LANDS DIRECTORATE
DIRECTION GÉNÉRALE DES TERRES

AREA SAMPLING STRATEGIES IN RELATION TO LAND USE MONITORING NEEDS AND OBJECTIVES

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AREA SAMPLING STRATEGIES IN RELATION TO LAND USE MONITORING NEEDS AND OBJECTIVES

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et objectifs de la surveillance de l'utilisation des terres

ABSTRACT

Given the need to monitor what is happening to Canada's land resources, the Canada Land Use Monitoring Program in the Lands Directorate of Environment Canada has already initiated projects dealing with land use changes in the urban-centred regions and prime resource lands of the country. Beyond these urban-fringe and unique areas, there are still vast areas of rural resource lands which are also undergoing various changes consequent upon urbanization and economic development. In this report, based on an appreciation of the nature of rural land use change, a conceptual framework for reviewing sampling strategies and a review of selected existing sampling programs in other countries, recommendations are made on the broad structure of a rural land use monitoring program for Canada and on the necessary next steps required prior to eventual implementation.

RÉSUMÉ

Étant donné la nécessité de surveiller ce qu'il advient des terres du Canada, les responsables du Programme de surveillance de l'utilisation des terres au Canada de la Direction générale des terres (Environnement Canada) ont déjà mis sur pied des projets portant sur l'étude des changements d'utilisation des terres situées en zones urbaines et des terres de choix. Outre ces terres, il y a de vastes régions rurales dont l'utilisation est en train de changer en raison de l'urbanisation et du développement économique. Le présent rapport est basé sur une évaluation de la nature des changements qui se produisent dans l'utilisation des terres rurales, sur un plan d'examen des méthodes d'échantillonnage et sur l'étude de certains programmes d'échantillonnage actuellement en cours dans d'autres pays; il contient des recommandations sur la structure globale que pourrait avoir un programme national de surveillance de l'utilisation des terres rurales ainsi que sur les prochaines étapes qu'il serait nécessaire de franchir avant l'application éventuelle d'un programme du genre.

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1. INTRODUCTION AND OVERVIEW

1.1 Objectives

The objectives of this report are twofold:

a) to undertake a review of existing sampling approaches designed to develop valid and systematic land use information in other countries, emphasizing the United States and West European experiences and paying particular attention to how such approaches relate to the expressed needs and objectives of the Canada Land Use Monitoring Program (C.L.U.M.P.);

b) to develop a framework encompassing various area sampling strategies and to make recommendations concerning the broad strategy that C.L.U.M.P. should follow in rural areas, including priorities of research efforts and any testing of alternative strategies needed to assess relative accuracies and costs.

In relation to the first objective, the approach used has been to utilize information currently available from the Lands Directorate on various foreign sampling programs, supplemented with a review of selected professional journals and other reports accessible at the University of Waterloo. Additional information was also acquired through personal contact with certain agencies. In relation to the second objective, a framework is developed based both on consideration of the literature relating to the various foreign programs and on an appraisal of the general literature dealing with sampling. The approach, elaborated upon in the body of the report, is thus both reflective and synoptic; no application of the various sampling strategies is therefore performed, though a selection of various hypothetical situations and examples are used in the report to illustrate key points. Reference is also made to selected previous tests of different sampling strategies as well as to a specific data set dealing with land use change that highlights the problems of monitoring through sampling.

1.2 Structure of the Report

Since this report is concerned with a review of sampling strategies with an emphasis on the monitoring and detection of change in relation to the needs and objectives of C.L.U.M.P., the first step is to set the scene by identifying these expressed needs and objectives (section 2). This is necessary in order to evaluate other programs in relation to these needs and objectives. Generally speaking, programs are set up in relation to specific goals and it is therefore necessary to establish any differences in this respect.

While certain statements have been made in the context of C.L.U.M.P. discussion papers regarding, for instance, levels of precision and reporting levels, these decisions on implementation should not be regarded as absolute. There may well be situations where a different set of implementation rules will be more appropriate, even though the general needs and objectives can still be met.

The emphasis of the review is on the ability of different approaches to detect land use and cover change, so a general review (section 3) of the nature of land use and cover change is presented. Some data are presented to illustrate right from the outset the difficulties of detecting certain types of changes. While the development of a framework that can be used to place the various approaches into perspective arose out of the review of the program examples selected and of the general literature, this framework is discussed in section 4 since it provides the backdrop against which the specific selected programs can be placed. At the same time, the role of different data sources, for example census data, medium level air photography and Landsat imagery, in contributing to a monitoring program is also noted, since different data sources may also allow different needs and objectives to be addressed.

In section 5, a selected number of foreign programs are reviewed, and key issues are identified and related back to the needs and objectives of C.L.U.M.P.

Finally, a set of recommendations is made which represent the authors' views on the priorities for a land use monitoring program, the evaluation of the various foreign programs reviewed and likely developments in information processing and retrieval in the future. Particular concern is expressed for developing a national program that is capable of being integrated with potential provincial and regional programs of monitoring, that permits a maximum utilization to be made of existing and ongoing independent data collection and storage systems (for example census data) and that would permit the integration of additional types of data that do not currently have a high profile in C.L.U.M.P.

2. NEEDS AND OBJECTIVES OF THE CANADA LAND USE MONITORING PROGRAM

At the most general level (Gierman, 1981), three objectives have been identified for Land Use Monitoring programs:

a) to monitor land use trends;
b) to monitor the amount, location and type of land use change; and
c) to monitor land use change in special areas.

The term land use is intended to incorporate the dimensions of cover, activity, tenure/ownership and resource quality (Gierman, 1981, p. 2). It is important to keep this broad interpretation of land use in mind; most of the discussion that has been documented in the Lands Directorate in relation to C.L.U.M.P. has focussed on cover, activity and resource quality. Land ownership characteristics have been largely put aside from the discussion because of cost considerations, despite the important relationships that can be identified between changes in land ownership and subsequent changes in land use. While this may be a reasonable position at the present time, it would be well to remember that certain strategies of data collection from rural areas could be used as a base for the collection of systematic data on land ownership more easily than others.

At a somewhat more specific level (L.U.M.D., 1980a), objectives for a Land Use Monitoring program have been identified as:

a) the monitoring of land use on national and regional scales with a view to producing statistics, maps, and reports;
b) to provide a national perspective and data base which will aid in the evaluation of federal government programs; and
c) generally, to allow the Lands Directorate to perform its watch-dog role in relation to the land resources of the nation.

In addition, it has been suggested (L.U.M.D., 1980b) that the C.L.U.M.P. program, while emphasizing the land cover and activity dimensions of land use, should provide opportunities for researchers to correlate C.L.U.M.P. data with other (socio-economic) data bases.

Finally, five sets of statements regarding implementation of a monitoring program based partially on sampling can be found in C.L.U.M.P. documents (for example C.L.U.M.P./H.Q., 1980), some of which have already been adopted. They are outlined here and commented upon briefly.

a) It is suggested that the country may be divided (loosely

stratified) into a number of major domains based on the type and change of major land uses, viz. urban-centred regions, rural areas, prime resource lands, and the wildlands domains.
The urban-centred region component of C.L.U.M.P., involving total inventory of cover and activity, is already being implemented.
Prime resource lands are selected on a priority basis. The first prime resource lands study, fruitlands, uses a total inventory approach for monitoring. However, future prime resource lands projects could employ a sampling approach. No firm statements are available on the wildlands domain. So the domain of primary concern for this review is the rural domain.

It is worth noting, however, that the specific delimitation of the urban-centred region versus the rural domain is not without considerable importance. As is argued later, any stratification is only effective if it results in relatively homogeneous strata being produced, unless of course the unit(s) defined has(have) some meaning in terms of a reporting unit. Furthermore, given the concern expressed above over compatibility of reporting units with other data sources (for example census data), some attention should be given to the specific delimitation of the urban-centred regions.

b) In terms of reporting levels, the primary reporting units given the national perspective that C.L.U.M.P. must take are the nation, the five main traditional groupings of the provinces and the provinces themselves.
C.L.U.M.P. had also expressed interest initially in a lower level of reporting units based on approximately 50 to 60 land use regions (C.L.U.M.P./H.Q., 1980); considerations of the primarily national role of C.L.U.M.P. as well as cost suggest that reporting units below the level of the provinces should not be the responsibility of the Lands Directorate. However, it is important to recognize that many other users would be more interested in a finer scale of reporting; with this in mind, it is appropriate to consider a national program that would permit the integration of regionally-initiated and supported endeavours aimed at monitoring change on a finer geographic scale. The combined questions of the scale of reporting units and flexibility to permit finer scales of reporting in the future are significant ones; they imply that, if some set of land use regions was to be utilized as a means of stratifying the rural domain in order to

develop cost-efficient estimates of land use change at the provincial level, there should nonetheless be a specific relationship between such strata and the potentially finer reporting scale. Furthermore, the number and size of the reporting units have implications for the magnitude of effort required to meet given levels of accuracy (see below).

c) A time frame for the urban-centred regions of complete inventory every 5 years has been adopted, and the suggestion has been made that a 10-year interval would be most appropriate for sampling rural areas.
In earlier statements regarding C.L.U.M.P. (L.U.M.D., 1980a, p. 9), these 10-year samples were seen as being embedded in a complete inventory every 30 years; one of the basic reasons for this was related to "quality" control of the sampling. However, quite apart from cost considerations, other forms of checks could be applied without necessitating complete inventory of the whole country, for example a denser sampling for some reporting units every other sample year, the use of census material as a gross check, and/or the maintenance of regional files documenting land use trends (for example planning studies, theses, etc.). As another comment here, the time frame used in a sampling program to detect change is particularly important since it affects the relative magnitude of the area undergoing a particular type of change. For this reason, given the slow pace of change in rural areas, a 10-year interval would be more appropriate than a 5 year one.

d) Land activity and cover data are to be developed, essentially from remote sensing data (at present from medium scale, black and white photography), within the context of the new classification adopted by the Lands Directorate (Gierman, 1981). For a given level of expenditures on a sampling program and for given levels of precision (see section 4 for definition of this term), the level of detail actually utilized from a given classification system is not independent of the number of reporting units across the country. As the number of reporting units increases, the level of classification detail attainable within a sampling program decreases. This issue is discussed at greater length below.

e) There has been a suggestion that in monitoring land use, only significant land uses should be identified. The tendency has been to associate this with a category that covers, for example, at least 3% (C.L.U.M.P./H.Q., 1980) of the area to be sampled - for example a land use region or a province. In relation to sampling, the figure of estimating each major land use with a maximum allowable error (see below) of 5% of the estimate at the 95% confidence level has also been suggested.

The question arises as to what really constitutes "significant" and whether, in any case, other approaches rather than sampling from remote sensing data might be appropriate for some uses. An alternative way of asking the question is how might one "rescue" uses that are not "major" at a specific point in time; might there not be some interest in having some data on minor uses that become major? It may require that attention be paid to any use or change, however insignificant statistically, that is noted; it would require further enquiry, for example through provincial and regional offices, to ascertain when such uses or changes might become of practical significance, thus necessitating, for example, modifications to the level of detail in land use reporting.

The above recommendations or suggestions gleaned from various Land Directorate documents and discussions with Lands Directorate staff should not be regarded as sacrosanct. In the general discussion of the nature of change and various sampling approaches that follows, comments are offered both on the nature of the general objectives of a C.L.U.M.P. as outlined above and on the specific suggestions for implementation enumerated above.

3. THE NATURE OF LAND USE CHANGE

An essential first ingredient to a land use monitoring program is not so much the classification system of land uses or the technology to be used to provide raw data but rather the identification of what is considered to be the types of land uses and changes worth detecting. Some land use changes may be considered significant because they involve the transfer of a resource with particular qualities irreversibly from one use to another, for example high quality agricultural land to urban uses, or land with a high capability for recreation to residential uses or extractive industry. If such resources are highly valued, then the impacts of such conversion on the resource base should be documented. In other instances, some land use changes may result in impacts not only on the resource base but on surrounding land uses, for example scattered nonfarm development and its impacts on agricultural development; a first step in evaluating such impacts is evidently to document the extent of the land use change involving such residential development. In still other cases, certain changes may have significant implications for the economic and social structure of an area, for example industrial development in a rural area. While it is impossible to identify all types of land use change that might be significant in the future, a reasonably comprehensive list could be made up.

Only then is it logical to consider how such uses and changes might be detected and what the basic source of data should be. In terms of the cover and activity dimensions of land use, a major source of data is remote sensing imagery combined with various degrees of field checking. With the new land use classification system (Gierman, 1981), conventional aerial photography would provide a major input. However, not all of the categories can be identified from remote sensing imagery. It is also important to note that, in representing an area with its various land use classes in cartographic form, certain types of land use may not be represented depending upon the scale of representation, for example scattered nonfarm residences. It is therefore important to match the classification system, the raw data base and the way in which the data are collected (for example for points versus areas) and represented against those land uses and changes which it is considered important to have information on.

Several approaches have been suggested to this question. Rump and Gierman (personal communication) have developed a suggested C.L.U.M.P. classification subset for cover and activity in rural areas (Table 1). It is based on two criteria. First, the classes occupy a sufficiently large area to be defined by a sampling approach with reasonable accuracy at the national level. Second, the classes reflect the distinction between the major land use activities that involve utilization of land as a renewable productive medium (agriculture, forestry, wildlife and recreation) and those activities dependent upon land as a site or for some nonrenewable resource quality.

However, the question still remains of whether monitoring of such classes can effectively shed light on some of the important processes affecting the rural areas. Much of the general process relating to the spread of urban and urban-associated uses into the rural environment may be accommodated by using such coarse categories through sampling, though the urban-centred region program in C.L.U.M.P. already deals with the

TABLE 1

SUGGESTED LAND ACTIVITY/LAND COVER CLASSES FOR NATIONAL MONITORING WITHIN RURAL AREAS

Land Activity Classes

Class	Code[*]	Name[*]
1	01110	Growing Annual Tillage Crops
2	01120	Growing Forage Crops and Grazing
3	02100	Productive Land-Forestry Activities
4	03100	Productive Land-Wildlife Activities
5	05100	Productive Land-Recreation Activities
6	01200, 02200, 03200, 04000 05200, 06000-10000	Site Activities[**]
7	12100	Former Agricultural Activities
8	11000, 12200-12900, 13000 14000	Other[***]

Land Cover Classes

Class	Code[*]	Name[*]
1	01100	Tall Trees
2	01200	Small Trees, Shrubs, Dwarf Trees
3	02100	Annually Cultivated Crops
4	02210	Improved Grass and/or Legume Cover
5	02220	Natural Grassland, Reeds and Sedges
6	03000	Denuded (Bare) Surfaces
7	04000	Constructed Cover
8	05000	Water

[*] Adopted from Gierman, 1981

[**] Activities which are located on the land and are not dependent on the land as a productive (renewable resource) medium. These include: Agriculture, Forestry, Wildlife and Recreation Site Activities; Extraction, Dwelling, Transportation and Communication, Manufacturing and Storing, Commercial and Institutional Activities.

[***] Includes Non-Agricultural Former Activities, No Perceived Activity, and Land in Transition.

areas of most intensive activity in this respect. However, it may not be easy to pick up through sampling with such coarse categories important processes such as rural industrialization which may have a profound effect on long-term rural resource use. And, of course, such classifications are not likely to provide much useful information on certain of the effects of some processes such as negative environmental impacts on the resource base from agricultural modernization and rationalization; this requires additional data and problem-specific enquiries where such problems have been signalled from other sources.

Furthermore, if there is a concern with providing valid and reliable estimates of the area under certain uses and undergoing certain changes (for example farmland abandonment), then regardless of whether inventory or sampling approaches are used, it is well to recognize the existence of other sources of possible errors. If there are biasses involved in, say, a land use classification system, the errors involved could be greater than the sampling errors introduced if sampling of some kind were used. Under certain circumstances, indeed, sampling may lead to a reduction in such classification errors by permitting more careful interpretation of each sampling unit. Based on the London urban-centred region example noted below, it is evident that such misclassification problems were substantial in the earlier stages of the original Canada Land Inventory (C.L.I.) system, especially in relation to the distinction between cropland and unimproved pasture and between productive and unproductive woodland. In terms of utilization of satellite imagery, such misclassification problems (for example Fitzpatrick and Chambers, 1977) continue to raise serious questions regarding its utility in a monitoring program based on any form of sampling; in Howarth's study (1982) for the Lands Directorate, for example, accuracy levels in a simulation study of the forthcoming developments in satellite imagery varied from 40 % to 100% depending upon the particular use. Careful instruction, checking and, for some data sources, technological advances may eliminate such problems; in other instances, the bias may be explicit, for example agricultural census data based on a specific definition of a census farm, so that care must be made in interpreting such data in relation to the land resource.

The types of change, and how they are represented in some classification system, represent only one dimension of change. Other important dimensions are the nature of the processes underlying land use change (for example, is it related to urban areas in a distance-decay relationship or is it related to particular resource endowments?) which may have a bearing on any stratification procedure used and the interval over which land use change is measured. The interval (for example 1 year, 5 years, 10 years) is important in relation to process. Some processes of change are, by nature, slow; given the problem of misclassification and the adoption of a sampling approach, misclassification error may obscure patterns of real change to a greater extent the shorter the interval over which change is to be detected.

Change in rural areas does tend to be slow; in the context of sampling approaches and in relation to the question of what is an important land use and change, this poses some considerable problems because it means that the areas undergoing specific types of change will often be rather small and suggests that the longer time period of 10 years compared to 5 years for the urban-centred region domain is a more reasonable time-frame for sampling the rural areas. Even taking the London urban-centred region (an area of approximately 98,000 hectares involving roughly a 16 km radius around the city of London, Ontario), it is evident that land use change does not account for large areas, even though the change in a specific land use may be very important measured by the initial magnitude of the land use. On Tables 2 and 3, the matrices of change in land uses for the London urban-centred region are given for the periods 1963-1970 and 1970-1976, based on the original C.L.I. land use classification and abstracted from a tape of land use change polygons provided by the Lands Directorate. On the one hand, it is important to note that only 5 of the land uses (A, B, K, T and U) meet the critical percentage of ⩾3% of total land area identified by C.L.U.M.P. (C.L.U.M.P./H.Q., 1980) and that none of the individual change categories (the off-diagonal elements) meets that threshold value. This has implications for the detection of change through sampling (see below). On the other hand, focussing on the 1970 to 1976 matrix because it appears that several of the relatively large changes between 1963 and 1970 (for example from K to A, K to B, A to K) could well be due to classification errors, only 4.05% of the total land area experienced some form of land use change between 1970 and 1976.

Taking the period 1963 to 1976 and accepting any misclassification, even though the total area undergoing change (Table 4) represents almost 20% of the regional area, no single type of change meets the 3% level, though changes A to B and K to A come close to it. Thus, using a longer time period certainly increases the probability associated with specific types of change but even so, the

TABLE 2

LAND USE CHANGE, LONDON URBAN-CENTRED REGION, 1963 - 1970*

C.L.I. Land Use Classes**		1970												TOTAL
		A	B	E	G	H	K	L	M	O	S	T	U	1963
	A	59707	2135	333	37	176	1208		3	191		166	486	64443
	B		8885											8885
	E	9	106	412			39			15			5	586
	G	39	47		201								4	292
	H	1100	93		5	174	30					6	2	1409
1963	K	2895	1571	49	9	22	4373			101		236	526	9781
	L							9						9
	M								20				4	24
	O									156				156
	S		8	26							9			42
	T	271	435	94		3	381		9	85		5114	1368	7762
	U	463	280	28		4	649	7		8		677	2346	4462
	TOTAL 1970	64484	13559	942	253	379	6681	16	34	556	9	6198	4742	97852

*Rounded to nearest hectare; 3% of area = 2936 ha.

**C.L.I. Land Use Classes:

A = cropland (including improved pasture and forage crops); B = built-up area; E = mines, quarries and gravel pits; G = orchards and vineyards; H = horticulture, poultry and fur operations; K = rough grazing and rangeland; L = non-productive land (rock and other unvegetated land); M = swamp, marsh or bog; O = outdoor recreation; S = non-productive (sand) that does not support vegetation; T = productive woodland; U = non-productive woodland.

TABLE 3

LAND USE CHANGE, LONDON URBAN-CENTRED REGION, 1970 - 1976*

C.L.I. Land Use Classes**		1976												TOTAL
		A	B	E	G	H	K	L	M	O	S	T	U	1970
	A	62302	710	87	3	45	987			84		68	197	64484
	B		13559											13559
	E	4	9	847			68			1			13	942
	G	2			251									253
	H	15	8			356								379
1970	K	119	130	6			5936			40		50	400	6681
	L							16						16
	M						2		30				2	34
	O		1							554				556
	S										9			9
	T	48	24	8			45					5540	533	6198
	U	37	13	6			93					110	4484	4742
TOTAL 1976		62525	14455	954	255	401	7131	16	30	679	9	5768	5629	97852

*Rounded to nearest hectare.

**See Table 2.

TABLE 4

LAND USE CHANGE, LONDON URBAN-CENTRED REGION, 1963 - 1976*

C.L.I. Land Use Classes**		1976												TOTAL
		A	B	E	G	H	K	L	M	O	S	T	U	1963
	A	57832	2813	397	41	204	2003		3	271		217	662	64443
	B		8885											8885
	E	9	108	344			101			16			10	586
	G	38	51		200								4	292
	H	1078	105		5	166	46					6	4	1409
1963	K	2783	1731	63	9	25	3941			126		266	836	9781
	L							9						9
	M						2		16				6	24
	O		1							155				156
	S		8	26							9			42
	T	304	465	92		3	387		11	92		4613	1796	7762
	U	481	289	33		4	65	7		19		666	2311	4462
TOTAL 1976		62525	14455	954	255	401	7131	16	30	679	9	5768	5629	97852

*Rounded to nearest hectare.

**See Table 2.

amount of land undergoing such change is still relatively small. If this is the nature of change in an Ontario urban-centred region, however, how much more slowly would land use be changing in more rural regions of Canada. The issue of trying to detect relatively small areas with a specific set of land use characteristics (including use at time t and (t+1)) is highlighted by the nature of the land use data that were identified in 1980 (C.L.U.M.P./H.Q., 1980) as being appropriate for reporting at each reporting level. To summarize, the data suggested as appropriate for reporting for each reporting level and unit are:

a) area data:
    i. area in each land use,
    ii. net change in each land use, and
    iii. the gross change from one land use to another (i.e. the off-diagonal elements of Tables 2 and 3) and the areas of stable land uses (the diagonal elements);
b) composition of land uses in the area (i.e. % distribution of land uses) and composition of land uses and change across all regions;
c) relationship of land use change to land capabilities, i.e. for agriculture, wildlife, recreation and forestry - this could lead to area estimates as well as estimates of relative importance (i.e. proportions, percentages); and
d) the tracing of trends over more than two time periods.

For the estimates involving the areas of gross changes, significant problems may arise with sample size and operational cost to attain given levels of precision. The problems are compounded when additional filters (for example agricultural land capability) are used, thus increasing the number of specific combinations of characteristics that potentially have to be estimated (see below). Despite such problems, it is clearly of importance to assess the relationship between gross change in land uses and land quality, as well as simply the movements between uses. Data on net change may be interesting at a general level; but a stable land use in terms of its importance in the land use structure over time may in fact mask considerable gross changes and a very dynamic situation. The matrix in Table 5 illustrates the point with a simple land use situation, covering an area with an assumed size of 100 hectares with four land uses A, B, C and D, inventoried at two points in time, 10 years apart.

In this hypothetical situation, 5% of the total area underwent a change in land use, even though by looking at the differences in the total

TABLE 5

HYPOTHETICAL SITUATION OF LAND USE CHANGE*

		Time (t + 1)				
	Use	A	B	C	D	Total area at time t
	A	62.5	+2.5	-	-	65.0
	B	+1.5	22.5	+0.5	+0.5	25.0
Time t	C	-	-	5.0	-	5.0
	D	-	-	-	5.0	5.0
Total area at time (t + 1)		64.0	25.0	5.5	5.5	100.0
Net shift in land use		1.0	0.0	0.5	0.5	2.0
Net change from initial land use magnitude (%)		-1.54%	0.0%	+10.0%	+10.0%	-

*Hectares

distribution of land uses it appears that there was a redistribution of only 2% of the land area. Even so, the area of each type of gross change even with a coarse land use classification system is not likely to represent a large proportion of a reporting unit (for example land use region) which poses problems for estimation of areas involved (Cochrane, 1963, p. 54). It might be worth considering whether under some circumstances the significant index of change to be measured is simply all land undergoing any type of change (in relation to the classification system used).

Assuming correct classification, complete inventory of land uses in an area eliminates these types of problems yet raises very real barriers in terms of cost, especially for an area the size of rural Canada (the agricultural "ecumene" of Canada is roughly 1.2 million square km while the area covered by the C.L.I. is 2.6 million square km). However, sampling provides a strategy for reducing costs while still providing information on land uses and land use change. However, there are many different ways of sampling for land uses, ranging from probability sampling in which levels of precision can be associated with estimates of relative importance and acreages at given levels of confidence, to judgemental sampling which may give an absolutely accurate picture without, however, the reliability measures, to the inventorying of indicative or representative areas (representative, that is, of each reporting unit); furthermore, the approaches may differ in terms of acceptability depending on whether the emphasis is on identifying net land use distributions or the patterns of change. It is not the case, however, that all land uses and changes should be measured through the same sampling strategy, or even by sampling at all. The earlier discussion has highlighted the relatively small areas involved in certain changes that are nonetheless very significant economically, socially or environmentally (for example quarrying), changes which may well be better documented in other ways. Given the objectives of this report, however, the focus in the next section is on a conceptual framework within which various sampling strategies can be viewed.

4. AREAL SAMPLING STRATEGIES - A CONCEPTUAL FRAMEWORK

4.1 Comparisons between Sampling Strategies

A large variety of sampling strategies exist. Critical differences exist between them on two fronts: a) their statistical efficiency and b) their operational efficiency.

a) Statistical comparisons between sampling strategies

Assuming that a given data set is being investigated, how can choices be made between different sampling strategies? To provide some insights into this, a number of terms need defining, viz. accuracy, precision, relative accuracy, relative precision and relative efficiency. In sampling where the objective is the evaluation or estimation of a population parameter (for example the true mean across the population of items, the true ratio between the totals of variables x and y), the critical point concerns variability of the estimates derived from a sample of items. With no variation between items (for example points, cells), then sampling is a simple matter! Given variation, repeated independent samples of the same type will yield a range of estimates. The degree of variation in a population is represented by the variance or

$$\sigma^2 = \left(\sum_{i}^{N} (y_i - \bar{Y})^2 \right) \div N$$

where $\bar{Y}$ = the mean across the N items in the population. Different sampling strategies differ in terms of how well they are able to capture or control for this variation and reduce the potential variation (known as sampling error or the standard error or standard deviation of the sampling distribution of the estimate) in the values, for example, of the sample mean, $\bar{y}$, used to estimate the population mean, $\bar{Y}$.

Accuracy refers to the degree of bias in measurement of the true population parameter, and is very difficult to identify since the true population parameter is usually not known. Precision refers to the range of results or estimates obtained by repeated application of the sampling strategy. In terms of statistical efficiency comparisons between two different strategies and as aids in the choice of a method (Berry and Baker, 1968), a number of different measures can be used (Yates, 1965, p. 247):

relative accuracy = the ratio of the sampling variances of the estimates of two samples.

relative precision = the ratio of the sampling variances of the estimates of two samples using different approaches but with the same number and same type of sampling unit.

relative efficiency = the ratio of the number of sampling units required by two different sampling strategies to achieve a given level of precision.

Note that relative efficiency in terms of number of required sampling units assumes equal costs of data collection per sampling unit under each strategy. To the extent that this is not the case, then consideration also must be given to <u>operational efficiency</u>.

b) <u>Operational efficiency</u>

With cost estimates of different strategies, it is possible theoretically to select a strategy that provides a given level of precision at least cost. In addition, there are other aspects of operational efficiency which may complicate matters, for example it may be possible to obtain greater classification accuracy with points than with areas because of greater concentration of effort. Finally, evaluation of cost is a delicate issue when the technology of certain types of data collection is rapidly changing, for example satellite imagery and automated interpretation. This is likely to be particularly significant in a long term monitoring program.

In a monitoring program based on sampling, four dimensions can be noted that can be used to characterize any specific areal sampling strategy: a) random versus systematic; b) stratification versus nonstratification, including extent of sampling in different domains; c) form of the areal sampling unit used; and d) the relationship between samples at time t and (t+1) in the detection of change. Each dimension is briefly discussed below in terms of statistical efficiency, and in terms of any operational issues involved in sampling from remote sensing sources. First, however, a brief section is devoted to the issue of variations in land use distributions.

4.2 Variation in Land Use Distribution and Land Use Change

It is important to distinguish between an elementary spatial unit (for example a point) and clusters of such elementary units (for example a cell or administrative unit). This determines the nature of the variable that is measured. With points, the measurement of land use is normally of a <u>qualitative variate</u> (i.e. a variable measured on a nominal scale) while with clusters, the measurement is of a <u>quantitative variate</u> (for example the percent or proportion of a cell's area or second-stage sampling units in a particular land use). In either case, composition of land uses and areas of land uses and change can theoretically be estimated, but size of cluster represents a significant decision (see below).

What are the dimensions of variability that exist across the population of, say, a map containing the distributions of several land uses and land use changes and how are they related to sampling strategy? Three aspects can be noted.

a) The magnitude (both in terms of area and of percent of total area) of a specific use or change category. This has an influence on sample size in detecting both the proportion of total area and the actual area undergoing a specific type of change. Relative magnitude of a use or change category is not independent of study area size (for example, the size of a reporting unit). With positive spatial autocorrelation for specific categories and spatial differences between different categories, one may expect a smaller range of categories to be present in any specific reporting unit than in an aggregation of such reporting units (contrast county with a province). Thus, the magnitude of some individual categories present in a small reporting unit is likely to be higher than in a more aggregated study area.

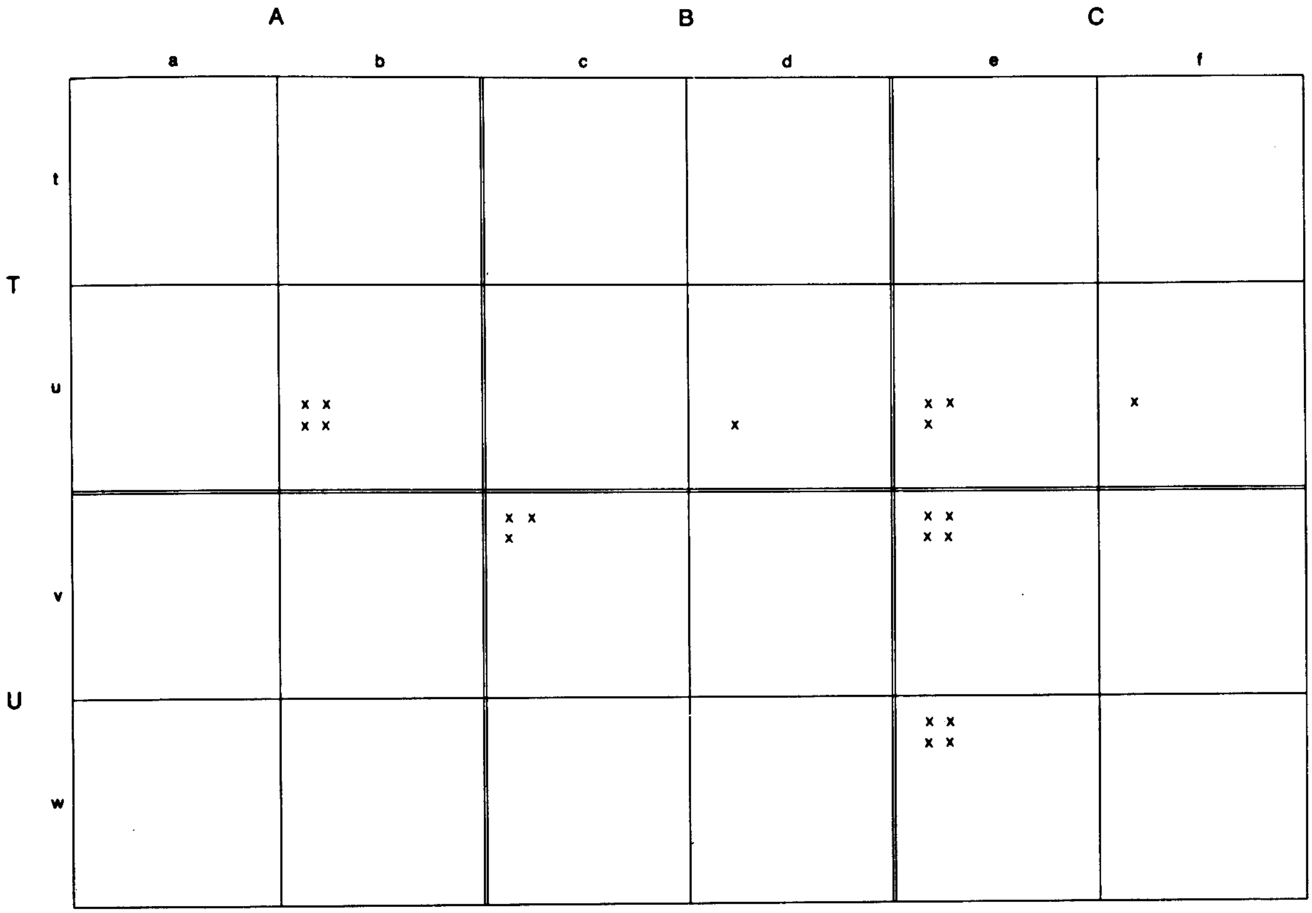
b) The spatial form or distribution of the phenomenon (for example is the pattern clustered/clumped, dispersed/uniform, random, linear or periodic?). The choice of strategy is greatly influenced by the distribution-type (Berry and Baker, 1968, p. 94). "If the underlying distribution has no pattern, it would seem not to matter which design we choose" (Taylor, 1977, p. 78).

The type of pattern is important because, with any form of cluster sampling, it influences the variability between sampling units and thus sample size. Furthermore, it may have a bearing on whether stratification is appropriate and on whether detecting the pattern in the context of a multipurpose sampling approach is indeed even appropriate. When the sampling units are in effect clusters, then the size of sampling unit influences variability. For instance, with a clumped pattern being sampled by grid cells (clusters of elementary sampling units, for example hectares of land), once the grid cells or clusters become larger than the individual clumps or land use concentrations in the pattern the variance across the population will decrease, up to a certain point.

In Figure 1, a simple land use distribution is depicted, which is sampled with two different sizes of grid cell. The data on the importance of this use can be abstracted using either 24 small cells or 6 large cells. The estimated variances and standard deviations of the two levels of aggregation are given in Table 6. Thus, at the finer level of aggregation, the variance is over five times the magnitude of the variance associated with the coarser level of aggregation. Cell size has an equally important influence on any research aimed at investigating relationships between two phenomena, each of which is spatially autocorrelated; with increasing cell size, if a correlation exists, the estimated correlation will increase to a certain level as the idiosyncratic terms or random disturbances cancel each other out (Taylor, 1977).

The reduction in variance that is associated with increasing cell size is related to the fact that each cell or cluster becomes more closely representative of the total population, a good situation for a cluster. With a fairly uniform geographic distribution with some random disturbances, once a threshold in cell size is reached, increasing cell size will not markedly influence the variance, and, of course, a perfectly uniform distribution will eventually yield a variance of zero at the appropriate grid cell size, or filter, scale. It is interesting in this respect to note the Lands Directorate's analysis of C.L.I. data for the Ontario study area, using grid cell sizes ranging from (2x2) sq.km. to (16x16) sq.km. and 8 different grid cell sizes (Figure 2). Measuring land use in percentage terms, it is interesting to note that cropland (use A) exhibits a very stable variance. The variance here remains relatively intact because, while there is significant spatial concentration of the uses, the concentration involves a broad geographic variation (general geographic trends) rather than the more scattered type of concentration found in a clumped pattern. In contrast, the substantial reduction in the variances for the built-up area (use B) and for mines, quarries and gravel pits (use E) can be appreciated because of their rather clumpy distribution. Finally, productive woodland (use T) shows a marked decline in variance from the (2x2) sq.km. to the (4x4) sq. km. sizes, but then exhibits a relatively slow reduction in variance thereafter. One interpretation is that the

FIGURE 1: DISTRIBUTION OF A 'POINT' LAND USE IN AN AREA †



		A		B		C	
		a	b	c	d	e	f
T	t						
	u		x x x x		x	x x x	x
U	v			x x x		x x x x	
	w					x x x x	

† 20 'points', each accounting for 5% (5ha) of the area of the smallest cell size and 1.25% of the area of the largest cell size. The variables, x, used in calculating the means, variances and standard deviations reported in Table 6 are thus the % of each cell occupied by the land use at each respective level of aggregation (e.g. at the finer scale, x_{ub} = 20%; at the coarser scale x_{TA} = 5%).

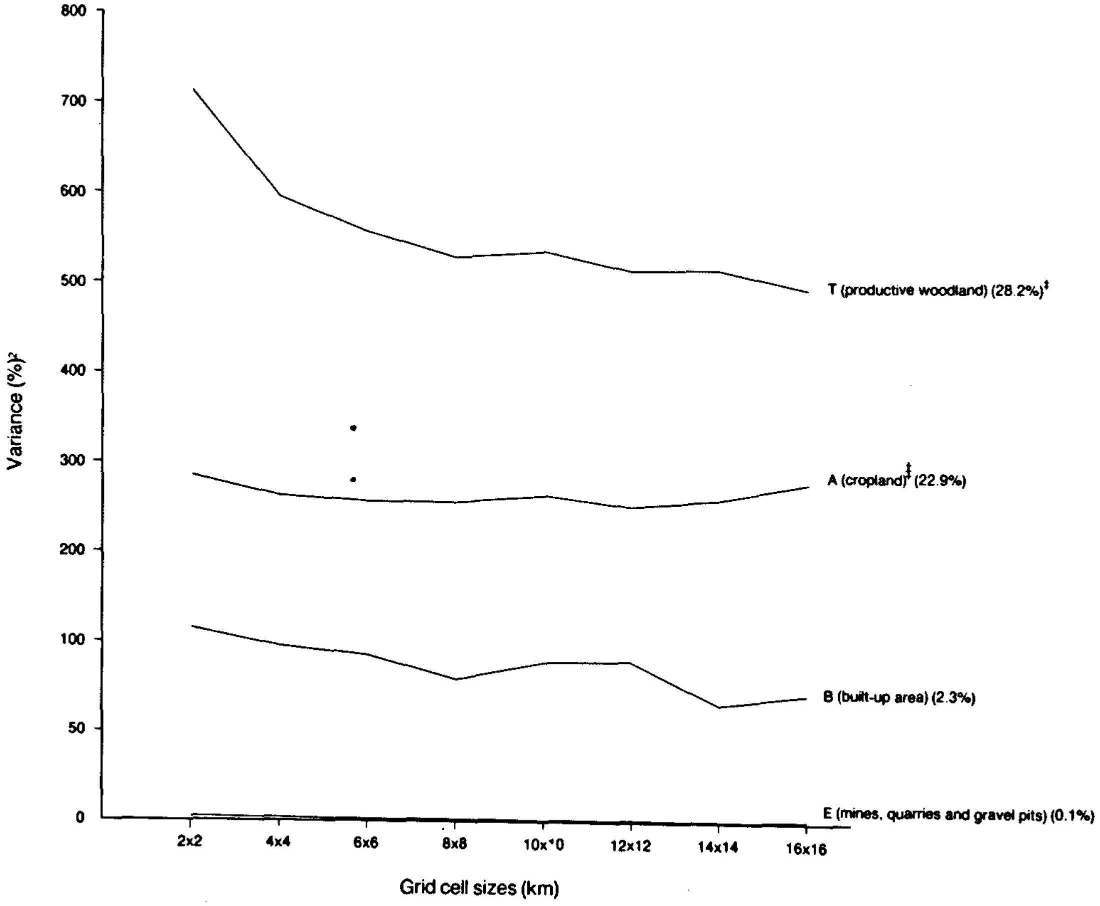
TABLE 6

VARIANCES FOR A LAND USE UNDER DIFFERENT CELL SIZES*

N = 24 cells	N = 6 cells
$\bar{X} = 4.17\%$	$\bar{X} = 4.17\%$
$\sigma^2 = \dfrac{\sum_{i=1}^{N=24} (x_i - \bar{X})^2}{N} = 53.5$	$\sigma^2 = \dfrac{\sum_{i=1}^{N=6} (x_i - \bar{X})^2}{N} = 10.24$
$\sigma = 7.3\%$	$\sigma = 3.2\%$

*The variances relate to the point distribution and cell sizes portrayed in Figure 1.

FIGURE 2: VARIANCES FOR SELECTED LAND USES FOR DIFFERENT GRID CELL SIZES †



† Data derived from the Ontario study area (Bircham, 1979).

‡ Percentages refer to the percent of the total area in Bircham's study that was categorized under each particular use.

⹋ Does not include improved pasture and forage crops.

second size of cell has reduced the effect of many relatively small scale clumps and that thereafter the variance reduction is much smaller because the pattern is then more the result of broad regional variations in woodland cover.

Clearly, the population distribution is of paramount importance; many times, a sample of units each comprised of several geographically adjacent elementary sampling units will not be as efficient as a sample of the original elementary units (with the same numbers of elementary sampling units in each sample) because the geographic cluster is comprised of like units (Yates, 1965). There may, of course, be other more persuasive reasons for sampling clusters.

c) Finally, <u>the variety of changes and uses</u> creates problems in developing a sample strategy to cope with many different estimates. It is relatively easy for many sampling strategies to develop a minimum of size of sample to get at given levels of precision, however, when there is an interest in several distributions, severe problems may be posed (Yates, 1965, p. 229). In other words, a sample of a given size and type may yield quite different standard errors (see below for definition) of the sample estimates for different characteristics of the sampling units. It may be that one must focus only on what are considered <u>critical</u> uses and changes, a decision that will be easier if there are very strong intercorrelations between the different uses.

However, problems may still arise where there is substantial variation in the magnitudes of the different uses or changes. In particular, uses or changes that are relatively small (in areal terms), but which may be <u>very</u> important economically or environmentally, pose major problems for multipurpose sampling strategies. If it is important to have relatively precise estimates of such uses, a different method of acquiring the information may be called for; for example, if the reporting unit is made up of administrative units, it may be quite a simple matter to acquire a list of all instances of a given land use (for example gravel pits, educational institutions) from which to either make an inventory or undertake a sample. It may therefore be possible, and more reasonable, to sample for certain "major" uses or changes ("major" in terms of their land use magnitude) from one source of information and to utilize another source of information to develop estimates for other uses. Sometimes, such a distinction may be appropriate, not only because of different land use magnitudes, but also because of differences in the level of detail implied in a classification system. Thus, the relative importance and area of the built-up area, or urban-associated land uses, may be quite easily estimated using some sample procedure from remote sensing data, but if there is an interest in, say, schools, it would be silly (as de Bruijn (1979) points out) to expend valuable resources trying to detect what is a school from remote sensing data, when other sources would provide an easier, quicker and perhaps ultimately more accurate picture of the land use in question.

4.3 Four Dimensions to Characterize Areal Sampling Strategies

Repeated application of the same sampling strategy provides a sampling distribution of the particular estimate under consideration. Sample size and type of strategy determines the precision involved. Once a sampling distribution can be identified, then it is possible to estimate, for example, sample sizes required to achieve given levels of precision. The difficulty is that for some strategies, the sampling distribution is quite easily derived, but for many others it is not (for example with systematic area samples (Yates, 1965, p. 41, 192, 229)).

4.3.1 Random versus systematic samples

A brief review of the simple random sample is in order (see Yamane, 1967; Cochran, 1963; Yates, 1965). The simple random sample with independence of selection of sampling units and with probabilities of selection equal provides a basis against which other strategies can be matched. The mean ($\bar{y}$) of a sample of size n is an unbiassed estimate of $\bar{Y}$; with a large population, the variance of the estimate of the population mean of a quantitative variate is simply

$$V(\bar{y}) = \frac{\sigma^2}{n}$$

and the standard error or sampling error is

$$S.E.(\bar{y}) = \frac{\sigma}{\sqrt{n}}$$

With a finite population, S.E. ($\bar{y}$) becomes

$$\sigma \cdot \sqrt{(1 - f) \div n}$$

where $f = \frac{n}{N}$ and N is the total number of sampling units in the population. With a normally distributed population, or with "large" samples from a nonnormal population, the sampling distribution of the mean will be normal, an important statement because it allows the use of the normal distribution in the development of confidence limits and the specification of sample size for required levels of error.

Thus, we can state that, with repeated drawings of a sample of size n, 95% of the sample estimates will fall in the interval $\bar{Y} \pm 1.96$ S.E.($\bar{y}$). In other words, $\bar{y}$ will lie in the interval ($\bar{Y}$ - 1.96 S.E.($\bar{y}$)) to ($\bar{Y}$ + 1.96 S.E.($\bar{y}$)) at a 95% confidence level. Since we do not usually know the population parameter, $\bar{Y}$, this can be reworked algebraically to state that

$$\bar{y} - 1.96 \text{ S.E.}(\bar{y}) < \bar{Y} < \bar{y} + 1.96 \text{ S.E.}(\bar{y})$$

at the 95% confidence level.

If we wish to specify a particular value of S.E.($\bar{y}$), providing we can estimate the population variance, it is a simple matter to specify the sample size required to attain a given level of precision.

Thus, with S.E.($\bar{y}$) = $\sigma \div \sqrt{n}$ or its estimate, $s \div \sqrt{n}$, where s is a sample standard deviation with denominator (n-1), then

$$n = \frac{s^2}{(\text{required S.E. }(\bar{y}))^2}$$

A sample of size n will thus allow us to state that the true mean, $\bar{Y}$, lies in the interval $\bar{y} \pm 1.96$ (required S.E.($\bar{y}$)) at the 95% confidence level. The S.E.($\bar{y}$) is expressed in terms of the original measurements (for example percent, acres, income in dollars); it is often more useful to think in terms of the level of precision in terms of the average or mean value of the characteristic being considered. Thus, the S.E.($\bar{y}$) can be expressed as a percent of the mean, giving the coefficient of variation or

$$\% \text{ S.E. }(\bar{y}) = 100 \cdot \frac{\text{S.E. }(\bar{y})}{\bar{y}}$$

$$\text{or} \quad 100 \cdot \frac{s}{\bar{y}} \div \sqrt{n}\,.$$

Thus, if S.E.($\bar{y}$) = 50 acres and $\bar{y}$ = 200 acres, the percent S.E. = 100(50 ÷ 200) = 25% of the mean; 95% of the sample estimates can be expected to lie between $\bar{y} \pm 98$ acres or between ± 1.96 (percent S.E.) of the true mean or within 49%, above or below, of the value of the true mean. The required sample size to attain a given level of precision in terms of percent S.E. is simply

$$n = \frac{\sigma^2}{\bar{y}^2} \div \left\{\frac{\text{required \% S.E. }(\bar{y})}{100}\right\}^2$$

If the maximum allowable error (M.A.E.) at a required level of confidence (say 95%) is specified, say 5% of the mean, then this can easily be converted to the percent S.E.($\bar{y}$) by calculating (M.A.E. $\div z_\alpha$) where z_α is the two-tailed normal ordinate at the given level of confidence α ; percent S.E.($\bar{y}$) equals 2.6% in this case. A finite population correction factor may be applied where appropriate.

With a qualitative variate (an attribute, for example use A, use B), similar formulae apply. In terms of the sampling distribution of the sample proportion p of units with a particular attribute as an estimate of the population proportion P (with Q = 1 - P), the variance of p is $\frac{PQ}{n}$ with mean P and standard deviation $\sqrt{PQ \div n}$ where n is the number of units in a large sample. The S.E.(p) is usually given as $\sqrt{pq \div n}$. As with a quantitative variate, where the normal approximation can be used, sample sizes can be estimated for a specified S.E.(p) although this is unwise where p (or q) is small. Thus,

$$(\text{S.E. } (p))^2 = \frac{pq}{n}$$

so

$$n = \frac{pq}{(\text{required S.E. } (p))^2}$$

Similarly, if we wish to specify a given level of precision expressed as a percent of the true value (either a proportion or the number of units possessing the attribute), the percent S.E.(p) can be defined as

$$\%\ \text{S.E. } (p) = \frac{100\sqrt{pq \div n}}{p}.$$

which gives

$$n = \frac{10{,}000\ q}{p\ (\text{required }\%\ \text{S.E.})^2}.$$

Again, if the maximum allowable error (M.A.E.) at a given level of confidence α is specified, this is simply converted to the percent S.E. by calculating M.A.E. $\div z_\alpha$. Again, the correction for a finite population can be applied by multiplying the n obtained through the above formulae by

$$1 \div (1 + \frac{n}{N})$$

thus reducing the size of sample required.

Some of the implications of the above outline can now be noted:

a) the larger the variance in the population, the larger the n required to attain a given level of precision (S.E.($\bar{y}$) or (p)).

b) the larger the required S.E., the smaller the sample.

c) for a qualitative variate, the value of n for a given S.E. is at its maximum when p = q = 0.5. The maximum value of pq may then be used to develop ultra-conservative estimates (overestimates) of sample sizes (Yamane, 1967) with very simple formulae. From the fact that n is at a maximum when p = 0.5, we can state that land uses of relatively small magnitudes may be identified with fairly small samples.

d) however, in terms of percent S.E., it is clear that for a given percent S.E. or a given M.A.E. (which equals $z_\alpha \cdot$ percent S.E. in any case), a small p, or a small $\bar{y}$, requires relatively large samples - hence the earlier comment that it is costly to use multipurpose samples to estimate the proportion or the number of units possessing an attribute within a given percent of the true value of the parameter when the attribute is scarce. It is under such conditions that alternative ways of collecting information on such characteristics should be considered.

In terms of simple random samples, while a major advantage is the ease of calculation of sampling errors, there are severe disadvantages operationally, viz.

a) the possibility of extreme sets of sampling units being selected, resulting in a rather broad scatter of possible estimates or a relatively low level of precision;

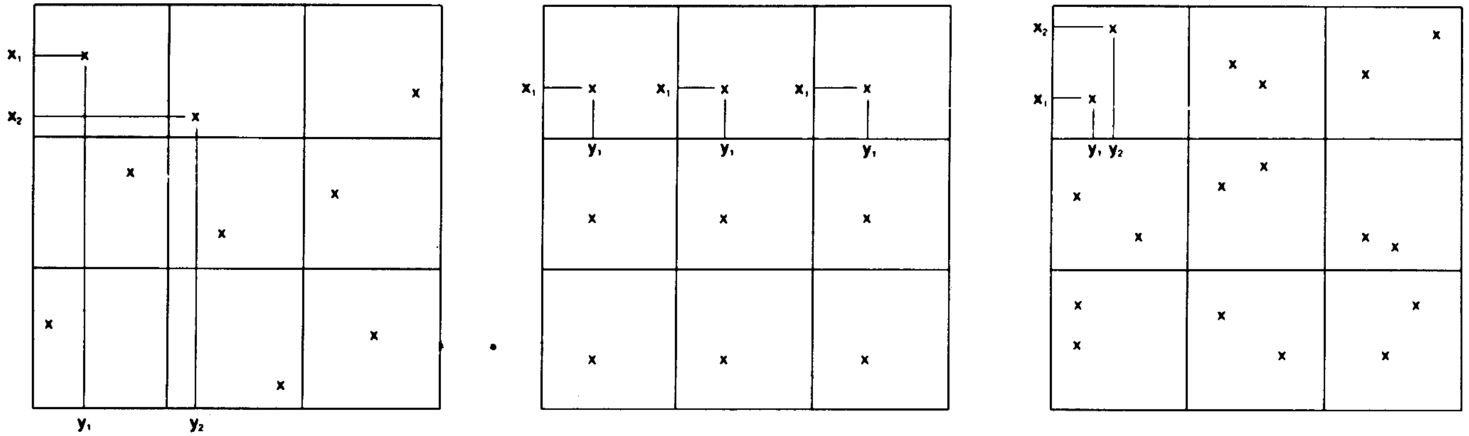
b) the possibility that some subsets of the population may not get adequate coverage; and

c) the costs involved in taking such a sample may be high, for example if the sampling units are located neither in an even nor a concentrated fashion. With conventional air photo imagery, for instance, a random set of points or cells in an area may involve very uneven unit costs of data acquisition from one sampling unit to the next.

Systematic samples present significant differences to simple random sampling, although they are still statistically objective and are not diametrically opposed to simple random samples as would be the case with judgemental samples. Systematic samples are very simple to use, since once an initial sampling unit is selected (which may be done randomly) from a frame (a list or, in our case, a 2-dimensional area), the remaining sampling units are predetermined, even in the case of the systematic unaligned sample (Berry and Baker, 1968) (Figure 3). Thus, the selection of sampling units is not independent. On the other hand, the set of units that make up the systematic sample can be regarded as a cluster of sampling units; if the initial unit was selected randomly, then the systematic sample can be viewed as a simple random sample of one cluster from all possible clusters under that strategy.

Nonetheless, there are severe difficulties in terms of estimating the errors in a systematic sample, short of doing it experimentally (Frazier and Shovic, 1980; Yates, 1965; Cochran, 1963; Norway Central Bureau of Statistics, 1980). Conservatively, it is possible to

FIGURE 3: DIFFERENT TYPES OF POINT SAMPLING STRATEGIES



a Random

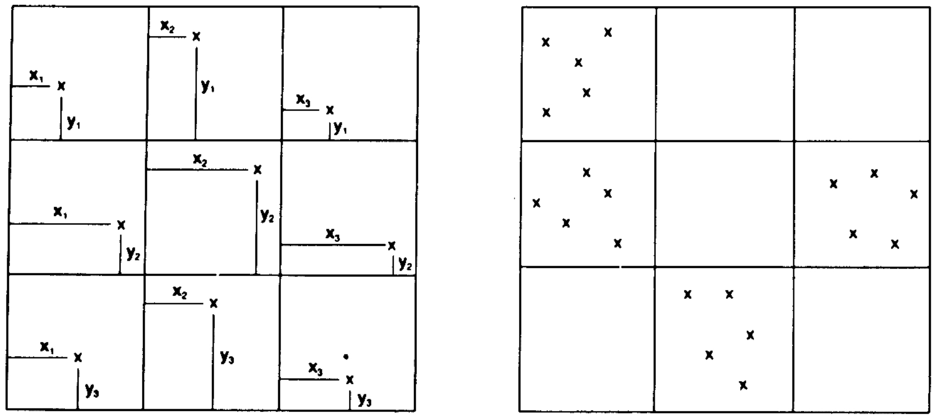
Allocation of 9 points by random selection of x y coordinates.

b Systematic (or geographic stratification with one point selected systematically in each cell)

Random selection of first point with same coordinates used in remaining cells.

c Stratified random

Two points (for example) selected randomly in each stratum (cell).



d Stratified systematic unaligned

A random coordinate for each row of cells (strata) defines the y coordinate in each row; another defines the x coordinate in each column.

e Two-stage cluster

Here, clusters (cells) are selected randomly and then points are selected randomly within each cluster. Clusters could be selected systematically as could the points within them.

treat a systematic sample as a simple random sample; if the population is randomly ordered in the frame this is a reasonable proposition in any case and systematic sampling may be undertaken purely for convenience. In the areal case, however, where there is likely to be some positive spatial autocorrelation in the phenomenon being studied, a systematic sample of, say, point locations may be expected to give a smaller range of estimates than a simple random sample. For this to happen, however, the systematic sample has to be a "good" cluster in that it should be heterogeneous. Hence, there are problems involved with certain types of population (for example in which periodicities may be present which could be picked up by the systematic sample). The basic problem of comparison between systematic and simple random sampling (or with stratified random sampling for that matter) is that the relative performance depends very much on the form of the population distribution in the frame even though experimentally systematic samples appear to give gains in precision over simple random samples and stratified random samples under a variety of conditions. Generally speaking, where estimates of the error involved in systematic samples can be developed, the errors will usually be overestimates of the real errors involved.

Despite these disadvantages, systematic sampling does present some advantages, viz. ease of application, and coverage if the population in the frame is ordered. Indeed, the systematic unaligned sample in the areal case seems to be highly rated by many people in terms of precision (Cochran, 1963; Berry and Baker, 1968; Taylor, 1977). In Berry's extensively recognized paper on land use sampling (1962), the roots of which lay in an earlier paper by Wood (1955) and in statistical material from Quenouille (1949) and Cochran (1953), it was concluded after some empirical testing that the stratified systematic unaligned sample was best in that it combined areal, random, and systematic elements. Though this conclusion has often been quoted, his empirical results do not seem quite that conclusive, however. In the first example, Coon Creek, based on one sample point for each 10 acres, the unaligned sample was clearly superior to simple random, stratified random, and systematic transverse samples. However, for the Montfort example where the point spacing was one per 160 acres, the unaligned sample was only marginally better. More recent work has provided further, though still not conclusive support for the stratified systematic unaligned sample (Fitzpatrick-Lins, 1981; Frazier and Shovic, 1980; Dickinson and Shaw, 1977).

From the operational perspective of using conventional air photography, however, the very fact of a broad geographic coverage in a systematic sample would likely entail undue costs of raw data acquisition. This would not preclude, however, second-stage systematic sampling from within the clusters of a first-stage sampling exercise and use of data sources other than air photos might require reconsideration of such a statement.

4.3.2 Stratification versus nonstratification

Stratification involves the subdivision of the population into different strata based on one or more characteristics. This process is normally undertaken prior to sample selection, though it may be undertaken after selection of the sampling units. There are two basic reasons for stratification:

a) to obtain a more precise estimate of desired population parameters. Generally, if properly applied, a stratified sampling scheme gives a more precise estimate of the population parameter than a simple random sample of the same size; thus, for a given level of precision, a stratified sampling scheme requires a smaller sample size (and thus cost) than a simple random sample (for example Frazier and Shovic, 1980). The aim of stratification in such cases is to reduce the sampling errors of the estimates and to produce strata that are as homogeneous as possible (i.e. within strata variances are minimized); taking random samples within each stratum, with strata samples being proportional in size to strata size, obviously eliminates the posssibility of taking some of the extreme sets of sampling units possible under simple random sampling. Obviously, to the extent that between strata differences are not maximized, then the differences between the stratified random sample and the simple random sample are reduced. Furthermore, if the variance within each stratum is not the same, then considerations of optimal allocation of units between strata will involve increasing sample sizes in strata with large variances and vice versa, with sampling fractions proportional to the standard deviation within each stratum (Yates, 1965; Norway Central Bureau of Statistics, 1980). Finally, costs of selection in different strata may vary, implying that more units be taken in strata where costs are less.

Two critical elements in stratification are noted: i) the choice of the stratification factors and ii) the delimitation of the strata.

i) The choice of the stratification factor(s).

In the Lands Directorate's analysis (Bircham, 1979) involving a comparison between an "ecological" criterion (analogous to ecoregions), agricultural land capability criteria and land use criteria, not surprisingly stratification by land use was found to be the most effective stratification factor in reducing sample requirements for estimating land uses. The relationship between, on the one hand, agricultural land capability and ecoregions and, on the other hand, land use is not likely to be a direct one because of intervening socio-economic variables. The ecoregions defined for Alberta, for instance (Strong and Leggat, 1981), are very dependent upon physical characteristics - vegetation, soil and moisture - and do not take into account socio-economic factors such as access to transportation facilities or farm structure. The link between any of these stratification criteria and land use change, of course, has not, been documented in any case. Even given the choice of a stratification criterion the delimitation of the boundaries between strata is very important and the possibilities for analysis here are extensive, let alone other possibilities concerning the relationship between strata and estimates of population parameters. Where the interest is on many land uses and where the processes affecting land use change are varied, it becomes more and more difficult to develop strata that will respond effectively for all these purposes (Holmes, 1967).

Geographic stratification is a fairly obvious - and simple - form of stratification; depending on the nature of the population and on the scale of the sampling unit, however, the impact of geographic stratification may be very modest or quite important. With significant positive spatial autocorrelation, the gains may be impressive, but in other cases, this may not be so. In terms of geographic strata defined by grid cells, the size of filter again poses problems, for at one scale, the cells may prove to be good strata (i.e. relatively homogeneous) but at another scale they may be good clusters (i.e. heterogeneous or with large internal variances).

In defining specific geographic limits to strata, whatever specific criteria are used as the stratification factors, it is useful to consider building them from aggregates of administrative units (for example counties) for which other sources of data are often available. Thus, it would be possible to develop stratification factors from census data (as in the Agriculture Enumerative Survey of Statistics Canada), as well as other mapped data. This would increase the utility of the strata beyond the function of greater precision. Such considerations would reduce the utility of the use of ecoregions for strata as currently defined (for example Strong and Leggat, 1981), though some of the variables could be incorporated in some fashion for administrative units if a link between them and land use change could be established, thus justifying their use in a stratification procedure. In addition, using such administrative boundaries does not prevent the effective use of grid-cell (segment, cluster) sampling for detecting land use change.

ii) the delimitation of the strata.

Concern here is what statistical or other rules are to be used in differentiating one stratum from another. Thus, the division between strata could be determined as the point at which between-strata differences are maximised; this, however, may become relatively difficult as the number of stratification criteria increases.

b) A second motive for stratification is to ensure good coverage of the population, not so much to reduce variation in population estimates, but to report such estimates for each stratum as a domain of interest. While strata may be defined by any type of characteristic, a basic geographic pursuit of this motive is to report estimates for particular reporting units, for example provinces or land use regions within the nation. The critical point to note here is that with k subdivisions (read strata or geographic areas) "if estimates with variance V are wanted for each of k subdivisions, the sample size must be roughly k times as large as is needed for an overall estimate of the same precision." (Cochran, 1963, p. 81). This is confirmed by the Lands Directorate's own estimates of numbers of samples required at different reporting level scales (Bircham, 1979).

Currently, the thrust of the Lands Directorate is towards developing estimates of changes at the provincial and national level. Thus, the primary role of any stratification would be in developing more precise estimates at the provincial, and ultimately, the national level. However, it is important to reiterate a point made earlier, i.e. that eventually the Lands Directorate and/or other users might be more interested in a finer scale of reporting. Such a move is quite possible, witness similar moves within Statistics Canada in terms of reporting agricultural land uses and related characteristics. Thus, it would be important in developing a monitoring system to provide the flexibility necessary. Thus, some consideration should be given to defining strata that could be integrated easily into a lower level of reporting units, either by aggregation or disaggregation of the geographic areas representing each stratum.

4.3.3 Form of the sampling unit in the areal case

Three basic types of areal sampling unit can be identified, the point, a cell (not necessarily a grid cell) and a line, the first two of which have already been introduced above.

The point sample is probably the most common way of sampling data arranged in two-dimensional space, and has been used at a great variety of scale levels (contrast Frondorf, McCarthy and Rasmussen (1978) with their analysis of landscape elements on a 430 ha. site to Norway's use of a point sampling system to provide national land accounts (Norway Central Bureau of Statistics, 1980)). Points as sampling units have the advantage of concentrating effort at classification so that classification accuracy may be greater than with a unit covering a specific area; and certainly the point does not eliminate placing the cover or use at that point into a broader context, witness Norway's classification based on 3 geographic levels. Furthermore, it does not require the digitizing of land use/change boundaries, and, of course, it is perhaps even better suited to large area coverage for characteristics other than those derived from remote sensing imagery, such as land tenure characteristics which are costly to collect, than units possessing areal value. Points as sampling units can, of course, be integrated into any of the above dimensions: c.f. random point sample, a systematic point sample which is like a stratified systematic sample with one point taken in each stratum, stratified random point samples, stratified systematic point samples and the much extolled stratified systematic unaligned sample (Figure

3). In a permanent point sample that might be developed for monitoring purposes (see below), one operational issue that must be faced is a means of ensuring easy identification of each point (which is in actuality a very small areal unit of land) to avoid the detection of "false" change.

The cell, which above was also introduced as a stratum as well, represents a cluster of elementary sampling units. If the frame (study area) is divided into cells, segments or clusters (for example grid cells, administrative units), then a number of these cells may be sampled (randomly, systematically, stratified). If all the elementary units in each cluster are "sampled", then the cluster effectively becomes the sampling unit. This may effect considerable savings in time and money of data collection, though at a certain loss in efficiency measured in terms of the numbers of elementary sampling units when the clusters are relatively homogeneous. A two-stage design is possible too, with for example a first stage sample of clusters (for example grid cells) and a second stage sample of points within each sampled cluster; another example would be the two-stage cluster sampling approach used by Statistics Canada in its development of agricultural statistics, involving a sampling of Enumeration Areas (first stage cluster) and then a sampling of areal segments (second stage cluster) within each sampled Enumeration Area. The two-stage design may have the effect of concentrating effort, a useful feature in any data collection exercise but one which may be particularly important if conventional air photography is to be used as the data source, both for reasons of cost of photography and for focussing interpretators' attention. However, care must be taken in the estimation of population parameters (Taylor, 1977; Cochran, 1963; Holmes, 1967) since such clusters are often not representative of the whole population.

Size of cluster is an important consideration, both practically and theoretically. Practically, size of cluster may be related to a size manageable by a field operator (if field surveying is necessary) and the scale of available secondary source data (for example air photos) and their costs. Theoretically, when the clusters are used as the units of observation, size of cell may have a profound influence on the results of statistical analyses of data so collected. However, when the focus is on estimating levels of changes, this concern is less important.

Finally, lines or transects may be taken. On the one hand, the data may be derived from the proportions of the line in each land use/cover/change category (the lines may be located randomly, systematically or in a stratified fashion); this constitutes a one stage sample. On the other hand, points may be sampled along a line, randomly, systematically or in a stratified way, thus constituting a two-stage sample. Transects at first sight seem to be peculiarly suited to conventional aerial photography because of being able to align traverses with flight lines; in fact, however, the advantage is more apparent than real, because the same raw data in most instances would provide an appropriate base for point or cell sampling which are much more amenable to realistic stratification.

4.3.4 Relationship between samples on successive occasions

The various sampling design dimensions noted above can be combined in a wide variety of ways. All can address the issue of attempting to estimate the land use distribution at a particular point in time. In terms of land use change, this has been represented so far by the proportion or percentage of an area undergoing a particular type of land use change as well as the acreage involved. Essentially, land use at time t and land use at time (t+1) have been treated as two characteristics of a given sampling unit. With a data base such as that which underlies the matrices in Tables 2 and 3, there is clearly no problem in sampling any point, cell or line and obtaining the information on change. However, in a monitoring program new data must be acquired periodically and it is clearly inappropriate to obtain a complete coverage of the desired data under the existing state of data retreival technology from satellite imagery. Thus, the question of the relationship between successive samples arises.

Four basic relationships exist between sampling at successive time shots: a) independent samples; b) a fixed sample; c) fixed sample with partial replacement; and d) subsampling on the second occasion (for example the case of an inventory at time t and a subsample at time (t+1) - thus constituting a 2 phase sample essentially).

a) independent samples at t and t+1.

Independent samples on two or more repeat occasions will certainly allow the estimation of net change, say, in the proportion of land in a given use. With the interest focussing on the difference between the two sample means, the variance of the sampling distribution of the estimated difference is given by the sum of the two separate variances:

$$\left\{\text{S.E.}_{(\bar{y}_1 - \bar{y}_2)}\right\}^2 = \frac{\sigma_1^2}{n_1} + \frac{\sigma_2^2}{n_2}$$

From sample data, assuming equal variances, the estimated variance is

$$\frac{(n_1 - 1)\, s_1^2 + (n_2 - 1)\, s_2^2}{n_1 + n_2 - 2}\left(\frac{1}{n_1} + \frac{1}{n_2}\right).$$

With normally distributed populations or where n_1 and n_2 are large, then confidence limits can be set on the significance of the estimated difference using either the normal or t distribution depending upon the circumstances. Similarly, two proportions at two different points in time can be compared, and

$$\left\{\text{S.E.}(p_1 - p_2)\right\}^2 = \frac{p_1 q_1}{n_1} + \frac{p_2 q_2}{n_2}.$$

Two major problems with independent samples are first, the relatively large errors involved, and second, the fact that they will not allow the monitoring of sequences of change, both of which represent a significant limitation from the perspective of C.L.U.M.P. needs and objectives.

b) fixed sample net.

With a fixed set of sampling units, one may anticipate a reduction in the sampling errors in estimating change. The variance of the sampling distribution of differences between two means is given by:

$$\left\{\begin{matrix}\text{S.E.} \\ \text{related } (\bar{y}_1 - \bar{y}_2)\end{matrix}\right\}^2 = \sigma^2_{\bar{y}_1} + \sigma^2_{\bar{y}_2} - 2 p_{12}\, \sigma_{\bar{y}_1} \sigma_{\bar{y}_2} .$$

where p_{12} is the population correlation coefficient between variables y_1 and y_2. Similarly, the differences between two proportions from a fixed net must take into account the covariation between the two characteristics, and

$$\left\{\begin{matrix}\text{S.E.} \\ \text{related } (p_1 - p_2)\end{matrix}\right\}^2 = \text{var}(p_1) + \text{var}(p_2) - 2 \text{ cov } (p_1, p_2) .$$

In both cases, since there is normally a positive covariance as measures are taken on the same sampling units, the effect of a fixed net is to reduce the sampling errors in estimating net change.

Furthermore, for both quantitative and qualitative variates on a fixed net, the operations are simpler even than the above formulae would suggest. For the quantitative variate, the difference for each observation is measured and becomes a single variate amenable to testing, for example, for a significant difference from zero. For a qualitative variable, the change from one category to another can be treated as another class of attribute (with k land use classes possible, the number of possible categories of change - including no change - is k^2 over one time period); thus, we can estimate the areas undergoing specific changes as before.

With relatively small changes occurring, the covariance terms in the above formulae will be strongly positive thus giving rise to a large reduction in sampling errors (Norway Central Bureau of Statistics, 1980, p. 18). Basically the higher the correlation between the two time shots, the greater the efficiency of a fixed sampling net compared to independent samplings. Since we have noted earlier the slow pace at which much land use change takes place, this would seem to be particularly appropriate for land use analysis and monitoring in rural areas.

A fixed sample also has the added advantage, assuming the population is nonhuman, of reducing the costs of sampling on future occasions; sample unit identification is undertaken once only. If information other than land use cover/activity is required at a future date, it also facilitates successive acquisition of such data, for example, land quality parameters or land tenure.

c) fixed sample with partial replacement.

This may be necessary with populations that are themselves subject to change (for example "births and deaths" in relation to people, firms, etc.). In addition, where the observations are made on human populations, partial replacement is often deemed necessary to reduce repeated intrusions on the respondents' privacy, for example farm operators. Partial replacement rates of from 20 to 33% are not uncommon in large scale annual surveys of farm operations, for example the Statistics Canada agricultural statistics and the U.S. Area Sampling Frame. In the context of land use analysis, this only arises if certain land uses can be regarded as "terminal" uses (for example urban development), or if new areas are to be incorporated into a domain. Systematic partial replacement may allow more accurate estimates to be made of population parameters at one point in time; the partial replacement strategy has much to offer in terms of accuracy because additional information can be used to revise previous estimates. In terms of estimating differences, however, given the magnitude of change is small, fixed samples will provide a more efficient estimate of change than partial replacement samples (the more so the greater the correlation between the two distributions), which in turn will be more efficient than independent samples.

d) subsample of observations previously made at time t (which could have been a total inventory) for time (t+1).

In this case, change can simply be estimated from the information obtained on those units common to both samplings, and thus is similar to a fixed sample net. If the observations made at time t constituted a full inventory of all observations or a much larger sample than the subsample, then considerable information is available on the precision of the sample estimates, both at time t and, by inference, at time (t+1). Thus, one way of providing greater control over the level of precision of sample estimates, short of a total inventory, would be to undertake a relatively larger sample (also fixed) at longer intervals than the subsampling.

4.4 Summary

From the comparisons of different sampling designs noted in the literature reviewed, a number of points can be made.

a) Random selection of sampling units generates rather imprecise estimates, but careful stratification will reduce this. The utility of stratification in reducing errors, however, can be expected to decrease as the number of phenomena under investigation increases.

b) Where tests (i.e. by repeated sampling of the same population (cf. Taylor, 1977, p. 78) have been carried out, random cluster sampling tends to be very imprecise, even though operationally it has many advantages. Systematic cluster sampling would presumably provide more precise estimates, but this would partly depend on the nature of the distribution being sampled.

c) Thus, the form of the population distribution (land use category, category of change) is of critical importance, as is the size of cluster used in cluster sampling.

d) The magnitude of a land use or change is important. Combining this with point (c), it seems inappropriate to use a general purpose sampling approach to try to elicit information on small changes that are very concentrated geographically. Such phenomena may be appropriately tackled using other sources of information or other sampling strategies.

e) It is critical that the level of classification to be used at a given scale be determined. Detailed classifications will produce greater imprecision in areal estimates than more general classifications. In this sense, ultimately use of satellite imagery across the nation for a sample of areas might provide the necessary general base; detection of change might then provide the delimitation of areas for more intensive study.

f) In terms of repeat sampling, a fixed sample appears to offer the most accurate way of getting at the types of land use change occurring in rural areas, though the small magnitude of that change still poses additional problems in terms of sample size.

g) In many respects, cells or clusters have advantages operationally in obtaining information. Points, however, do present advantages in terms of additional concentrations of effort (for example in classification) and in terms of acquisition of data other than land use cover/activity. A two-stage design, of clusters and their points, is worth investigating to see whether the benefits of both forms of unit can be achieved.

h) In the case of areal sampling, the role of the form of the distribution of uses and change seems to be of paramount importance and it is clear that there is room for extensive experimentation on comparisons of strategies under different conditions. Furthermore, the size of cells or segments in a design in which cluster sampling of some form is used is clearly of practical significance. While it is possible to attempt to define an optimal size of cluster in relation to a specific land use (and perhaps process of change), the fact that usually interest in a survey or a monitoring program focusses on several variables of differing magnitudes and distribution means that practical considerations will likely play a prominent role in determining cluster size. For instance, the (1x3) mile segments used in the area frame sampling for agricultural data by Statistics Canada is of a size that is easily manageable by a field person in a reasonably short period of time.

i) The determination of reporting levels (number and scale) has a profound effect upon sample requirements as a finer level of reporting requires a larger sample to achieve the same levels of precision. Furthermore, where the possibility may exist of developing a finer scale of reporting units in the future, it is important to consider the relationship between, on the one hand, the initial use of stratification factors and their geographic manifestation and, on the other hand, the likely configuration of those future reporting units.

5. REVIEW OF SELECTED EXISTING AREA SAMPLING APPROACHES EMPHASIZING THE MONITORING OF CHANGE

5.1 Estimating Inventories or Monitoring Change

After assessing material provided by the Lands Directorate and other literature available in regularly published journals and government agency reports, it would appear that no land use sampling program of the type contemplated by the Lands Directorate is currently operative. Considerable activity is underway in a number of countries but much of it relates to estimating land and resource distribution at a particular point in time rather than monitoring per se, a distinction which is crucial.

Monitoring is taken to mean land use change detection; further investigation of change is possible whenever change exceeds a specified magnitude or is unduly concentrated between specific uses. Consequently, as noted in section 3, the focus in monitoring is on <u>change itself</u> and not on the detection of what land use distributions exist at a point in time (inventory). Nonetheless, if change is detected, actual land use distributions can be replicated with acceptable degrees of precision using an appropriate areal sampling strategy.

Currently under the C.L.U.M.P. program, urban-centred regions which can exhibit significant rates of change are dealt with on a complete inventory basis at five-year intervals. Allowance in C.L.U.M.P. is also made for complete land use inventory studies of special areas as need is identified. Both these programs to date rely on conventional air photo interpretation with some field checking. To maintain a complete <u>land inventory</u> for the large areas of rural land use, a strong possibility in the future is the use of high altitude satellite imagery to provide an ongoing record of land use classified at the most general level (i.e. Level I) (Mausel, Leivo and Lewellan, 1976). The technology exists to provide the raw data regularly; the only area that seems to require more development is that of automated interpretation for very large areas and the only major concern at this general level of classification would be in terms of misclassification error and costs. Such general inventory information linked with the specific change detection approach could well provide a comprehensive coverage of the major land use domains identified by the Lands Directorate at some point in the future.

5.2 Review of Existing Work

5.2.1 Organization and background

The review of ongoing work which follows was undertaken in the context of: a) the monitoring-inventory distinction; b) C.L.U.M.P. objectives; and c) the concerns, problems, and approaches arising from areal sampling strategies reported in various countries. The Lands Directorate land use/cover classifications are taken as a given; however, the level of land use detail possible in a change detection program does depend partly on the data gathering method, for example, field check, point or area interpretation on conventional air photos or Landsat digital data. Since the focus of the discussion is rural land use sampling, the considerable literature on urban land use change detection (for example, Rhind and Hudson, 1980; Adeniyi, 1980) is largely ignored, and a large literature in forestry, vegetation, geomorphological, and agricultural data gathering which has an areal connotation and a considerable history is only marginally covered. The focus as outlined in the frame of reference is on assessing land use inventory and monitoring strategies in Western European countries and the United States and evaluating the utility of different sample design strategies in the Canadian context.

The focus is on how different government agencies in other countries are attempting to deal with national land use reporting. An overriding impression left by the review is one of groping and uncertainty during the 1970's spurred by the advent of satellite imagery and its uncertain potential for monitoring land use changes, except at a very general level of classification, even though conceptually the use of satellite imagery would appear to provide an ideal system for land cover monitoring (Howarth, 1982). Further factors contributing to this considerable activity were the poor crops of the mid-1970's which spurred attempts at estimating crop areas and potential yields and rising concern over urban conversion of, and impact on, agricultural land. Simultaneously, the implementation of legislation related to environmental degradation and resource use concerns led to further activity. In short, increasing technological sophistication has provided much greater potential for national level land use monitoring at the same time that impacts on national resource bases have pointed to the need for much greater efforts.

Data gathering methods and methodology, a long time concern in forestry, spilled over into agricultural and other land uses once it was realized that basic inventories were lacking. Significant national thrusts in Canada and the U.S.A. had surfaced in the 1960's with Canada gaining world prominence with its pioneering efforts in land capability inventory and computerized land data bank development. In the United States meanwhile, first attempts at national land use inventories were undertaken by the Soil Conservation Service using a county-based sampling approach, while land use classifications evolved to meet more sophisticated demands and to match the capability of high altitude remote sensing imagery (Anderson et al., 1976; Gierman, 1981).

5.2.2 Basic approaches

National scale demands led to various approaches once it was realized that land use data were needed in greater detail than provided by the most general level of classification (Level I). One general sampling approach is to define special land use areas for study such as in the urban-centred region program of the Lands Directorate, Environment Canada. No other country could be found at present which provides systematic land use information at a national scale over time within a land capability context for the critical urban-rural interface areas. Instead, more generally a second type of general sampling approach is followed which involves instituting a sampling design intended to provide an estimate of the distribution of land uses (areas and proportions) at specified points in time or at varying time periods determined by some identified need (Milazzo, 1980). Usually the monitoring function is an implicit objective only, with information being maintained as a data bank and sometimes expanded to map form. Many of the specific approaches in Western Europe seem more readily feasible in the geographically smaller and more densely populated Western European countries (for example, Norway) because of cost considerations. However, certain sampling design aspects have validity regardless of country. In the following subsections, then, the attempts at land use inventory, monitoring and sampling that have been undertaken in selected Western European countries are assessed followed by a similar review of United States experience. This information is summarized in Table 7.

5.2.3 Western Europe

In reviewing West European experience, it is well to emphasize the small size and high population densities of many of the countries (Table 7). The Norwegian approach discussed below, for example, though comprehensive and well-thought out, would generate very high per capita and total costs in the Canadian context if the same sampling densities were used. On the other hand, direct translation of sampling densities into the Canadian context is not possible because the geographic structure of land use regions (if these were used as strata) would be different depending on the geographic scale at which land use variations were important. Associated with the relative smallness of West European countries is the relative ease of providing complete air photo coverage in a single year by a national agency as occurs, for example, in West Germany, France and Switzerland. Also part of the different context of West European countries from Canada and, to a lesser extent, the United States, is the centralization possible in non-federal government systems, and their direct link with local municipalities or other local and regional representatives of national agencies who may be directed to gather land use data for change detection purposes.

West European countries discussed below are selected partly because of information availability and partly because they represent a range of approaches to collecting systematic land use data. The United Kingdom though having a long history of involvement in land use data collection, still has no monitoring program; the Netherlands epitomizes the complete inventorying approach, while France, Norway and Switzerland represent different sampling approaches at various stages of development.

5.2.3(i) United Kingdom

Land use mapping has a respectable history indeed in the United Kingdom (Rhind and Hudson, 1980, Ch. 4 to 6). Yet despite the fame of the Stamp and Coleman Land Utilization surveys, a satisfactory land use monitoring program still seems to be lacking (Dickinson and Shaw, 1977). As mapping programs are spread over a number of years, the real result may be valuable land use maps but no real monitoring possibilities. Land use change statistics intended for national level monitoring are required from municipalities under a Department of the Environment circular annually

TABLE 7
SUMMARY CHARACTERISTICS OF SELECTED FOREIGN PROGRAMS

Country	Characteristics				
	Land area ('000 sq. km.)	Population* (millions)	Sampling system	Purpose and reporting level	Stratification
CANADA	Total: 9,861 Agricultural ecumene: 1,200	24.1	C.L.U.M.P.	National and provincial estimates of land use change.	
UNITED STATES	9,255	226.5	U.S.D.A. area sampling frame.	Annual estimates for crop and livestock items at state, region and nation level.	Land use regions within states. Geographic factor too.
UNITED KINGDOM	241	55.7	None. Comments on proposal by Dickinson and Shaw (1977).	National level monitoring of land use change. Seen as input to land use planning.	No comment made.
NETHERLANDS	42	14.0	None. Comments on full inventory program.	National and local detailed monitoring of land use change. Input to land use planning.	Not applicable.
FRANCE	538	53.6	Ministry of Agriculture program.	Mainly annual estimates of major agricultural items (region and nation) plus general land use.	Land use regions and "special needs" (nation, region, county); geographic.
NORWAY	320	4.1	Central Bureau of Statistics.	National land accounts; land use for urban areas. Monitoring; planning input.	Urban areas by urban size. Rural areas by general land use.
SWITZERLAND	41	6.4	Federal government. See Kolbe and Trachsler (1980).	Land use and change statistics for nation for land use planning purposes.	No. But sampling density can be increased where desired.

*As reported in Whitaker's Almanac, 1982.

TABLE 7 (con't)

Country	Characteristics					
	Sampling units	Sampling unit selection method	Temporal relationship	Field work (role of)	Non-land use data	Cycle length
CANADA					Land cover, tenure, quality.	10 years.
UNITED STATES	Area segments as first stage units. Farms as second stage units.	Random or systematic (sometimes replicative) for first stage.	Partial replacement.	Data collection.	Agric. variables.	Annual.
UNITED KINGDOM	Point sampling.	Systematic.	Permanent net.	Data collection.	No comment made.	No comment made (presumably annual?).
NETHERLANDS	Not applicable.	Not applicable.	Not applicable.	Data collection.	No comment made.	2 years.
FRANCE	1:25,000 scale photos as first stage, points as second stage units.	Systematic at both first and second stages.	Permanent net.	Data collection.	Interest in land quality.	Annual, plus 3 year one for more detail.
NORWAY	Point sampling.	Systematic.	Permanent net.	Some data collection.	Important future role.	10 year urban cycle indicated.
SWITZERLAND	Point sampling.	Systematic.	Permanent net.	Field checking of air photos.	Possible future role.	6 years.

(U.K. Department of the Environment, 1974). But three problems greatly weaken these data according to Dickinson and Shaw (1977):

a) land use classifications are not consistent between municipalities;
b) no standardized approach exists to define the unit reported on; and
c) there is no efficient means of linking such data to other information sources.

To correct these problems, Dickinson and Shaw urge three measures:

a) a standardized classification;
b) an unambiguous set of units for which land use is measured; and
c) a point sampling application which is easy to computerize, eliminates ambiguity over uses, and eliminates area measurement error.

Their recommendation is a permanent systematic sample defined by intersections of National Grid lines on Ordinance Survey maps. Local authorities should collect the data, an approach used in the Netherlands (see below). Such a direct link between national government and local municipalities is difficult in the Canadian context, though the sampling approach suggested merits consideration. An ongoing problem in the United Kingdom in relation to monitoring seems to be lack of agreement on a national land use classification (Rhind and Hudson, Ch. 4).

5.2.3 (ii) Netherlands

The Netherlands, a very small country compared to Canada (Table 7), has been developing a land use information base around a complete inventory of land use and change at relatively small intervals of time. Based on limited information (Netherlands Central Bureau of Statistics, 1980), the initial thrust involving questionnaires on land use completed by the municipal administrations was replaced by an extensive land use map compilation program in the mid-1970's.

Using 1:10,000 scale topographic maps as the base, municipalities had to map land uses according to a 31 category classification, within a grid-system in which each cell represented a square 500 metres by 500 metres (thus, giving some 168,000 cells for the entire country). Processing of these map data was undertaken manually (by planimeter) and measuring the whole country was estimated to have taken 30 man-years over the period 1976-1979. Change in land use is to be based on municipal information, every two years, based on mapped changes in land use over the intervening period; this change information is processed by the

Cental Bureau of Statistics and a revised land use pattern established, and land use transition matrices (such as those in Tables 2 to 4) can be produced for a variety of geographic units, down to the 1/4 sq. km. cell. Given their initial experience with manual transcription and measurement of data, it is not surprising that consideration was being given in 1980 to digitizing the mapped data, the rationale being not so much any reduction in time needed for processing as the enhanced possibilities of manipulation of the resulting data.

This type of complete inventory of land use and change is interesting because of the capability (especially when processing involves digitizing) of focussing on change per se. It is clearly capable of meeting the objectives of a land use monitoring program. However, its specific system of operation depends on coordination of state and municipal effort as well as involving the higher costs of complete inventory over sampling; for both reasons, such a program is not likely to be a feasible proposition in the Canadian context.

5.2.3 (iii) France

France has had an active recent history of involvement in land use statistics, although her experience with information sources (census, surveys, etc.) is, of course, much longer. Various special-purpose surveys have been developed (for example, the rather slow-moving forest resources inventory (Bulletin Interministériel du Ministère de l'Agriculture, 1974)) and currently much interest is being expressed in land use inventorying from Landsat imagery (for example, I.N.S.E.E., 1980a; Ballut, Delavigne and Lenco, 1980). Furthermore, a number of tests have been conducted in France on the relative merits of point sampling at various times. For instance, Poissonet (1968) compared the accuracy of point sampling of land uses with complete inventory of each use, using a 95% confidence level interval, and a 1000 random point sample; in only 1 of 20 land uses did the true proportion determined by the complete inventory fall outside the interval developed from the sample. Similarly, Laskar (1974) measured gross land uses using point sampling in the four central départements of the Paris region.

But the most significant program in France is that undertaken by the Service Central des Enquêtes et Études Statistiques (S.C.E.E.S.) of the Ministry of Agriculture in the course of producing annual agricultural statistics. The roots of the present program dates back to the late 1960's; a number of changes occurred in 1975, both in terms of classification and procedure, so the comments are restricted mainly to the recent procedure. The procedure is essentially a two-stage sample based on sampling of air photos, with data collection of land use and function being undertaken by field observation. The field component to such agricultural data collection programs is also found in the Statistics Canada agricultural statistics program and in the comparable U.S. program.

The original purpose was, and still is to a large extent, the production of statistical tables on the areas under different crops at national and regional (région de programme) levels, with less frequent reporting at département levels. The agricultural purpose is reflected in the classification used (Fournier, Gilg and Jeanton, 1980; S.C.E.E.S., 1976 and 1980), even though this is much expanded to cover non-agricultural uses compared to the pre-1975 era (Lenco, 1973). The classification is based both on land cover at a particular point and on the function (activity) of the land use (thus distinguishing, for example, between a point falling in a parking lot attached to a commercial centre and one attached to an industrial development); Fournier, Gilg and Jeanton (1980) suggest this classification is unique in Europe, though it does bear some similarities to the different geographic levels of the Norwegian classification system. The detail in the agricultural area of the classification practically necessitates extensive field work for accurate classification on such a large scale. Altogether, over 100 different classes were noted in the 1980 instructions (S.C.E.E.S., 1980) with over 80 involving physical land use (cover) and about 25 functional (activity) categories.

The basis for the sampling is a sample of air photos, stratified by geographic area. The air photos are the first-stage sampling units; they do not constitute the data source in themselves, but rather are used in the location and identification of the set of second-stage sampling units. Clearly, other means of selecting first-stage sampling units would be possible in an adaptation of this system, for example, portions of topographic maps. The pre-1975 situation involved a sampling of about 100 photos (1:25,000 scale) per département and a systematic point sampling of 72 points per sample. From 1975 on, a more systematic approach was taken, starting at the national level. First, a 12 km. x 12 km. N-S, E-W grid was placed across the country. Each grid cell was then given a set of 8 fixed points (a systematic sample) based on a grid oriented NE/SW, NW/SE; the national sample then involves at least 1 photo per grid cell systematically located with the photo being choosen the centre of which is closest to the located point on the map. The actual density of photos selected varies from between 1 and 8 however, as a function of the stratification into general land use regions at the national, regional and département levels or as a function of local need, so that the total national annual sample of photos is approximately 8,000 (S.C.E.E.S., 1975). At a second stage, each sampled photo is then sampled systematically with 36 points, each being approximately 300 metres apart. The points thus selected comprise a permanent sample, which is then visited annually by field workers in each département's Ministry of Agriculture office; a verification is undertaken on 1/6th. of the points. This forms the base of national and regional statistics on land use.

In addition, a 3-year cycle involved, in 1977, the addition of another approximately 7000 photos to provide a better base for reporting at the département level. Again, the density of sampling of photos is based on a stratification at the regional and département levels.

Critical points in relation to this strategy are:

a) it is a geographically stratified, two-stage sample. The first stage is the systematic selection of sample photos from a national grid, with density of selection varying by strata (for example, land use). The second stage sample is essentially a cluster (the air photo) of point sampling units selected systematically within each sampled photo.

b) the two cycles permit a greater economy of effort by only undertaking the densest sampling every three years to provide more accurate data at relatively disaggregated levels.

c) the data collected are, however, dependent upon field work, a task facilitated a) by the small size of the country compared to Canada (Table 7) and b) by the organizational structure of the Ministry of Agriculture. Nonetheless, a similar two-stage sampling procedure could be developed, relying solely upon air photo interpretation with the necessary ground truthing.

d) the accent is placed on estimating the composition and areas of land uses (especially agricultural) at a given point in time. While monitoring has been mentioned (Fournier, Gilg and Jeanton, 1979), and even the possibility of change matrices suggested (Lenco, 1973), it would appear that little in the way of systematic analysis of change has been carried out. Part of the problem appears to be the fact that until 1980 (Mariette, 1982), while the sample was fixed, the number actually surveyed varied as a function of budgetary conditions, thus making it difficult to develop systematic and valid estimates of change. Problems also arise to some extent in terms of locating the same sample points year after year on the ground. Furthermore, the problems of small land uses, concentrated spatially, has been noted (I.N.S.E.E., 1980a). In this respect, it is interesting to note that the total agricultural reporting program does not rely solely on this system, and special purpose surveys are undertaken for specific uses. This program warrants closer scrutiny, even though some of the data the Lands Directorate is interested in ultimately (for example, land quality) has not been incorporated into the base. The system does have the flexibility, however, to incorporate such data in the future.

5.2.3 (iv) Norway

Norway is another country which has moved towards developing a sampling strategy to provide systematic information on land use and, ultimately, land use change. Being much larger than the Netherlands but much smaller than Canada (Table 7), it is interesting that the rationale for developing a sampling strategy is a cost one (Garnasjordet and Longva, 1979). The system is one that has been evolving in the late 1970's and early 1980's, though it involves use of some data sources that have been developed over much longer periods. The evolving system is set in the context of a need to provide detailed information on land accounts for government agencies involved in establishing national land use policy, and clearly has a monitoring thrust. Ultimately, data would be integrated from a variety of sources (censuses, registers, maps and map-derived registers) on a geo-coded basis; the most important link between the various sources of data is the sample point, located within the national grid on topographic maps.

Specifically in terms of land use and land use change, the key priorities for the land accounting system were noted in 1980 (Norway Central Bureau of Statistics 1980a) as:

a) the production of comprehensive land use statistics for urban areas (those with populations of over 1,000, of which there were about 250);

b) the production of a survey of total national land use; and
c) the development of land accounts for pilot counties.

Land use classification for the urban settlements is based on an interesting distinction between geographic scales of observation at a particular point, ranging from the cover ("physical structure and surface") at the smallest scale, to the field (or parcel level) and to the area level at the most general level. The smallest scale is essentially a cover classification while the other two levels are dominantly activity classes - the relationship between this and the French one discussed earlier is clear.

The most important aspect of the implementation of both the urban settlement and the national land use objectives is that it is based on a stratified, systematic permanent point sampling (the points being approximately 0.1 hectare in size and being located within the national grid), with the suggestion that the sampling be repeated every 5 or 10 years. For the urban area component, points are located at 100 metre, 200 metre or 300 metre intervals depending upon the size of urban area, and a net of points 600 metres apart is developed in the remainder of the urban region (roughly the commuting zone). The finest mesh of points thus gives a maximum of 100 points per square kilometre. In 1979 (Garnasjordet and Longva, 1979), the urban area sample size was estimated at around 100,000 and a program was under way to provide land use and land use change statistics for the urban areas based on interpretation of air photos from 1955, 1965 and 1975. By the beginning of 1980, 150 of the urban areas had been completed.

It is important to notice that municipal involvement is again significant in field checking so that it is not easy to produce cost estimates of such a strategy. Nevertheless, accepting that several important cost components were "hidden", the Central Bureau of Statistics (1980a) estimated the cost per sample point at approximately $1 US in 1980.

In terms of errors, it was noted that the intention is to report a more limited set of land use classes for small urban areas owing to relatively small samples. A major problem that appears in the Norwegian documentation is the recognition of a 10% classification error - this combined with the inevitable sampling error may well create problems in relation to acceptable levels of precision in estimates, especially with respect to the land use transition matrices the

Norwegians are interested in. On the other hand, if attention is shifted away from the individual urban area as a reporting unit, the errors would be more reasonable.

For the national land use survey, additional point sampling covers the whole country. Again, the sample is a permanent one with stratification depending upon broad land use distinctions. Above the forest line, sample points are 12 km. apart, and below it, 6 km. apart. Separations of 1 km. and 3 km. are also used in some areas. This yields a total sample of some 7,000 points for the country, for which a variety of information is recorded, including existing information (for example, from the National Forest Survey) and some air photo - derived data (Norway Central Bureau of Statistics, 1980a, 1980b).

The Norwegian Central Bureau of Statistics (1980a, 1980b) considers the point sample to be particularly advantageous in terms of cost-savings and, together with its three level classification system, in terms of easing problems of interpretation of land use. The permanent nature of the sampling net is also seen as increasing the precision of estimates of change. It is interesting from the perspective of the urban-centred region component of C.L.U.M.P. that Norway would develop a sampling system for its urban areas. Furthermore, it is interesting to note that point sampling is common to both the French and Norwegian systems reviewed, but that the French system is a stratified 2-stage sampling strategy (systematic at the second stage) whereas the Norwegian one is simply a stratified systematic sample. The fact that France has a national territory close to 70% greater than Norway is perhaps not an unimportant factor in the choice of the presumably less expensive cluster sample in France.

5.2.3 (v) Switzerland

Switzerland is taken as a final West European example. A small country, roughly of the same order of magnitude as the Netherlands (Table 7), it has a long history of interest in land use statistics. Until recently, any land use statistics had been based on the cadastral survey with results published in 1912/13, 1925, 1952 and 1972 (Kolble and Trachsler, 1980); this suffered from lack of uniformity and incomplete national coverage. A different land use information system was initiated in the 1960's based on topographic maps - which meant that the amount of information was quite limited. Then, despite the country's small size, interest increased in the late 1970's in developing a land use information system with a regular update capability, based on sampling of air photos. While the question might well be asked "why sample" for such a small country (compare the Netherlands), it is noteworthy that the Swiss terrain is relatively very complex and that field surveys would be relatively more time-consuming.

The Swiss government has now decided to implement a national land use survey, based on a systematic point sample on a 100 metre grid transferred directly to 1:25,000 air photographs, with a 6 year cycle. Kolble and Trachsler (1980) suggest that automatic image processing was too expensive and not reliable enough for a country with complex patterns of industrialization, whereas point sampling on air photographs provides a high level of capability of integration with other data sources (because the land use data is "well-defined" geographically) and, since the sample would be a permanent one, the monitoring capability would be enhanced considerably (greater precision in estimating change). Furthermore, since on a new update cycle the interpretation films for the new air photos would contain the land use codes of the previous land use survey, it was felt that even greater savings would be effected. Finally, it would be possible, of course, to increase the intensity of sampling in some areas should it be thought desirable.

The Swiss have undertaken some extensive testing of this choosen sampling strategy prior to making their decision. Although it is very difficult to estimate costs from experimental work (Trachsler et al., 1981), in 1981 a rough estimate was made of 1.9 million Swiss francs (about 1.1 million Canadian dollars in 1981) for the initial national land use survey over a 6 year period (including some purchase of capital equipment), with subsequent updates being evaluated at about 1 million Swiss francs (about 0.6 million Canadian dollars in 1981).

From the perspective of C.L.U.M.P., the nationwide coverage by air photos and the intensity of the Swiss sampling would not be transferable into the Canadian context because of cost; however, the use of a systematic point sample from air photos at some stage in a sampling strategy certainly merits further attention (compare France and Norway).

In summary, four major points can be made concerning West European experience in land use data acquisition. First, because of size differences (Table 7) and relative costs, some aspects of the strategies are not transferable to Canada, assuming continued use of conventional aerial photography. Thus, the complete inventory of the Netherlands and the dense systematic sampling of Switzerland and of the urban area component of Norway's program probably fall into this category. Second, several approaches, though involving sampling and air photo applications, have a strong field component; while this can be a costly undertaking, it is noteworthy that the area sampling frame of Statistics Canada for agricultural data does involve extensive annual data collection through surveys in the field. The ultimate decision on whether this is necessary in a land use monitoring program depends upon what variables are seen as critical. Third, operationalizing inventory-monitoring programs directly from the national government to the local municipality as in the Netherlands and Norway and as has been suggested for the United Kingdom would be difficult to achieve under the Canadian political system. Fourth, where sampling is undertaken (Norway, Switzerland, France) or has been proposed (U.K.), systematic point sampling has been the preferred option, with the net being a permanent one (cf. Norway, Switzerland and (theoretically) France). This merits further attention by C.L.U.M.P., particularly in the context of an initial cluster sample (cf. France) which would then reduce coverage costs.

5.2.4 United States

In the United States, among the many agencies at state and federal levels involved in land use planning and thus land use data acquisition, three major government agencies stand out, of which two are in the Department of Agriculture (U.S.D.A.), and which have the broad perspective that is necessary in investigating many land uses simultaneously.

a) Since 1974, the U.S. Geological Survey (U.S.G.S.) has been undertaking nationwide baseline mapping of land use and cover at a 1:250,000 scale with an increasing shift towards the 1:100,000 scale (Milazzo, 1981).

b) Within Agriculture, the National Resources Inventory of Soil and Water Conservation Needs program of the Soil Conservation Service (1979) first provided national level data in 1957 and has repeated the process in 1967 and 1977 (N.A.L.S., 1981b). In addition, a Potential Cropland Study was undertaken in 1978 (Diderikson, Hidlebaugh and Schmude, 1977) which also dealt with rural land conversion rates to urban and water use. Two related programs, the Soil and Water Resource Conservation Act Appraisals (R.C.A.) passed in 1978 and the Forest and Rangeland Renewable Resources Planning Act (R.P.A.) passed in 1974 require continuing appraisal, expected to be undertaken approximately every 5 years (U.S. Soil Conservation Service, 1980; U.S. Forest Service, 1980). The recently completed National Agricultural Lands Study (N.A.L.S., 1981a) pulled together agricultural land use data for the United States.

c) A second agency in the U.S. Department of Agriculture, the Statistical Reporting Service, charged with estimating national agricultural data could also provide land use data as a consequence of a highly sophisticated sampling approach.

The two U.S. Department of Agriculture agencies depend on multistage sampling involving states, general land use/cover strata, counties and county subareas. The overwhelming impression, however, is one of overlapping effort and inconsistent land use/cover classifications. Only the U.S. Geological Survey provides map output dependent primarily on high altitude imagery. Two of these three programs are selected for more detailed comment below.

Various land use mapping programs usually related to environmental concerns also exist at the state level but the magnitude of assessing these efforts is well beyond the scope of this report. Hawaii and Oregon have adopted state-wide land use planning programs with special emphasis on farmland protection and consequent land use monitoring (Bryant and Russwurm, forthcoming 1982); and the Soil Conservation Service at the state level is undertaking multiresource inventories using a sampling approach, for example, Louisiana (U.S. Soil Conservation Service, 1980) as part of the RCA requirements.

5.2.4 (i) <u>The program of the Statistical Reporting Service</u>

Of the U.S. programs reviewed, that of the Statistical Reporting Service appears to have the greatest value to the C.L.U.M.P. intention of monitoring rural land use at national and provincial scales while retaining the flexibility to report at subprovincial scales. In approach, it is a hierarchical, multistage area sampling effort still in the process of evolution but with roots in the late 1930's (Houseman, 1975). Practicality in application is combined with rigourous statistical controls (for example, Fecso and Johnson, 1981). The dominant concern is with agricultural land use (specifically to provide statistically reliable estimates at national, regional and state levels of crop and livestock data) rather than land use generally and involves field interviewing (cf. the comparable Statistics Canada agricultural statistics reporting program).

The overall strategy involves an area frame sampling rather than sampling from a compiled list of farms, although specified "large" farms are contacted with a probability of one as in the comparable Statistics Canada program; the strategy is thus a multiframe one. The area frame used is a multistage approach, combining stratification and random cluster sampling components. Operational constraints are that states are the essential organizational entities and that field interviews have to be undertaken in the selected area cluster (Fecso and Johnson, 1981). In effect, the samples are organized by states and then resulting data are aggregated to national totals. Annual June Enumerative Surveys are undertaken using the area frame for common agricultural items. The area frame sampling is combined with list sampling for very large operations and special crops in order to report adequately on less frequent and irregularly occurring phenomena.

In the area frame, areal breakdown proceeds from generalized land use strata to areal segments (cells) within strata, within which field interviews are then conducted. For the continental United States 25 standard strata are defined based on broad land use categories (Table 8). Individual states then use pertinent strata or modifications thereof (listings provided in U.S.D.A. Statistical Reporting Service Manual, 1981). In California, a pioneering effort in 1979 involved the use of Landsat imagery in developing the land use strata (Fecso and Johnson, 1981).

Strata within states are broken down into segments (cells or areal units) and segments sometimes into smaller tracts. Random or systematic sampling is used to select segments (areal units) within strata. Usually county boundaries are respected and paper strata (geographic combinations of homogeneous segments) may be used as substrata to reduce possible variance. Also, attempts are made to establish count units (based on number of farms) prior to establishing segments to minimize size differences between segments; these count units are larger than segments and may consist of several homogeneous counties or consist of only a partial county (Pratt, 1974; Houseman, 1975). They are not used as sampling strata but only to improve segment delimitation.

Obviously, the area frame sampling procedure is both general and specific. The general nature (for example, the land use strata) allows retention of much of the area frame as changing land uses occur. This is important because area sampling frames can be costly to establish initially, for example, one estimate suggests 4 man years to construct an area

TABLE 8

STANDARD LAND USE STRATA FOR THE UNITED STATES AGRICULTURAL AREA SAMPLING FRAME

	Stratum number	Definitions
Cultivated land	10	Dryland Grain, 33% or more cultivated
	11	More than 75% cultivated
	12	50 - 75% cultivated
	13	50% or more cultivated
	14	50% or more cultivated, 50% of total land irrigated
	15	50% or more cultivated, 25 - 50% irrigated
	16	50% or more cultivated, 10 - 25% irrigated
	17	Orchards
	18	Vineyards
	19	Vegetables
	20	15 - 49% cultivated
	21	33 - 50% cultivated
	22	10 - 33% cultivated
Cities and Towns	31	Agri-urban, more than 20 dwellings per square mile, residential mixed with agricultural
	32	Residential-commercial, more than 20 dwellings per square mile
	33	Resort, more than 20 dwellings per square mile
Range	41	Open range or pasture less than 15% cultivated
	42	Woodland range or pasture less than 15% cultivated
	43	Desert range - less than 15% cultivated
	44	Public grazing lands - virtually no cultivation
	45	Public land - no known agricultural activity
Non-Agricultural	50	Non-agricultural
Water	61	Proposed water - lakes, reservoirs, canals under construction
	62	Actual water - lakes, rivers, canals, etc.
	63	Swamps

Source: U.S.D.A. Statistical Reporting Agency, 1981, p. 504.

sampling frame for Canada's agricultural areas (Wigton and Bormann, 1978). Furthermore, states may elect for variations in application, which individually by state permits greater statistical control over sampling error. A number of states use replicative sampling, either systematic or random, to generate sample sizes just sufficient for agreed on confidence limits (Pratt, 1974; Fecso and Johnson, 1981). Part of the general nature is the use of all known sources of ancillary information (maps, census, etc.) to reduce variance within strata and segments; such common sense efforts are endorsed by more practically-oriented statistical texts (for example, Blalock (1960) and Kish (1965)). One of the most important specific features is how segment size may be varied to reflect the nature of the agricultural land uses; thus, in intensively cultivated areas, the segment sizes would tend to be small (from one-half to two square miles) while in open range and woodland areas the segments would be considerably larger (one to one hundred square miles).

For the continental United States 16,000 sample segments are enumerated each year of approximately 3 million in total or about one half a percent of the total. Approximately 20% of the segments are replaced from year to year (Wigton and Bormann, 1978). Relative standard error (coefficient of variation) for major items is between 2 and 4% at the national and regional level and between 3 and 12% at the state level (U.S. Statistical Reporting Service, 1981).

From the perspective of C.L.U.M.P., the hierarchical, cluster approach involved in this U.S. area frame sampling program is clearly of interest for a national scale land use monitoring program. While the specific feature of replacement is not one that appears to have significant merit when dealing with land use derived essentially from remotely-sensed data, the general features of stratification and of clustering are significant and, in this respect, bear some similarity with the French system even though the data collected and the delimitation of clusters are different.

5.2.4 (ii) The Geological Survey mapping program

While the primary purpose of the Geological Survey program is different to that of C.L.U.M.P. in that it involves ongoing map creation somewhat akin to topographical mapping programs, monitoring concerns are recognized in using the criterion of change rather than the elapsed-time approach to update maps. While this variable time interval again is a departure from present C.L.U.M.P.

practice and intentions, it should not be without interest for C.L.U.M.P. in the future; it could be argued that a more efficient use of resources could be achieved by recognizing different rates of change in rural areas.

How can "change" be detected for such purposes? In the U.S.G.S., a variety of criteria have been suggested (Milazzo, 1980) to identify maps for initial cursory photoinspection which then is undertaken to determine the need for actual update. Initial criteria involve grouping maps on the basis of "change potential", based on the dominant land use. Land use and land cover have been mapped using Level I and II categories (Table 9); based on dominant land use characteristics, five main categories of "change potential areas" have been suggested (Milazzo, 1981) together with suggested update frequency (Table 10). Other areas would be updated based on contemporary priorities (for example, areas having undergone drastic or catastropic change) as well as the time of the last update and photoinspection.

Once selected, photoinspection of the maps would then help determine those maps which should actually be updated. Landsat multispectral scanning, despite the large errors involved, seems to be widely accepted as most appropriate for detecting _gross_ land use and land cover changes and for assisting in the update selection process for these manually compiled land use and land cover maps (Milazzo, 1980, p. 8).

Although the U.S.G.S. thrust is a mapping one, the change potential typology (a stratification) bears some resemblance to the C.L.U.M.P. domains, i.e. the urban-centred regions, prime resource lands, rural lands and wildlands. Thus, the 5-year cycle for monitoring in the urban-centred component of C.L.U.M.P. and the 10 year one for the rural domain can be justified on presumed rates of change in land use and need. In addition, the recommended use of Landsat imagery to detect gross changes in order to determine the need for more detailed investigation (map update in the U.S.G.S. case) clearly has a role to play in a monitoring program even with the current state of technology, for example, in determining priorities for investigating particular prime resource lands in detail. Ongoing research in the U.S. and elsewhere on change detection using Landsat digital data (for example, Howarth and Wickware, 1981; Schwarz and Gaydos, 1975; Todd and Gehring, 1980), on the accuracy of classification from Landsat data (for example, Howarth, 1982; Fitzpatrick-Lens, 1981; Stow and Estes, 1981; Hord and Brooner, 1976) and on various Landsat applications such as crop estimation (for example, Hixson _et al._, 1981; Curtis, 1978)

TABLE 9

UNITED STATES GEOLOGICAL SURVEY LAND USE AND COVER CLASSIFICATION SYSTEM FOR USE WITH REMOTE SENSOR DATA

Level I	Level II
1. Urban or built-up land	11 Residential
	12 Commercial and Services
	13 Industrial
	14 Transportation, Communication and Utilities
	15 Industrial and Commercial Complexes
	16 Mixed Urban or Built-up Land
	17 Other Urban or Built-up Land
2. Agricultural Land	21 Cropland and Pasture
	22 Orchards, Groves, Vineyards, Nurseries, and Ornamental Horticultural Areas
	23 Confined Feeding Operations
	24 Other Agricultural Land
3. Rangeland	31 Herbaceous Rangeland
	32 Shrub-Brushland Rangeland
	33 Mixed Rangeland
4. Forest Land	41 Deciduous Forest Land
	42 Evergreen Forest Land
	43 Mixed Forest Land
5. Water	51 Streams and Canals
	52 Lakes
	53 Reservoirs
	54 Bays and Estuaries
6. Wetland	61 Forested Wetland
	62 Nonforested Wetlands
7. Barren Land	71 Dry Salt Flats
	72 Beaches
	73 Sandy Areas other than Beaches
	74 Bare Exposed Rock
	75 Strip Mines, Quarries and Gravel Pits
	76 Transitional Areas
	77 Mixed Barren Land
8. Tundra	81 Shrub and Brush Tundra
	82 Herbaceous Tundra
	83 Bare Ground Tundra
	84 Wet Tundra
	85 Mixed Tundra
9. Perennial Snow or Ice	91 Perennial Snowfields
	92 Glaciers

Source: from Anderson et al., 1976, reproduced in Milazzo, 1981, Table 1,p. 3.

TABLE 10

UNITED STATES GEOLOGICAL SURVEY LAND USE/COVER CHANGE POTENTIAL AREAS

Land use/cover environment	Level II categories[*]	Update cycle (years)
Urbanizing and urban	Urban/built-up (11-17); Transitional (76)	5-7
Critical environment areas	Water (51-54); Wetland (61,62); Beaches (72)	7-10
Energy resource areas	Stripmines (75); Quarries - gravel pits (75); Transitional (76)	7-10
Agricultural, range and forest land	Agriculture (21-24); Rangeland (31-33); Forest (41-43)	10-15
Stable land areas	Barren (71, 73, 74, 77); Tundra (81-85); Snow-ice (91-92)	15-20

[*] Numbers refer to the classification code on Table 9.

Source: modified from Milazzo, 1981, Table 2, p. 7.

holds out hope that eventually Landsat data will play a major role in systematic land use monitoring.

Considerable interest in developing reliable land use inventories and in land use monitoring is thus apparent in a wide range of countries (Table 7). Sampling is evidently widely accepted as an appropriate means of collecting the necessary data, notwithstanding the need to control the level of precision attained. The programs reviewed have been developed under a wide range of conditions (size of country, population, economic structure, political structure). It is thus difficult to translate programs directly from one country to another. In several instances, an important role is played by either municipal governments or by regional agencies of national governments. In the case of the Netherlands, and Norway, the crude cost estimates given in the documentation available almost certainly ignored substantial "hidden costs" shouldered by other government bodies.

Size of country also plays some part in determining feasible strategies (contrast Switzerland with Canada). On the other hand, it is important to compare not the total land area of Canada, but rather the area covered by the rural area or the "agricultural ecumene" (Table 7) - thus, Canada's rural area is only about 2 1/4 times the size of France. The programs of the two larger countries reviewed (the United States and France) both involve a clustering approach, and any monitoring program in the rural areas of Canada would almost inevitably involve a similar approach (cf. the existing Statistics Canada program for providing crop and livestock estimates). Thus, taking the minimum density of air photos that could be used in the French annual agricultural survey (1 photo at the 1:25,000 scale, representing roughly 3.25 sq. km., per (12 x 12) km. cell), just over 8,000 photos would be required to cover Canada's agricultural ecumene. Using the actual French photo density (1 photo per 67 sq. km.), the number of photos would be approximately 18,000 and using the higher density in the French 3 year cycle of 1 photo per 36 sq. km., just over 33,000 photos would be required to cover Canada's agricultural ecumene.

Stratification is a common aspect to many of the programs reviewed, although it is not usually very easy to ascertain exactly how strata have been created because of incomplete documentation, and, in some cases, the nature of programs that are in the process of evolving. Permanent point sampling, either as the basic sample unit or as a second stage sampling unit, is also a popular component - the permanent sample allowing for greater precision in the estimation of change and the point sample being held to reduce ambiguity in classification and to provide a more effective means of integrating land use data with other sources of data.

Unfortunately, little hindsight evaluation can be made of these programs for land use monitoring in rural Canada because they are either still in the stage of implementation (for example, Norway) or they were not specifically conceived of as providing general land use data (for example, the U.S.D.A. programs). However, evaluation can be made of those aspects that are most likely to be of benefit to C.L.U.M.P. - these are contained in the most general first recommendation of the last section. Other recommendations are then made concerning the nature of further research that is needed to develop a land use monitoring system for rural Canada.

6. RECOMMENDATIONS REGARDING FUTURE LAND USE MONITORING RESEARCH IN THE CANADA LAND USE MONITORING PROGRAM

Based on the review of Western European and United States experience and on the general literature, a number of recommendations can be made concerning both the types of implementation decision suggested in C.L.U.M.P. documents, the broad outline of a rural land use monitoring program (L.U.M.D.) for Canada and a set of priorities for research.

6.1 Recommendations Regarding Existing Canada Land Use Monitoring Program Implementation Suggestions

Stratification. As noted in section 2, the urban-centred region component and the prime resource lands component of C.L.U.M.P. are already being implemented. There is thus a primary stratification of a sort that has been adopted, viz. between urban-centred regions, rural lands and wildlands, since prime resource lands can fall within any of the other domains. Given the total rural area, it is recommended that, for national and provincial land use reporting, the distinction between the urban-centred region and the rural area be initially set aside, since it has not been demonstrated statistically that the distinction is related to land use and cover change across the nation. Indeed, in terms of the agricultural sector, recent research has tended to stress the communality between agricultural changes in the rural-urban fringe and in the broader rural hinterland (for example, Bryant and Russwurm, 1981).

The general notion behind the domains currently identified is intuitively appealing, and the focus on the urban-centred regions in that particular domain is important in its own right. However, from the point of view of stratification, it seems reasonable not to accept such a priori definitions. Ultimately, in any case, the land use and land use change characteristics identified through the complete inventory of the urban-centred regions would still be used in compiling provincial and national land use statistics; these regions would simply represent a separate sampling frame from which the objects (the urban-centred regions) are sampled with a probability of one and which is interwoven within a broader area sampling frame of the total rural area.

Reporting levels. The primary focus of C.L.U.M.P. is, properly so, at the national, major region and provincial levels for reporting statistics. Provinces thus become the major organizational building blocks of a rural L.U.M.P. Below the provincial level, stratification is a necessity based on international experiences. But consideration should be given to defining strata in such a way that they may be readily used as a framework for reporting at a finer level, i.e. it should be possible to aggregate or disaggregate strata geographically to produce useful reporting units. Use of major administrative or existing census reporting units is indicated.

Time frame. The existing 5-year cycle for urban-centred regions and the suggested 10 year one for the rural domain are intuitively appealing, since they reflect notions of rate of change potential and need for update. It is recommended, however, that consideration be given to varying the length of cycle within the rural areas, depending upon analysis of actual rates of change, or failing that, change potential.

Land use and cover classification. Given the use of remotely-sensed data, initially medium scale conventional aerial photography, and the broad scale of the reporting units, the classes of greatest concern would be at a level suggested by the classes listed in Table 1. Depending upon particular patterns and magnitudes of change, however, it may well be possible for greater detail to be reported for certain reporting units.

Significant land uses. However, while focussing on the most general classes circumvents some of the statistical problems associated with small land uses at finer levels in the classification, further thought should be given to identifying those uses that are small in magnitude, yet significant economically, socially and/or environmentally, and that should be monitored in some other way (for example, through a register).

6.2 Broad Structure of a Rural Land Use Monitoring Program

Five general suggestions have been made regarding the creation of a valid sampling network (Sayn-Wittgenstein and Aldred, 1976).

a) The sampling design must be statistically sound and allow estimation of sampling errors.
b) The design and location of points (read sampling units) should not require major changes over time.
c) Precise classification of uses and standardized measurement techniques are required.
d) Use of constant probabilities eases the moving to smaller areas out of a national scale framework should the need arise, although this is not essential.
e) Multistage sampling is usually required to link effectively with other data sources, for example, Census material.

Kolble and Trachsler (1980) reiterate the importance of the classification system and the need to define the data precisely geographically in order to facilitate an eventual link with other data sources. In addition, since a land use monitoring program would inevitably be a long term one, consideration must be given to likely changes in the technology of data acquisition (particularly through satellite imagery) and to how these could be incorporated into the program.

Six main dimensions of a rural land use monitoring program for Canada are recommended.

a) Provinces should be the framework within which sample sizes should be determined and stratification undertaken. The implication is that a greater sampling is needed for this than if the nation were the sole object of interest, but smaller than if reporting levels were subprovincial.

b) Stratification at the subprovincial level is a must in most provinces. The nature of the criteria still need further research (see section 6.3) since research is lacking into the link between stratification factors and land use/cover change (as opposed to land use at a given point in time).

c) To increase flexibility in linking to other data sources eventually, strata should be defined using data units such as Census Divisions. Census Divisions in a national context generally are reasonably homogeneous units and there is a wealth of information available at this scale.

d) Because of the size of Canada, and several of the provinces, a multistage sampling is indicated, based on an <u>initial sampling of clusters</u> (cells, segments) within strata (cf. the U.S.D.A. Statistical Reporting Service program and the French program). Within strata, there would be considerable advantages to defining these clusters on a grid-system. Selection of clusters could be systematic (cf. the French program) or random; cluster size need not be uniform across the country (cf. the size of segments (clusters) in the U.S.D.A. area sampling frame) and might profitably be related to the level of complexity of land use and land use processes in a given stratum. Various cluster sizes were found in the review, with great variety in the U.S.D.A. Statistical Reporting Service program, to the effective 3.25 sq. km. represented by the systematically selected points on a sampled photo (the cluster) in the French program to the (6 x 6) sq. km. selected by Bircham (1979) in his analysis of sample requirements for Canada. While Bircham (1979) found that, for given levels of precision and magnitudes of land use, the number of sampled clusters required decreased with increasing cluster (grid-cell) size, he also noted that the total <u>area</u> sampled increased significantly with implications for costs of photo acquisition. Thus, given the use of conventional aerial photography, the minimum size should certainly not be less than the French size, but the actual size will more likely reflect other pragmatic considerations such as cost of aerial photography and ground truthing, since in a multipurpose sample (i.e. several land uses being estimated) the actual sampling errors will differ for different land uses. Clustering would be compatible both with use of conventional aerial photography and Landsat data ultimately.

e) Within sampled clusters, sampling may again be undertaken (for example, if conventional aerial photography is used) and certainly there is scope for investigating the merits of complete inventory of sampled clusters versus a point sampling.

f) Based on the nature of rural land use change, a permanent sampling network is indicated. This is supported by the French, Norwegian and Swiss examples and by the proposal noted for the United

Kingdom (Dickinson and Shaw, 1977). A 10-year cycle seems appropriate both in terms of rates of change in rural areas and in order to tie in with census years; however, it may be useful to consider varying the length of cycles depending upon observed (or initially presumed) rates of change, using an interval with a multiple of 5 years to allow integration with census data.

These various general points would permit a comprehensive network to be developed, while still maintaining future flexibility to move towards other levels of reporting and to integrate other data sources.

6.3 Future Land Use Monitoring Research

Landsat developments. It is clear that the analysis of Landsat digital data has a role to play in a land use monitoring program. At present, that role may be relatively modest owing to classification problems though it may be an appropriate means of detecting gross changes in land use. Abstraction made of the cost factor, this would seem to make it ideal for providing information upon which to base a stratification for monitoring land use/cover change in more detail and certainly could be used in the more limited geographic studies in prime resource areas for priorizing study sites.

It is equally clear that the capabilities of this data source are changing and it is recommended that C.L.U.M.P. not only follow such changes closely but that it also becomes involved in encouraging research in change detection analysis that would also link in with conventional aerial photography analysis.

Stratification. Stratification at the subprovincial level is a must. The major problem is that there is a lack of research on this dealing with land use change as the "dependent variable" even though there are a host of "plausible" stratification criteria, for example, physical environment parameters, agricultural land use and structure, population structure, and relationship to the urban-industrial complex. The problem is a "chicken-or-egg" one - to stratify for land use change detection, one needs to have analyzed the link between the criteria and change, but to do this one needs theoretically to acquire data on change. A number of reasonable approaches are suggested however, all of which could be pursued to a certain extent.

First, it would be possible to begin a monitoring program with a skeletal framework; after the first cycle of measuring change, analyses can be made of the characteristics of the sampled units and change, and this information fed into a stratification process that would see additional sampling units selected in some strata. Realistically, this type of improvement of a program as information becomes better would take place in any case.

Second, an initial stratification might be attempted by undertaking change detection analysis using Landsat data. Cost and classification problems might make this prohibitive at present.

Third, an analysis should be undertaken to compare the stratifications produced by using a number of different criteria (for example, physical parameters, agricultural census data) and/or by testing existing "stratifications" for their similarity (for example, ecoregions, crop reporting districts). Such an analysis would begin by an identification of the major types of land use and cover change that are likely to be present in rural areas, determining whether they can in fact be identified with the current classification system and developing a reasoned framework that would link such changes to key indicators (stratification criteria). The indicators selected would then be analyzed independently and in combination and the resulting strata compared. This type of analysis could be fruitfully organized within a selected province. At the same time, those uses that are not large enough to be sampled effectively but for which it is considered important to possess data should be identified and alternative strategies developed for monitoring them.

Alternative sampling strategies. Probably the most significant aspect of a future sampling design for land use monitoring is stratification, which has already been noted above. Given the comments made in section 6.1, another aspect of a sampling design needing further research is the form of the sampled cluster, the size of the sampled cluster and whether or not the cluster should be the object of a complete inventory or whether it should be sampled on a point sampling basis. It is recommended that this should be tested, as a second priority after the consideration of the stratification factors, in a particular region where land use and cover data exist for two points in time. Currently, such land use data exist for some of the urban-centred regions, though the small size of these relative to a provincial and national sampling would pose some problems in evaluating different sizes of clusters or grid cells. Certain principles could nonetheless be tested in terms of complete inventory of sampled cells versus sampling within cells. Furthermore, it would be useful to evaluate the costs involved in terms of interpretation time in each strategy though this, of course, would necessitate working with actual air photography rather than with already processed data.

Finally, it is recommended that C.L.U.M.P. maintain a close contact with those international programs that are most directly pertinent to the needs of C.L.U.M.P., specifically France and Norway, and, to a lesser extent Switzerland. The U.S.D.A. area frame sampling, especially recent developments in California with Landsat, also warrants close attention. Particularly in the West European examples, the length of time of operation of any real monitoring program is so short that it is imperative to develop direct links with these programs so that their experience as it is acquired can be of benefit to C.L.U.M.P. in the early stages of further developments in monitoring land use in Canada.

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