Application of transect method to soil survey problems

Agriculture Canada

Research Branch | Direction générale de la recherche

Canada

Application of transect method to soil survey problems

C. Wang
Land Resource Research Institute

LRRI Contribution Number 82-02

Research Branch
Agriculture Canada
1982

Copies of this publication are available from:
Land Resource Research Institute
Research Branch, Agriculture Canada
Ottawa, Ontario
K1A 0C6

Produced by Research Program Service

CONTENTS

LIST OF TABLES

LIST OF FIGURES

SUMMARY

Traditionally, in soil survey, much more effort has been put into the taxonomic unit than the map unit. Some of our map units are not well defined. Here, a method is described which can facilitate accuracy of mapping through the survey from legend development to completion.

The principle of the method is discussed and the procedures outlined. Examples from studies conducted in various regions of Canada and of the United States are given to illustrate various applications of the transect method. The statistical methods used in data compilation are described. The misconceptions about the transect method are also discussed.

Résumé

En matière de prospection pédologique, on a depuis toujours investi beaucoup plus d'efforts dans l'unité taxonomique que cartographique. Certaines de nos unités cartographiques no sont pas bien définies. La présente décrit une méthode susceptible d'accroître la précision de la cartographie pendant tout le processus de prospection, de l'élaboration de la légende jusqu'à son achèvement.

L'ouvrage étudie le principe qui sous-tend la méthode et en expose les techniques. Il donne des exemples de diverses régions du Canada et des Etats-Unis pour illustrer les applications de la méthode du transect. Il décrit également les méthodes statistiques utilisées dans la compilation des données, et examine les idées préconçues sur la méthode du transect.

1. INTRODUCTION

There is a general agreement among the pedologists that the taxonomic unit is conceptual while the map unit has geographical implications (Soil Survey Staff 1975, Mapping Systems Working Group 1981). Traditionally, much more study and effort has been put into the taxonomic unit than the map unit (Soil Survey Staff 1975, Canada Soil Survey Committee 1978). Taxonomic unit identification has been the subject of concern for correlation, while map unit definition has been left largely to the survey party leader. Thus the quality of map unit definitions has varied with the interest in and ability of the survey party leader to analyze the landscape and indentify the components thereof (Amos and Whiteside 1975).

A good soil survey report starts with a reliable soil map; a reliable map requires well-defined map units. Well-defined map units not only have the dominant soils and subdominant soils quantitatively defined, but also have the soil variability well defined within and between the different map units.

If one accepts the above requirements then it may be stated that some of our map unit descriptions prepared in the past were not well defined. We recognized these problems some years ago and thereafter began the work of developing a "mapping system for Canada" (Mapping Systems Working Group 1981). There have been numerous methods developed to check the accuracy of a map after the field work is completed; most depend on a return to selected sites for sampling on a more intensive scale.

The emphasis, however, needs to be placed on the development of procedures that facilitate accuracy of mapping throughout the survey from legend development to completion. These procedures should help us to understand and clearly describe to other specialists, and to the general public, the degree of variability among the components included in the map units.

One of the reasons the map unit was not adequately defined in the past was that the soil observations and samples were biased (Amos and Whiteside 1975). Although transects have been conducted by soil mappers for many years, this proposed "stratified random transect" (described in Section 3) is a fresh look at methods of examining landscapes and soils, of eliminating biased samples, of recording the observations, of analyzing the results, and of describing the variability observed. This refurbished and expanded approach should assist us to achieve better control of quality and accuracy (correlation) of the survey at all stages from beginning to completion and, of equal importance, enable us to inform the users of the data as to their reliability.

2. MISCONCEPTIONS ABOUT TRANSECT METHOD

Some common misconceptions about the transect method will be briefly discussed as follows:

2.1 It will Slow Down Soil Mapping

The differences between transect method mapping and the conventional or so called "free mapping" are in the approaches to a landscape and in the method of treating and collecting soil information.

In free mapping, one first tries to establish the relationship between soils and landforms by observing soils frequently on strategic points of a landform, including crests, midslopes, toes and depressions etc. Once the soil-landform relationship is established with some confidence, the "free" mapper will increase the rate of mapping on similar landforms by observing less frequently and only on relatively few strategic points (such as crest). Soil information is routinely collected from the observations of these strategic points. As a consequence, the soil information collected is close to that for the central concept of the soils occurring on the landscape, even though many descriptions were made and soil samples were taken and analyzed. The range of variation ascribed to the soil in the legend and report is usually much narrower than the real occurrence on the landscape.

By using the transect method, one may approach the same landscape by randomly selecting a few representative transects wherein observations will be made at fixed interval along the transects. Once the soil-landscape relationship is established (this may be indicated by the repetitive pattern among the similar landforms observed), the rate of mapping can be increased due mainly to the fact that fewer transects will be needed for the similar landscapes. Soil information collected by the transect method is distributed on a landscape without bias, and therefore a better estimate is determined of the real range of the variation of the soil (or map unit). The methods of selecting representative transects on a landscape and of the compilation of soil information will be discussed later in this paper.

The adoption of the transect method for soil mapping should not increase the field workload as compared to our conventional "free mapping" method. In fact, Steers and Hajek (1979) demonstrated that in a certain area of Alabama, the transect method increased mapping productivity up to 500% over the conventional method while maintaining the same map quality.

2.2 It will Increase the Soil Laboratory Workload

The workload in a soil Laboratory is controlled by the nature of the soil survey project, how well the project leader wants to define his soil map units, the kind of soil properties to be characterized, whether all map units are to be defined to the same level of detail and accurracy (confidence level). The transect method provides a statistically sound system for soil sampling and observation, the samples chosen should be less biased than those taken in a conventional survey. The laboratory workload is not necessarily increased by use of the transect method.

If one is not satisfied with the accuracy of defined soil map units in our traditional soil survey reports and wants to have a much more accurately defined map units, then more soil laboratory data will be required as the need to improve soil survey reliability increases.

2.3 Its Use should be Restricted to Soil Correlation and for Checking Map Accuracy

Some people think of the transect method as a statistical sampling procedure designed for soil correlation and spot checking of map accuracy. They do not consider the transect method as a tool for quantifying map units or as a method for routine soil mapping.

It is true that the transect method is a good sampling method for soil correlation and spot checking. But as has been explained in section 2.1 the transect method is superior to the conventional "free mapping" method for routine survey. Some of the daily transect records compiled during the routine mapping can be used to quantify map units and thereby will greatly facilitate soil correlation and checking of soil map accuracy.

3. TRANSECT METHOD

Johnson (1961) explains the transect method as:

> Transect methods of area determination depend on the principle that total length of a given body along a straight line transect is directly proportional to the area of that body within the limits of the larger delineation transected.

Two kinds of transects may be used. The line intercept method (or line transect), requires the knowledge and prompt recognition of the soils along a transect and of the boundaries among them. The point intercept method (or point transect) identifies soil units at predetermined intervals. Dos Santos (1978) compared the two transect methods on various types of terrain and found the point transect method to be superior. In this publication, the transect method refers mainly to point transect.

The transect method defined in this paper can be applied to soil survey in two tiers: setting up map units and associated routine mapping; and soil correlation for checking mapping accuracy and quantifying map units.

In setting up map units and in routine mapping, the transects commonly pass through one or more soil delineation lines. The information obtained along these transects is used to form the concepts of specific map units as well as to delineate one map unit from another. In this situation, the information gathered along the transect should not be used in statistically quantifying the map units of the delineations involved.

A data set which was gathered to form and test the concept of a map unit should not be used to test the accuracy of (or for quantifying) the same map unit. However, if the entire transect was within a delineation, the information obtained from this transect can be used to quantify (or test the accuracy) of the map unit.

In soil correlation, checking mapping accuracy and quantifying map units, new transects are normally required. The exceptions would be those transects which neither crossed polygon boundaries nor resulted in modifying those boundaries.

3.1 Selection of representative transects

The selection of unbiased transects for observation is the most crucial part of the transect method. The principle of random and stratified random sampling as well as some examples are to be discussed.

3.11 The principle of stratified random sampling

It is important to have the biased transects eliminated and to have the transect mapping information and the characteristics of the soil map units defined by unbiased samples.

The principle of random selection is to eliminate biased samples. Usually the more one knows of a certain population the better one can eliminate the biased samples, and fewer samples will be needed to characterize the population. The material that follows introduces some basic statistical concepts and indicates how to reduce the number of samples required.

Variance of a mean $S^2_{\bar{x}} = S^2_{\bar{n}} \left(\frac{N-n}{N}\right)$ ....(1)

where, S^2 = population variance; n = sample size; and $\left(\frac{N-n}{N}\right)$ is the finite population correction. In soil survey, the number of selected transects (n) is always much smaller than the potential available transects (N). Therefore, $\frac{N-n}{N} = 1$ and the equation (1) becomes $S^2_{\bar{x}} = S^2_{\bar{n}}$ .....(2).

In a soil map unit, one can view soil characteristics such as pH, color, texture etc. of the map unit as populations, each of which has a range of variations, within delineations and between samples. The estimated mean population property ($\bar{x}$) is often expressed in term of confidence interval ($\bar{x} \pm tS^2_{\bar{x}}$), where t is a constant when degree of freedom and confidence level are fixed. The narrower the confidence interval (associated with small $S^2_{\bar{x}}$ value) the more precise the statement. In order to narrow the confidence interval, from equation (2), one may either increase the sample size n (more observations and transects) or decrease the population variance S^2. And the confidence interval can also be narrowed by lowering the confidence level.

Steel and Torrie (1960) stated that the obvious way to decrease a population variance is to construct strata from the sampling units, the total variation being partitioned in such a way that as much as possible is assigned to differences among strata. In this way, variation within a stratum is kept small. Variation among the means from different strata in the population does not contribute to the sampling error of the estimate of the population mean (Steel and Torrie, 1960).

The principle of stratified sampling can be applied to the routine transect method of mapping. For instance, before one goes into an area to survey, much soil-related information pertinent to the area is readily available. Examples are: information on geology or geomorphology, aerial photographs, vegetation patterns, topographic maps, and sometimes even an old soil map and report. We should use this available information to stratify the soil population, and to eliminate biased transects. These selected unbiased transects hereafter will be called stratified random transects (SRT).

3.2 Examples of Selecting Stratified Random Transects (SRT)

3.21 Size of delineations

The size of delineations of a certain map unit usually varies widely on a soil map. If one wishes to use the transect method to characterize that map unit, one should stratify the transect observations in accordance with the distribution of delineation size. For example, suppose that map unit A has a total of 100 delineations on a map and the size of delineation varies from less than 1 cm^2 to nearly 50 cm^2. Among the 100 delineations 70 of them have an area less than 5 cm^2 and account for about 30% of the total area of map unit A. The other 30 larger delineations make up the remaining 70% of the area of map unit A. In a random transect selection assuming a normal distribution of polygon size, theoretically one transect should be placed on each delineation. Thus each delineation of whatever size will have equal chance to be selected to represent map unit A. As a result of this theoretical approach, 70% of the transects would be selected from 30% of the area (the smaller delineations). Obviously these would be biased samples. By using the information on size distribution of delineations, one can stratify the samples in accordance with the distribution of the population (in this case, the size of delineations). Thus we will randomly select 30% of the SRT from the smaller delineations and 70% of the SRT from the larger delineations.

3.22 Distribution of a certain map unit

Transect samples can also be stratified according to the known geographical distribution pattern of a certain map unit on a soil map. For example, if 50% of the area of a certain map unit is concentrated in the northeast corner of a map, then, one should have about 50% of the transects used to characterize the map unit selected from the northeast corner of the map.

In the initial stage of soil mapping, the selection of SRT is based mainly on the available information on geomorphology, geology, landform, vegetation etc. The experienced soil surveyors can also acquire much information from aerial photos. Transects will be then selected to test some of the hypotheses of the surveyors. Analyzing these preliminary transect data will indicate some soil-landform or soil-vegetation patterns and a preliminary map legend (or map key) can be established. As mapping progresses by the transect method, the soil-landform-vegetation patterns can be better established, map units better defined and map legend improved.

4. DETERMINE OBSERVATION INTERVAL OF A TRANSECT

Observation interval can be determined arbitrarily or by defined statistical means. The merits and limitations of these methods are discussed in this section.

4.1 Observation

Along a selected transect at fixed intervals on-site observations are made. Usually a brief soil description is recorded, and if analytical data are desired, soil samples are collected. To record the relevant site information, the soil surveyor can design a data form(s) to suit the immediate need. An example of this type of form is shown in Table 1. A modified CanSIS Daily Sheet (including a transect identification module) can also be used to record site information.

In transects located for the purpose of soil correlation or for checking of accuracy of a soil map, on each site of a transect one often only wants to decide either "Yes, it belongs in the certain map unit" or "No, it does not". In this kind of situation, Arnold's "Graphical solution of binomial confidence limits in soil survey" (1979) provides a basis for the reliable determination by a graphical method of confidence limits and thereby, eliminates all the statistical calculations. The Graphical method is discussed in section 6.4 of this paper.

4.2 Observation Interval (OI)

The interval between two consecutive observations on a transect is here called the OI. The OI is scale dependent; usually the smaller the map scale, the longer the OI. It varies also with the nature of landscape, the complexity of the soil map unit, the objective of the transect operation, and with consideration of cost effectiveness.

4.21 Optimum OI

Optimum OI is defined as the OI which will need the least equivalent effort in man-hours per km^2 for a defined map accuracy and confidence level, either to estimate map unit components, or to map a certain area.

Dos Santos (1978) estimated map unit components in some survey intensity level 5 soil maps by using survey intensity level 1 or 2 soil maps as ground truth. In a defined accuracy (90%) and confidence level (95%), he showed that the equivalent effort in man-hours per km^2 varied widely among the different OI (Figure 1). The OI which provides the minimal effort is the optimum OI.

Table 1. SOIL TRANSECT DATA SHEET

Page No. ________

Location		Map Unit
Transect No.	Observation Interval	Length (m)
Date	Photo	By

Remarks

Profile No. ________

Percent Slope | Aspect

Position on Slope

Horizon	Depth cm	Color	Mottles	Texture	Structure	Consis-tence	Others

Additional Notes*

Classification | | Series

Profile No. ________

Percent Slope | Aspect

Position on Slope

Horizon	Depth cm	Color	Mottles	Texture	Structure	Consis-tence	Others

Additional Notes*

Classification | | Series

* If soil sample is taken for analysis, check (✓) the appropriate horizon where sample was taken and record the soil sample no. as additional notes.

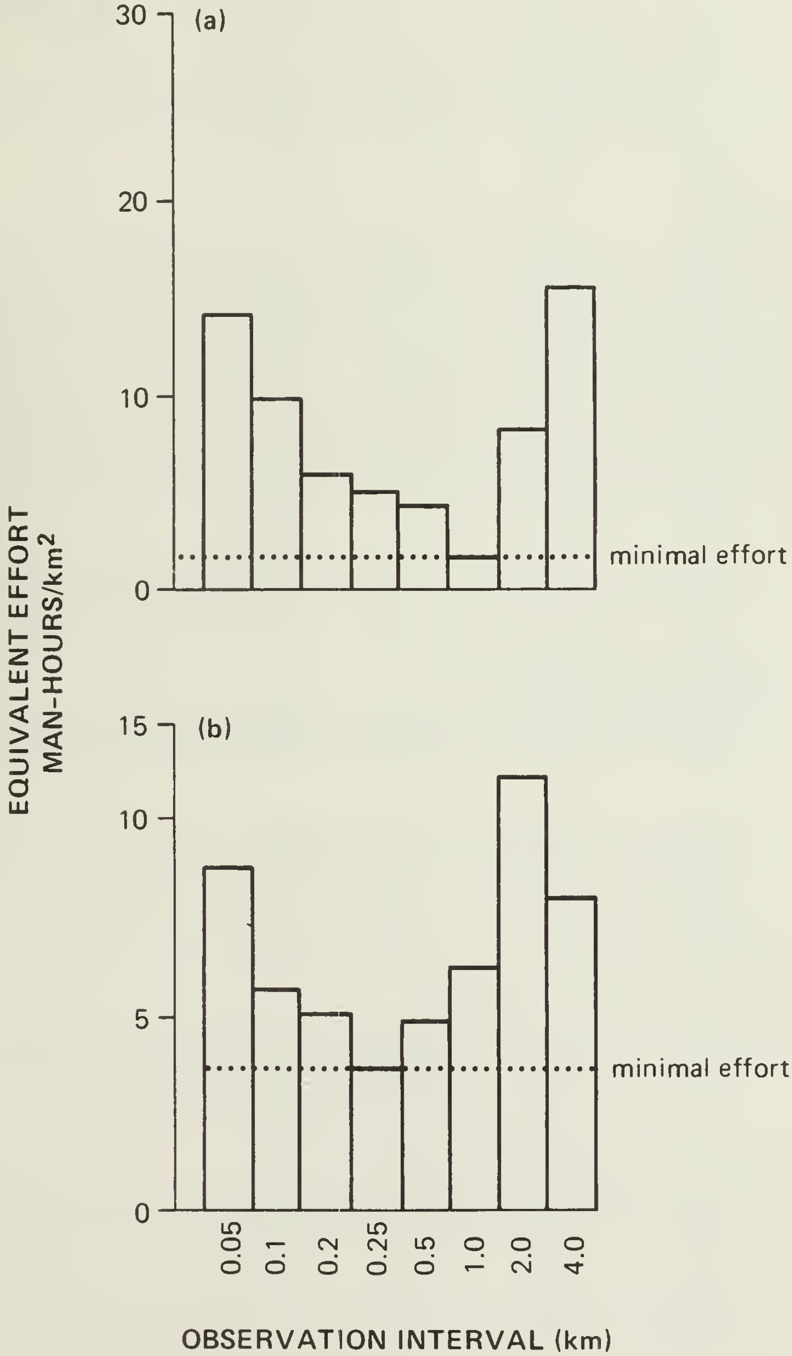

Figure 1. Equivalent effort in man-hours per km^2 in
(a) Irrigated crop land of near level terrain
(b) Forest land of mountain terrain (after Dos Santos, 1978)

The optimum OI will vary from one map unit to another and from one kind of landscape to another (Figure 1). The optimum OI usually increases when the map area is less complicated.

Although the optimum OI can be determined for all the map units, the procedures involved are time consuming and the method (Dos Santos 1978) is not suitable at the start of a survey project. Therefore, some more arbitrary methods to determine OI are necessary, at least in the earlier stage of mapping. The optimum OI of the major map units can be easily calculated from the transect information sheets in the latter stage of soil mapping in according to the method described by Dos Santos (1978).

4.22 Arbitrary OI

There are at least two arbitrary methods to determine OI: 1) One tenth to one twentieth of the length of a transect is used as OI - this is a convenient method with every transect having 10 to 20 observation points, therefore, all the transects carry equal weight in the statistical analysis. 2) Use half of the length of the shortest available transect of the map unit being studied as OI (usually about 0.5 cm on map) - in this way, the OI for many map units will be the same regardless of the length of the transect. It also becomes map scale independent in terms of cm on a map rather than km on the ground. However, within each transect, the number of observations will vary widely.

Method one is prefered because it gives every transect the same degree of freedom (i.e. 9 to 19) and makes the statistical compilation easier.

5. HOW MANY TRANSECTS ARE NEEDED

The major factors that determine the number of transects needed to characterize soil properties of a certain map unit are discussed in this section.

In estimating how many transects are needed, both Arnold (1979) and Hajek (1977) used the same equation:

In the equation $y = \frac{t^2 \ S^2}{d^2}$ .... (3)

where, y = number of transects needed

t = student "t" = $\frac{\bar{x} - \mu}{S_{\bar{x}}}$, $\bar{x}$ and μ are "estimated population mean" and "population mean" respectivity, where $S_{\bar{x}}$ is "standard error".

S^2 = variance

d = deviation allowed from the mean = $tS_{\bar{x}}$

There are three factors that control the number of transects needed to characterize a map unit or certain soil properties:

5.1 Confidence Level (CL)

Confidence level is an expression of the probability that a statement is correct. For instance, CL 90% means 9 out of 10 times, the statement is correct. In equation (3), the CL is reflected by "t" value. The higher the CL the higher the "t" value (Table 2), and consequently, more transects will be needed to achieve a higher CL.

Table 2. Student "t" Table.

Degree of freedom (df=n-1)	t value Confidence level			
	70%	80%	90%	95%
1	1.963	3.078	6.314	12.706
2	1.386	1.886	2.920	4.303
3	1.250	1.638	2.353	3.182
4	1.190	1.533	2.132	2.776
5	1.156	1.476	2.015	2.571
6	1.134	1.440	1.943	2.447
7	1.119	1.415	1.895	2.365
8	1.108	1.397	1.860	2.306
9	1.100	1.383	1.833	2.262
10	1.093	1.372	1.812	2.228
11	1.088	1.363	1.796	2.201
12	1.083	1.356	1.782	2.179
13	1.079	1.350	1.771	2.160
14	1.076	1.345	1.761	2.145
15	1.074	1.341	1.753	2.131
16	1.071	1.337	1.746	2.120
17	1.069	1.333	1.740	2.110
18	1.067	1.330	1.734	2.101
19	1.066	1.328	1.729	2.093
20	1.064	1.325	1.725	2.086
21	1.063	1.323	1.721	2.080
22	1.061	1.321	1.717	2.074
23	1.060	1.319	1.714	2.069
24	1.059	1.318	1.711	2.064
25	1.058	1.316	1.708	2.060
26	1.058	1.315	1.706	2.056
27	1.057	1.314	1.703	2.052
28	1.056	1.313	1.701	2.048
29	1.055	1.311	1.699	2.045
30	1.055	1.310	1.697	2.042
40	1.050	1.303	1.684	2.021
60	1.046	1.296	1.671	2.000
120	1.041	1.289	1.658	1.980
∞	1.036	1.282	1.645	1.960

5.2 Soil Variability

The complexity and variability of a soil or of certain soil characteristics, or of map unit components, is represented by S^2 in equation (3). A complex soil or map unit usually has larger S^2 values and will need more transects for its characterization.

5.3 Confidence Interval (CI)

The CI is an estimated range of a population mean ($\bar{X}$) of a certain property of a soil or map unit. It is commonly expressed as $\bar{X} \pm tS_{\bar{x}}$, where $S_{\bar{x}}$ = standard error. The CI is represented by d in equation (3), where d is the allowed deviation from the mean (arbitrarily set by surveyor or researcher); it equals $tS_{\bar{x}}$. Therefore, the smaller the deviation (d) allowed, the larger the number of transects needed.

The number of observations on each transect is important. By using equation (3), the inclusion of 10 or more observations per transect is assumed (Steers and Hajek 1979).

6. <u>OUTLINE OF TRANSECT METHOD PROCEDURES</u>

Some transect method procedures currently used in the United States are modified and outlined here.

6.1 In Legend Establishment and Field Mapping

The transect method involves the following steps (modified after Hajek 1977):

6.11 An adequate amount of time is devoted to soil identification and landscape evaluation so that the key soil association patterns for the mapping units can be established. After the map units are designed, areas are traversed and delineated on field sheets. All delineations are investigated to some extent and projected boundaries are checked by on-site soil investigation.

6.12 As a part of the preliminary (25%) field mapping and investigation, available transects* are identified which in the soil scientist's judgement (principles of how to select SRT are used here) fairly represent all delineations of the map unit. These available transects are distributed evenly among the map unit delineations in the survey area in order to characterize areas representative of the map units, for the most common probable use. These transects are examined and site data recorded.

Each delineation, no matter how large or small, should include a minimum of 1 potentially available transect. Transects are commonly located at right angles to an observable pattern whether the pattern be drainage, elevation etc. The important thing is to include as much of the complete range in variation as possible, and represent the typical landscape for the area delineated.

---

* Those transects reasonably accessible to the surveyor.

Table 3. Percent of Various Soils Observed in Transects of Eustis-Troup Map Unit (Data obtained from Hajek 1977).

Soil	Transects															
Series	1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	ΣX
									%*							
Eustis	37	25	29	37		13	13	8			8	25	9	36		240
Dorovan	9	8			7		6				21	16				67
Esto	18	17	14	10	28	13	13	15	45	18	35		17		17	260
Osier	9	8	7	9	7	8	6	8				25	8	19		114
Troup	18	25	36		43	33	31		19	8	14	17		36	34	314
Bibb	9		7	9				8	9	8	8		17		8	83
Norfolk		17	7	18	15	33	31	61	27	58	14	17	41	9	41	389
Goldsboro				18						8			8			34

* % of a certain soil in a transect

Table 4. Statistical Analysis of Eustis-Troup Map Unit

	Eustis	Dorovan	Esto	Osier	Troup	Bibb	Norfolk	Goldsboro
ΣX	240	67	260	114	314	83	389	34
$\bar{X} = \frac{\Sigma X}{n}$ (%)	16.0	4.5	17.3	7.6	20.9	5.5	25.9	2.2
$\Sigma(X^2)$	6672	927	6408	1538	9506	837	14679	452
$(\Sigma X)^2$	57600	4489	67600	12996	98596	7744	151321	1156
$\Sigma(X - \bar{X})^2 = \Sigma(X^2) - \frac{(\Sigma X)^2}{n}$	2832	627	1901	672	2933	378	4591	3752
$s^2 = \frac{\Sigma(X - \bar{X})^2}{n - 1}$	202	45	136	48	210	27	328	27
$s_{\bar{X}}^2 = \frac{s^2}{n}$	13.5	3.00	9.0	3.2	14.0	1.8	21.9	1.8
$s_{\bar{X}}$	3.67	1.73	3.00	1.79	3.74	1.34	4.68	1.34
$t\, s_{\bar{X}}$ at 80% confidence level	4.9	2.3	4.0	2.4	5.0	1.8	6.3	1.8
Confidence interval A (%) $\bar{X} \pm ts\bar{X}$	11.1-20.9	2.2-6.8	13.3-21.3	5.2-10.0	15.9-25.9	3.7-7.3	19.6-32.2	0.4-4.0
Confidence interval B (%) $\bar{X} \pm \bar{X}\ (0.3)$	11.2-20.8	3.1-5.9	12.1-22.5	5.3-9.9	14.6-27.2	3.8-7.2	18.1-33.7	1.5-2.9
No. of transects needed for confidence interval B $y = \frac{t^2\ s^2}{d^2}$	15	44	9	16	10	17	10	112

Where:

- $\bar{X}$ = mean percentage of a certain soil found in a map unit
- n = number of transects observed. In this example, $n = 15$
- s^2 = estimate of variance
- $s\bar{X}$ = standard error
- t = see Table 1. In this example, at 80% confidence level and df = 14, $t = 1.345$
- y = number of transects needed for a specific confidence level and specific confidence interval
- d = deviation allowed from the mean $(\bar{X}) = ts\bar{X}$

6.13 A record of each transect completed is maintained and evaluated (method described in section 6.15). After a sufficient area of a particular mapping unit is mapped (about 25% of its expected occurrence), some initial estimation of the map unit can be provided, and some soil-landform patterns can be formulated or suggested. More transects will be selected during the routine mapping to test these patterns. The total number of transects for initial sampling varies with estimated probable extent of the unit, the number of delineations, the complexity of soil patterns, and the objectives of the survey project.

6.14 Transects should include between 10 and 20 observations. Intervals between observations vary depending on the length of transects. (There are other options, which have been discussed earlier in this paper.) Data are recorded in terms of percent composition of various included soils (or any other soil characteristics of the map unit) (Table 3). The first and last observations of a transect were usually located at half of the observation interval from the boundary of delineation.

6.15 Statistical analysis includes a simple one-way analysis of variance (Steel and Torrie, 1960) that provides estimates of variance and gives the following useful parameters (Table 4):

a. arithmetic mean for each specific soil component,
b. number of traverses (y) (On average, should have at least 10 observations per transect.) needed to determine soil components at a specific confidence level (80%)*, and
c. confidence interval (of a mean) at a specific confidence level (80%).

6.16 The statistical data are used by party leaders in writing their mapping unit descriptions. These data become the basis for land use planning and interpretations before completion of the survey. Some delineations of a few map units may be inconsistent in soil composition at the first sampling. Further study of these map units likely will reveal that some delineations are mapped too broadly for the original mapping unit definition. In these instances a reinvestigation of questionable delineations should be performed, and an additional map unit should be designed and evaluated by the same stratified random transect procedures. Such inconsistencies commonly show up at the time transects are completed and before statistical analysis.

6.2 In Finalizing the Soil Map Units and in Soil Correlation

After 80-100 percent of field mapping is completed another stratified random sampling is conducted. A guide for the number of transects (sample size) needed is determined by considering data from the initial sample. In determining the number of transects for final sampling, one uses "y" values that give the transects needed to characterize about 80% of soil

---

* The confidence level can be set at any desirable level (see Table 2).

occurrence. Populations for final random sampling include the complete available transect population and each has an equal possibility of being selected. These data are analyzed in the same manner as the initial sample, summarized, recorded, and used in preparation of the soil survey manuscript.

Tables 1, 3 and 4 show the field data form used, summarized data, and a statistical worksheet for the Eustis-Troup complex map unit in Alabama. The number of transects needed to characterize this unit at confidence interval A (Table 4) was based on the highest "y" value (i.e. 15) calculated from among the series that make up 80 percent of the map unit that is, Eustis, Esto, Troup and Norfolk. Although the four major soils deviate less than 30% from the mean (i.e. $\bar{x} \pm \bar{x}d$, where $d \leq 0.3$), the minor soils deviate much more than 30% of the mean (Interval A of Table 4). If d is allowed to deviate not more than 30% of the mean of all soils in Eustic-Troup Map Unit (confidence interval B), some of the minor soils, such as Dorovan and Goldsboro will need 44 and 112 transects respectively to characterize their percentage occurence. Obviously, this is unrealistic and unnecessary. In most occasions, we will simply indicate the proportion of the minor soils (inclusions) as less than 5% or 10%. Therefore, only a few transects will be needed to characterize the minor soils.

For less complicated map units of the Alabama study area, the calculated "y" value was almost always found to be less than 10 and usually less than 5 at the stage when 25% of the mapping was completed. These values were confirmed when 95% of the area was mapped.

6.3 In Soil Interpretation

Certain properties of map units often hold the key to interpretations. For example, hydraulic conductivity is the key to interpretation for septic tank; soil texture, climate and drainage for interpretation related to frost action; slope and texture for interpretation about erosion etc. Each soil property of a map unit observed during the field survey and the analytical data measured in the field or laboratory can be analyzed by modern statistical methods and quantitatively expressed.

6.4 Arnold's Graphical Method

For the purpose of soil correlation and as a check for map accuracy Arnold (1979) introduced the graphical binomial confidence limit method (Fig. 2 and 3), which is simple but effective. The transects used are randomly selected by methods similar to those described above.

6.41 Use of Confidence Level

In making probability statements there are trade-offs to be evaluated. For any set of observations, one can vary the chances of being wrong (confidence level) or one can vary the limits of accuracy (degree of correctness). It is always a compromise.

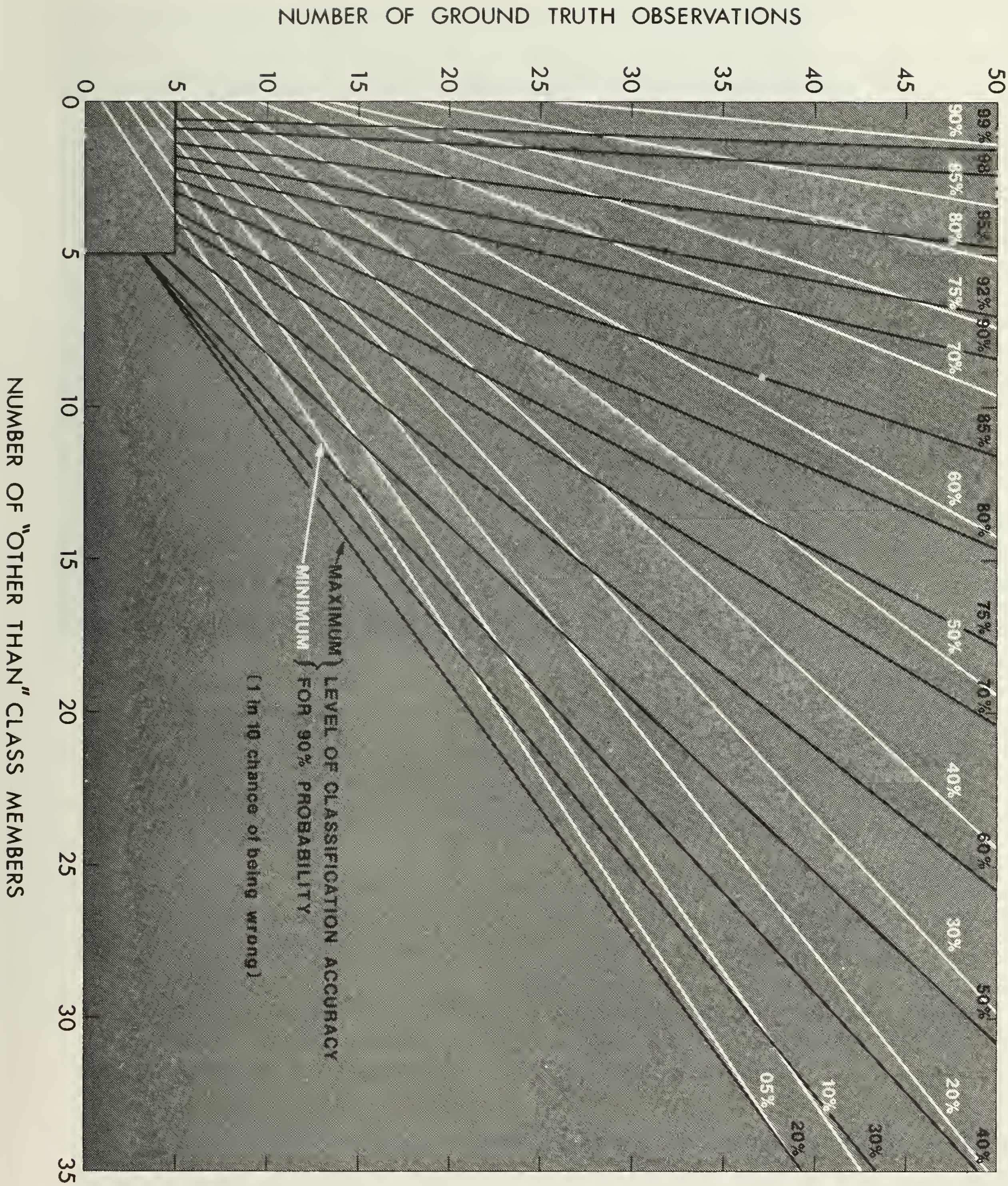

Figure 2. Arnold's Binomial Confidence Limit Graph for 0 to 50 Samples.

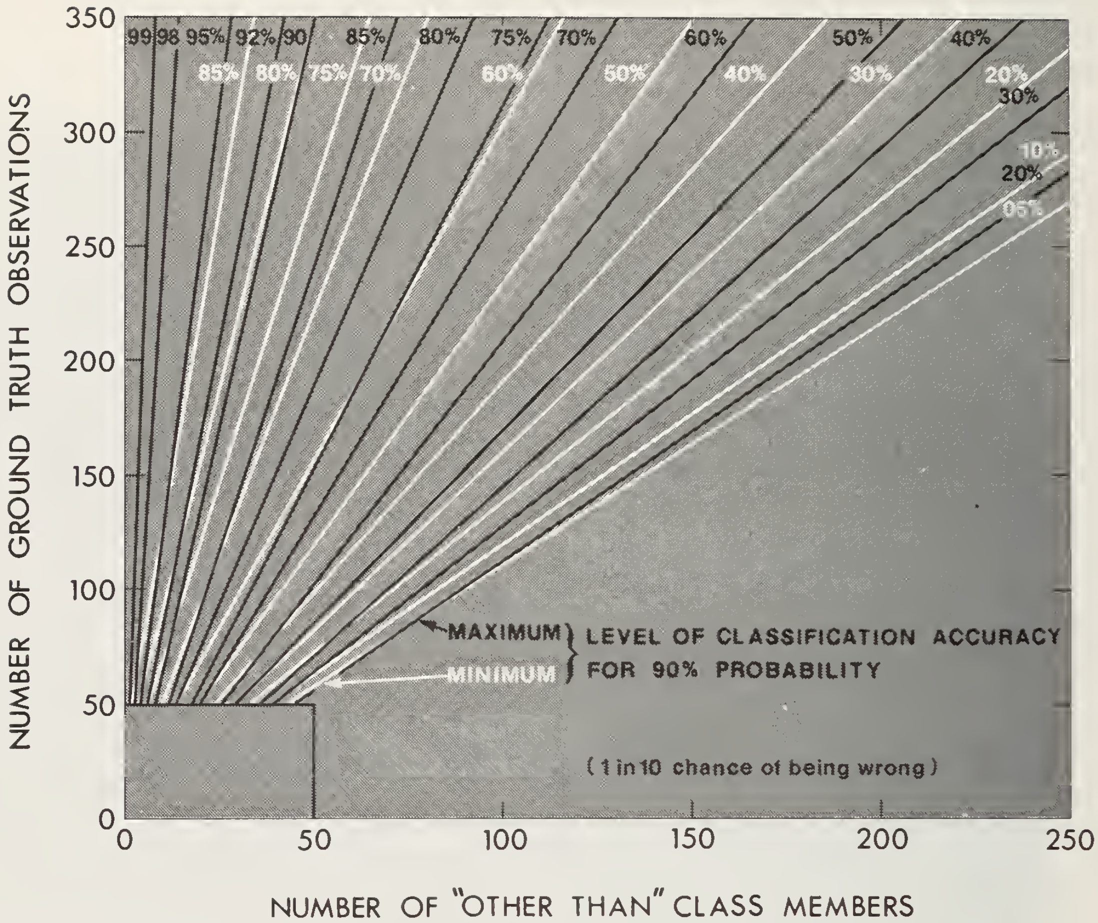

Figure 3. Arnold's Binomial Confidence Limit Graph for 50 to 350 Samples.

For illustration purposes, the graphs presented here represent only one level of confidence, 1 in 10 chances of being wrong (90% confidence level). For each confidence level there are 2 graphs; Figure 2 gives confidence limits for 0 to 50 samples, Figure 3 for 50 to 350 samples. Thus one has some flexibility in the size of sample chosen.

A lower limit (or minimum accuracy) lets the surveyor make an at least statement. An upper limit (or maximum accuracy) lets him make an at most statement.

Assume the surveyor completes 4 transects having 13, 9, 7, and 11 observations for a total of 40. Out of that 40 only 30 belong to the same class. The predicted maximum accuracy is calculated to be about 83%, the minimum accuracy about 62%. He therefore estimates the map unit contains between 62 and 83% of the major component based on the observations and acceptance of a 1 in 10 chance of being wrong.

6.42 How Many Samples to Take

The minimum number of observations to make varies with the chances of being wrong (confidence level) and the level of accuracy (degree of correctness) desired.

The graphs for the lower confidence limit can be used to estimate how many samples are needed. If one sets the probability at 90% and desires the estimates to be at least 80% accurate when applying the sample results to the rest of the map unit, then Figure 2 is used in the following manner.

Follow the 80% line for minimum level of classification accuracy down to the Y axis where there are 0 "other than" class members and read 14. This means there will be 14 random observations all belonging to the same class, that is, 14 out of 14. If, on the other hand, one finds 3 observations that belong to other classes, then go to 3 on the X axis and vertically to intersect the 80% accuracy level and over on the Y axis where it indicates a need for about 34 observations. This means that with 31 out of 34 observations belonging to the same class, one will expect an 80% accuracy of the major component.

Another way to think about the number of samples required is exemplified by the following. Two hundred observations must not include more than about 27 of "other" classes if 80% accuracy is to be achieved.

The graphs for upper confidence limits are not applicable to estimate sample numbers. By looking at one of the upper limit graphs, the reader will see that the lines do not intercept the Y axis above zero, because we do not know what constitutes a negative sample.

7. SOME LOCAL EXAMPLES

An example from Alabama (Table 3 and 4) demonstrated how the transect method can be used to characterize a very complex map unit. The discussion of the Alabama example is presented in section 6.15 and 6.2.

Three more local examples (one from Ontario, two from Quebec) are presented here to illustrate some other functions of the transect method in soil survey operation.

7.1 Quantifying Some Chemical and Physical Properties of a Map Unit.

7.11 Situation

A relatively uniform soil map unit, Dalhousie (D/4.1), on the soil map of Gloucester and Nepean Townships (Marshall et al, 1979) near Ottawa was studied. Dalhousie is developed on marine clay with nearly flat topography. All delineations of the studied Dalhousie map unit are cultivated.

7.12 Purpose

To define quantitatively some selected soil properties of the Dalhousie map unit and to determine whether there is a significant difference between small and large delineations?

7.13 Method

All the delineations of the Dalhousie map unit were numbered on the map. The numbered delineations were divided into two groups, in one group all the delineations were larger than 50 hectares, and in the other group, less than 50 hectares.

Because the marine clay is relatively uniform in composition and landform, we randomly chose only five delineations from each group, and one transect was randomly located by spinning a pencil on each of the chosen delineations (the transect was located more or less near the center of the delineation). For each transect, a total of ten sites at an observation interval of one tenth of the length of the transect were examined. A brief soil description and two soil samples: a surface sample at 0 to 15 cm (Ap); and a subsoil sample at 50 to 60 cm (CBg); were taken from each site. Soil samples were air dried, sieved (passing 2 mm sieve) and analyzed for a number of selected soil properties.

7.14 Results and Discussion

Selected results are presented in Tables 5, 6 and 7. Methods for calculated means ($\bar{x}$), standard deviation (S) and deviation of means ($S\bar{x}$) are in Table 4. The equation for calculating pooled deviation (Sp) is the same as for calculating standard deviation (S) for each transect, except that the number of samples (n) is 100 rather than 10 (as all samples in 10 transects were pooled together). The following are our main findings:

1) Because the samples were randomly selected laboratory data (Table 5 and 6) as well as field data (Table 7) they can be treated by statistical means.
2) The real range of soil properties quantified by the random transect method is wider than the range estimated by intuitive judgement based upon the central concept or modal profile method.

Table 5. % Org. Carbon in A Horizon

Transect No.	$\bar{x}$ (Mean)	S (Standard Deviation)
T1	2.03	0.76
T2	2.45	0.65
T3	1.71	0.25
T4	3.07	0.94
T5	3.58	0.73
T6	2.29	0.56
T7	3.08	2.19
T8	2.67	0.47
T9	2.09	0.63
T10	2.83	0.55

Mean ($\bar{x}$) of 10 transects	Deviation of means ($S\bar{x}$)	Pooled deviation (Sp) (100 samples)
2.58	0.54	0.90

At 80% confidence level:

1. Mean % Org. Carbon for a randomly selected transect

   $= \bar{x} \pm S\bar{x}t$

   $= 2.58 \pm 0.54 \times 1.38$

   or, from 1.83 to 3.32 (%)

2. Range of % Org. Carbon for a randomly selected sample

   $= \bar{x} \pm Spt$

   $= 2.58 \pm 0.9 \times 1.38$

   or, from 1.34 to 3.82 (%)

Table 6. % Clay in Subsoil (50-60 cm)

Transect no.	$\bar{x}$ (Mean)	S (Standard Deviation)
T1	34.0	4.9
T2	36.8	7.5
T3	42.7	8.5
T4	40.1	6.6
T5	25.6	5.0
T6	47.1	5.3
T7	49.0	3.4
T8	34.1	6.1
T9	31.8	9.6
T10	35.4	4.6

	Mean ($\bar{x}$) of 10 transects	Deviation of means ($S\bar{x}$)	Pooled deviation (Sp) (100 samples)
	37.7	6.8	6.8

At 80% confidence level:

1. Mean % Clay for a randomly selected transect

   $= \bar{x} \pm S\bar{x}t$

   $= 37.7 \pm 6.8 \times 1.38$

   or, from 28.3 - 47.1 (%)

2. Range of % Clay for a randomly selected sample

   $= \bar{x} \pm Spt$

   $= 37.7 \pm 6.8 \times 1.38$

   or, from 28.3 - 47.1 (%)

Table 7. Soil Color (value)

Transect no.	$\bar{x}$ (Mean)	S (Standard Deviation)
T1	4.0	0.447
T2	3.5	0.415
T3	3.4	0.436
T4	3.4	0.450
T5	3.0	0.000
T6	3.9	0.391
T7	3.9	0.320
T8	2.8	0.403
T9	3.1	0.150
T10	3.1	0.350
	Mean ($\bar{x}$) of 10 transects	Deviation of means ($S\bar{x}$)
	3.4	0.396

At 80% confidence level:

Range of value = $\bar{x} \pm S\bar{x}t$

$= 3.4 \pm 0.396 \times 1.38$

or Range from 3 to 4

3) There is no difference between large and small delineations in this map unit among the properties tested.
4) Should a major map unit be deemed to have too wide of a range of certain characteristics, the transect method can detect this problem at the early stage of mapping.
5) The statistical methods here described can be used to quantify soil properties only if the properties have a normal frequency distribution (i.e. % of clay and % of Org. C. in Figure 4). For the properties which are not normally distributed (i.e. Exch. Ca. and pH in Figure 4), a statistician should be consulted to transform the data into normal distribution before the final analysis.

7.15 The use of stratification in quantifying map unit

In the last example, the Dalhousie map unit is basically a single series unit and associated with a nearly level landscape. In this case soil characteristics of each soil delineation of the map unit can be treated as a statistically uniform entity. And soil properties such as means of clay and organic carbon content for each transect were the average of all the observation sites of the transect.

Most map units, however, contain more than one soil and have a more complicated landscape than the Dalhousie map unit. Due to the existance of different soils in a delineation, most map units cannot be treated as a statistically uniform entity. And the average of certain soil properties of all observation sites on a transect often make no sense. In order to make sense, stratification should be used in quantifying most map units. For example, a map unit in the undulating sandy coastal plain of New Brunswick often has clayey pockets associated with local depressions, and these clayey pockets are too small to delineate on a 1:50,000 scale map. Assume in a transect, we observed 8 sandy sites and two clayey sites. The overall average of the soil texture for this transect could be loamy if this map unit was treated as a uniform entity. Obviously, this would be wrong, since no part of the soil in this delineation had a loamy texture. Therefore, it is important to stratify soil and landform within a map delineation. In this New Brunswick example, the sandy and clayey soils and their associated landforms within a map delineation should be stratified so that they will be characterized as two separate entities.

7.2 Set Up Map Units for a Delta Terrace in Quebec.

7.21 Situation

A delta terrace of several km long and about 1 to 2 km wide is situated on a large deltaic plain of a agricultural community near Sorel, Quebec. The land on the shoulders of both sides of the terrace has been cleared (map unit C on Figure 5), and the plateau is largely wooded (map unit A and B). Map units A and B were separated mainly by the tone of the vegetation pattern on aerial photograph, whereas map unit C was based on the topographic position.

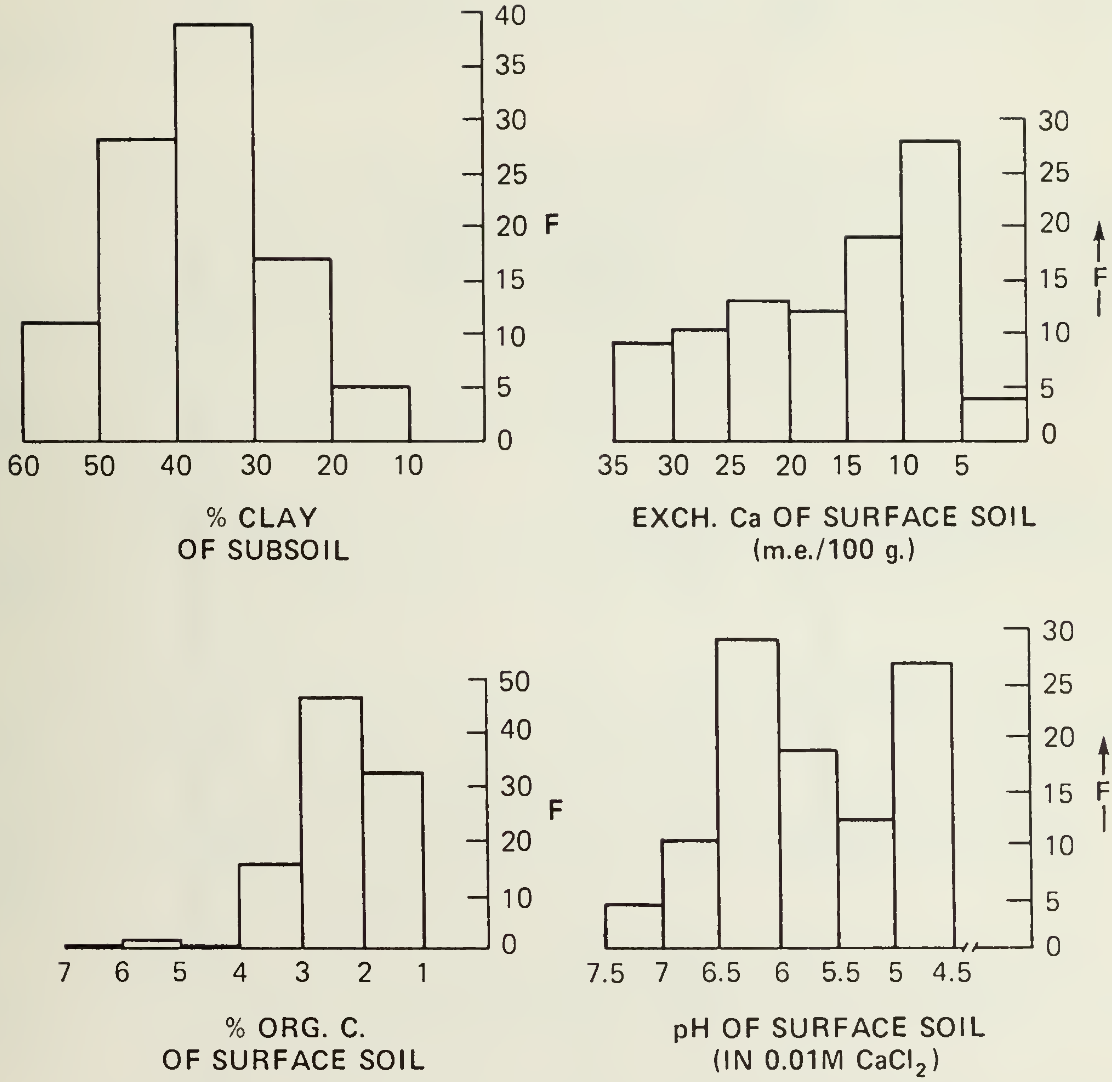

Figure 4. Frequency Distribution of a few Selected Soil Properties of Dalhousie Map Unit.

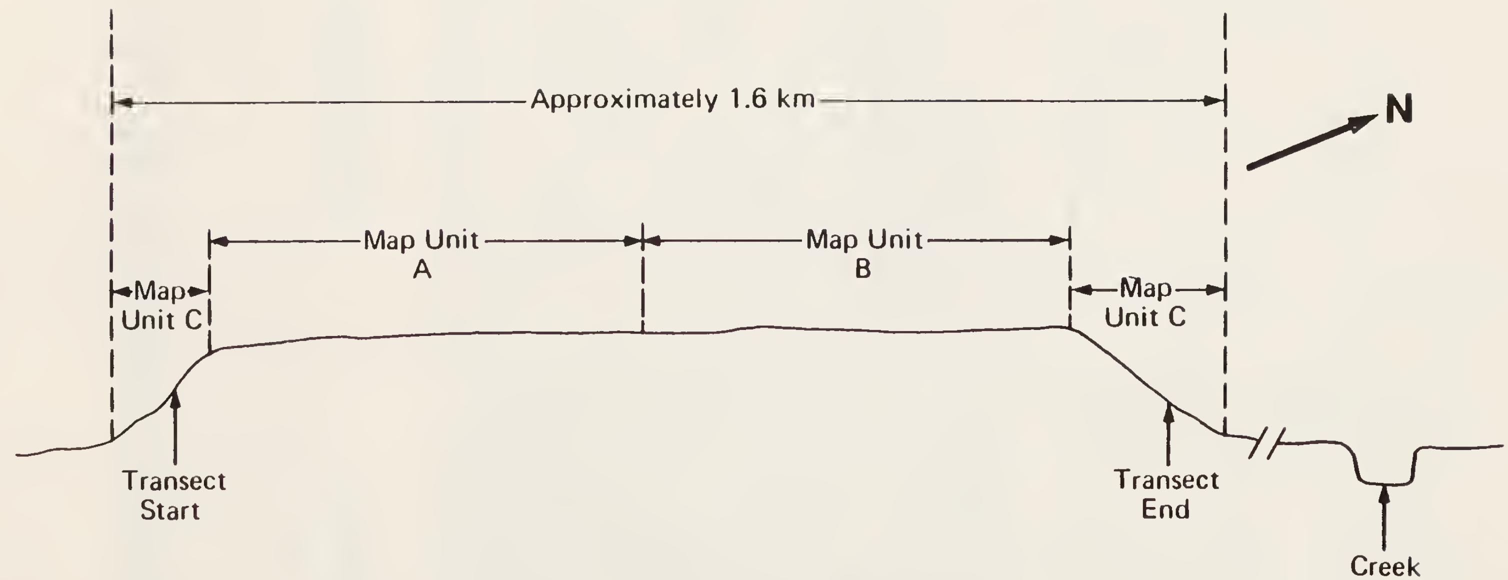

Figure 5. A Sketch of the Transect Across a Delta Terrace in Québec.

The soil survey Intensity Level (SIL) for this general area is SIL2. However, due to the lack of accessible roads in wooded areas, SIL3 is intended for the plateau area of the terrace. Although the wooded area has poor accessibility, there are a few roads across the delta terrace at about 2 km interval.

7.22 Questions

Is the range of the three map units delineated from an aerial photograph realistic? Are the topography and vegetation patterns reliable indicators to separate the map units?

7.23 Method

Since there is no reason to think that any of the roads across the terrace are biased, all the roads can be considered as potentially available Stratified Random Transects (SRT). For this preliminary study, only one of the roads was randomly selected (Figure 5). The transect is about 1.6 km long with the observation interval arbitrarily set at 100 m. Every observation site was about 10 m off the road to the west to avoid possible influence by the road. Relevant soil properties of each site were recorded (examples on Table 8). A total of 15 observations were made on the transect in about 3 hours.

7.24 Results

Some soil characteristics of the three map units were summarized in Table 9. Both map units A and B were dominated by Orthic Humic Podzols whereas map unit C was basically all Gleyed Humo Ferric Podzol.

7.25 Discussion

The differences in the map unit A and B are considered to be small and low contrast for most of the land use purposes. The soils are the same in texture and drainage. Therefore, in a SIL3 survey, map units A and B should be combined as one unit. And the vegetation patterns on an aerial photograph which were used to separate A and B units are considered to be unimportant in identifying map units. In map unit C, the range of variation is narrow and all the observations are of the same soil (Table 9).

Therefore, as a result of this preliminary study, two map units can be distinguished: one associated with the shoulder positions of the terrace, and the other associated with the plateau of the terrace.

This preliminary transect also indicated that the variation within each map unit was small. Thus only a few transects (3 to 5) are needed to characterize adequately the map units associated with the delta terrace in this general area.

7.3 Mapping and Defining Map unit on a Flat Agricultural Area in Quebec.

SOIL TRANSECT DATA SHEET

Page No. ________

Table 8. Data Sheet of the Delta Terrace in Quebec.

Location Sorel, Que.		Map Unit	
Transect No. 81-001	Observation Interval 100 m		Length (m) 1.5 km
Date 81-6-17	Photo	By C. Wang etal.	

Remarks

Profile No. 1

Percent Slope 7% | Aspect S

Position on Slope near shoulder

Horizon	Depth cm	Color	Mottles	Texture	Structure	Consis-tence	Others
Ap	0-20			Lfs			
Bf	20-35	10YR 4/6		Lfs			
Bfj	35-55			Lfs			
C + Cg	55-100			S			

Additional Notes* Prominent mottles at 75 cm

Classification Gleyed H.F. Podzol | Series

Profile No. 2

Percent Slope level | Aspect

Position on Slope

Horizon	Depth cm	Color	Mottles	Texture	Structure	Consis-tence	Others
LFH	10-0						
Aeh	0-20	10YR 4/2		Lfs			
Bh	20-30	5YR 3/2		Lfs			
Bfjg	30-50			Lfs			
Cg	50+			S-Ls			

Additional Notes*

Classification Orthic Humic Podzol | Series

* If soil sample is taken for analysis, check (✓) the appropriate horizon where sample was taken and record the soil sample no. as additional notes.

Table 9. Summary of some soil characteristics of a transect on a delta terrace in Quebec.

Range of Map Unit A (6 observations)

Thickness in cm				Depth to	Texture		Classification
Ae	Bh	Bfg	Solum	Prominent Mottles	Surface	Subsoil	
5-20	3-30	0-30	35-70	10-50 cm	Lfs	Lfs-s	4 O.HP 1 Gl. HFP 1 Gl. HFP to OT.HFP

Note: Four had Bh horizon ≥ 10 cm
Two had Bfg horizon ≥ 10 cm

Range of Map Unit B (6 observations)

Thickness in cm				Depth to	Texture		Classification
Ae	Bh	Bg	Solum	Prominent Mottles	Surface	Subsoil	
0-15	0-17	0-13	25-60	0-45 cm	Lfs	Lfs-s	4 O.HP 1 O.HP to GL.HFP 1 O.HG

Note: Four had Bh horizon ≥ 10 cm
One had Bfg horizon > 10 cm
Three had Ap horizon
One had Bg horizon > 10 cm

Range of Map Unit c (3 observations)

Thickness in cm			Depth to	Texture		Classification
Ap	Bf	Solum	Prominent Mottles	Surface	Subsoil	
20-28	12-20	55-60	60-81	fsL	Lfs	GL.HFP

7.31 Situation

A SIL2 survey project is scheduled for a vast marine plain overlain by various kind of glaciofluvial material near Ste.Victoire, Quebec. This area is predominantly agricultural and has virtually no relief. Most of the area has been tile drained and a 40 yr old soil map is available (SIL 3). In the old soil map, most soil delineations are complexes of soil series. Three soil series dominanted:

St-Aimé	loam B over clayey C horizon;
Kierkosky	clay loam B over clayey C horizon; and
Aston	sandy B over clayey C horizon.

7.32 Questions

Can the transect method be useful in defining map units when there are no apparent soil-landform and soil-vegetation patterns? What is the best way to map an area like this?

7.33 Method

A random transect was selected, observation interval was arbitrarily set at 150 m. On every observation site, depth, color and texture of Ap, B, and C horizons and the depth to a calcareous layer were recorded (examples on Table 10). A total of 19 sites were observed on this transect in about 4 hours.

7.34 Results

All 19 sites are classified as Orthic Humic Gleysols. The colors of Ap, Bg and Ck are very similar for all sites. For the whole transect, surface texture (Ap) ranged from SL to L; thickness of Ap ranged from 20-28 cm; depth to calcareous layer (i.e. Ck) from 50 to 100 cm, but between 55 and 80 cm for 15 out of 19 sites; all but one Ck horizon had a texture of SiCL to SiC; two Bg horizons had sand layers more than 10 cm thick, two other Bg horizons had a clayey texture, the rest of the 15 Bg horizons had fine silty texture (mostly silt loam).

7.35 Discussion

The surface texture is relatively uniform therefore a surface texture phase may not be necessary. Color and texture of C horizons are not good criteria to differentiate the soils (or map units) because they were very much the same among all sites. Depth to a calcareous layer also varied within a reasonably narrow range.

The main differences were in the texture of the Bg horizon. The whole transect can be considered as dominanted by St.Aimé (fine silty Bg) with inclusions of Kierkosky (clayey Bg) and Aston (sandy Bg). Aston, however, has a highly contrasting sand layer of 10 cm or more within the top 50 cm. It may significantly affect the soil behaviour for agricultural use. In an SIL2 survey, all effort should be made to delineate Aston from other soils. If Kierkosky were treated as an inclusion in St. Aimé, this would not significantly affect the interpretation for agricultural use because the Bg of Kierkosky is only slightly more clayey than that of St. Aimé.

SOIL TRANSECT DATA SHEET

Page No. ________

Table 10. Data Sheet of the Ste. Victoire Area, Quebec

Location Ste. Victoire, Que.		Map Unit
Transect No. 81-002	Observation Interval 150 m	Length (m) 2.8 km
Date 81-6-18	Photo	By C. Wang etal.

Remarks

Profile No. 1

Percent Slope level | Aspect

Position on Slope

Horizon	Depth cm	Color	Mottles	Texture	Structure	Consis-tence	Others
Ap	0-22	10YR 3/2			SL		
Bg	22-53	10YR 5/2			SiL-CL		
IICkg	53+	10YR 4/2			CL-SiC		

Additional Notes* Silt lenses in Bg

Classification Orthic Humic Gleysol | Series Ste Aimé

Profile No. 2

Percent Slope level | Aspect

Position on Slope

Horizon	Depth cm	Color	Mottles	Texture	Structure	Consis-tence	Others
Ap	0-23	10YR 3/2		SL			
IIBg	23-75	10YR 5/2		CL-SiCL			
III Ckg	75+	10YR 4/2		SiC			

Additional Notes*

Classification O. Humic Gleysol | Series Kierkosky

* If soil sample is taken for analysis, check (✓) the appropriate horizon where sample was taken and record the soil sample no. as additional notes.

Therefore, if a few more transects give similar results, the recommendation would be to use a 150 m grid to map this area. Most of sites need only be observed to 50 cm, with inspections to 100 cm for every 5th hole to insure that the subsoil material is uniform. The key to the observation is the texture of Bg horizon, and effort should be made to delineate Aston from other soils.

From the examples discussed in this paper, one can see that the transect method can be used in various stages of soil survey operations as well as in solving various problems associated with survey. These examples also illustrated that some of the applications of the transect method need statistical analysis and compilation (the Ontario and Alabama examples) but the others (the two Quebec examples) need only the common sense of the surveyors to solve the problems.

This is only the first approximation of a report on the application of the transect method to soil survey problems. I would appreciate comments as well as examples of the application of transect method for future revision of this paper.

LIST OF REFERENCES

Amos, D.F. and Whiteside, E.P. 1975. Mapping accuracy of a contemporary soil survey in an urbanizing area. Soil Sci. Soc. Amer. Proc. 39:937-942.

Arnold, R.W. 1979. Strategies for field resource inventories. Agronomy Mimeo 79-20. Dept. of Agronomy, Cornell Univ., Ithaca, New York. 14853.

Canada Soil Survey Committee. 1978. The Canadian system of soil classification. Can. Dept. Agric. Publ. 1646. Supply and Services Canada. Ottawa, Ont. 164 pp.

Dos Santos, H.G. 1978. Some strategies of quality control for reconnaissance soil survey. Unpublished M.S. Thesis, Cornell Univ. Ithaca, N.Y. 128 p.

Hajek, B.F. 1977. Evaluation of map unit composition by the random transect method. Agronomy Mimeo No. 77-23. Dept. of Agronomy, Cornell Univ. Ithaca, New York. 14852.

Johnson, W.M. 1961. Transect methods for determination of composition of soil mapping units. Soil Survey Technical Notes, SCS/USDA.

Mapping Systems Working Group. 1981. A soil mapping system for Canada: revised. Land Resource Research Institute Contribution No. 142. Agriculture Canada, Ottawa, 94 pp.

Marshall, I.B., Dumanski, J., Huffman, E.C. and Lajoie, P.G. 1979. Soils, capability and land use in the Ottawa urban fringe. Land Resource Research Institute, Research Branch, Agriculture Canada.

Soil Survey Staff. 1975. Soil taxonomy. U.S. Dep. Agric. Handbook No. 436. U.S. Government Printing Office, Washington, D.C. 754 pp.

Steel, R.G.D. and Torrie, J.H. 1960. Principles and procedures of statistics. McGraw-Hill Book Co. Inc.

Steers, C.A. and Hajek, B.F. 1979. Determination of map unit composition by a random selection of transects. Soil Sci. Soc. Am. J. 43: 156-160.

ACKNOWLEDGEMENT

The author is grateful to R.W. Arnold who first brought to his attention in the spring of 1979, the new look of transect method and its application to soil survey.

He also would like to acknowledge many people who helped him in the field work: A. Montgomery, J.A. McKeague, C. Tarnocai and K. Wires in Ontario; R. Baril, M. Nolan and J. Cossette in Quebec; and R. MacMillan in Alberta.

Thanks are also extended to G.M. Coen, G. Patterson, W.W. Pettapiece, R. MacMillan, J.H. Day and J.A. McKeague for reviewing the manuscript. G.M. Coen's critical but constructive comments are most gratefully acknowledged.