 6 and 8) by Survey Periods

Survey Period (Date)	Average Depth $\bar{D}$ (in.)	Standard Deviation, S_D (in.)	Standard Error of Average Depth, $S_{\bar{D}}$ (in.)	Coefficient of Variation C_D
2.1.69	13.4	3.13	.494	.234
15.1.69	16.0	4.25	.672	.265
27.1.69	9.3	3.74	.591	.400
5.2.69	10.2	5.18	.818	.505
†26.2.69	9.4	5.76	1.052	.610
*14.3.69	11.2	4.52	1.009	.404

---

† OSC-1 excluded)
) 0 or $<$ 50% snow cover
* OSC-1 and 2 excluded)

Table 4

Standard Deviations and Variations of Basin Snowpack Measured Water Equivalents for the Most Uniform Snow Courses (OSC-1, 2, 6 and 8) by Survey Periods

Survey Period (Date)	Average Water Equivalent $\overline{W}$ (in.)	Standard Deviation, S_W (in.)	Standard Error of Average Water Equivalent, $S_{\overline{W}}$ (in.)	Coefficient of Variation C_W
2.1.69	2.8	.35	.055	.126
15.1.69	3.7	1.00	.156	.268
27.1.69	2.9	1.14	.181	.400
5.2.69	2.7	1.67	.265	.620
†26.2.69	2.6	1.51	.276	.589
*14.3.69	4.0	1.42	.316	.358

---

† OSC-1 excluded)
) 0 or $<$ 50% snow cover
* OSC-1 and 2 excluded)

Table 5

Statistical Association of Basin Snowpack Measured Depths and Water Equivalents by Survey Periods

Survey Period (Date)	Average Water Equivalent $\overline{W}$ (in.)	Intercept A (in.)	Regression Coefficient, b	STANDARD ERROR OF			Coefficient of Determination r^2	F-Value
				Estimate S_e (in.)	Intercept S_A (in.)	Regression Coefficient S_b		
2.1.69	2.8	1.81	.07	.330	.183	.014	.25	27.9
15.1.69	3.3	.32	.21	.711	.290	.019	.58	117.8
27.1.69	2.5	.46	.25	.707	.212	.024	.57	105.2
5.2.69	2.1	-.19	.28	.686	.150	.016	.79	306.2
†26.2.69	1.5	.01	.26	.518	.090	.012	.88	503.4
*14.3.69	2.7	.19	.33	.534	.139	.015	.93	496.8

† OSC-1 excluded)
) 0 or < 50% snow cover
* OSC-1, 2, 3 and 5 excluded)

Table 6

Statistical Association of Basin Snowpack Measured Depths and Water Equivalents for the Most Uniform Snow Courses (OSC-1, 2, 6 and 8) by Survey Periods

Survey Period (Date)	Average Water Equivalent $\overline{W}$ (in.)	Intercept A (in.)	Regression Coefficient, b	STANDARD ERROR OF			Coefficient of Determination, r^2	F-Value
				Estimate S_e (in.)	Intercept S_A (in.)	Regression Coefficient S_b		
2.1.69	2.8	2.02	.06	.306	.245	.016	.23	12.4
15.1.69	3.7	1.46	.14	.812	.626	.031	.34	21.4
27.1.69	2.9	.82	.22	.810	.492	.035	.50	40.0
5.2.69	2.7	-.19	.28	.830	.594	.026	.76	121.7
†26.2.69	2.5	.36	.23	.705	.536	.023	.78	104.9
*14.3.69	3.9	.82	.28	.651	.863	.033	.79	71.7

† OSC-1 excluded)
) 0 or < 50% snow cover
* OSC-1 and 2 excluded)

Table 7

Statistical Association of Basin Snowpack Measured Depths and Water Equivalents by Survey Periods for the Regression O(0,0)

$(W_c = bD)$

Survey Period (Date)	Average Water Equivalent $\overline{W}$ (in.)	Regression Coefficient, b	Standard Error of Estimate, S_e (in.)	Standard Error of Reg. Coef. S_b
2.1.69	2.8	.22	.497	.016
15.1.69	3.3	.23	.717	.021
27.1.69	2.5	.31	.728	.029
5.2.69	2.1	.27	.693	.028
✝26.2.69	1.5	.26	.519	.024
*14.3.69	2.7	.36	.547	.023

✝ OSC-1 excluded)
) 0 or < 50% snow cover
* OSC-1, 2, 3 and 5 excluded)

Table 8

Statistical Association of Basin Snowpack Measured Depths and Water Equivalents for the Most Uniform Snow Courses (OSC-1, 2, 6 & 8) by Survey Periods for Regression 0(0,0)

$(W_c = bD)$

Survey Period (Date)	Average Water Equivalent $\overline{W}$ (in.)	Regression Coefficient b	Standard Error of Estimate S_e (in.)	Standard Error of Reg. Coef. S_b
2.1.69	2.8	.21	.558	.023
15.1.69	3.7	.23	.897	.035
27.1.69	2.9	.31	.867	.045
5.2.69	2.7	.27	.836	.042
†26.2.69	2.6	.28	.731	.038
*14.3.69	4.0	.35	.725	.035

---

† OSC-1 excluded)
) 0 or < 50% snow cover
* OSC-1, 2, 3 and 5 excluded)

Appendix IV

Table 1

Areal Distribution of Snow Courses (Thiessen's Method)

Snow Course OSC-	Site Elevation - Feet (a.s.l.)	Sub-Basin Drainage Area in Mi^2				Areal Coverage (Mi^2)	Percent Areal Coverage (%)
		0-1	0-2	0-3	0-4		
1	600	-	-	.66	-	6.62	8.8
2	625	-	-	.02	.19	7.06	9.4
3	625	-	-	10.97	3.76	18.99	25.2
4	725	2.67	4.85	14.78	-	14.78	19.5
5	775	-	-	1.65	3.06	6.88	9.1
6	800	-	-	3.66	2.33	5.99	7.9
7	850	6.26	6.26	8.91	-	8.91	11.8
8	1,000	6.29	6.29	6.29	-	6.29	8.3
Total Area (Mi^2)		15.22	17.40	46.94	9.34	75.52	100.0
Percent Area (%)		20.2	23.0	62.0	12.3	100.00	

Mi^2 = square miles

a.s.l. = above sea level

Table 2

Area-Elevation and Zonal-Area Distribution of Snow Courses

Elevation - Feet (a.s.l.)	Area Below Elevation (Mi^2)	Area Enclosed (Mi^2)	Zonal Area (Mi^2)	Snow Course & Distribution Factor
		1.05		
600	1.05			
		8.91		
625	9.96			
		12.85		(OSC-1, 2 & 3)
650	22.81			
		7.66		
675	30.47			
		5.06		
700	36.53		36.53	.484
		7.32		
725	43.85			
		1.65		(OSC-4, 5 & 6)
750	45.50			
		8.65		
800	54.15		17.62	.233
		8.78		
850	62.93			(OSC-7)
		.97		
900	63.90		9.75	.129

Table 2 (cont'd)

Elevation - Feet (a.s.l.)	Area Below Elevation (Mi^2)	Area Enclosed (Mi^2)	Zonal Area (Mi^2)	Snow Course & Distribution Factor
		1.25		
950	65.15			
		2.37		
1,000	67.52			
		.05		(OSC-8)
1,050	67.57			
		3.34		
1,100	70.91			
		1.46		
1,150	72.37			
		3.15		
1,200	75.52		11.62	.154

Mi^2 = square miles

Table 3

Arithmetic Averages of Basin Snowpack Indices by Survey Periods

Survey Period (Date)	BASIN INDEX - Average -		
	Depth, $\overline{D}$ (in.)	Water Equivalent, $\overline{W}$ (in.)	Density, $\overline{d}$ (in.)
2.1.69	12.7	2.8	.22
15.1.69	14.4	3.3	.23
27.1.69	8.1	2.5	.30
5.2.69	8.0	2.1	.25
26.2.69	5.2	1.3	.22
14.3.69	4.0	1.4	.28
24.2.69	0.0	0.0	.00

Table 4

Weighted Averages (by Thiessen's Method) of Basin Snowpack Indices by Survey Periods

Survey Period (Date)	BASIN INDEX - Weighted Average -		
	Depth, $\overline{D}$ (in.)	Water Equivalent, $\overline{W}$ (in.)	Density, $\overline{d}$ (in.)
2.1.69	12.5	2.7	.22
15.1.69	13.7	3.2	.23
27.1.69	7.5	2.3	.31
5.2.69	7.1	1.8	.23
26.2.69	4.2	1.1	.21
14.3.69	3.3	1.2	.29
24.3.69	0.0	0.0	.00

Table 5

Weighted Averages (by Area-Elevation Method) of Basin Snowpack Indices by Survey Periods

Survey Period (Date)	BASIN INDEX - Weighted Average -		
	Depth, $\overline{D}$ (in.)	Water Equivalent, $\overline{W}$ (in.)	Density, $\overline{d}$ (in.)
2.1.69	13.0	2.7	.22
15.1.69	14.4	3.2	.23
27.1.69	8.2	2.4	.31
5.2.69	8.2	2.0	.23
26.2.69	5.3	1.4	.21
14.3.69	4.0	1.1	.27
24.3.69	0.0	0.0	.00

Table 6

Area-Isohyet Distribution and Basin Weighted Average Snowpack Depth by Survey Periods

		AREA ENCLOSED		SNOW DEPTH	
Survey Period (Date)	Isohyet (in.)	Mi^2	%	Average Isohyet (in.)	Weighted Average (Accumulative) (in.)
2.1.69	10.0				
		36.3	48.0	10.9	
	12.0				
		23.1	30.6	13.0	
	14.0				
		5.8	7.7	15.0	
	16.0				
		3.8	5.0	17.0	
	18.0				
		6.5	8.7	18.1	12.8
	20.0				
15.1.69					
	10.0				
		15.1	20.0	11.1	
	12.0				
		25.3	33.5	13.0	
	14.0				
		15.5	20.6	15.0	
	16.0				
		7.8	10.3	17.0	
	18.0				
		4.6	6.1	19.0	
	20.0				
		7.2	9.5	20.3	14.5

Table 6 (cont'd)

Survey Period (Date)	Isohyet (in.)	AREA ENCLOSED		SNOW DEPTH	
		Mi^2	%	Average Isohyet (in.)	Weighted Average (Accumulative) (in.)
27.1.69					
	4.0				
		19.1	25.6	4.9	
	6.0				
		23.1	31.0	7.0	
	8.0				
		16.6	21.0	9.0	
	10.0				
		6.8	9.0	11.0	
	12.0				
		8.4	11.2	13.0	
	14.0				
		1.5	2.2	14.0	8.1
5.2.69					
	4.0				
		31.2	41.4	5.0	
	6.0				
		18.9	25.0	7.0	
	8.0				
		10.0	13.2	9.0	
	10.0				
		3.3	4.4	11.0	
	12.0				
		3.0	4.0	13.0	
	14.0				
		3.0	4.0	15.0	
	16.0				
		6.1	8.0	17.0	7.9

Table 6 (cont'd)

Survey Period (Date)	Isohyet (in.)	AREA ENCLOSED		SNOW DEPTH	
		Mi^2	%	Average Isohyet (in.)	Weighted Average (Accumulative) (in.)
26.2.69					
		13.4	17.6	1.0	
	2.0				
		30.4	40.3	3.0	
	4.0				
		15.9	21.0	6.0	
	8.0				
		7.8	10.3	10.0	
	12.0				
		5.4	7.1	14.0	
	16.0				
		2.6	3.7	16.2	5.3
14.3.69					
		34.0	45.0	1.0	
	2.0				
		11.2	14.8	2.0	
	4.0				
		14.1	18.6	6.0	
	8.0				
		8.5	11.3	10.0	
	12.0				
		7.8	10.3	13.5	4.4

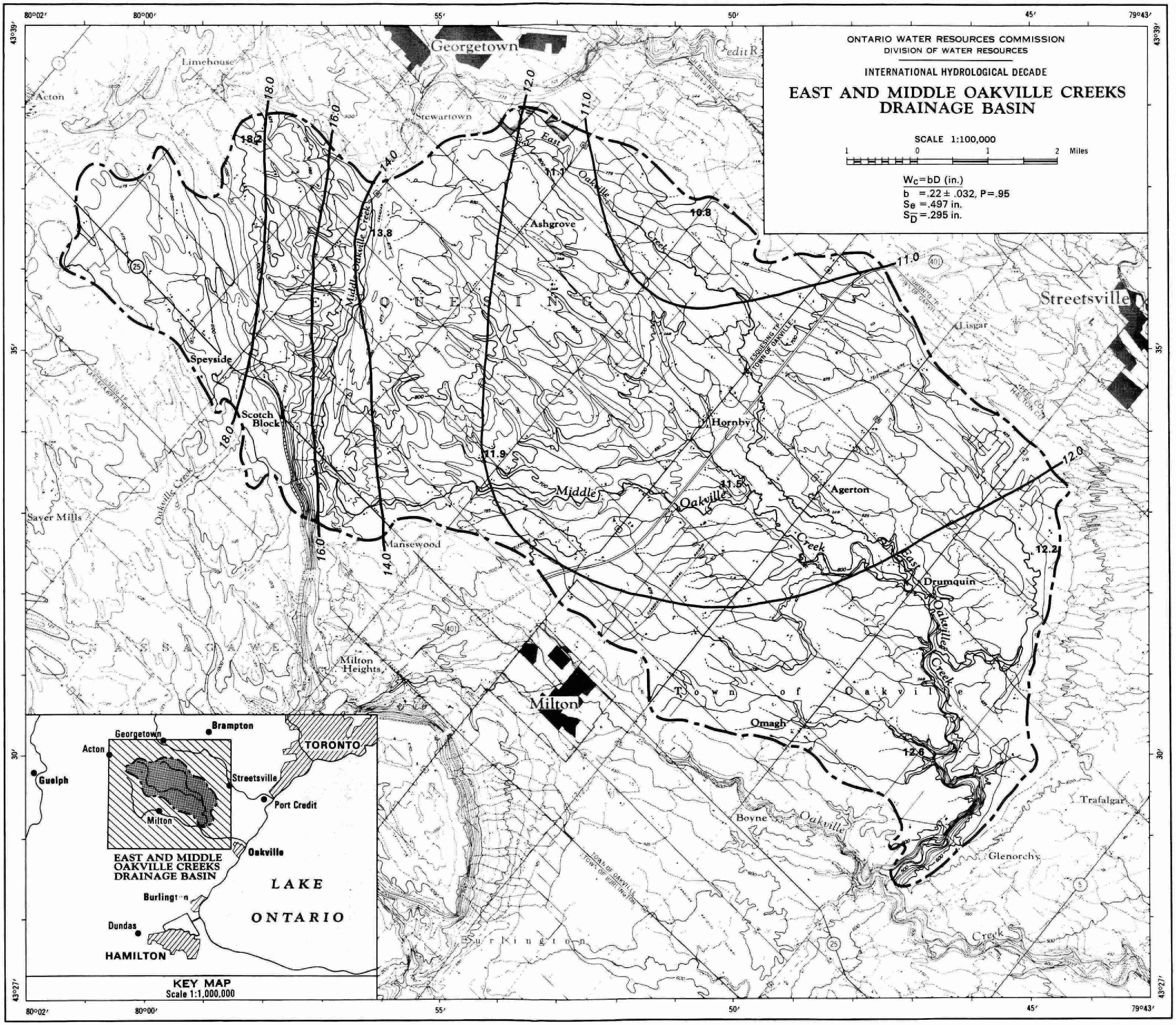


Figure 1. Isohyets of snowpack depth in inches – Survey period 2.1.69.

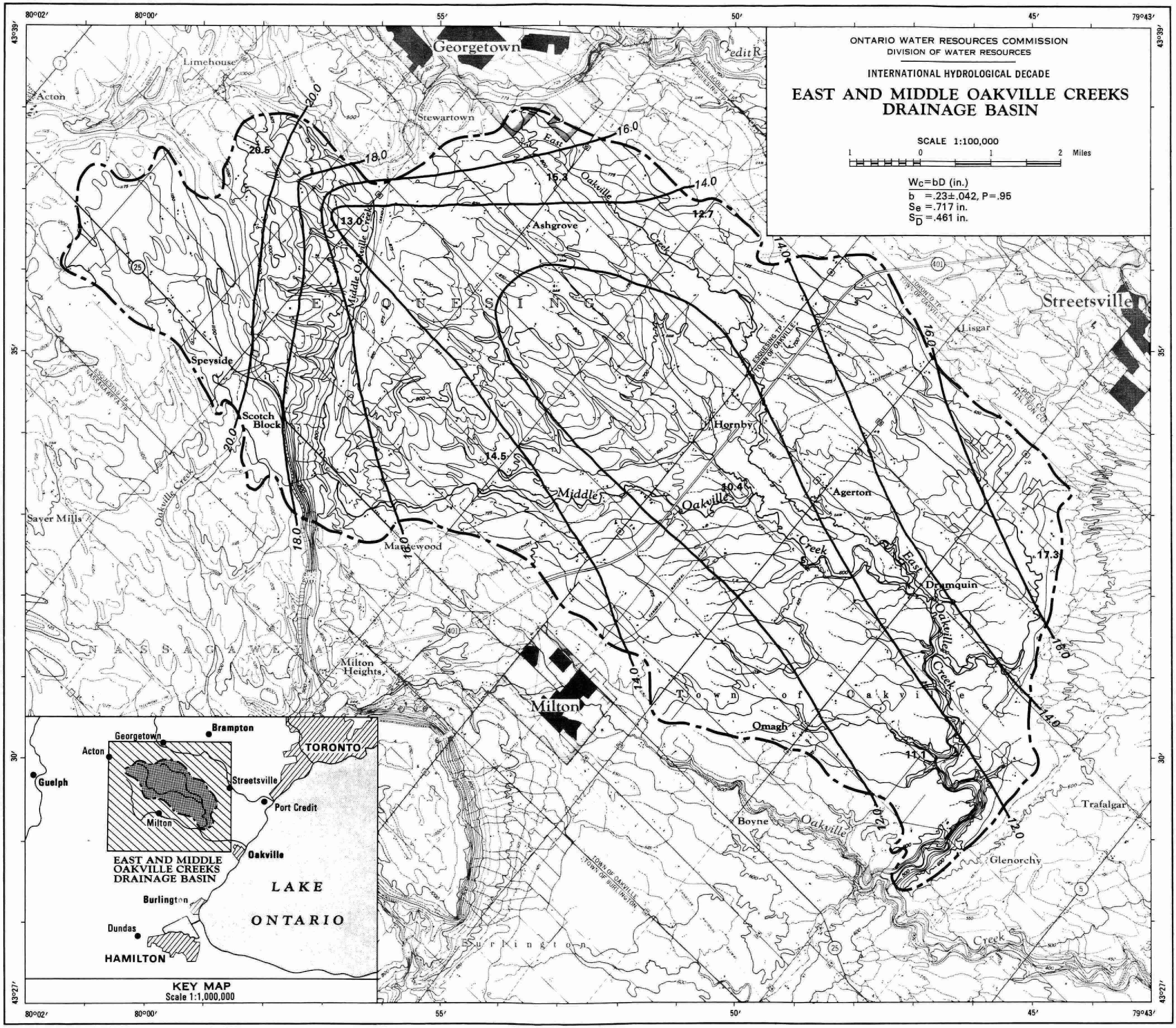


Figure 2. Isohyets of snowpack depth in inches – Survey period 15.1.69.

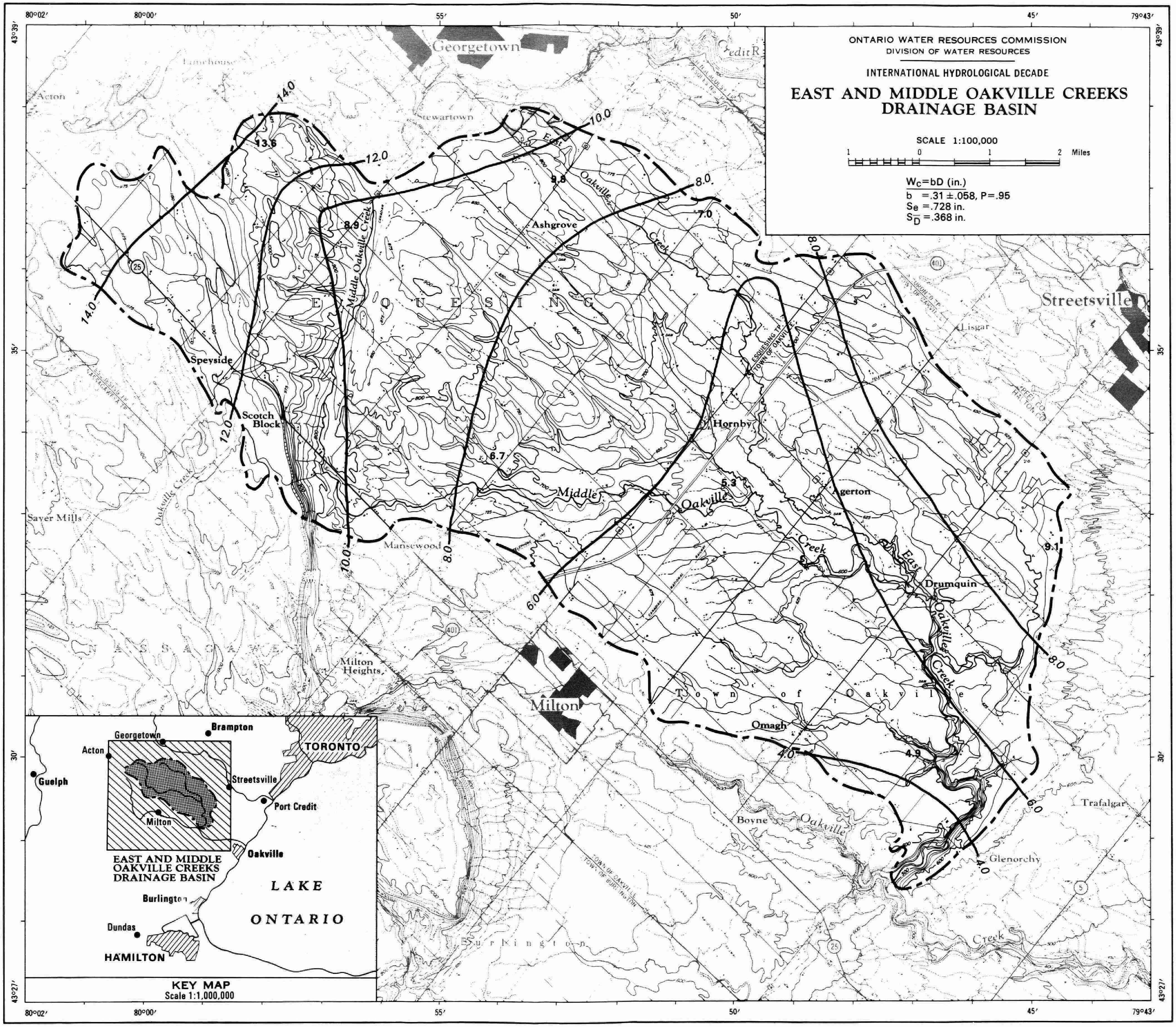


Figure 3. Isohyets of snowpack depth in inches – Survey period 27.1.69.

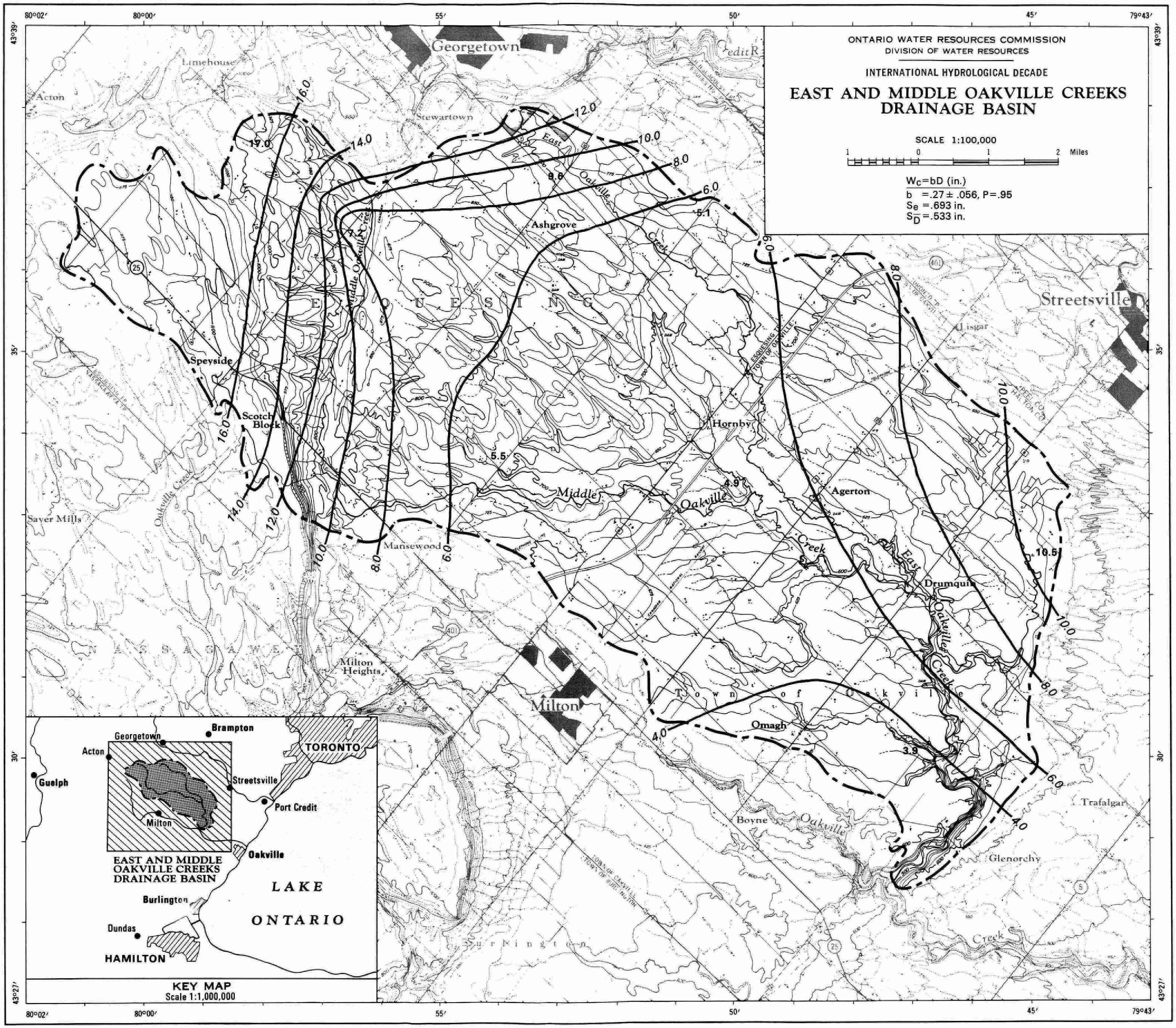


Figure 4. Isohyets of snowpack depth in inches – Survey period 5.2.69.

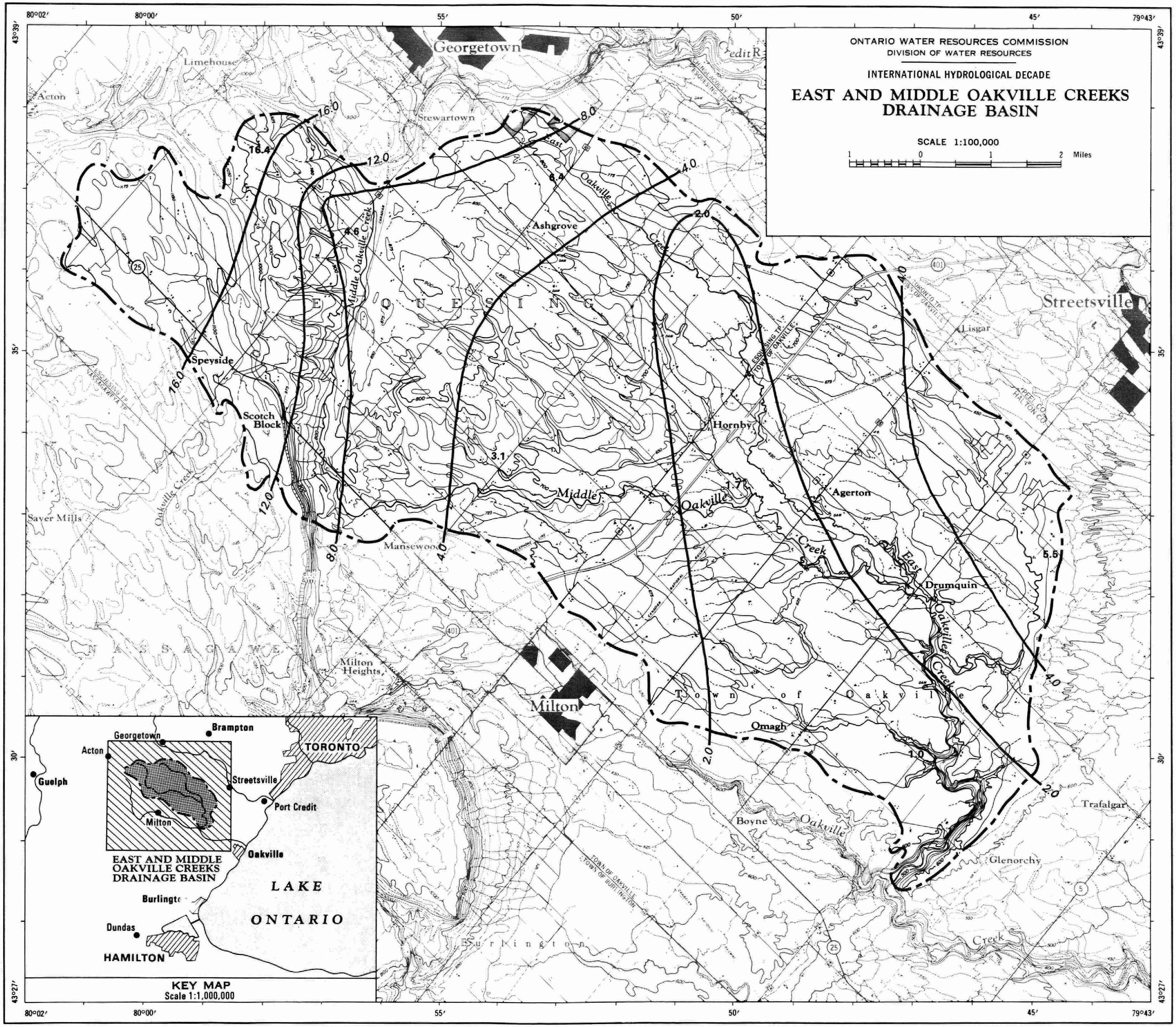


Figure 5. Isohyets of snowpack depth in inches – Survey period 26.2.69.

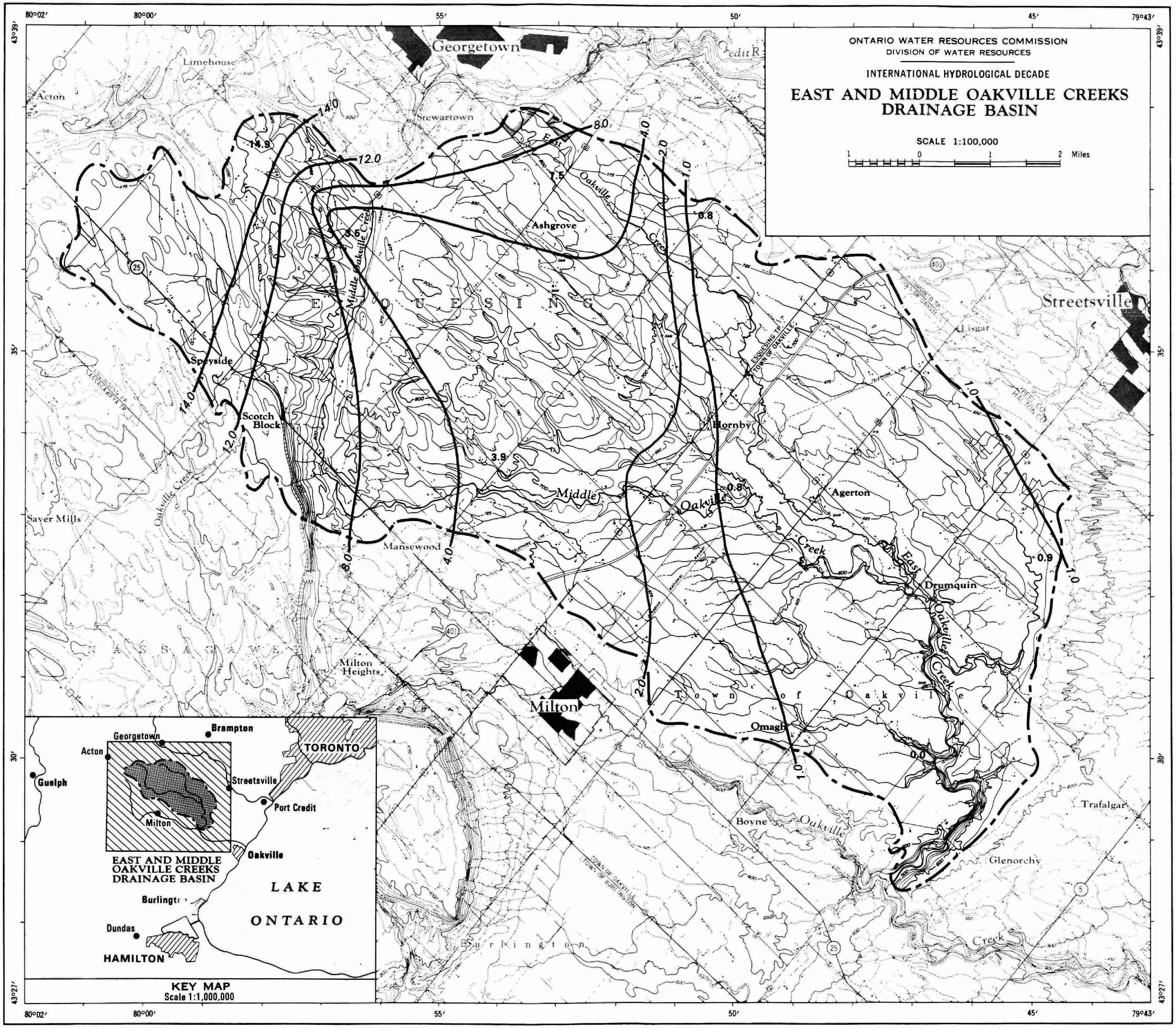


Figure 6. Isohyets of snowpack depth in inches – Survey period 14.3.69.