Soil Mapping Systems

Prepared by the:
Environmental Research and Engineering Department
The Alberta Research Council

R.A. MacMillan - Senior Author
W.L. Nikiforuk, M.D. Fawcett, I.R. Whitson,
R.L. McNeil, L.W. Turchenek - Associate Authors and Contributors
R.W. Howitt, B.J. Sawyer - Editors

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EXECUTIVE SUMMARY

The purpose of this literature review and subsequent proposals is to establish a common understanding of soil mapping in Alberta in relation to other mapping options that may be available to produce soil map products for identified users in a time efficient manner.

Soil mapping has been an ongoing activity in Alberta since the early 1920's and has been conducted through cooperation between the Federal and Provincial Governments. Financial support for mapping in Alberta has declined from both levels of government over the past several years and continuation of the program has been subject to considerable discussion.

This document is a detailed review of the literature relating to mapping systems (Section II) leading to: a discussion of mapping system options and options for comparing mapping systems (Section III); a rationale for selection of mapping systems and evaluation / comparison options (Section IV); and then a series of proposals to produce and compare map products (Section V).

One mapping system was proposed for implementation in the 1992/93 fiscal year. The top down approach to mapping was deemed most likely to meet all of the criteria as discussed in Section IV. The extrapolatory mapping option (option 4) was used in the 1991/92 field season in conjunction with the County of Forty Mile soil survey and it was proposed that this mapping system be evaluated and compared to SIL3 1:50 000 mapping. Two map comparison techniques were proposed for implementation in the 1992/93 fiscal year. These techniques will be used to compare extrapolatory and top down mapping to SIL3 1:50 000 mapping.

BACKGROUND

- R.W. Howitt

I.A. INTRODUCTION

This document reviews soil mapping systems and proposes revised mapping systems to enhance the production of soil survey products for users of soil information. This document was prepared under the auspices of a Memorandum of Agreement between Agriculture Canada and the Alberta Research Council.

Soil surveys have been conducted in Alberta over the past 15 years at a scale of 1:50 000 as defined by Survey Intensity Level (SIL) 3 standards (Mapping Systems Working Group (MSWG) 1981). The SIL3 1:50 000 program evolved as a result of the recognition of the necessity to update older map products for current needs in decision support. The standards by which the SIL3 1:50 000 mapping was conducted were defined in terms of specific characteristics of the soil survey process (procedure intensity, method of field inspection, publication scale, taxonomy, rate of progress and typical survey objectives) (MSWG Table 2. 1981). These characteristics defined each SIL in terms of the physical effort required to make a soil map.

In Alberta, the SIL3 1:50 000 mapping standard requires approximately 10 person days of field effort per township, limits progress to approximately 10 townships per field party per year and results in costs ranging from $13,500 to $18,000 per township mapped. An estimate developed for the Alberta Coordinating Committee for Soil and Land Inventory (ACCSLI) in 1989 would see an increased effort in soil survey, resulting in the completion of the SIL3 1:50 000 mapping program for the settled area of the province in 15 years at a cost of 62 million dollars. The Federal Government has stated that field mapping is no longer part of its program (ECSS meetings 1990) and the Provincial Government, while supporting the SIL3 1:50 000 field mapping program, is not prepared to increase its financial commitment to the program at this time.

I.B. PROBLEM DEFINITION

Agencies involved in soil survey have concluded that neither continuing at the present rate of soil map production nor increasing the effort to produce soil maps are viable options given the current fiscal realities. Coupled with resource limitations, there is an increased demand by municipalities for soils information for the soil conservation program and for farmland assessment programs. Six requests for soil survey were reviewed and prioritized by ACCSLI in the fall of 1989 and several more requests have been received since that time. The demand for soil information and the slow pace at which soil mapping can be provided necessitated a review of soil mapping and soil inventory products for decision support.

The concept of mapping faster and with fewer field inspections has been discussed informally and at great length in Alberta over the past 10 years but little progress has been made in this area. Mapping evolved into a process defined by the number of observations per unit area as compared to developing and testing hypotheses about landscape systems.

The purpose of this document is to review alternate approaches to the production of soil inventory products and to propose an effective mapping system for the Province that will result in the production and dissemination of soil information products in a short turn around time. The proposed mapping systems would increase the rate of progress of providing soil inventory products to the user audience. The proposed mapping systems are designed to reduce the cost of field mapping, to increase the efficiency of mapping and to produce map products targeted for specific uses i.e. farmland assessment, soil conservation planning, and rangeland management to mention only a few. Two mapping systems were presented in the form of work plans for the Forty Mile and Rocky View projects (Howitt, pers. comm., (memo) July 17, 1992). A third mapping system involving the interpretation of existing surficial material and soil information, aerial photo interpretation and representation of the data using current terminology and technology has been discussed. This third approach involves limited field inspection. Each mapping system is discussed at some length in this document in light of other possible approaches.

Each mapping system will be compared to the SIL3 1:50 000 mapping standard in terms of accuracy, precision, utility and cost of production. The issue of comparing map products for specific uses is addressed in that information needs, which are required for decision making by different users, are variable.

I.C. REFERENCES

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PART 1:
LITERATURE REVIEW

INTRODUCTION

This literature review is intended to review existing published material on soil mapping systems in Canada and elsewhere. There are 6 major sections designed to review the soil mapping, user needs, traditional mapping, SIL3 1:50 000 mapping in Alberta, new and non-traditional mapping techniques, techniques for evaluating mapping and finally sampling strategies for mapping and map comparison.

II.A. THE PURPOSE OF SOIL MAPPING

- R.A. MacMillan

A.i. Introduction

The following section presents a discussion of the purpose of soil survey. It addresses the questions of why we make soil surveys, what we are trying to do when we make them and how we may measure if we have been successful in accomplishing our goals. It investigates both the institutional and technical objectives of soil surveys and discusses how to judge whether these are met by current soil surveys.

Two reasons have been advanced in support of the production of soil surveys. The first is institutional in nature and justifies soil survey in terms of the provision of decision support products to identified users. The second is technical in nature and presents an argument that the purpose of soil survey is to produce maps that partition the landscape into repeating units that, when described, assist users in making judgements about the potential uses or limitations of the mapped soils.

Two assertions about soil survey have been repeated so often that they have become operational paradigms. The first paradigm of soil survey is that the production of soil maps is not an end in itself but rather is undertaken to provide information in support of societal needs and objectives. The second paradigm is that the purpose of soil survey is to divide the landscape into repeatable landform units that contain a less variable assemblage of soils and soil properties than the landscape as a whole.

A.ii. Institutional Objectives and Rationale for Soil Surveys

The purpose of soil survey, from an institutional point of view, is to support the needs of users with reliable information about soil and land resources that will help them to manage or make decisions about use of the land. In Canada, the most important part of a soil survey plan is a clear statement of its objectives (Expert Committee on Soil Survey (ECSS) 1987). It is recognized that "the objectives of a soil survey will govern how a map is made", including specification of "the differentiating criteria for map units, the smallest area to be mapped, the type of legend, the survey inspection density and the publication scale" (Mapping Systems Working Group (MSWG) 1981).

Similarly, in the United States, it has been repeatedly emphasized that "you should not make a soil survey without knowing why you are doing it" and that "you must design your legend so that when a map is completed you are able to make the important interpretations that are needed for the use for which the soil is apt to be put" (Smith 1986).

Soil inventory agencies have explicit procedures to ensure that the design and planning of inventory programs produce the information required to fulfill the identified program objectives. In Canada, the procedures for planning and implementing a soil survey (Figure 2.1) specified in the Soil Survey Handbook (ECSS 1987) are followed by most soil survey agencies.

Internationally, the FAO framework for land evaluation (FAO 1976; Beek 1978) defines the most widely used procedure for identifying the land evaluations required of a soil survey and the land qualities on which the land evaluations are to be based. The creation of "matching tables" (Burrough 1989) is used to establish a link between the land qualities required to make evaluations and the land characteristics measured and recorded during the soil inventory.

Coulombe et al. (1981) provide an excellent conceptual analysis of the procedures and feedback loops (Figure 2.2) involved in the specification of inventory objectives and the design of appropriate soil surveys. Design specifications are based on legal mandates and program needs. Final designs are tempered by considerations imposed by existing theory and data and limitations imposed by available technologies. The design phase follows a succession from evaluation to characterization to inventory to classification. The intent is to define the evaluation products first, then the characterizations (land qualities) required

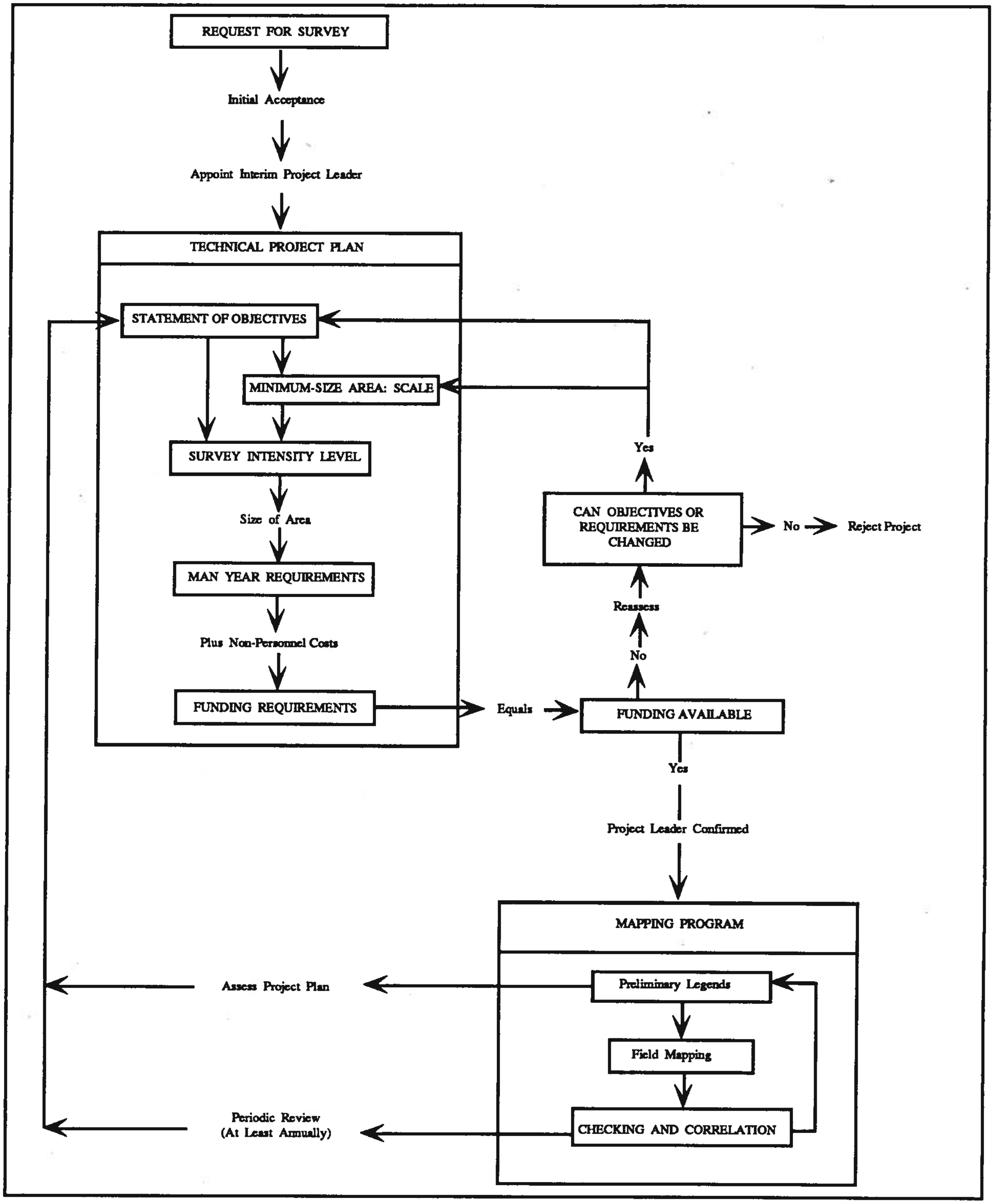

Figure 2.1 Flow diagram for planning a soil survey (ECSS 1987).

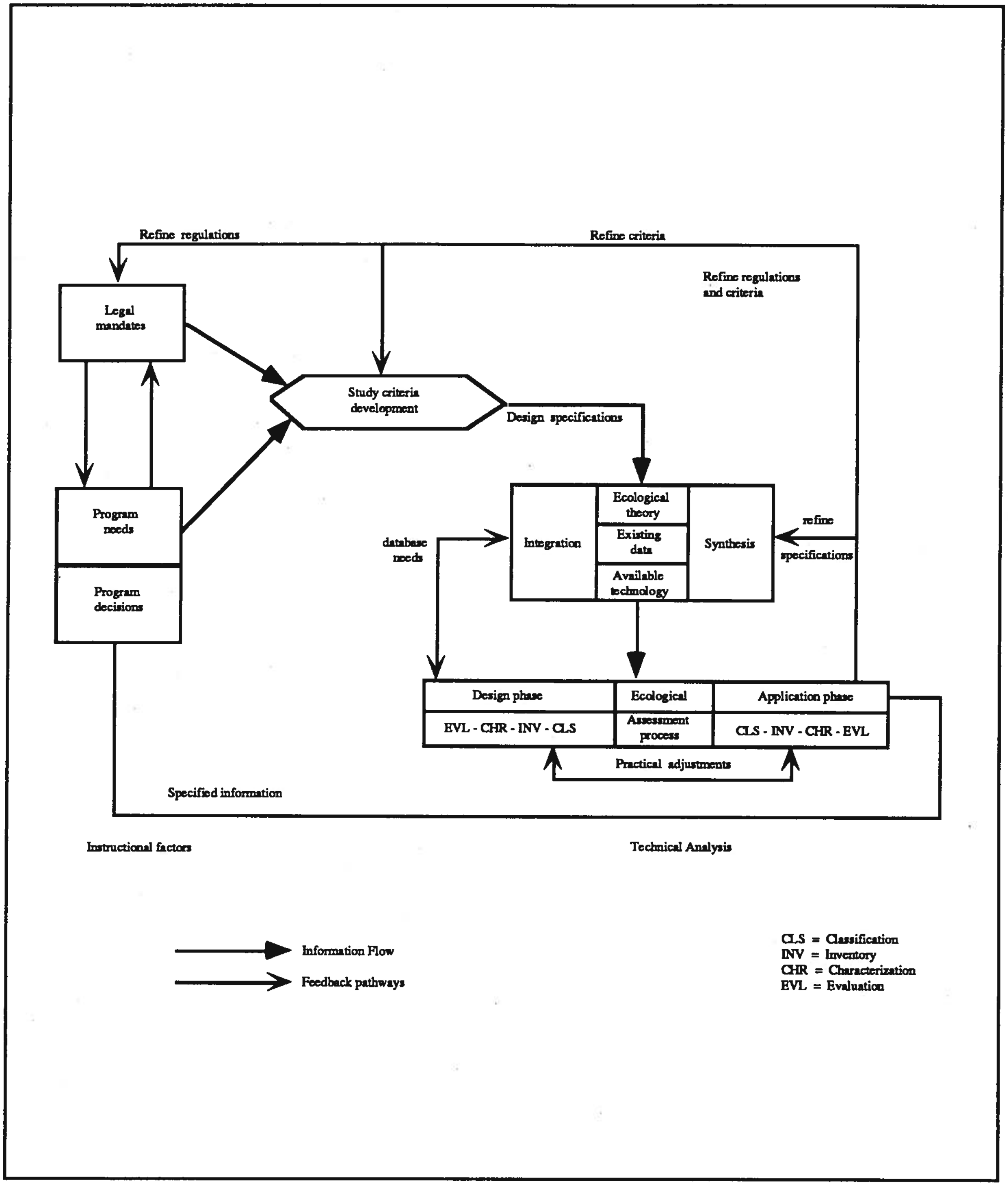

Figure 2.2 Information flow and feedback network in the design of information systems (adapted from Coulombe et al. 1982).

to do the evaluations, then the inventory product (land characteristics) required to estimate the land qualities. The final step is to define the classification procedures needed to support the inventory. In the application phase, the sequence is reversed so that classification of sites in the field is used to produce the inventory product (map) which supplies the characterization data on which the required evaluations are based.

A.iii. Technical / Scientific Objectives and Rationale for Soil Survey

Stated simply, the technical objective of soil survey is "to make a soil map" (ECSS 1987). The practical objective (ECSS 1987) is to produce a map which is a pictorial, two dimensional representation of our understanding of soil distribution across the areal extent of a three dimensional landscape (Coen 1983).

The function of soil maps is to "show the distribution of kinds of soils so that the knowledge gained in one locality about the usefulness or behavior of a kind of soil may be extended to other bodies of the same soil elsewhere" (Simonson 1971).

The process of making a soil map involves "the identification, description and delineation on a map of the different types of soil, based on direct field observations or on indirect inferences from such sources as aerial photographs" (MSWG 1981). This process involves two principal activities (MSWG 1981) namely:

a) the classification of the complete range of soil characteristics within the survey area into a limited number of classes (soils), followed by;
b) the delineation of areas (map units) where these classes occur.

The activity of classifying soils produces a listing, or inventory, of the major kinds of soils in a given area together with a description of their principal characteristics. This listing does not require a spatial component (i.e. a map) in order to be useful. Many questions asked of soil survey information simply require knowledge of the kinds and relative extent of different soils in an area and not their absolute location.

The activity of outlining delineations of different kinds of soil produces the map which provides a spatial representation of the location and extent of the various kinds of soil identified during the classification stage. A delineation is an individual area of soil outlined on a map and differentiated from surrounding areas. A map unit is the sum of all delineations that have been identified as similar and given the same name or identifying label. Map units represent real portions of the soil landscape (ECSS 1981) but are described according to the aggregate or generalized characteristics of all delineations identified as comprising a given map unit (ECSS 1981). Thus, although map units describe real portions of the landscape, most map units are conceptual entities because "their total range of properties is made up of the aggregate of all their component delineations, and no one delineation will contain the full range of properties" described for the unit (ECSS 1981).

The major assumption implicit in the creation of soil delineations or "map units" is that each delineation represents an area of land that differs from the surrounding landscape area in some clearly recognizable fashion that is judged to be important relative to the use or interpretations for which the map is being made.

A.iv. The Concept of Partitioning and Limiting Soil Variability in Soil Survey

The requirement that areas delineated on a soil map should be different in some meaningful manner has consistently been extended to embrace the notion that each delineated area should contain a more narrow range of soil types and soil conditions than the landscape as a whole (Forbes et al. 1985). Thus, Beckett and Webster (1971) argued that since the purpose of soil surveys was to "resolve the whole landscape into areas, blocks or parcels that can be managed uniformly" this required the definition of map units "in which (it is hoped) the soil is less variable than in the larger landscape". Arnold (1979b) argued that the basic premise of creating map delineations was to define areas in which the variance (of soil properties) within the delineated map unit was less than the variance within the population of soils as a whole. He compared this activity to the statistical concept of partitioning of variance.

This assumption of minimized variation within map units is pervasive and is implicit in the definition of soil map units in Canada. The Canadian system of soil mapping advises that "insofar as possible, at any given scale, the range of properties of the map unit should allow the entire unit to be treated the same for the kinds of management indicated by the purpose of the survey" (MSWG 1981). This leads to a definition of map units as "mappable portions of the soil landscape that together have attributes varying within more or less narrow limits" such that a "map unit contains predominantly one or more than one soil or non soil mapping individual plus an uncertain proportion of unnamed and undescribed inclusions" (MSWG 1981). A less restrictive definition requires only that map units be bodies of soil that can be recognized as natural units that can be identified and delineated on maps and described in terms of defined kinds of included soils (ECSS 1987).

In practice, it is not always possible to base the definition of map units on the concept of minimizing variability within the defined map unit. Field soil surveyors often find it necessary to delineate and describe areas possessing a high degree of local variability in soil composition and soil properties in order to isolate these highly variable areas from other delineations with a more restricted range of soils and soil properties. Thus, some map units may be defined as highly variable in order to permit adjacent map units characterized by low internal variability to be defined. Regardless of the degree of variability contained in an area, the resultant map unit is named for its principal component soils and described in terms of the properties of these components, their relative proportions and other external land attributes (MSWG 1981).

A.v. Sub-division and Agglomeration in Soil Survey

The actual delineation on a map of areas of defined and minimized soil variability is accomplished by applying one or both of the procedures of sub- division or agglomeration (Figure 2.3) to the area of interest (MSWG 1981).

Sub-division involves a top-down partitioning of the landscape into smaller areas assumed to possess a more limited range of soils and soil properties using criteria that are known to influence the distribution of soils and related properties in the landscape. Agglomeration involves a bottom-up grouping of observations and site classifications into coherent spatial entities that possess a relatively consistent and uniform assemblage of soils and soil properties (MSWG 1981).

Sub-division

Sub-division is the most common approach used to define map delineations in soil survey (MSWG 1981). In Canada, the term stratification has been applied when sub-divisions are formally incorporated into the design and presentation of map legends (MSWG 1981). Stratification is "the orderly sub-division of the survey area on the basis of criteria that will form primary separations between groups of soils" (MSWG 1981.

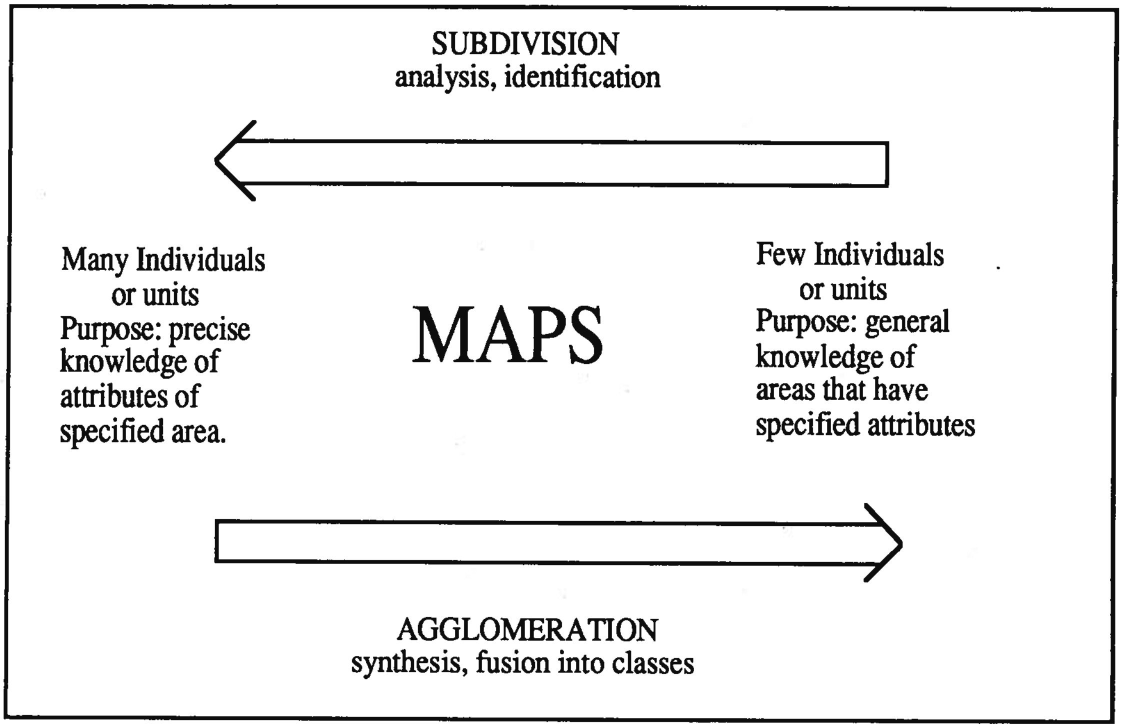

Figure 2.3 The roles and contributions of subdivision and agglomeration in classification for soil mapping (MSWG 1981).

Typically, the criteria used to stratify the landscape reflect the current state of knowledge about the spatial pattern displayed by the principal soil forming factors (Jenny 1946) and soil forming processes for the area in question. The factors of soil formation are (1) climate, (2) vegetation, (3) parent material, (4) topography (including drainage) and (5) time (Jenny 1946). These factors have long been observed to exert different degrees of influence over different distances and scales (Arnold 1979a). For example, the influence of climate on soil formation is strongest at a regional scale measured in terms of tens to hundreds of kilometers. Vegetation influences act predominantly at a regional scale (i.e. forest versus grassland) but also affect soil formation at a local scale (tens to hundreds of meters) primarily in response to changes in vegetation caused by changes in aspect (climate) and topographic position (drainage). The major changes in parent material composition typically occur at an intermediate scale (hundreds to thousands of metres) and are associated with changes in mode of geological deposition (i.e. change from upland till plains to glaciolacustrine basins). Short range variation in composition of the parent material and its influence on soil properties is generally associated with local changes in topography that influence the redistribution of material by water under the influence of gravity. Topography influences climate and vegetation at a regional scale through major changes in elevation, and at a local scale through changes in aspect and drainage position. Topography has the strongest and most obvious influence on patterns of soil distribution at a local scale of tens to hundreds of metres. Recognition of topographic controls on the distribution of various type of soils forms the basis for most soil surveyors' models of soil-landscape relationships.

The scientific basis of soil mapping by means of sub-division is that the locations of soils on the landscape have a degree of predictability (Miller et al. 1980). This predictability is based on an understanding of how the various factors and processes of soil formation influence the development and distribution of different types of soil in various locations in the landscape. Soil surveyors build conceptual models of soil-landscape associations which are subjected to testing through field observation and sampling (Miller et al. 1980). If field observations confirm the validity of these models, they can be used to construct descriptions for map units which are then applied to similar landscape features.

Application of techniques of sub-division to produce soil maps involves an explicit recognition of the existence of a hierarchy of controls on the factors influencing the distribution of soils and on the resultant distribution of the soils themselves. Imposition of a hierarchical system for stratification of soil areas based on scientific principals and knowledge produces a more orderly arrangement of soil delineations and a more useful context for the resultant set of map units.

Agglomeration

Agglomeration is a less common procedure for delineating areas of similar soil and producing soil maps. It is used most often at larger scales for mapping small areas that lack clearly apparent soil-landform relationships or other external clues to the factors controlling the distribution of soils. In this approach, closely spaced inspections are recorded and similar inspection sites are grouped to create delineations consisting of all contiguous sites of similar soil (MSWG 1981). The delineated areas are then described in terms of the suite of individual soils grouped within them.

A.vi. Accuracy and Precision in Delineating and Describing Soil Map Units

Accuracy in soil survey has been defined as "the closeness with which the information conveyed in a soil map, legend and report conforms to the actual or "true" soil conditions in the field (MSWG 1981). The same meaning has been attached to the terms "thematic reliability", "reliability", and "purity" of map units (Arnold 1979a; MSWG 1981).

The term precision, as it applies to soil survey, has generally been less consistently defined and understood. In Canada, the official definition of precision for soil survey is "the closeness with which individual pedons from one soil (or individual exposures and sites within a map unit) resemble one another" (MSWG 1981). In an amplification of the initial definition precision is considered to be a measure of "how closely repeated observations of a soil or map unit characteristic conform to the mean value of that characteristic for the soil or map unit" (MSWG 1981). This is much closer in meaning to the more general definition of precision given by Forbes et al. (1985) as "the repeatability of a measurement, often expressed as the ratio of the standard deviation of a measurement to its mean".

In actual use, the term precision is most often applied to describe the specificity or exactness with which map units or soils are described. Examples of such usage include statements such as "precision is an expression of the range of a soil or map unit" (MSWG 1981) and "professionals wanting precise information on a large scale map will not be served best by the same legend as one on a small scale map intended for non-technical users" (MSWG 1981). Moon et al. (1987) observed that "if the number and precision of classes being used is higher than that required to meet interpretive needs, then we may argue that the soils are being too narrowly defined".

Forbes et al. (1985) defined specificity of a map unit as "the degree to which the map unit name, description, or interpretation give information which makes it possible to predict the performance of the land". Given the fuzziness surrounding usage of the term precision, it is proposed that specificity be used in preference to precision to describe the exactness with which soils or map units are described. As an example, a soil map unit might be described with a low degree of specificity as having a range in texture from fine sandy loam to clay loam. A higher degree of specificity (precision) would be attached to a description of the same area as having a percent clay content of 33-36% and percent sand of 23-28%. Similarly a map unit might be described with low specificity as being comprised of "mostly" soil A with "inclusions" of soil B or with high specificity as being composed of 67-74% soil A and 26-33% soil B.

The number and kinds of interpretations or evaluations for which a soil map is to be used exercise a significant influence on the precision and accuracy that the soil map must achieve with respect to the delineation and description of map units. It has been widely accepted that, since map units are the basic interpretive element of soil surveys, "the success of transmitting information contained on a map and of predicting likely soil behavior based on the map is determined by the reliability of the map unit descriptions" (Miller et al. 1980). Similarly, the degree of detail, or specificity (Forbes et al. 1985), with which the composition and properties of the map unit are described will determine how useful the map units are for making the required interpretations.

In the Canadian system of soil mapping, it is recognized that different purposes and scales of soil survey require different levels of precision in the definition of their map units. For example, "if a very large area is to be mapped for regional planning at intensity level 4, class ranges of relevant criteria must be broad" while "on the other hand, in a level 2 survey for corn production over a more limited area, the class ranges would have to be more precise and more criteria directly relevant to corn production would have to be considered" (MSWG 1981).

A.vii. Assessing the Utility or Success of Soil Survey Products

Users of soil survey information typically want answers to several different types of questions, some with a spatial component and some without. In general, the principal types of questions asked of soil surveys are:

a) Non spatial questions: questions for which there is no requirement to know the actual location of any soil or the type of soil for any location. For example:
   i) What are the various types of soils in the area and what are their properties?
   ii) How much of the total mapped area is soil A?
   iii) How many soils in the area are affected by problem Y?

b) Site specific questions: questions for which there is a requirement to know the actual type of soil or value of a soil property for a specific location. For example:
   i) What kind of soil is found at location X?
   ii) What are the properties of soil A at location X?
   iii) What are the problems or limitations of soil A at location X with respect to some desired use?

c) Attribute specific questions: questions for which there is a requirement to know all of the locations where a certain soil or set of soil conditions may be found. For example:
   i) Where are all of the locations within the mapped area where soil A may be found?
   ii) Where are all of the locations in the mapped area with soils having a given set of soil properties?
   iii) Where are all of the locations within the mapped area where the soil is suitable for a specific use Z?

The utility of any given soil survey product is measured by the success with which it is able to answer each of the sets of questions outlined above.

All soil surveys supply the following elements which are used to address one or more of the sets of questions outlined above:

a) A soil identification legend which lists all of the major kinds of soil encountered in the map area and describes the properties and classification of each.

b) A map unit descriptive legend which provides a generalized description of the areas of land that have been delineated on the map, the mix of soils located within these delineations and the relative extent and soil-landscape position (if relevant) of each or these soils within the delineated area.

c) A soil map which illustrates the spatial distribution of the map units within the mapped area.

d) An interpretive legend which evaluates the various soils and map units in terms of the uses for which the inventory was designed.

Non spatial questions do not require reference to a soil map and may be adequately answered by simply consulting a) the soil identification legend or b) the map unit descriptive legend.

Site specific questions often require detailed knowledge of the kinds of soil found in a specific area and the exact location of each kind of soil. These questions require use of a soil map, usually the more detailed the better. In the absence of a detailed soil map, a comprehensive map unit legend may prove useful to efforts to enhance the existing, lower resolution, soil map. A detailed legend, used in conjunction with a low resolution soil map, can provide the information required to locate and delineate the individual soils identified for a particular site at a greater level of detail than presented on the original map.

Attribute specific questions require both a soil map and a comprehensive legend. Questions of the type c) (i.e. where are all the locations where the soil has property Y) are most often germain to regional studies or evaluations. In these types of studies, it is often not essential to know the exact locations of small bodies of soil. It is more likely that the desired goal is to illustrate the general regional pattern of distribution of certain soil types or soil problems. These kinds of questions are less likely to require detailed soil maps. Too much detail may even hamper effective use for regional evaluations.

A.viii. Summary

In summary, soil survey maps and related products are produced to provide information to support informed decision making for clearly identified uses. The inventory process results in the creation of more than just a map. It also produces an itemized listing and description of the major types of soil in an area, a map legend and a series of interpretations for each soil or map unit. The soil name list provides a convenient framework for the sharing of information and knowledge about the main soils in the area and supports further efforts to improve on the soil information base for a given area. The map legend captures the knowledge and expertise of the surveyors about how the various soils are arranged on the landscape relative to one another and to controlling factors such as landscape position, climate, vegetative cover and internal or external drainage. The map unit legend can also be invaluable in supporting further efforts to enhance the initial soils data base. The interpretive legends provide a summary of the existing state of knowledge about the suitability or limitations of different soils and landscape patterns for various uses and of the procedures, or algorithms, by which soils and land are judged suitable or non suitable for a particular use. Finally, the soil maps provide a representation of the distribution of the various kinds of soil throughout the mapped area. The soil delineations and map units are described in the most precise terms possible given the objectives and scale of the survey. Efforts are made to ensure that map units contain the most narrow range of soils and soil properties possible and that the descriptions of map units are as reliable (accurate) as possible.

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II.B. SOIL SURVEY PRODUCTS AND USERS IN ALBERTA

- W.L. Nikiforuk

B.i. Introduction

The objective of soil survey is to provide understandable, accurate and precise information to people who need to understand and use soils as they occur in the landscape (Brown 1985). Surveys must be broad in scope, dynamic and responsive to user needs. Surveys have changed over time with the advancements in soil science and with increasing numbers of purposes for which they are used (Soil Survey Staff 1975). The uses of the information have changed from interpretations about farming, grazing and forestry to include non-farm activities (recreational, engineering, pipelines, mines, and so on).

The chapter is divided into 4 sections. The first section provides information on the history of soil survey in Alberta. The second section examines report and map products that have been produced since the initiation of surveys (including current products). The third section reviews the types of users and their survey needs. The last section provides a summary of the chapter.

B.ii. History of Soil Survey in Alberta

The history of soil survey in Alberta has been well documented by Bowser (1965), McKeague and Stobbe (1978) and more recently by Nikiforuk (in prep) (Appendix A).

Soil surveys in Alberta were initiated in 1920 by Dr. Frank A. Wyatt of the Department of Soils at the University of Alberta (Bowser 1965). The purpose of the first survey project was to delineate the province into broad soil - climatic zones. This project was completed in 1925 (Bowser 1965; McKeague and Stobbe 1978). Since then, this map has been revised and updated (Alberta Institute of Pedology 1967) based on new information and knowledge of the soils and landforms of the province.

Early soil surveys were conducted in response to government concerns related to the threat of wind erosion of soils and abandonment of farmsteads in southern Alberta. These surveys illustrated differences in soil texture across southern Alberta and provided soil interpretations related to issues of soil fertility and management of soils susceptible to wind erosion. During the period 1922 to 1926, over 2.8 million hectares were surveyed in the southern portion of the province (Bowser 1965; McKeague and Stobbe

1978). The work was financed by the University of Alberta and the provincial Department of Agriculture. Later soil surveys incorporated soil taxonomy and a field classification system that evolved as a function of field mapping and theoretical knowledge of soil genesis.

In 1945, representatives from all survey units in Canada met for the first time to exchange ideas, unify survey and soil classification methods and evaluate the work that had been completed to that time (Bowser 1965; McKeague and Stobbe 1978). One of the highlights of this meeting was a proposal for a field classification system of soils for Canada. The system had seven categories; soil region; soil zone; soil subzone; association or catena; soil series, members or associates; soil class or type; and soil phase. The classes within the categories were real bodies in the landscape that included all the soil variability within an area. The system was not intended to be a scientific or taxonomic one in which the classes had a defined range of properties (McKeague and Stobbe 1978). Rather it was intended to be a system for classifying and naming soil mapping units in the field. The soil series was adopted as the basic unit of classification.

The Alberta Research Council revitalized the soil survey in 1945 and continued with work in the northern portion of the province. The purpose was to update the work done between 1928 to 1931 and to continue the evaluation of lands relative to their suitability for arable agriculture (Bowser 1965). Soils maps were produced at 1:190 000 using the soil series names listed according to their predominance in the map areas that they occupied. The series were recognized on the basis of uniformity of soil zone, parent material, surface texture, drainage, landscape position and some profile characteristics.

In 1955, the first Canadian taxonomic system of soil classification was outlined (McKeague and Stobbe 1978). This was a significant period for soil survey because soil series were recognized on the basis of observable physical properties. The term soil series was redefined from being a field entity to being part of the soil taxonomic system for Canada.

During the period 1955 through 1975, the majority of soil surveys in Alberta were conducted and published at a scale of 1:126 000. Map legends were uncontrolled, in that any combination of soil series was used to describe polygons on the map. More than one line in the legend has to be consulted to gain information about delineations that contain more than one soil (Mapping Systems Working Group (MSWG) 1981).

During the late 1960's the Alberta Soil Survey began investigating what scale of mapping would be appropriate for the resurvey of the province. The County of Two Hills was mapped at a scale of 1:31 000 to determine if this scale was suitable and feasible. Upon completion of mapping the 1:31 000 scale was deemed inappropriate because of the length of time and effort required to conduct the survey (Agriculture Canada, Research Branch 1975). As a consequence a decision was made to map Alberta municipalities at 1:50 000. This scale was appropriate because the information content of soil surveys was maximized while the resource requirements to complete surveys was minimized.

During the mid 1980's reconnaissance surveys became a cooperative effort between Agriculture Canada and the Alberta Research Council. The federal soil survey unit also continued to map soils in the southern portion of the province. In 1989, field mapping was discontinued by the Federal unit. The Alberta Research Council continues to map municipalities at a scale of 1:50 000 as defined by SIL3 standards. To date 11 municipalities have been completed or are currently being surveyed at 1:50 000 (Agriculture Canada 1990). Eight formal requests for soil survey from Alberta municipalities remain unfulfilled because of the limited resource available to provide SIL3 1:50 000 mapping.

B.iii. Survey Products

Over the 70 or so years of soil survey in Alberta a variety of products have been published for public use. Soil survey reports have had the same basic format since their inception. The most common product is a soil survey report with a map of the area of interest. Earlier reports were not technical and tended to be user friendly for the non-soil scientist. In 1945, a standard soil survey report format was proposed and adopted (Stobbe 1945). This format has remained constant with only minor revisions to the contents.

The format of the reports and maps has been fairly standard for each of the time periods when mapping took place. The format of maps has evolved from colour maps on NTS base maps to soil maps on an uncontrolled photo mosaics base, to black and white maps on the NTS base map. The content and format of soil survey reports has also evolved over time. Further, the basic classification system for soils and the way soil series / associations are described and represented have changed as well.

Characterization of Soil Landscapes in Soil Survey Products

Early soil survey maps were based on a numbering system which was generic for the maps produced at the time. Number codes were used for soil zone, parent material and mode of soil development. Colours were used to identify texture differentiation and cross hatching was used to represent topography classes. These maps are outdated by todays mapping standards. The information contained in these maps is still valuable to soil survey users, however a trained pedologist may be needed to translate this data into modern terminology.

Later maps used soil series designations, colours and cross hatching to describe soil and landscape models. These models were not always clearly described and documented in the soil survey reports but were used consistently during mapping and map production. These later maps also used an open legend concept wherein any combination of soil series could be used to describe a single polygon. Each series was described in the map legend but the model of the soil / landscape was not conveyed in the legend or report.

Current soil survey products use a closed legend model wherein soil and landscape models are explicitly described and are based on theoretical and empirical data on soil and landform development. These legends use a combination of a soil series code and a number modifier to characterize map units. Closed legends have all unique combinations of soils, phases and topography listed and described in the legend. Current thinking is that the closed legend is superior to the open legend because the soil / landscape models are explicitly described for the user and the concept of repeating soil landscape units is reinforced.

Many maps were published with uncontrolled legends in which soil associations were used to characterize soil landscapes. The soil association was defined as a group of "closely interrelated soil series developed on similar parent materials and under essentially same climates" (Dumanski et al. 1972). The soil associations were a combination of map units. Therefore it was possible for a single map delineation to contain as many as nine named soil series; however, proportions of the series which occupy a single map unit were not defined. The concept of using soil series to describe soil / landscapes followed the concept of soil associations.

Some confusion exists as the result of the use of soil series as the basic unit for soil mapping. In the last 70 years the term soil series has had several meanings. During the

1920's the term referred to a land or field unit. It was analogous to a geological formation (Agriculture Canada Expert Committee on Soil Survey 1987). Between 1935 to 1945 the concept of soil series referred to a combination of soil zone, mode of deposition of parent material and profile variation (Wyatt et al. 1938). Odynsky and Newton (1950) defined soil series as the individual soils which make up a soil catena. During this time a soil catena was defined as a group of soils developed on similar parent materials. The soil series were defined as "a result of a variety of local environmental factors that affect drainage, temperature, moisture relationships, vegetation and give rise to differences in colour, depth and structure of the profile" (Odynsky and Newton 1950). After the development of a formalized soil classification system, soil series became a taxonomic rather than a field unit. The series is presently defined as a conceptual entity that has defined limits. "The link between the conceptual entity, soil series, and real bodies of soil is the pedon" (Agriculture Canada Expert Committee on Soil Survey 1987).

Because the taxonomic system and the concept of the soil series have changed over the last 70 years, some series established prior to the development of the present classification system include pedons that may belong to different subgroups, great groups or orders. For example, the Codesa soil series has been classified in different soil survey reports as an Orthic Gray Luvisol, a Brunisolic Gray Luvisol, an Eluviated Eutric Brunisol and a Cutanic Podzo Regosol.

Other series were representative of a particular landscape position. For example Navarre (meadow) soils were found in depressional areas of the landscape and classified as Orthic Humic Gleysols. In contrast, Navarre soils were found in upland positions and classified as Orthic Black Chernozemic. Navarre (meadow) soils have been renamed and are now Haight soils.

The effect that these kinds of changes have on the continuity of characterization of soil landscapes in soil survey reports is considered to be confusing. This is particularly true for users of soil survey data who do not have a significant amount of training or background in soil survey (which includes most of todays' users). There are common threads in how soil landscapes are characterized in soil survey reports over time but considerable expertise is necessary to identify and explain the common characteristics.

Modern Soil Survey Products

Since the early 1970's there have been changes in the method of presentation of soil survey information. The production of coloured maps was discontinued in favour of black and white aerial photo mosaic maps (Two Hills, Beaver, Warner for example). Air photos were utilized as the base for soil maps until the mid 1980's. This base was well liked by the user community because of the ease of identifying one's location on the soil map and the easy recognition of geographic features. The advent of computer systems resulted in a change from the air photo mosaic base to a more stable National Topographic System (NTS) base. The NTS base was required so that the soil information could be geo-referenced to real world coordinates. In addition to being a stable base for digitizing, this product was also inexpensive to reproduce.

The most recent development in soil survey products is the provision of electronic soil information. The Soil Inventory Database for Management and Planning (SIDMAP) data base was developed in the late 1970's and is a quarter section, gridded system. For each of the 515,000 quarter sections in the database there is a listing of the dominant and subdominant soils, topography, soil classification, soil texture and a variety of other soil properties. SIDMAP is considered to be accurate at a scale of 1:250 000 and is therefore a very generalized soil information product.

Geographic Information Systems (GIS) technologies have facilitated the development and distribution of polygon based soil information systems subsequent to the development of SIDMAP. Portions of the soil mapping for the Province have been digitized in Ottawa by Agriculture Canada and portions have been digitized locally. This form of data is not readily available to the public at this time. The future will undoubtedly result in object oriented data bases and soil information products that will enhance and encourage the continued use of soil survey data as a basis for decision support and land use management.

B.iv. User Needs

The information presented in the early Alberta soil surveys reflects what was known at the time about soil classification and genesis. These reports use non-technical and easily understandable language as demonstrated by Wyatt and Newton (1925) and Wyatt et al. (1930). They often contained only surface texture and topography data but evolved to include soil profile development information.

As soil survey continued, the level of knowledge has grown, reports have become technically complex and scientific terminology has replaced simple language. The scientific terminology has been often referred to as jargon to connote the lack of meaning to many users of soil survey products. The users of the information have been given the responsibility of deciphering and interpreting information specific to their area(s) of interest based on the content of the report for their area of interest. However, some users have little or no technical background in soil survey methods or terminology (Valentine et al. 1981; Souster and Peters 1991). As a result, some soil survey information is not understood or effectively utilized (Sombroek and van de Weg 1983; Valentine 1983; Valentine et al. 1981; Anderson et al. 1982).

User Needs - Types of Users

The identification of the users and determination of their information needs is fundamental to the soil survey process. Fessenden (1984) states:

> "...to be truly effective, a service agency has to know more about a client's needs than the client knows themselves. It is not good enough to ask the client what he needs. Rather it is necessary to make a thorough study of the roles and responsibilities of the client, to thoroughly understand their working environment and to anticipate and suggest the natural resource information products which are likely to be of some assistance".

The first step of the soil survey process should be the identification of the users and their information needs. Butler (1980) suggests that a soil map should have a purpose:

> "in some cases a soil survey has no particular problem but is made to provide a general stock taking of the soils of a project area. This type of survey has the potential of producing too many boundaries and it will require comprehensive investigations to show which are the relevant ones for particular problems".

MacMillan (1985) identified 66 public sector users of soils information in Alberta. The users had a total of 72 management programs requiring soil and land information. Some of the users were responsible for collection and dissemination of soils information, others utilized soils information generated by other users.

Fessenden (1984) defines two types of users; those who have the capability of collecting and interpreting information on their own; and those who do not have the capability of collecting information and want interpretations provided for them. Users who lack familiarity with basic classification inventory and the assumptions that went into the creation of the resultant products do not always appreciate the potential that those products have for producing interpretations that would be useful to them.

Cheel (1991) categorizes users on the basis of their familiarity with soils terminology, the level of detail they require and the level of involvement they have in the collection of soils information. Applying these criteria, Cheel (1991) defines 3 types of users; the pedologist who is not involved in field survey; the pedologist who conducts field mapping; and the non- pedologist, who is unfamiliar with soils terminology.

Once the users and their needs have been identified, specific data elements can be collected and interpretations specific to their needs can be made. Soil surveys in Alberta have been conducted to meet the needs of various user groups. The first soil surveys in Alberta were initiated in order to solve or identify the magnitude of wind erosion in southern Alberta. Soil surveys in northern Alberta were initiated in order to determine the suitability of lands for arable agriculture.

More recently the objectives of soil surveys have been stated but these objectives are rarely explicitly addressed. For example, the soil survey of the County of Flagstaff was initiated to address suitability of soils for deep plowing. However, the objective was never satisfied and the purpose of the inventory became the collection of data to update the existing soils database. The change in objective is a function of the high cost of soil survey that predicates the production of a general purpose inventory product targeted at a variety of users. Another justification for the collection general purpose information is the difficulty in identifying who the users of the information are.

Different types of users encounter different issues when using the published soil survey reports for decision support. Often, problems of soil survey interpretation and understanding arise if the user has to use more than one report. These problems are the result of the issues documented in the discussion of soil survey products (B.ii.).

However, a variety of mapping concepts, taxonomic systems and mappers all contribute to potentially confusing variation between soil maps. For example, some users may consult portions of the Wainwright and Vermilion map sheet (Wyatt et al. 1944) and the soil survey of the county of Flagstaff (MacMillan et al. 1988). The reports are representative of the level of soil knowledge that existed at the time they were compiled.

However, because of the difference in scale and level of technical information, the user may prefer the friendlier, older product or choose the updated and more technically demanding product. Most users appear to choose the latter, but never appear to fully understand all of the information presented in the modern report.

Users have few problems once they become familiar with the style and format of a single survey report or a single vintage of mapping. An example is the farmland assessor in the County of Flagstaff who can eloquently describe the soils and landforms of the County based on the published in the 1940's through 1960's. The more recent SIL3 1:50 000 soil survey report for the County has little meaning to this user because it is conceptually and physically very different from his understanding of the earlier soil survey products.

In summary, there are a variety of users of soil survey. Each user group has different needs and different skill bases when using soil surveys for decision support. The current soil information data base, as presented in published soil survey reports, is inadequate in meeting the needs or the wide range of users. It may be that a variety of soil information products are necessary to meet the needs of the wide range of users. The production of soil information and its dissemination may be two very different kinds of activity that should be treated as separate functions.

User Needs - Content

MacMillan (1985) identified 66 public sector users of soils information in Alberta. The users had a total of 72 management programs requiring soil and land information. The soil information requirements were split into 3 main classes; descriptive, analytical and interpretive (Table 2.1). Each of the main classes were subdivided into additional categories. The determination of the soils information required by each user group was subjective. User groups were amalgamated to form 12 distinct groups. For example, the Alberta Agriculture user group represents 8 departments; the Municipal Affairs Planning Commissions group represented 12 user groups; the Forestry, Lands and Wildlife group represented 6 user groups; and so on. It was reported that all the users required soil map information and the majority required some chemical or physical data and some interpretive information (Table 2.1).

Stobbe (1945) writes, "it is obvious that the report (*soil survey*) can neither be a simply written Farmers Bulletin type of report nor a highly technical treatise intended for other soil scientists". This statement is supported by Valentine et al. (1981), who conducted an evaluation of users and user needs in British Columbia. Results from the survey indicated that 51% of people had difficulty getting information from soil maps. Many people complained about unfamiliar terms, non standard legends and symbols. Most users regarded information such as taxonomy and chemical analyses with at best "antagonism". The types of map products that users need are varied.

Table 2.1 User groups and their respective soil information needs.

USER GROUP	SOILS INFORMATION								
	Descriptive		Analytical		Interpretive			User	Producer
	profile	MU	phys.	chem.	agric.	rec.	eng.		
Alberta Agriculture	X	X	X	X	X			X	X
Forestry, Lands, and Wildlife	X	X		X	X	X		X	X
Alberta Environment	X	X	X	X	X		X	X	X
Municipal Affairs - Planning Commissions		X	X		X	X	X	X	
Municipal Affairs - Cities and Municipalities		X	X		X	X	X	X	
Municipal Affairs - MD's and Counties	X	X	X	X	X			X	X
Municipal Affairs - Boards, Commissions, and Divisions		X			X		X	X	
Transportation		X	X				X	X	
Agriculture Canada	X	X	X	X	X	X	X	X	X
PFRA	X	X	X	X	X			X	
Environment Canada		X	X	X		X		X	
Indian and Northern Affairs		X	X	X	X	X	X	X	

MU = map unit; phys. = physical; chem. = chemical; agric. = agricultural; rec. = recreational; eng. = engineering

In Alberta there have been a range of map products produced and utilized. Colour maps were used from the inception of soil survey in 1920 until the mid 1970's. Since the 1970's black line and air photo mosaic maps have been produced. Valentine et al (1981) reports that in British Columbia most people requested a topographic base map (56%); 28% preferred orthophoto mosaics; and colour maps were preferred over black and white (because black and white maps were difficult to read). Nikiforuk (in prep) reports that municipal conservation planners preferred colour maps; and on- farm conservation planners preferred air photo mosaic maps.

The content of soil survey reports should enhance the objectives of soil survey (to provide understandable, accurate and precise information to people who need to understand and use the soils as they occur in the landscape (Brown 1985)). Given the variety of user needs it is difficult to adjust the content of soil survey reports to meet all of the needs of all of the users. The current state of soil survey in Alberta is such that many users of soil survey information are inconvenienced by the nature and content of the data base. Current Green Plan proposals would see an effort to consolidate and enhance the existing soil information data base to support user needs.

User Needs - Map Scales

Scale preference was described by MacMillan (1985). The results indicated that the majority of the respondents (51%) preferred scales larger than (1:14 000); 17% preferred scales between 1:14 000 and 1:40 000; 21% preferred scales between 1:41 000 and 1:80 000; 2% preferred scales between 1:80 000 and 1:160 000 and; 7% preferred scales smaller than 1:160 000. The large number who preferred large scale information represented cities and regional planning commissions. Those who preferred the 1:41 000 to 1:80 000 map scale range "appeared to be recognizing the fact that this is generally the smallest scale at which consistent regional coverage is available" (MacMillan 1985). Some of the respondents indicated that this was also the most practical scale for regional compilations and planning. MacMillan (1985) summarized the scale requirements:

1. The majority of scale preferences favoured large scale detailed information, but other scales were deemed desirable for specific uses.
2. Detailed scales were used most often by programs in which decisions were made about individual parcels of land.
3. Intermediate scales (1:50 000) were used where single region overviews were needed, primarily for planning purposes.

4. Small scale information was used primarily for province-wide and regional overview programs concerned with policy development.

In a survey of soil survey users in British Columbia, Valentine et al. (1981) reported that most users preferred a less precise map that would be available in 1 year over a more precise map that takes 4 years to deliver. This implies the production of small scale versus large scale maps. MacMillan (1985) reports that the map products that were most preferred were those produced by a single consistent methodology. This created broad regional availability of a similar product and consequently generated acceptance and use.

B.v. Summary

Soil surveys in Alberta were initiated approximately 70 years ago. Since the initiation of mapping, a variety of mappers, scales, mapping concepts, taxonomic systems and products have been used to deliver information to the users. Initial surveys were conducted for specific purposes. Over time, the objective of survey has changed to updating the existing data base. This shift has resulted in some user needs not being addressed or met.

Mapping scales have changed from 1:190 000 (1920 to about mid 1950's) to 1:126 000 (mid 1950's to early 1970's). Since the early 1970's most reconnaissance soil surveys were conducted at 1:50 000. Survey reports have remained relatively consistent in format and content. Maps have been published on colour, air photo and black line formats.

The wide variety of user needs in Alberta are recognized in terms of soil survey content and map scale. Proposals are in place to consolidate and enhance the existing soil information data base to support user needs. New technologies are being utilized to distribute soil information in electronic form. These technologies should enhance the use of soil information in decision support for many soil survey users.

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II.C. TRADITIONAL MAPPING APPROACHES AND SAMPLING STRATEGIES IN ALBERTA AND OTHER PARTS OF CANADA

- W.L. Nikiforuk, R.A. MacMillan and I.R. Whitson

C.i. Introduction

This section describes the methods used for conducting 1:50 000 (Survey Intensity Level 3 (SIL3)) reconnaissance level soil mapping in Alberta. The concept of SIL3 mapping is explored in detail. An analysis of the methods used in soil survey provides an understanding of the soil mapping process in Alberta. A discussion of mapping in Saskatchewan and other parts of Canada is presented.

C.ii. Survey Intensity Level - Discussion

Survey Intensity Level (SIL) is an expression of the amount of work done (emphasis on field work) and the detail or precision of information collected during a soil survey (Mapping Systems Working Group (MSWG) 1981; Valentine and Lidstone 1985). The SIL of any project is dependent upon the objectives of that project. Therefore the level of precision with which soils must be described and mapped is defined (MSWG 1981). There are two levels of criteria used to differentiate the five categories of SIL; the amount of work; and the detail with which soils are described and mapped.

The amount of work is defined by the level of field activity undertaken. Intensive surveys require more field work, less intensive surveys require less field work. The measure used to determine the level of field activity is the number of soil inspections made within a project area. The MSWG (1981) define an inspection as "a ground examination which the pedologist can use to verify the differentiating characteristics of a map unit". The location of the site must be recorded. An inspection can be anything from an exposure of the soil with a shovel or auger to a note about a road cut or saline area.

Valentine and Lidstone (1985) list the measures used to differentiate levels of SIL. They are:

1. Area represented by one inspection,
2. Proportion of delineations having one or more inspections,
3. Spacing of traverses,
4. Spacing of inspections,
5. Proportion of the length of all soil boundaries inspected during the course of field work,

6. Rate of progress of field mapping,
7. Methods of travel in the field,
8. Proportion of survey time spent in the field,
9. Proportion of soil classes that are fully described and sampled for analysis.

The criteria used to evaluate the level of detail are accuracy, precision and scale. Accuracy is defined as "the closeness with which the information conveyed in a soil map, legend and report conforms to the actual or true conditions in the field" (MSWG 1981). Precision is defined as "the closeness with which individual pedons from one soil (or individual exposures and sites within a map unit) resemble one another" or "how closely repeated observations of a soil or map unit characteristic conform to the mean value of that characteristic for the soil or map unit" (MSWG 1981).

Valentine and Lidstone (1985) imply that field inspection quantity reflects accuracy and detail. That is, the more inspections, the higher the accuracy and level of detail. This point is contentious for two reasons. First, the statement implies that small scale maps are inaccurate compared to large scale maps because there are fewer field inspections compared to large scale maps. Second, this approach does not consider mapper experience nor does it recognize varying degrees of complexity of landscapes. That is, some mappers may require fewer observations to accurately characterize a landscape and some landscapes are simpler to characterize than others.

The use of SIL criteria provide an objective and measurable basis by which soil survey maps can be evaluated and presented in terms of accuracy and precision. The criteria are based on the collective wisdom of the soil survey community in Canada and as such serve the soil survey community very well. The criteria do not take into consideration the economics of producing soil survey products nor the utility of soil survey products for specific user communities (appropriately so). The reasons for discussing and rationalizing soil survey in Alberta are linked to the economics and user needs of soil survey. The perception of the authors is that the way in which SIL standards have been applied in Alberta has hampered the effectiveness by which soil survey products are delivered to the user community and has resulted in unreasonably high costs associated with soil mapping in Alberta. The time required to complete the field work in an average municipality is 3 years and the time to final publication is approximately 5 years from the inception of the project. The lengthy turn around time is seen to be counter productive given the current demand for soil inventory products. The cost of a SIL3 1:50 000 soil survey is defined by physical effort required to collect the data that allow the final map product to be classified as SIL3 1:50 000. The balance between cost of production and time to delivery must be evaluated. In Alberta, we are producing high quality soil maps and reports at a high cost (on average $15,000 per township) over a long period of time (up to 10 years start to finish). At present, the demand for soil inventory products is high and the ability to provide SIL3 1:50 000 maps is low (because of human resource constraints and limited financial support for the program) therefore the SIL3 1:50 000 program is being challenged and evaluated. This proposal is targeted at identifying and testing alternative mapping systems to enhance, both in terms of time and cost, the delivery of soil inventory products.

C.iii. Stages of Mapping

The soil mapping process for Canada has been documented in the soil survey handbook (ECSS, 1987). The handbook describes "procedures for precise and efficient soil survey programs in Canada". Four distinct levels of activity are identified: soil surveys in Canada; planning for soil surveys: The Committees; project planning and management and conducting soil surveys. Each activity is described in considerable detail; particularly the the one dealing with conducting soil surveys. Three further sections are described but not documented and these include: application of soil survey information; soil survey investigations; information and display systems.

Shovic and Montagne (1985) describe 6 generic steps in the mapping process:

1. Compilation of existing data,
2. Preliminary field studies and initial stratification,
3. Development of initial mapping legend,
4. Field mapping including additional soil inspections,
5. Interim correlation and remapping,
6. Final correlation and report writing.

Pettapiece (1977) lists two additional steps in the process. These steps are undertaken prior to the steps outlined by Shovic and Montagne (1985). The two steps are critical in the mapping process. They are:

1. The definition of objectives and requirements of the project. This includes the size of the area, scale, funding and time frame (in which the project is to be completed) and
2. A review of the objectives and requirements to ensure that they are realistic and achievable.

The following discussion describes in detail each of the eight steps as they occur in Alberta.

Steps 1 and 2. Definition of Objectives, Requirements and Ongoing Reviews

This is the most important step in the soil mapping process. Since the early 1980's the objectives and requirements of survey projects have been documented using CORRELOG (MSWG 1981). CORRELOG is equivalent to a soil survey project plan. Steps in the survey plan include identification of the project, project definition and objectives, schedule and resource requirements, project management details, survey operations (including mapping strategies, correlation responsibilities, sampling strategy, interpretations and report format), resource allocation (including manpower), scheduling and public information and feedback.

The project plan should be revisited during the course of the survey to ensure that the objectives and requirements are being met.

Step 3 and 4. Compilation of Existing Data, Preliminary Field Studies and Initial Stratification

During this stage background information on climate, surficial and bedrock geology, hydrogeology, hydrology, topography, vegetation and soils is collected. The purpose of compiling background information is to provide the pedologist a regional overview of the area to be mapped. The information can also be used to develop preliminary landscape units.

Initial stratification allows the mapper to develop preliminary map unit concepts. This step can be conducted in the office or by field visits to the project area. The goal of preliminary field studies is for the mapper to become familiar with the soils and landscapes in a project area before production mapping starts.

Step 5. Development of Initial Mapping Legend

The legends of SIL3 map products provide estimates of the proportions of each soil component of a map unit. Accurate assessments are possible if the relationships between soils and landscapes are predictable. Purposive sampling in these landscapes establishes no explanation for soils observed in sampling. However, a result of purposive sampling may be the conclusion that soil distribution within landscapes is unpredictable. Initial stratification to separate simple (predictable) and complex (unpredictable) landscapes may emphasize the need for different sampling strategies to solve mapping problems.

Initial map legends are developed in two ways. First, the map legend may be adapted from published (or existing) soils maps. This method is desirable in that time is saved and correlation is enhanced during the preliminary field study step. Second, the legend may have to be developed from observations made during preliminary field studies. This method is time consuming in that time spent building concepts could be spent on operational field mapping. The extra time spent on legend development may be necessary to reach the level of confidence necessary for SIL3 1:50 000 mapping. This approach is taken when there are no appropriate legend models on record and has the advantage of increasing the mappers confidence in map unit composition. The initial mapping legend may undergo repeated revision during the mapping process. After a working legend has been established, field mapping commences and the legend is updated as mapping progresses.

Soil mappers in Alberta have adopted a standard map unit numbering system for SIL3 maps. The numbering system continues to evolve but has been used for the majority of SIL3 maps. Some deviations from the system do occur in earlier mapping projects. The system is as follows:

UNIT No.	DESCRIPTION
1	A pure unit; named dominant soil occupies approximately 80% of delineated area.
2	Delineations include significant amounts (15-40%) of wet soils.
3	Delineations include significant amounts (15-40%) of saline soils.
4	Delineations include significant amounts (15-40%) of rego or calcareous soils.
5	Delineations include significant amounts (15-40%) of fine textured soils compared to the dominant soil.
6	Delineations include significant amounts (15-40%) of coarse textured soils compared to the dominant soil.
7	Delineations include significant amounts (15-30%) of solonetzic soils.
8	Delineations include significant amounts (15-30%) of wet soils in association with significant amounts (15-30%) of rego or calcareous soils.
9	Delineations include significant amounts (15 - 30%) of wet soils in association with significant amounts (15 - 30%) of coarse textured soils compared to the dominant soil.

Step 6. Field Mapping

In Alberta, SIL3 mapping is commonly conducted using 1:30 000 scale black and white aerial photographs. Initial stereoscopic examination of the photos is carried out in the office followed by a general field reconnaissance. This is followed by more intensive photo interpretation and ground truthing. During mapping, attempts are made to traverse all roads and trails in a county or municipality. Occasional traverses by foot are made where necessary to verify soil and landscape conditions in areas without vehicle access. Soils are examined to the 1 metre depth using a shovel and hand auger. Soil inspections are done at an intensity of approximately one recorded inspection per quarter section (65 hectares). Each recorded inspection is supplemented by information obtained from several inspections to determine the local distribution and variability of different soils associated with each inspection site.

Data collected at inspection sites includes horizon type, thickness, color, structure, texture and sequence; presence of lime, salts, mottles; slope position, length and steepness; landform; drainage; mode of deposition and texture of parent material. Data is recorded on field sheets or in notebooks.

As the survey progresses, soil and topography lines are determined along the lines of the traverse and projected between them using landscape features and stereoscopic examination of aerial photographs. These boundaries are drawn on a field map consisting of an aerial photograph of the township enlarged to a 1:30 000 scale. Map delineations are identified with the appropriate map unit symbol. Each completed township is compared, checked and correlated with those of adjoining townships.

After all field data is gathered, checked and correlated, the soil boundaries and accompanying map unit symbols are transfered to 1:50 000 scale mylar topographic base maps. These in turn are digitized and the resultant digital files are used to produce the final soil maps, as well as various interpretive maps for the survey area. Finally, the soil survey information is compiled and a report is written that summarizes and describes the soils in the mapped area.

Step 7. Interim Correlation and Remapping

During mapping, attempts are made to consistently apply map unit concepts over a project area. However, mappers are not consistent and frequently there is inconsistency between mappers because of mapping experience. These problems require correlation to improve and correct the soil survey maps.

The job of the correlator is to verify polygon boundaries and to ensure that map unit concepts are applied consistently and uniformly across a project area. The process may involve re-driving roads to check boundary placements or making additional soil and landscape inspections. The process is continual and occurs on a regular basis.

Once an area has been mapped and correlated, the map is filed until the field season is over and map and legend compilation are started. Usually, soil boundaries are not changed during the final compilation. Map units are consolidated and map unit names change frequently during this process, however. One tool that correlators use during the correlation process is polygon summaries.

Polygon summaries are records of the characteristics of each delineation. They allow mappers to record soil and landscape information unique to each delineation on a map. The summaries are compiled for two reasons. First they are a tool used by correlators in the absence of the principle mappers of an area. The correlator is provided with documentation on what the mapper observed in the landscape and the factors that might have contributed to the naming of a delineation. Second, polygon summaries are used for legend building. Storage in electronic form allows for quick and easy access to the information. Sorted data is used in the map compilation process for reducing the number of map units and determining the areal extent of map units.

The information recorded on polygon forms includes the map unit symbol, delineation number, location, size, estimated proportion of soils, parent material type and texture, landform, proportions of topographic classes and general comments. The amount and type of information collected varies between projects. For example, polygon summaries used in the soil surveys of the counties of Paintearth and Flagstaff (Wells and Nikiforuk 1988; MacMillan et al. 1988) contained map unit symbol, polygon location and size.

The philosophy of consolidation is that a balance must be achieved between cartographic simplicity and landscape detail (Hole and Campbell 1985). Map unit consolidation is a process that is used to reduce the number of map units (in a mapped area) to a workable number. Ideally, the number of map units developed to characterize soil distribution patterns should be minimized. In practice, the size of the legend is usually limited by cartographics.

In the process, map units that are only slightly different may be amalgamated. Those that occupy minor areas can be added to similar map units. Brierley et al. (1991) state that the primary concern in the map unit consolidation process is the degree to which a compromise affects the resulting land use interpretation. When a compromise is not possible the unique soil map unit is retained.

Step 8. Final Correlation and Report Writing

The final correlation ensures that a uniform and consistent map has been produced for a project area. The vehicle used for final correlation is CORRELOG form 2. The survey report is written after the correlated maps have been compiled.

C.iv. SIL3 Soil Mapping in Alberta

The soil mapping program in Alberta has evolved from reconnaissance mapping to SIL3 1:50 000 standards. This evolution is a result of completion of reconnaissance mapping and a recognized need to update existing mapping in terms of the current state of knowledge and gaps or inconsistencies in existing mapping. The SIL3 1:50 000 mapping program has produced 11 soil surveys for municipalities in east-central and southern Alberta. Some of these soil surveys were targeted for specific uses i.e. deep plowing interpretations in the County of Paintearth but in general these surveys were aimed a generalized user audience that includes: farmland assessment, soil conservation planning, deep plowing, grazing land management, pipeline construction and pipeline reclamation. These soil surveys tend to have many uses but have been criticized for their technical nature and lack of specific focus (other that the pedology focus). It can also be argued that these characteristics make these reports more useful than those with a narrow focus, for example, the soil survey of Warner County was found to do as good a job for irrigation ratings compared to the ratings developed specifically for irrigation but the soil survey has broader application i.e. erosion, salinity, and the like compared to the irrigation maps.

SIL3 mapping has the following characteristics:

1. At least one inspection in 60 to 80% of the delineations.
2. Some traverses on foot, many by vehicle (up to 4 km apart).
3. Profile descriptions for all major named soils, samples from the majority of soils.

4. Range of publication scale 1:30 000 to 1:130 000 (usual scale of publication is 1:50 000).
5. Inspection density of 0.2 to 2 per cm^2. One inspection represents 20-200 hectares on the ground.
6. Soil surveyor should map 20-200 km^2 every 20 days.

Advantages of SIL3 1:50 000 Mapping for Alberta

1. Improved representation of the soil resources in the Province

The evolution to producing SIL 1:50 000 soil survey products was a result of the recognition of a need to better portray the spatial distribution of Alberta's soil resources. The SIL3 1:50 000 maps provide a solid base of information for decision support for the municipalities that have been mapped to date. The results of this program coupled with the national interest in soil conservation has resulted in a demand for 1:50 000 mapping that cannot be met with existing government resources. At present there are 8 formal requests for soil survey by Alberta Municipalities.

2. Improved models of soil and landscape relationships

The continuing collection, collation and management of soil information resulting from SIL3 1:50 000 mapping has improved the understanding of soil and landscape models in the Province. Map legends have been standardized within each mapping project and significant progress has been made to standardized legends between projects. The concept of repeating soil - landscape features has been embraced in modern soil survey products and is reflected in the closed legend concepts currently in use. Soil series are better defined and delineated as a result of the program. The influence of soil morphology on land management is enhanced by the continuation of this program.

3. Improved interpretations for decision support

Many of the soil interpretations for land use have been modified and improved over time and these improvements are reflected in the SIL 1:50 000 soil survey reports. The soil survey of the Calgary Urban Perimeter (MacMillan 1987) is an excellent example of the integration of interpretations for a variety of land uses as adjunct to soil map production.

4. Continued training for junior pedologists for the private and public sector

The soil mapping program (regardless of scale of mapping) has historically resulted in the training of soil scientists in the description and understanding of the spatial variability of soils in the Province. Many of these scientists have moved to the private sector consulting industry both in and out of Alberta and many are in government positions wherein knowledge of soils is important.

Criticisms of SIL3 1:50 000 Mapping for Alberta

1. Rate of progress in Alberta

SIL3 mapping is criticized for its slow rate of satisfying user demand for information. The SIL3 mapping has a predictable rate of progress. Inspection of 100 to 120 sites per township takes between 4 to 10 days. Edge matching of adjacent townships and correlation takes 2 to 3 days to complete. Approximately 10 townships per year can be mapped by one individual. The time required to collect information is a function of the complexity of soils, parent materials and landscapes, mapper experience and access. Whether or not a faster rate of map production would satisfy the user needs is one impetus for this research.

2. Cost

The cost of SIL3 1:50 000 is greater than the public purse is willing to bear. The combined financial reports of the Alberta Research Council and Agriculture Canada indicate that the cost of SIL3 1:50 000 mapping in Alberta ranges from $13,500 to $18,000 per township mapped. The total cost of mapping the remaining 2400 townships in the province (at SIL3) is estimated to be between $32 and $43 million dollars. On the other hand, the cost of SIL3 1:50 000 mapping is about the same per unit area as the cost of a tillage operation for the same area. To date, individual land holders, municipal governments and the provincial and federal government have been unable to increase financial commitments to this mapping program and in fact financial commitments for actual mapping have declined.

3. Increased technical knowledge required to decipher soil survey

Soil survey reports have become increasing technical and are on the level of a M. Sc. thesis in terms of scientific complexity. This results in difficulties for non-technical users when using soil surveys for decision support.

C.v. Soil Mapping in Saskatchewan

Conventional Mapping

The standard approach to SIL3 mapping in Saskatchewan is similar to that in Alberta (H. Rostad pers. comm. 1991). Air photo interpretation is used extensively to delineate patterns of landforms that are expected to be associated with changes in parent material and soil properties (i.e. drainage, salinity etc). There are about 15-17 soil surveyors actively mapping in a normal field season. Typically, each mapper completes an average of 9 townships in a field season. This works out to about 80 hours of field checking per township (8 10 hour days or 10 8 hour days). The maximum number of townships completed in a single field season by experienced mappers operating in familiar terrain is 13-14. The rate of progress varies by location as well as by mapper. The most rapid rates of progress (1 twp per week) are realized in the brown soil zone where access is good, land use is uniform and consistent and soil landscape patterns are readily visible on photos and on the ground. Mapping is typically slower (up to 10 days per twp) in the Black and Dark Gray soil zones where variation in land use can mask soil-landscape patterns, differences in soil drainage are not as readily apparent and access can be reduced due to smaller and more numerous ownership units.

The experience in Saskatchewan is that, regardless of the number of townships mapped during the field season, the activities of map compilation and report writing fully occupy staff over the winter and limit the rate at which field information can be processed and converted into published maps.

Mapping in Saskatchewan is conducted according to a published SIL3 methods manual entitled "Saskatchewan Soil Survey Field Manual" (H. Rostad pers. comm. 1991).

Accelerated Mapping

A modified approach to mapping was developed and implemented in Saskatchewan for mapping conducted in the northern portion of the province in the summer of 1991. The modified approach was adopted in order to make use of a substantial amount of existing information. The area had been surveyed in the 1940's at a reconnaissance level. In addition, municipal affairs data was available for the entire area on a 1/4 section basis. Municipal affairs assessment methods in Saskatchewan classify soils by series in exactly the same way as conventional soil survey. The assessment records also list limitations arising from salinity, erosion, poor drainage, slopes and other characteristics of interest. It was felt that with these two sources of information available, a more rapid approach to upgrade the information into the new 'standard' format was justified. The final product is meant to be similar in all respects to what is produced in other areas using standard mapping techniques.

In practice, the success of the revised method in 'accelerating' mapping was found to depend partly on the skills and attitudes of individual mappers and partly on the degree to which the landscapes to be mapped were familiar and provided external clues to their composition that could be interpreted from air photos (H. Rostad pers. comm. 1991). All mappers found the landscapes to be quite different from what they were used to in the south of the province. The area was very complex, with multiple glaciations, mixed materials and gentle slopes which did not provide strong clues to changes in parent material and soil characteristics. Many of the landscapes were dominated by imperfectly drained soils. Most mappers were unfamiliar with imperfectly drained landscapes and found it difficult to infer imperfect drainage from air photo interpretation.

Individual mappers responded to the 'accelerated' methodology in different ways. Some mappers were unable to realize any increase in map productivity. They simply couldn't bring themselves to 'speed up'. They had trouble accepting the 'second hand' information provided by secondary sources and spent considerable time and effort 'digging out' errors in the source material. H. Rostad (pers. comm. 1991) noted that similar errors would likely be uncovered in any map, including any new map produced by the surveyors themselves. Other mappers found the secondary source information useful and were able to increase their rate of mapping. H. Rostad (pers. comm. 1991) found he was able to reduce the number of field digs per township to between 30 and 40 and was able to complete field checking of up to 2 townships per week. He noted (H. Rostad pers. comm. 1991) that the rate was sensitive to the types of soils and topography in any given area. He also noted that there was some reduction in the precision of statements that could be made about some of the units which displayed a weak relationship between soils and landform. H. Rostad (pers. comm. 1991) concluded that the accelerated mapping approach was not worthwhile implementing in Saskatchewan given that their current SIL3 mapping program was nearing completion and would be done in 3-4 years. The effort to introduce the change might be counter-productive to the operational mapping program.

C.vi. Soil Mapping in Other Parts of Canada

A thorough discussion of mapping in other parts of Canada is not presented at this writing. Mapping programs have been scaled down in some provinces and in other provinces the approaches taken are sufficiently different from Alberta and Saskatchewan that detailed review would not be fruitful to the discussion of revising the mapping system for Alberta.

C.vii. Summary

Soil surveys in Alberta are conducted using a generic approach to mapping. Eight steps are recognized in the process including: definition of objectives, requirements and ongoing reviews; compilation of existing data, preliminary field studies and initial stratification; development of an initial mapping legend; field mapping; interim correlation and remapping; and final correlation and report writing. All of the steps are necessary for the successful completion of a SIL3 1:50 000 map product. One step not mentioned is a follow-up to the final survey report which involves a continuing dialog with the users of the soil survey information. The follow-up dialog is intended to enhance the use of the soil survey by providing a technology transfer function.

Soil mapping in Alberta and Saskatchewan has been conducted using SIL3 1:50 000 standards for the past 15 years. Advantages of SIL3 1: 50 000 mapping include: improved presentation formats; improved models of soil and landscape relationships; improved interpretations for decision support and continued training of field mapping personnel. Criticisms of SIL3 1:50 000 mapping include: the slow rate of progress; high costs and the complexity of the final product for non-pedologists. These criticisms can be applied to other soil survey scales and Survey Intensity Levels.

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II.D. NEW / NON TRADITIONAL MAPPING APPROACHES

- R.A. MacMillan

D.i. Introduction

This section identifies and describes some of the more common alternative systems of mapping used in Canada, and elsewhere, to delineate the spatial distribution of soils or land units. For convenience of discussion, the various alternatives are grouped into two broad categories, namely heuristic (rule based) approaches and stochastic (statistically based) approaches. The various heuristic approaches are based on the principal of applying existing knowledge and expertise about soil-landscape relationships to the process of sub-dividing the entire map area into smaller units with a more limited range of soils and soil properties. The various statistical approaches are based on the assumption that rules governing the spatial pattern of distribution of soils or soil properties are unknown or ineffective but that quantitative rules can be uncovered through the examination and statistical analysis of representative sample data.

D.ii. Heuristic (rule based) Approaches to Mapping Soils and Landscapes

All approaches that make use of existing knowledge and theory to help sub-divide the landscape into more or less homogeneous soil-landscape units may be classed as heuristic or rule based. They all make use of the oft-repeated maxim that the location of soils in the landscape is predictable (Miller at al. 1980). Wilding (1988) observed that "pedologists have long stratified the continuum of soils into classes in making soil surveys based on systematic changes in soil forming factors in a given landscape" and that their "intent was to decrease the total variability of soil properties in the process". This led him to conclude (Wilding 1985) that "landforms serve as the best predictive inferences for systematic changes in soils" and thus serve as the best "basis to build soil-geomorphic models for soil mapping" (Wilding 1988). He further noted (Wilding 1988) that "few major breakthroughs have occurred over the past three decades that reduce the labor intensive surface ground truthing and elevation control required to establish soil-geomorphic relationships".

Most traditional methods of mapping soils (described elsewhere in this document) make use of knowledge about soil-landform relationships. Some of the knowledge and rules used to define soil-landscape units is widely accepted and explicitly recognized in soil survey publications and procedures manuals (Mapping Systems Working Group

(MSWG) 1981). Much of the knowledge and expertise used to guide the delineation of soil-landscape map units at the local level is undocumented or receives minimum and inconsistent documentation in the individual soil survey reports where it has been applied. Overall, soil surveys have not documented how rules for identifying and delineating soil-landscape units are developed and applied and have not provided a consistent theoretical framework for the development and application of those rules. In Canada, some of the theoretical framework is presented in the Soil Survey Manual (ECSS 1985) and the System for Soil Mapping in Canada (MSWG 1981) but neither presents a comprehensive review of the theory involved in the development of soil landscape units. One especially noticeable gap is the absence of a theoretical framework and hierarchy on which to base and justify the criteria for establishing soil-landscape map units. This theoretical and hierarchical framework is often present at a local level (i.e. in Alberta) but is not usually explicitly documented.

D.iii. Ecological (bio-physical) Land Classification (ELC)

Ecological (bio-physical) land classification (Sub-committee on Bio-physical Land Classification (SBLC) 1969) was developed as a rapid, cost effective methodology for physical land classification at a reconnaissance level in Canada. It was meant to provide a set of guidelines to "differentiate and classify ecologically significant segments of the land surface, rapidly and at a small scale (SBLC 1969). Its initial emphasis was on reconnaissance level mapping of forested areas covered by undisturbed natural vegetation (SBLC 1969). It aimed to present a methodology that was consistent with the current level of knowledge of ecological theory and patterns of distribution of ecological controls.

The initial design for ecological land classification (SBLC 1969) envisaged a hierarchical system with four units of classification, namely:

LEVEL	CLASSIFICATION	SCALE OF MAPPING
Level 1	Land Region	1:1 000 000 to 1:3 000 000
Level 2	Land District	1:500 000 to 1:100 000
Level 3	Land System	1:125 000 to 1:250 000
Level 4	Land Type	1:10 000 to 1:20 000

The Land Region was defined as "an area of land characterized by a distinctive regional climate as expressed by vegetation" (SBLC 1969). Land regions were expected to be of large areal extent and heterogeneous composition. Delineation of Land Regions was to be based on "gross form or major physiographic variations (and the implied associated climate)" since sufficiently detailed information to permit the delineation of climatic regions on climate data alone usually did not exist.

The Land District was defined as "an area of land characterized by a distinctive pattern of relief, geology, geomorphology and associated vegetation" (SBLC 1969). It was viewed as a sub-division of the Land Region based primarily on the separation of major physiographic and/or geologic patterns.

The Land System was defined as "an area of land throughout which there is a recurring pattern of landforms, soils and vegetation" (SBLC 1969). It was viewed as a complex mapping unit consisting of "a broad sub-division of the landscape identifiable and mappable from air photos primarily as a pattern of landforms and vegetation" (SBLC 1969). Within Land Systems, "the soil and vegetation were expected to be heterogeneous", but repeated patterns could "be identified and related to patterns of landforms" (SBLC 1969). The Land System was acknowledged to be the working level unit at which most reconnaissance scale delineations would be made. It was proposed that Land Systems be described in terms of the pattern of landforms they contained. Landforms and landform patterns were to be classified and separated in terms of a) mode of origin or deposition of landforms, b) properties of the materials which composed the landforms (including texture, thickness, compaction and chemical or mineralogical composition) and c) topography and relative relief of the landforms. Guidelines were presented for defining and assigning the proposed classes (SBLC 1969).

The Land Type was defined as "an area of land, on a particular parent material, having a fairly homogeneous combination of soil (at a level corresponding to the Soil Series) and chronosequence of vegetation" (SBLC 1969). Land types were not expected to be physically delineated in most reconnaissance surveys but were still viewed as the "basic unit for which interpretations were to be made" (SBLC 1969). Even though they were not physically delineated, the characteristics and distribution of land types within the geographic patterns of Land Systems were to be clearly described in order to support interpretations and subsequent, more detailed, mapping (SBLC 1969).

Part of the rationale for adopting a hierarchical system of classification in ELC was that "to assess the characteristics of land, one needs both generalized information on a regional basis and detailed, site specific information, on a local basis" (Oswald and Senyk

1977). The hierarchical organization of ELC was designed to permit higher levels in the hierarchy to provide broader information on the "amount and distribution of landscapes" whereas lower levels could provide the "site specific information on a single landscape on which various interpretations, including its productive capability and sensitivity, can be made" (Oswald and Senyk 1977).

Application and Evolution of ELC in Canada

Ecological Land Classification was always intended to be a flexible set of guidelines rather than an arbitrary set of rules. For example, Rowe (1979) acknowledged that it might not be desirable to restrict classifications to the four levels that he defined, stating that "there could be two or twelve (levels) so long as legitimate purposes are served". Rowe (1979) did argue that it was advantageous to have a basic framework consisting of a relatively few units (whatever they may be called) to which all land classifiers can relate and between which other units can be interpolated as required".

In the light of Rowe's (1979) comments it is not surprizing that ecological land classification as presently practiced has undergone significant revision arising from increased practical experience obtained since the initial system was proposed. The Ecological Land Survey of the Northern Yukon (Wiken et al. 1981) serves as an example of the modifications and extensions to the initial system developed to recognize local needs and to reflect increased experience with the system. The revised units of classification and the approximate scales at which they were to be mapped were given by Wiken et al. (1981) as:

LEVEL	CLASSIFICATION	SCALE OF MAPPING
0	Ecoprovince	1:5 000 000 to 1:10 000 000
1	Ecoregion	1:3 000 000 to 1:5 000 000
2	Ecodistrict	1:500 000 to 1:1 000 000
3	Ecosection	1:50 000 to 1:250 000
4	Ecosite	1:10 000 to 1:25 000
5	Ecoelement	1:2 000 to 1:5 000

Wiken et al. (1981) modified the traditional Canadian concepts of bio-physical land classification to embrace a more ecological perspective. Definitions of land region and land district were opened up to include a variety of controlling factors rather being biased towards vegetation at the level of land regions and physiography at the level of land districts (Wiken et al. 1981). This study did not define or describe units lower in the hierarchy than the Ecodistrict.

The Geological Survey of Canada developed a system for reconnaissance mapping that they called "Terrain Mapping" (Fulton et al. 1974). Terrain mapping may, in many respects, be viewed as the implementation of ELC principals within the Geological Survey of Canada. The main goal of terrain mapping was to "provide an accurate abstraction of terrain conditions" rather than to "provide a definitive study of the taxonomy of slopes, surface deposits and landforms" (Fulton at al. 1974). The concept was that the terrain model represented a model of the earth's surface rather than an explicit inventory of the earth's characteristics. A strong distinction was made between classifying which was taken to mean "grouping or segregating into classes which have systematic relationships" and modelling which was used in the sense of "a complete description produced by a process of identifying and representing the salient aspects" (Fulton et al. 1974).

Terrain mapping was designed to provide the following three things (Fulton et al. 1974):

1. A description of the static land surface and the material underlying it.
2. An analysis of the processes currently acting on the landform materials.
3. A presentation of the quaternary history.

Application of the procedures of Terrain Mapping involved acceptance of the following assumptions and criteria:

1. The terrain elements identified must be based on criteria observable on aerial photographs. Logistical limitations often make it impossible to trace boundaries on the ground and hence units based on criteria that can only be obtained from the ground are impractical.
2. The scheme must be constructed so that it can be used equally well in all parts of the country. The composition of terrain units will vary from one part of the country to another but the scheme should be devised in a way that someone familiar with the coding system can easily understand terrain conditions in areas with which he is unfamiliar.
3. The system must be independent of the operator (i.e. it must be such that any two people would come up with essentially similar products).
4. The scheme must be independent of the ultimate use planned for the information. The emphasis should be placed on gathering fundamental data that completely describes the nature of the terrain. If this is done, then the

> data gathered should apply as equally well for forestry applications as it would for groundwater potential studies or engineering considerations.

The Bio-geoclimatic Classification (BGC) of Krajina (1965) and variations of it (Beil et al. 1976; Pojar 1983) are widely used throughout British Columbia to map ecological units as expressed by vegetation. In many ways, BGC represents the implementation of ELC concepts as configured for British Columbia conditions and needs. The system is based on vegetation because "vegetation is considered to be the best integrator of the combined influence of a variety of environmental factors affecting the site (Meidinger and MacKinnon 1989).

"The BGC system organizes ecosystems at three levels of integration - local, regional and chronological - with the intention of showing the relationships among ecosystems in form, space and time" (Meidinger and MacKinnon 1989). A detailed review of the BGC system is not presented here. It is sufficient to note that it bears many similarities in design and concept to 'traditional' ELC and that its focus on vegetation is entirely appropriate in British Columbia with its large tracts of natural forests. The great local variability in relief and topography present throughout much of B.C. exerts a strong influence on the distribution of vegetation and provides a basis for fairly accurate prediction of ecological site conditions and resultant habitat type. These conditions are not common outside of the mountain parks portion of Alberta and the system is less well suited for delineating ecologically significant areas in the grasslands and boreal forests that cover most of Alberta.

Application and Evolution of ELC Concepts for Mapping in Alberta

The original concepts and guidelines of ELC have been freely adapted to suit local conditions and requirements throughout Canada. A number of implementations of ELC principals have been used for mapping in Alberta, primarily within the forested portions of the province.

Biophysical Land Classification (Boyacioglu 1974) represented an early implementation of the principals of Ecological Land Classification in Alberta. This system adopted the initial four tier ELC classification of Lacate (CBLC 1969) with very little modification. In practice, only the top three levels in the hierarchy were used and map areas were described at the level of Land Systems and delineated at a scale of 1:125 000 (Boyacioglu 1975).

The main emphasis of biophysical analysis was to "divide, and then classify, the land surface into areas of similar environment" (Boyacioglu 1975). The intent was to "provide an initial overview and inventory of the patterns of slope, soil, parent material, land form and vegetation within a prescribed study area" (Boyacioglu 1975). The standard assumption was made that "the areas are sufficiently 'the same', at the chosen map scale, to allow estimates of their potential for various land uses to be made" (Boyacioglu 1975).

In keeping with other similar approaches, biophysical analysis used the interpretation of air photos to "segment the landscape by interpreting such factors as slope, landform, parent material and vegetation" (Boyacioglu 1975). A limited number of field checks were carried out to "verify the accuracy of the outlined 'biophysical areas' and to compile pertinent soil, vegetation and other information for the eventual land capability ratings" (Boyacioglu 1975).

Demands for increased detail and specificity of information led to the development of a two tier system of mapping for forested areas in Alberta. Physical Land Classification (PLC) was adopted to provide a comprehensive description of the physical characteristics of land areas at scales as detailed as 1:50 000. The physical information was subsequently integrated with vegetation and other ecological information to construct Ecological Land Classification maps (Archibald et al. 1984).

Physical Land Classification uses a four-tiered hierarchy to separate the landscape into discrete units (Archibald et al. 1984) as follows:

LEVEL	CLASSIFICATION	SCALE OF MAPPING
1	Physiographic region	1:1 000 000 to 1:3 000 000
2	Physiographic subregion	1:250 000 to 1:1 000 000
3	Geomorphic system	1:50 000 to 1:250 000
4	Geomorphic unit	1:5 000 to 1:50 000

Physiographic regions were defined as "topographically alike landscapes with similar relief, structural geology and elevation" (Archibald et al. 1984). Physiographic subregions were defined as having "distinct patterns of relief, geology, geomorphology, drainage pattern and density" (Archibald et al. 1984). Geomorphic systems were defined as "recurring patterns of landform as differentiated by origin, composition and surface expression with soils classified and described to either the great group or subgroup level" (Archibald et al. 1984). Geomorphic units were defined as "homogeneous land units differentiated on mode of origin, composition, surface expression, texture, slope, aspect and drainage" with soils classified and described to the level of "subgroup, family, series, or type" (Archibald et al. 1984). Geomorphic units were delineated to "provide the greater detail which is useful for site specific planning and operational management" (Archibald et al. 1984).

PLC used an open legend concept to label areas of land delineated at a scale of 1:50 000. A typical legend was illustrated by Archibald et al. (1984). The label identified the genetic type of parent material, its surface expression and modifier and its texture. It further classified the slope and aspect of the delineated area and gave the subgroup classification and drainage class of the two (or three) most extensive soils found within the delineation.

The inventory procedures adopted for mapping forested areas in Alberta have seen Ecological Land Classification (ELC) maps prepared concurrently with PLC maps but retained as separate entities. Ecological Land Classification as practised in Alberta retains most of the concepts and definitions associated with the more recent examples of ELC elsewhere in Canada. It utilizes four of the six tiers in the ELC hierarchy as described by Wiken et al. (1981) corresponding to levels 1 to 4 (Ecoregion to Ecosite). Ecoregions are differentiated according to a "distinctive regional climate as expressed by vegetation" (Archibald et al. 1984). Ecoregions are delineated through consultation of the map Ecoregions of Alberta (Strong and Leggat 1981) with modifications necessitated by more recent field knowledge. Ecodistricts are defined to recognize "distinct physiographic and/or geologic patterns; similar relief, geology, geomorphology and genesis of parent material" (Strong and Leggat 1981). Ecosections are defined to capture "recurring patterns of slope, landform, soil and vegetation" (Strong and Leggat 1981). Ecosites represent a "unique recurring combination of vegetation, soil, landform and other environmental components" (Strong and Leggat 1981).

In practice, ELC and PLC units share the same boundaries at most levels in the hierarchy (Table 2.2). Ecodistricts and physiographic subregions share the same boundaries as do ecosections and geomorphic systems. Ecoregions and physiographic regions do not share the same boundaries since "vegetation and climate (which define ecoregion), while interacting with major physiographic differences, do not correspond exactly to divisions at the physiographic region level (Archibald et al. 1984). As with most similar systems ELC in Alberta relies heavily on airphoto interpretation to divide the landscape into discrete units to the level of geomorphic systems or ecosites. Existing natural resource information and a limited number of field inspections are used to describe, characterize and check the delineated areas.

Table 2.2 Levels of land classification.

LEVEL	PLC CLASSIFICATION	ELC UNITS	SCALE OF MAPPING
1	Physiographic region	Ecoregion	1:1 000 000 to 1:3 000 000
2	Physiographic subregion	Ecodistrict	1:250 000 to 1:100 000
3	Geomorphic system	Ecosection	1:50 000 to 1:250 000
4	Geomorphic unit	Ecosite	1:5 000 to 1:50 000

The principals of ecological land classification have been used implicitly by many soil survey mapping projects in Alberta and explicitly adopted for several large studies. All of the mountain national parks have been mapped using an explicit application of ecological land classification principals and methods. Holland and Coen (1983) mapped Banff and Jasper national parks to the level of ecosites. They defined ecoregions, ecosections and ecosites but did not use the category ecodistrict. Turchenek and Lindsay (1982) adopted an ecological land classification approach for the reconnaissance inventory of the Alberta Oil Sands Environmental Research Program (AOSERP) study area. They mapped the extent of ecoregions and ecodistricts and gave conceptual descriptions of ecosections (which they called ecosystems). The most detailed level of spatial description was the soil map unit which was nested within ecodistricts but differed from ecosystems in that it did not incorporate vegetation as a defining criteria (Turchenek and Lindsay 1982). The principals of ecological land classification have been implicitly utilized to define and describe assemblages of soil-landscapes in several recent SIL3 soil survey mapping projects. MacMillan et al. (1988) described land systems and sub-divisions of land systems called land units in the county of Flagstaff. A similar approach was used by Brierley et al. (in press) in the county of St. Paul. Kocaoglu (1975) described land units for the Sand River area that were closely similar in concept to ecosystems as used in ecological land classification.

Similarities and Differences Between ELC and Soil Survey

Borys and Mills (1979) argued that examination of most soil surveys showed that all of the environmental factors which were built into current ecological land classifications were also included on soil maps. They concluded that "a soil survey is very much an ecological land classification but differs from the current definition in that the integration of ecologically related elements takes place in the soil rather than receiving recognition as separate components of the landscape (Borys and Mills 1979).

ELC and traditional soil survey share many similar objectives, concerns and methodologies. For example, in common with soil survey, the objective of ELC has been given as "to develop a method of integrated survey that will provide units of land significant for resource use and conservation" in order to "fill a need in current land use planning and management" (Rowe 1979). In common with soil survey, ECL "sets out to divide the earth's surface into significant areal units of various scales, each assumed to have a certain internal homogeneity and functional integrity" (Rowe 1979).

Both approaches share an awareness and concern with the confusion that results from imprecise understanding of the distinction between taxonomic units used to classify and describe areas and map units used to portray the spatial extent of similar areas (Rowe 1979). In ELC "taxonomic units and mapping units are distinct" (Boydell 1979) where "taxonomic units are considered explanatory while mapping units are often necessarily composites of such units".

Both soil survey and ELC recognize the need to employ both agglomeration and division (stratification) to classify and delineate areal units and both conclude that the prevalent method should rely on stratification (Rowe 1979). This is clearly evident in the following quotations from Rowe (1979):

> "The situation is different with earth science areas, with landscapes. Discrete units are not 'given'; therefore, a variety of land individuals can be cut out of the geographic continua at different scales for different purposes. The usual method is divisive, from above, providing units believed to have genetic and functional significance as signalled by particular spatial associations of observed features. The invention of units is a necessary procedure to which purely logical taxonomies, building classes from below, lend no assistance."
>
> "The important point is that sub-dividing (classifying from above) so as to identify important functional units of the landscape is not only a legitimate approach to ELC but also an indispensable one."

Despite the bias towards logical division from above, Wiken et al. (1981) observed that in practice "there is often a little of both (sub-division and agglomeration), as each route tends to substantiate or modify the results of the other throughout the classification process".

Both ELC and soil survey share an interest in what criteria and rules to use to identify and bound (delineate) areal units. ELC makes a somewhat stronger effort to present a systematic framework and theoretical justification for the criteria used to define and outline areal units, particularly those at the higher levels in the hierarchy. Rowe (1979) asserted that "if the mapping is to be understandable by others, reasons must be given for the boundary placements" and suggested that the "solution is to look for indicators (visible on air photos and on the ground) that can be identified with generators of function and process in various sized units of land" (Rowe 1979). The primary criteria for boundary placement in ELC, at all scales, thus becomes climate as reflected by changes in climate related to readily perceivable changes in patterns of vegetation, landform or drainage (Rowe 1979).

Another commonality between soil survey and ELC is the shared reliance on both observation and inference in the delineation and interpretation of mappable areas of land. Both use readily observable features of the landscape as criteria for sub-dividing the landscape while simultaneously making inferences about what the readily observable properties may imply about the past development history and presently active processes associated with the landscape. Rowe (1979) offers the following classification of clues used to delineate map areas:

Observed: 1. Inherent (morphological),
2. Contextual (spatial or chronologic),
Inferred: 3. Developmental (morphogenetic or chronologic),
4. Functional (ecologic-physiologic).

Mappers observe inherent properties (1) such as shape or surface color along with contextual properties (2) such as relative position (above/below, next to, etc.) from which they deduce certain inferred characteristics such as the geological process (3) most likely responsible for deposition of the parent material or the landform and (4) the likely present patterns of flow of water and energy between the landform and its adjacent neighbors (i.e. presently active processes). Both observed and inferred properties are used in deciding where and whether to place boundaries around areas of land at any given scale.

Soil survey and ELC share a variety of institutional concerns in addition to the philosophical and methodological similarities discussed above. Both have identified a 'communication gap' between the spatial data base and its users (Boydell 1979), the gap being caused by "delays in the delivery of data to the user and the volume and complexity of the data with which the user is presented". Measures suggested by the Canada Committee on Ecological (Biophysical) Land Classification (CCELC) (1979) to reduce this gap included "increased communication between the mapper and the user to aid in mutual understanding, avoidance of jargon, and simplification of data presentation" (Boydell 1979). All of these sound very familiar to the soil surveyor.

Standardization of products and methodologies is another shared concern with both groups debating the needs for rigid standards or flexible guidelines to define how maps should be made and how the information should be presented. The CCELC could not achieve consensus on this subject in 1979 with one group concluding that "detailed guidelines would not achieve an early consensus" (Boydell 1979) and a second identifying "an immediate need for revised guidelines" (Boydell 1979). A similar debate has been ongoing in soil survey with a similar lack of resolution. In both cases, the question has consistently been 'resolved' by recommending loose 'guidelines' that allow for 'regional variation in approach' (Boydell 1979).

Both ELC and soil survey have consistently recognized a need for better interpretations and interpretive guidelines to "communicate ELS work to other organizations and to the public" (Boydell 1979). Both share concerns with the exchange and use of information produced by mapping activities. The CCELC recommended in 1979 (Boydell 1979) that they:

> "develop a vehicle that will inform and teach resource managers, specialists, contractors, politicians and the public in the ways of application, feasibility, methodology, benefits and costs of ELS and prepare general information packets for such people."

Another shared concern is the costs and benefits of producing maps and the means by which these can be assessed. The CCELC expressed concern in 1979 with "demonstrating cost-benefit aspects of current ELS projects" and "selling the ecological benefits of ELS" by "explaining the ELS approach in layman's terms", and circulating questionnaires to project leaders in order to compare the costs of ELS to studies conducted using the 'single discipline approach'. Finally, and here is where we find ourselves again today, the 1979 meeting recommended that "a cost-benefit analysis should involve an assessment of the predictive value of ELS and the monitoring of user satisfaction and user scrutiny of ELS with respect to applicability of the data" (Boydell 1979).

Dent and Young (1981) argued that "a land systems map is not of itself a soil map although land systems are closely related to soil surveys". Similarly Beckett and Bie (1978) maps of land systems were "not the same as maps of soils or vegetation".

Northcote (1984) recognized that land systems maps were not soil surveys but still argued for the adoption of many of the concepts of ELC when he stated that "it is time to rethink the methodology of soil survey". He proposed that 'soil landscapes' be adopted as the basic mapping unit for soil surveys. Soil landscapes were defined in a manner quite similar to that employed to describe Land Systems in ELC as "natural areas of land of recognizable and specifiable topographies and soils that are capable of presentation on maps and of being described by concise statements (Northcote 1984). Northcote (1984) contended that the adoption of soil-landscapes as the basic units of mapping would permit description of the actual variation in soils and soil properties as found within the landscape and would free the mapping unit from doubling as a taxonomic unit.

Application of the Principals of ELC Using Computer Technologies

Recently, a variety of individual project-oriented inventories have demonstrated how the principals of ELC could be applied to produce maps more consistently and quickly with the aid of computerized information systems. None of the examples represents a formalized system for land mapping or classification but they do illustrate how the basic principals and methods of ELC can be updated using currently available technologies.

The approach to terrain inventory adopted for use with the Integrated Land and Water Information System (ILWIS) developed at the International Training Centre (ITC) in the Netherlands (Meijerink 1988) represents and example of how traditional concepts for hierarchical ecological mapping can be adapted to make better use of computerized information system technologies. The system described is an adaptation of the "ITC System" of geomorphologic mapping (Verstappen and van Zuidam 1975) as extended by van Zuidam and Cancelado (1979) for terrain analysis. It uses geomorphologically based terrain mapping units (TMU's) to group natural associations of geology, geomorphology, morphometry and soils (Meijerink 1988). The TMU's are defined by traditional methods relying on interpretation of air photos, satellite imagery, and existing thematic and topographic maps. The principal difference is that the TMU's are defined before any entry of information into a GIS in such a manner as to minimize the proliferation of unit boundaries and reconcile marginally different boundaries for different themes of information.

A full review of the ILWIS approach to the definition of TMU's is not presented here. A principal attraction of the TMU approach is that it integrates a wide variety of terrain characteristics (geology, soils, relief, drainage, geomorphology) into a single set of polygons. Construction of a similar set of information by overlay of multiple independent sets of single factor, single discipline maps was shown in initial trials to produce a confusing maze of non-coincident polygons (spaghetti) in comparison to the single set of comprehensive and consistent polygons produced by application of the TMU approach (Meijerink 1988). A further advantage of the ILWIS approach was that TMU's were designed to include a definition of their hydrological connectivity (i.e. TMU 1 drains to TMU 2) and to permit specification of a variety of hydrological attributes (i.e. stream density, valley density and slope steepness, slope lengths). The basic structure of TMU's recognizes that they are subdivisions of watersheds or sub-watersheds thereby creating a hydrologically consistent topology. This hydrological and topological information facilitates the interpretation of TMU's for many behaviors of interest (i.e. erosion potential, flooding hazard, crop yield modelling) (Majerink 1988).

An opposite approach to the integration of various layers of initial data to produce a useful composite map is described by Robinson and Miller (1989). They described a procedure for creating integrated ecological maps by overlaying individual single discipline maps. This procedure created numerous non-significant or 'spurious' polygons. Robinson and Miller (1989) argued that a knowledge based approached could be used to identify spurious polygons arising from the overlay of several single theme maps with non-coincident polygon boundaries. They proposed a series of rules for nominating polygon line segments for automatic adjustment or removal. The resultant map was 'clean' and of uniform spatial 'texture'.

The method used to construct data layers for the Flathead National Forest GIS (Hart et al. 1985) illustrates how information systems technology can be used as a automated substitute for the manual delineation of soil/landform units at the level of ecosections or ecosites. Supervised classification of a Landsat 2 MSS image using a conventional clustering technique did not create classes that adequately discriminated between land cover types. A digital elevation model with a horizontal (ground) resolution of 50 x 50 m was obtained, geometrically corrected to a UTM map projection and processed to compute slope gradient and aspect (Hart et al. 1985). The elevation and slope data were combined with the initial spectral classifications of the landsat imagery and 3,600 unique combinations of elevation, slope, aspect and spectral classification were identified. These were resolved into 189 land cover classes that were far more effective in delineating actual vegetation/landform classes. These units could be considered similar to ecosites as would be delineated using conventional analysis of air photos. A significant advantage is that the 'rules' used to define classes and determine class boundaries could be explicitly defined and consistently applied.

Lowell (1990) compared traditional manual methods of producing ecological land type (ELT) maps for a forested area with a GIS approach for 'automated mapping' of ELT's. ELT's were described as the basic, or smallest, unit in an eight level hierarchical Ecological Classification System (ECS) developed for use by the U.S. Forest Service. Ecological Land Types (ELT's) were defined as ecologically uniform areas capable of a particular level of production or use that are characterized by regional landform, soil type, slope steepness, topographic aspect and natural vegetation (Lowell 1990). Lowell (1990) argued that "with the increasing use of ECS and similar systems, it is desirable that a methodology be developed to allow ELT's to be mapped relatively quickly and accurately". Lowell (1990) described an automated procedure for making ECS maps that involved computing slope gradient and aspect from a DEM and overlaying this information with a pre-existing map of soils. His comparison of the automated and manually produced maps led him to conclude that "manual and automated techniques will not produce the same ELT maps" (Lowell 1990). He also concluded that "until computer compatible data bases for all necessary parameters (DEM, remote sensing) become available, the production of ELT maps by automated techniques cannot be considered time-efficient".

Another example of integration of DEM, remote sensing and ancillary data (geological maps) to automatically define ecologically significant land units is provided by Warner et al. (1991). They used a probability density function classification algorithm (Cetin and Levandowski 1991) to recognize six forest classes of various mixtures of coniferous-deciduous vegetation based on spectral reflectance values (DN's). A 30 by 30 m DEM was produced by manual digitizing of a 1:50 000 scale topographic map. The DEM was processed to compute slope gradient and aspect. A local measure of relative relief was also computed to produce an estimate of relative convexity or concavity (upness or downness) in order to separate wet flat sites from dry flat ridges. The topographic variables were used to identify and classify four types of landforms, namely; flat moist areas, flat dry areas and ridge tops, north facing slopes steeper than three degrees and south facing slopes steeper than three degrees (Warner et al. 1991). Analysis of the various combinations of vegetation class by topographic class and underlying geological material demonstrated a relationship between vegetation community and landform type for areas underlain by iron rich (mafic) geological rocks.

Twery et al. (1991) illustrated how rule based methods could be applied to digital elevation data to help predict tree species composition. The basic assumption of a relationship between topographic position and vegetation is essentially similar to that of a soil landscape model as used in ELC or soil survey. Twery et al. (1991) observed that the "use of a knowledge based approach allows more efficient use of time and effort by developing and refining hypothesis in situations where practical circumstances rule out large-scale field data collection and traditional statistical methods". Twery et al. (1991) classified terrain as represented by a triangular irregular network (TIN) elevation model into five elements, namely: channels, lower slopes, middle slopes, upper slopes and ridges. A regional landform allocation was superimposed to determine the scale of resolution of the areal units required to sub-divide the terrain into these classes. Two spatial qualities were considered in defining areal units, local or site characteristics and relative location. Local characteristics included slope gradient, aspect and elevation. Relative location in the regional context was assessed in terms of regional physiography and position of TIN elements relative to channel or ridge lines (i.e. slope position in the context of drainage lines).

Twery et al. (1991) composed four key questions with respect to the application of expert knowledge to predict vegetation conditions. These were:

1. Can less expensive, more readily available data be combined with rules to generate new, surrogate measures of species composition?
2. Are the new variables useful?
3. What precision and accuracy do we need for specific scientific questions?
4. Can we refine the surrogates to be more useful?

Substitute the words "soil map unit" for "species" in the above and the questions apply equally to the present problem of how to make soil maps more rapidly and more accurately. Twery et al. (1991) claimed to have answered all of the above questions in the affirmative (to some degree) and recommended adoption of rule based approaches to develop, test and refine hypothesis about landform-vegetation relationships.

A growing number of researchers have shown that techniques for "automated feature extraction" can be used to define "fundamental landscape units" starting with a base of digital elevation data (Band and Wood 1988; Band 1989a; Miller 1984). The rationale underlying this approach is that the "rules" by which fundamental landscape units are delineated through the process of manual interpretation of stereo airphotos can be replicated in a systematic way through automatic processing of digital elevation data. Pike (1988) referred to the concept of a "geometric signature" which could be used as a "topographic fingerprint" to differentiate different landforms with a view to linking geometric form to "the materials and processes that underlay and shape the topography". The technique differs from the top-down stratification approach inherent in most systems of manual ecological land classification in that it is agglomerative rather than divisive. Agglomeration is used to cluster, or group, individual elevation grid cells or TIN elements to define "fundamental landscape entities" (Band 1989b). These fundamental units are usually defined according to hydrological criteria and are based on the concept of establishing "topology" by tracing paths for the flow or water (or energy) under the influence of gravity as it passes from element to element.

A comprehensive review of the methods and results of individual studies is not presented here. The concepts discussed below are extracted from a series of papers by Band (1986a,1986b; 1989a, 1989b, 1989c; Band and Wood 1988; Morris and Heerdegen 1988; Jenson and Dominique 1988; Jenson and Trautwein 1987; Miller 1984; O'Callaghan and Mark 1984; Mark 1983; Hutchinson 1988; and Bork and Rhodenburgh 1986). Band (1989c) observed that "digital terrain models are used to automate the partition of the watershed into different sets of hillslopes and for the computation of topographic complexity within and between units. The hillslope is chosen as the "basic functional unit for these efforts because it has well defined hydrologic and geomorphic boundaries and effectively delimits the patterns of vegetation, soil and microclimate into fairly distinct surface regions in many environments" (Band 1989c). It is clear that these techniques parallel traditional mapping methods in that they assume that patterns of variation of soil and vegetation are best represented by delimiting landform units and assuming that variation of soil (or vegetation) is less within the delimited landforms than within the region as a whole. The concept here is simply to apply a set of consistent rules for defining and delineating the landform entities that will be used to partition the landscape into areas of less variation that will then be characterized and described.

The end result of "automated" agglomeration is the definition of a series of landform elements that resemble individual slope facets as would be defined by manual airphoto interpretation. The slope facets are generally further grouped into sub-watershed units and watersheds according to the "hydrological connectivity" established between adjacent slope facets. A variety of topographic indices are usually calculated for each element contained within a defined slope facet. Typical topographic and geomorphic indices include slope gradient and aspect; down-slope and cross-slope curvature (Evans 1972, 1980; Eyton 1985; Zeverbergen and Thorne 1987; Niemann et al. 1989); up-slope catchment area and down-slope dispersal area (Pennock et al. 1987) and relative local relief (Pike 1988; Band 1989c) (variation in elevation within a specified surrounding window). These local values can be used to sub-divide individual facets, for example, so as to define a sub-facet with a uniform and limited range of slope gradient, aspect and curvature. The slope facets and sub-facets defined in this manner often resemble ecoelements or ecosites as defined manually for Ecological Land Classification mapping. Boundaries between sub-facets will often resemble those that would be allocated manually by airphoto interpretation. Boundaries will generally occur at locations of maximum rate of change of slope, since slope gradient is used as a prime variable in defining the sub-facet.

These techniques of automated feature extraction are really only applicable where the scale at which available, and practical to use, elevation data matches the scale of the landscape elements that must be defined. The horizontal and vertical resolution of the digital elevation data must be such that the individual landform segments can be properly "captured" and defined by the available elevation data. In practice, these techniques work best in areas with integrated drainage, high relief and large, relatively uniform, slope facets such as are found in mountainous areas of alternating large ridges and valleys. In these types of areas, the landforms are sufficiently large and continuous that each individual slope or sub-facet will invariably contain large numbers of elevation data points in digital elevation models of the resolution currently available and practical to use (i.e. 10 to 30 m horizontal resolution). Similarly, the relative relief of the main landform elements of interest in such areas will usually be measured in terms of hundreds of metres and will be adequately captured by available DEM data sets with vertical resolutions of 1 to 10 m. Consequently, the available DEM data will be of sufficient density and vertical precision to "capture" and define the slope facets and landforms of interest.

Application of these techniques to areas of low relief and complex topography with a view to defining entities for display at regional scales (1:50 000 to 1:100 000) poses problems. Niemann et al. (1989) showed that the relative relief in a glaciated area with hummocky topography and slopes less than 4% ranged from 0.5 to 2 m. They did not report on the average length of slope or range in slope lengths but experience indicates that major changes in slope direction (points of inflection) occur at horizontal distances of between 50 and 200 m in typical hummocky glaciated landscapes. The best digital elevation data sets readily available in Alberta offer a horizontal resolution of 30 m and a vertical resolution of 10 m absolute and 1 m relative. These data sets are sufficiently coarse, relative to the subdued topography of hummocky glaciated terrain, that there can be no guarantee they will properly "capture" and describe the topography of these areas. A suitable DEM would have, as a minimum, a horizontal resolution of 5-10 m and a vertical resolution of 0.1-0.5 m.

Problems still remain relative to regional SIL3 level mapping even if a DEM were available at sufficient resolution to define individual slope facets and sub-facets in subdued morainal landscapes. The problem is that, at that level of mapping, the entities being described in areas of subdued morainal landscapes do not often correspond to individual slopes or slope facets. As a general rule, map units delineated at SIL3 delineate "repeating patterns of landforms", that is an assemblage, or succession, of individual slope facets arranged in some characteristic and repeating pattern. The pattern in glaciated terrain often consists of a series of repeating knolls and depressions, separated by slopes of varying length. The depressions are not hydrologically connected in any predictable pattern that could be used to group them according to logical and consistent rules. Manual mapping is generally based on human "pattern recognition" in which areas are delineated according to the frequency, size and pattern of included observable features such as shallow ponds or eroded knolls. These can be recognized and delineated manually on airphotos but, to date, there have been few examples of successful algorithms for recognizing such patterns automatically from DEM data, from satellite imagery or from some combination of the two.

Pennock et al. (1987) applied the techniques of automated terrain classification to hummocky glaciated landscapes of low relief in the Canadian prairies. They extended the concepts inherent in the nine unit geomorphic model of Dalrymple et al. (1968) to apply to hummocky glaciated terrain. They proposed a set of rules for classifying landscape segments at a local scale according to slope gradient, cross-slope and down-slope curvature. The intent was to delineate three dimensional landform segments corresponding to Ruhe's (1960) two dimensional concepts of convex shoulder, concave footslope, linear backslope and gently sloping summits and toeslopes. The seven landform segments proposed by Pennock and de Jong (1987) are listed and defined in Table 2.3.

Table 2.3 Description and classification of landform elements as proposed by Pennock and de Jong (1987).

Landform element	Description	Criteria*	Morphology
DSH	Diverging water flow, shoulder	PROF >0.100^0/m CCURV >0.00^0/m	Convex Convex
CSH	Converging water flow, shoulder	PROF >0.100^0/m CCURV <0.00^0/m	Convex Concave
DBS	Diverging water flow, backslope	PROF >-0.100^0/m, <0.100^0/m GRAD >3.00^0 CCURV >0.00^0/m	Linear High slope Convex
CBS	Converging water flow, backslope	PROF >-0.100^0/m, <0.100^0/m GRAD >3.00^0 CCURV <0.00^0/m	Linear High slope Concave
DFS	Diverging water flow, footslopes	PROF <-0.100^0/m CCURV >0.00^0/m	Concave Convex
CFS	Converging water flow, footslopes	PROF <-0.100^0/m CCURV <0.00^0/m	Concave Concave
L	Level, water flow negligible	PROF >-0.100^0/m, <0.100^0/m GRAD <3.00^0	Linear Low slope

(SOURCE: Pennock and de Jong 1987).

Pennock et al. (1987) sampled the the landform segments they defined to test whether the assumption of lower variability of soil properties within individual landform elements was supported. They reported that variation of the soil morphological properties of A-horizon thickness and depth to calcium carbonate was not significantly different between all landform units but was significantly different with respect to groupings of the landform elements. The automated classification of the landscape into landform elements was concluded to provide a reasonable basis for sub-dividing the landscape for quantification of surface morphology of an area and for defining the differences between landform elements. The methods presented by Pennock at al. (1987) and Pennock and de Jong (1987) are appropriate for use in subdued hummocky landscapes such as are common in Alberta. The methods are, however, more applicable for detailed site studies than for regional mapping exercises. In regional mapping, they might be best employed to characterize selected sites within mapping units in order to quantify the relative frequencies and characteristics of the seven landform elements.

The efforts of Niemann et al. (1989) illustrated how the scale of topographic features that could be extracted from available DEM data in Alberta did not correspond well with the scale and concepts used to describe soil-landscape units employed in traditional SIL3 soil survey mapping in Alberta. The DEM data was appropriate for calculating the topographic indices of individual landform elements (dimensions 30 x 30 m) whereas the soil survey map attempted to describe larger landscapes (dimensions 1000 x 1000 m) composed of a repeating pattern of landscape elements (Niemann et al. 1989). Niemann et al. (1988) observed that the parametric analysis of DEM topographic indices showed a "tendency to analyze individual landform elements in isolation and not treat the landscape as an integrated unit described by a variety of shape attributes". Conversely, the soil survey maps delineated landscapes that had a repeating pattern of slopes and landforms but then described the soil map units in terms of a single and narrow range of slope gradients and curvatures not supported by detailed analysis of individual elements within the landscapes.

The conclusion must be that, at present, none of the current techniques of automated feature extraction are suitable for delineating landscapes of repeating patterns of individual landforms in subdued glaciated topography at the scales employed for SIL3 level soil mapping. These techniques work in areas where individual landforms are of sufficient size that they can be recognized and mapped at the desired scale from available DEM data. The utility of detailed analysis of high resolution DEM data for SIL3 level mapping is more likely to be in terms of quantifying the distribution of slope gradient, curvature, slope length and other individual element attributes within delineated landscapes so as to better describe the landscapes rather than as a tool for automatically delineating the landscapes themselves.

D.iv. Statistically Based Techniques for Mapping Soils and Landscapes

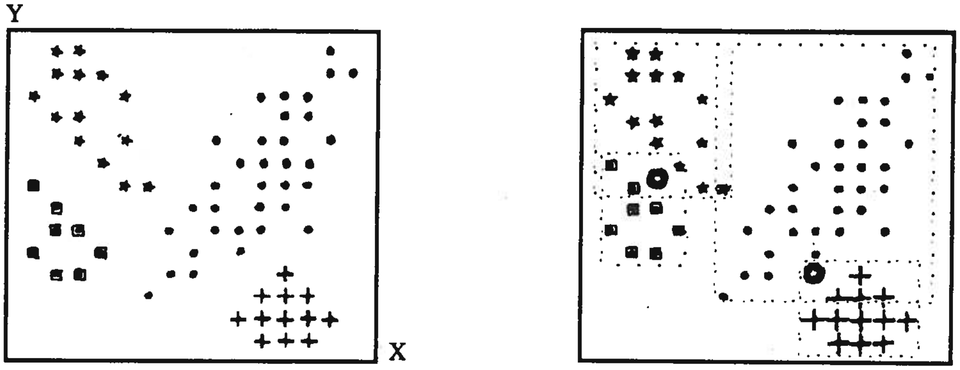
A variety of approaches for classifying and mapping ecologically significant landform units are based on the premise that there is a strong association between the spatial distribution of patterns of soil and controlling topographic and edaphic variables, but that the rules governing this association are unknown or too poorly understood to effectively delineate different soil-landscape units. A variety of techniques have been proposed to identify and test formal, quantitative procedures for the development and application of rules for sub-dividing landscapes in an environmentally significant manner.

Techniques of 'Supervised Classification' Associated with Remote Sensing

The techniques of supervised classification used in remote sensing and image analysis can be used to create a set of quantitative rules for classifying entire areas based on observations and classifications obtained from a limited number of point sites. The "rules" generated by supervised classifications are really nothing more than a series of boolean or mathematical expressions that define the boundaries between classes of data based on observed patterns of distribution of the variables used to characterize and classify the data. The "rules" are generated by mathematical analysis of the relationships between observed values of parameters selected to effect the classification and a "training set" of sites where the decision regarding the correct classification to apply has been made manually.

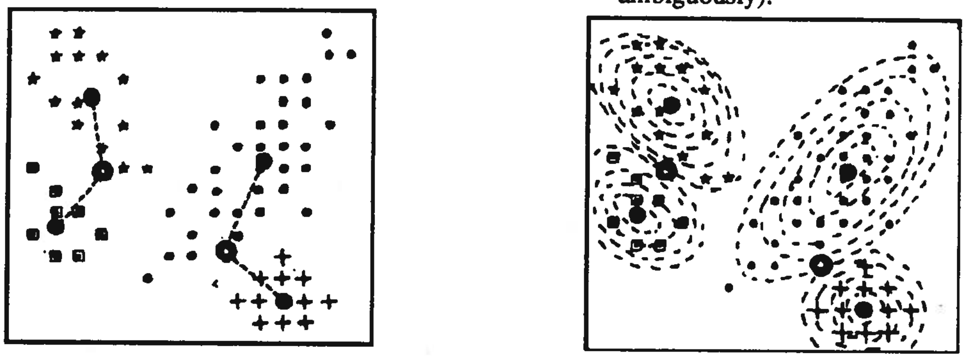
Common techniques for defining and applying rules arrived at by supervised classification include discriminant classification, maximum likelihood classification, and minimum distance classification. Each is simply a way of drawing lines in n-dimensional "feature space" that define the boundaries for different classes of data and assign individual sites to a particular class based on the values at that site of the parameters used in the classification (Figure 2.4).

Su et al. (1989) integrated digital terrain data (slope, aspect and elevation) with remotely sensed imagery (Landsat TM, SPOT MSS) and conducted a supervised classification in an attempt to produce a map for comparison with a second-order soil survey of an area of rangeland (scale 1:24 000). The "rules" for classification were established by selecting "training sites" in seven classes of soil units as shown on an existing "traditional" soil survey map of the region. A Gaussian maximum likelihood classifier (Jensen 1986) was



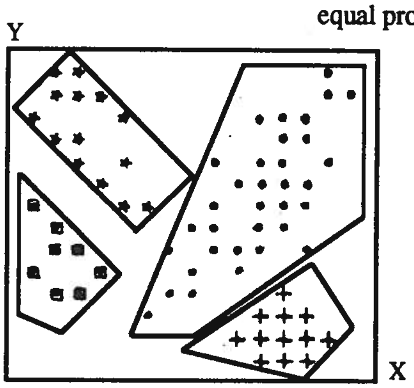
A - unclassified (raw) data in 'naked' clusters

B - Parallellepiped (box) classification (points represented by black circles and white stars are classified ambiguously).



C - Minimum distance classification method - classification may still be ambiguous.

D - Maximum likelihood classification- the dash contours are lines of equal probability.



E - Discriminant classification method- straight lines oblique to axes define boundaries of classes.

Figure 2.4 Classification algorithms used to define boundaries and assign individual soils to classes in two dimensional feature space (adapted from Burrough 1986 - with one addition (E)).

applied to different combinations of data obtained from different spectral bands from the satellite imagery or from the three topographic indices (slope, aspect, elevation) extracted from the DEM. The effectiveness of each classification was evaluated using a statistic called transformed divergence, which is a measure of the statistical distance between class or site pairs of interest and provides information on their separability (Swain and Davis 1978).

The best classification, as measured by transformed divergence, utilized the three topographic indices and TM bands 4 and 5. Application of the classification using four (4) combinations of spectral and terrain data produced four (4) maps showing the distribution of the seven classes of soil map units for which training sets had been identified. The image maps when compared to the original "traditional" soil map agreed with the original classification at between 41 and 56% of all sites. This agreement was referred to as the "accuracy" of the image classification, though clearly, the original soil map could not be expected to be 100% accurate and form a suitable basis for determining the true "accuracy" of the image classification.

The significance of the study by Su et al. (1989) is that it demonstrated that supervised classification techniques, applied to a combination of spectral imagery and topographical data (DEM) could be used to develop "rules" for recognizing and classifying soil-landscape units as a first approximation in stratifying an area relative to its soils and landforms.

Techniques for Developing Quantitative Rules Based on Decision Tree Analysis

Moore et al. (1991) tested the use of "decision tree analysis" to develop rules for "cost effective methods for mapping mature forests". They noted that after initial thoughts that "multispectral satellite data could be digitally analyzed to produce vegetation maps with little investment of labour" research and experience had shown that "image processing is of limited value" and "the production of reliable vegetation maps from aerial photographs or satellite data requires a significant investment of field work for interpretation and verification" (Moore et al. 1991). They proposed instead that rules for classification and mapping be based on "predictive models" created using decision tree analysis based on preclassified data from selected "training sites". Maps of vegetation were produced by applying "predictive models" to geographic data bases of environmental variables. The models "described the associations between forest communities and the environmental variables that are correlated to their distribution" (Moore et al. 1991). This approach differs from that described above for the application of heuristic rules in that the rules are not specified by experts but rather are constructed by analysis of quantitative associations between pre-classified training sites and environmental factors recorded at each training site and determined to be significant in differentiating the prescribed classes.

In comparing statistical classifications with those done using expert systems, Moore et al. (1991) observed that the main advantage of expert system models was that "being rule based, rather than parametric, there are no assumptions about the frequency distribution of the vegetation classes" such as may invalidate many statistically based analyses. They noted, however, that the main problem with expert system models was that "while experts may have a general understanding of the relationships between vegetation and environmental variables, it is difficult to quantify such information to produce the empirical rules required by an expert system (Moore et al. 1991). They concluded that decision tree analysis offered a systematic, effective means of establishing the "rules" by which to recognize vegetation classes.

Moore et al. (1991) used only geology as mapped on existing maps and topography as derived from processing of a gridded DEM as sources of environmental variables for the development of classification rules. The DEM data was processed to produce 10 topographic indices as detailed in Table 2.4. The geological data was "improved" by sub-dividing one of the geological units into three sub-units based on observed patterns of association with elevation (stratification) and watershed area (geographical distribution). An initial "learning sample" of 171 sites was obtained and all 171 sites were assigned to vegetation classes. The vegetation classes were initially derived by numerical analysis of the site sample data. This analysis produced a floristic key that could be used to assign each sample site to one of the vegetation classes.

The logical foundation of "decision tree analysis" is based on the concept of "minimizing impurity" in groupings of individuals at each successive level in a multi-level hierarchy (Moore et al. 1991). The "learning sample" is split into two groups using each of the environmental variables in turn and each group is tested to determine its "purity". The rule that results in the greatest increase in class purity becomes the first "splitting rule" of the decision tree (Moore et al. 1991). This procedure is continued iteratively "until either the classes have been sufficiently sorted or the tree has attained maximum complexity" (Moore et al. 1991). The rules are then formalized in the form "if variable j is less than x" for ordered variables or "if attribute j has state x" for nominal (classed) variables.

Table 2.4 Ten topographic variables derived from elevation data.

1	Slope	The maximum gradient between each cell and its immediate neighbors.
2	Azimuth	The angle, in degrees from north, of the azimuthal aspect of each cell. This variable has a sinusoidal frequency distribution that is not always dealt with effectively by the decision tree analysis.
3	Aspect	The variable azimuth was classified into eight classes: north, northeast, east, southeast, etc. This avoided the problems associated with the sinusoidal frequency distribution of azimuth.
4	Horizon	The average angle to the horizon in five directions: 300, 330, 0, 30, and 60 degrees from north. This proved a good index of exposure to the northern sky.
5	Downhill	Distance downhill from the nearest ridgeline.
6	Uphill	Distance uphill from the nearest streamline.
7	Position	An index of topographic position: (uphill + downhill)/downhill. This variable was found to have less discriminatory power than the variables from which it was derived.
8	Catchment	The square root of the area contributing drainage to each cell. The square root of the catchment area increases linearly along drainage lines, whereas true catchment area increases exponentially.
9	Steepness	Not the same as slope, this variable is a measure of the diversity of elevation values within a 10 X 10 cell neighborhood. Steepness enabled erosional environments to be distinguished from depositional environments.
10	Watershed	Individual watersheds were defined as the area around a peak bounded by drainage lines. The peaks that form the seeds of the watershed are at least 50 m apart. This variable was not used in the analysis but was used to improve the geological data.

(SOURCE: Moore et al. 1991)

Once formalized, the rules developed with the "learning sample" can be applied to the appropriate environmental variables for all of the map area to produce a classified map (in this case of vegetation). This procedure is referred to as top down induction of decision trees (TDIDT) by Quinlan (1986). Moore et al. (1991) described an additional "bottom up" extension of the method in which the decision tree is initially defined to a greater complexity than required and then selectively "pruned back" to remove branches that do little to reduce impurity while maintaining branches that result in effective separations.

The process of "building rules" was also iterative as the classification and map produced by each set of rules was examined to identify and rectify probable sources of misclassification. Areas determined to be misclassified on earlier versions of the maps were resampled in greater detail to provide more "learning sites" which were in turn used to improve the decision rules. Moore et al. (1991) described four iterations involving 171, 352, 558 and 183 "learning sites" for a total learning sample of 1257 (sic) sites. Relative rate of misclassification was used as a measure of model success and areas with a high rate of misclassification were selected for resampling. Moore et al. (1991) emphasized that the iterative prediction and examination of predicted distributions was "essential in gaining an understanding of the environmental relationships among the vegetation communities". Through examination of the predicted distributions "it was possible to identify not only regions and topographic situations that had been inadequately sampled, but also additional variables needed to improve the accuracy of the models" (Moore et al. 1991).

The final model and map of vegetation communities produced by "decision tree analysis" was determined by Moore et al. to have a misclassification rate of only 17% and was judged to be quite reasonable. Moore et al. (1991) concluded that decision tree analysis was "an efficient method for determining the extremely complex models needed to predict the distribution of vegetation, on the basis of environmental variables" for their study area. They argued that the specification of classes and boundaries had greater ecological validity than descriptions based on statistical parameters such as means, standard deviations and cross-products (Moore et al. 1991). They further noted that "unlike parametric techniques, decision tree modelling does not identify the range of environmental conditions occupied by vegetation units but attempts to identify the precise conditions associated with vegetation boundaries. (Moore et al. 1991). A drawback of the method is that decision tree models produced for any given area are specific to that area and can not be extrapolated outside that area without further sampling and modification. In addition, "the relative efficiency of predictive modeling techniques such as the one described here will depend in part on the degree to which suitable mapping units are correlated to variables that can be derived from available cartographic and digital data.

Techniques for Developing Quantitative Rules Using Neural Networks

Neural networks are an emerging technology for classification. They attempt to mimic the learning process that occurs in the human brain (Ritter and Hepner 1990). The technique is well suited to the recognition of spatial and spectral patterns such as is required for the classification of remotely sensed images. Ritter and Hepner (1990) cautioned, however, that the use of an artificial neural network for satellite image processing is still at the "proof of concept" stage.

The concept behind using neural networks is that "rules" for classification can be "learned" by a neural network computer program when presented with a "learning set" of input data that has been pre-classified by manual procedures. In the case of satellite imagery, manual classification of "training sites" incorporates human perceptions of both spectral and spatial patterns and associations. When presented with both the raw data and the assigned classifications for selected "training sites" neural network software builds a series of classification rules through an iterative "learning" procedure.

The mechanism by which rules are developed in a neural network involves taking raw input data from an "input layer" passing it through one or more "hidden layers" (Ritter and Hepner 1990) and assigning the classified output to a neuron in the output layer. An iterative procedure is followed and after each cycle, the classified data in the output layer are compared to the "correct" classification as defined for the training site. "Learning" is achieved by minimizing the "backward propagation of the error signal" (Ritter and Hepner 1990). The learning process is explained by Ritter and Hepner (1990) as follows:

> "The network is forced via the back propagation of error signals between the two sets of images to develop an internal representation of the transfer function from the input data to the target images. In the back propagation mode, the network cycles through the spectral and spatial associative data for each pixel attempting to achieve synapse coefficients and neuron responses that modify the input data to the required output. At the end of each cycle, the difference in the output signal and the desired signal acts as feedback to the network to modify the synapse coefficients for the next cycle".

The "rules" developed in this way reside in the hidden layer as a series of functions and numbers that control how input data is transformed into output classifications. Each neuron in the input layer is connected to every neuron in the hidden layer which is, in turn connected to every neuron in the output layer. Each interconnection, termed a synapse, is assigned an adaptive coefficient (weight) that modifies the computation (signal) that occurs between any two given neurons (Ritter and Hepner 1990). The degree to which the neural network has "learned" to properly classify pixels is assessed after each cycle in terms of the percent of unexplained variance between the input layer and the output layer relative to the "correct" classification. Ideally, the amount of unexplained variance decreases after each cycle until an optimum level is achieved. Ritter and Hepner (1990) observed that "it took almost 750 iterations to minimize the variance to the 10% level deemed necessary for reliable classification by the network".

Once "rules" have been developed and accepted the second stage in neural network processing involves applying the rules to produce a complete classification of the raw data for all pixels (not only those used for the learning exercise). Ritter and Hepner (1990) call this "operation of the network in forward-feed mode". The rules developed using backward propagation training are used to classify raw image data in the forward-feed mode without retraining. In the example provided by Ritter and Hepner (1990) the classification achieved using a neural network approach was compared to a traditional maximum likelihood classification and judged to be slightly better. The neural network approach was rated as having 70% accuracy relative to 59% accuracy for the conventional supervised method.

The neural network approach was considered to offer several advantages over conventional statistical approaches to defining "rules" for classification. For instance, "unlike conventional statistics which rely primarily on spectral characteristics, the neural network should be able to use the spatial association of image and map objects at multiple scales to recognize features and patterns much as a human does in image and map recognition (Ritter and Hepner 1990). Additionally, most conventional classifications are designed to be used with data that has some a priori statistical distribution. Neural networks, on the other hand, do not require the training data to possess any known statistical distribution (Hecht-Neilsen 1989). Neural networks are particularly well suited to developing "rules" for classification where expert understanding is incompletely developed or difficult to quantify. Ritter and Hepner (1990) observed that "many complex functions in the real world are not understood completely" and even if understood "algorithms may not exist for their implementation". In a seeming contradiction, the same tasks that appear intractable for complete automation can often be done quite successfully by humans applying their experience and inspiration. Neural network classification offers a mechanism for capturing this experience and formalizing it as a set of consistent and applicable rules.

Techniques for Statistical Estimation of the Spatial Distribution of Individual Soil Properties

A large number of statistical techniques has been used to estimate the likely spatial distribution of values for individual soil properties. All of the techniques attempt to estimate the most likely value for a given soil property at points where the actual value is unknown. In a sense, statistical associations and patterns are used to develop a quantitative set of 'rules' for predicting the spatial distribution of soil properties given observed relationships among variables. Common techniques include geostatistics (kriging and co-kriging); time series analysis; and correlation/multiple linear regression.

Burrough (1986) provides a thorough review and critique of the relative advantages and disadvantages of traditional choropleth methods of describing the distribution of soil properties in the landscape versus the continuous approach employed for statistical estimation. He observed that, in traditional choropleth mapping, "the methodology assumes that through a proper understanding of the object of study (the landform, the soil pattern and so on), natural units can be recognized that will serve as universal vehicles for information storage and transfer (Burrough 1986). He noted that this method only succeeds when there is a close correlation between the critical or discriminating properties that are used to define and describe the entity and the information that a user really needs. In other words, the values of properties of interest must co-vary strongly with the properties used to define and delineate the landscape based soil units.

A second criticism of choropleth mapping is that it ignores, or only superficially recognizes, spatial variation in properties within a choropleth map unit. The choropleth unit is traditionally described in terms of one or more "type areas" or "modal profiles" that are characterized by a mean value and possibly some indication of range or variance. The result is "that the original observations, including the information about all spatial structures and scales, have been superseded by an artificial line network that describes only one kind of structure at one spatial scale. All accurate, qualitative information about within-map unit variability has been lost." (Burrough 1986). According to Burrough (1986) decisions made during conventional choropleth mapping about scale and about which structures and which attributes are important result in thematic maps that only present information about spatial variation at a fixed scale, over large areas (i.e. with respect to the map scale) with little or no information about local, within-map unit variations. Burrough (1986) proposed that, for many uses, it might be better to retain original site observations and data so that individual properties could be mapped separately using an appropriate method of interpolation. Burrough (1986) proposed the following rules for classification:

1. Don't classify if:
    a) you have complete spatial coverage of an area (e.g. with pixels) and the original data values must be used for further processing.
    b) you have data collected at a set of sample points. Use interpolation techniques first to apply the data to the whole area and then classify if necessary.
2. Classify if:
    a) data are multivariate and if identification of a cluster with an 'object' or 'type' (i.e. a series) is essential for further analysis,
    b) identification could make use of information that is available to the user but that is outside the current database (i.e. accessory properties of soil series)
3. Classify for display and presentation of spatial data but not for data storage. Don't use arbitrary scales and treat exogenous scales warily. Idiographic scales may sometimes be useful, but use objectively defined serial scales when at all possible.

Kriging and Co-kriging

The geostatistical techniques of kriging and co-kriging have been promoted as superior alternatives to traditional landscape based approaches for describing the spatial distribution of individual soil properties (Burrough 1986). It has been argued that they provide an "optimal" estimate of the value for individual soil properties (Burrough 1986). The estimates are optimal in that the variance of the predicted value from the true value is minimized. A second advantage is that the estimates vary continuously across the landscape in contrast to the choropleth approach inherent in landscape based map units in which single, discrete values are assigned to polygonal map unit areas and abrupt changes in value are postulated to occur at the boundaries of map units (Burrough 1986).

A thorough review of techniques of kriging and co-kriging is not presented here. The reader is referred to the treatments provided by Burrough (1986), McBratney (1984), Vieira et al. (1983) and Oliver (1987) for specific details. Two aspects of kriging are of relevance to this review. Firstly, kriging and co-kriging are methods of interpolation. Accordingly, they require data from individual sample points that encompass the entire geographical area of interest. The method cannot be used to establish "rules" for mapping that can be extrapolated beyond the area for which data is available. Secondly, kriging and co-kriging only operate on single numerical variables measured on a continuous scale. The techniques cannot be used to estimate the spatial distribution of a soil characteristic such as horizon structure or color or a soil classification such as Orthic Black. They can only operate on numerical data such as bulk density or percent clay. If one can confidently name all soil properties for which information is required for all anticipated uses, and if the properties are continuous and display spatial structure, then it can be argued that a series of individual, interpolated data layers for each soil property would be preferable to a multi-theme choropleth soil map. If the intention is to produce a choropleth soil map with single set of polygons used to convey information about a wide range of soil properties (some of them unknown or unsampled at the time of making the map) then kriging of individual soil properties offers little advantage.

The theory underlying kriging is that soil and other land related properties exhibit some degree of spatial structure or "self similarity" up to some maximum distance. The degree of similarity is expressed as a function of the distance between individual sites. The degree of similarity is actually a function of the degree to which the physical processes that produced the soil have been similar at any two sites. For example, with respect to parent material texture, we would expect that two sites close together in a lacustrine basin would be more similar that a third site at some distance in a till upland. The physical process involved in the deposition of the parent material within the lacustrine area are mostly similar and will produce soils of similar texture. A portion of the change in texture with distance will be systematic and will be related to the physical processes involved in parent material deposition (i.e. differential sorting out from shore in a lacustrine environment).

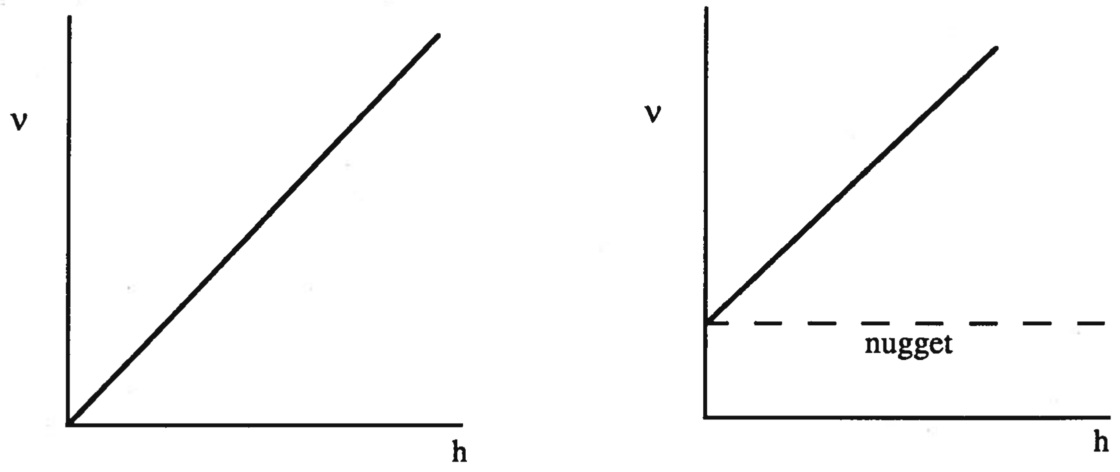
Technically, the degree to which soil properties show a predictable change with distance is referred to as the "structure" or "signal" associated with that soil property (Burrough 1986). Changes, or variation, that do not seem to be related to distance and cannot be explained are referred to as "noise". These terms are relative, and what appears as noise at one level of sampling may become explainable as structure if samples are taken at a shorter sample interval. Application of the principals of geostatistics involves the following three activities:

1. creation of a semi-variogram: this portrays the semi-variance of point sample data relative to distance of separation between sample pairs to determine if a variable exhibits spatial "structure",
2. modelling of the semi-variogram: this involves fitting a mathematical function, or equation to the observed "structure" to define the relationship between distance between pairs of sites and strength of association,
3. weighted interpolation (kriging): this involves using the equation fitted to the semi-variogram to compute a weighting factor during numerical interpolation.

The initial exercise in kriging is the creation of a semi-variogram. The semi-variogram is used to determine if a numerical variable exhibits any spatial structure over the distances at which it has been sampled. A sampling scheme is required that produces a number of observations of soil property value a variety of distances apart. Samples are paired according to the distance by which they are separated. A minimum separation distance called the lag is selected to represent the minimum distance over which variation is to be assessed. The lag distance generally corresponds closely to the minimum distance between sample sites for the adopted sample strategy. Once a lag distance has been selected, all of the sample data for pairs of sites that are within one lag distance of each other (i.e. from 0-100 m if the lag is 100 m) are sorted into one group. The difference in value of the variable at points xi and xi+h, where h is the lag distance, is computed for every pair of sample sites separated by distance h. The difference is squared and the sum of the squares of the differences is computed for the total of all pairwise comparisons. This is multiplied by 1/2 of the total number of pairwise comparisons M(h) according to the formula (Oliver 1987):

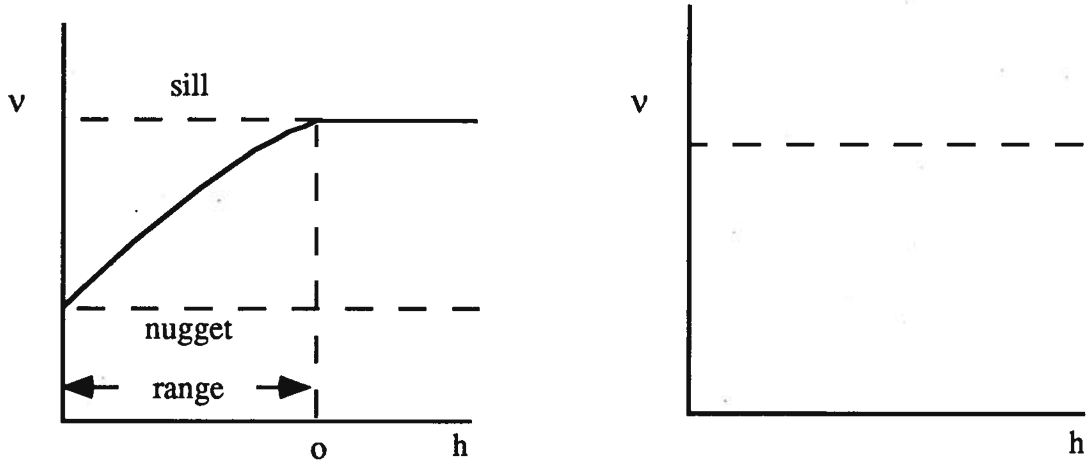
> gamma(h) = 1/2 M(h) SUM, i=1, M(h) {[Z(xi) - Z(xi+h)]2}
>
> where gamma(h) is the semi-variance, M(h) is the number of pairwise comparisons at lag h, and Z(xi) and Z(xi+h) are the values for the variable at any two places separated by the lag distance h.

The semi-variogram is produced by plotting the semi-variance (gamma(h)) against each lag (separation) distance. The variable of interest exhibits spatial structure if the semi-variogram illustrates a systematic change in semi-variance with lag distance. Examples of some characteristic forms of semi-variograms are given in Figure 2.5 (Oliver 1987).



(a) Continuously increasing variation with distance, zero nugget, no sill, no second order stationarity

(b) Continuously increasing variation with distance. Intercept on the ordinate indicates the presence of a 'nugget' variance which is the random component of variation not captured by the smallest sampling interval.



(c) Variance increases to a maximum and flattens out. The maximum value is the sill. The distance over which the variance increases is the range. Samples further apart than the range have no spatial interdependance.

(d) Illustration "of pure nugget" effect. The maximum variation operates over all sampled distances. Sampling would have to be at shorter distances to reveal any structure.

Figure 2.5 Illustration of the components of a variogram and examples of some characteristic forms of semi-variogrms (Oliver 1987).

A typical semi-variogram displays some level of semi-variance at even the shortest lag separation. This is referred to as the nugget variance and represents the proportion of the variance that operates below the level of resolution of the smallest sampling distance. It is often described as noise or random variation because is not predictable given the scale of sampling. Ideally, the semi-variance increases in some regular manner with increasing lag distance and then 'flattens out' when it reaches a maximum distance beyond which paired sample points no longer exhibit any spatial dependance. The value at which semi-variance no longer increases is termed the sill. The distance (number of lags) over which the semi-variance increases regularly before 'flattening out' is termed the range. Points farther apart than the range exhibit no spatial inter-dependence and will not provide meaningful data for interpolation.

The second step in kriging is to fit a mathematical equation to the observed distribution of semi-variance against lag as plotted for the semi-variogram. The most common equations fitted to semi-variograms are linear (straight line), spherical and exponential or some combination of the above (Oliver 1987). Typically, different types of equations are fitted to the observed semi-variance data. For each equation, the sum of the squares of the

difference the semi-variance predicted by the equation and the observed semi-variance at each lag distance are compared. The equation with the smallest sum of squares of difference is identified as providing the "best fit" to the observed distribution of semi-variance. This equation becomes the semi-variogram 'model'. The model describes the degree to which the value of the variable in question at a point at some distance D away from any starting point is related to the value at the starting point.

The third step in kriging is to use the semi-variogram model as a basis for the interpolation of a regular grid of values starting from an irregular set of sample points. The model is used in several ways. In the first instance, the semi-variogram is examined to determine if there is any spatial structure (i.e. increasing semi-variance with increasing distance). If there is no spatial structure, then all sample points, even those closest together, are independent and cannot be used to predict the value of the variable at intermediate points. In this case, there is no advantage to be gained by interpolation using kriging (Burrough 1986). If spatial structure is present, then the semi-variogram model can be used to 'explain' that portion of the total semi-variance captured by the model (i.e. sill variance - nugget variance). The semi-variogram model is used to determine the maximum distance over which a spatial pattern is observed (the range).

During interpolation, all observation sites within the range distance may be used to produce a meaningful estimate of the predicted value at the interpolation point. The value estimated for the variable at the interpolation point represents a weighted average based on the observed value of the variable at n surrounding sample sites. In calculating the weighted average, the value of the variable at each sample site within the range distance is weighted, using the semi-variogram model, according to its distance away from the point for which the estimate is being made. That is, observed values close to the point for which a estimate is to be made are weighted strongly while those farther away have less influence on the value estimated for the interpolated point. The concept is similar to the inverse weighting function offered in standard interpolation packages, in that points farther away exert less influence on the value estimated for the central point. The main difference is that the distance weighting factor is based on a best fit to the observed pattern of change in variance with distance, rather than on some assumed linear decrease in importance with distance. The weighting factor calculated using the semi-variogram model ensures that the contribution of the observed value at each sample point towards the value estimated for the interpolated point is given a weight that is directly related to the distance between the observation point and the point to be estimated and that the relation is a function of the observed pattern of change in variation with distance.

Potential users of geostatistical methods of interpolation (kriging) need to be aware of several assumptions and limitations inherent in the the technique. Depending on the approach used, geostatistical estimation assumes that the variable of interest exhibits stationarity with respect to its mean value and its variance (or semi-variance). Full second order stationarity requires that the mean and the variance of the variable of interest do not change in any systematic fashion within the area of interest. Geostatistical techniques based on analysis of spatial autocorrelation require full second order stationarity. The basic techniques of point and block kriging relax the assumptions somewhat and require only that the mean value of the variable and the variance of samples a given distance apart (the semi-variance) remain stationary. The assumptions made for universal kriging are relaxed even further and can accommodate 'drift' or systematic change in the mean for the variable of interest.

In practical terms, assumptions of stationarity will be violated if there is any abrupt change or any regular trend or pattern of change in the mean value of a variable or in its semi-variance with change in location across a landscape. An abrupt change such as would be expected at a boundary between a glaciolacustrine and a fluvial landscape would violate the assumption of stationarity. A typical example of a regular trend would be a continuous reduction in sand content and corresponding increase in clay content in deltaic sediments as one progressed outward from the source of the sediment. An example of violation of the principal of stationarity of the semi-variance would be of any area containing a mixture of relatively uniform deep water lacustrine sediments and highly variable, shallow water fluvial deposits. The two areas would display distinctly different patterns of variation in texture with distance and could not be considered to exhibit stationarity with respect to semi-variance.

Oliver (1987) recommended 'detrending' data that exhibited a trend by fitting a surface to the trend and subtracting the trend surface from the observed data values. Burrough (1986) explained how universal kriging could be used with data sets that exhibited well defined local trends, but concluded that the extra effort was seldom worthwhile when dealing with soils data with large nugget variance. Burrough (1986) illustrated how different geomorphic units displayed markedly different patterns of mean and variation of clay content and consequently violated the assumptions of stationarity inherent in the methods of kriging. Separate semi-variograms for the two landscape units revealed a strong and consistent pattern of spatial variation in one and random noise (pure nugget effect) in the other.

The significance of these and similar studies (Van Kuilenburg et al. 1982; Giltrap 1983) was that very often in typical soil landscapes, "the essential assumption in kriging that spatial variation is homogeneous appears to have been violated and so the quality of the results has been impaired" (Burrough 1986). Burrough (1986 concluded that "if interpolation techniques are to be of real value they should be used in conjunction with, and not instead of, conventional landscape mapping methods". Geostatistical analysis of the spatial pattern of variation of individual properties is best applied to individual soil landscape units that are already more or less uniform with respect to the mean value of most soil properties and to the degree of variability of those properties across the area (Stein, Hoogerwerf and Bouma 1988).

Violation of the principals of stationarity is virtually certain for complex areas containing numerous different kinds of landscapes and soils. Geostatistical methods are therefore not appropriate for developing boundaries for a high level stratification of an area into less variable soil-landscape units. Stein, Hoogerwerf and Bouma (1988) recommended that "when no soil maps are available, it would be advisable to distinguish major land units by means of common soil survey techniques, including remote sensing, and to focus further variability studies on these units rather than on the landscape as a whole with random observations". They saw the role of geostatistics as "to determine the internal variability of existing major land units so as to allow statistically founded quantitative predictions of relevant land qualities rather than qualitative estimates based on the properties of "representative" profiles" (Stein, Hoogerwerf and Bouma 1988).

The role of geostatistical analysis in regional (level III) soil mapping is therefore likely to be to document the degree of spatially dependent soil property variation within defined soil-landscape units rather than to define and delineate the spatial extent of high level soil-landscape strata. Useful information may be obtained by statistical analysis of pre-defined soil-landscape strata to determine the distances (range) over which individual soil properties display coherent spatial structure and to determine the proportion of the total observed variation in any given property that is spatially controlled. It is unlikely that kriging will provide the best method for identifying the location and extent of the high level soil-landscape strata which form the basic units for level III mapping.

Co-kriging is an extension to kriging that utilizes data from other, more spatially extensive sources to improve the estimate made for any given property. Co-kriging operates on the assumption that a spatially correlated relationship between a readily observed, or easily sampled variable and a second, less easily sampled or observed variable can be used to estimate the likely value of the second, less extensive variable. The basis of co-kriging, is the cross-semivariogram which captures the degree of cross-correlation between two spatially distributed variables. Typical examples of co-kriging in soil science use data from more easily measured properties such as percent clay or silt to assist in estimation of the distribution of more difficult to measure properties such as hydraulic conductivity (Vieira et al. 1983) or soil moisture deficit (Stein, vanDooremolen, Bouma and Breght 1988; Stein Hoogerwerf and Bouma 1988). McBratney and Webster (1983) co-kriged topsoil silt using sparse measurements of topsoil silt, together with more intensive measurements of subsoil silt and sand. Vauclin et al. (1983) used co-kriging to estimate available soil water content and water held at pF 2.5 using additional information from more densely sampled sand content.

One criticism of kriging and co-kriging, from the point of view of the field mapper, has been that the techniques fail to make any use of the strong relationship that is typically observed between soil properties and landscape position. The value of any soil property estimated by kriging is based solely on the values observed for that property at several surrounding sample points. Interpolation between the sample points proceeds as though there were no readily observable data between the sample points that might be of some influence in determining the value at the point of estimation. Field mappers are strongly aware that surface shape and relative position in the landscape exercise a strong control on the manner in which soil properties change and are distributed. Surprisingly, given the strong relationship between soil properties and topography, no reported cases can be found of co-kriging in which one or more of the terrain derivatives that can be extracted from elevation data were used as the source of densely sampled available information to assist in co-kriging of a soil property known to co-vary with topography.

Time Series (or Fourier) Analysis

A small number of studies have observed the cyclical nature of soil variation and attempted to describe it quantitatively by obtaining a best fit of the observed variation to a periodic wave function defined as some linear combination of sine and cosine waves. Burrough (1986) reported that two-dimensional Fourier analysis had been used with some success by Burrough et al. (1985), Webster (1977) and McBratney and Webster (1981) to investigate soil-landscape relationships. Kachanowski et al. (1985a, 1985b) analyzed soil morphological variables in a Saskatchewan landscape for periodicity in the frequency domain by examining their power spectra. They concluded that relationships between variables were complicated by phase shifts and opposite correlations in different frequency ranges, thereby limiting the usefulness of the technique. Burrough (1986) concluded "that most surface features of the earth, excepting such obviously periodic features as ripples and sand dunes, are too complex to show strict periodic variations unless the variations are man-made and thus trivial, and so other methods of interpolation are preferred.

Burrough (1983a,b) investigated the use of fractals to examine periodicity in soil and landscape properties. Calculation of the fractal dimension was shown to reveal information regarding the scale and frequency of repetition of cyclical patterns in soil and landscape properties. Fractal analysis has not been found widely useful for mapping soils or landforms, only for quantifying their periodicity.

Regression and Trend Surface Analysis

Statistical analysis by regression involves establishing a mathematical expression for the relationship between a property of interest (the dependent variable) and one or more predictor variables (independent variables) believed to exercise some influence on the value of the dependent variable. The relationship is quantified by computing the "best fit" of a line, or surface, of regression of the dependent variable against the independent variable(s). Regression analysis has been used to predict the spatial distribution of soil properties in two quite different ways. Trend surface analysis is a form of regression in which the spatial coordinates X, Y are the independent, predictor variables and the (soil) property of interest is the variable to be predicted (the independent variable). Burrough (1986) classifies trend surface analysis as a global method of interpolation, since the entire set of data points is used in the calculation of the surface which "best fits" through all of the data points. The concept is to fit a surface through all of the available data points such that the sum of the squares of the differences between the predicted surface and the actual data values is minimized (Figure 2.6).

Two dimensional trend surfaces may be described using a) linear, b) quadratic, c) cubic or even higher order equations. Burrough (1986) observed that trend surfaces were most useful for modelling broad features, or spatial trends, in the data and that it was increasingly difficult to assign physical meaning to complex, higher order polynomials.

"The main use of trend surface analysis, then, is not as an interpolator within a region, but as a way of removing broad features of the data prior to using some other local interpolator" (Burrough 1986). For example, trend surface analysis can be used to 'detrend' spatial data prior to geostatistical analysis.

Regression analysis can also be used as a local method of prediction. In this approach, the unknown (dependent) variable is estimated based on the observed correlation between it and a series of predictor (independent) variables which may be any combination of soil or landscape properties that are known or can be easily measured at all X, Y locations. Pennock et al. (1987) observed that "many attempts have been made to model the influence of slope morphology on soil distribution, primarily using regression analysis to analyze the correlation between slope morphology and soil variables". They provided an example of an attempt to correlate the morphological variables thickness of A horizon and depth to calcium carbonate with five topographical indices of surface form derived from a digital elevation model. Both relationships were significant, but the amount of variability explained was low (Pennock et al. 1987). Zebarth and de Jong (1989a;1989b) and Zebarth et al. (1989) developed a correlation between electrical conductivity and topographical variables as well as between snow depth and water equivalent and topographical variables. This approach is intuitively attractive to the field soil scientist since it accepts the notion that there is a strong relationship between topographical

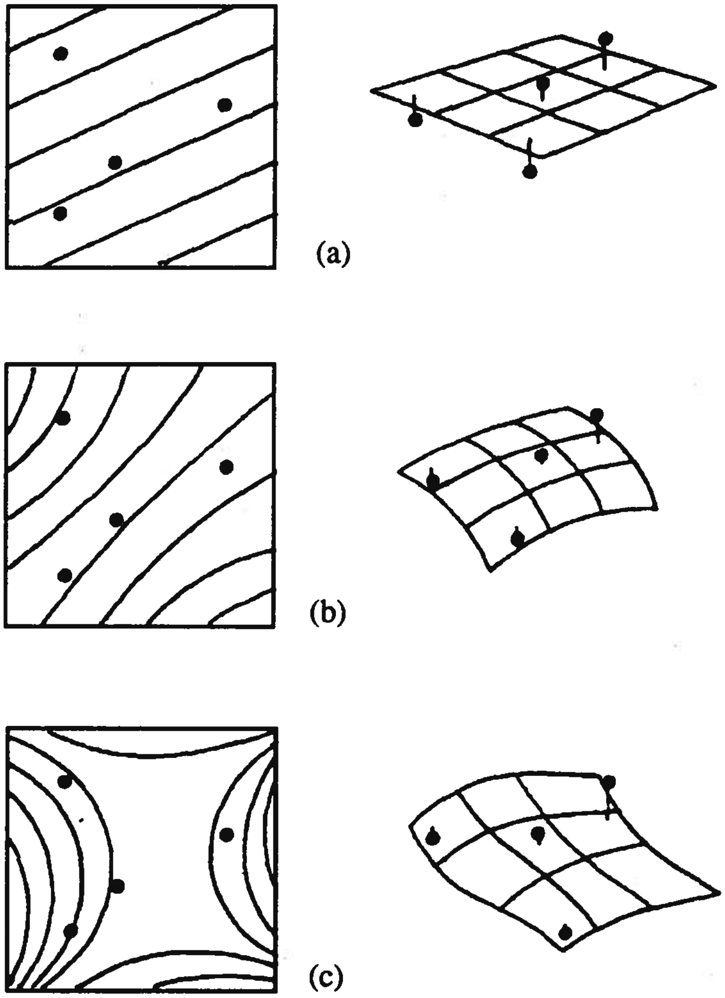


Figure 2.6 Illustration of trend surfaces in two dimensional a) linear, b) quadratic, and c) cubic (Burrough 1986).

controls and the spatial distribution of soil properties and attempts to quantify this relationship. Unfortunately, strict topography-soil property relationships have seldom been clearly evident, perhaps due to the fact that multiple superimposed processes can act on hillslopes.

As with geostatistical methods, the utility of regression analysis is limited to estimating the spatial distribution of individual soil properties that can be measured on a continuous interval or ratio scale. The technique cannot be used to predict the spatial distribution of classes of soil. If a soil can be uniquely defined through a combination of individual numerical properties, it might be possible to predict the likely value of each individual soil property using regression analysis and then apply boolean logic to classify the soils on the basis of these unique combinations. A concern with this approach is the potential it has to accumulate a large amount of error. Burrough (1986) has identified the high rate of propagation of error produced when multiple layers of data, each possessing its own degree of error, are superimposed. A further concern is that the classification of most soils, as presently conducted, requires some information of a non-numerical nature (i.e. color, structure) which could not be estimated by regression techniques.

D.v. Summary

The main conclusion arising from this review of advanced methods of mapping soils is that traditional soil survey has been slow to alter conventional mapping techniques based on intensive manual field investigations. Soil survey has been reluctant to adopt new techniques or to dramatically alter existing procedures. Current procedures for mapping soils in Alberta (and elsewhere) have not undergone any significant technical changes since the widespread adoption of aerial photographs in the 1950's. This is astounding in view of the incredible pace of technological developments over the last 30 years. Most examples of innovative mapping approaches have come from outside official soil survey organizations. Many of the most original examples have arisen from the efforts of ecologists or foresters to obtain land data required for predicting site characteristics in support of ecological or simulation modelling.

The review concluded that the principals of ecological land classification (ELC) are directly analagous to the concepts of soil-landscape relationships that form the basis of most soil survey mapping. Manual application of these principals of consistent and systematic use of formal rules by organizations other than soil survey is concluded to result in more more rapid rates of mapping and in more consistent maps. It is concluded that soil survey would benefit from adoption of a formal, systematic methodology for "top-down" stratification in the production of SIL3 soil maps. Benefits would include greater consistency among different mappers, faster rates of production of maps and a more uniform and familiar product for users. A further anticipated benefit would be increased accuracy and reliability of the map product arising from better use of existing data, more consistent application of rules, and improved documentation of ecological knowledge as represented by formalized rules for mapping.

A wide variety of advanced techniques were observed to offer considerable potential for automation of present manual mapping procedures. The common thread in these innovative approaches is the concept that ecological theory can be captured in a set of systematic rules. These rules can then be applied to a series of data sets of easily obtained information to predict the most likely distribution of soils and landform characteristics. Increasingly, the data sets are in digital format and incorporate remotely sensed data (DEM's, satellite or airborne imagery) as well as thematic information (geology, climate, soils) derived from pre-existing maps or data bases. Increasingly, the rules capturing ecological theory have been developed using computer based technologies such as discriminant classification, neural networks, expert systems or fuzzy logic. Many of the computer based approaches can be seen to have a theoretical foundation in the principals of manually applied ecological land classification. They are simply techniques for rendering the manual procedures of ecological land classification more explicit, systematic and reproducible.

In summary, soil survey mapping procedures must change to become more rapid and cost effective and to produce more reliable and "user friendly" maps. Some potential for increasing the speed and consistency of mapping, while reducing costs and maintaining quality may be achieved by adopting more formal, systematic manual mapping procedures patterned after ecological land classification (ELC). Further improvements in speed, accuracy and consistency will only be obtained when soil survey begins to adopt currently available and emerging technologies for automated mapping and site classification.

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II.E: TECHNIQUES FOR COMPARING / EVALUATING MAPS

- M.D. Fawcett and R.A. MacMillan

E.i. Introduction

Traditionally, soil survey projects have not included an evaluation component to determine the accuracy or overall quality of the final product, thus implying that the map is correct as reflected in the legend. This leaves the product user to assume a certain level of accuracy. Most assume that the reliability or accuracy of a map product is closer to 85% (Ragg and Henderson 1980). Recent studies have shown that this may be optimistic on the part of the user (Moon et al. 1987b; Selby and Moon 1987; Fawcett et al. 1991). As indicated earlier in this document, there is a need to investigate an alternative mapping procedure to the traditional 1:50 000 SIL3 approach in Alberta. One of the requirements of any new procedure is that the quality of the soil map product be maintained, and so a method of comparing and evaluating the 'new' vs. the 'old' maps is needed. Any change in quality of map product (positive or negative) must be evaluated and this is one of the intents of this research. A change in information content may enhance use as well as degrade use for different users of soil survey products.

When examining the techniques for comparing and evaluating soil maps, quality is the central issue. In order to evaluate or compare map quality, four measures of map quality have been determined and are depicted in Table 2.5. These four measures and the various techniques used to quantify them in determining map quality are reviewed and discussed in this section.

Table 2.5 Measures of map quality.

QUALITY			
Accuracy	Cartometrics	Consistency	Information Content
soil information	readability	correlation	descriptive precision
ground location	precision		spatial precision
			legend design

(SOURCE: adapted from Marsman and de Gruijter 1986).

E.ii. Ground Truth Accuracy

The accuracy of a soil map can be defined as the closeness with which the soils information presented on the map reflects the actual ground truth information and can be measured in two ways. The first and most common measure of accuracy is the reliability of the soils information presented (Moon et al. 1987a; Forbes et al. 1985). "How accurately does the map describe the soils present and their variability within the landscape?" The second measure of accuracy is the ground location accuracy (Moon et al. 1987b; Marsman and de Gruijter 1986; Forbes et al. 1985). "How closely do the soil boundaries on the map correspond to their location on the landscape?"

The ground location accuracy of a soil map is independent of the reliability of the soils information. It is closely related to the cartometrics of the soil map and is dependent upon the base map quality as discussed by Forbes et al. (1985) and the soil surveyors ability to accurately position a soil boundary on the map (Marsman and de Gruijter 1986). The base map quality is beyond the control of the surveyor and the surveyors ability to accurately locate soil boundaries is influenced by a variety of production techniques (Moon et al. 1987b).

Forbes et al. (1985) propose two methods for assessing the ground location accuracy of a map: (1) location by ground control points; and (2) location by interpolation. Both of these methods can be used for determining the accuracy with which soil boundaries have been placed on the soil map. Location by ground control points involves estimating the distance between a soil boundary and an easily identifiable landscape feature on the soil map. By calculating the means and variances of the differences between map distance and the actual distance measured in the field, the accuracy of the boundary location can be determined. Calculating ground location accuracy by interpolation is dependent upon the density and texture of identifiable landscape features. This method assumes that the more landscape features shown on a map, the more accurately will the soil boundaries be placed. It also assumes that the landscape features have been accurately located on the base map. If any features are not correctly located, this assumption is invalidated and the ground location accuracy will be overestimated.

When testing the reliability of the soils information, it must be remembered that several inputs (eg. base maps) and processes (eg. boundary transfer from air photos to the base map) are involved in the production of a soil map and report (Moon et al. 1987b; Forbes et al. 1985). Any errors which may have been made along the way to a published soil information product will accumulate into the final product (Fawcett et al. 1991). Almost all methods of testing the ground truth accuracy of a soils map do not account for these sources of error. The accuracy is reported with the implication that all errors are attributable to a flawed model or concept of the soil system being mapped. The results produced are a test of the final product, not a test of the individual soil mappers ability (Fawcett et al. 1991).

There are several methods of testing the descriptive accuracy (reliability) of soil maps and a number of different ways to report the results. All testing procedures fall into one of two broad categories. These are (1) binary (right/wrong) classifications and (2) degree of similarity. The right/wrong system simply asks whether or not the observed site characteristic was predicted by the soil map. The degree of similarity method attempts to determine the size of any differences between the observed value and the predicted value and if the difference is significant. The sampling method used and data gathered for analysis and determination of map accuracy must be independent of that used to make the map (Western 1978) and must be statistically valid (Hord and Brooner 1976). Several sampling procedures are available such as nested sampling (Riezebos 1989), transects, grids, and various random sampling methods (Forbes et al. 1985). These are discussed more fully in Section II.F. Once the sampling scheme has been chosen and the required sample size determined, the sample points must be chosen. When locating the sample points, there are two requirements. The first is that the sample point is within the survey area and the second is that the points are not located too close to a soil boundary (Forbes et al. 1985). Howitt and Moran (1991) suggest that a buffer zone of 100 m should be used to ensure that the sample point is located within the desired polygon. The buffer zone is used in an attempt to eliminate boundary location errors due to poor base maps and to take into account that the boundry of a polygon represents the area of greatest change from one mapping model to the adjacent model. Once the sampling points have been chosen, data collection and analysis can take place. All of the accuracy testing methods use slightly different sampling schemes, and the reader is refereed to the original authors for a detailed description of each.

There are two types of ground truth accuracy with respect to the soils information presented on the map. These are (1) the overall accuracy of the map, and (2) the accuracy of the stated map unit composition (Forbes et al. 1985). When testing for the overall ground truth accuracy, not all map units need to be sampled, but the map units and polygons sampled must be chosen randomly over the entire map area. When checking for map unit composition accuracy, the map unit to be tested must be preselected, then the polygons and sample sites within the polygons chosen randomly after that. Following are brief descriptions of the various testing methods which have been used and what those methods are intended to show.

Forbes et al. (1985) describes a scoring system of 1 - 4 based on ground truth error. Scoring is dependent on the severity and number of discrepancies between the predicted and ground truth classes of selected site characteristics. This is a non-proportional test and is used to test the overall ground truth accuracy of a soil map. Adequacy criteria suggested are (1) it is 90% certain that more than 15% of the map area is strongly contrasting - score = 4 - with respect to the defined map units or (2) it is 90% certain that less than 50% of the map area is pure - score = 1 or 2 - with respect to the defined map units. If either of these two criteria are met, the soil map is rejected as having unacceptable ground truth accuracy (Forbes et al. 1985). These two criterion could also be reversed such that a map would be acceptable only if it had less than 15% contrasting soils and more than 50% purity. This would strongly bias the criteria against the mapper but would ensure the acceptance of only highly accurate maps (Forbes et al. 1985).

A binary or yes/no system using the 1 - 4 scoring system to decide if an individual observation resembles the constituents being tested has also been described by Forbes et al. (1985). This procedure requires that a number of sample subsets be taken in several polygons belonging to the same map unit. Each subset is then analyzed for percentage of observations which correspond to the map unit constituents being tested. The means and standard deviations of the constituents in the map unit can then be calculated using the percentages as observations. If one of the calculated constituent means falls outside of the predicted ranges, the map unit composition could be rejected as inaccurate.

A similar system has been used by Goldin (1988) to compare two different maps for agreement in map unit content. He compared the taxonomic classification at a number of grid point locations on each of the two maps and grouped them as either same, similar, different management, or different. By labeling the 'same' and 'similar' classifications as yes and the 'different management' and 'different' classifications as no, Goldin (1988) was able to calculate the percent similarity between the two maps.

Edmonds and Lentner (1986) and Edmonds and Crouch (1991) have used binomial probabilities to determine the number of observations needed to estimate the probability of observing the stated proportion of soil X in a map unit at a chosen level of confidence. Once the required number of observations has been made randomly within a map unit, the probability of finding the stated proportion of soil X within the map unit can be calculated using equation 1:

$$P_{(x)} = \frac{n!}{n!\,(n-x)!}\; p^{x}q^{n-x} \qquad (1)$$

(Edmonds and Lentner 1986; Edmonds and Crouch 1991). The user may then decide if the map is adequate based on the calculated probabilities. If the probability of finding soil X in the proportions stated by the map is not high enough, the user can reject the map as unsuitable for the desired purpose.

Arnold (1981) used binomial confidence limits to develop a graphical solution for estimating the accuracy of soil maps. Arnold (1981) suggests that the accuracy of a soil map can be predetermined. By selecting a probability level and a limit of error for a desired level of accuracy, the number of samples needed to estimate the map unit composition at the chosen accuracy levels can be calculated. Arnold (1981) presents a number of graphs for determining the sample sizes needed to achieve a range of probabilities, limits of error, and accuracy levels. If the soil surveyor wishes to estimate the population proportions to a given level of accuracy and within specific limits, he selects the appropriate graph and visually determines the number of samples needed. In this manner, the surveyor can adjust the accuracy of the soil map to the desired level. Often this is not practical because of the large numbers of samples which would be needed since the procedure must be followed for every map unit. Arnold (1981) recommends determining the accuracy levels already achieved by a soil survey rather than trying to preselect the level of accuracy as a better approach. He suggests using a 90% probability level when determining minimum accuracy levels and has provided graphs that allow one to do so for up to 350 observations (Arnold 1981, Figures 10 and 11). If the number of ground truth observations which are not predicted by the map unit description are plotted against the total number of ground truth observations, the minimum level of classification accuracy can be estimated at the 90% probability level (i.e. a 1 in 10 chance of the accuracy estimate being wrong). Arnold (1981 Figures 12 and 13) has also provided graphs for estimating the maximum level of classification accuracy at the 95% probability level in the same manner.

Moon et al. (1987a) proposed a method for determining the degree of error which may be found in a soil map. This method has been used by Moon et al. (1987b); Selby and Moon (1987); and Fawcett et al. (1991). It is intended to answer the question "If it is wrong, how wrong is it?" and can be used for ranked, categorical data. The concept developed was called the Error Value (EV) and is an objective measure of how close the predicted observation and the ground truth observation are. The Error Value is calculated using equation 2:

$$EV = D/k-1 \qquad (2)$$

where D = the number of deviations between the predicted class and the observed class, and k = the number of possible classes for the characteristic being observed (Moon et al. 1987b).

Once the Error Value has been determined, the observation may be classed as correct, similar, dissimilar, or contrasting based on EV limits set out by Moon et al. (1987b). If a sufficiently large sample population is evaluated using this system, the proportions of the soils information contained in the map and legend which are correct, similar, dissimilar, or contrasting to the ground truth may be determined.

Marsman and de Gruijter (1986) and Moon et al. (1987b) describe a method for calculating percent purity and associated confidence intervals for use in determining the accuracy of a soils map. In this system, an observation is correct or incorrect based on whether or not the map unit description predicts it as occurring in the polygon in which the observation was made. Percent purity is calculated using the formula:

$$\%\ \text{purity} = \frac{\text{no. of observations agreeing with soil map}}{\text{total number of observations}} \times 100 \qquad (3)$$

(Marsman and de Gruijter 1986).

Other authors which have used percent purity as a measure of map accuracy include Powell and Springer (1965); Bascomb and Jarvis (1976); Hord and Brooner (1976); Ragg and Henderson (1980); Swartwout et al. (1981); Selby and Moon (1987); Fawcett et al. (1991).

If the percent purity for a particular soil type is calculated, the associated confidence interval may be used to determine if the proportion of that soil estimated by the map unit equals the true proportion at the desired significance level (Moon et al. 1987b). If the estimated proportion is outside of the confidence interval, then the difference is statistically significant and the tested delineation is inaccurate with respect to that map unit description.

The Mapping Systems Working Group (MSWG) (1981) uses the level of unmapped inclusions as an estimate of map accuracy. A map unit may have up to 10% contrasting soils, up to 15% contrasting + dissimilar soils, and up to 20% contrasting + dissimilar + similar soils occurring as unmapped inclusions before that map unit is rejected as incorrectly mapped. Selby and Moon (1987) calculated that 4, 4, and 5 unmapped soils respectively in ten observations would cause a polygon to exceed the defined acceptable levels at the 95% confidence level. By sampling a number of map units and determining the proportion which contain an unacceptable amount of unmapped inclusions, an estimate of the map accuracy can be made.

Riezebos (1989) used nested analysis of variance to determine the homogeneity of mapping units. This method of accuracy testing was used to determine how much of the soil variability was captured by the map unit description and whether or not widely separated polygons of the same map unit should be grouped together with respect to derived interpretations. If the variance between polygons is low, there is little problem in assuming that they will react the same under the same management conditions. A large variance within and between polygons of the same map unit indicates very heterogeneous units and the precision with which the units are described is not warranted or the units should be described as having low precision associated with them.

The continued interest and increasing variety of uses to which remote sensing techniques are being applied has produced a number of measures for checking the validity and accuracy of those techniques (Aronoff 1982a, 1982b). One of the uses of remote sensing is the production of land-use maps (Hord and Brooner 1976; Ginevan 1979). Two basic measures of accuracy have been used to test these maps. The first is the error matrix (Aronoff 1982b) from which numerous statistical inferences can be made (Aronoff 1982b; Congalton and Mead 1983). The second measure of accuracy is refereed to as producer/consumer risk and is based on the concept of acceptance sampling (Ginevan 1979). All of the map accuracy test methods mentioned here were designed specifically for use with land-use maps derived from remotely sensed data. The general principles involved may be applicable to soil survey products and are discussed here.

The statistical concept of acceptance sampling and its application to land-use maps is discussed by Ginevan (1979) and Aronoff (1982a, 1982b). Both authors describe the problem as being one of acceptance or rejection of a land-use map derived from remotely sensed data and use binomial probabilities as a solution. Acceptance sampling uses the terms producer risk and consumer risk (Ginevan 1979). Producer risk is the probability of rejecting an acceptable map. Consumer risk is the probability of accepting an inaccurate map. Ideally, the producer and consumer risks would be zero, but the cost of data acquisition to achieve zero risk may be prohibitive because of the large number of samples required. A probability level must therefore be specified for both consumer and producer risks. Ginevan (1979) suggests 0.05 as an acceptable consumer risk, and 0.10 as an acceptable producer risk. The reason for the different probability levels is the sample size needed to determine map accuracy. The more samples taken, the lower the risk. The map producer will want to minimize the cost of map checking and so may be willing to accept a higher risk while the consumer will want only those maps which meet the specified accuracy level and so will want the lowest risk possible. Once the desired producer and consumer risks have been selected, an accuracy acceptance level must be chosen. This is the map accuracy below which the land-use map will be rejected as unacceptable. Ginevan (1979) suggests using 85% or 90% and has provided look-up tables based on these two accuracy standards. From these tables, the sample size and number of allowable misclassifications needed to test the accuracy of the map can be determined (Ginevan 1979). The consumer risk/producer risk evaluation of map accuracy does not determine the true map accuracy. It will only indicate whether or not the true map accuracy is above or below the accuracy acceptance level.

Aronoff (1982b) proposes that rather than simply state whether a map has passed or failed a specified accuracy level, results should be reported in the form of an error matrix. An error matrix is "a tabulation of accuracy test results which shows the number of points correctly and incorrectly identified" (Aronoff 1982a). The percent correct (labeled percent purity earlier in this section) can be calculated for individual classes or for the entire sample population from the error matrix. As well, the percent commission (recognition of a component not actually present) and percent omission (failure to recognize a component which is present) errors can be calculated. Formulas for calculating the percent commission error and percent omission error can be found in Agbu and Nizeyimana (1991). Reporting the map accuracy in this manner allows the consumer to evaluate the accuracy results specific to their needs (Aronoff 1982b). For example, a single accuracy estimate usually refers to the entire map. A low accuracy with respect to the recognition of Solonetzic soils will affect the accuracy of the entire map, even though the accuracy for wet soils was very high. A user interested in the distribution of wet soils may find the map to be more than adequate even though the overall map accuracy is low. An error matrix would allow the user to decide whether or not the map is sufficient for their needs.

All of the above analysis techniques are based on the assumption that agreement between the ground truth data and the land-use map is due to a correct interpretation by the mapper (i.e. the mapper knew what he was doing) and make no allowance for 'luck' on the mappers part. A statistical method of comparison has been developed called the Kappa statistic (Cohen 1960 in: Rosenfield and Fitzpatrick-Lins 1986) for analysis of error matrices. It is described by Greenland et al. (1985) as "the proportion of agreement over and above chance agreement" and can be calculated from the following formula:

$$K = \frac{\text{observed agreement - expected chance agreement}}{\text{1 - expected chance agreement}} \qquad (4)$$

(Greenland et al. 1985)

Congalton and Mead (1983) have used this technique for analyzing the differences between photointerpreters, to test the consistency of one photointerpreter over time, and to test for differences between photointerpretation variables such as photo type, season, and scale. Agbu and Nizeyimana (1991) used the Kappa statistic to compare two soil maps, one derived from Landsat imagery and the other prepared from field investigations.

The Kappa statistic as described in Greenland et al. (1985) and Rosenfield and Fitzpatrick-Lins (1986) is a measure of total map accuracy and makes use of all the elements of the error matrix. Rosenfield and Fitzpatrick-Lins (1986) have also described conditional Kappa, which is a measure of individual category accuracy. This measure can be used to evaluate the accuracy of an individual component of the error matrix. It is possible then to compare the accuracy of an individual component to the accuracy of the entire matrix.

The above methods for comparing land-use maps are not applicable directly to current soil survey products. Land-use maps tend to say that a particular sample site is category X while soil survey maps say that a chosen sample site may be one of soil A, B, C, etc. The general principles involved, however, may be applicable to soil survey products. Modified sampling schemes and adaptation of the error matrix may provide a valuable technique for assessing the accuracy of soil maps.

E.iii. Cartometrics

Cartometrics usually refers to the scale of presentation and the texture of a soil map. Both can be related directly to the usefulness of the soil map through its readability (Marsman and de Gruijter 1986) or its legibility (Forbes et al. 1985). In addition to scale and texture, cartometrics and map readability are affected by the legend design (Ellehoj 1984).

The evaluation of whether or not the map scale is adequate for a given use is dependent upon the needs of the user and the purpose of the survey. There are two criteria described by Forbes et al. (1985) for determining the adequacy of the map scale. The first criteria is the 'maximum location accuracy' and indicates the precision with which a ground point may be plotted on the map. The smaller the map scale, the less precise are the distances indicated between points. In order for a map scale to be adequate, the maximum location accuracy must be less than or equal to the location accuracy of ground points needed by the user. The second criteria is the 'minimum legible area' and is dependent upon the minimum size map delineation. The smallest delineation that can easily be discerned at any map scale is given as 0.4 cm^2 (Forbes et al. 1985) to 0.5 cm^2 (MSWG 1981). Forbes et al. (1985) use the minimum legible area to help determine the adequacy of a given map scale for a user and calculate it based on 0.4 cm^2 and the formula:

$$\text{Minimum Legible Area (ha)} = \frac{(\text{Map Scale})^2}{2.5 \times 10^8} \qquad (1)$$

(Forbes et al. 1985)

The minimum legible area must be less than or equal to the smallest area of interest to the user in order for the map scale to be adequate.

Map texture refers to the sizes and pattern of delineations on a map (Forbes et al. 1985). The pattern of map delineations is difficult to assess and is as dependent upon the surveyors esthetic concepts as it is upon the variability of the landscape. For this reason, map texture is usually only measured in terms of delineation size (Forbes et al. 1985). Marsman and de Gruijter (1986) state that users generally dislike maps whose delineated areas are very small, but conversely maps which have very large polygons are usually presented at a scale larger than necessary (Forbes et al. 1985).

There have been two separate methods proposed for calculating the adequacy of map texture through delineation size. The MSWG (1981) uses an index called 'map delineation density' and calculate it using the formula:

$$\text{Map Delineation Density} = \frac{\text{Minimum Size Delineation}}{\text{Average Size Delineation}} \times 100 \qquad (2)$$

(MSWG 1981)

The map delineation density should be about 5%, meaning that an average size delineation 20 times greater than the minimum size delineation would be ideal when evaluating map texture (MSWG 1981).

Forbes et al. (1985) also proposed a method of quantifying map texture. They compared the average size delineation to the minimum size delineation using the term 'index of maximum reduction'. This index is the reduction factor at which the average size delineation would become equal to the minimum legible area if the map scale were reduced by the calculated factor. They suggest that an index of maximum reduction of 2.0 is optimal and calculate it using the formula:

$$\text{Index of Maximum Reduction} = (2.5 \times \text{Average Size Delineation})^{0.5} \qquad (3)$$

(Forbes et al. 1985)

Forbes et al. (1985) suggest that the lowest acceptable value for this index is 1.58. A value lower than this indicates that the map legibility is below an adequate level and that the physical size of the map should be increased. An index value greater than 2.0 indicates that the map is very legible and could even be reduced in size without reducing the legibility. Forbes et al. (1985) also provide a second measure of map legibility called the 'optimum legible delineation' and suggest that this is 4 times the size of the minimum legible delineation.

Forbes et al. (1985) suggest a sampling scheme for estimating the average size delineation. Their system involves counting the number of delineations inside a known area, and then calculating the average size of the delineations using an empirical formula.

Marsman and de Gruijter (1986) used a simple ranking strategy for determining map readability based on the assumption that map users generally dislike maps with a large number of very small polygons. Maps having an even distribution of mapping units in terms of the percentage of map area, maps having the fewest polygons, and maps having the largest average polygon size were considered to be the most readable. This is a subjective system, however, in that maps having too few polygons or polygons which are too large may not be precise enough for the needs of many users.

Ellehoj (1984) discusses cartographic readability in terms of the legend design. He indicates that the more 'cluttered' a map is, the less readable it becomes and recommends the use of a closed legend. No specific test for checking the adequacy of legend design is proposed by Ellehoj (1984), however. He only suggests that a map with fewer polygons and fewer symbols per polygon is more readable than a map with a large number of either.

E.iv. Consistency of Application of Map Unit Models

The process of testing whether or not map unit models have been applied consistently is a test of map quality, usefulness and overall accuracy and is the job of the correlator (Expert Committee on Soil Survey (ECSS) 1987; Hole and Campbell 1985). All soil surveys or soil inventory projects should have a correlation component in them. The correlator, as part of his job, continually checks each area as it is mapped to ensure that consistency is maintained by individual mappers and more importantly that there is consistency between mappers (Dent and Young 1981; Western 1978).

The method most commonly used by correlators to check consistency is to sample selected sites using both transects and random observations (MacMillan 1987) and then use the data to verify the map unit name given to a polygon and to check the map unit descriptions (Western 1978). The map unit models used in the project are then updated and improved as more data are gathered by the mappers and the correlator (Dent and Young 1981). Ensuring that the models are consistently applied is thus part of the survey project and cannot be verified 'after the fact' by some checking program.

Another method used by correlators to check the application consistency is to sample two different delineations and compare the results. The problem with this is that most map unit models are built to encompass a range of variability within and between different polygons of the same map unit (Dent and Young 1981). Two polygons with slightly different soil compositions may both fit the same model. Differences between two polygons does not necessarily indicate mapping inconsistencies.

Inconsistencies in the application of the models will affect the accuracy of the soil map. As well, it is possible to apply a landscape model consistently during the entire length of a project and still have a very low accuracy because the model was wrong. There is no way to distinguish, then, if a correct model was inconsistently applied across the project or if an incorrect model was consistently applied. The correlators function is to ensure that there is consistency in the application of the map unit models being used (Dent and Young 1981). We must assume that the correlator did his job when we evaluate a soil map. Then we can check how good the model used was through the ground truth accuracy.

E.v. Information Content and Utility

The information content of a soil inventory product and the utility of that product are of concern to the product user because they determine if additional sources of information will be needed to achieve the desired interpretative results. Who the user is and what the user requires are the most important considerations when evaluating maps for information content and utility.

Map utility depends upon the correctness (accuracy) of its predictions. The predictive accuracy of the map over the whole survey area measures its utility (Bie and Beckett 1971). To test the utility of a soil map, therefore, one must test the ground truth accuracy of the map. This is discussed in section E.ii.

The adequacy of the information contained in a soil survey is dependent on the user (Cheel 1991) and the precision required by the user (MacMillan pers. comm. 1992). Precision refers to the level of detail or specificity of the mapping units (Hole and Campbell 1985) and is discussed more fully elsewhere in this document. The level of precision required by a user is very important. For example, if users require very narrow slope classes, they will not be satisfied with a legend that provides only broad groupings of slope classes. As well, the map that is sufficient for one user may be entirely inadequate for another user. For example, most soil surveys contain no information on slope lengths. The user interested in the distribution of soil textures over an area may find the map very relevant and highly useful but the user trying to estimate erosion potentials using the USLE will find that the map contains insufficient information.

There are two types of information which are important on the soil map. These are (1) the polygons, which provide a spatial description of the survey area; and (2) the map unit legend, which provides the non-spatial description of the survey area (Cheel 1991). The adequacy of the spatial information is related to the cartometrics of the map and is discussed in section E.iii. The map legend is used to convey information about the surveyed area to the user. When attempting to evaluate the information content of a map and its legend, the ground truth accuracy of the map is not the concern. The evaluation should attempt to determine if the information of interest to the user is included and if the information is clearly presented (Forbes et al. 1985). Beckett and Burrough (1971) list eight questions which a soil survey product should be able to answer. All of the questions are similar and can be summarized into (1) What kinds of soils are found in the area of interest? and (2) What are the properties or characteristics of those soils? Forbes et al. (1985) considers that the non-specialist will find the usefulness of a map legend is greater if general attributes (land qualities) of the map units are presented rather than specific attributes (land characteristics). In practice, only the land characteristics are mapped since soil surveys are produced for a broad range of users (Cheel 1991; MacMillan 1985) and different users will find different land characteristics of importance (Forbes et al. 1985).

The methodology used by MacMillan (1984) to compare the adequacy with which two different map products identified irrigability rating data elements can be adapted for evaluating the information content of a legend. By checking to see if the information needed to make the desired interpretation (eg. land irrigability rating) is contained in the report and on the soil map, the user can assess how relevant to their needs the map is. Only if the required information is contained in the legend does the accuracy of the soil inventory product become a concern to the user.

E.vi. Summary

The methodologies described in this section can all be used to compare and evaluate soil survey products. Not all of the techniques have been designed specifically for use with soil maps, but the general principles involved can be applied to soil maps. The accuracy, cartometrics, consistency, and information content of a soil survey product all contribute to the quality of that product.

The ground truth accuracy of soil maps can be calculated and expressed in a number of ways. The first measure of ground truth accuracy is the reliability of the soils information. Percent correct is the most common method of determining map accuracy and is a simple measure of the number of ground truth points correctly predicted by the map. Binomial probabilities are used to describe what the chance of getting a correct prediction by the map is. Measures of degree of similarity or degree of difference are used in an attempt to show how large any differences between the ground truth data and map data are and if the differences are significant. Measures of variability have also been used to quantify map accuracy. These are all measures of the reliability of the soil information to be found on a soil map. A second measure of ground truth accuracy is the ground location accuracy. The ground location accuracy is influenced by the base map quality and the surveyors ability to accurately locate a soil boundary on the base map.

Cartometrics is closely related to the ground location accuracy and can be quantified by calculating the minimum legible area, the map delineation density, and/or the index of maximum reduction. Determination of the cartometric quality of a soil survey product should be accomplished jointly by the producer and the user of the product.

Ensuring that the consistency of application of the map unit concepts across the entire map and between polygons is maintained is a correlation function. Each soil survey project should have a correlation component built into it, and there is no method to evaluate how well the correlator did his job. It is impossible to determine if a correct model was applied inconsistently across the project area or if an incorrect model was applied consistently across the project area. It must be assumed that the correlation job was done correctly and consistency was maintained. Then the accuracy of the soil model can be evaluated.

The information content and utility of the soil map can be evaluated in terms of the descriptive precision, the spatial precision, and the legend design. A soil survey product which provides the user with the information needed and in a form that the user can understand is acceptable as having adequate information and high utility. All three measures of information content and utility should be discussed by the user and producer together.

How future soil maps are evaluated will be discussed later. The methodologies used in the determination of accuracy, cartometrics, consistency, and information content have been discussed in the above section. Not all analyses described above are needed to determine the quality of a soil survey product, but some quantification of quality is needed in order to allow the user to understand the products weaknesses and strengths. This will enable the user to make better and more informed interpretations of the landscape.

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II.F. SAMPLING TECHNIQUES

- M.D. Fawcett and R.A. MacMillan

F.i. Introduction

Within the scope of this section, sampling is defined as the process by which observation sites are located on the landscape. The data elements collected at an observation site are not considered here.

There are two reasons for sampling the soil population. The first reason is to characterize the full range of soil variability within the landscape, enabling the soil surveyor to partition the landscape into discrete polygons and to estimate soil composition of individual map units, i.e. to make a soil map. In this case, the purpose of soil sampling is "to either confirm or reject the soil scientists' hypothesis of what soil is expected on a given landscape unit" (Miller et al. 1980), but does not require statistical validity. The second reason for sampling the soil population is to make an independent determination of map reliability (Western 1978). In this case, the purpose of soil sampling is to test the accuracy and the precision of both the soil map and the map unit description (Schellentrager 1990) and does require statistical validity (Hord and Brooner 1976).

All sampling schemes and designs involve two sampling levels or stages (Table 2.6). Level I deals with the sampling location within the map area, i.e. where on the landscape do we make a site investigation. Level II deals with the technique employed at each sampling location for determining observation sites, i.e. what kind of an investigation do we make. A third level, orientation, could also be described but does not apply to all Level II techniques. Orientation will therefore be discussed with each Level II technique to which it applies and not as a discreet level or stage of sampling.

Table 2.6. Level I and Level II sampling techniques.

Level I	Level II
purposive	individual points
random	line transects
grid	radial arm transects
nested	random clusters
	grid clusters

The sampling techniques listed under Level I and the techniques listed under Level II are closely related. Any Level II technique can potentially be used in conjunction with any Level I technique. As well, there is a certain amount of similarity among the techniques. Some techniques lend themselves to use for characterization of the landscape (eg. purposive, individual points) while others are most useful in the determination of map reliability (eg. random, radial arm transects). The actual combination or combinations of Level I and Level II sampling techniques used will depend upon the time and cost of data collection versus benefits gained from the techniques. There is no one best combination of techniques for all uses (Schellentrager 1990).

Wilding (1986) comments that "the question of sampling scheme, statistical analysis to be employed, and observational interval continue to plague most pedologists". He suggests that "the answers really depend on objectives of the work, nature of classes being sampled and precision of the results expected at a given confidence level."

In this document, sample size and sampling criteria for both map production and map evaluation will be discussed. As well, a short description of each sampling technique will be presented along with advantages, limitations, and potential modifications of each technique.

F.ii. Sampling Criteria - Map Production

When choosing a sampling strategy for map production, there are a number of conditions which must be met and criteria which must be considered. These are:

1) The objective or end use of the survey must be known before a suitable sampling strategy can be chosen (Miller et al. 1980). The appropriate sampling scheme is often determined by the number of observation sites required which in turn is dependent upon the objective of the survey. If the objective of the survey is unknown, an appropriate sampling scheme and sampling density cannot be chosen.

2) The cost and time requirements of the chosen sampling technique must be feasible given the objectives of the survey (Miller et al. 1980).

3) The sampling technique must allow the soil surveyor to determine the pattern of soil variation in the study area (Miller et al. 1980). This criterion demands that the soil surveyor be allowed to sample both the most representative landforms as well as the landforms which differ from the norm.

4) The sampling technique must allow the soil surveyor to either confirm or reject a hypothesis of what soils are expected in a given landscape unit (Miller et al. 1980). This criterion presupposes that the soil surveyor is able to "read and predict the relationship between the landscape and the soils that have formed on it" (Miller et al. 1980).

F.iii. Sampling Criteria - Reliability

There are several criteria that must be met by any sampling strategy in order to successfully evaluate all aspects of soil mapping accuracy and precision. These are:

1) The sampling technique must be statistically valid (Hord and Brooner 1989). The implication of this criterion is that every point on any given map to be tested must have an equal chance of being selected for observation (Cline 1944; Forbes et al. 1985; Moon et al. 1987; Edmonds and Crouch 1991). Statistical validity is assumed to result in two criterion specified by de Gruijter and Marsman (1985) being met. These are (a) unbiased estimates of the soils composition of the map area and (b) an objective quantification of map accuracy.

2) It should permit the evaluation of accuracy and precision for the overall map area as well as for individual map units or delineations (Moon et al. 1987). Observations should not be restricted to specific map units or polygons, unless results are needed only for the specific polygon or map unit.

3) It should produce multiple observation sites within individual delineations of map units. It may be necessary to accomplish this in the absence of a-priori knowledge of the location and boundaries of map unit polygons. The criterion of multiple observation sites is required to permit assessment of whether soil entities or properties are present in any given delineation in approximately the proportions predicted by the legend. The condition specifying that sites may require to be chosen without reference to existing polygon boundaries is necessary if the same test data set is to be used to compare two or more different maps, produced by different methods and having non-coincident polygons and polygon boundaries.

4) It should permit decisions to be made about the relative similarity of observed soils to the soils predicted by the map legend. This criterion is included in order to allow for the fact that soil series names as used in map unit descriptions are often intended to represent not simply a given series but also any largely similar soils. It may be

possible, and preferable, to evaluate the similarity of observed to predicted soils by comparing interpretive ratings of the respective soils rather than attempting to compare taxonomic similarity.

5) It must be feasible, practical and cost effective for routine field application (de Gruijter and Marsman 1985). This criterion acknowledges that, notwithstanding the need to maintain maximum statistical rigor, the method must allow for rapid, simple and effective location of sample points in the field (de Gruijter and Marsman 1985; Di et al. 1989).

Not all sampling strategies will satisfy each of the five criteria. The correct sampling strategy will depend upon the objectives of the map reliability study and the number of observation points required.

F.iv. Sample Size

The intensity of data collection (i.e. number of observation sites) depends on the objective of the project (Miller et al. 1980). If the objective is to produce a soil map or survey product, then the most efficient sampling size will be determined by the complexity of the landscape and the experience of the soil surveyor. If the objective is to evaluate the accuracy of a soil survey product, then a more rigorous approach is needed for the selection of sample size.

The number of sample points needed for a statistically valid estimation of map accuracy varies with the testing procedure used and the degree of confidence desired. For most tests, Level I sample sizes of less than 30 will result in unreliable statistical inferences while a sample size greater than 50 is not likely to provide an increased statistical benefit equal to the increased cost of data collection (Forbes et al. 1985). Other authors (Hay 1979) have recommended a minimum sample size of between 50 and 100 in order to minimize the influence of asymmetrically distributed errors. These estimates are based on ten or more observation points at each Level I sampling location, a number suggested by Steers and Hajek (1979). If the Level II technique to be used is individual points, the number of Level I sample locations must be equal to the required number of observation sites.

For the evaluation of the soil map as a whole, the total number of observation points needed will be larger than if a single polygon is to be evaluated. The spatial density of observation sites will be much lower if the whole map is being evaluated, however. It is recommended that approximately 70 Level I sample locations be selected for evaluating the overall accuracy of soil maps. It is hoped that up to 50 of these locations can be evaluated (Forbes et al. 1985). The 20 extra provide a measure of insurance if it proves impossible to locate or gain access to a selected polygon. If the objective is to evaluate the accuracy of a single map unit, it is recommended that between 50 and 100 individual observation points be selected from the map unit. If the objective is to evaluate the accuracy of an individual polygon, it is recommended that between 30 and 50 individual observations be made.

If the sample sizes recommended here are not considered adequate or sufficiently accurate, a more rigorous method of calculating the sample size can be used.

Wang (1982) has identified three factors which control the sample size:

1. Confidence level: an expression of the probability that the statement is correct.
2. Soil variability: highly complex and variable areas will need more samples.
3. Confidence interval: an estimated range of the population mean. The smaller the range, the larger the number of samples which will be needed.

These three factors are roughly equivalent to the variables used in a more common equation for calculating sample sizes:

$$n = t^2 s^2 / L^2 \qquad (1)$$

where n = sample size
t = student statistic (~confidence level)
s = standard deviation (~soil variability)
L = allowable error (~1/2 the confidence interval)
(Dos Santos 1978)

A disadvantage of using equation (1) is that in order to select the correct t value and to estimate s, one must take a small data subset first. The standard deviation is calculated from the data subset as well as the degrees of freedom (df = n - 1) needed to select the t value.

Wilding (1985) suggests that a confidence level of 70 to 80% is an acceptable and realistic level for soil sampling. Confidence levels higher than this are generally not feasible in terms of time and money inputs needed. Dos Santos (1978) used 80% probability with 10% allowable error around the mean in order to calculate the number of sampling locations needed. An 80% confidence level is suggested for selecting the t value. The allowable error of 10% used by Dos Santos (1978) indicates a confidence interval (CI) of 20%. This is often not realistic in soils (Wilding 1985). A suggested CI is 40%, resulting in an L value of 20. This will permit sufficiently accurate estimates of the mean at a reasonable sample size (Wilding 1985).

F.v. Level I Sampling Techniques

Purposive Sampling

Purposive or representative sampling is the most commonly used method of Level I sampling for map production. It is used both to evaluate the landscape and to characterize the soil population of map units (Hajek 1977). Miller et al. (1980) describe the purposive sampling method as follows:

1) Use preexisting knowledge of the area and known relationships between soils, landforms, and vegetation to infer which soils occur in a given area.

2) Traverse the landscape on foot or by vehicle and select sample locations which represent unique landform elements in which a specific soil type is expected. Those landforms which are most representative are chosen along with landforms which differ from the norm.

3) Use the selected Level II sampling technique at each representative sampling location to choose the individual observation sites.

The inferences drawn about which soils will occur where in the landscape in step 1 are the soil surveyors hypotheses of what soils occur in a map unit. The representative landforms chosen in step 2 are used to either confirm or reject the hypothesis formulated in step 1.

Advantages of purposive sample locations are:
a) It is a fast and practical method of characterizing the soils in a mapping area. Soils can be predicted, stratified, and mapped with a certain level of reliability (Miller et al. 1980). The purposive method of sample location allows the predictions of the surveyors' soil model to be confirmed or rejected quickly.
b) The experienced soil surveyor can easily locate the representative sample locations in the field.

Limitations of purposive sample locations are:
a) Each location is chosen as a standard and often is not representative of the entire population of the delineated area (Steers and Hajek 1979).

b) Purposive sampling is biased in that each location is intended to be a representative sample. It is not a statistically valid sampling scheme, therefore, and cannot be used in an objective evaluation of map reliability.

A potential modification to the Level I purposive sampling scheme is:

a) Traverse the landscape making representative soil observations before attempting to develop any map unit models. Use the data gained from these preliminary traverses to help develop the map unit models in step 1 above. This will allow more accurate models to be developed, which can then be confirmed and/or modified by subsequent sampling.

Random Sampling

Random sample locations are selected corresponding to the intersection points of a cartesian coordinate system superimposed over the entire area of the map to be tested. The UTM grid is recommended since it is already defined and appears on published 1:50 000 UTS topographic maps. Grid coordinate pairs are selected by reference to a random number table (as detailed below) or by using a random number generator. Any point falling within the mapped area and not falling on a polygon boundary is accepted.

The procedure for selecting sample locations using a random number table should be as follows:

1) Point to a starting point on a random number table.

2) Read the first number as the 10's digit of a UTM easting value.
   2nd " " " 100's "
   3rd " " " 1000's "
   4th " " " 10000's "

   If the 4th number is outside or exceeds the range which defines the extent of the study area skip to the next number and so on until a number is encountered which is within the range for the study area.

3) Continue reading the random number table to define a 4 digit UTM reference for northing in the same manner.

4) Locate the identified point on a 1:50 000 map (Figure 2.7). If it is within the mapped area and does not fall on a road or obvious non-soil area enter it into the list of selected Level I sample locations.

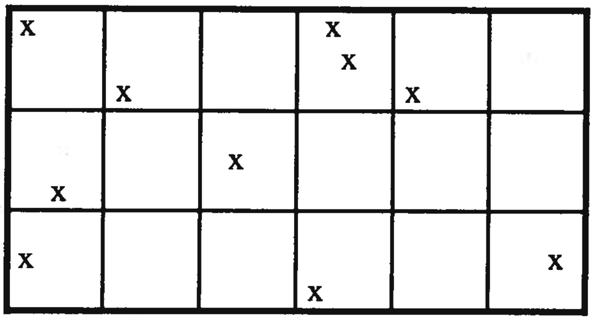
5) Locate the randomly selected sample locations in the field and proceed with an appropriate Level II sampling technique at each location.

If a random number generator is used, steps 1 - 3 become automated with the generator producing four digit numbers. Generated numbers (eastings or northings) which fall outside of the study area are rejected entirely and a new number is used.

There are two variations to the random sample location method, with replacement and without replacement. Random sampling with replacement allows a coordinate pair (sample location) to be chosen more than once (Hord and Brooner 1976; de Gruijter and Marsman 1985). A disadvantage of replacement is that a very small area of the map can be overly represented in the data set if a pair is chosen twice. Random sampling without replacement ensures that each location can be selected only once (Congalton 1988) and is recommended. This variation of random sampling ensures that sampling locations are not overly represented and has been used by several authors (Selby and Moon 1987; Congalton 1988; Fawcett et al. 1991).

Advantages of random sample locations are:

a) It is quick and simple to select sample locations when the UTM grid is used in conjunction with a random number generator.
b) It is statistically sound in that every point on the map has an equal chance of being selected (Arnold 1979). This reduces or eliminates bias in selecting sample points.



x <- reject this coordinate

Figure 2.7. Random sample locations selected by cartesian coordinates.

Limitations of random sample locations are:

a) The process can be long and tedious if there is not a convenient grid overlying the map area or if a large number of grid coordinates must be chosen using a random number table.

b) One practical disadvantage is that it can take considerable time and effort to accurately locate each sample location in the field (Arnold 1979).

c) There is considerable opportunity for bias in the final selection of the inspection site when translating a grid coordinate on a map to a site in the field (Arnold 1979).

d) The random sample technique will not test individual map unit or delineation reliability when applied to a map area having multiple map units and polygons (Moon et al. 1987). It does not guarantee delivery of a sample location in each map unit or each polygon. Without multiple sample locations, it is not possible to determine whether the soils observed in a particular delineation occur in the proportions specified by the map legend for that delineation. It is highly desirable, when evaluating map unit accuracy, to be able to compare the observed proportions of various soils in a sampled delineation to the predicted proportions. This is not supported by data collected by random point selection.

e) Random sampling may produce clusters of sample locations that oversample some areas (Burrough 1991). This can result in minor portions of the landscape contributing more to the data set than is warranted.

Potential modifications to the Level I random sampling method are:

a) Use a random number generator to choose the cartesian coordinate pairs. This will increase the speed and the efficiency of the method.

b) Prestratify the map area by choosing specific map units or polygons and accepting only those sample locations which are located in the selected areas (Moon et al. 1987). This will allow individual map units or polygons to be tested for their reliability.

Grid Sampling

Grid sampling is most commonly used when the researcher wishes to estimate the variability of a soil property over a given area. The regular spacing of the sample locations also facilitates block kriging (Burrough 1991) and reduces the error for attribute prediction based on computer modelling.

The procedure used in grid sampling may be described as follows:

1) Select the area to be sampled and choose a grid interval suitable for the desired analysis. Reported grid intervals range from 30 m x 30 m spacings (Di et al. 1989) to 1.6 km (Goldin 1988). The chosen interval should be relative to the purpose of the study. Soil properties which vary over large distances can be studied with large grid intervals while soil properties with a large amount of short range variation will require smaller grid intervals.

2) Overlay a regular grid of the chosen interval distance on the map area and locate each sample location in the field.

3) Proceed with the appropriate Level II sampling technique to locate the individual observation sites in the mapping area.

The orientation of the grid system on the landscape requires special attention in order to avoid a biased data set. If the grid is laid out parallel to a systematic variation in the landscape (eg. stream channels or parallel ridges), there is the potential for a biased sample (Cline 1944) and much of the true variability in the landscape may be missed. Random orientation of the grid overlay is prefered, but at the same time care must be taken to insure that the orientation does not conform to some regular pattern in the landscape.

Advantages of grid sample locations are:

a) A systematic grid sample ensures that all areas of the map are sampled and is easily controlled (Bascomb and Jarvis 1976).
b) It provides an effective data set for evaluating overall map accuracy if a sample population of sufficient size is taken.
c) It is quick and easy to locate the sample locations on a map sheet and inexperienced staff can be trained to sample on a grid basis quickly and easily (Cline 1944).
d) It is very well suited to geomorphic-pedogenic studies and grid data sets can be used in computer generated surface modelling exercises (Wilding 1985).

Limitations of grid sample locations are:

a) It does not guarantee that there will be multiple sample locations in each sampled delineation. This limits its usefulness in cases such as soil maps where it is desirable to assess the relative proportions of observed soils versus predicted soils in each map delineation if individual points are to be used as the Level II sampling technique.

b) The fixed grid spacing may be an additional disadvantage if the sample spacing happens to correspond to some natural landscape pattern. In such cases, sampling may be biased towards certain landscape positions and corresponding soil types.

A potential modification to the Level I grid sampling method is:

a) Use a triangular grid layout for sampling (Parkhurst 1984). The distance between a sample location and the boundary of the area it represents varies less with a triangular grid than with a square grid, resulting in a more efficient sampling strategy than a square grid. The main advantage of the triangular grid is that predictions of attribute values will have the smallest errors with this method. A disadvantage is the difficulty in laying out a triangular grid, a problem which may outweight the advantage of smaller prediction errors (Burrough 1991).

Nested Sampling

Nested sampling schemes are usually carried out for the purpose of collecting a hierarchical dataset to be used in nested analysis of variance (Riezebos 1989). An analysis of variance of a given soil characteristic will give an indication of the spatial covariance of that characteristic. The soil surveyor can then decide whether or not to attempt to delineate map units based on that soil characteristic. If the spatial covariance of a soil characteristic is such that most of the total variation occurs over a distance of less than the minimum delineation size, then that characteristic is a poor measure for the differentiation of map units.

Nested sampling uses individual points as a Level II sampling technique almost exclusively.

A nested sampling scheme was used by Riezebos (1989) and can be described as follows:

1) Arbitrarily choose four sampling distances such that the shortest distance will encompass most of the short range variation and the longest distance will encompass variation due to large structures. Riezebos (1989) used 2000 m, 400 m, 40 m, and 4 m while Mateos et al. (1987 from Burrough, 1991) used 250 m, 60 m, 10 m, and 2 m.

For ease of description, a 20 township map sheet with 5000 m, 500 m, 50 m, and 5 m sampling distances will be used. 5 m corresponds to the maximum location accuracy of a 1:20 000 scale map while 5000 m can be expected to account for any large scale variation expected.

2) Subdivide the survey area into squares approximately 5000 m X 5000 m (each township divided into 4 squares). The centre of each square becomes the starting point for the second stage, such that the intersampling distance is 5000 m. This results in 80 sampling squares per 20 township map sheet.

3) From the centre of each square choose a second stage sampling location approximately 500 m distant in a randomly chosen direction. There are now two sampling locations in each large square.

4) At each sampling location, choose a third stage sampling point in a randomly chosen direction about 50 m distant.

5) From each third stage point, choose the fourth stage sampling point about 5 m distant in a randomly chosen direction. There are now 640 nested observation points on the map sheet.

The sampling distances chosen in step 1 should be adjusted to each individual study area such that between 50 and 100 observation points are chosen over the entire map area. On a 20 township map sheet, it will be desirable to increase the first and second stage sampling distances (steps 2 and 3, respectively).

Advantages of nested sample locations are:

a) Analysis of variance requires only relatively small sample sizes for the construction of crude variograms (Burrough 1991). Estimates of the minimum required sampling distance needed for a grid survey can be made quickly and cheaply. The net result is a saving of field time and money in producing the soil survey product.
b) Nested sampling can be used to make an estimate of the homogeneity of mapping units and therefore an estimate of the accuracy of the map unit interpretations. Interpretations based on a homogenous map unit description can be deemed to be innaccurate if a nested analysis of variance indicates that the map unit is too heterogenous for the interpretation to be made reliably (Riezebos 1989).

Limitations of nested sampling locations are:

a) When applied to a large area (eg. several townships), it cannot be used to produce reliable estimates of map unit composition because it does not produce multiple observation points within individual map units or polygons.
b) If nested sampling is applied to an individual polygon, multiple observation points are produced but there is very little control over where the points are located. This makes it

difficult to extrapolate the calculated soils composition to other polygons with a high degree of confidence on the mappers part.

Potential modifications to the Level I nested sampling method are:

a) Use a much larger distance than 5000 m (eg. 10,000 m) during the first sampling stage. This will still account for large scale variation and have the added advantage of reducing the number of field observations to one quarter of the amount needed at 5000 m.

b) The single observation sites used at the 5 m sampling stage could be replaced with line transects at the 50 m sampling distance. This would not be a very practical modification, however, as it would not encompass the short range variation expected at 5 m and would increase the number of observations made.

F.vi. Level II Sampling Techniques

Individual Points

The use of individual points is a Level II sampling technique in which the sampling location identified during Level I sampling becomes the observation site. In this case, there is no defined procedure for locating the observation sites within the sampling location. If Level I purposive sampling is used, the representative location is observed and the required data collected at the site chosen by the soil surveyor. If other Level I sampling techniques are used, the observation site is taken as the grid coordinate location with no additional observations at that location.

This method of Level II sampling is most commonly used in association with purposive sampling in the production of soil maps but can also be used with Level I grid, random, and nested sampling techniques. The efficiency of individual point sampling is greatest when used in conjunction with purposive sampling during the production of soil survey products.

Advantages of the individual point sampling scheme are:

a) It is quick and easy to determine the observation site at each sampling location.

b) It is an efficient method of determining soil characteristics which have limited variation over a large area (eg. soil parent materials such as till). It is also an efficient sampling technique for estimating the areal extent of soil properties having limited short range variation.

Limitations of the individual point sampling scheme are:

a) There is no guarantee of multiple observation sites within individual map units or polygons. This makes it difficult for use in an accuracy check of map unit composition or polygon labels.

b) It is a relatively slow technique for data collection when a large number of observation sites are required and when those sites are spread out over a large area.

Line Transects

The line transect method of sampling is a Level II sampling technique and is strongly advocated by practical field soil surveyors (Arnold 1977, 1979; Steers and Hajek 1979; Wang 1982). This method permits rapid selection and field location of multiple sample points within individual map delineations. The procedure for line transect sampling may be described as follows:

1) Locate a starting point within the landscape using an appropriate Level I sampling location technique. This starting point becomes observation point number one.

2) Orientate the transect such that it crosses at right angles to the drainage pattern at that location (Wang 1980) (Figure 2.8, #1).

3) Beginning at the starting point (step 1), locate the second observation point at a specified distance from the starting point in the direction of the transect.

4) Repeat step 3 until 10 observation points have been located in the landscape. A suggested interval between observation points is 50 m (Arnold 1977).

Line transect sampling is meant to represent specific delineations and typify the existent populations (Hajek 1977). This can help in achieving better quality control and is a quick and reliable method in correlation exercises (Wang 1980).

The orientation of line transects on the landscape can be related to a known trend in the soils distribution (de Gruijter and Marsman 1985) as described here or it may be randomly oriented (Figure 2.8, #2), commonly refered to as an unaligned transect. When selecting the direction of a line transect, care must be taken to avoid orientations which are obviously not representative of the landscape (Arnold 1979). For example, transects which parallel a ridge top or stream will not accurately reflect the soils distribution in a landscape.

Figure 2.8. Aligned (1) and randomly oriented (2) line transects.

Advantages of the line transect sampling scheme are:

a) The data can be used to evaluate the proportions of observed soils in a delineation and/or in a map unit (Arnold 1977).

b) The data can be used to compare observed soil proportions to those predicted by the map legend.

c) Second and subsequent points can be located in the field quickly and easily once the initial transect starting point has been located (de Gruijter and Marsman 1985; Burrough 1991).

Limitations of the line transect sampling scheme are:

a) Sample sites tend to become concentrated in selected map units and polygons. This can happen even when polygons are weighted by their area so that, theoretically, every area of the map has an equal chance of being sampled. This clustering of sample points into only a restricted number of polygons and map units can make the data unsuitable for assessing overall map accuracy.

b) The transect method, as most frequently applied, often leads to a bias in sampling that over-samples the interiors of polygons and under-samples the regions near boundaries where there is the greatest likelihood of rapid change and of encountering soils not identified in the legend (Selby and Moon 1987).

c) Spatial resolution is limited to the observational interval (Burrough 1991). Long intervals between observation points will tend to underestimate the variability of the soils in a map unit or polygon while very short intervals become prohibitive in terms of time and cost of data collection.

There are a number of modifications which can be made to the procedure described above. Each modification will generally decrease the bias which can result from aligned and fixed interval transects. Potential modifications to the line transect sampling scheme are:

a) The distance between observation points can be held at a fixed interval but distances can be varied from as little as 20 m (de Gruijter and Marsman 1985) to as much as 4000 m

(Dos Santos 1978). Hajek (1977) suggests that the interval used should be between 30 m and 90 m. The fixed interval distance used may be chosen arbitrarily or randomly.

b) Systematically choose the interval distance. This can be done by estimating the directional width (i.e. the distance between the boundaries of the polygon in the direction of the polygon) of the polygon being sampled and divide the total distance by the number of observation sites. The result is the interval distance to be used.

c) Use randomly chosen interval distances between observation points along the transect. By generating two digit numbers from a random number table or generator, each interval will be different. This will eliminate the chance of a biased sample population due to a regular, repeating pattern in the landscape which coincides with a fixed interval.

d) Orient the transects in a random manner on the landscape (de Gruijter and Marsman 1985). This can be done using a randomly chosen compass direction or by using a simple device such as a card with a spinning arrow (Arnold 1979).

e) The number of observation points along an individual transect can be varied. Most transects use between 10 and 20 observations (Hajek 1977; Wang 1980) but binomial probability techniques can also be used to estimate the number of observation sites per transect (Arnold 1981).

Radial Arm Transects

Radial arm sampling (Wilding 1985) is a Level II technique and is essentially an extension of the line transect procedure for selecting multiple observation sites at a given sampling location. It is independent of directional bias and is recommended if the intention of the sampling scheme is to obtain multiple sites within delineation sized areas but without reference to any given polygon boundaries. It may be described as follows :

1) Locate a starting point within the map area to be tested using random grid coordinates corresponding to the intersection points of a cartesian coordinate system overlaying the entire map area. This starting point becomes sample point number 1.

2) Randomly select a number between 0 and 359 to represent a compass azimuth bearing (Figure 2.9).

3) Trace a transect from the starting point 300 m distant along the previously defined direction (Figure 2.9).

4) Define two other transects at 120 degrees to the initial transect from the initial starting point (Figure 2.9).

5) Mark off points at 100 m, 200 m, and 300 m along each radial transect (Figure 2.9).

6) Read a random 2 digit number from 1 to 99 from a random number table. Use this to compute the location of sample point #2 as xx% of the distance from the starting point towards point A (Figure 2.9).

7) Repeat (6) above to determine the distance between points A and B where sample point #3 should be located. Continue until a point has been identified at some randomly specified point in each of the 3 distance intervals along each of the 3 radial transects (Figure 2.9).

The result should be 10 sample points, randomly selected along three radial transects. The intent of this method is to randomly select a sufficient number of sample points in close enough proximity that most are likely to occur within a single delineation when the sampled sites are located on any polygon map of the area. At the very least, any polygon superimposed on this sampling scheme should contain several sample points. This should permit some estimation of proportions.

Advantages of the radial arm sampling scheme are:

a) After the initial centre point has been located, all subsequent points can be located quickly and easily using simple compass and pace methods.
b) The radial design removes the threat of directional bias in the samples.
c) The scheme produces a cluster of sample points in relatively close proximity. This provides some assurance that there will be sufficient points within any given polygon superimposed over the sample data to enable proportions of soils or soil properties to be assessed on a per polygon basis.
d) The method does not require a-priori knowledge of polygon locations, size or boundaries.
e) The method can be used to provided a data set for comparing two or more different polygon maps of the same area produced by different techniques or people.
f) All points in the map area have an equal chance of being sampled.

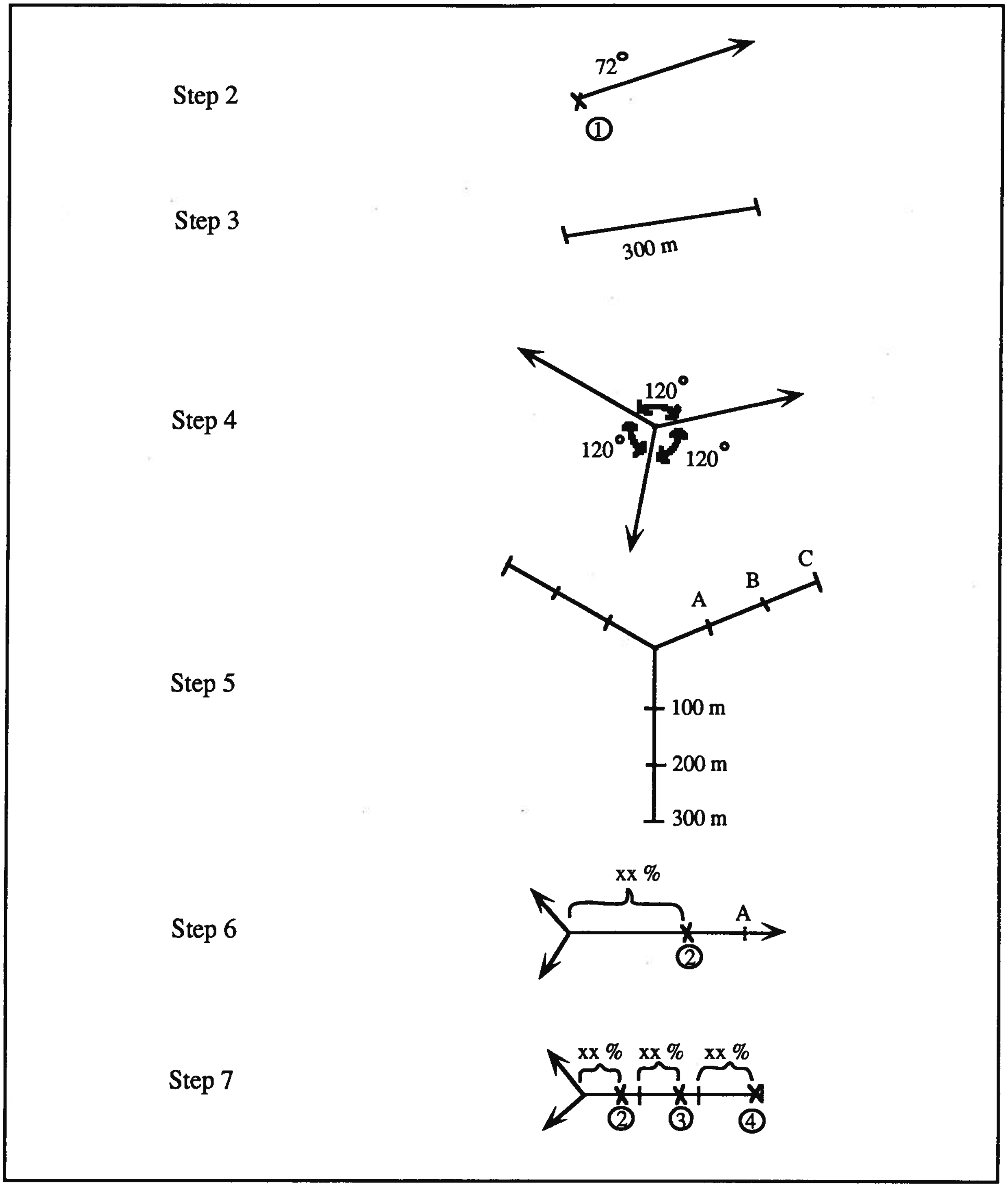


Figure 2.9 Steps in the execution of radial arm sampling (adapted from Wilding 1985).

Limitations of the radial arm sampling scheme are:

a) Operationally there will be some backtracking in going to and returning from sample points.

b) The method does not guarantee that samples will be taken from all portions of an overlain polygon nor that these samples represent the full extent of any overlain polygon.

c) The method does not guarantee that there will always be a sufficient number of sample points in every polygon to determine if observed soil proportions match the predicted proportions.

A number of modifications can be made to the above sampling scheme, either independently or in conjunction with other modifications. Each modification has a particular use and may not be appropriate for all purposes. Potential modifications to the radial arm sampling scheme are:

a) Randomly locate a sufficient number of points as described in step 1 above. Use this starting point for polygon selection only. Repeat step 1 using the selected polygon as the entire map area. Continue with steps 2 through 8 until sufficient sample points are located within the selected polygon, rejecting all points which fall outside of the polygon boundaries. This modification ensures that each polygon will have enough sample points to estimate the soil proportions. A disadvantage of this modification is that if the initial starting point is located near the boundary, a large number of sample points may be clustered very close together and may not cover the full range of variability to be found in the polygon.

b) In conjunction with modification a), place a buffer zone around the inside of the selected polygon equal to the length of a transect arm. Place the starting point inside of the buffer zone. This will allow all subsequently chosen points to be used. None need be rejected because they fall outside the polygon boundaries. The disadvantage of this is that some of the smaller polygons may be taken up entirely by the buffer zone and subsequently are not available for sampling. Forbes et al. (1985) have used a method similar to this modification in which the buffer zone was created around the sample point. If the polygon boundary line was inside of the sample point buffer zone, the point was rejected.

c) The length of each radial arm can be varied, using either randomly chosen lengths or arbitrary lengths such as 300 m or 500 m. A suggestion for arbitrary radial arm lengths would be to set the length equal to the radius of either (i) the minimum size mapping area or (ii) the average size mapping area.

d) The number of arms in each radial can be varied as well. Larger sample sizes per radial transect (eg. 15 or 20) may be handled easier with more radial arms. The degrees between arms must be reduced as more arms are added to the transect. For example, four arms will require 90 degrees and six arms would require 60 degrees to the initial transect (see step 4). A disadvantage of increasing the number of radial arms is that more work would be required to locate each arm. This extra work may be offset by having shorter arms and thus shorter walking distances.

e) The direction of each arm can be chosen randomly as opposed to a fixed bearing from the first arm. This may result in a tightly clustered sample population but would increase the randomness of site location.

f) The number of sample points along each arm can be varied. The sample points need not be distributed evenly among the radial arms. If this modification is used, the length of the arms should also be varied (modification c) above) and the sample points distributed proportionately according to arm length. This will avoid a large number of samples tightly bunched with a few additional samples widely dispersed.

g) The sample points can be fixed distances from each other along the selected radial arms. For example, points A, B, and C (step 5) become the sample points rather than interval markers.

h) Step 5 can be deleted from the procedure. Steps 6 and 7 can use the entire length of each radial arm rather than selected intervals. This allows for more random point locations along each arm. A disadvantage of this is that two or more points may be located very close to one another and unevenly distributed along the length of the transect.

Random Clusters

This Level II technique is very similar to the Level I random sample location method. The Level II technique for locating random cluster observation points is described as follows:

1) Locate the chosen Level I sampling location in the mapping area.

2) Overlay a 300 m X 300 m grid on the sampling area, with each side of the grid divided into 30 m intervals. The centre of the 300 m grid should be placed at the chosen Level I sampling location.

3) Select ten x,y coordinate pairs randomly using a random number table or a random number generator. Each x,y pair represents one observation point (Figure 2.10).

4) Locate each of these ten observation points in the field and sample for the required data elements.

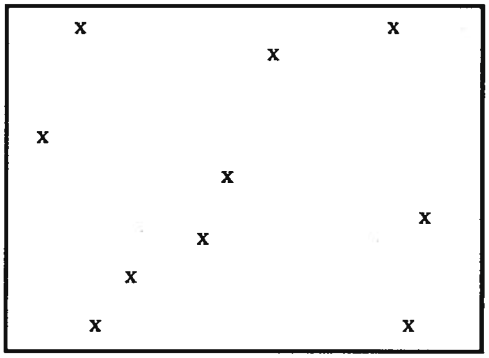


Figure 2.10. Random sample locations selected by cartesian coordinates. (adapted from Wilding 1985)

The orientation of the grid on the landscape can be either random or purposive. A purposive orientation will not bias the data set because the observation points are chosen randomly within the grid after the grid has been located in the field. A suggested orientation of the grid is in a north - south direction. This makes it easier to locate each observation point with a compass.

The main advantage of this sampling method is that it provides an additional level of randomness to the process of selecting observation points in the field.

Disadvantages of the random cluster sampling scheme are:

a) It may be difficult and time consuming to locate the correct starting point for the 300 m X 300 m grid in the field.
b) Once the grid has been located and marked in the field or on the map, finding each observation point in the field will take time which is often not justified by the increased randomness.

Potential modifications to the random cluster sampling scheme are:

a) Use the procedure outlined above but use the Level I sampling location as the starting point for the southwest corner of the 300 m grid. This will make it easier to locate the grid and observation points in the field.

b) The orientation of the grid can be chosen using a random compass direction. This will add more randomness to the data set but may not be warranted due to the increased difficulty of locating observation points.

c) Use each sampling location as chosen in Level I sampling as a polygon identifier only. Then select a fixed number of 10 observation points according to the method outlined by Moon et al. (1987). Moon et al. (1987) selected potential observation points by drawing a base line transect at a random tangent to the selected polygon. This transect was then divided into 10 intervals, such that an equal area of the target polygon was contained within the region defined by any two adjacent interval points. Random numbers were selected to determine the proportion of the distance from a given starting point to the next interval point and the distance in from the polygon boundary along a normal to the transect line. This procedure ensures that the samples are taken from the entire extent of a given polygon and that every portion of the polygon has an equal chance of being sampled.

d) Use the method outlined by Moon et al. (1987) but restrict the base line transect and the distance in from the polygon boundary to a maximum distance of 1000 m. This modification has been used with success by Fawcett et al. (1991).

Grid Clusters

Grid clusters are used as a Level II sampling technique in the same manner as Level I grid sampling. Grid clusters enable the researcher to estimate the variability of the soils to be found at a given sample location and can be used effectively when estimating the short range variability in a nested sampling scheme. The procedure for locating observation sites may be described as follows:

1) Determine the number of observation points to be made at each sampling location. A suggested number of points is 9 or 16. These allow for a square grid with a regular interval spacing while at the same time keeping the number of observation points to an acceptable minimum. The square grid is important if bias due to directional orientation is to be minimized.

2) Determine the interval spacing between observation points. A suggested spacing is 50 m. The interval distance used may vary but if the spacing is too small, intermediate and long range variability will be missed. If the interval distance is too large, excessive time will be needed to traverse the area and maintaining a regular grid becomes difficult.

3) Locate the selected Level I sampling location in the field.

4) Lay out a regular grid with the selected number of observation points and the selected interval spacing at the sample location. Randomly select one of the grid observation points and place it at the starting point for laying out the grid. The starting point is the coordinate pair used for selecting the Level I sampling location.

5) Traverse the sampling location and collect the required data elements at each grid observation point.

By using a square grid cluster, the potential bias due to orientation along a regular pattern is avoided. If a corner point of the grid cluster is used as the starting point, the direction of the traverses (i.e. north and east or south and west) must be constant for all of the grid clusters used to locate observation points. This reduces the tendency to sample in preferential areas at each sampling location.

Advantages of the grid cluster sampling scheme are:
a) Once the Level I sampling location has been determined, each observation site can be found quickly and easily if the observation interval is not too large.
b) Inexperienced staff can be trained to sample quickly and easily (Cline 1944).
c) Short range variation of soil properties can be measured and analyzed quickly and easily.

Limitations of the grid cluster sampling scheme are:
a) Each sample point must be individually located in the field. If the grid interval is large this can consume considerable time and also is subject to a bias in final site selection.
b) If the chosen interval spacing corresponds to a regular pattern of soils distribution or a natural landscape pattern, the sample population will be biased towards certain landscape positions and soil types.

Potential modifications to the grid cluster sampling scheme are:
a) Randomly choose the number of observation sites (between 10 and 20) to be investigated at each Level I sampling location. The grid must then be arranged to accommodate each of the observation points.
b) Use a rectangular grid. This is prefered to a square grid if the number of observation points is other than 9 or 16. The regular interval spacing must be maintained, however.

c) Use a triangular grid for the Level II grid clusters (Parkhurst 1984). The advantages and disadvantages of the triangular grid have been explained in the Level I grid sampling section.

d) Randomly choose the interval spacing between observation points or choose a distance other than 50 m. A larger number of observation points will usually have a smaller observation interval.

F.vii. Summary

The production of soil survey map products does not usually require a statistically valid sample data set. What is required is a knowledge of the soils found in an area and the variability of those soils. Earlier, four criteria for selecting a sampling strategy for map production were described. The first, knowledge of the end use or objective of the survey, is usually met before sampling schemes are even considered. The other three criteria can be met by most of the described sampling schemes.

The most common objective of soil surveys is to produce a soil map for a variety of users. General knowledge of the soils and their variability is needed by the users in order to make informed decisions and interpretations about the appropriate landuse. The sampling strategies which best enable the surveyor to provide this information while at the same time meeting the described criteria are:

Level I - purposive sampling; and

Level II - individual points.

Purposive sampling is the cheapest and fastest way for the soil surveyor to determine the pattern of soil variation in a study area and to either confirm or reject a hypothesis of what soils are expected in a landscape unit. Individual points are recommended because they are a fast and efficient method of determining soil variability when statistically valid estimates are not needed.

In cases where statistically valid estimates are needed, the objective of the survey must be known and the appropriate sampling strategy selected. Random sampling, grid sampling, and nested sampling are all statistically valid Level I procedures but each has its own unique uses, advantages, and disadvantages. The appropriate strategy must be based on these.

As mentioned earlier, not all sampling strategies will satisfy the criteria for effective sampling when conducting a map reliability study. Some of the sampling methods outlined here are more rigorous than others, while some may not be practical in terms of time and cost requirements. The most appropriate sampling scheme will depend on the final objective of the study. Based on the advantages and disadvantages of each sampling method, it is concluded that the following be used for evaluating maps:

Level I - random sampling; and

Level II - radial arm transects.

The potential modifications listed for each sampling method may or may not be applied without losing statistical rigor or validity. Individual projects must be assessed for the need to modify the sampling scheme prior to selecting the sampling locations and observation points. Prestratification may be used with the Level I sampling strategy if required in light of the identified objectives of the study (i.e. evaluation of the overall map, a specific map unit, or an individual polygon).

The number of samples needed for each of these objectives will be different and must be determined for each study project. Selection of an appropriate sample size may be based on the earlier recommendations or can be made using equation (1).

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PART 2:
OPTIONS AND RATIONALE FOR NEW MAPPING SYSTEMS

III.A. OPTIONS FOR MAPPING AND MAP COMPARISON

- R.A. MacMillan

A.i. Introduction

This section presents a discussion of a variety of options proposed for increasing the rate of production of soil inventory products in Alberta and for evaluating the utility and accuracy of the maps produced by different methods. The material is organized into two parts.

The first part of the discussion presents a number of options with potential for increasing the rate of production of soil inventory products in Alberta. The options are listed in tabular format (Table 3.1) and their essential characteristics are briefly described using a standard template. The principal characteristics, advantages, disadvantages, resource requirements and material constraints associated with all of the methods are summarized in an overview table (Table 3.2).

The second part of the discussion presents a number of options for measuring the utility and predictive capacity of soil inventory products created using any of the proposed methods of mapping. The options are listed in tabular format (Table 3.3) and described using standard template which is different from that used to describe the methods of mapping. A summary table (Table 3.4) presents an overview of the principal characteristics, advantages, disadvantages, resource requirements and material constraints associated with each of the proposed methods.

The methods proposed for evaluating the 'quality' of maps and legends produced by each of the methods address two general considerations. First, methods are proposed to facilitate an analysis of whether the maps and legends contain the kinds of information required for the main anticipated uses and whether this information is described with the precision required for the envisaged uses. Both precision in the description of attribute values and classes and precision in the delineation of spatial location are considered. Second, methods are proposed for assessing the reliability of the maps and legends in terms of their 'predictive accuracy'. These methods are meant to provide measures of overall map accuracy as well as predictive accuracy of specific major map units.

Emphasis is placed on identifying methods that can provide a single, easily understood numerical value for predictive accuracy so as to facilitate a relative comparison and ranking of maps produced by the various alternative mapping methods.

A.ii. Options for Mapping in Alberta

Ten different methods (Table 3.1) have been proposed as options for mapping soils at a level approximately equivalent to SIL3. The different proposals are based on consideration of the forgoing literature review in combination with the practical field experience of the group of individuals involved in the production of this report. The options are not exhaustive but are representative of the range of possible approaches to regional mapping that have been attempted elsewhere or that are judged to be feasible.

Table 3.1 List of options for regional mapping of soils in Alberta.

No	Option	Description
1.	Conventional soil survey**	Continue to map as at present.
2.	Top-down bench exercise	Apply formal rules for top-down stratification in combination with bottom-up agglomeration using all available data on soils, geology, physiography, etc. to delineate and characterize SIL3 polygon units.
3.	ERSSUM	Re-interpret area to standard legend using existing data including assessment data and limited field work.
4.	Extrapolatory mapping	Use detailed mapping to build and test legend models then apply to adjacent areas with little extra field verification.
5.	Landscape characterization	Build soil-landscape model by detailed mapping in parts of each distinctive type of landscape then apply models to remainder of each area with only limited field checking.
6.	Top-down with hi-tech	Apply formal rules for top-down stratification in combination with bottom-up agglomeration using high resolution DEM and RS data and all available data on soils, geology, physiography etc to delineate & characterize SIL3 polygon units.
7.	3 Stage random transect	Similar to present SIL3 mapping except use 1st set of transects to build map unit models, 2nd as sampling strategy to test and refine models for selected pre-typed MU polygons, 3rd to test final map for accuracy.
8.	No-series landscape mapping	Apply formal rules for top-down stratification. Sample a few representative polygons from each pre-typed class to establish the full range of soil properties (drainage, texture). Describe as such with no reference to series names.
9.	Grid cell mapping	Define cells of fixed dimensions, physically visit and record soil for each cell or visit 'training cells' and build models to predict soils at unvisited cells from data and properties easily obtained for all cells.
10.	Single property interpolation	Determine and select 'most important' individual soil properties. Sample on predefined pattern then interpolate individual properties to fixed grid.

**Denotes that this approach is not described in detail in the text with a template description. A detailed description is found in Section II.

Table 3.2 Comparison of mapping options.*

	Option No.									
RATIONALE	1	2	3	4	5	6	7	8	9	10
Uses existing information[a]	2	3	2	2	2	3	2	2	3	1
Limits field checking	no	yes	yes	yes	yes	yes	no	yes	yes	no
Type of mapping rules[b]	2	1	3	3	4	4	1	3	1	4
Focuses on landscape	yes	yes	yes	yes	yes	yes	yes	yes	no[c]	no
Uses digital data and/or processing	no	no	no	no	no	yes	no	no	yes	yes
Type of sampling[d]	P	P	P	P	P,T	P	T	P	G	G
Thematic maps	no	no	no	no	no	no	no	no	no	yes
Uses series names	yes	yes	yes	yes	yes	yes	yes	no	yes	no
METHODS USED										
Top down approach	no	yes	yes	yes	yes	yes	yes	yes	no	no
Develops landscape models	yes	yes	yes	yes	yes	yes	yes	yes	no	no
Apply models by API	yes	yes	yes	yes	yes	no	yes	yes	yes	no
Type of legend utilized [e]	C	C	C	C	C	C	C	O	O	N
RESOURCES										
Human[f]	1	1,2	2	1,3	2	1,2,4	1,2	1	1,4	1,4
Field (days / township)	6-10	1	3-5	2-4	4-5	1-2	6-10	2-4	1-2	5-10
Office (days / township)[g]	10	2-4	5	10	10	2[c]	12	5	?	?
Materials ($ per township)[h]	e	e	add 150	less 75	e	add 250	e	e	add 250	e
Capital equipment	no	no	no	no	no	yes	no	no	yes	yes
Laboratory support	no	no	no	no	no	no	no	no	no	yes
Relative speed (compared to 1:50 000)	n/a	6 to 10x	2x	2x	2x	5x	0.9x	3x	n/e	n/e

Products vs 1:50 000	n/a	same	same	same	same	same	same	diff.	diff.	diff.
Advantages vs 1:50 000[i]	n/a	2	2	2	2	1	1	2	3	1
Disadvantages vs 1:50 000[j]	n/a	none	1,7	2,6,7	8	2	7,9	5	3,2	4

* see codes on following page

Key to codes used in Table 3.2

a Utilizes existing information

1	slightly
2	moderately
3	highly

b Type of mapping rules

1	rigid and formal
3	flexible and adhoc
2	flexible and formal
4	adhoc

c In a local context only

d Type of sampling

P	purposive
G	grid
T	transect

e Type of legend

C	closed
O	open
N	no legend

f Human resources

1	junior mapper
2	senior mapper
3	senior mapper with knowledge of the geographic area
4	computer programmer

g Initially would take more time

h Same as previous SIL3 1:50 000 mapping projects

i Advantages

1	defines precision and accuracy
2	increased speed
3	easily automated

j Disadvantages

1	less precise and accurate
2	more general
3	grids, not polygons
4	isopach type maps
5	no series names
6	requires senior mapper with experience in the geographic region
7	poor recognition of some soils
8	logistical problems
9	slower mapping speed

A.iii. Detailed Descriptions of Mapping Options Presented

Option 1. Conventional Soil Survey

As described in part 1 literature review (section II C.i.).

Option 2. Top-down Bench Exercise

2.1 Rationale

The soil survey process can be made faster and more consistent by adopting a formalized 'top-down' approach to stratification of landscapes.

2.2 Theory and assumptions

The top-down method assumes that identifiable environmental factors exercise control on the formation and distribution of soils and that this control is reflected to varying degrees at various scales. It is assumed that a formalized methodology for hierarchical subdivision of Alberta into successively smaller segments based on the known spatial pattern of these environmental variables will result in more rapid production of better and more consistent maps of soil and land properties. Climate is assumed to be a major influence at all scales and to be the dominant influence at the largest (regional) scale. Initial subdivision of Alberta into regional strata based on climate (Soil Correlation Areas (SCA's)) provides the best means for restricting the expected range of soil types and soil properties. It is assumed that further subdivision on the basis of gross physiography will further restrict the range of intrinsic soil properties and associated sub-regional climate for smaller mappable areas (Agroecological Resource Areas (ARA's) or Soil/Land Districts (SLD's)). It is assumed that further subdivision (of SLD's into Soil/Land Systems (SLS's)) based on a combination of geological, hydrogeological, topographical and biological factors can be achieved using available information sources and that this subdivision will further restrict the range of soil properties and soil types expected in any given area. It is assumed that this formal subdivision to the level of SLS's will make further subdivision to the level of SIL3 polygons faster, more consistent, more reproducible and more understandable. It is further assumed that the range of types of soil and kinds of landforms to be expected within any given SLS will be so limited as to prove very helpful in delineating and labelling SIL3 polygons.

2.3 Procedure / methodology

1. Subdivide Alberta into areas of more or less uniform regional climate as expressed by vegetation and gross physiography (SCA's).

2. Subdivide SCA's into Soil/Land Districts (SLD's) on the basis of gross physiography according to physiographic districts as portrayed on the map Physiographic Subdivisions of Alberta (Pettapiece 1986).

3. Subdivide SLD's into Soil/Land Systems (SLS's)based on a combination of surficial and bedrock geology; regional hydrogeology; local topography and drainage; and natural vegetation or dominant land use in areas where the natural vegetation has been disturbed by man.

4. Subdivide SLS's into SIL3 polygons (proposed name Soil/Land Types= SLT's) based primarily on consideration of readily visible patterns of topography and drainage with additional consideration given to recognizable but unmappable inclusions of soils of varying texture; salinity; degree of development or erosion; and degree of development of solonetzic features. Use available information sources (i.e. assessment data, existing soil maps) where ever possible to assist in recognition of patterns of salinity, erosion, solonetz and wetness.

2.4 Differences from traditional SIL3 mapping

1. Operational differences: The top-down procedure described above generally reflects activities undertaken as part of any given recent SIL3 soil survey. The main difference is that the procedure is formalized and that the hierarchy of subdivision is made explicit. Formal criteria are proposed for definition and delineation of entities at each level in the hierarchy. Valid scientific and practical reasons are provided for the criteria adopted to define each level of the hierarchy. Justification is also provided for recognition of each of the hierarchical levels. The top-down procedure places greater emphasis on the use and knowledgeable interpretation of available information sources than traditionally used for conventional soil survey. More time and effort would be expended in office compilation of existing data and in interpretation of the data to aid in delineation of formally defined units of stratification. Less time and effort would be allocated to field validation of models or field examination of differences in subsoil properties.

2. Product differences: The top-down product would include maps of the area presented at different scales for each of SCA's, SLD's, SLS's and SLT's. The products would reflect and illustrate the various hierarchical classifications. The lowest mapped level of stratification (SLT's) would probably not be described as precisely and mapped in as much spatial detail as traditional SIL3 map unit polygons. The level of precision used to describe subsoil attributes not readily identifiable from landscape features observable on air photos would be particularly reduced in comparison to SIL3 polygons.

2.5 Evaluation / critique

The formal methodology of the top-down method is a major advantage in that it provides a consistent set of rules for subdivision and for display and description of areas of land at each level or scale. A consistent methodology leads to a more consistent product. Improved consistency also leads to increased familiarity and ease of use of standard products among soil survey clients. A formally documented theoretical and methodological framework helps mappers to better agree on what they are attempting to do when they map and why they are doing it. An explicit methodology also helps promote the scientific validity and acceptability of the product among end users. Finally, the top-down method places strong emphasis on the multi-disciplinary and inter-disciplinary nature of soil survey and forces mappers and users to recognize and appreciate these inter-relationships. Improved consideration of inter-relationships promotes better appreciation of the linkages between environmental factors and patterns of soil distribution and can lead to better mapping models and better maps.

One disadvantage of the top-down approach is that formal rules reduce the flexibility often required to respond to unexpected or previously unknown conditions. The method promotes a tendency to rigidly impose boundaries from a higher level onto strata mapped at a lower level. This 'cookie cutter' approach needs to be avoided. Boundaries defined at higher levels in the hierarchy need to be adjusted to fit the more detailed information available at the larger scales associated with lower level strata. Rigid adherence to the rules of stratification can lead to situations in which very similar soil/landscape entities will be identified differently if they occur in areas differentiated at a higher level in the hierarchy. It may be necessary, at lower levels in the hierarchy, to relax the rules of stratification to permit the same labels to be applied to entities located within two or more higher level strata.

2.6 Resources required

1. Human Resources: Requires a one time investment of effort by a collection of the most experienced mappers available to describe, review, accept and document the formal methodology and to apply it for the entire province of Alberta down to the level of Soil/Land Districts. This would need to be a collective effort over a period of 6 months to 1 year. Consistent application of the method for operational use would require that all field mappers undergo a period of formal training (or indoctrination) in the methodology. All would need to be able to operate from a minimum knowledge base that permitted them to fully appreciate both the method and the significance of the various data sources utilized by the method. Once trained, it is expected that the shared perception of methods and rationale would lead to faster, better and more consistent mapping.

2. Field Resources: Requires no additional field resources or equipment. Could benefit from hard copy or digital satellite imagery and digital elevation data, but these are not mandatory. Reduced level of field inspection translates into reduced requirements for vehicles, field accommodation, or subsistence allowances. Rate of progress of SIL3 mapping is dependant on the strategy selected for SIL3 legend development and field verification. Field time may be expected to range from present norms (6-10 days per twp) to significantly increased rates of map production (1 day per twp).

3. Material Resources: The method would require the development of a mapping methods manual accompanied by a series of maps defining the extent and describing the major higher level strata (SCA's = done, SLD's = needs to be done, SLS's = done in conjunction with individual projects as they are conducted). No other material resources are mandatory although satellite imagery, digital elevation data and equipment to process and display this data would be desirable.

Option 3. Experimental Reconnaissance Soil Survey Update Method (ERSSUM)

3.1. Rationale

In areas where there is already a considerable amount of soil information, it makes sense to utilize this information to speed up mapping. Rates of progress associated with conventional soil mapping can be increased by maximizing the use of existing information and minimizing the amount of time spent in checking soil types and properties in the field.

3.2. Theory and assumptions

The method makes the standard assumptions that there is a strong and consistent relationship between soils and landscapes and that delineation of landscapes is the most effective way to differentiate soils. An additional assumption is that existing soils information, from a variety of sources, can supplement, or even replace, field inspections as a vehicle for testing map unit concepts and for characterizing the composition of delineated soil landscape units. A final assumption is that small investments of time in collecting, collating and plotting existing soils information can translate into large savings in time by reducing the field effort required to delineate, characterize and describe soil landscape areas.

3.3. Procedure / methodology

1. Apply a typical top-down approach, based on existing sources of regional information about climate, physiography, vegetation, geology, hydrology and soils to sub-divide the landscape into entities approximately equivalent to ELC land systems.

2. Develop conceptual models of soil landscape relationships through review of information from existing older soil surveys and from modern surveys in the same region.

3. Apply the soil landscape models, via standard techniques for air photo interpretation, to delineate soil-landscape segments by determining the locations for initial boundaries for SIL3 soil map units on 1:30 000 scale B&W air photos.

4. Use non-conventional sources of soils information to assist in identifying and describing soil-landscape segments delineated on the aerial photographs. The information sources will include erosion and land use survey data for the municipality and farmland assessment information about soils.

5. Conduct field checking to verify, by visual inspection, the polygon boundaries delineated using air photo interpretation and to test the soil-landscape models by digging soil pits at a frequency of about one observation site per section.

6. Finalize polygon boundaries, map unit symbols and descriptions of map units and compile as final map and report.

3.4. Differences from traditional SIL3 mapping

1. Operational differences: Initial steps in the ERSSUM procedure do not differ significantly from those of conventional SIL3 soil mapping (i.e. develop and apply soil-landscape models using air photo interpretation of observable soil-landscape relationships and review of existing soils and natural resource information). The ERSSUM approach required about one week of field time per township for the actual mapping component and close to two weeks per township when all other preparatory and completion activities (i.e. digitizing, drafting, documentation, editing) were taken into account. Turchenek et al. (1990) report this rate to be about twice as fast as conventional SIL3 1:50 000 mapping.

2. Product differences: The maps appear similar to conventional SIL3 soil survey maps. Application of the ERSSUM resulted in achieving about 70% of the reliability and 80% of the precision of a product obtained by conventional 1:50 000 methodology. However, it is considerably more detailed than the 1:190 000 reconnaissance products currently available.

3.5. Evaluation / critique

In applying ERSSUM, difficulty was encountered mainly in recognizing areas of Solonetzic soils, differentiating types of poorly drained (Gleysolic) soils, determining proportions of thick Black versus thin Black soils, and recognizing some types of parent materials such as thin eolian veneers. Examination of soils information from existing maps, municipal affairs assessment records and MD conservation surveys was determined to be helpful in delineating and describing soil landscape units and in speeding up mapping by up to 50%.

3.6. Resources required

3. Human resources: requires skilled field soil surveyors to assimilate existing information, produce initial soil-landscape models and apply the models through the interpretation of air photos and ancillary information. Probably requires a greater degree of experience and confidence in air photo interpretation of soil-landscape models than could be expected from junior mappers or from any mapper unfamiliar with a particular area and its particular soil-landscape patterns.

2. Field resources: estimated reduction in field survey component is 50%. Additional time required to collect, collate, plot, assimilate and use the additional data sources is 1-2 days per township or 10-20% assuming a 5 day per township rate.

3. Material resources: additional costs associated with reproducing, collating and plotting existing assessment and conservation data were not recorded. Much of this could be done by technical or summer student personnel. Supply and service costs might run $100-$200 per township for xeroxing and plotting existing data. Material costs would otherwise be comparable to conventional soil mapping.

Option 4. Forty Mile Extrapolatory Approach

4.1. Rationale

The soil survey process can be accelerated by applying systematic procedures to develop soil-landscape models in selected representative areas. These models can subsequently be extrapolated to adjacent areas of similar landscapes. Time consuming pedon investigations are reduced and are supplanted by visual confirmation of landscape attributes and boundaries.

4.2. Theory and assumptions

The extrapolatory method makes the standard assumptions that there is a strong and consistent relationship between soils and landscapes and that delineation of landscapes is the most effective way to differentiate soils. Successful sub-division to the level of land systems relies on a systematic procedure for top-down stratification of the overall area into 'mapping districts'. Mapping districts are landscapes with a characteristic 'signature' or pattern that is recognizable both on imagery and on the ground. It is assumed that the development of a thorough understanding of soil-landscape relationships, expressed as models of map unit concepts, can be achieved through detailed legend building and mapping in a limited number of representative areas. Once developed, these models can be extrapolated to adjacent areas of similar landscapes using a much lower intensity of time-consuming ground truth observation. The model hypotheses represent an enhancement of the knowledge base founded on an analysis of previous data and observations combined with pedologist inference developed from an examination of landscape patterns. The hypotheses can be applied with confidence to adjacent portions of 'mapping districts'.

4.3. Procedure / methodology

1. Apply a typical top-down approach to sub-divide the area into 'mapping districts' on the basis of existing environmental information in combination with the pedologist's familiarity with the region.
2. Develop conceptual models of soil-landscape relationships through review of information from existing, older surveys and air photo interpretation.
3. Select 'representative' areas within 'mapping districts' to test and revise initial map unit concepts.
4. Conduct conventional SIL3 mapping of selected 'representative' areas and revise map unit concepts and legend accordingly.
5. Finalize and adopt working legend and soil-landscape map unit concepts.
6. Apply the soil-landscape models to extrapolatory areas to delineate strongly and moderately contrasting soil map units (SIL3 map unit polygons).
7. Assign initial map unit symbols to all polygons in extrapolatory areas and develop initial descriptions for these map units.
8. Identify weakly contrasting and problematic soil map units for special attention during field verification in extrapolatory areas.
9. Drive all road allowances in extrapolatory area to verify map unit boundaries and field test legend concepts (< 20 pedon investigations or catenary sequence transects per twp, some only examine surface texture, depth of Ah, or degree of solonetzic development).
10. Write notes directly on the working map/photo to comment on validity of lines, topographic classes and other observed features (salinity, stones).
11. Finalization of polygon boundaries, map unit names and map unit descriptions from air photo interpretation and field verification (takes place in office during and after field season).

4.4. Differences from traditional SIL3 mapping

1. Operational differences: Extrapolatory mapping proceeds at a faster rate of progress than conventional level 3 soil survey (2-4 days/twp vs 6-10 days for conventional). Field site examination is reduced from about 90-150 sites per twp to less than 20 sites in extrapolatory townships. Extrapolatory mapping conducts correlation and edge matching concurrently with air photo interpretation and field verification.

2. Product differences: The final product of the extrapolatory method would be very similar in appearance to conventional SIL3 soil survey maps. Map unit descriptions may be more general than for conventional maps (i.e. inclusions of soils described by characteristic (i.e. coarse) rather than by series name and proportions). Method may not be able to recognize and delineate some 'weakly contrasting' areas (i.e. areas with sub-surface characteristics that are weakly related to surface expression or other external clues).

4.5. Evaluation / critique

The extrapolatory method permits mapping to progress rapidly over large areas. One senior mapper is responsible for checking and finalizing map unit boundaries. This has an advantage in maintaining more consistent mapping concepts and achieving better correlation. The method works well and makes maximum use of existing soils knowledge where this knowledge is available (i.e. well defined soil correlation areas). A disadvantage of the method is that it is dependent upon the availability of a senior soil mapper with extensive familiarity of the regional soils and landscapes. Difficulties sometimes arise in accommodating the need to simultaneously complete both office air photo interpretation and ground truthing. Scheduling activities can be difficult. The limited amount of pedon investigations may result in not detecting areas that have sub-soil changes not reflected by landscape characteristics visible on air photos.

4.6. Resources required

1. Human resources: The extrapolatory method requires the availability of a senior mapper with extensive regional experience. The method makes effective use of junior mappers who can make a useful contribution from the start of mapping.

2. Field resources: Field resources are similar to conventional mapping but the rate of progress is faster. An increase in mapping rate of approximately 50% is achieved, reducing field resource requirements accordingly.

3. Material resources: The method requires no additional material resources relative to conventional soil mapping. In fact, material resources are reduced. Township enlargements are not used for mapping the extrapolatory townships. Instead mapping is done exclusively on working air photographs. As with conventional mapping, the method anticipates using a GIS system to digitize for final publication.

Option 5. Landscape Characterization

5.1. Rationale

An individual mapper will be able to describe and delineate an entire landscape faster, with more confidence, and with fewer soil profile observations if he is able to view the area as a whole.

5.2. Theory and assumptions

A landscape (i.e. an area of hummocky moraine) is composed of a set of unique mapping units. Each mapping unit consists of a repeating pattern of soils and landforms. It is assumed that if one surveyor has responsibility for an entire landscape, he will be able to better recognize and characterize the variability of the landforms and soils. When the full range of variability within a landscape is known and understood, delineation of a landscape into unique mapping units of similar polygons can be done faster and with more confidence. The mapper will also be more consistent in the delineation of the landscape and in the application of map unit names to the polygons. The correlator should find that little effort is required to ensure uniformity within landscapes and less time is needed to check and verify map unit concepts. The main job of the correlator will be to ensure that boundaries between the separate landscapes are correctly placed and that legend design and control is consistent between the surveyors involved in the project.

5.3. Procedure / methodology

1. Delineate the mapping area into unique landscapes according to the top-down approach to soil survey.

2. Assign the landscape units equally among the surveyors involved in the project.

3. Office photointerpretation of each landscape and description of preliminary mapping units using available information such as surficial geology maps, previous surveys, etc. using the top-down approach.
4. Collection of field data through a combination of transects and random observations.
5. Characterization of the mapping units within each landscape using the feedback approach. Integration of field data and previously derived information (mapping option 5.3, step 3).
6. Finalization of polygon boundaries, map unit names and map unit descriptions.
7. Correlation of the landscape boundaries.
8. Each surveyor to write a brief description (< one page per landscape) of the landscape mapped.
9. Compilation of the final map product.

5.4. Differences from traditional SIL3 mapping

1. Operational: the landscape system of mapping requires less time in the field for data collection and less time is required for correlation of the project area. Average soil profile observation density is approximately 1 per 250 ha.
2. Product: the final product of the landscape system of mapping will not differ from the traditional SIL3 product. The final product will still consist of a soil report and maps.

5.5. Evaluation / critique

The landscape system of mapping works very well. The only difficulty occurs when a landscape covers several field sheets and two separate mappers need the same field sheet. The suggested solution is to produce field sheets based on the landscape units outlined in mapping option 5.3, step 1, rather than on the traditional township by township grid.

5.6. Resources

1. Human resources: skilled soil surveyors capable of recognizing and delineating unique soil mapping units composed of uniform soil and landform characteristics.

2. Field resources: the equipment necessary to carry out a traditional soil survey program. Field time required is estimated to be 4-5 days per township equivalent area.

3. Material resources: similar to those used in traditional SIL3 mapping projects. Field sheets produced on a landscape basis rather than on a township grid.

Option 6. Top Down Stratification with High Tech Component and Feedback

6.1. Rationale

The conventional approach to mapping using top-down stratification can be made more explicit, more consistent and more accurate by operating in a digital environment using available soil and land information, and incorporating into the process high resolution remote sensing (RS) and digital elevation (DEM) data and formal rules by which to use the data.

6.2. Theory and assumptions

Using existing knowledge and available information it is possible to accurately subdivide the landscape to the level of land systems. If made highly explicit and systematic, computer techniques for applying 'rules' for landscape stratification will result in more uniform and consistent delineation of soil landscapes at the level of land systems. Current methods for delineating and describing landscapes, particularly the topography and drainage characteristics of landscapes, can be improved by using available satellite imagery (RS) and elevation data (DEM). RS and DEM offer the possibility of explicitly measuring and predicting topographic and drainage conditions at a high level of spatial resolution in place of the present approach of providing generalized descriptions based on qualitative observations. The high resolution RS and DEM data can be used both to provide a synoptic overview of the area to aid in top-down stratification and to provide detailed site-specific data to aid in 'bottom-up' characterization of landscapes.

6.3. Procedure / methodology

1. Formalize 'rules' for hierarchical top-down stratification of landscapes to the level of land systems and soil map units within land systems (for all of Alberta).

2. Compile, in computer format, all data required to implement the 'rules'.

3. Apply 'rules' to delineate 'first approximation' soil landscape units at the level of land systems and SIL3 map unit polygons.

4. Process RS and DEM terrain data, examine visually, and use to adjust or refine initial 'first approximation' land system and map unit boundaries.

5. Conduct limited field inspections (25-35/twp) and 'drive through' examinations (1-2 days/twp) to verify polygon boundaries and estimates of main included topographic classes, drainage conditions and component soils.

6. Revise and finalize land system and soil map unit boundaries.

7. Use RS and DEM data to measure and characterize the distributions of topographic and drainage classes by defined polygon unit.

8. Retain high resolution, pixel specific, classifications of topography and drainage as 'added benefit' high resolution data base for site specific questions.

9. Revise or add to initial 'rules' to reflect changes and experience arising from current mapping effort.

6.4. Differences from traditional SIL3 mapping

1. Operational differences: Method envisages greatly reduced field effort. Accuracy is improved by directly measuring those elements of a traditional soil survey that are directly measurable from high resolution DEM or RS data (i.e. topography & drainage) and at least maintained by consistent application of formalized 'rules' for polygon delineation and classification.

2. Product differences: The polygon map product would be similar in appearance to current soil survey maps. It would likely have larger, more generalized polygonal map units than present maps. The topography and drainage of these polygonal entities would be characterized much more completely than in present map units. The assemblage of soils in each map unit would still be described in terms of proportions of major included soil series with three dimensional or cross sectional diagrams used to illustrate the relative locations in the landscape most frequently occupied by each soil.

6.5. Evaluation / critique

This approach has not yet been tried for operational survey either in Alberta or elsewhere in Canada. It seems reasonable that we should take advantage of recent advances in techniques for the acquisition of data that enable us to measure directly, and at a high spatial resolution, several aspects of the landscape that, until now, we have been only able to observe manually and incorporate into generalized, qualitative descriptions of recurring spatial patterns (i.e. topography and drainage). The adoption of formalized 'rules' and their systematic application in a computerized environment offers some promise for increased consistency and therefore improved maps. Opportunities also exist for discovering improvements or advances that cannot presently even be envisaged (i.e. automated techniques for feature extraction, pattern recognition and rule development).

6.6. Resources required

1. Human resources: requirements would change initially to demand a higher level of computer skills and training in image analysis, digital elevation modelling than currently available. Once the procedures were proven and established, it is possible that systematic application of fixed rules and procedures might require less soils or computer expertise than current mapping approaches. We would need a period of research, learning and training to adopt the high tech approach but I believe current staff can be trained to implement the new procedures.

2. Field resources: expect that resources for field activity could be reduced by 50 to 75% (i.e. 1-2 days per township). Field checking would require personnel at least as skilled and knowledgeable as for conventional SIL3 soil survey mapping.

3. Material resources: additional costs would be associated with purchasing RS and DEM data (estimated at $100 and $150 respectively per twp). Processing of RS and DEM data would either require capital expenditures on the order of $50,000 for hardware and software purchase or service expenditures of perhaps $5-10,000 per county for contracted processing of RS and DEM data. Increased costs for digital data and processing facilities are less that the savings realize through reduced field mapping component.

Option 7. Three Stage Random Transect Mapping

7.1. Rationale

Stratified random transects are more efficient than conventional methods of soil survey for: a) building initial soil-landscape concepts; b) collecting field data to test concepts and describe map unit composition; c) testing of degree of correspondence between the soil legend and the final soil map.

7.2. Theory and assumptions

The method makes the standard assumptions that there is a strong and consistent relationship between soils and landscapes and that delineation of landscapes is the most effective way to differentiate soils. It departs from conventional methods of soil survey in the assumption that stratified random transects are a more effective and more rapid way of collecting ground truth information than traditional purposive sampling. It assumes that similar soil landscapes can be recognized and delineated by a competent soil surveyor. The method further assumes that all individual landscape delineations may exhibit the full range of soil components and soil properties characteristic of the unit. Additionally, a random selection of transects is assumed to be the best method for collecting unbiased observations and samples to permit a quantitative evaluation of the proportions of soils occurring in the map unit and of the range of soil properties characteristic of the map unit. Finally, it is assumed a few random transects across a limited number of map unit delineations will properly characterize other delineations of the same map unit containing no field observations of any kind. It is claimed that the total number of field inspections and the total amount of field time can be reduced if all field activity utilizes the random transect approach and purposive sampling is abandoned.

7.3. Procedure / methodology

1. Apply a typical top-down approach, based on existing sources of regional information about climate, physiography, vegetation, geology, hydrology and soils to sub-divide the landscape into entities approximately equivalent to ELC land systems.

2. Develop, revise and finalize conceptual models of soil-landscape relationships (i.e. the working legend) by field application of the random transect method to sample and describe initial soil-landscape delineations.

3. Apply the soil landscape models defined via mapping option 7.3, step 2 transect sampling. Use standard techniques for air photo interpretation to delineate soil-landscape segments by determining the locations for initial boundaries for SIL3 soil map units on 1:30 000 scale B&W air photos.

4. Use a second stage of transects to sample a random selection of polygons for each major map unit. Use the results to modify map unit descriptions or adjust concepts and rules for the placement of boundaries as the survey progresses.

5. Produce a final map of polygon boundaries and map unit symbols and a final legend of descriptions of map units based on mapping option 7.3, step 4 transect sampling.

6. Conduct a third stage of transect sampling to assess the accuracy of the final soil map and legend. Do not change the map or legend based on this data. It is to be used only to record and present information on the tested degree of correspondence between the final legend and the final map.

7.4. Differences from traditional SIL3 mapping

1. Operational differences: Initial steps in the three stage transect approach to mapping differ only slightly from those of conventional SIL3 soil mapping. The main difference is the use of a systematic unbiased procedure (transecting) for building soil-landscape models and determining the composition and characteristics of soil landscape units. A major difference occurs during operational mapping when a limited number of transects in randomly selected delineations replaces regular, systematic purposive sampling as the vehicle for testing, refining and applying map unit concepts. With random transects, large regions of the map area may never be visited or examined. Transect mapping will require about as much field effort as conventional mapping and will collect about the same number of field observations. The main difference is that the observations will not be regularly spaced over the entire area but will be clustered along transects through selected map units.

2. Product differences: The map and legend produced from transect mapping will look similar to a conventional soil survey map. The main difference will be that statements of the proportions of soils present in any tested map unit will be quantitative and of known accuracy and precision. The legend will be superior because increased confidence can be placed in the estimates of soil proportions and soil properties reported for each map unit. It is likely that differences in sub-soil

properties not easily inferred from external landscape features will not be differentiated as well or as often as in conventional maps where comprehensive site investigations will usually uncover and map initially unsuspected sub-soil differences.

7.5. Evaluation / critique

The main advantage of the transect method is that it is systematic and produces quantifiable, and testable, descriptions of the composition and characteristics of map units. The formalized field procedures impose a certain consistency to mapping that is harder to realize in conventional approaches. The transect method offers the possibility of utilizing less experienced personnel to collect the field observations, since less expert judgement is exercised in determining where to examine the soil to build or test map unit concepts. The rigor of the method offers several advantages for training mappers to observe and appreciate soil-landscape relationships and thus become better mappers. There have been claims that transect mapping can be made faster than conventional mapping by reducing the number of field observations once it is determined that map units have been well quantified by initial transect samples. Experience to date has been that transect mapping takes more time and requires more effort. This may be because most efforts to date have been experimental and haven't settled into a comfortable production mode that builds on past experience. A major criticism of the transect method is that it precludes making systematic observations in a regular pattern throughout the entire area and so is bound to result in 'missing' certain changes in sub-soil properties than can only be detected through direct observation (digging out). This criticism reflects the surveyor's concerns that the soil-landscape relationship is imperfect and cannot be used to predict the likely type and properties of the soil in all cases without some field checking.

7.6. Resources required

1. Human resources: requires skilled soil surveyors to assimilate existing information, develop initial soil-landscape models and apply the models through the interpretation of air photos and ancillary information. Probably requires a greater degree of experience and confidence in air photo interpretation of soil-landscape models than could be expected from junior mappers. Actual field checking may be done with less senior and less experienced personnel.

2. Field resources: No estimate of reduction or increase in field time possible, likely to be similar to current SIL3 rates of progress. Additional office time (1-2 days/twp) required to pre-type landscapes and to prepare and select transects.

3. Material resources: Virtually the same as presently required for conventional mapping (i.e. field equipment, travel costs, air photos, maps). Can be done with existing computer equipment, but ideally would utilize field computers to record observations and compute proportions and confidence levels ($1,000-$2,000 per mapper).

Option 8. Soil Landscape Mapping Model (no series concepts)

8.1. Rationale

It is better and faster to map actual landscape units visible on air photos and to describe them in terms of the observed range of soil and landscape properties than to try to describe map units in terms of the artificial concepts of taxonomic soil series.

8.2. Theory and assumptions

The (no series) soil-landscape method makes the standard assumptions that there is a strong and consistent relationship between soils and landscapes and that delineation of landscapes is the most effective way to differentiate soils. Successful sub-division to the level of land systems relies on a systematic procedure for top-down stratification of the overall area. The method further assumes that the imposition of an artificial (exotic) taxonomic classification complicates and reduces the effectiveness of efforts to describe variation in the landscape (Burrough, 1986). It is assumed that the most effective way to map is to delineate what is mappable and to describe it in terms of the observed range of soil and landscape properties. Soil landscape units may be identified by names and symbols associated with a dominant parent material (i.e. similar to soil associations in Saskatchewan) or may simply be given a numerical identifier patterned after the old soil zone/parent material numbering system.

8.3. Procedure / methodology

1. Apply a typical top-down approach to sub-divide the area into land systems and SIL3 map units on the basis of existing environmental information in combination with the pedologist's familiarity with the region.

2. Develop conceptual models of soil-landscape relationships through review of information from existing, older surveys and air photo interpretation.
3. Select 'representative' areas to test and revise initial map unit concepts and descriptions.
4. Conduct conventional SIL3 mapping of selected 'representative' areas and revise map unit concepts and legend accordingly.
5. Finalize and adopt working legend and soil-landscape map unit concepts.
6. Apply the soil-landscape models to unmapped areas to delineate map units (SIL3 map unit polygons).
7. Assign one of a limited number of symbols to all polygons delineated by air photo interpretation (closed legend) and develop initial descriptions for these map units.
8. Drive all road allowances to verify map unit boundaries and field test legend concepts (< 20 pedon investigations or catenary sequence transects per twp, some only examine surface texture, depth of Ah, or degree of solonetzic development).
9. Write notes directly on the working map/photo to comment on validity of lines, topographic classes and other observed features (salinity, stones).
10. Finalize polygon boundaries, map unit names and map unit descriptions based on air photo interpretation and field verification (takes place in office during and after field season).

8.4. Differences from traditional SIL3 mapping

1. Operational differences: The no-series method involves few operational differences from conventional mapping. The main difference is that soil series names are not used to describe the characteristics and variation of delineated soil-landscape units. This reduces the time and effort required for correlation and permits faster progress. By borrowing ideas for characterizing landscapes from the 'extrapolatory' and 'Rocky View' approaches, it may be possible to reduce field mapping by up to 50% relative to conventional mapping (2-4 days per twp vs 6-10). The method is similar to ELC mapping in that soils would be described in terms of sub-groups on parent materials. Landscape units would be named/identified in terms of a 'zonally normal' soil on a

dominant parent material (i.e. an association) and numerals would be used to identify the kinds of variation within delineated areas that departs from the zonally normal soil.

2. Product differences: The final product of the no-series landscape method would be somewhat different in appearance than conventional SIL3 soil survey maps. Map units would be named and described in terms of the dominant parent material much like associations in Saskatchewan. Variation in degree and type of soil development (i.e. solonetz, saline, gleyed) would be identified by a standard numbering system. The range of texture, drainage status, salinity etc observed within a set of similar soil-landscape units would be described as found for groupings of similar soil landscape units and not in terms of named soil series.

8.5. Evaluation / critique

No experience exists on which to base an evaluation of this method. The advantage of dropping soil series as the vehicle used to describe and interpret soil-landscape based map units is that variation can be described as found instead of in terms of artificial conceptual entities with prefixed definitions. The full range of variation could be described. Users would be less likely to assume or demand a level of homogeneity within map units that is implied by describing them in terms of soil series but which is precluded by natural variation. There are numerous disadvantages with not using soil series. Many soil survey clients have adopted series as their standard for describing and interpreting soils. They would find lacking any map that did not identify soil series. Internally, the use of named soil series is a prime component of the correlation process used to ensure consistency in mapping and interpretation of soils in Alberta.

8.6. Resources required

1. Human resources: The no-series soil-landscape method requires field mappers with a good understanding of soil-landscape relationships and good skill in air photo interpretation.

2. Field resources: Field resources are similar to conventional mapping but the rate of progress could be faster. An increase in mapping rate of 20-50% is anticipated.

3. Material resources: The method requires no additional material resources relative to conventional soil mapping.

Option 9. Grid or Raster Cell Mapping with No Soil-landscape Units

9.1. Rationale

Reporting of the types and characteristics of soil according to some regular, systematic decomposition of the map area could be faster and more effective than the present approach of describing soil distributions in terms of soil-landscape units. Map units based on concepts of soil-landscape associations are imperfect, difficult to determine and describe and not relevant for many users.

9.2. Theory and assumptions

The grid method assumes that using soil-landscape units is an ineffective and undesirable way of partitioning and describing the distribution of soils in an area. The corresponding assumption is that it is more effective and more economical to describe the distribution of soils in terms of the kinds and proportions of soils located within arbitrarily defined regular cells or grids. An assumption retained from conventional mapping is that the soil series is the most useful and convenient vehicle for describing the entire range of soil properties found at a particular location and for interpreting the likely behavior and utility of the soil at a site. An implicit assumption is that users may find a soil map based on a regular decomposition of space more useful than one based on irregular areas defined by landscape patterns. This is particularly true if the regular decomposition corresponds to ownership or management units (i.e. 1/4 sections, field blocks).

9.3. Procedure / methodology

1. Subdivide the entire area to be mapped into regular units of fixed dimension (1/4 sections, 100 m grid cells, 10 m cells, whatever).

2. Assemble all existing information about soils, geology, climate, physiography, topography, vegetation and 'rasterize' to the same grid.

3. Build 'rules' to estimate most likely kind of soil (series) in each grid cell based on existing information and knowledge.

4. Conduct limited field checks of individual cells to determine if the actual soil matches the predicted soil.

5. Based on field observations, revise 'rules' for predicting the most likely soil (i.e. use expert systems, statistical classification, fuzzy logic or some other systematic method to formalize rules).

6. Reapply new rules to predict most likely soil (or soils) for each cell.

7. Interpret or directly measure topographic and drainage conditions for each cell (from air photos, DEM or RS) and report by cellular unit.

8. Publish cell based map in which each cell is described in terms of the main soil (or soils) contained within it and the main landscape features contained within it (i.e. slope, drainage, etc).

9.4. Differences from traditional SIL3 mapping

1. Operational differences: This method is significantly different than conventional soil survey and should require a greatly reduced field effort. Predictions of the most likely soil type for each cell are based primarily on direct use or interpretation of existing information sources. A limited amount of field sampling (1-2 days per twp) by grid cell unit, is recommended to test and revise the rules used to estimate the most likely soil composition of cells. Accuracy is improved for some attributes by explicitly measuring those elements of a traditional soil survey that are directly measurable from high resolution DEM or RS data (i.e. topography & drainage). Field survey could be conducted by relatively junior personnel.

2. Product differences: Grid or cell based maps would be quite different from current soil survey maps but very similar, in many respects, to the current SIDMAP product. They might be prepared to a higher spatial resolution than the current SIDMAP product (i.e. 100 m or even 10 m) but would otherwise appear similar. They would list the name(s) of the main soil (or soils) thought to occur within the parcel and would also list slope and drainage characteristics. Interpretations would be based on consideration of the modal properties of the named soil(s) along with the recorded topographic and landscape (drainage) characteristics. The product would be most amenable to distribution and use in electronic form (GIS). Determining and assigning a scale to the product would be more problematic than for current polygon maps. Scale would probably be reflected by grid cell size and would be determined by how successfully predictions could be made at any given cell size.

9.5. Evaluation / critique

A grid cell approach has not yet been tried for operational survey either in Alberta or elsewhere in Canada. A parallel exists with the SIDMAP data base, but SIDMAP represents an after-the-fact compilation of soils data for delivery and analysis rather than reflecting an initial decision to map in this manner. An advantage of the grid cell approach is that it very easily accommodates automation in both the production phase and the end use phase. It is easy to envisage the development of a systematic procedure for producing grid cell maps automatically. The procedure could adopt some formal system for producing 'rules' for automatically classifying grid cells based on existing data and knowledge supplemented by new 'training site' data collected in the field. The rules could be heuristic or statistical and could be applied using GIS and boolean or fuzzy logic, mathematical formula (Discriminant analysis, maximum likelihood) or expert systems. Quantification of the accuracy of grid maps would be easier and more straight-forward than for current polygon maps. A disadvantage of grid mapping is that it is not well suited to the spatial generalization of individual cell data into areal descriptions of repeating patterns of landforms (i.e. landscapes). The generalized entities useful for understanding and interpreting landscape patterns on a regional scale would be difficult to produce using this method.

9.6. Resources required

1. Human resources: Personnel would have to acquire a higher level of computer expertise than currently present in order to collect, prepare and process the grid data to predict likely soil types. It is possible that, once a formalized procedure was in place, much of the computer work could be done routinely by suitably trained technical personnel. Field sampling could be done by junior personnel because there is no need for field surveyors to develop and apply complex models of soil landscape relationships. All that is required is the collection of a series of observations and measurements at predetermined grid cell locations.

2. Field resources: expect that resources required for field activity could be reduced by 75% (i.e. down to 1-2 days per township). Field checking and data collection would require only suitably trained junior personnel.

3. Material resources: If we assume that grid mapping would be done using computer processing to merge data and predict the most likely soil(s) automatically, there

would be a requirement to procure appropriate software and hardware. No clear idea of costs is possible but a rough estimate might be in the range of $50,000 to $100,000 to develop or purchase appropriate software and the hardware to run it on. Additional costs would be associated with purchasing RS and DEM data (estimated at $100 and $150 respectively per twp) if these data sources were included in the design. Increased costs for digital data and processing facilities would likely be recovered by savings realize through a reduction in field mapping expenditures.

Option 10. Thematic Mapping and Interpolation of Individual Soil Properties

10.1. Rationale

Users might find single thematic maps of individual soil or landscape properties more useful that the current soil survey choropleth maps in which all soil and landscape properties are described in terms of a single set of map unit polygons based on concepts of soil-landscape relationships.

10.2. Theory and assumptions

The single property (thematic) method of mapping assumes that it is more effective and more economical to describe the distribution of individual soil or landscape properties by sampling specific properties at specific locations and then using some method of interpolation to estimate the value of each property at all unknown locations. An implicit assumption is that using soil-landscape units is an ineffective and undesirable way of partitioning the landscape and describing the distribution of soils in an area. A further implicit assumption is that the use of soil series as a vehicle for conveying information about a whole range of soil properties is not as effective as describing the observed variation of each individual soil or landscape property. The thematic interpolation method assumes that all information of interest to the user can be expressed as a continuous numerical variable. It further assumes that there is some degree of spatial 'structure' controlling the distribution of each soil property of interest and that this systematic variability can be modelled using a mathematical function and used to interpolate between points of known value.

10.3. Procedure / methodology

1. Identify all soil and landscape properties of interest that can be expressed as continuous numerical variables (i.e. %clay, pH, %slope).

2. Conduct preliminary regional geostatistical sampling and studies to determine which variables exhibit spatial structure and how much of the variation is explained at each of several potential sampling intervals.
3. Fit regional semi-variogram models to each of the numerical variables that exhibits a significant degree of spatial structure over separation distances that are far enough apart to permit cost-effective sampling.
4. Determine the optimum sampling strategy in terms of sample pattern (grid, triangular, irregular) and separation distance (minimum sample distance).
5. Visit sites according to the optimum sampling strategy; record numerical observations of morphological properties and take samples for laboratory determination of physical and chemical properties.
6. Fit variogram models to sample data and interpolate to a regular grid of suitable dimensions (say 100 m or 1000 m).
7. Investigate whether interpolation can utilize more spatially extensive secondary data sources (such as DEM derivatives) to improve on estimates.
8. Collect a second sample set to compare the degree of correspondence between interpolated and actual values as a measure of map error.
9. Build grid soil map by applying 'rules' to individual numerical soil property values to classify grid points into classes of soil similar to current concepts of soil series (can't be exactly like soil series).
10. Distribute both soil or landscape property maps and soil class map in electronic format.

10.4. Differences from traditional SIL3 mapping

1. Operational differences: This method is significantly different than conventional soil survey. Procedures used to make the maps are not based on human understanding of the factors controlling the distribution of soil and landscape properties. Rather, the 'rules' are based on observed patterns of statistical relationships. The method requires very little understanding of soils or soil-landscape relationships. The maps would result much more from office based statistical processing than from field based model

building and testing. Field operations could be conducted by technical personnel with little soils expertise apart from an ability to make a series of standard profile observations and measurements. Depending upon the selected sampling interval, field operations could require very extensive site inspection and sampling and could therefore take at least as much time as conventional mapping techniques. At a minimum, one could expect to spend 5-10 days per township to record observations and collect samples (30 per day times 5 days = 150/twp).

2. Product differences: Interpolation would produce grid or cell based maps very different from both the current SIDMAP product and from current soil survey maps. For one thing, it would not be possible to describe the soil at any point in terms of soil series as we presently define them. Definition of soil series requires information about non-numerical data such as type and degree of structure, soil consistence, color and drainage class. This type of data is not amenable to interpolation. The interpolated product would not be able to describe the short range variation in properties occurring at distances less than the minimum sampling distance. In conventional soil survey maps, this short range variation is captured in the map unit descriptions which describe the variation in soil conditions associated with changes in topography and drainage within a described map unit. The interpolated product would not be very useful for describing regional soil-landscape patterns as presently described in polygonal soil landscape unit descriptions. It would describe single properties at individual sites with no description of the inter-relationships between sites.

10.5. Evaluation / critique

Interpolation of individual properties has been used mainly for site specific research studies. It has seldom been used for regional mapping. The method has numerous disadvantages from the point of view of users of conventional soil survey products. In the first place, it does not result in a map showing the distribution of soil series. Many users have become committed to the use of soil series concepts to convey information about a multitude of soil properties and to attach interpretations of likely behavior to named series. In the second place, interpolated maps show only the variation that can be predicted from the sample spacing used for the degree of variation shown by that variable over those distances. No further information about variation over shorter distances is possible. Interpolated maps give information for individual points but do not provide a means of describing how individual points are inter-related and how they combine to form distinctive landforms and landscapes. A further disadvantage is the high cost associated with field sampling and subsequent laboratory analysis. The advantage of single interpolated maps is that they provide the best (optimum) estimate for a specific soil property at a specific point given the available sample data.

10.6. Resources required

1. Human resources: Designing the mapping system and putting in place the software and procedures required to support interpolation mapping would require personnel with skills not presently available in house. Once established, application of the procedures in a routine way would require only suitably trained technicians. Collection of field data would require only junior technical staff provided with a short period of training. Depending upon the selection of data to record, there might be a very high requirement for laboratory analyses and a corresponding requirement for laboratory staff.

2. Field resources: The method requires extensive field observation and sampling. At a minimum one would estimate 5-10 days per township for field sampling. Costs might be lower than for conventional survey if lower paid technical staff could be used but overall operating expenses would likely be similar to present conventional survey.

3. Material resources: Interpolation mapping would require computer programs and resources presently not available in house. These would have to be developed or acquired at an undetermined cost. A conservative estimate for acquiring hardware and software might be $50,000. Considerable material costs could be associated with laboratory analysis depending upon the number of soil variables selected that would require determination in a laboratory.

A.iv. References

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III.B. OPTIONS FOR CHECKING AND EVALUATING MAP FUNCTIONALITY AND RELIABILITY IN ALBERTA

- M.D. Fawcett and R.A. MacMillan

B.i. Introduction

Eight methods (Table 3.3) have been described and presented as options for comparing or evaluating soil survey products. These options are based on the literature review in Section II. Each presents a unique aspect of the reliability estimates which can be made of a soil survey product. They represent the full range of useful reliability test methods which have been used by others and considered applicable to the situation in Alberta. Each method can be used to test any of the mapping options presented in section III.A.

One option provides a technique for determining if the product contains the information required in a form acceptable to the user (option 1). Another option outlines a method for comparing two different maps without reference to any independently collected ground truth data (option 2). Six options describe ways to evaluate the accuracy, similarity, or degree of error of the map in relation to an independently collected ground truth data set (options 3-8).

The different proposals are based on consideration of the literature review in combination with the combined field experience of the group of individuals involved in the production of this report. The options are not exhaustive but are representative of the range of possible approaches to comparing map products that have been described elsewhere or that are judged to be feasible. The pros and cons of each method are summarized in Table 3.4 and discussed in the detailed descriptions.

Table 3.3 List of options for comparing / evaluating soil survey products.

No.	Option Name	Option Description
1.	Adequacy of Information	Document the kind of information, the descriptive precision, and the spatial precision of the soil survey product in order to evaluate the utility of the product.
2.	Map Correspondence	Use a grid point comparison to evaluate the degree of correspondence between two different maps in order to determine their relative degree of similarity.
3.	Percent Correct	Calculate the percentage of sample observations which were predicted by the legend to occur in the map unit in order to obtain a simple measure of map accuracy.
4.	Probability of Soil X	Use binomial probability function to calculate the probability of finding the predicted soils in the proportions stated. Also calculates the probability of finding a chosen soil at a given observation point. Both calculations provide a measure of map utility.
5.	Error Value	Provides a quantitative estimate of the degree of error between the predicted characteristics of a site and the observed characteristics. This option uses ranked, categorical data to answer the question "If it is wrong, how wrong is it?".
6.	Error Matrix	Used to calculate the percent omission and percent commission errors of a soil map. Presents the accuracy data in a disaggregated format such that the users can evaluate the ground truth data specific to their own needs.
7.	Kappa Statistical Analysis	Measures the proportion of agreement between a soil survey product or land-use map and ground truth data after correcting the data for chance agreement. Can be used to evaluate the difference between mappers or maps produced by different methods, the consistency of one mapper over time, and differences between photographic variables.
8.	Similarity Matrix	A non-statistical but systematic and reproducible method for assessing how similar the soils and soil properties predicted by a map are to the actual soils observed at selected sample points. Answers the question "How close is the map to being correct?"

Table 3.4 Comparison of map testing procedures.

	Option No.*							
MEASURE OF QUALITY	1	2	3	4	5	6	7	8
type of information provided by the map	X							
percentage of required content provided	X							
descriptive precision of attribute data	X							
spatial precision of delineated areas	X							
degree of correspondence between different soil surveyors		X						X
degree of correspondence between different map products		X						X
percentage correct, absolute			X			X		X
probability of soil x at a given site				X				
probability of stated proportions being correct				X				X
degree of error of the map relative to the ground truth data					X			X
degree of error between observations					X			X
percent omission (type 1 error)						X		
percent commission (type 2 error)						X		
relative similarity (predicted vs. observed)								X
proportion of agreement corrected for chance agreement (Kappa)							X	

RELEVANT LEVEL OF APPLICATION								
entire map area	X	X	X			X	X	X
map unit description	X	X	X	X	X	X		X
polygon label	X	X	X			X	X	X

PRESENTATION FORMAT								
single value describing agreement / quality		X	X	X			X	X
multiple values	X			X	X	X		
disaggregated data relative to classes						X		X
binomial probability of correctness				X				
compares map to ground truth data	X		X	X	X	X	X	X
compares map to map	X	X				X	X	

ANALYTICAL METHOD								
binary (yes / no)	X	X	X	X		X	X	
degree of error					X	X		
degree of similarity	X							X

FIELD RESOURCES								
person days per township (estimated)	0	0	0.6	1.5	1.0	0.8	0.8	1.5
observation sites per 20 township map sheet (estimated)	0	0	200	450	300	250	250	450

MATERIAL RESOURCES								
statistical analysis software	X	X	X	X	X	X	X	
spreadsheet / data management software	X		X	X	X	X	X	X
GIS capability	X	X	X					

Assumptions**	1	2	3,4	1,4,5	3,4,5	3,4,6	4,7	1,2,3,7
Restrictions**	1,3,4	2,3,4,6	3	3	3,5	3,6	3,6	2,3

* as listed in Table 3.3

** as defined on following page

Assumptions

1. Information content and/or utility can be measured quantitatively.
2. High correspondence between two or more products means approximately equal utility.
3. The ground truth data is collected independently of the mapping procedure.
4. The sample population and sampling procedure are statistically valid.
5. The map unit description encompasses the full range of variability in the landscape.
6. The user requires access to the raw data set in order to conduct their own accuracy assessment.
7. There is a certain amount of 'chance' involved in correctly describing map unit concepts and in correctly naming individual polygons.

Restrictions

1. Results are dependent on who the user is and what the user wants.
2. For a valid comparison of two different maps, the maps must be of the same area.
3. The level of precision used to make the map determines the level at which evaluations can be made.
4. Does not provide any measure of ground truth accuracy.
5. Can be used for ranked, categorical data only.
6. Cannot be used for complex map units. Single attributes only (assumes homogeneous, single class map areas.

B.ii. Detailed Descriptions of the Options Presented

Option 1. Adequacy of Information

1.1. Purpose / use

The purpose of evaluating the adequacy of the information contained in a soil survey product is to determine the utility of that product. The utility or information adequacy of a map is used by a product user to determine if the map is sufficient for their needs of if other information sources are required.

1.2. Assumptions

The adequacy of information contained in a soil survey product can be measured in three ways. The first measure is what kind of information is contained in the map (eg. Does the map give information on slope lengths?). The second measure is the descriptive precision of the map (eg. Are the class definitions narrow enough to be of use to the user?). The third measure of information adequacy is the spatial precision of the map (eg. Is the mapped area delineated into parcels small enough to be of interest to the user?).

The information content of a soil map can be measured by quantitatively comparing the data elements required by the user against those supplied by the map.

The descriptive precision can be measured in terms of the number of interpretations which can be made from the information contained in the legend and report of a soil map.

The spatial precision can be measured in terms of both maximum location accuracy and the minimum legible area. It is assumed that all distinct (as defined in the legend) soil and landform units which could be shown on the map (given a minimum size map delineation of 0.4 cm^2) were delineated.

1.3. Restrictions

The adequacy of the information contained in a soil survey product is dependent upon the users needs. A measure of descriptive and/or spatial precision must be carried out based on who the user is and what that user wants. A map that is sufficient for one user may be of only very limited value to another user. It is therefore impossible to provide a single value for the information adequacy of a soil survey product which will be of use to all users.

This method of evaluating soil maps does not provide a measure of the ground truth accuracy of the soil map. It determines if the map may be useful to the user, accurate or not.

1.4. Procedure

1. Determine who the user is and what the user will be using the map for.
2. Determine what information is needed and how detailed the information must be for the desired use. For example, information is needed on topography and the user needs to know the slope percentage to within 2% of the actual slope.
3. Determine what information is provided by the map and how detailed that information is. For example, the map provides slope classes for each polygon and the slope classes are 5% wide (eg. class A 0-5%, class B 6-10%, class C 11-15%, etc.).
4. Calculate a percentage value for the information content of the map using the formula:

$$\%\ \text{content} = \frac{\text{data elements supplied}}{\text{data elements required}} \times 100 \tag{1.1}$$

5. Make or attempt to make the desired user interpretation for each map unit.
6. Total the number of map units which supplied sufficient information and in enough detail to make the interpretation.
7. Calculate the descriptive precision as a percentage using the formula:

$$\%\ \text{precision} = \frac{\text{number of map units interpreted (1.4.6)}}{\text{total number of map units}} \times 100 \tag{1.2}$$

8. Determine the ground location accuracy required by the user. For example, boundary location is needed to be within 10 meters.

9. Measure the maximum location accuracy of the soil map by using the formula:

$$\text{ground distance (m)} = \text{map distance (mm)} \,/\, \frac{1}{\text{map scale}} \times \frac{1000\text{ mm}}{1\text{ m}} \qquad (1.3)$$

(Forbes et al. 1985).

If 1 mm is used as the map distance (this is the smallest actual map distance used), the maximum location accuracy in meters can be determined.

10. Determine the minimum size area for which information is needed by the user.

11. Calculate the minimum legible area in hectares which can be represented on the map using the formula:

$$\text{minimum legible area (ha)} = \frac{(\text{map scale})^2}{2.5 \times 10^8} \qquad (1.4)$$

(Forbes et al. 1985).

1.5. Interpretation of results

The information content of the soil survey product is evaluated using the results from map checking option 1.4, step 4. If a sufficiently large percentage of the required information is provided, the map is adequate. Ideally, all of the required information will be shown on the map. If the result in map checking option 1.4, step 4 is less than 100%, the user will require information from additional sources.

The descriptive precision of the map is interpreted using the results from map checking option 1.4, step 7. The higher the percent precision, the more useful the map becomes to the user.

Compare the required ground location accuracy (map checking option 1.4, step 8) to the calculated maximum location accuracy (map checking option 1.4, step 9). If the calculated ground distance is less than or equal to the required ground location accuracy, the map scale is adequate for the users needs.

Comparison of the minimum required area and the calculated minimum legible area (map checking option 1.4, step 11) will determine if the spatial precision of the map is adequate for the user. The minimum legible area must be less than or equal to the smallest area of interest to the user in order for the map scale and therefore map precision to be adequate.

1.6. Resources

1. Human resources: someone capable of making the comparisons and interpretations described above.
2. Field resources: no field resources are required to evaluate the information content of a soil survey product using this method.
3. Material resources: a data management system and statistical analysis package capable of performing the calculations described above.

Option 2. Map Correspondence

2.1. Purpose / use

The map correspondence method of comparing maps can be used for two purposes. The first is to compare two or more maps produced by different mapping systems. The second purpose is to compare two or more maps made by different soil surveyors using the same mapping system.

The method is used to compare the degree of correspondence or degree of similarity between different maps.

2.2. Assumptions

Two maps with a high degree of correspondence in terms of map unit names and/or elements will have approximately equal utility.

2.3. Restrictions

For this method of comparison, all maps in the study must be of the same area and be designed for the same purpose. If two maps made for different purposes are to be compared, only those elements common to both maps may be used.

The correspondence method of comparing maps does not use ground truth information in the comparison. The method does not compare the accuracy of maps, only the degree of correspondence between maps and their utility. It will not indicate which map has the greater utility.

2.4. Procedure

1. Overlay a grid on top of each map to be compared.

2. At each grid point, record the map unit name and/or elements to be compared.

3. Classify the recorded names or elements at each grid point as same, similar, dissimilar, or contrasting.

4. Calculate the total number and percentage of points classified as same, similar, dissimilar, or contrasting.

5. Calculate the total percentage difference between the maps as follows:

% difference = (% same, map A - % same, map B) + (% similar, A - % similar, B) + (% dissimilar, A - % dissimilar, B) + (% contrasting, A - % contrasting, B). (2.1)

2.5. Interpretation of results

A high percentage difference (4.5) between the maps indicates a low degree of correspondence and a difference in the general utility of the maps. A low percentage difference indicates a high degree of correspondence between the maps and approximately equal utility.

2.6. Resources

1. Human resources: will vary with the number of maps to be produced and the time required to produce each map, generally assume one surveyor per map; the actual comparison of the maps will require only one person with the capability of operating a digital mapping system and statistical analysis software.

2. Field resources: will vary depending on the techniques used to make the maps.

3. Material resources: a digital mapping system capable of overlaying a grid on one or more maps and making a comparison of the data associated with each grid point; a data analysis package capable of computing interpretations and calculating percentage totals.

Option 3. Percent Correct

3.1. Purpose / use

The purpose of calculating the percent correct value is to make a quantitative estimate of the proportion of discreet soil entities which are predicted as occurring in the landscape by the soil survey product. Percent correct can be used to evaluate the map as a whole, individual map units and even individual polygons if desired.

3.2. Assumptions

It is assumed that the ground truth sample population is representative of the soil population as a whole and is independent of the data used to make the map product.

It is also assumed that the sample population used to calculate the percent correct value is large enough to make a statistically valid estimate and that the sampling method used is statistically valid.

3.3. Restrictions

Percent correct is a binary system which says yes, the soil was predicted or no, the soil was not predicted. There is no allowance for 'close' in the percent correct evaluation. Soils which are similar to but not the same as the series concept must be classed as incorrect even though the difference may not be great enough to affect any interpretation which may be made (for example O.BL vs. E.BL).

A percent correct evaluation of a soil map can only be made at the level of precision used to make the map. For example, if the soils in the landscape are only described to the subgroup level, the percent correct for soil series cannot be calculated.

3.4. Procedure

1. Choose a sample size sufficiently large such that a statistically valid estimate can be made and select or design a statistically valid sampling method.
2. If the entire map is to be tested, randomly select the required number of polygons and randomly locate the required number of sampling points within the selected polygons. If an individual map unit is to be tested, randomly locate all of the sample points

within polygons of the selected map unit. If an individual polygon is to be tested, randomly locate all of the sample points within that polygon.

3. Collect the required data from each sample point.

4. Classify each sample point as either correct (i.e. predicted by the soil map) or incorrect (i.e. not predicted by the soil map). Use only the map unit description for the polygon in which the sample point occurred when deciding if the observed soil entity was predicted by the soil map.

5. Total the number of 'correct' sample points and calculate the percentage correct using the formula:

$$\% \text{ correct} = \frac{\text{number of 'correct' observations}}{\text{total number of observations}} \times 100 \qquad (3.1)$$

(Marsman and de Gruijter 1986).

3.5. Interpretation of results

A high percentage correct value indicates that the map is accurate to the calculated level. A suggested accuracy level of 80% can be used for comparison.

3.6. Resources

1. Human resources: people capable of collecting the field data are required; people capable of entering the data into a computer and overlaying the ground truth data on a soil map (digital or hard copy); data analysis capabilities are also required.

2. Field resources: the equipment necessary to collect the desired ground truth data is needed.

3. Material resources: digital mapping equipment with multi-layer data capabilities are needed; data management and analysis capabilities are needed.

Option 4. Probability of Soil X

4.1. Purpose / use

There are two purposes for this method of evaluating maps. The first purpose is to calculate the probability of finding soil X in the proportions stated in the map legend and report. The second purpose is to calculate the probability of finding a given soil at a given site. The results of this method can be used to decide if the survey product is adequate for the desired purpose.

4.2. Assumptions

The utility of a soil map is related directly to the probability of finding the described soils in the stated proportions. It must be assumed that a low probability indicates a low utility.

It is assumed that the sampling procedure is statistically valid and that the sample population is representative of the soil population being tested.

4.3. Restrictions

This method of evaluating soil maps does not give an indication of the ground truth accuracy of the map unit descriptions.

The similarity of the map unit descriptions to the ground truth data cannot be measured using this method of evaluating soil maps.

4.4. Procedure

1. Choose a desired level of confidence for the probability calculations. A suggested level is the 90% confidence level. This assumes a one in ten chance of the final estimate being wrong. A 95% confidence level may also be chosen but this requires a prohibitively large sample population. An 80% confidence level may also be used but this assumes a one in five chance of being wrong, too high for most users.

2. Calculate the required number of observations and randomly locate the sample points within the map area to be tested.

3. Collect the required data from each sample point.

4. Digitally record and sort the collected data.

5. Calculate the desired probabilities using the binomial probability equation as follows:

$$P_{(x)} = \frac{n!}{n!\,(n-x)!}\; p^x q^{n-x} \qquad (4.1)$$

(Edmonds and Lentner 1986; Edmonds and Crouch 1991).

4.5. Interpretation of results

If the calculated probabilities are not high enough for the user, the map can be rejected as unsuitable and an alternative source of information must be found. The probability of finding the predicted proportions should be calculated along with the probability of finding a specific soil at a given site. This will allow the interpreter to evaluate how close the actual probability of finding a given soil is to the predicted probability. For example, the probability of finding the described proportion of soil X may be very low. If the actual probability of finding soil X is not calculated, it cannot be determined if the described proportion was too high or too low. By calculating the actual probability, the user can decide whether or not the map is adequate, even though it does not meet previously defined limits.

4.6. Resources

1. Human resources: soil surveyors capable of collecting the desired ground truth information; someone who understands the principles of binomial probabilities and is capable of computer analyzing the collected field data and calculating the desired probabilities.

2. Field resources: the equipment necessary to collect the desired ground truth data; estimate one day of field time for every 25 soil profile observations. The number of observations needed will vary with the desired confidence level.

3. Material resources: computer data management and analysis capabilities are needed.

Option 5. Error Value (EV)

5.1. Purpose / use

This method of evaluating soil survey products is used to determine the degree of error which may be found in soil map and can be used for ranked, categorical data. The error value can also be used to define the level of error between different observations. The purpose of this test is to answer the question "If it is wrong, how wrong is it?".

5.2. Assumptions

It is assumed that the error value provides a quantitative indication of how close the predicted site characteristic came to the observed site characteristic.

This method of evaluating maps also assumes that the modal description of a map unit encompasses the full range of variability to be found in that unit. Any deviation from the modal description is assumed to be a 'wrong' observation and indicates an error in the map.

5.3. Restrictions

The error value method of evaluating maps cannot be used for categorical data unless some logical method of ranking the data can be devised. Data elements such as soil series or parent material type are not easily evaluated using this evaluation technique.

5.4. Procedure

1. Select the area to be tested and the site characteristics to be tested.

2. Choose an appropriate sampling scheme and sample size then locate the sample points at which data will be collected both on the map and in the field.

3. Collect the data required at each of the sample points.

4. Calculate the error value for each characteristic at each sample point according to the formula:

   $$EV = D/k-1 \qquad (5.1)$$

   where D = the number of deviations between the predicted class and the observed class, and k = the number of possible classes for the characteristic being observed (Moon et al. 1987).

5. Define error value limits such that each characteristic can be classified as correct, similar, dissimilar, or contrasting to the modal map unit concept. Suggested limits are those defined by Moon et al. (1987):

correct - an EV of 0.0
similar - an EV of 0.2 or less
dissimilar - an EV > 0.2 and < 0.4
contrasting - an EV of 0.4 or greater

6. Classify each site characteristic according to the defined limits.

7. Calculate the percentage of sample points classified as correct, similar, dissimilar, and contrasting for each site characteristic evaluated.

5.5. Interpretation of results

The use of the calculated error value (map checking option 5.4, step 4) without classifying each characteristic (map checking option 5.4, step 6) will give an indication of how much the observed value for each site characteristic deviated from the modal concept for that site when a value of 1.0 is considered to be the maximum possible deviation. A large error value indicates a large deviation from the modal concept.

The percentage of sample points classified as correct, similar, dissimilar, and contrasting give an indication of how accurately the modal concepts in the map legend and report describe the soils and their variability in the landscape. A high percentage of correct and similar sample points indicates that the map unit descriptions have adequately captured the landscape variability.

5.6. Resources

1. Human resources: soil surveyors and/or technologists capable of locating sample points in the field and capable of making the required observations correctly; familiarity with and capability to operate a data analysis system.

2. Field resources: the equipment necessary to collect the required ground truth data.

3. Material resources: computer data management and analysis capabilities are needed.

Option 6. Error Matrix

6.1. Purpose / use

The purpose of the error matrix is to report test results in a disaggregated format such that the user can decide whether or not the map is useful with respect to their specific needs.

The error matrix is used to calculate the % omission, % commission, and % correct can be calculated from the results reported in an error matrix.

6.2. Assumptions

The error matrix format assumes that users will be more interested in a table of results which shows the range of classifications possible plotted against the range of classifications which were made than they will be in a single accuracy value.

Calculation of % commission and % omission assumes that commission (recognition of a component not actually present) and omission (failure to recognize a component which is present) errors are important to the users. It assumes that the map users have a need to know what is in the landscape and what is not, rather than a general knowledge of the soils and their distribution in the landscape.

6.3. Restrictions

The error matrix can only be used for those site characteristics which are predicted as being singular for the entire map unit and for which there are a finite number of possible classification outcomes. This method usually works best with land-use maps where each cell or polygon has a single predicted use or characteristic, not a range of uses. The use of soil series within an error matrix is only possible when the map legend predicts only one possible soil series per polygon.

6.4. Procedure

1. Select the soil properties and/or site characteristics which are to be tested. The data elements selected must be predicted as definitely occurring at a given sample point by the soil map. For example, slope class can be used or map unit name.

2. Select a sampling scheme that will allow the selected data elements to be plotted in an error matrix. If slope class is to be used, the sampling scheme need only be random without a minimum number of sample points per polygon. If map unit names are to be used, for example, the sampling scheme must allow for enough sample sites per polygon such that the proper map unit name can be estimated with a reasonable level of confidence.

3. Locate the required number of sample points as dictated by the chosen sampling scheme and collect the data needed.

4. Record the data in an error matrix as illustrated in Table 3.5.

5. Calculate the % correct, % commission, and % omission according to the following formulas:

$$\% \text{ correct} = \frac{\text{number of correct predictions}}{\text{total number of observations}} \text{ X } 100 \tag{6.1}$$

$$\% \text{ commission} = \frac{\text{number observed as other classes}}{\text{total number predicted}} \text{ X } 100 \tag{6.2}$$

$$\% \text{ omission} = \frac{\text{number of observations not predicted}}{\text{total number of observations}} \text{ X } 100 \tag{6.3}$$

(adapted from Agbu and Nizeyimana 1991).

6.5. Interpretation of results

A high percent correct value indicates that the map does a good job of describing or predicting data element (class) being considered. A high percent commission indicates that the percent correct value will be low (% correct + % commission = 100). If the % commission value is high, the map is incorrectly recognizing which classes describe the different landscapes and a poor landscape model is indicated. A high percent omission value indicates that the map has failed to recognize a large portion of the variability to be found in the landscape and consequently may have a low utility for some users.

Table 3.5 Map accuracy error matrix.

CLASSES								
	observed							
predicted	A	B	C	D	E	Total	% correct	% commission
A	26	1	0	0	1	28	93	7
B	1	5	0	0	3	9	56	44
C	2	0	43	1	2	48	90	10
D	4	1	2	76	13	96	79	21
E	0	0	2	1	29	32	91	9
Total	33	7	47	78	48	213		
% omission	21	29	9	3	40			

(SOURCE: adapted from Aronoff 1982.)

6.6. Resources

1. Human resources: skilled pedologists capable of making the required observations during data collection are needed as well as people capable of constructing and running an error matrix in digital form.

2. Field resources: the equipment necessary to collect the data is needed.

3. Material resources: computing equipment capable of running an error matrix and making the required calculations is needed.

Option 7. Kappa Statistical Analysis

7.1. Purpose / use

The purpose of calculating the Kappa statistic (K) is to measure the proportion of agreement after correcting the data for chance agreement as illustrated by Greenland et al. (1985):

$$K = \frac{\text{observed agreement - expected chance agreement}}{\text{1 - expected chance agreement}} \qquad (7.1)$$

(Greenland et al. 1985).

The Kappa statistic can be used for analyzing the differences between maps and/or photointerpreters, the consistency of one photointerpreter over time, and differences between photographic variables such as scale, season, and photo type. The Kappa statistic can also be used to measure the total map accuracy and individual category accuracy against ground truth data.

7.2. Assumptions

The Kappa statistic uses an error matrix as the base data format and so assumes that the error matrix is an acceptable way of reporting data. Kappa also assumes that there is an element of 'luck' involved in making a soil map, that a certain proportion of the map area will be labeled or described correctly purely by chance. It assumes that the common measure of % correct overestimates the true accuracy of the surveyor and/or the map unit description.

7.3. Restrictions

The error matrix can only be used for those site characteristics which are predicted as being singular for the entire map unit and for which there are a finite number of possible classification outcomes. This method usually works best with land-use maps where each cell or polygon has a single predicted use or characteristic, not a range of uses. The use of soil series within an error matrix is only possible when the map legend predicts only one possible soil series per polygon.

7.4. Procedure

1. Select the type of test desired (eg. Landsat imagery soil map vs. traditional SIL3 soil map) and the data elements to be compared (eg. slope class).
2. If map accuracy is to be compared against ground truth data, select a valid sampling scheme and collect the required field data. If two maps are to be compared against each other for a measure of agreement, use a point comparison method for collecting the required data from each map.
3. Record the data collected in an error matrix.
4. Calculate the % correct value for the error matrix created in map checking option 7.4, step 3.
5. Calculate the Kappa statistic value using the methods outlined by Cohen (1960, *In* Rosenfield and Fitzpatrick-Lins, 1986) for total map accuracy or using the method outlined by Rosenfield and Fitzpatrick-Lins (1986) for individual category accuracy.

7.5. Interpretation of results

The interpretation of the Kappa statistic value can be done in two ways. The first way is to let it stand alone as a measure of accuracy. For example, a K value of 80% would mean that the product or products tested are in 80% agreement. The second way to interpret the Kappa value is to compare it to the % correct value calculated in map checking option 7.4, step 4. The K value will always be lower than the % correct value. The difference between the two indicates the amount of chance agreement. A large amount of chance agreement indicates one of two things: (1) the landscape is highly variable and cannot be reliably delineated at the level of precision used; or (2) the concepts applied in delineating the landscape were poor.

7.6. Resources

1. Human resources: skilled pedologists capable of making the required observations during data collection are needed as well as people capable of constructing and running an error matrix in digital form.

2. Field resources: the equipment necessary to collect the data is needed.

3. Material resources: computing equipment capable of running an error matrix and making the required calculations is needed.

Option 8. Similarity Matrix

8.1. Purpose / use

To devise and apply a method for assessing the relative degree of similarity between the soils predicted to occur in any given map unit and the soils observed to occur at selected sampling locations within that map unit.

To provide a means of computing a measure of overall map similarity between predicted and observed soils for each of several types of mapping approaches.

8.2. Background

It has long been recognized that the utility of a soil survey is not inexorably linked to its taxonomic purity. Cline (1961) recognized that "the quality of a soil survey should be measured in terms of the amount and accuracy of the information it provides as a basis for judgements about soil potentials and behavior for land use". Miller et al. (1979) emphasized that "the primary objective of soil surveys is not to map delineations having taxonomic purity, but to provide the user with information as a basis for judgements about soil behavior and behavior for various land uses". Hudson (1990) argued that "obsession with the variability in map units is unfounded" and noted that "if variation within map units is such a problem, it should be affecting the use of soil maps in the field". He argued that most users had been successful in interpreting soil map units as if they were uniform areas of homogeneous soil as described in the legend and concluded that soil maps functioned well in practice despite the theoretical shortcomings associated with taxonomic impurity.

Byrd (1991) agreed with Hudson (1990) that people who use soil survey maps don't worry about supposed 'deficiencies' resulting from taxonomic impurity because the maps work for them. He concurred with Hudson (1990) that most of the detail in current soil survey maps was used to meet purposes of classification rather than interpretation, and that, if anything, soil survey map units were described in greater detail than could be used for many interpretations. Byrd (1991) supported the notion that the test of map adequacy should be whether a soil map converted to an interpretive map satisfactorily, not whether it correctly predicted taxonomic composition.

Byrd (1991) argued that new systems of soil classification (i.e. Soil = Taxonomy) had introduced greater precision into the naming of component soils in map units but that no similar increase was achieved in the precision with which map units could be delineated. The 'art' of map making was recognized to still rely on dividing the landscape continuum into segments that could be shown on a soil map. Byrd (1991) observed that these landscape units had been found to correspond fairly well with the discrete areas for which users desired interpretations to assist them in making decisions about land management. Byrd (1991) concluded that soil scientists' concerns with taxonomic impurity had "resulted from trying to be more 'scientific' in classification than nature will accommodate in the mapping of those landscapes". He suggested that soil scientists were overlooking the obvious which is that nature controls the areal variability of soils, not soil scientists. He argued that soil scientists needed to accept that which was possible; that being to map and describe landscapes as found and not to try to make them less variable than they are.

Schellentrager (1990) argued that evaluation of the accuracy of soil survey map units was hindered by the inappropriate emphasis placed on taxonomic purity of map units relative to interpretive success. He noted that "statistical analysis of a map unit's taxonomic composition assists in the the definition and description of the map unit; it does not improve our assessment of the accuracy of soil interpretations of that map unit". He concluded that "a method of evaluating the accuracy and reliability of those soil properties used in rating a map unit for a specific use must be developed" (Schellentrager 1990). He suggested that one possible solution would be "to improve the concept and definition of similar and contrasting (dissimilar) soils by defining similarity or contrast on the basis of fundamental soil properties (i.e. depth, texture, coarse fragments, etc)." Map units could be tested and described in terms of the degree of similarity of each of the observed soils to each of the predicted soils. He reasoned that "because contrasts (or similarity) are based on properties that effect most interpretations, the user would have a better idea of the implications for management" (Schellentrager 1990).

Many other investigators have recognized that evaluation of soil map accuracy in terms of binary (right/wrong) assessments is too stringent a test. For example, Marsman and de Gruijter (1986) recognized, as a limitation of their procedure, the fact that "all deviations from the (expected) class deviations are equally weighed, regardless of their type or extent". They proposed the concept of 'partial purity' in which each unit was evaluated in terms of its 'partial purity' with respect to a number of important soil attributes (i.e. drainage class, soil texture, slope, taxonomic classification, etc). The individual 'partial purities' were summed for all sample sites in a given unit (or map) and an overall 'average purity' was computed. This 'average purity' could be used as a measure of the degree of similarity of the observed soil to the predicted soils. Sites with 'average purities' greater than some prescribed minimum could be considered similar and therefore judged to be 'correct'.

Selby and Moon (1987) also demonstrated a clear recognition of the need to assess the relative degree of difference between predicted and observed soils when evaluating map reliability. They proposed a measure termed the error value (EV) as in option 5. The error value relates the number of classes by which a site is in error (relative to any given soil attribute) to the maximum number of classes by which it could be in error according to the formula:

$$EV = D/(k-1) \tag{8.1}$$

where EV = error value; D = the number of deviations between the observed and predicted class; k = the total number of classes in the classification for that attribute (Moon, Hall, and Selby, 1987).

Selby and Moon (1987) argued that EV represents a standard measure of relative degree of error for categorical data. The greater the difference between the predicted and observed class (D), the greater the relative error (EV). Similarly, the error value is higher if there are only 2 possible classes (k=2; k-1 = 1) and the observed class difference is 1 (D=1; EV=0.5) than if there are 5 classes (k=5; k-1=4) and the observed class difference is still 1 (D=1; EV=0.25). Selby and Moon (1987) computed EV for each of several classified soil properties considered important for defining or interpreting their soil taxa (i.e. coarse fragments, soil depth, slope, drainage class, texture class). The computed EV was used to determine the degree of difference (or similarity) between the observed soil and the most similar of the soils names in the map legend for any given polygon. The following classification of degree of similarity was adopted:

Correct:	no property has an EV greater than 0.0.
Similar:	no property has an EV greater than 0.2.
Dissimilar:	one or more properties has an EV greater than 0.2 and no property has an EV equal to or greater than 0.4.
Contrasting:	one or more properties has an EV of at least 0.4.

The scientific rigor of the EV method or Shelby and Moon (1987) is never in doubt. The proposed concept of error value (EV) is formal, consistent and systematic. Despite this, one is left with the feeling that it still fails to effectively assess the degree of similarity of observed soils to predicted soils. It is perhaps too formal and too rigid. It concentrates on highlighting differences and expressing these differences as error rather than focussing on similarities and expressing these as degree of similarity. For this reason, a less stringent, more forgiving measure of degree of similarity of soils is proposed. It is termed the similarity index and is determined by construction and application of entities called similarity matrices.

8.3. Assumptions

The similarity matrix method assumes that many of the soils encountered when testing a given map unit polygon are similar, in some greater or lesser degree, to one or more of the soil series used to name or describe the map unit. The method seeks to systematically appraise and quantify this similarity. The method assumes that a relative 'degree of similarity' can be manually estimated for all combinations of classes for all important soil attributes. The degree of similarity between any two classes for any given attribute can be stored in and read from a 'similarity matrix' constructed for that attribute. A further assumption is that an overall similarity of observed to predicted soil can be computed as some arithmetic average or cross product of the individual soil property similarities. A final assumption is that the relative degree of similarity between predicted and observed soils computed for any given map unit or entire soil map provides and effective indication of the likely utility of that map unit or map for making the interpretations required of it.

8.4. Restrictions

The basic concept of a similarity index is scale independent. As such, computation of the degree of similarity between observed and predicted soils for any map unit does not determine whether the pattern of distribution of soils is displayed with sufficient spatial precision to satisfy the intended use. An entire map area could be enclosed by a single polygon described in such broad terms that all soils would be similar to one or another of the described soils. In such a case, the degree of similarity of predicted to observed soils could be perfect and yet the map might be virtually useless because of lack of spatial detail. The degree to which one class is deemed to be similar to another class is strictly arbitrary and so is subject to criticism. Measures of absolute similarity should not be relied upon for judgements, but relative degrees of similarity between different types of maps may prove useful and reliable.

8.5. Procedure

A systematic, formal procedure is proposed for assessing the degree of similarity of any two soils based on a comparison of the main soil properties affecting interpretations. The procedure is based on the concept of developing similarity matrices to provide a semi-quantitative expression of the degree of similarity between classes of individual soil properties (i.e. texture, drainage, salinity). The contrast (or similarity) between any two soil profile types is then determined by a quantitative analysis of the difference between the observed profile and the reference profile with respect to the sum of all individual soil property class differences.

The basic steps involved in development and application of the method can be summarized as:

1. Identify a limited number of classifications of specific soil properties that are deemed to be essential for classification and interpretation of most soils.

2. Build 'similarity matrices' for each soil property classification scheme and arbitrarily allocate each class a measure of similarity to all other classes in the classification.

3. Build 'similarity matrices' for all soil series that are expected to be encountered in any given area. Calculate the relative similarity of Soil A to Soil B, C, D. etc by computing a measure of overall similarity of each soil to every other possible soil.

The measure suggested is the average of the individual similarity values for each of the individual soil properties used to differentiate the soils.

4. Visit sample sites selected according to any unbiased sampling design.

5. Compare the soil observed at each sample site to each of the soils described for that polygon in the map legend. Use for comparison the similarity value for each observed soil property classification relative to the predicted classification as indicated in the 'similarity matrix' created for each soil property classification.

6. Compute the 'overall similarity' of the observed soil to the predicted soil as the average of the individual soil property similarities. Compute for each type of soil listed in the map unit description for that polygon.

7. Compute overall similarity of the observed map unit to the described map unit.

8. Compute the overall similarity of soils predicted by map A to those observed in a sample of map A. This yields a single number for similarity of map A to its legend. Do likewise for each map made by a different method. Use overall similarity to effect an overall relative comparison of the different methods of mapping.

A limited number of soil properties can be identified as generally most important for classification and interpretation of soils. An analysis of map legends for typical Alberta soil maps reveals that mapping in Alberta tends to concentrate on recognition of the following soil and landscape properties:

1. Type of parent material (or materials if layered).
2. Texture of the (topmost) parent material.
3. Texture of the underlying parent material (if any).
4. Subgroup classification of the soil.
5. Drainage class of the soil.
6. Degree of solonetzic development of the soil.
7. Salinity class of the soil.
8. Thickness of topsoil (related to degree of erosion).
9. Depth of profile development (related to amount of water infiltration and degree of erosion).
10. Dominant slope gradient of the map unit landscape.

It is proposed that 'similarity matrices' be prepared relating every possible classification for each of the attributes identified above to every other possible classification. This concept is best explained by reference to an example (Table 3.6).

In the example drainage class similarity matrix (Table 3.6) the relative degree of similarity of any two drainage classes is manually and arbitrarily assigned. The surveyor exercises judgement regarding how similar any class is to any other. For example, a moderately well drained soil is judged to be 60% similar to a rapidly drained soil for most uses. This relative rating is purely arbitrary but does have several advantages. Since similarity is defined on an interval scale using integer numbers, it becomes possible to use the numbers to compute simple statistics such as means and standard deviations. It is proposed that similarity indices be produced for each of the ten (10) soil and landscape properties identified above.

Table 3.6 Illustration of the concept of a similarity matrix developed for comparing the degree of similarity of soil drainage classes.

DRAINAGE	ext. rapid	rapid	well	mod. well	imper- fect	poor	very poor
ext. rapid	100	80	60	40	20	0	0
rapid	80	100	80	60	40	20	0
well	60	80	100	80	60	40	10
mod. well	40	60	80	100	80	60	20
imperfect	20	40	60	80	100	80	40
poor	0	20	40	60	80	100	80
very poor	0	0	10	20	40	80	100

The concept of 'similarity matrices' for individual soil properties such as drainage class can be extended to embrace 'similarity matrices' for soil series. This matrix would relate every soil series expected to be encountered in a given area to every other series as illustrated in Table 3.7 below.

The numbers presented in Table 3.7 are simply for illustration purposes. The actual numbers could be allocated in one of two ways. In the first method, degree of similarity could be assigned manually based on the expert judgement of a knowledgeable soil surveyor. These numbers would be completely arbitrary but would most likely provide a reasonable indication of the relative degree of similarity of any two soils. A second approach might involve a more systematic calculation of degree of similarity of any two soils based on the concept of overall 'average similarity'. Average similarity would be computed by comparing series in terms of degree of similarity with respect to each of the ten identified soil and landscape properties. For example KLM soil might be 100% similar to EOR with respect to parent material type and texture but 80% similar with respect to drainage and 50% similar with respect to degree of solonetzic development. The overall average similarity could be computed as a simple mean of the 10 individual property similarities. Alternatively, the different properties could be weighted differently or could be cross multiplied to produce a more restrictive definition of overall similarity. This second method of assessing overall soil similarity by series would be more formal, more reproducible and more defensible.

Table 3.7 Illustration of the concept of similarity matrix as applied to soil series similarity.

	EOR	HER	IRM	KLM	ROS	HLK	WWR	etc.
EOR	100	78	65	60	70	50	40	
HER	78	100	60	80	65	60	50	
IRM	65	60	100	50	80	40	80	
KLM	60	80	50	100	60	80	40	
ROS	70	65	80	60	100	50	70	
HLK	50	60	40	80	50	100	50	
WWR	40	50	80	40	70	50	100	
etc.								

Once similarity matrices are created for all soil properties and soil series, a suitable sampling scheme should be chosen and used for unbiased selection of a number of sample points at which to evaluate the correspondence between the map legend and actual ground truth. Each site should be visited and the soil examined. The actual soil encountered in the field at each site should be compared with each of the soils predicted, by the legend, to occur in the map unit. Comparison should be in terms of degree of similarity of observed to predicted soil relative to the 10 main soil and landscape properties and to overall soil similarity.

Compute a measure of overall map unit similarity for each map unit. Base this on the average similarity of all observed soils to predicted soils for the total map unit. If the legend describes soil A as occupying 60-80% of map unit A1 then only compare 68-80% of the sites in any polygon to that soil. All other sites must be compared to any of the other soils described to occur in that map unit. In all cases, the sites that compare most closely with soil A should be used to assess overall similarity with soil A, and those most similar to soil B used to assess similarity with respect to soil B (but only up to the maximum amount permitted for soil A or soil B in the map unit description). Overall map unit similarity should be computed as the arithmetic average of all site similarity values for sites within a polygon or map unit.

An overall index of similarity or predicted to observed soils can be computed for the whole map as a simple average of the individual site similarities as determined for each map unit. The advantage of this measure is that it provides a single, easily understood number that can be used to compare and rank the various different maps produced by different mapping methods. This is very attractive for producing a final relative ranking or alternative methods.

8.6. Interpretation of results

It is believed that the measure of 'soil similarity' described above will prove to be a flexible but fair method for assessing the degree to which soil maps predict the values of important soil and landform attributes at points within map polygons. The method is far less severe than EV as a measure of map reliability. It emphasizes degree of similarity rather than degree of difference. It permits degree of difference to be expressed on a continuous scale rather than being limited to four categories as with the EV method. The method produces a series of easily interpreted numbers that should provide an adequate assessment of relative map reliability.

8.7. Resources

1. Human resources: The method requires the initial participation of a senior mapper to design and populate similarity matrices for each of the ten individual soil properties and to develop and explain the method for computing overall similarity of soil series and of map units. Once developed, it is expected that the method could be applied by any competent field technician.

2. Field Resources: No additional field resource requirements are envisaged.

3. Material Resources: It would be desirable to develop an automated computerized procedure for computing similarity of observed to predicted soils based on input of observed soil property values and expected soil series names. The method could be applied manually but would be faster and more consistent if automated. No other

material resources are essential. An EM-38 could prove useful for measuring soil salinity as a guide to allocating each site a salinity rating.

B.iii. Summary

Ten options that offer potential for increasing the rate of production of soil inventory products were presented. Many of the methods share a number of common assumptions and techniques, but each is unique in some way. Each method has advantages and disadvantages and it would be interesting to try to apply and compare all of the alternative methods. Practical considerations of time, resources and potential confusion preclude any such comprehensive examination. It is necessary to restrict actual test application of the alternatives to only a limited number of options. A set of guidelines is required to rationalize the selection of limited number (2-3) of the available options for implementation and evaluation. These guidelines are presented, discussed and then applied to each of the proposed options for mapping in the next section .

A similar set of concerns exists relative to the wide variety of techniques identified as possible options for evaluating the utility and quality of soil survey products. Eight options have been described but not all can be selected for implementation. The first two options evaluate the information content and cartometrics of soil maps respectively. Information content is considered in terms of whether the maps contain the kinds of data required by the majority of users and whether that data is described in terms that are sufficiently precise for the intended uses. Cartometric evaluation is concerned with whether the maps delineate areas of different soil with the spatial precision required to address identified user needs, with the degree to which the resultant maps are clearly readable, and allows a comparison of spatial precision between two maps. The remaining six options pertain to different techniques for evaluating the quality of maps in terms of their 'predictive accuracy'. Each of these methods has advantages and disadvantages but practical considerations preclude the adoption and application of all options.

A set of guidelines is required to rationalize the selection of limited number (2-3) of the available options for implementation and evaluation. These guidelines are presented, discussed and then applied to each of the proposed options for mapping in the next section. An over-riding consideration in developing these guidelines is the need to be able to provide a simple index or measure of overall map 'utility' and reliability. This index should permit the various options to be quantitatively rated and then ranked in relative order of performance as compared to conventional SIL3 1:50 000 soil survey maps. The focus should be on simplicity and ease of interpretation rather than on scientific complexity and precision of quantitative assessments of accuracy or error.

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IV. RATIONALE FOR SELECTING NEW MAPPING SYSTEMS AND ADOPTING METHODS OF EVALUATING MAP PRODUCTS

Introduction

The purpose of this section is to evaluate each of the mapping options and each of the map comparison options in light of a set of defined criteria. The objective was to select a subset of options with an understanding of why each option was selected or rejected. The options with the best potential for further investigation are identified. The selected options are discussed in greater detail in Section V (Proposals).

IV.A. RATIONALE FOR SELECTING NEW MAPPING SYSTEMS

W.L. Nikiforuk

A.i. Rationale for Adopting Different Options For Mapping Systems

Ten potential mapping options were described and characterized in Section III.A. (Tables 3.1 and 3.2). Each of the mapping options was evaluated based on a set of criteria. Those options that met the guidelines established for selection were identified. Options which were not considered feasible for further research are identified and reasons for the rejection of these options are provided and discussed.

A.ii. Criteria Used For Evaluating Mapping Options

The single most important criteria for judging each of the mapping options is scientific validity. In the opinion of the authors, each of the proposed mapping systems meets this criteria and is defensible. Thus, scientific validity was not considered explicitly as a criterion for rationalizing the selection of mapping options.

Four criteria were used for evaluating the rationale for selecting options (Table 4.1). The criteria were divided into two classes based on the degree to which each limits the selection of a mapping system. Feasibility (speed, cost, technology and available manpower) and transferability were defined as primary criteria in the decision making process because they are the most limiting. Feasibility is the most critical criteria (that is, it has the greatest impact in the decision making process) because the proposed option must be delivered quickly and within economic realities. Historical precedence and client acceptance were considered to be secondary criteria. While important to the rationalization of selecting mapping systems, these criteria are less limiting than the first

2. For example, options that have high historical precedence and strong client acceptance may not be achievable given the availability of resources. SIL3 1:50 000 mapping would fall into this category.

Map reliability was considered as an important criteria for selection but evaluating the reliability of mapping options is not possible until the options have been tested. Thus, reliability is not considered in the rationalization of mapping options. No one option completely satisfies all of the listed criteria. The options selected for further investigation must meet the requirements of delivering soil inventory products effectively and efficiently. That is, at minimal cost and maximum reliability. The criteria for rationalizing the selection of mapping systems are:

1. Feasibility
    a) Manpower - must be able to conduct the research with available resources.
    b) Technology - is the option technologically feasible. That is, are the methods used realistic and achievable?
    c) Cost - the option must fall within the budgetary realities that have been established. That is, given the current economic conditions and limited funding, is the option economically feasible?
    d) Time/speed (rate of progress in days/township or townships/year) - the option must meet the demands of producing a uniform map product for the province as quickly as possible and within given economic realities.

2. Transferability
   The method must be transferable to any geographic region of the province and it must be possible for any reasonably knowledgeable soil mapper to apply the method.

3. Historical precedence
   Soil names have evolved as the primary vehicle for describing and interpreting soils in Alberta. Any feasible method must recognize this precedent and adopt the use of soil names. Additional historical precedents include the depiction of polygonal map units and the delineation of map units in terms of patterns of soils and landscapes.

4. Client/user acceptance
   The option should be acceptable to the agencies involved in gathering, using, or gathering and using soil survey information.
   a) The method should complement mapping systems developed by other agencies.
   b) The method must use soil names because clients are committed to the use of series.

All options presented have advantages and disadvantages for implementation. Options chosen for further study have the fewest (or most minor) disadvantages. Each option was evaluated for each of the criteria (Table 4.1, Figure 4.1). Acceptance or rejection of each option as a viable alternative to SIL3 mapping was based on the evaluation of each option.

A.iii. Discussion

The decision tree in Figure 4.1 contains 2 levels of criteria. The primary criteria are those which relate to the physical capability to do the work (i.e. number of people and skill level) and financial resources available. Mapping options 2, 3, 5, and 8 meet these criteria (i.e. they can be executed given current known resources). Secondary criteria are those that influence decision making from external stakeholders and historical precedence. Mapping option 2 is the only option that meets all of the criteria (primary and secondary) in the decision tree. Mapping options 3 and 5 were judged to not meet client acceptance by todays standards but client acceptance of these options could be managed through a technology transfer process.

Table 4.1 Mapping options - rationale.

	Option No.									
FEASIBILITY	1	2	3	4	5	6	7	8	9	10
Estimated cost per township mapped [a]	13.5 - 18	1.7 - 3	6.8 - 9.1	6.6 - 8.9	6.7 - 9	2 - 3.25[b]	13.5 - 18	4.5 - 7.2	?	?
Speed: days/twp	20	3	10	var.	15	3	22	7-9	?	?
Speed: twps/year	10	60-80	22	20	15	60-80	10	25-30	?	?
Manpower[c]: quality	A	A	A	A [d]	A	NA	A	A	NA	NA
Manpower[c]: quantity	NA	A	A	A	A	NA	NA	A	NA	NA
Technology available	yes	yes	yes	yes	yes	no	yes	no	no	yes
Transferability	same	yes	yes	? [e]	yes	yes	yes	yes	yes	yes
Sets an historical precedent[f]	no	no	no	no	no	no	no	yes	yes	yes
Client/User acceptability[g]	N	Y	M	M	M	Y	N	N	N	N
Appearance	same	same	same	same	same	same	same	diff.	diff.	diff.
Content	same	same	same	same	same	same	same	same	diff.	diff.

[a] in thousands of dollars

[b] does not include estimated capital equipment costs of $50,000 to $100,000

[c] Manpower
A = available
NA = not available

[d] only one person

[e] dependent upon the availability of SM+ personnel

[f] Sets an historical precedent
No = sets no historical precedent
Yes = sets an historical precedent

[g] Client/User acceptability
Y = acceptable
N = not acceptable
M = could be acceptable

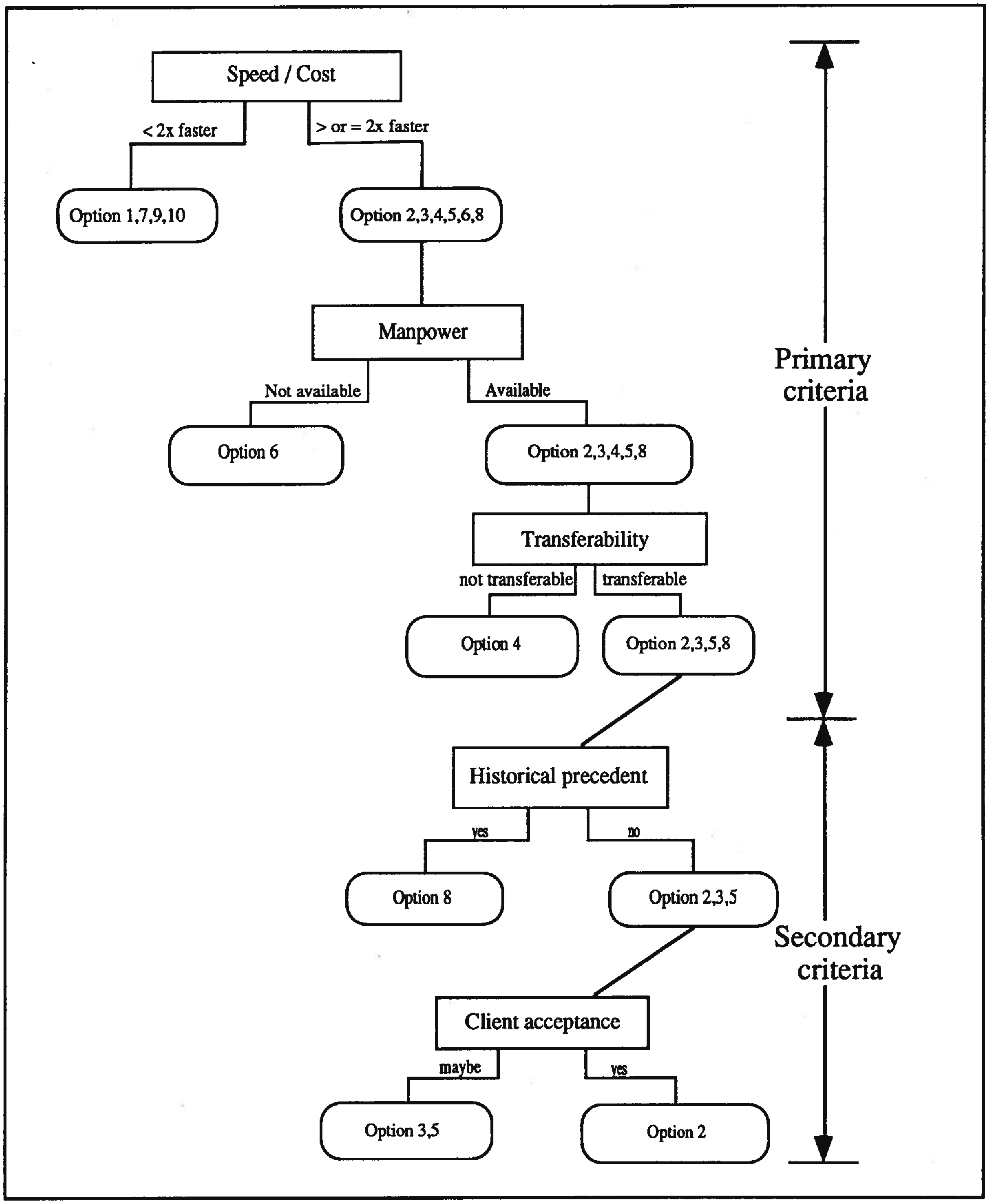

Figure 4.1 Evaluation of mapping options based on criteria for selection of new mapping systems.

A.iv. Option Number and Reasons for Rejection

1. Slow speed, high cost, lack of manpower required to complete mapping of the province, political acceptance.
2. None (most promising method).
3. Slow speed, high cost, unproven method (has some potential).
4. Lack of transferability to other geographic regions, slow speed, high cost, lack of necessary expertise, unproven method (has some potential).
5. Slow speed, high cost, unproven method (has some potential).
6. Lack of manpower with sufficient computing skills, high capital cost, technology unproven.
7. Slow speed, high cost, political acceptance.
8. Historical precedent, client acceptance.
9. Slow speed, historical precedent, different appearance and content, unproven technology, manpower with necessary skills are unavailable, unproven method.
10. Slow speed, historical precedent, different appearance and content, unproven technology, manpower with necessary skills are unavailable, unproven method.

A.v. Summary

Some options could be considered viable if minor changes are made to their methodologies. For example, potential exists for reducing costs and increasing mapping speeds in options 3 and 5. Further the perceived lack of client acceptance for options 3 and 5 could be managed through a technology transfer process. Some options meet the speed and cost criteria but require large capital expenditures to complete the initial mapping projects. These options are viable if costs are considered over the duration of a province wide mapping program.

IV.B. RATIONALE FOR ADOPTING METHODS OF EVALUATING MAP UTILITY AND ACCURACY

- W.L. Nikiforuk and M.D. Fawcett

B.i. Introduction

Eight potential options for checking map utility and accuracy were described in Section III.B. (Table 3.2). Each of the checking options were evaluated based on a selected set of criteria in order to rationalize the selection of one map evaluation technique.

The single most important criteria for judging each of the map testing options was scientific validity and statistical rigor. In the opinion of the authors, each of the proposed map testing options met this criteria and is defensible. Thus, scientific validity and statistical rigor were not considered explicitly as a criteria for rationalizing the selection of map evaluation options.

Those options that meet the guidelines established for selection are described first. Options which are not considered feasible for operational use are identified and reasons for the rejection of these options are provided and discussed.

B.ii. Criteria Used for Evaluating Map Utility and Accuracy

1. Objectives
   The objectives in using the option (map comparison or accuracy/reliability assessments) must be defined.

2. Simplicity
   The results of the method must be easy to convey to users of the information.

3. Evaluation
   The method must be able to be applied to various map components.

4. Time/speed and cost
   The option must fall within the budgetary realities that have been established. That is, given the current economic conditions and limited funding is the option economically feasible. The option must meet the demands of evaluating soil maps in the province as quickly as possible and within given economic realities.

B.iii. Discussion

All options presented have advantages and disadvantages for implementation (Figure 4.2). The most important criteria to consider in choosing an appropriate map evaluation method is to define the objectives of the option. Option 1 provides information on the adequacy of information collected. Option 2 can be used for comparing two or more maps compiled in the same geographic area. Option 3 provides information on map accuracy in an easily understood manner. Options 4 through 8 provide information on map accuracy but the results are difficult to convey to average users.

B.iv. Summary

Four criteria were used to evaluate methods of evaluating map utility and accuracy. These criteria were applied to the 8 potential options for map comparison. Options 4 through 8 meet the first 2 criteria of objectives, simplicity and evaluation. The third and fourth criteria (evaluation, time/speed and cost) differentiate among options 4 through 8. Future discussions and feedback on this document will determine the option selected for implementation in the 1992 field season.

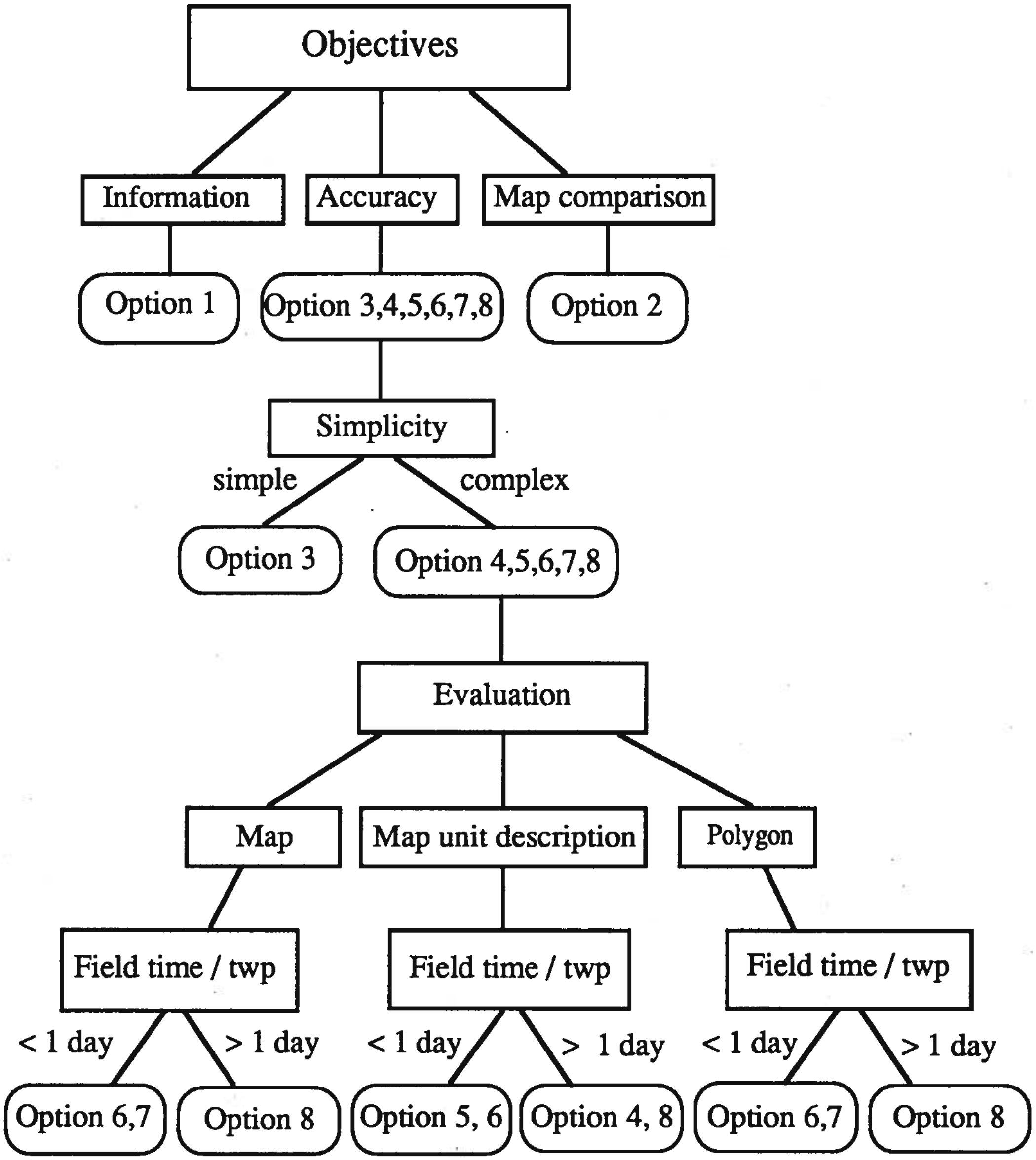

Figure 4.2 Evaluation of map utility and map accuracy options.

V. PROPOSALS FOR MAPPING SYSTEMS AND MAP COMPARISON TECHNIQUES

V.A. MAPPING SYSTEMS PROPOSALS

A.i. Top-down Bench Exercise

- R.A. MacMillan

Introduction

Top-down mapping (option 2) has been identified in the foregoing section as the technique with the greatest potential for achieving significant gains in the rate of production of soil maps in Alberta. Additionally, top-down mapping is expected to offer the most potential for maintaining, or in some areas even improving, the quality and reliability of SIL3 soil maps. Gains in quality would be associated with uniformity of the product across the province. Reliability would be maintained, or possibly even improved, as a result of the consistent application of a set of formal, systematic procedures for top-down stratification, office pretyping of SIL3 polygons and rapid and consistent field checking of polygon boundaries and map unit models. Some of the increase in reliability might be achieved through a reduction in the descriptive precision of statements used to characterize map unit polygons or in the spatial precision of boundaries used to outline described areas (i.e. reducing map scale).

Top-down mapping is based on the same concepts and procedures used by current methods of SIL3 mapping in Alberta. The main differences are that top-down mapping introduces more systematic and consistent procedures and that it relies more on office use and interpretation of existing data and knowledge and less on in-field collection and evaluation of new data. It is felt that the benefits arising from a formal consistent method for using existing data and knowledge may outweigh the limitations arising from reducing the effort spent in the field building and checking soil-landscape models.

Objectives

A proposal is made to investigate the feasibility of adopting a formal, systematic method of top-down stratification for mapping soils in Alberta. The objectives of the research project are to:

1. Define a formal, systematic procedure for top-down mapping of soils that can be applied anywhere in Alberta by any suitably trained mapper.

2. Apply the defined procedures to produce a map (or maps) for one or more suitable 'test areas'.

3. Evaluate the utility, reliability, advantages and disadvantages of the method as a possible replacement for current procedures for SIL3 mapping in Alberta.

4. Fully describe the procedures to produce a 'methods manual' documenting how to conduct 'top-down mapping' to produce maps at SIL3 for any portion of Alberta.

Methods

The top-down method will be applied to 2 or 3 individual townships in 2 or 3 different geographic regions. It is proposed that the selected townships be located in the MD of Rocky View, the County of Forty Mile and one other area (County of Starland or Stettler). This recommendation recognizes the need to compare the top-down maps to conventional SIL3 maps and maps made using one or more alternate methods. It is desirable to compare each method within common geographic areas. Comparing different methods applied to different geographic areas makes it difficult to determine whether map reliabilities differ because of the method of mapping or because of differences in the inherent variability of soils in different geographic areas. The townships should be selected so as to be representative of a variety of data sources of differing age and spatial precision. The methods proposed for top-down mapping are not universally accepted. It is therefore necessary that there be an interaction with other producers of soils information in Alberta and with concerned clients so as to provide them with an opportunity to comment on and suggest revisions to the proposed top-down methods. The methodology proposed for this project incorporates this requirement. The proposed methods may be summarized in point form as:

1. Schedule and conduct meetings to review and revise proposed top-down method.

2. Meet to consider and select area to map.

3. Identify, acquire and collate data needed to implement top-down approach.

4. Apply top-down method for subdivision and pretyping of area(s) in office.

5. Spend 0.5-1 day per twp to drive mapped area, checking boundaries and unit concepts.

6. Produce final map and accompanying report.

7. Write generic 'methods manual' for the top-down method.

8. Analyze sample data collected for quantitative assessment of map utility and map accuracy relative to SIL3 and others.

9. Write final report comparing top-down approach to conventional SIL3 mapping and to all other tested methods.

Treatment of Results (products)

The following products are envisaged:

1. A map or maps of the selected area(s) presented at a scale of 1:100 000 and prepared according to the procedures described for top-down mapping.

2. A report detailing the map legend and map unit concepts for the mapped area(s) and describing the methods used to produce the map for that area.

3. A "methods manual" documenting the generic procedures for applying top-down mapping anywhere in Alberta.

4. A qualitative evaluation of the advantages and limitations of the top-down approach in comparison with conventional SIL3 mapping.

5. A quantitative evaluation of the utility and accuracy of the map(s) produced by the top-down method compared to maps produced by conventional and other means.

Discussion

Two major decisions must be made relative to the development and application of a 'top-down' method of soil mapping. The first decision is the where to conduct the evaluation. The second decision is exactly what methods to adopt.

The following considerations are relevant to selecting the most suitable location(s) for conducting and assessing top-down mapping:

1. Does the area contain a variety of the most common landscapes and soils typical of agricultural portions of Alberta?
2. Is the area to be mapped covered by a representative variety of sources of secondary data of varying age and reliability or is it all covered by source data of a single age and reliability?
3. Has the area been mapped recently using current SIL3 techniques for mapping and a current SIL3 map legend?
4. Has the area been mapped using one or more of the other methods proposed as alternatives to current procedures for SIL3 mapping?
5. Are there political or institutional reasons for wanting to obtain map coverage for any given area as an outcome of the map testing procedure?

These considerations lead to the identification of two basic options, namely:

1. Conduct top-down mapping in one or both of the two areas where both conventional SIL3 mapping and one of the alternative methods have already been completed (i.e. Rocky View and/or Forty Mile).
2. Conduct top-down mapping in a 'new' area in which neither recent SIL3 mapping nor any of the alternative methods have been applied but for which there is political interest in producing an updated soils map (i.e. Stettler or Starland).

The advantage of the first option is that it facilitates comparison, for the same geographic area, of top-down mapping with both conventional SIL3 mapping and one or more of the alternative methods. This means that comparisons can be made directly among methods with no confusion arising from unknown differences due to differing patterns of variation in soils and landforms in separate geographic areas. One disadvantage is that some data is presently available for specific areas (i.e. Stettler) while it might have to be purchased in other areas (i.e. Rocky View or Forty Mile). Another disadvantage is that this option as proposed does not result in the production of an updated soils map for an area currently lacking recent coverage. One advantage of conducting top-down mapping in a 'new' area is that it might be possible to 'piggyback' on other projects and so obtain data at low cost. Another advantage is that this approach could lead to the completion of an updated soils map for an area with a current high need for such a map.

It is recommended that option a) be selected and that top-down mapping be conducted for selected townships within both the MD of Rocky View and the County of Forty Mile. This recommendation is based on the technical opinion that it is preferable to compare all mapping methods for the same geographic area rather that comparing different methods applied in different areas.

The following considerations are relevant to selecting which specific elements of the top-down approach to adopt:

1. Is there general agreement among the major producers of soil survey information in Alberta on the specifics of the top-down approach as described in the options section and accompanying documents?

2. Is it desirable to map an entire county or MD using the top-down approach or is it preferable to map only selected townships also already mapped by conventional and alternative methods?

Recommendations

It is recommended that:

1. An inter-agency dialogue be undertaken to review and revise the top-down method as described for option 2 and to select areas consisting of several individual townships, for testing the method.

2. The revised top-down approach be implemented for the selected map area(s).

3. The area(s) mapped by the top-down approach should correspond to areas already mapped by conventional and alternative methods so as to permit a direct comparison of relative map quality.

4. An additional component be added to the top-down approach to investigate the advantages and limitations of using high resolution digital elevation data (DEM) and satellite imagery (RS) data.

Recommendation 4) has been made with the intention that consideration be given to the expected increase in map quality with the addition of improved topographical and drainage data associated with DEM and RS data. If DEM and RS data were to be used, the information gained would be added to the map production process between mapping option 2.3, steps 3 and 4. The method would be to process digital DEM and RS data to define slope classes, drainage classes, etc. before applying the top-down method for subdivision and pretyping. It is envisaged that the inclusion of DEM and RS data into the top-down mapping approach will increase the efficiency of the mapping system and produce a map product with increased utility and reliability.

A.ii. Extrapolatory Mapping

- R.L. McNeil

Introduction

In the 1991/92 field season, eleven townships in the County of Forty Mile were mapped using option 4 as described in Section III.A. This option does not meet all of the criteria discussed in Section IV.A. In particular, it does not meet the transferability criteria because it requires specific human resource skills and experience. However, it was selected for application because the existing SIL3 1:50 000 mapping project in the County provided a venue to explore this approach to mapping within the context of the existing mapping program.

Objectives

Given the availability of extrapolatory mapping in the County of Forty Mile the objective of this proposal is to compare and evaluate extrapolatory mapping to SIL3 1:50 000 mapping using quantitative statistical sampling and analysis techniques as described in Section V.B. (Map Comparison Proposal).

Methods

Map comparison techniques identified in Section V.B (Map Comparison Proposal) of this document will be used to compare extrapolatory mapping to SIL3 1:50 000 mapping.

Results of this proposal

This proposal will result in both a client report for Agriculture Canada and publications in the scientific literature.

V.B. MAP COMPARISON PROPOSAL

B.i. Evaluation of Map Quality

- M.D. Fawcett and R.A. MacMillan

Introduction

Selected alternative mapping systems are to be implemented and tested as potential replacements for traditional 1:50 000 SIL3 mapping in Alberta. An identified prerequisite for any new mapping system is that the utility and reliability of the resulting soil survey product must be maintained at a level equal or close to traditional 1:50 000 SIL3 mapping. This prerequisite produces a need to evaluate and compare the selected alternative mapping systems relative to each other and to traditional 1:50 000 SIL3 mapping.

A number of methods of testing and evaluating the utility and reliability of different mapping systems were discussed in the literature review (Section II.E.). These methods were condensed into eight potential options for evaluating and comparing the utility of the soil survey products produced by alternative methods of mapping to maps produced by traditional 1:50 000 SIL3 methods (Section III.B). Section IV.B identified two options (checking options 1 and 3) which are considered sufficiently rigorous, feasible and cost effective to adopt for evaluating and comparing alternative mapping systems.

Objectives

A proposal is made to implement the two options for checking soil maps identified in Section IV.B. The specific objectives of this proposal are to compare each of the implemented alternative mapping systems to each other and traditional 1:50 000 SIL3 soil survey methods with respect to:

1. The information content of each legend (checking option 1).
2. The descriptive precision of the statements describing the individual map units (checking option 1).
3. The spatial precision of the soil map (checking option 1).
4. The predictive accuracy of the entire map relative to ground truth data (checking option 3).

All of the implemented mapping systems (alternative and traditional) will be compared and given a relative ranking according to the utility of each method as defined by the information content, descriptive precision, spatial precision, and predictive accuracy of each. It is hypothesized, that the comparison and ranking of the alternative mapping systems with and in relation to traditional 1:50 000 SIL3 soil mapping will indicate the degree to which map utility and reliability is maintained by the alternative approaches.

Methods

The methods used to meet the objectives of this proposal are adapted from options 1 and 3 for evaluating and comparing maps. These were identified in Section IV.A. of this document as being the most appropriate for comparing and evaluating alternative methods of mapping.

1. Evaluation of information content

In order to evaluate the information content of a soil map, the required data elements must be known. It is proposed that between two and five of the most common interpretive uses of soil maps be selected and evaluated according to checking option 1.4, steps 2-4.

2. Evaluation of descriptive precision

The precision with which the individual data elements are described is important to the utility of a soil map. If the precision is too low, the needed interpretations cannot be made. It is proposed that the descriptive precision of the tested mapping systems be evaluated according to checking option 1.4, steps 5-8 using the interpretations selected above.

3. Evaluation of spatial precision

The spatial precision of a soil map is dictated by map scale which can be measured by both the ground location accuracy and the minimum legible area of a soil map. It is proposed that the adequacy of the map scale used by each mapping system be evaluated according to checking option 1.4, steps 9-11.

4. Evaluation of predictive accuracy

The predictive accuracy of a soil map can be estimated through the calculation of the percent correct value of a soil map in relation to a ground truth data set. It is proposed that a data set of appropriate size be collected independently from the data set used to produce the soil maps to be tested. This data set will be gathered through the use of radial arm transects in randomly selected locations within the mapping area. Separate data sets must be gathered for each mapping area to be tested, but one data set can be used for several maps if all of the maps cover the same area. Using the collected data set(s), it is proposed that the percent correct value of each soil map to be tested be calculated according to the procedure outlined in map checking option 3.

5. Comparison of the utility of the tested mapping systems

The relative utility of one mapping system versus another can be determined by ranking them through a comparison of the four evaluations proposed above. The ranking of the systems will be expressed as an overall percentage value with traditional SIL3 1:50 000 soil mapping being ranked at 100%. It is proposed that the mapping systems to be tested be compared to each other by ranking them by information content first, descriptive precision second, spatial precision third, and lastly by predictive accuracy.

Results of this Proposal

The main result of this project will be a quantification of the relative utility and accuracy of the selected alternative mapping systems in relation to the traditional 1:50 000 SIL3 soil mapping system. This will enable the soil inventory community to evaluate the new system(s) in relation to the current soil survey products and decide whether to implement a new system or continue to use the traditional approach until a better alternative can be found. Only with a rigorous, unbiased evaluation of a new system can informed decisions be made about its relative utility and reliability.

It is proposed that the results of this study be delivered to the client in report format. Recommendations for future uses and/or acceptance of each mapping system tested will be made along with a review of the evaluation technique proposed here. It is suggested that the results of this study be summarized and submitted for publication to a soil survey journal.

B.ii. Summary

One mapping system was proposed for implementation in the 1992/93 fiscal year. The top down approach to mapping was deemed most likely to meet all of the criteria as discussed in Section IV. The extrapolatory mapping option (option 4) was used in the 1991/92 field season in conjunction with the County of Forty Mile soil survey and it was proposed that this mapping system be evaluated and compared to SIL3 1:50 000 mapping. Two map comparison techniques were proposed for implementation in the 1992/93 fiscal year. These techniques will be used to compare extrapolatory and top down mapping to SIL3 1:50 000 mapping.

APPENDIX A:

HISTORY OF SOIL SURVEY IN ALBERTA

- W.L. Nikiforuk

Soil surveys in Alberta were initiated in 1920 by Dr. Frank A. Wyatt of the Department of Soils at the University of Alberta (Bowser 1965). The purpose of the first survey project was to delineate the province into broad soil - climatic zones. This project was completed in 1925 (Bowser 1965; McKeague and Stobbe 1978). Since then, this map has been revised and updated (Alberta Institute of Pedology 1967).

The second soil survey was started by F.A. Wyatt and J.L. Doughty (Wyatt and Newton 1925) in response to a government concerns related to the threat of wind erosion of soils and abandonment of farmsteads in southern Alberta. This survey was initiated in 1921 in the MacLeod area and completed 4 years later (Wyatt and Newton 1925; Bowser 1965; McKeague et al. 1978). The final report and map illustrated differences in soil texture across the surveyed area. Soil interpretations related to issues of soil fertility and management of soils susceptible to wind erosion. During the period 1922 to 1926, over 2.8 million hectares were surveyed in the southern portion of the province (Bowser 1965; McKeague et al. 1978). The work was financed by the University of Alberta and the provincial Department of Agriculture.

In 1925 C.F. Marbutt, the head of soil classification in the United States, visited Alberta for the first time. His visit was significant because he stimulated interest in the study of the complete profile and in the importance of the type and arrangement of horizons within the profile (Bowser 1965). In 1927, as part of the field tours of the first world soil science congress, Marbutt as well as a number of world renown soil scientists visited Alberta (Bowser 1965). These two visits stimulated an exchange of ideas which brought forward additional criteria for the mapping of soils. Until this time soils were separated only on the basis of texture. Subsequent to the visits additional profile characteristics were recognized. These characteristics included differentiation of horizons and sampling and chemical analysis of different soil horizons (Bowser 1965). During this period (1925 - 1927) work started on the St. Ann sheet west of Edmonton (Wyatt et al. 1930). This survey represented a step forward in mapping techniques in that it incorporated the concepts of the soil profile and the soil series. Soils were separated on the basis of soil belts (Black, Wooded and Incipient Podsolic Wooded), surface texture, stoniness and topography. That is, the system of classification was a combination of genetic features and desirability for cultivation (Bowser 1965).

In 1928, the Alberta Research Council began soil survey in response to demand for homestead lands in the Peace River region of Alberta (Bowser 1965). The mapping involved the identification and classification of lands suitable for homesteading and farming. The soils were split into 6 categories: parkland soils, 3 classes of wooded soils, organic soils and eroded soils. Mapping was conducted at a scale of 1:250 000 and approximately 8.1 million hectares were mapped. The survey was completed in three years. It was terminated because of a lack of funding caused by government cut backs due to the depression. Termination of the survey also marked the end of soil inventory activities by the Alberta Research Council for the next 17 years.

Concurrent with the arable land survey, the University of Alberta conducted surveys of lands in some of the irrigation projects. These surveys covered about 56,000 hectares (Bowser 1965). During this period there was no program in place to systematically survey the province. Rather, surveys were done as needed. The onset of the great depression resulted in the termination of all soil survey field activities. Survey activity was confined to the office until 1935. In 1935, the Canadian government passed the Prairie Farm Rehabilitation Act (PFRA), the purpose of which was to rehabilitate the drought stricken prairies. The importance of the Act was that soils information was deemed necessary and basic for reclamation and rehabilitation of lands. As a consequence soil survey was revived. The PFRA provided funding necessary to conduct the field work to the University of Alberta and the Experimental Farms Service of the Canada Department of Agriculture. The area surveyed lay within the Palliser triangle and occupied about 8.1 million hectares (Bowser 1965). Soil legends were open. Soil maps which have open legends have a unique symbol within each map delineation and there is no limitation on the number of symbols that may be used (Mapping Systems Working Group (MSWG)1981). The result of using an open legend was that a large amount of different polygon labels were used. The soils were mapped at 1:190 000 using a three number code which had evolved during the St. Ann survey. The code characterized soil zone, type and mode of deposition of parent material and soil profile development. Soil texture was shown on the maps by a colour code and topography by cross hatching. The position of the landscape that the soils occupied was not documented.

In 1945, representatives from all survey units in Canada met for the first time to exchange ideas, unify survey and classification methods and evaluate the work that had been completed to that time (Bowser 1965; McKeague et al. 1978). One of the highlights of this meeting was a proposal for a field classification system of soils for Canada. The system had seven categories; soil region; soil zone; soil subzone; association or catena; soil series, members or associates; soil class or type; and soil phase. The classes within the categories were real bodies in the landscape that included all the soil variability within an area. The system was not intended to be a scientific or taxonomic one in which the classes had a defined range of properties (McKeague et al. 1978). Rather it was intended to be a system for classifying and naming soil mapping units in the field. The soil series continued to be the basic unit of classification.

The Alberta Research Council reentered the soil survey in 1945 and continued with work in the northern portion of the province. The purpose was to update the work done between 1928 to 1931 and to continue the evaluation of lands relative to their suitability for arable agriculture (Bowser 1965). The soils were mapped at 1:190 000 using the soil series names listed according to their predominance in the map areas that they occupied. The series were recognized on the basis of soil zone, parent material, surface texture, drainage, landscape position and some profile characteristics.

In 1955, the first Canadian taxonomic system of soil classification was outlined (McKeague et al. 1978). This was a significant period for soil survey because soil series were recognized on the basis of observable physical properties. The term soil series was redefined. No longer was the series a field entity, rather it became part of the taxonomic hierarchy. In Alberta, soil surveys during the next 10 years were conducted at 1:126 000. Soil legends were uncontrolled. In an uncontrolled legend combinations of series are not listed or described. More than one line of the legend has to be consulted to gain information about delineations that contain more than one soil (MSWG 1981).

In 1963, at the request of the Agricultural Rehabilitation and Development Act (ARDA) the survey units in Canada agreed to prepare an agricultural capability classification of the settled portion of Canada. This program led to an increase in the level of survey activity. The Alberta Research Council continued to conduct work in the northern portions of the province while Agriculture Canada began mapping projects in the central portions of the province (Edmonton, Buck Lake and Wabamun and Tawatinaw map sheets) (Bowser 1965). The northern survey work continued until 1978.

During this period there were significant changes in the way soil survey information was displayed. Maps had uncontrolled legends in which soil associations were used to characterize landscapes. The soil association was defined as a group of "closely interrelated soil series developed on similar parent materials and under essentially same climates" (Dumanski et al. 1972). The soil associations were a combination of map units. Therefore, it was possible for a single map delineation to contain as many as nine named soil series; however, proportions of the series which occupy a single map unit were not defined.

During the late 1960's the Alberta soil survey began investigating what scale of mapping would be appropriate for the resurvey of the province. The County of Two Hills was mapped at a scale of 1:31 000 to determine if this scale was suitable and feasible. Upon completion of mapping the 1:31 000 scale was deemed inappropriate because of the length of time and effort required to conduct the survey (Agriculture Canada, Research Branch 1975). As a consequence a decision was made to map Alberta municipalities at 1:50 000. This scale was appropriate because the information content of soil surveys was maximized while the resource requirements to complete surveys was minimized.

During the mid 1980's reconnaissance surveys became a cooperative effort between Agriculture Canada and the Alberta Research Council. The federal soil survey unit also continued to map soils in the southern portion of the province. In 1989, field mapping was discontinued by the Federal unit. The Alberta Research Council continues to map counties at 1:50 000. At present there is no systematic approach to mapping counties. The decision on which county is mapped is made by the Alberta Coordinating Committee for Soil and Land Inventory (ACCSLI). To date, 11 counties or municipalities have been completed or are currently being surveyed at 1:50 000 (Agriculture Canada 1990). Presently, most legends are closed and use a combination of a soil series code and a number modifier to characterize map units. Closed legends have all soils, combinations of soils, phases and topography listed and described in the legend.

The creation of the taxonomic system in 1955 contributed to a focus on soil taxonomy in soil surveys for approximately 25 years. The emphasis has created many problems for those responsible for compiling, mapping and correlating soil series information because taxonomic rules forced mappers to separate soils which had very similar field properties. The result was that many similar soils series were created that cannot be easily recognized and separated in the field. Even more confusion was created because many of the similar soil series were not properly recorded or documented.

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