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RURAL LAND-USE CHANGES AND THE PHYSICAL ENVIRONMENT

AN INVESTIGATION OF THE RELATIONSHIP BETWEEN RURAL LAND-USE CHANGES AND THE PHYSICAL ENVIRONMENT

by

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ABSTRACT: A detailed land-use study is performed in a small rural area in Central Ontario. The physical characteristics of the study area are classified as five distinct land units. The land-use patterns are mapped and described using panchromatic aerial photography flown in 1954 and 1971. Using the sequential photography, land-use changes are identified and described. In order to evaluate the hypothesis that the land-use changes are related to the study area's physical environment, a numerical analysis is performed. Statistical tests indicate a strong relationship between the land classification and the types of land-use change. The research results concur with previous observations in physically similar areas.

ACKNOWLEDGEMENTS

The co-operation of the Clerk and secretarial staff at the Hamilton Township Offices in Cold Springs was much appreciated. The local residents and farmers of the study area provided valuable historical information and personal insight concerning problems of farming in the area. Bill Bell, the Statistics Advisor at the McMaster Computer Centre, helped with the numerical analysis. Several members of the Geography Faculty volunteered advice through the course of the research. Many thanks especially to Dr. Reeds, my supervisor, for his patience, support and assistance as editor of preliminary text. His willingness to help whenever approached is much appreciated. Finally, many thanks to Jennifer Johnson, who typed the report under the most adverse conditions but did an admirable job.

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INTRODUCTION

This is a micro-level study of rural land-use changes in a small area of Central Ontario and is based on air photo interpretation for the years 1954 and 1971. The study's main objective is to test the hypothesis that the spatial distribution of the land-use changes is associated with the variations in the physical characteristics of the study area.

Detailed field surveys and interviews were carried out during the summer and fall of 1976, in order to gain an understanding of the land's physical characteristics and its past uses. The township's assessment rolls were found to be an unreliable source of land-use data.

The Study Area

The study area consists of 1836 hectares or just over 18 square kilometers of the morainic hills in the northwest corner of Hamilton Township, Northumberland County (Figure 1). It is centred approximately at 44°5'N and 78°9'W. The delimitation of the area was performed to include strictly this rolling, sandy landscape, occurring within the township. Its west and east limits coincide respectively with County Road 15 and the township boundary. The eastern portions of Concessions V, VI and VII comprise the relevant area from south to north (Figure 2).

Towns and villages are absent within the study area. The sparse

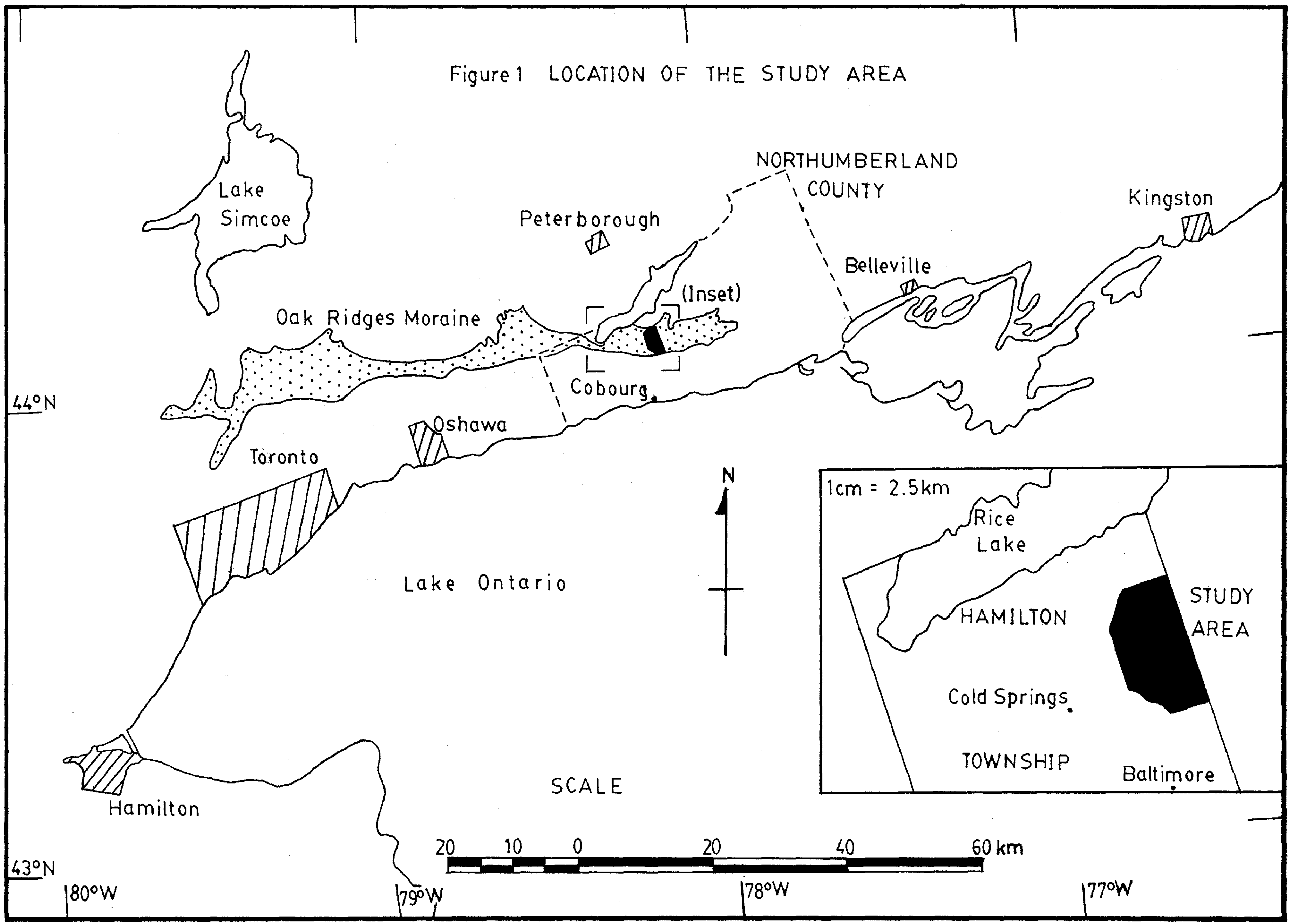
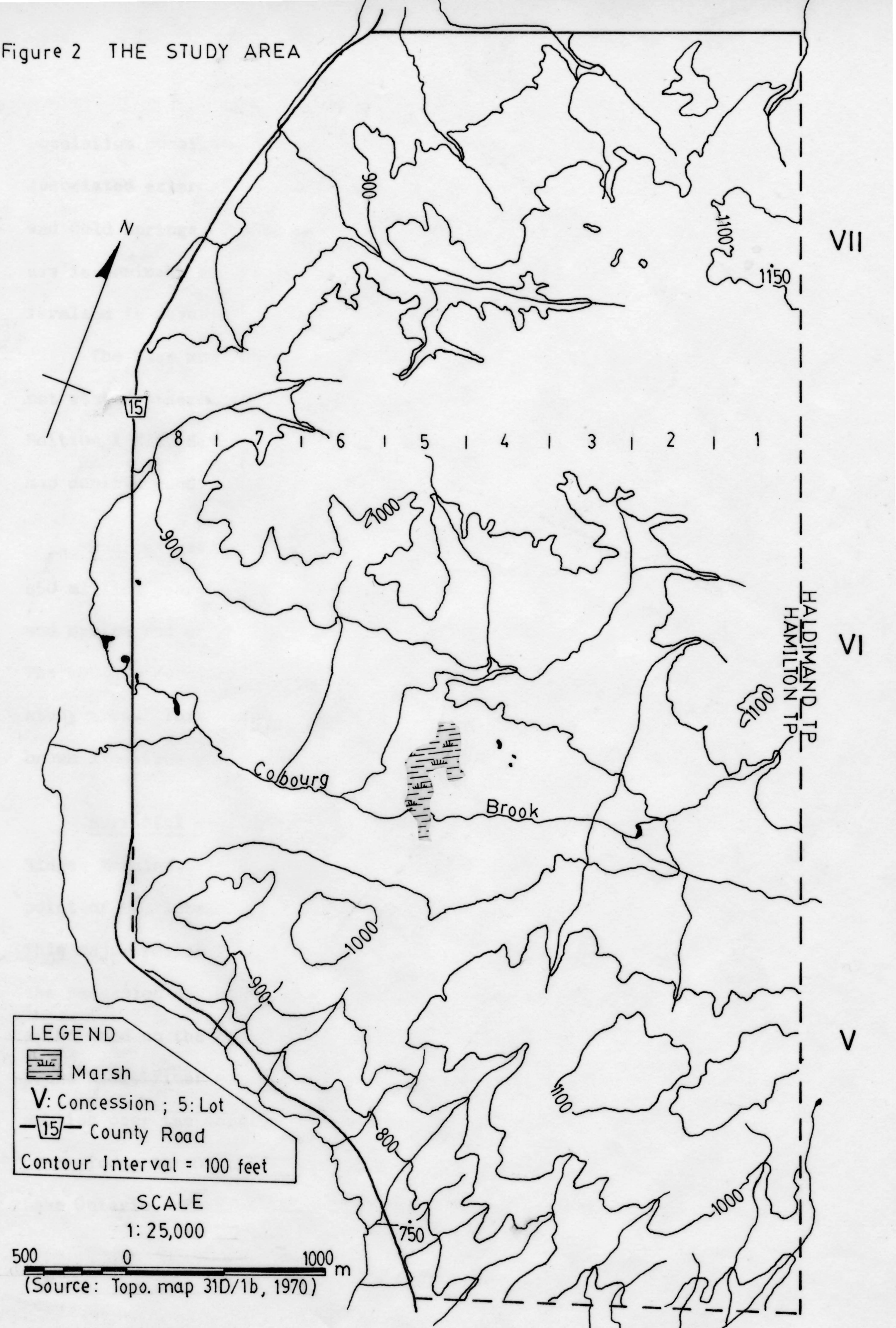


Figure 1 LOCATION OF THE STUDY AREA
Lake Simcoe
Peterborough
NORTHUMBERLAND COUNTY
Kingston
Belleville
(Inset)
Oak Ridges Moraine
Cobourg
44°N
Oshawa
Toronto
N
Lake Ontario
1cm = 2.5km
Rice Lake
HAMILTON
STUDY AREA
Cold Springs
TOWNSHIP
Baltimore
SCALE
Hamilton
20 10 0 20 40 60 km
43°N
80°W
79°W
78°W
77°W

Figure 2 THE STUDY AREA



population consists of a few farmsteads and sporadic non-farm dwellings. Associated external population centres are the hamlets of Baltimore and Cold Springs, due south and west respectively. Agricultural land use is dominant and is of the general farming type. The majority of farmland is devoted to grazing and fodder crops.

The base map for Figure 2 and all subsequent illustrations, if not stated otherwise, is the Cold Springs Topographic Sheet 31D/1b, Edition 1 MCE, Series A 851, scale 1:25,000. The information on the map depicts conditions as they were in 1965.

Bedrock geology. During the Middle Ordovician, approximately 450 million years B.P., the Palaeozoic seas invaded Southern Ontario and marine and deltaic sediments were deposited, buried and lithified. The Cobourg Formation of the Trenton Group carbonates underlies the study area. This bedrock consists of dense to finely crystalline brown limestone containing minor shale partings (Hoffman and Acton, p.9).

Surficial deposits. The landform dominating the area is the Oak Ridges Moraine. It is an interlobate moraine which represents the meeting point of two lobes of ice which moved from the north and from the south. This major relief form was constructed about 12,900 years B.P. during the recession of the Wisconsin ice. Meltwater from the parting ice lobes piled sand on the crest of the morainic till. Between 12,800 and 12,700 years B.P., finer materials were deposited by an ice-dammed lake which emptied over the moraine (Chapman and Putnam, pp42-43).

Today the Oak Ridges Moraine forms the height of land north of Lake Ontario. Much of it is till but the crest is extensively covered with sand and gravel in the hills and fairly level terraces. A knob or ridge of till will occaisionally project above the fluvial-glacial materials. Lacustrine beds of stratified sand, silt and clay are common. The till contains a great deal of limestone derived from the bedrock, has a high lime content and is highly impervious to water, due to having been overridden by a short-lived readvancement of the ice. The sand is fairly high in phosphorous and low in potash content (Chapman and Putnam, p.73). These features of the Oak Ridges Moraine are typical of its portion occurring in the study area.

Soils. The glacio-fluvial deposits represent the parent material from which the soils of the study area developed. Differences in the nature of these deposits result in differences in texture, relief and drainage of the soils (Hoffman and Acton, p.9). Table 1 provides the soil series occurring within the study area and the Great Group to which each belongs, some soil characteristics and associated parent materials. The Pontypool Sand covers almost half and the Bondhead Sandy Loam over one-quarter of the total study area (Figure 3(a)).

Vegetation. The natural vegetation is determined by climate and soil, and vegetation in turn influences the development of the soil. The extent of this influence varies with types of vegetation.

The study area is within the Great Lakes-St. Lawrence Forest Region and the dominant indigenous species observed in the aerial photography are as follows. In the northern portion of the study area, on the well-drained, sandy soils, red oak, trembling aspen and white pine are common. The dominant species on the imperfectly drained, sandy

Figure 3 SOILS OF THE STUDY AREA

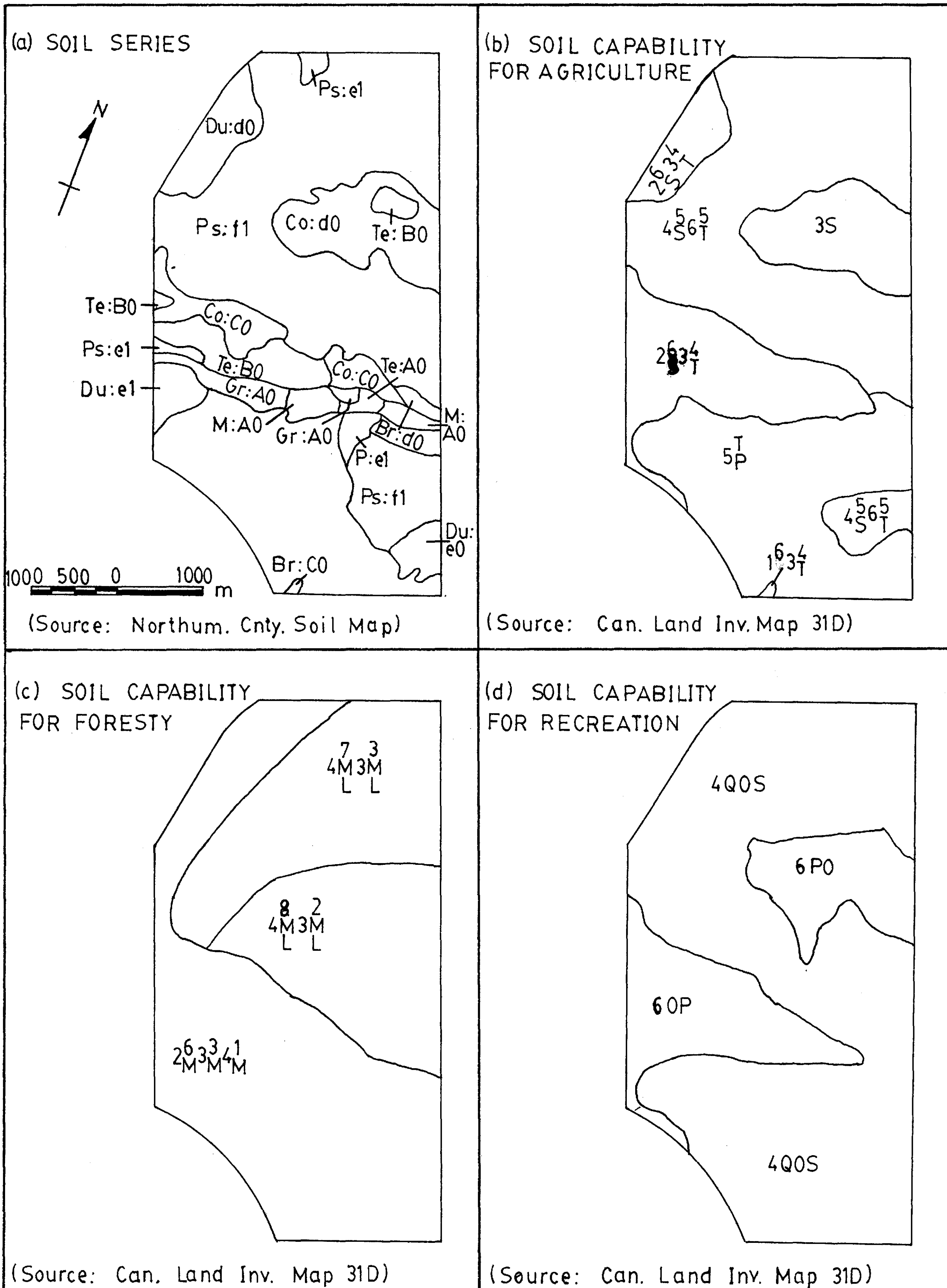


TABLE 1

THE SOILS OF THE STUDY AREA

Soil Series and Map Symbol		Soil Type	Great Group	Drainage	Stoniness	Slope Topography	Parent Materials:	
							Type	Depth(cm)
Bondhead	Bs	sandy loam	G.B.L.	good	very	complex, very steep	till	24+
Brighton	Br	sandy loam	M.B.	good	stonefree	complex, gentle	outwash	14+
Colborne	Co	sandy loam	G.B.L.	good	stonefree	complex, gentle	outwash	26+
Dundonald	Du	sandy loam	G.B.L.	good	slightly	complex, gentle	outwash	26+
Granby	Gr	sandy loam	H.G.	poor	stonefree	smooth basin	outwash	15+
Muck	M		H.	very poor	stonefree	smooth basin	organic	16+
Pontypool	Ps	sand	G.B.L.	rapid	slightly	complex, steep	outwash	25+
Tecumseth	Te	sandy loam	G.B.L.	imperfect	stonefree	smooth level	outwash	27+

SOURCE: Hoffman, D.W. and Acton, C.J., 1974, The Soils of Northumberland County, (Ottawa, Ont.: Research Branch, Agriculture Canada and the Ontario Agricultural College), Report No. 42, Ontario Soil Survey. 83-107 and the Soil Map of Northumberland County.

NOTE: G.B.L.: Grey Brown Luvisol; H.: Humisol; H.G.: Humic Gleysol; M.B.: Mulanic Luvisol.

loam soils of the study area's central lowland are silver maple, red ash and white elm. The swampy, organic soils of the central depression are mainly covered by black spruce and silver maple (Hoffman and Acton, pp10-11).

Climate. In general, the macroclimate of the region is characterized by a warm summer, cold winter, with adequate annual rainfall and the likelihood of drought on the gravelly and sandy sites. Fourty-four years of climatic data collected at Belleville, approximately fifty-six kilometers due east, is assumed to be the most reliable source to represent temperature and precipitation conditions within the study area (Table 2).

TABLE 2

CLIMATIC DATA

Month	Mean Precipitation (cm)	Mean Temperature (°C)	Month	Mean Precipitation (cm)	Mean Temperature (°C)
Dec.	6.5	-5.6	Jun.	6.8	18.3
Jan.	8.3	-7.2	Jul.	6.4	21.1
Feb.	6.2	-7.2	Aug.	7.3	20.0
Winter	21.0	-6.7	Summer	20.5	20.0
Mar.	6.7	-2.2	Sept.	7.0	15.6
Apr.	5.5	5.6	Oct.	5.8	8.3
May	6.0	12.2	Dec.	7.3	1.7
Spring	18.2	5.0	Winter	20.0	8.3
Annual	79.7	6.7	May 1-Oct. 1	33.5	17.2

SOURCE: Hoffman, D.W. and Acton, C.J., 1974, The Soils of Northumberland County, Report No. 42: 12-13.

Besides precipitation and temperature, there are other climatic parameters that are significant in determining the quality of agricultural and natural vegetative growth. The average length of the growing season is 206 days within the study area. The average length of the frost free period is 148 days and the mean annual total of growing degree days is 3400 (Webber and Hoffman, pp11-12). About 42% of the rainfall occurs in the growing season. The mean annual snowfall is 190.5cm.

Relief and drainage. The study area is dominated by a knob-and-basin relief, which is typical of end moraines. The elevation above sea level ranges between 351 meters and 228 meters and the sandy ridge in Concession VII represents the height of land between Lake Ontario and Rice Lake. The hummocky surface topography begins at the northern and southern borders of the study area and rapidly changes into a central, level basin.

The southern and central hills provide springs and the source tributaries for the Cobourg Brook, which flows into Lake Ontario. An unnamed creek flowing into Rice Lake has its source in the hills in the northern portion of the study area. The central basin provides a wide, level lowland through which a major tributary of Cobourg Brook flows in an east-west direction and in which marsh and natural woodland are characteristic.

Soil capability. Many of the soil characteristics are used in the interpretative classification known as soil capability. Classification or suitability ratings are provided for special uses or purposes, such as agriculture, forestry and recreation, which are particularly germane to the study area.

Land classifications differ because the soil and land essentials vary. While an irregular topography might serve as a limiting factor with respect to agricultural activities, it can also be an asset when considering recreational uses. The subclasses of the classification for outdoor recreation are based on kinds of recreational features, while on the other hand, the classification criteria for the other land-use ratings are general soil limitations (Hoffman and Acton, p.54).

Figures 3(b), (c) and (d) show the Soil Capability Classifications for Agriculture, Forestry and Recreation respectively, as developed by the Canada Land Inventory. Explanations of the ratings are provided in Appendix A. Soil capability ratings of the Northumberland Soils closely approximate those of the study area and are tabulated according to the relevant soil series (Table 3).

TABLE 3

SOIL CAPABILITY FOR AGRICULTURE, WASTE DISPOSAL, RECREATION AND URBANIZATION

Soil Series	Slope %	Agriculture	Recreation	Waste Disposal	Urbanization
Bondhead	31-60	4T	3T	3T	4T
Brighton	6-9	3F,M	2A	2A	2A
Colborne	6-9	3F,M	2A	3A	3A
Dundonald	6-9	3F,T	2F	2A	2A
Dundonald	10-15	3F,T	2F	2A,T	3A,T
Granby	0-0.5	5W	4W	5W	5W
Muck	0-0.5	Organic	Unsuitable	Unsuitable	Unsuitable
Pontypool	10-15	6M,T	3A	4W	3A
Tecumseth	0.5-2	2F	2W	3W	3W

SOURCE: Hoffman, D.W. and Acton, C.J., 1974, The Soils of Northumberland County, Report No. 42: 77-79.

NOTE: see Appendix A for explanation of ratings.

The ratings are for the dominant slope class representing each series present in the study area. The soil capability of the Bondhead Sandy Loam was altered to accommodate the very steep slopes, which were not classified.

Review of the Literature

While initially independently developed and applied, the general methodology of this present study is styled after that of Martin (1976), who performed a very similar examination of land-use changes in the Toronto urban fringe. It dealt mainly with the market for land and variations in land ownership. This study follows its methodology of data collection and presentation.

The effect of physical factors on land use in the Bondhead fine sandy loam was examined in an area due east of Hamilton Township in Richards (1945). Bondhead is a light soil, characterized by rolling topography and sheet erosion on the steeper slopes, quite similar to its occurence within the study area. Richards measured and classified soil slopes and erosion in the field and crudely analysed the distribution of present land use according to these variables. He observed: "Because of the steep topography and suseptability to erosion there has been a tendency to retire the areas having steep slopes to permanent cover of woodland or pasture," (p.276). Finally, based on the measurement of four factors, soil type, present cover, degree of slope and erosion, he established five categories on the basis of physical characteristics which determine the capability of the land for agricultural uses (pp277-278).

Putnam (1962) analysed changes in rural land-use patterns using census data, field observations and aerial photography. He identified three gross land-use changes in an area just east of Toronto, between 1931 and 1956: (1) an overall decrease in farmland and cropland; (2) a decrease in the number of farms; and (3) an increase in pasture (p.63). In addition to socio-economic factors, Putnam considered physical conditions of the area on the scale of physiographic regions. In terms of land capability, "poorer or abandoned farms showed a high incidence on the moraine (Oak Ridges) and sand plain," (p.66).

The roles of soil slope and texture as the criteria used in this study's land classification scheme were derived from the extensive review of emperical results in Amato (1976). Light-textured soils are generally considered ideal for most agricultural enterprises, depending on soil depth and topography, since they are easier to cultivate and tend to warm up and dry earlier in spring (Krueger, 1959, p.66). Droughty, sandy soils, such as the Pontypool sand, are very suseptible to wind erosion, which exposes stones in the subsurface and facilitates the occurrence of "blowouts" and sand patches (Hoffman and Acton, p.35). Very sandy soils are often associated with idle land, particularly on steep slopes, greater than 25%, and impeded drainage tills (Adams, 1960).

Relatively flat land, 0-5% slopes, provides few problems to mechanized farming and is associated with minimal erosion. Rolling lands inhibit mechanization and are subject to accelerated erosion, requiring special soil management procedures (Hidore, 1963). According to Hidore, the proportion of land in crops decreases as the slope gradient increases. Similarly, the acreage of pasture and idle land increases as land becomes steeper until the land is so steep, that it is given over to woods (Adams, 1946).

The Study Objectives

The objectives of the present study provide the general problem-framework upon which the balance of the report is based. These objectives are: (1) land classification on a relatively micro-scale, resulting in a number of defined physical land units; (2) land-use mapping and description for two points in time, 1954 and 1971; (3) land-use change mapping and description between two points in time, 1954 and 1971; and (4) analysis of land-use changes with respect to land classification, evaluating the hypothesis that land-use changes are spatially associated with the site associations.

The text is sectioned so as to deal with each one of these objectives, the basic aim being a detailed land-use study of a small rural area. Evaluation of the study hypothesis will be the final problem and the culmination of the preceding exercises.

CHAPTER I

LAND CLASSIFICATION

To allow ready reference and enable subsequent comparative analysis, the physical characteristics of the study area's soils were generalized and then classified in a systematic manner. Five well-defined physical land divisions were determined and mapped. Amato (1976) performed a similar but less systematic land classification when he attempted to clarify the nature of the role of the physical environment in the spatial organization of agricultural land-use types.

Methodology

Nature of the data. The data necessary for the determination of land classes, according to the criteria adopted, was derived directly from the Soil Map of Northumberland County and the accompanying Report No. 42 of the Ontario Soil Survey (Hoffman and Acton, 1974). The soil series was chosen as the basic mapping unit and is defined as a

> group of soils developed from a particular parent material and having the same arrangement of horizons and other differentiating characteristics that are similar, except for the texture of the surface soil (Webber and Hoffman, 1967).

Framework. The deliniation of the study area's physical land divisions is based entirely upon a concept developed by Hills (1961) known as "ecological land-use planning". All classification is performed on an ecological basis, which considers the "totality of patterns of relationships between the organisms of a region and their environment, which determine its productivity" (Hills, 1970, p.6).

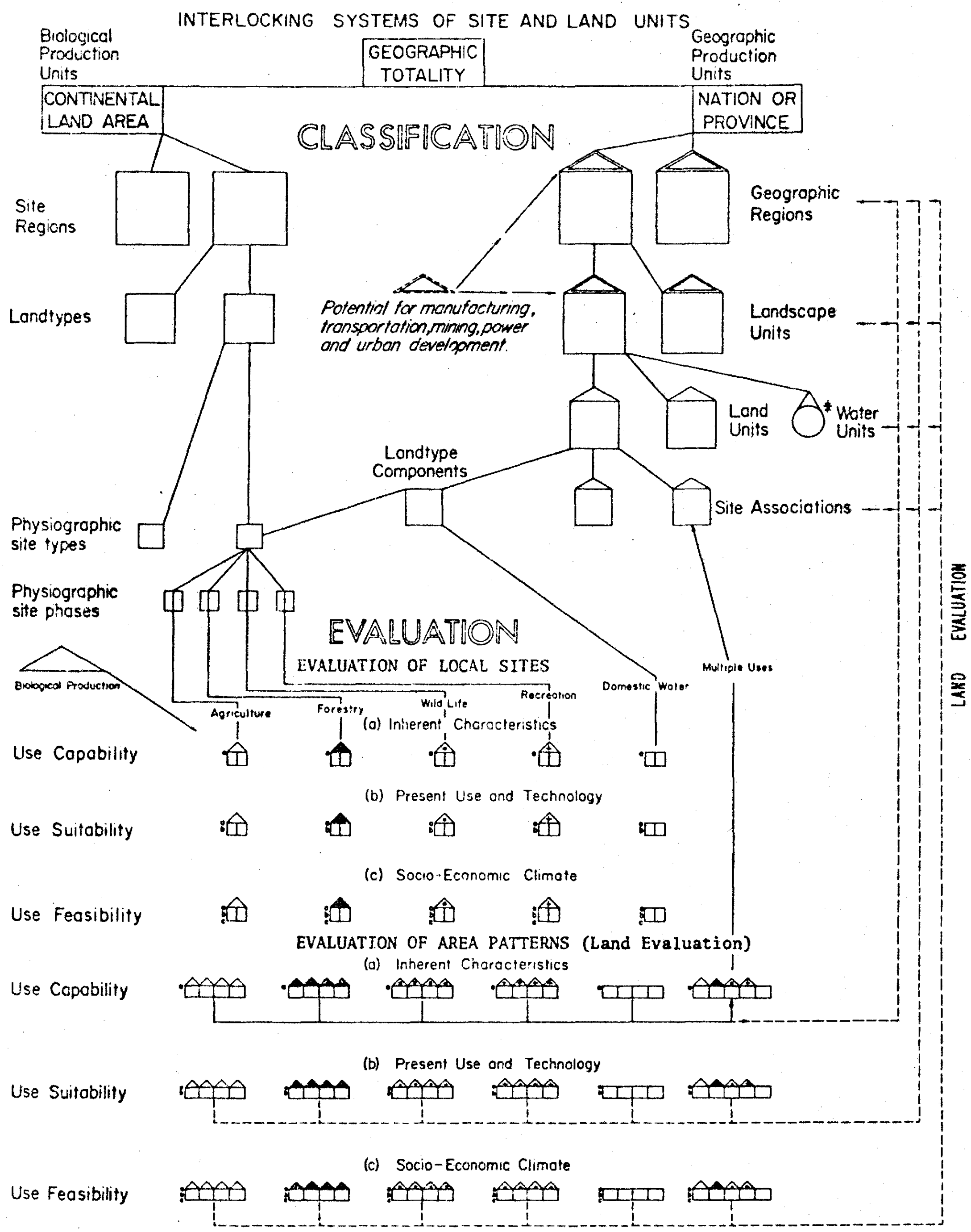
Each locality, which is basically an association of soil materials, water and atmosphere, has unique problems in terms of its productivity. Land use is the interrelationship between land, crops and man, in which land is the basic environmental control (Hills, 1961, pp6-7). Land-use ecology deals with changes in both the living and non-living portions of the ecosystem as it develops (Hills, 1970, p.8).

"Holistic land classification" includes both the processes of classification and of evaluation as applied to both site (biotic) and land (human) ecosystems (Hills, 1970, p.40). Site classification, a grouping based on ecological grounds, is the scheme related directly to this study. It is the specific system of land classification which

> subdivides the continuous mantle of land and water (earth's surface)...into physiographic site units suitable for studying specific relationships between the physiographic environment and the series of biotic communities which it supports (Hills, 1970, p.44).

Land classification, the grouping of site units on geographical rather than ecological grounds, can procede directly from site classification, both of which describe a hierarchy of land and site units that progressively decrease in size (Figure 4). Applying this scheme to the study area, the Site Region 6E is described by Hills (1961) as the vegetation-landform relationships in an area roughly conforming to that commonly known as Pleistocene Southern Ontario. The relevant landtypes, recognized by the texture and depth of the parent materials, as well as the mineralogical composition of the bedrock and parent soil material, can be extrapolated from Table 1. Physiographic site types are subdivisions of landtypes based on moisture regime, local climate and significant variations in soil depth. These site types

Figure 4



* *The evaluation of water units follows a pattern similar to that of land units*

SOURCE: Hills, G.A., et al, 1970, Developing A Better Environment, Toronto, Ont.: The Ontario Economic Council. p.43.

are subdivided into site phases on differences such as stoniness, steepness of slope and other features which are important in production processes. This site unit is the smallest mapping unit and is assumed to be directly related to the soil series unit in the study area.

As an integrating process, land classification is the grouping of site phases, established by site classification, first into site associations, then land units, and so on (Figure 4). The final classification based on the study area's natural characteristics is the site association. A site association is a "local grouping of physiographic site phases which are so intimately associated that as a unit they exert a combined effect upon biological and/or some phase of geographic production" (Hills, 1970, p.51). It may, and in the present case does, represent two or more landtypes.

The geographic criteria considered to establish and classify site associations are those that influence production methods and operations, which vary with the kind of general land use. In this study, the site associations are considered units for management of agricultural and forest lands. The two basic criteria chosen are (1) soil texture and (2) slope topography. The rationale underlying the choice of site associations based upon the soil texture and slope is derived from the emperical results examined by Amato (1976). He concluded that

> texture implies knowledge of soil drainage, soil tilth, water holding capacity, chemical soil fertility and degree of stoniness,...texture gives an indication of what the most important soil characteristics are apt or most likely to be under given conditions (Amato, pp30-31).

An organic and two textural categories were identified in the study area: muck, sand and sandy loam.

Slope topography may often be the critical factor influencing production methods, particularly in agricultural operations. Based on the degree of difficulty presented to the use of agricultural machinery, Amato established a "critical topographic boundary" which divided topographic classes into two general groups (Table 4).

TABLE 4

TOPOGRAPHIC CLASSIFICATION

Simple Topography (Single Slope)		Complex Topography (Multiple Slope)		Slope %
A	Smooth basin	a	Irregular basin	0-0.5
B	Smooth level	b	Irregular level	0.5-2
C	Smooth very gently sloping	c	Irregular very gently sloping	2-5
D	Smooth gently sloping	d	Irregular gently sloping	6-9
E	Smooth moderately sloping	e	Irregular moderately sloping	10-15
F	Smooth steeply sloping	f	Irregular steeply sloping	16-30
G	Smooth very steeply sloping	g	Irregular very steeply sloping	31-60
H	Smooth hilly	h	Irregular hilly	>60

NOTE: — · — · — · - Critical topographic boundary
— — — — — — — Secondary topographic boundary

Group One slopes, simple topography with single slopes between 0 and 9 percent, will present no problems to agricultural mechanization. These are termed "level, smooth" slopes in this study. Group Two slopes, simple topography with single slopes greater than 9%, and all multiple slopes, will cause increasing problems to mechanized agriculture with increasing complexity and slope percentage. These are called "sloping, irregular" slopes. The subdivision of Group One by the secondary topographic boundary to create a "level, basin" class was necessary to deliniate a topography generally unique from "level, smooth" slopes in terms of soil drainage, poor, and vegetative association, woodland. This third group has a simple topography with single slopes between 0 and 0.5%.

The Site Associations

The soil series, the mapping units, were presented separately on two maps, one depicting textural classes and the other topographic groups. These two maps were superimposed and the combination of the textural categories with slope groups yielded five different site associations within the study area (Table 5).

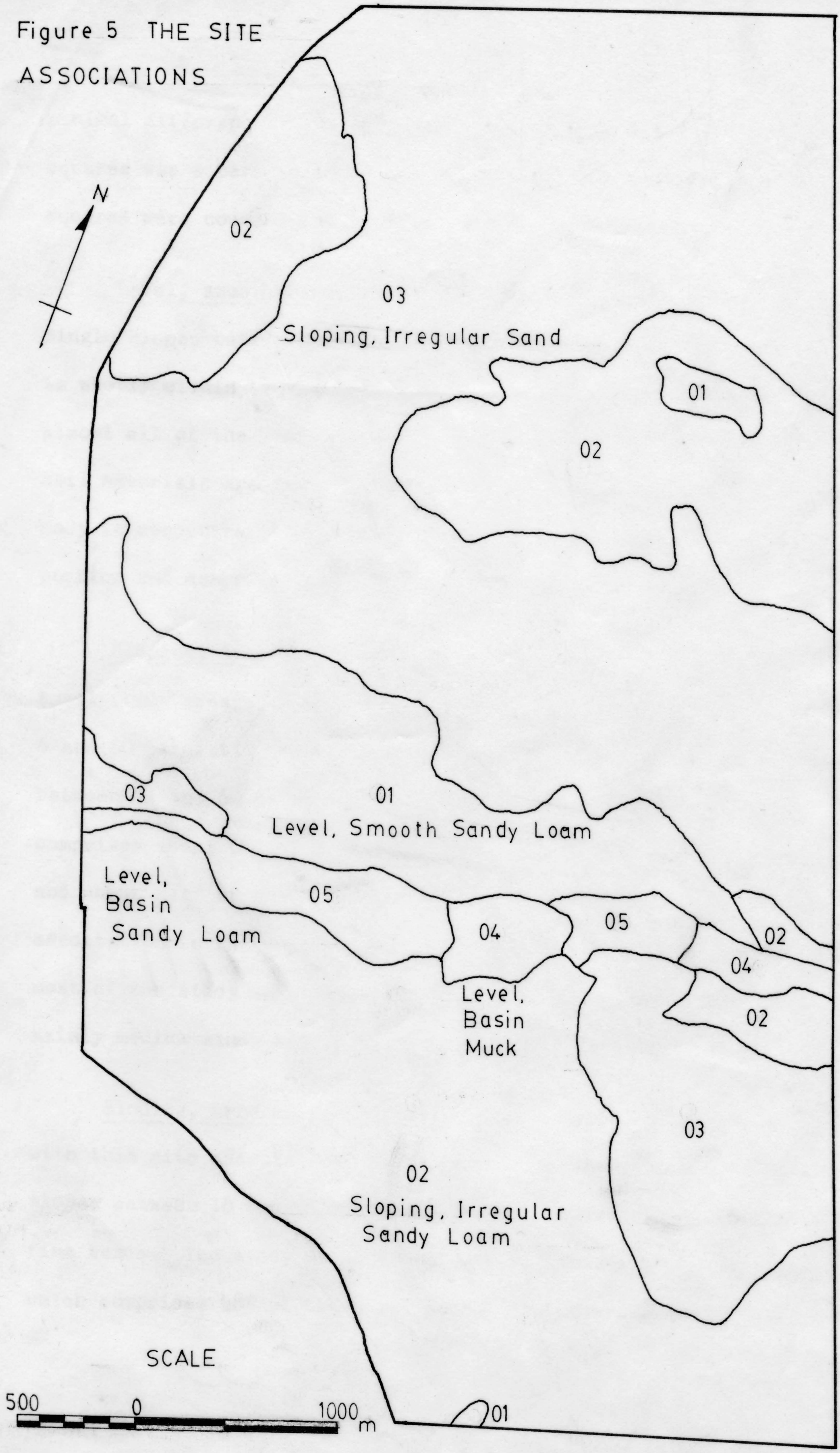
TABLE 5

THE SITE ASSOCIATIONS

Map Symbol	Title	Area Hectares	Area Percent
01	level, smooth sandy loam	183	10.0
02	sloping, irregular sandy loam	693	37.7
03	sloping, irregular sand	881	48.0
04	level, basin muck	29	1.6
05	level, basin sandy loam	50	2.7
		1836 Total	100.0

As a mapping unit, the site association is commonly mapped at a scale of 1:15,840, and individual patterns range in size up to four hectares (Hills, 1970, p.46). However, "a recurring pattern of such individual patterns may occupy areas of many acres (hectares)" (Hills, 1970, p.52), as is the form of application in this study. The site associations were initially drawn at a scale of 1:63,360 but were photographically enlarged to the base map scale of 1:25,000 (Figure 5). All hectarage data were measured twice by the method of squares, with

Figure 5 THE SITE ASSOCIATIONS



minimal differences, and then averaged. A grid drawn with one-hectare squares was superimposed on the map and all whole as well as partial squares were counted and totalled.

Level, smooth sandy loam (01). The topography is simple with single slopes between 0.5 and 9%. The occurrence of the Brighton series is wholly within this site association. About half of Colborne and almost all of the Tecumseth series occur in this site association. The soil materials are medium to fine sands. The site association's main body is concentrated as a strip across the study area's central portion and comprises ten percent of the total hectarage.

Sloping, irregular sandy loam (02). Covering over 37% of the total study area, the topography is complex with multiple slopes between 6 and 60 percent. The occurrence of the Bondhead series, with slopes between 31 and 60 percent, is wholly within this site association and comprises about 60% of its area. The remainder of the Colborne series and about half of the Dundonald series occur as patches of the site association in the northern part of the study area. The main body covers most of the study area's southern half. The soil materials are mainly medium sand, with occaisionally finer deposits.

Sloping, irregular sand (03). The Pontypool series is coincident with this site association and has a complex topography with multiple slopes between 16 and 30 percent. The soil materials are medium and fine sands. The study area is dominated by this site association, which comprises 48% of the total hectarage, covering most of the northern half and a large patch near the southeast corner.

Level, basin muck (04). The occurrence of muck in the central lowland of the study area is coincident with the spatial distribution of this site association. The topography is simple with single slopes between 0 and 0.5 percent. The soil materials are organic deposits, usually wet and forest covered. This site association totals just over 1.5% of the total hectarage.

Level, basin sandy loam (05). Also associated with thestudy area's central lowland, this site association is dominated by and contains all of the Granby series. A small patch of the Tecumseth series is also included. The topography is simple with single slopes between 0 and 0.5 percent. The soil materials are medium sands, usually wet and forest covered. Just over 2.5% of the total hectarage is classified as this site association.

For more detailed descriptions of the soils affiliated with each site association, the reader is referred to Figure 3(a) and Table 1.

CHAPTER II

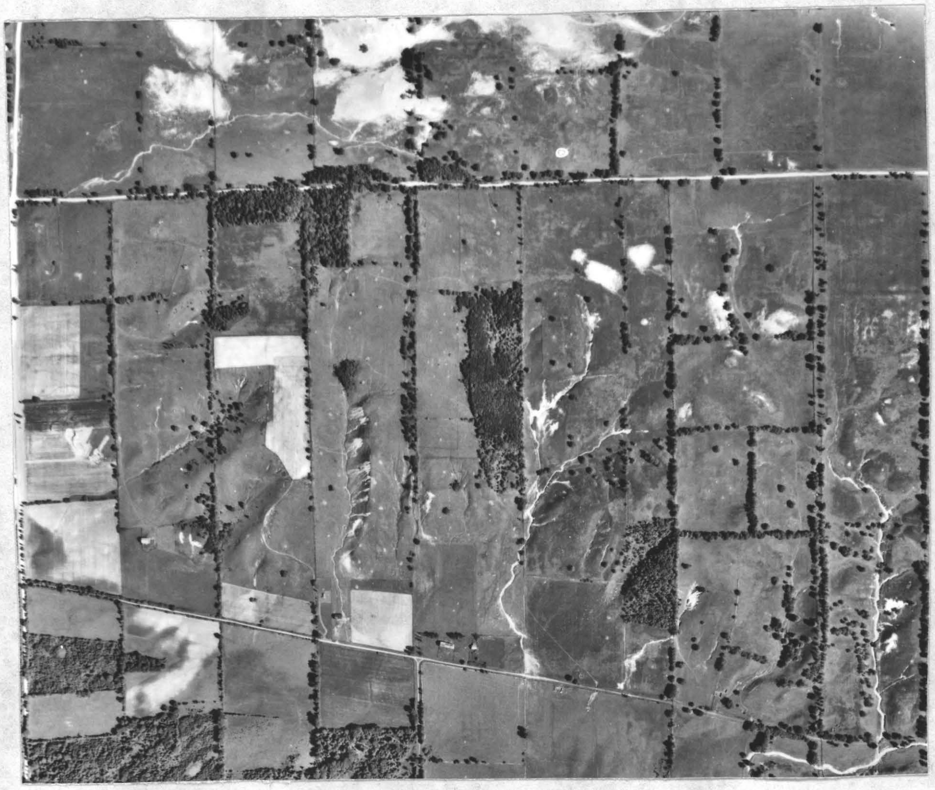
STATIC LAND USE: 1954 AND 1971

The mapping and description of land use at two points in time is an essential first step before initiating an analysis of land-use changes. The scale of the aerial photography permitted a relatively detailed land-use classification. In addition, general associations between the spatial distribution of land use and the area's physical characteristics become apparent.

Methodology

Nature of the data. The principal source of land-use data were standard, panchromatic aerial photographs and information extraction was accomplished through well-established methods of air photo interpretation (Figure 6). Due to the small quantity of the 9" X 9" contact prints involved and the lack of complications in interpretation resulting from similar flight dates and identical photographic scales, the process of data extraction was simplified (Table 6). The photographs were individually scanned using a pocket-type stereoscope and frequently employing a ten-times power hand magnifier for maximum clarification. Land use was identified according to key photographic evidence, based on units defined by natural or unnatural fragmentation of the study area. In most cases, well-defined fields and areas of non-agricultural vegetation were classified as to the present land use and this information was

Figure 6 AERIAL PHOTOGRAPHY



(a) Photo 54 11-142, June 8, 1954.

SCALE

1:15,840

(305 ha. each)

(b) Photo 1.71 55-46, August 7, 1971.

TABLE 6

CHARACTERISTICS OF THE AERIAL PHOTOGRAPHY

Photo Number	Date of Flight	Scale
54 4403 12-49	June 8, 1954	1:15,840
54 4403 12-51	June 8, 1954	
54 4404 11-152	June 8, 1954	SOURCE: Ontario
54 4404 11-153	June 8, 1954	Department of Lands
54 4404 11-48	June 8, 1954	and Forests, Toronto
44171 W	1954 Mosaic	
1.71 4403 10-157	July 15, 1971	1:15,840
1.71 4403 10-158	July 15, 1971	
1.71 4404 55-46	August 7, 1971	SOURCE: Ontario
1.71 4404 55-47	August 7, 1971	Ministry of Natural
1.71 4405 27-42	July 15, 1971	Resources, Toronto

simultaneously transferred to a semi-controlled mosaic of the study area, at the same scale. The mosaic was considered a simple but reliable tool for areal correlations of land-use data interpretted from the contact prints and the representation of that information in map form. The final land-use maps were traced directly from the work-sheet mosaic. The maps were photographically reduced to the text scale and all hectarage data were measured twice and averaged, using the method of squares.

Framework. In Report No. 1 (1971), the Canada Land Inventory summarized their classification for present land use and a slightly altered version of this scheme was applied to the study area (Table 7). This sudy's land-use classification displays reduction and modification of the basic Canadian categorization to accomodate the quantity and quality of photographic evidence representing the particular mix of agricultural and forest lands peculiar to the area. The major alteration is the division of forest lands into woodland, scrubland

and plantation (reforestation), the latter being an addition necessary to represent a dominant and distinct land-use phenomenon. The expanded definition of unproductive land (sand) was required to include tracts of inactive so dominated by the erosional features listed that they were assumed incapable of serving any functional forest or agricultural purpose at the time. The photographic appearance provided an arbitrary criterion, based on the relative frequency of erosional features.

TABLE 7

CLASSIFICATION FOR PRESENT LAND USE IN THE STUDY AREA

Category	Map Symbol
I URBAN	
Land used for urban and associated non-agricultural purposes.	
1. Residential (Residences on large, scattered lots, between 1 and 12 hectares or with 30.5 meters of frontage or more)	•
2. Sand and Gravel Pits (Land used for the removal of earth materials, including associated structures)	E
II AGRICULTURAL LANDS	
Land used for agricultural purposes, including associated structures.	
1. Structures (Land used for barns, animal shelters, residences and other farm purposes)	+
2. Cropland (Land used for animal field crops, the production of hay and other cultivated fodder crops, including land being cleared for these purposes)	A
3. Improved Pasture (Land used for cultivated, improved pasture)	P
4. Rough Pasture (Areas of natural grasslands, sedges and herbaceous plants actively grazed)	K
5. Inactive (Abandoned farmland or farm structures, including ruins, dominated by no other land use)	□, I
III FOREST LANDS	
Land covered with tree, scrub or bush growth.	
1. Woodland (Natural areas of wooded land with trees having over 75% canopy cover)	T
2. Scrubland (Natural areas of trees and bushes having over 25% but less than 75% canopy cover, including rough lands	

TABLE 7-Continued

Category	Map Symbol
and covered wetlands not pastured)	U
3. Plantation (Artificially reforested areas, regardless of age)	Y
V UNPRODUCTIVE LAND	
Land which does not support vegetation, eg. eroded soil or rock and active depositional features.	
1. Sand (Sand flats, eroded river banks and eroded steep slopes, including inactive land dominated by these features and no other land use)	S

SOURCE: Canada Land Inventory, 1971, Summary of Classification for Present Land Use, Canada Land Inventory Report No. 1: 49-51.

Air photo interpretation. A consistent and standard procedure for extracting information was developed through the experience of preliminary trial-and-error and the establishment of criteria based on photographic evidence discussed in the relevant literature. Goodman (1959, 1965) accomplished differentiation of black and white aerial images by unique tonal and textural qualities and by objects usually in association. McLellan (1968) categorized problems of interpretation resulting from variations in the scale scale of the photography, its age and the time of year it was flown. Identification of the greatest number of agricultural uses in most cases occurs in the mid-summer period (p.29). Tests by Wood (1968) with geography students identifying land uses after a few weeks of study showed an overall accuracy of a 70% to 90% level of success. He concluded that "the human eye detects differences in textures, micro-patterns and tonal variations" (p.108). Wood also provided accumulated observations and data he used in panchromatic air photo interpretation of agricultural land use in

Southern Ontario. Ryerson (1973), summarizing the analysis of temperate agriculture using aerial photographs, showed that panchromatic imagery at a scale between 1:12,000 and 1:30,000 gives a high accuracy of separating agricultural from non-agricultural uses and cultivated land from pasture, particularly in July (p. 324). Accumulated criteria (Appendix B) were used as the framework to identify land use within the study area. It seems appropriate at this point to indicate that the key proposed here will obviously apply to the identification of land-use changes.

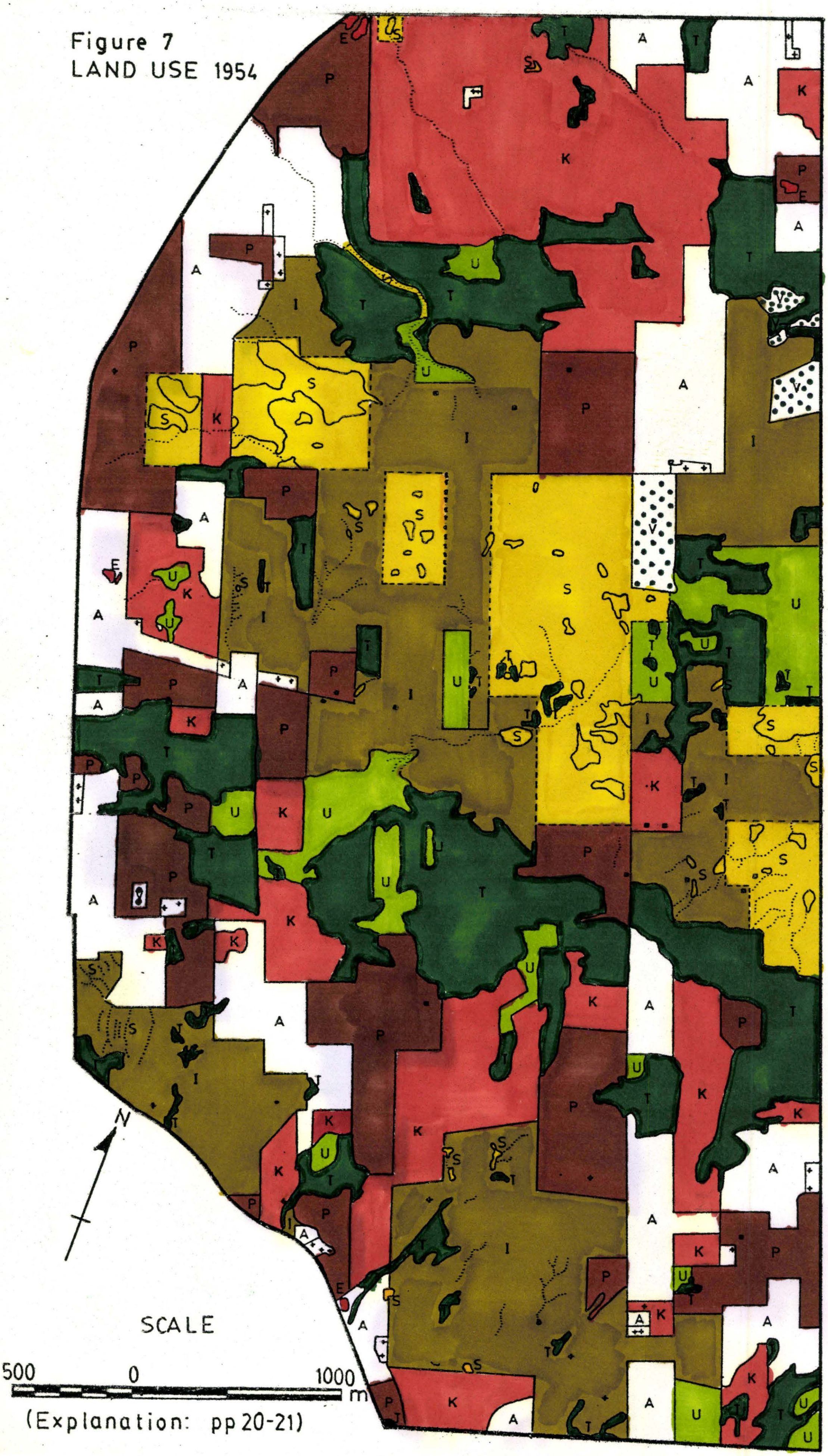
Analysis

Land-use maps were constructed and data extracted, providing supportive hectarage tables, for descriptive purposes at the time of the photography 1954 and 1971. The dominant patterns of land use in 1954 and 1971 are illustrated by Figures 7 and 8. The dissemblance between the two years is clearly recognizable and invites further detailed examination of each map.

Agricultural land use is dominant in the 1954 map, occupying 44 percent of the study area, excluding idle farmland (Table 8). Cropland (14 percent) is almost equalled in area by improved pasture (12 percent) and both are exceeded by rough pasture, which accounts for almost 18 percent of the total land usage. Nearly 19 percent of the study area is classified as inactive land.

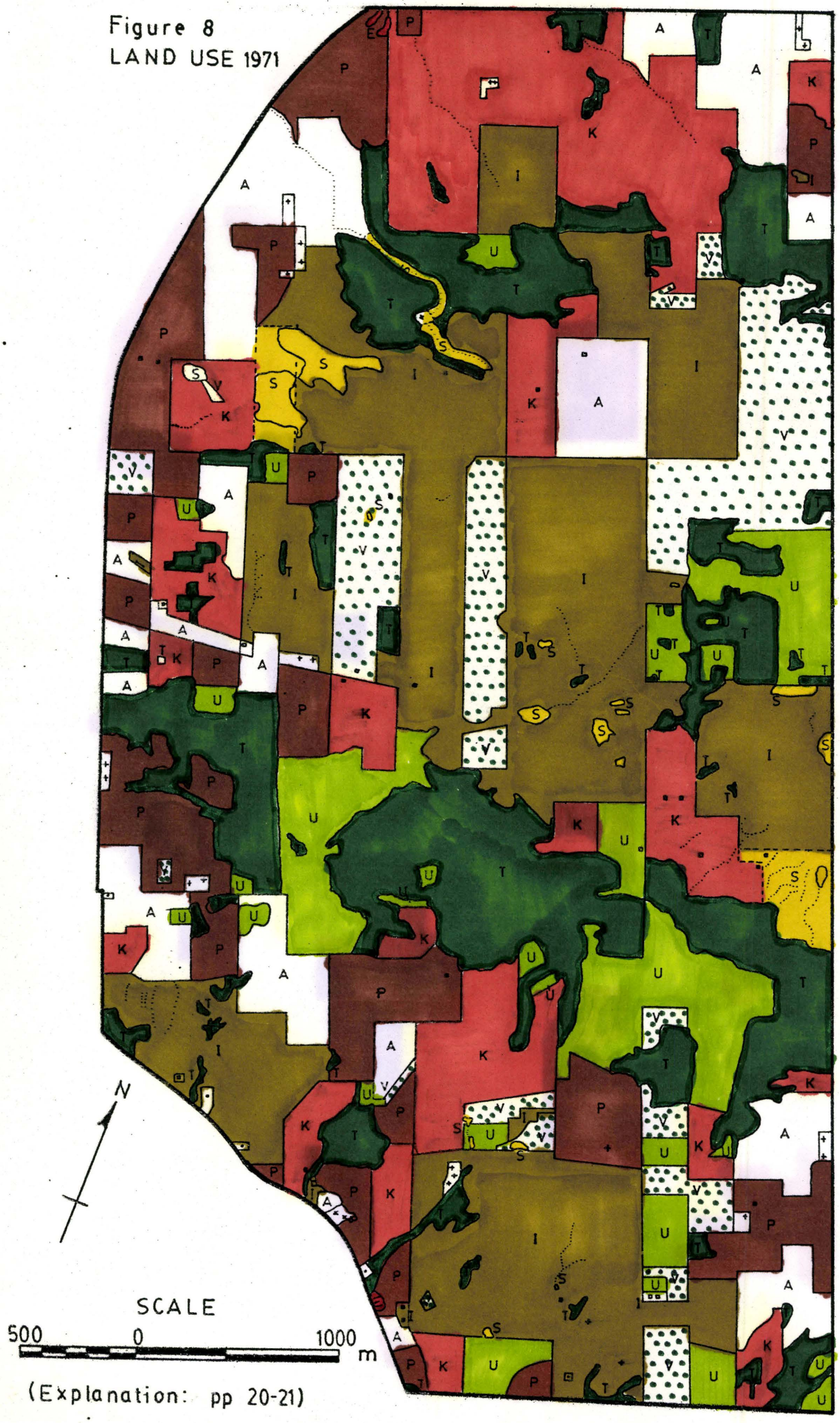
Forest and unproductive lands account for remaining hectarage, urban land uses being insignificant. Just over 27 percent of the study area is forest land, the great majority of this identified as woodland and the difference classified as either scrubland or reforestation.

Figure 7
LAND USE 1954



(Explanation: pp 20-21)

Figure 8
LAND USE 1971



(Explanation: pp 20-21)

Unproductive land, that which is so dominated by erosional features and large sand patches that it is rendered virtually useless for vegetal growth, represents, at over 9.5 percent, a very significant proportion of the total area.

In contrast, agricultural and forest lands appear equally dominant in 1971 (Figure 8). The breakdown of agricultural land use, 36.5 percent excluding inactive land, again shows equal importance of cropland and improved pasture, the latter slightly more, in terms of hectarage (Table 8). Rough pasture remains the most significant agricultural land use in the study area, at 15 percent. Over 24 percent of the study area is shown as inactive land.

While the natural wooded area is essentially unchanged as one would expect, significant and approximately equal proportions of the land in 1971 are dominated by scrubland and reforested areas, each around 8 percent. Only about 2 percent of the study area is classified as unproductive land and the final 3.5 percent is in non-rural uses.

In general, the maps and related hectarage data draw attention to the almost equal dominance of gross land-use patterns in both years by agricultural and forest interests (71.3 percent in 1954 and 73.6 percent in 1971). Idle land is a notably large proportion of the total area and reached almost one-quarter in 1971. The relatively high figures representing inactive land, the insignificance of cropland with respect to improved and rough pasture and the large areas of forest lands are likely associated with the study area's physical geography. In a survey examining the influence of physical factors on land use in a soil type common in the present study area, fine sandy loam, Richards (1945) attempted to show a relationship between present land use and soil type, present cover, degree of slope and erosion. His data indicated that

> because of the steep topography and susceptability to erosion, there has been a tendency to retire the areas having steep slopes to permanent cover of wookland or pasture(p. 276).

TABLE 8

LAND-USE HECTARAGE, 1954 AND 1971

Land-Use Category	1954 Hectares	1954 Percent	1971 Hectares	1971 Percent
I Urban				
1. Residential	0.0	0.0	2.5	0.14
2. Sand and Gravel Pits	1.9	0.1	1.0	0.05
II Agricultural				
1. Structures	9.55	0.52	8.25	0.45
2. Cropland	253.95	13.82	184.75	10.06
3. Improved Pasture	220.5	12.01	199.0	10.84
4. Rough Pasture	326.05	17.76	277.25	15.1
5. Inactive	347.9	18.95	446.0	24.3
III Forest				
1. Woodland	361.25	19.68	383.25	20.87
2. Scrubland	84.4	4.6	145.0	7.9
3. Plantation	53.5	2.91	154.0	8.39
V Unproductive				
1. Sand	177.0	9.64	35.0	1.91
Total	1836.0	100.0	1836.0	100.0

Features indicating accelerated erosion are common throughout the study area, much of it being hilly sandy soil subject to blowing. "Blow-outs" are frequent and even in quite level areas. The original surface horizon of the soil is often covered by patches of sand. Unproductive land in the form of excessively eroded areas and the large proportion classified as inactive land were probably farmland. The fields had been cleared, cultivated and used as cropland or pasture, thus increasing the possibility of soil erosion. Putnam (1962) studied rural land-use patterns in Central Ontario and suggested that land capability at least partially explained the high incidence of poorer or abandoned farms on the Oak Ridges moraine and associated sand plain (p. 66).

It is clear that the lack of widespread intensive practices such as cropland and cultivated pasture is a response to the physical factors donimating the study area. The light soils, complex topography and lack of natural cover enhance accelerated erosion and necessitate less intensive uses such as rough pasture and forest lands. Unproductive sandy areas are the result of poor erosion control and idle farmland represents abandonment of highly erodible soils which would have been better left uncultivated and covered.

CHAPTER III

DYNAMIC LAND USE, 1954 TO 1971

The previous chapter described land-use patterns in 1954 and 1971, purposely limiting discussion of the changes that were obvious, as illustrated by the maps and hectarage tables. Detailed description and analysis of dynamic land use within the study area will now be presented. The introduction of the temporal factor in this new topic justifies the basic distinction between dynamic and static land use. These two different perspectives allow exclusive evaluation but also provide mutual corroboration.

Methodology

The two land-use maps (Figures 7 and 8) were superimposed at the air photo scale of 1: 15,840, to maximize the quantity and consistency of data extraction, and land displaying changes in use between 1954 and 1971 was delineated. In addition, the imagery listed in Table 6 was compared by matching individual aerial photographs, the pairs in all cases representing the same real ground surface for both 1954 and 1971. Changes identified by eye according to the criteria previously applied in land-use classification (Appendix B), were drawn on the mosaic work sheet and used as a check for the map-extracted information. These two independent methods ensured acceptable accuracy in identifying the land-use changes. Once the final map was completed, it was reduced photographically to the text scale of 1: 25,000.

Numerous types of land-use changes were identified and areal measurements were carried out using the method of squares at the level of accuracy previously mentioned. A table was constructed illustrating the changes in land use using the hectarage data.

The "comparison method" in air photo interpretation was used in Canada by Philpotts (1957) and is described in detail by Dill(1959). In general, the land-use researchers employing sequential black and white imagery worked with a photographic scale between 1: 15,000 and 1: 20,000.(Putnam, 1962, Avery, 1965, Philpotts, 1966, Martin, 1976). Dill demonstrated that for small areas

> detailed data on changes in land use ... could be obtained from air photo interpretation in a short time, with minimum expenditure of funds and with a small technical staff (p. 47).

The numerical presentation of land-use changes and illustration by paired land-use maps from air photos enhance the process of explanation. The evaluation of changes in turn can provide the basis for either the continued support of past trends or the initation of effective policies to alter these trends for the benefit of all concerned.

Analysis

The historical perspective provides important background information about the pre-1954 land-use changes in relation to the trends between 1954 and 1971. Reliable verbal and documented accounts describe both the study area and the landform it represents, Oak Ridges moraine, as being completely cleared by the settler' exploitation of timber in the nineteenth century (Chapman and Putnam, 1973). Similarly, the entire area of the moraine was immediately occupied by farmland, including the study area, which was treeless and farmed as late as 1900. Personal communications with the established farmers still settled in the study area were consistent and established that cropping in the sandy, level areas tapered off beginning in 1923 due to reduced yields. These areas were never cropped after 1926 and accelerated erosion became a problem. In 1935, a flash flood created serious gullying which took up to five years to repair. The sand on the higher land drifted annually until anchored by tree plantations in the early 1950's. The surface improved and the level areas were cropped again in 1956, but a bad wind the next year removed over 15cm of top soil. The land was again abandoned.

The 1954 land-use data (Table 8) indicate the reduced but continuing dominance of the study area by agricultural land uses. The problems associated with steep slopes and the light soil are represented by the high percentages of both idle farmland and reproductive land. On the other hand, the comparative 1971 figures show the increasing importance of forest lands and the reduction of unproductive land, perhaps a response to attempts of improvement of land quality. This relationship between land-use changes and physical factors will be examined in Chapter Four.

A given piece of land can normally be put to a number of uses and hence evolves the principle of land-use competition (Found, 1971). Found assumes that farmers are income optimizers, i.e. economic men' , whose primary objective in using land is to earn an income, "rather than 'blending with nature'", (p. 22). If variations occur in the production functions due to the natural environment which are greater than the regional variations in prices and costs, the land use yielding the highest income will vary likewise. In this case, land-use changes "would be expected to bear a strong relationship to land quality"(p. 23).

It appears that such a variation in the "highest" land use has taken place in the study area, beginning with its initial settlement and continuing between 1954 and 1971. Land-use hectarage changes (Table 9) not only indicate that almost 30 percent of the study area was involved (531 hectares), but that in general between 1954 and 1971, inactive and forest lands have increased their hectarage at the expense of unproductive and agricultural lands, respectively. It should be pointed out that the conversion of unproductive land to inactive land represents a reduction of erosion features to a degree at which they no longer dominate the landscape, but that area remains idle.

Over 27 percent of the 1954 cropland, representing the greatest absolute loss of agricultural land, was converted in approximately equal quantities to improved pasture and inactive land. The rest was almost equally divided between scrubland and plantation. Half of the change in improved pasture actually represents an exchange with cropland, indicating its similar condition and adaptability to crop growing. However, the rest of the change in improved pasture was mostly to rough pasture and scrubland. Small areas were converted to inactive land and plantation. The greatest change in rough pasture was its alteration to scrubland and to a lesser extent, inactive land. Relatively smaller quantities became plantation and natural woodland. While much of the inactive land that changed became plantation, a significant quantity was put back to agricultural use as rough pasture. In terms of idle land, it seems safe to assume that its variation through time may involve either its reuse as farmland or its conversion to forest land. In light of the physical conditions of the study area, the latter option was most favourable between 1954 and 1971. However, the persistence of a large percentage of inactive land likely represents land suspended between agricultural and forest uses.

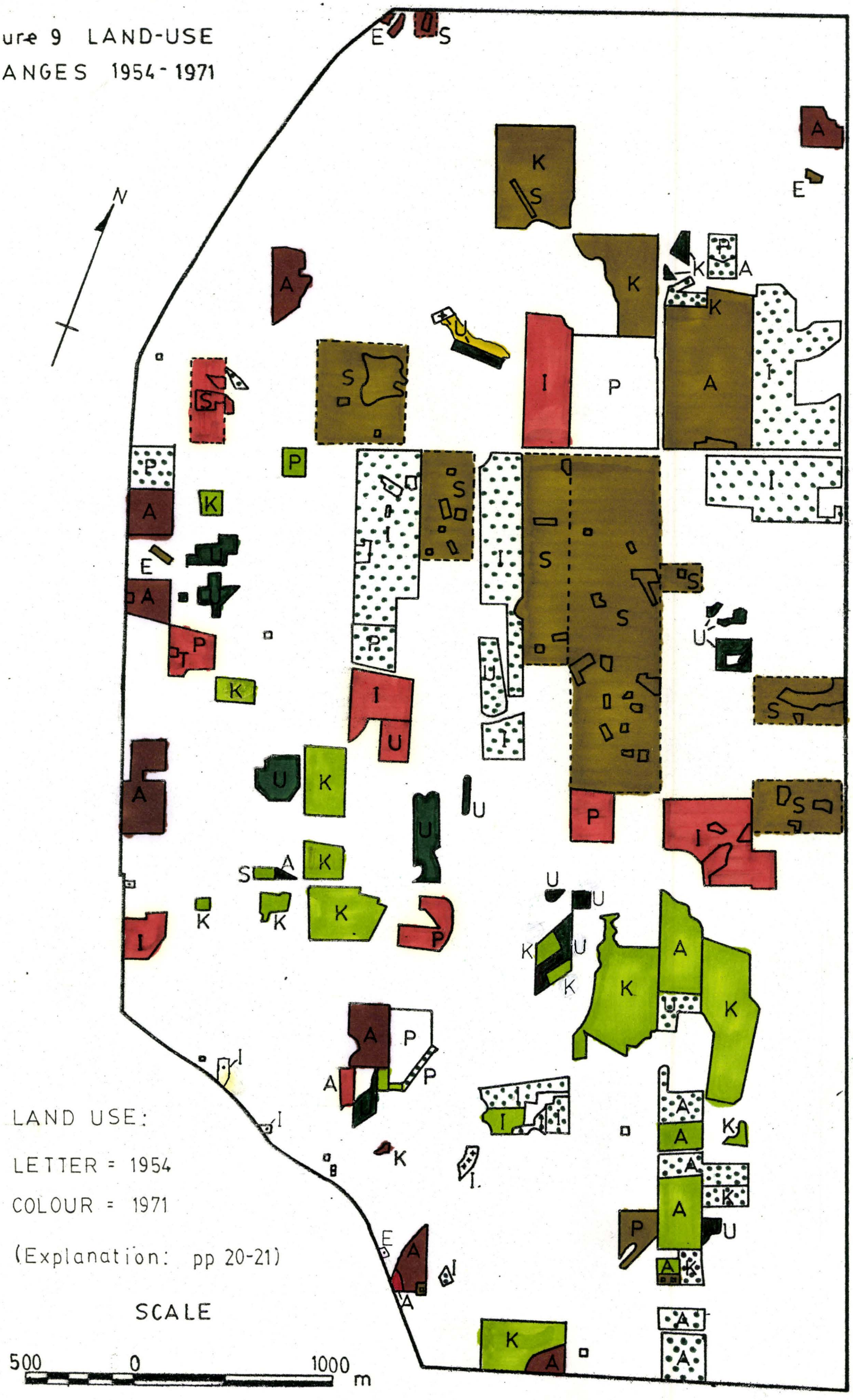
TABLE 9

LAND-USE HECTARAGE CHANGE, 1954 TO 1971

1954	1971 •	E	+	A	P	K	I	T	U	V	S	Total Area
Urban (•)												0.0
Residential Extractive (E)	0.5						1					1.5
Farm (+) Structure							2.5					2.5
Cropland (A)	0.7				33	1.5	28		14	18		95.2
Improved Pasture (P)				26		12	4		8	4.5		54.5
Rough Pasture (K)	0.3						27	2	63	9		101.3
Inactive (I)	1.0	0.6	0.8			36			3	65		106.4
Woodland (T)												0.0
Scrubland (U)			0.4			3		20				27.4
Plantation (V)												0.0
Sand (S)							142					142.0
Total Area	2.5	0.6	1.2	26	33	52.5	204.5	22	88	100.5	0.0	530.8
Net Change	2.5	-0.9	-1.3	-69.2	-21.5	-48.8	98.1	22	60.6	100.5	-142	
	URBAN 1.6		AGRICULTURAL -140.8				INACTIVE	FOREST 181.3			UNPRODUCTIVE	

The land-use changes map shows virtually no part of the study area was exempt from land-use variation between 1954 and 1971. (Figure 9). The overall pattern of agricultural lands being converted to forest land is

Figure 9 LAND-USE CHANGES 1954-1971

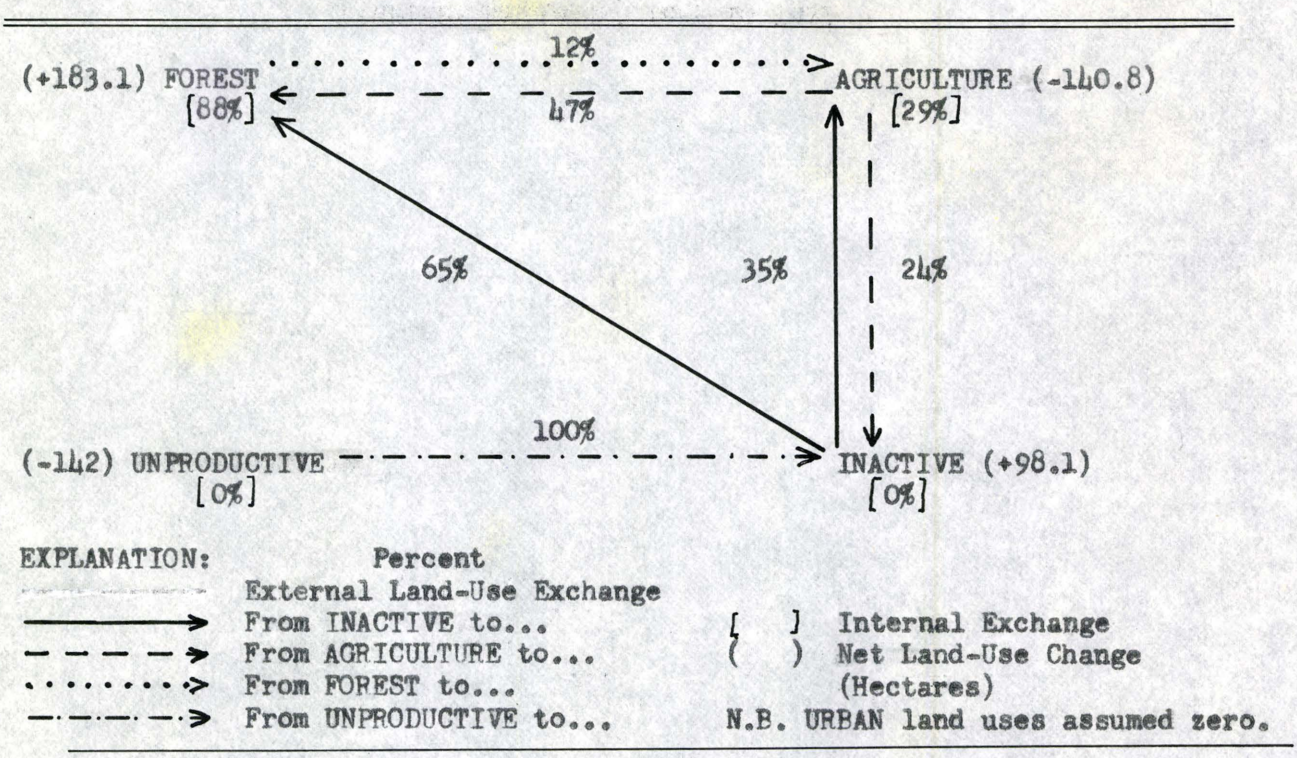


clear, as is the increase in unactive land due to the general reduction of erosional sand features and the increasing abandonment of farmland. The sporadic incidence of urban residences, particularly adjacent to County Road 15, is striking but insignificant in terms of aerial change. It sould be noted here that the areas on the map enclosed by dlashed boundaries represent formerly unproductive land, the erosional features (sand) of which have been significantly reduced, that required reclassification as inactive land, apparently suitable for vegetative growth.

The following flow chart (Figure 10) summarizes as a simplified model the dynamic land-use tendencies in the study area.

FIGURE 10

LAND-USE EXCHANGE, 1954 TO 1971



The preceeding observations suggest a variation in land use with respect to land quality in the study area. Any surface unprotected by vegetation and not continuously moist may be eroded by the wind. These surfaces, particularly the steeper slopes, are especially susceptible to water erosion. The hilly topography and unprotected light soils of the study area readily meet these criteria. On nearly level topography, the soil is characteristically draughty and unstable under cultivation or pasture (Chapman and Putnam, p. 278).

> Cultivated crops, particularly row crops, usually increase soil erosion because they : (1) reduce soil granulation and the organic matter content of the soil thereby lowering the water-holding capacity and increasing the surface run-off; (2) do not occupy the soil throughout the year; and (3) do not cover the soil completely (Richards, p. 275).

With the information at hand, a sequence of land-use variation is suggested as follows. The initial clearing and farming of the entire study area in time resulted in decreasing yield and increasing soil erosion. Problems with steep slopes and light soils necessitated conservation methods (since the 1940's) such as contour farming, strip cropping and tree and grass planting to continue agricultural practices. However, a return to intensive agriculture, cropping and cultivated pasture, again resulted in accelerated soil erosion.

The trend over the most recent two decades shows a declining agricultural land use and the extension of forest lands. Less intensive agriculture such as rough pasture dominates the dwindling farmland. Forest cover, particularly reforestation, is increasing significantly.

> Permanent cover crops such as hay, pasture and woodland tend to hold the soil in place and reduce erosion because: (1) they cover the soil completely the year around, and (2) add to the organic matter and granu-

> lation of the soil thus increasing the water-absorbing capacity which in turn decreases surface run-off (Richards, p. 275).

Reforestation on the ridges and severely eroded land and grass planting as the level topography help fix wind-blown sand. The 1950's and 1960's pine plantations have been very effective in reducing erosion in the study area. The reforestation and natural forests are needed to maintain springs in the hilly areas, which are the sources for the streams and creeks flowing through the study area. The droughtiness of the soil might ultimately be reduced.

These findings concure with Putnam (1962) and Chapman and Putnam (1973). Putnam observed three gross changes between 1931 and 1956, using air photos, farmer interviews and census data: (1) overall decreases in farmland and cropland; (2) a decrease in the number of farms; and (3) an increase in pasture. He attributed these trends to the proximity of the area to Metropolitan Toronto and the resulting conflict of land uses in this "rural-urban fringe" (Putnam, p. 61). However, he associated at least partially, the persistence of some general farming and the high incidence of poorer or abandoned farms on the moraine and sand plain to physical site limitations. These areas were incapable of supporting intensive agricultural practices.

Chapman and Putnam used census data to calculate a general decrease of 30 percent in the 1950's and 1960's in the area of farmland over the entire Oak Ridges moraine. While much of this landform is still farmed, the poorer, hillier farms are being abandoned (Chapman and Putnam, p. 279). They summarized the trend in changing land use as one of declining agricultural lands and increasing forest areas.

It now remains to be determined if these land use variations bear a significant relationship to the physical characteristics of the study area, as defined earlier by the establishment of five site associations (Chapter One). Even if the farmer as a decision-maker is assumed to be behaving like economic man; seeking to optimize his income,

> the existance of such a strong relationship could be regarded as putting the focus on man as a decision-maker who is very sensitive to variations in the land resource base (Found, p. 22).

CHAPTER lV

SITE PHYSIOGRAPHY AND DYNAMIC LAND USE

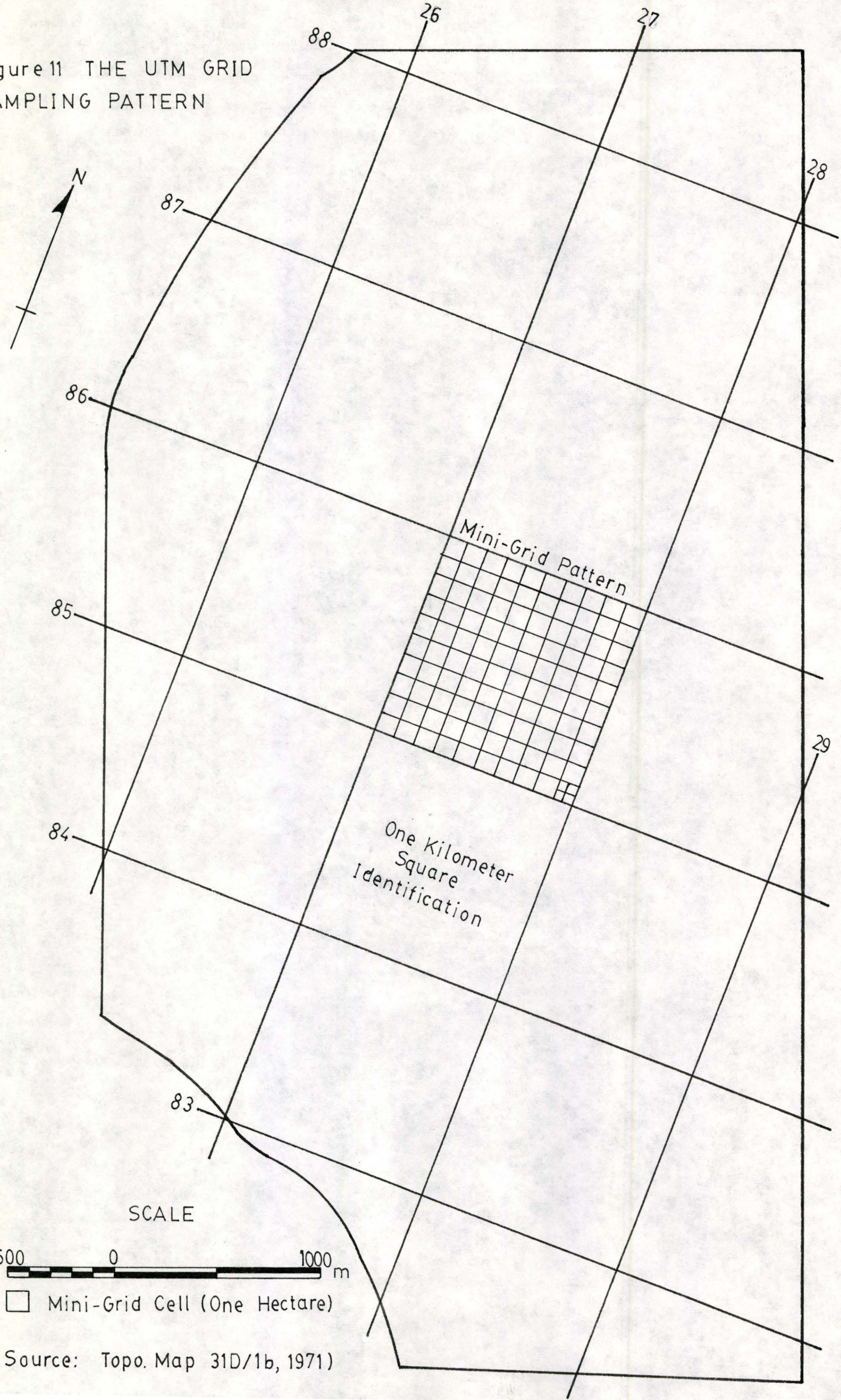
The land-use change data invite further analysis of variations in land use through time with respect to the physical characteristics of the study area, as defined by the land classification scheme in Chapter One. Numerical and cartographic evaluations are presented in order to test at a rather elementary level the hypothesis that land-use changes are spatially associated with the site associations.

Methodology

Data Collection. Utilizing a method of sampling similar to that in Amato (1976), data was collected from Figures 5 and 9. A grid pattern developed from the UTM grid of the Cold Springs topographic map was composed of approximately 1800 mini-cells, each equalling one hectare in area (Figure 11). The convenience of the one-hectare mapping unit is obvious with respect to counting and consistency with previous aerial measurements. The boundaries of the study area and the five site associations (Figure 5) were superimposed upon the grid pattern and the product was in turn superimposed upon the land-use change map (Figure 9). It was then possible to aggregate and classify as a site association each mini-grid cell within which a certain type of land-use change had taken place.

Following preliminary data accumulation, criteria were developed to standardize the selection of the cells. In order that

Figure 11 THE UTM GRID SAMPLING PATTERN



(Source: Topo. Map 31D/1b, 1971)

a mini-grid cell be elegible for incorporation into the study analysis, it must : (1) have 100 percent of its area within the study area; (2) include some type of land-use change; (3) give over at least 50 percent of its area to one site association and at least 50 percent of its area to one type of land-use change; and (4) give over at least 75 percent of its area to one site association and at least 75 percent of its area to one type of land-use change, only if there is included within the cell more than one site association or more than one type of land-use change. A "floating mini-grid cell" divided into four equal parts was engaged to test the criteria when necessary. The decisions in classifying the cells were therefore based on an area of one-half hectare or less.

The total number of cells accepted was 424, a sample representing about 80 percent of the total area of land-use changes previously identified. Twenty-two specific types of land-use changes were included in the sampling, excluding only two observed earlier in the study. Each of these was assigned a code which generalized the type of change, for example, from agricultural to forest land: A/F (Table 10).

All five site associations were sampled and the 424 mini-cells represent 23 percent of the total study area. The three dominant site associations are best represented while relatively poor samples were taken of the other two (Table 11). However, since 29 percent of the study area showed evidence of change in land use and about 80 percent of this figure was sampled, proportioned almost identically among the site associations, it was assumed that the overall sampling procedure was effective.

TABLE 10

GRID-SAMPLED LAND-USE CHANGES, 1954 TO 1971

No.	Secific Type	# of Cells	% Total	Code
01	Unproductive to Inactive	127	30.0	U/I
02	Inactive to Plantation	65	15.3	I/F
03	Rough Pasture to Scrubland	49	11.6	A/F
04	Inactive to Rough Pasture	24	5.7	I/A
05	Cropland to Improved Pasture	21	5.0	A/A
06	Cropland to Inactive	16	3.8	A/I
07	Rough Pasture to Inactive	26	6.1	A/I
08	Improved Pasture to Cropland	19	4.5	A/A
09	Scrubland to Woodland	17	4.0	F/F
10	Cropland to Plantation	10	2.4	A/F
11	Cropland to Scrubland	9	2.1	A/F
12	Improved to Rough Pasture	14	3.3	A/A
13	Rough Pasture to Plantation	6	1.4	A/F
14	Improved Pasture to Scrubland	6	1.4	A/F
15	Improved Pasture to Plantation	3	0.7	A/F
16	Scrubland to Plantation	2	0.5	F/F
17	Improved Pasture to Inactive	3	0.7	A/I
18	Scrubland to Rough Pasture	1	0.2	F/A
19	Inactive to Scrubland	2	0.5	I/F
20	Farm Structures to Inactive	1	0.2	A/I
21*	Rough Pasture to Woodland	2	0.5	A/F
24	Cropland to Rough Pasture	1	0.2	A/A
		424	100.0	

NOTES: * 22 Inactive to Urban
23 Urban to Inactive
were not sampled.

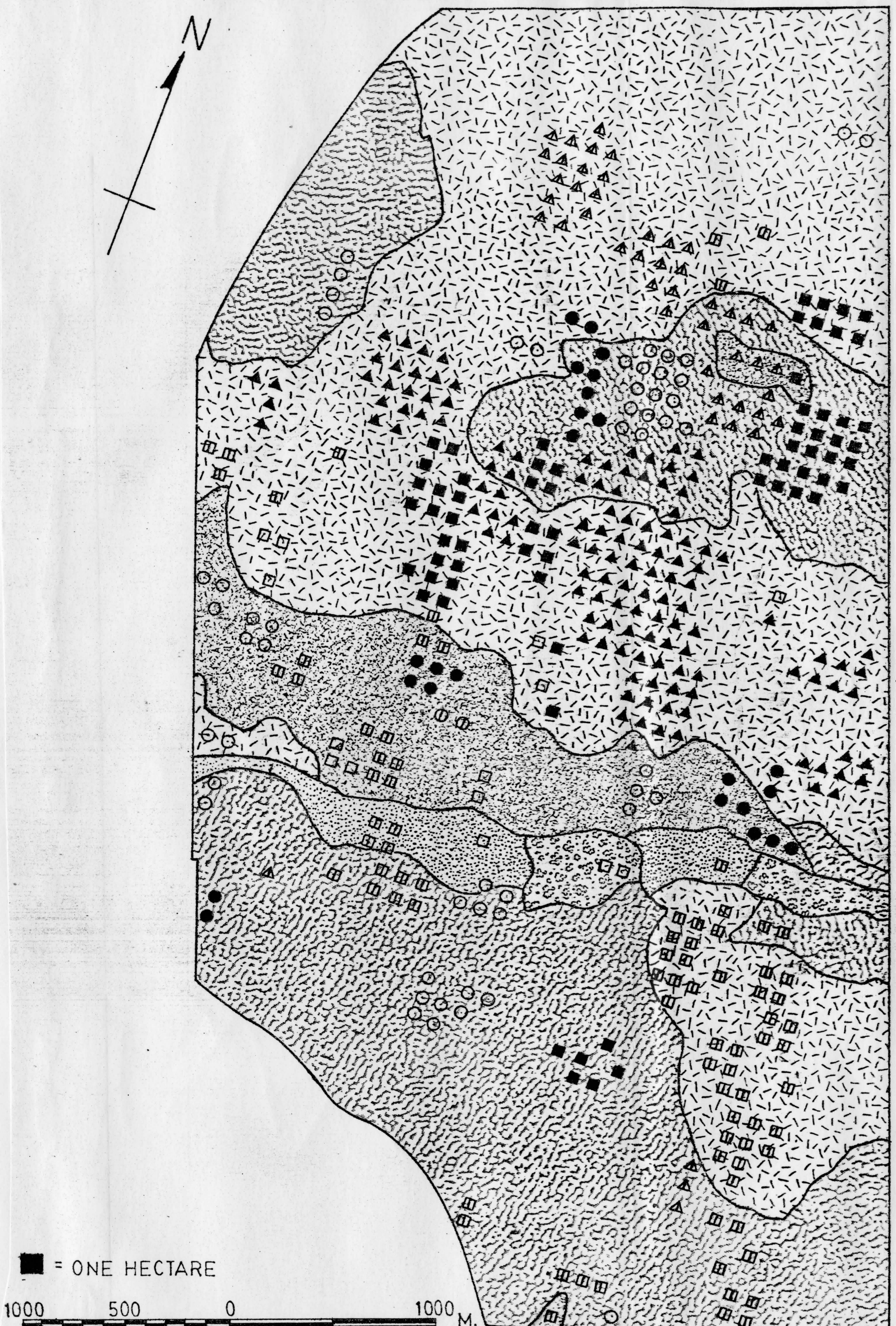
A = Agricultural, F = Forestry,
I = Inactive, U = Unproductive.

TABLE 11

GRID-SAMPLED SITE ASSOCIATIONS

No.	Site Association	# of Cells	% Sample	% Real Area	Real %
01	Level, smooth sandy loam	39	9.2	21.3	10.0
02	Sloping, irregular sandy loam	145	34.2	20.9	37.7
03	Sloping, irregular sand	231	54.5	26.2	48.0
04	Level, basin muck	2	0.5	6.9	1.6
05	Level, basin sandy loam	7	1.7	14.0	2.7
	Total	424	100.0	23.1	100.0

Figure 12 LAND-USE DYNAMICS & SITE PHYSIOGRAPHY

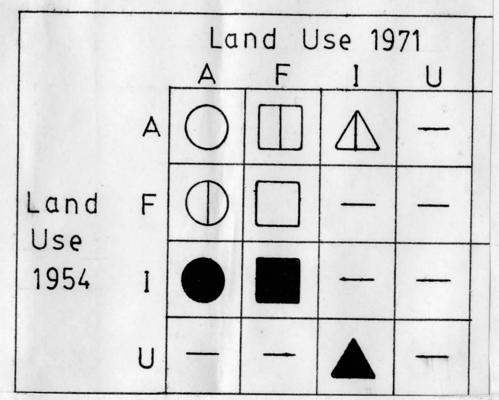


LEGEND

LAND-USE CATEGORIES:

A - AGRICULTURAL (CROPLAND, PASTURE, FARM BUILDINGS)
F - FOREST (SCRUBLAND, WOODLAND, PLANTATION)
I - INACTIVE (LAND & BUILDINGS)
U - UNPRODUCTIVE (ERODED, VERY SANDY LAND)

SYMBOLIZATION:



— = NOT OBSERVED

LAND CLASSIFICATION:

LEVEL, SMOOTH SANDY LOAM

SLOPING, IRREGULAR SANDY LOAM

SLOPING, IRREGULAR SAND

LEVEL, BASIN MUCK

LEVEL, BASIN SANDY LOAM

MAPPING UNIT:

EACH SYMBOL REPRESENTS ONE (1) HECTARE CHANGE IN LAND USE

Data Presentation. The nature of the data and the hypothesis being examined suggested employment of a relatively simple method of data description and analysis. The sampled numerical information was organized in matrix form as an r x c contingency table, commonly referred to as a frequency table (Table 12). The twenty-two land-use changes were listed as columns (c) with respect to the five site associations, which formed the rows (r). Each cell thus formed in the table therefore contains a numeral representing the observational frequency, more specifically the number of sampled mini-grid cells, of each type of land-use change with respect to each site associations. The totals utilized in Tables 10 and 11 were extracted from this frequency table. The contingency table effectively illustrates the frequency distribution of the sampled data.

To test whether relationships apparent in the frequency distribution are due purely to chance rather than the result of some true correlation, the chi-squared (χ^2) test was applied to the data. This statistic is particularly applicable when testing the independence of two classifications (King, p. 69). A contingency table is constructed, having r rows and c columns. Table 12 however, is unsuitable because many of the cells have frequencies of less than one and the resulting statistic would be a poor approximation (Wetherill, p. 203). To avoid this problem, the rows and the columns were condensed to eliminate the zeroes. Two methods were employed. First, to condense the columns, the land-use changes were generalized according to the coding in Table 10. Secondly, the two least dominant site associations, numbers 04 and 05, were dropped. The choice of rows and columns continues to suit the analysis objective, the aforestated hypothesis. The general

SAMPLE DATA FREQUENCY TABLE

Site Associations	Land-Use Changes: 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	24	Total
01	1	1	8	8	5	2	-	-	5	-	-	8	-	-	-	-	-	1	-	-	-	-	39
02	20	30	15	12	11	14	-	19	3	2	3	5	5	-	-	-	3	-	1	1	-	-	145
03	106	34	22	4	5	-	26	-	6	8	5	-	1	6	3	2	-	-	1	-	2	-	231
04	-	-	-	-	-	-	-	-	2	-	-	-	-	-	-	-	-	-	-	-	-	-	2
05	-	-	4	-	-	-	-	-	1	-	1	1	-	-	-	-	-	-	-	-	-	-	7
Total	127	65	49	24	21	16	26	19	17	10	9	14	6	6	3	2	3	1	2	1	2	1	424

NOTE: - No observation

TABLE 13

SITE ASSOCIATION AND LAND-USE CHANGE DISTRIBUTIONS

Site Associations	Land-Use Changes: 01	02	03	04	05	06	07	08	09	10	11	12	13	14	15	16	17	18	19	20	21	24
01	0.8 / 2.6	1.5 / 2.6	16.3 / 20.5	33.3 / 20.5	23.8 / 12.8	12.5 / 5.1	- / -	- / -	29.4 / 12.8	- / -	- / -	57.1 / 20.5	- / -	- / -	- / -	- / -	- / -	100 / 26	- / -	- / -	- / -	- / -
02	15.7 / 13.8	46.2 / 20.7	30.6 / 10.3	50.0 / 8.3	52.4 / 7.6	87.5 / 9.7	- / -	100 / 13.1	17.6 / 2.1	20.0 / 1.4	33.3 / 2.1	35.8 / 3.4	83.3 / 3.4	- / -	- / -	- / -	100 / 2.1	- / -	50.0 / 0.7	100 / 0.7	- / -	100 / 0.7
03	83.5 / 45.9	52.3 / 14.7	44.9 / 9.5	16.7 / 1.7	23.8 / 2.2	- / -	100 / 11.3	- / -	35.3 / 2.6	80.0 / 3.5	55.6 / 2.2	- / -	16.7 / 0.4	100 / 2.6	100 / 1.3	100 / 0.9	- / -	- / -	50.0 / 0.4	- / -	100 / 0.9	- / -
04	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	11.8	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -
05	- / -	- / -	8.3 / 57.1	- / -	- / -	- / -	- / -	- / -	5.9 / 14.3	- / -	11.1 / 14.3	7.1 / 14.3	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -	- / -

EXPLANATION: A / B
A Percent of column total given over to each site association
B Percent of row total given over to each land-use change
- No observation

trends in land-use change are well-defined and easily expanded by referral to the more specific changes they represent. The incidence of land-use change within site associations 04 and 05 is very insignificant with respect to the other three, and by dropping them, only 9 of the 424 observations are lost. The contingency table to be used in the analysis is shown by Table 14. The land-use changes involving urban uses and classified as "forest to agricultural", F/A, are omitted from the table due to insufficient data.

TABLE 14

THE ADOPTED rXc CONTINGENCY TABLE

	U/I	I/F	A/F	I/A	A/A	A/I	F/F	Σr_i
01	1 (11.7)	1 (6.2)	8 (7.3)	8 (2.2)	13 (5.0)	2 (4.2)	5 (1.5)	38
02	20 (49.5)	31 (23.5)	25 (28.0)	12 (8.4)	36 (18.9)	18 (16.1)	3 (5.6)	145
03	106 (70.9)	35 (37.4)	47 (44.6)	4 (13.4)	5 (30.1)	26 (25.7)	8 (8.9)	231
Σc_i	127	67	80	24	54	46	16	414 T

EXPLANATION: A Observed frequency; (B) Expected frequency

NOTE: L.U.C. F/A; S.A. 04 and 05; URBAN L.U.C. were omitted due to insufficient data.

The statistic is calculated to test validity of the relationships suggested in the cross-tabulation between the land-use changes and the site associations. The null hypothesis proposed is : that a certain land-use change is independent of the related site association. The method of calculation is universal (Cox, 1970; Freund, 1973; King, 1964; Wetherill, 1972). The analysis begins with the calculation of the expected or theoretical frequency for each cell using the equation

$$e = (\Sigma c_i \cdot \Sigma r_j) / T \qquad \text{EQ. 1}$$

where e is the expected frequency, Σc_i and Σr_j are the column and row totals respectively associated with the cell , and T is the grand total of observations, or the sample size. These results are presented in Table 14 beneath the observed frequencies. The chi-squared statistic is then calculated, using the formula

$$\chi^2 = \Sigma (f - e)^2 / e \qquad \text{EQ. 2}$$

where f is the observed frequency and e is the expected frequency. The values for each cell are shown in Table 15.

The value for χ^2 is 131.74. This figure is compared to χ^2_α for (r-1) (c-1) degrees of freedom at a chosen level of significance α. Tables listing these values are common and Freund (1973) shows $\chi^2_{0.01}$ as 21.217, at 12 degrees of freedom (Table III, pp. 476-477). Since the calculated value of χ^2 exceeds $\chi^2_{0.01}$, the null hypothesis is rejected. Indeed, the large value of χ^2 allows the rejection of the null hypothesis of independence at any level of significance. Therefore, there is a dependence (or relationship) between the type of land-use change and the related site association.

TABLE 15

THE CHI-SQUARED RESULTS

	U/I	I/F	A/F	I/A	A/A	A/I	F/F	Total
01	9.8	4.4	0.1	15.3	12.8	1.2	8.2	51.8
02	13.5	2.4	0.3	1.5	15.5	0.2	1.2	34.6
03	17.4	0.2	0.1	6.6	20.9	0.04	0.1	45.34
Total	40.7	7.0	0.5	23.4	49.2	1.44	9.5	131.74

The statistical analysis is accompanied by a cartographic presentation of the physical characteristics of the study area and the associated land-use changes (Figures 12). As a result of the grid-sampling scheme referred to earlier, each one-hectare change in land use was paired with one of the five site associations. The symbolization is relatively simple. The circle, square and triangle represent respectively the following land uses of 1971: agricultural, forest and inactive. The gradation in shading symbolizes the "intensity" of land-use change, the darkest being a relatively major change, an open symbol meaning strictly internal exchange between more specific categories and the slashed symbol being all other changes. While this ranking of "intensity of change" has no objective basis, its simplicity and cartographic effectiveness overrule any serious objection.

Analysis

The frequency table (Table 12) shows the apparent associations between the land-use changes and the site associations. The frequency distribution of the sampled data is perhaps more clearly illustrated by Table 13, which displays for each cell: (1) the percentage of each column (land-use change) total given over to each site association, and (2) the percentage of each row (site association) total given over to each land-use change. For example, there appears to be a strong relationship between the conversion of unproductive to inactive lands, code 01, and sloping, irregular sand, code 03, since the incidence of the former is within this site association in over 83 percent of the cases. One would initially expect most of the unproductive land identified in the 1954 air photography to be associated with this type of land, which for obvious reasons is highly susceptible to accelerated erosion. Thus, the reduction of erosional features and these areas' reclassification as inactive land in 1971 are strongly associated with site association 03.

Similarly, over 87 percent of the incidence of land-use change 06, from cropland to inactive land, took place within site association 02, sloping irregular sandy loam. The following explanation might be put forth. Sandy loam is a favourably-textured soil for agricultural activities, particularly the cultivation of crops. In 1954, this must have been a relatively dominant factor which outweighed the steep, complex topography of the land in the decision to raise crops. However, in light of the increased probability of soil erosion associated with land planted in crops, especially on steep slopes, the effect of such practices over time might be assumed adverse to land quality. Therefore, by 1971, a significant hectarage of cropland had been abandoned and left idle.

Additional relationships might be inferred from Table 13, but it is suggested that the cross-tabulation percentages within site associations 04 and 05, and those representing land-use changes coded greater than 13 are not reliable for such analysis. Not only is there a high incidence of zeros in these areas of the table, but in addition, the cell samples are very small, usually less than five. In these cases, the poor quality of the frequency distribution would likely cause most apparent associations to be attributed to chance.

The chi-squared statistic was calculated to test whether these apparent relationships were due purely to chance or reflected a true correlation. The value of χ^2 is very large and the results of the test are highly significant. The level of significance of a χ^2 value of 131.74 with 12 degrees of freedom is 1.000, meaning that greater than 99.999 percent of the time, the relationships will not be due purely to chance. In other words, by rejecting the null hypothesis, it has been shown that there is a dependence between the site associations and the land-use changes. The probability of these relationships being chance occurrences is virtually nil.

If some of the expected frequencies are less than five, the strength of the χ^2 results is weakened(Freund, p. 328, Wetherill, p. 203). However, only 3 of the 21 cells have an expected frequency less than five. Furthermore, the very large value calculated for χ^2 and its high degree of significance nullify any possible adverse effects these cells might inflict on the strength of the dependence of the row and column classifications.

By consulting Table 14, the manner in which the classifications are dependent may be examined. Significant results may be interpreted by comparing the observed and expected frequencies (Wetherill, p. 209). The expected frequencies as well as the observed frequencies for the generalized land-use changes U/I, I/F, A/F andA/I, all tend to increase progressively within site associations 01, 02, and 03, which are also increasing in sampled area in that order. This expected variation of land-use change incidence with the sample size of the site associations is not as significant as the three types of land-use change which deviate from this general trend. The conversion or reactivation of idle land to agricultural uses, I/A, has unexpectedly higher observed frequencies in site associations 01 and 02. This might be explained as a temporary abandonment of relatively good farmland, particularly O1, which has been put back to use, most often as pasture, especially on the hillsides of O2 (Table 10).

> Cattle seem to thrive on the sparse pastures, perhaps because of the lime and phosphorus which the soil inherits from the local limestones (Chapman and Putnam, p. 277).

The two other oddities might also be at least partially explained by the variations in the site physiography. The generalized land-use changes A/A and F/F refer to variations in more specific uses between 1954 and 1971. For example, the larger observed frequencies of A/A in O1 and especially O2, than that of O3 may be related to the generally better suitability of these two site associations for agricultural activities. Table 10 shows high frequencies but an almost equal tradeoff between cropland and improved pasture. The difference is the conversion of improved pasture to rough pasture. The majority of these exchanges occurred on the sloping, irregular sandy loam, O2, a site association condusive to cropland but more popular as pasture (Table 13).

As expected, the conversion of scrubland to either woodland or reforestation, F/F, occurred most frequently on the steep, sandy slopes, O3. It is on the ridges that permanent vegetation is most necessary and beneficial in anchoring the blown sand and maintaining springs as stream sources. Perhaps the preference for the sloping sandy loam, O2, as pasture retards its conversion from grazed scrubland to woodland or plantation.

Other general trends evident in Table 15 and substantiated by the more specific frequency distributions include the very high incidence of the conversion of inactive and agricultural lands to forest land, I/F and A/F, on the steep, complex slopes of sandy loam and sand, site associations 02 and 03 respectively. Virtually all of the changes from unproductive to inactive land, U/I, took place in site association 03.

The relationships between the land-use changes and the site associations are supported cartographically in Figure 12. These relationships, statistically inferred by general trends in the frequencies of Table 14 and the dominant effect of a few observed frequencies and confirmed by the chi-squared data, concur with the tentative observations made earlier in the study. The hypothesis that the land-use changes are spatially associated with the site associations has received strong support.

CONCLUSION

This research report is the result of a detailed land-use study performed in a small rural area in Central Ontario. Following the initial assessment of the study area's physical base and the preliminary observations of land-use variations, the problem of explaining change over a 17-year period emerged. It was hypothesized that land-use changes were related to the landscape site types.

The text is based on the study's four primary objectives : (1) the classification of the study area on a microscale basis, resulting in a number of defined physical land units; (2) the mapping and description of land use for two points in time, 1954 and 1971; (3) the mapping and description of land-use changes between two points in time, 1954 and 1971; and (4) the explanation of land-use changes by the testing of the hypothesis.

Summary

The main purpose of the study was to perform a micro-level examination of rural land-use changes in a small area based on air photo interpretation for the years 1954 and 1971. The land classification scheme utilized was based on that developed in Ontario by G.A. Hills. In this study, the micro-variations in the surface soil texture and topography were examined. Five site associations were generated :(1) level, smooth sandy loam; (2) sloping, irregular sandy loam; (3) sloping, irregular sand; (4 level, basin muck; and (5) level, basin sandy loam.

The land use presented for 1954 and 1971 used a slightly modified version of the classification put forth by the Canada Land Inventory and criteria accumulated from the literature for purposes of interpreting sequential air photography. The two sets of black and white contact prints were flown at approximately the same time of the year and at the same photographic scale of 1:15,840, which enabled detailed comparable land-use descriptions.

Based on photographic evidence, land use for the two years was mapped and hectarage data extracted. Gross land-use patterns were described and analysed in light of the study area's physical characteristics.

Land-use changes were identified by superimposing the two land-use maps. The sequential contact prints representing the same real surface area were located by stereo-study and outlined on the later set of photos. The boundaries were transferred to a semi-controlled mosaic of the study area and a land-use changes map constructed. Hectarage figures were presented as supportive data.

Twenty-four types of specific land-use changes were identified and subsequently summarized into changes between and exchanges within four general categories: agricultural, forest, inactive and unproductive lands. The gross trends in land-use change were described and analysed, referring comparatively to the losses and gains in hectarage by the various land-use categories. Possible sequences of land-use changes were proposed while commenting on the associated physical characteristics of the study area. Finally, a very simple model was presented to summarize the changes in land use between 1954 and 1971.

The preceding analysis of the study area's physical base and the identification of land-use changes resulted in general observations which invited objectively-based scrutiny. A large sample of the changed area was collected using a grid pattern system which aggregated mini-cells of land-use change with respect to the site association within which each occurred. Once the data were collected, representing almost 80 percent of the land-use changes, cross-tabulation and frequency distribution analysis were carried out. The chi-squared test was applied to a condensed r x c contingency table to discover whether these associations between the two classifications was a matter of chance or not. The null hypothesis of independence was rejected, indicating a relationship between the two variables.

In light of the statistical analysis, the validity of the study's hypothesis was evaluated. General trends in the relationship and several deviations were analized by referring to the chi-squared results. Some explanations were put forth and discussed.

Conclusions

The study area is a rural landscape typical of the sandy , rolling topography of the Oak Ridges moraine. Agricultural activities are decreasing as forest lands expand. Inactively used land and severe soil erosion indicate the dominant influence of the physical environment in determining land-use changes. The very large chi-squared statistic infers that this relationship has essentially zero probability of being due to chance.

Both Putnam (1962) and Chapman and Putnam(1973) observed under the same environmental conditions similar general trends. It was suggested that:

> Increasingly, the Oak Ridges will come to be considered a non-agricultural area. It should be regarded as a reserve of open space for amenity purposes which might be directed thither in order to conserve good agricultural land in other areas (Chapman and Putman, p. 280).

Theoretically, from the economic perspective, man the decision-maker, appears sensitive, at least within the study area, to the variations in the land resource base (Found, 1971). The trend that displays ideally a change in the "highest" land use,(that which yields the highest income) from agricultural to forest is clearly shown in this study.

> Man's main purpose for using land is to gain some sort of personal satisfaction, such as earning an income or providing recreation, rather than "blending with nature". Of secondary consequence, but quite possible, is that "blending with nature" may help him achieve his primary objective (Found, p. 22).

The study area, in fact most of the Oak Ridges moraine, is unfavourable to agricultural development. This research suggests that erosional features such as " blow-outs" and gullying are closely related to intensive agricultural activities on relatively unstable soils and slopes. It is recommended that reforestation schemes continue, particularly on the ridges and the badly eroded level areas. Erosion continues in the areas previously covered by grass and there is a need for further reforestation at these locations (Hoffman and Acton, p. 35).

Once the land has recovered sufficiently, its varied topography and forest resources should be used to advantage. The land going out of agriculture should be converted to recreational uses, such as rural retreats, golf courses or ski resorts in the very hilly areas (Chapman and Putnam, p. 280). Conservation areas should be established to preserve interesting natural landscapes and improve environmental conditions for the survival of local flora and fauna. While the parent materials of the study area invite commerical extraction of sand and gravel, such industrial enterprises should be concentrated rather than dispersed in order to preserve the aesthetically pleasant aspects of the landscape. Urban growth should be confined to local villages and towns.

This research has systematically examined and analyzed the physical characteristics of a small rural area and the associated changes in land use. The main objectives have been accomplished and the statistical results support a relationship between the spatial distribution of land-use changes and the physical environment. The study in one of few which utilizes a quantitative analysis type of approach at the micro-level. One can conclude that physical environmental factors relating to landforms and soils are a dominant factor in explaining land-use changes in this particular area. The strength of this conclusion might be tested by the use of more sophisticated analytical techniques. Its relevance to other differing environments remains to be determined.

APPENDIX A

SOIL CAPABILITY CLASSIFICATIONS
FOR
AGRICULTURE, FORESTRY, RECREATION,
WASTE DISPOSAL AND URBANIZATION

TABLES 16,17 AND 18

SOIL CAPABILITY CLASSIFICATION FOR AGRICULTURE

*** CLASS 1** SOILS IN THIS CLASS HAVE NO SIGNIFICANT LIMITATIONS IN USE FOR CROPS.

The soils are deep, are well to imperfectly drained, hold moisture well, and in the virgin state were well supplied with plant nutrients. They can be managed and cropped without difficulty. Under good management they are moderately high to high in productivity for a wide range of field crops.

*** CLASS 2** SOILS IN THIS CLASS HAVE MODERATE LIMITATIONS THAT RESTRICT THE RANGE OF CROPS OR REQUIRE MODERATE CONSERVATION PRACTICES.

The soils are deep and hold moisture well. The limitations are moderate and the soils can be managed and cropped with little difficulty. Under good management they are moderately high to high in productivity for a fairly wide range of crops.

CLASS 3 SOILS IN THIS CLASS HAVE MODERATELY SEVERE LIMITATIONS THAT RESTRICT THE RANGE OF CROPS OR REQUIRE SPECIAL CONSERVATION PRACTICES.

The limitations are more severe than for Class 2 soils. They affect one or more of the following practices: timing and ease of tillage; planting and harvesting; choice of crops; and methods of conservation. Under good management they are fair to moderately high in productivity for a fair range of crops.

CLASS 4 SOILS IN THIS CLASS HAVE SEVERE LIMITATIONS THAT RESTRICT THE RANGE OF CROPS OR REQUIRE SPECIAL CONSERVATION PRACTICES, OR BOTH.

The limitations seriously affect one or more of the following practices: timing and ease of tillage; planting and harvesting; choice of crops; and methods of conservation. The soils are low to fair in productivity for a fair range of crops but may have high productivity for a specially adapted crop.

CLASS 5 SOILS IN THIS CLASS HAVE VERY SEVERE LIMITATIONS THAT RESTRICT THEIR CAPABILITY TO PRODUCING PERENNIAL FORAGE CROPS, AND IMPROVEMENT PRACTICES ARE FEASIBLE.

The limitations are so severe that the soils are not capable of use for sustained production of annual field crops. The soils are capable of producing native or tame species of perennial forage plants, and may be improved by use of farm machinery. The improvement practices may include clearing of bush, cultivation, seeding, fertilizing, or water control.

*** CLASS 6** SOILS IN THIS CLASS ARE CAPABLE ONLY OF PRODUCING PERENNIAL FORAGE CROPS, AND IMPROVEMENT PRACTICES ARE NOT FEASIBLE.

The soils provide some sustained grazing for farm animals, but the limitations are so severe that improvement by use of farm machinery is impractical. The terrain may be unsuitable for use of farm machinery, or the soils may not respond to improvement, or the grazing season may be very short.

CLASS 7 SOILS IN THIS CLASS HAVE NO CAPABILITY FOR ARABLE CULTURE OR PERMANENT PASTURE.

This class also includes rockland, other non-soil areas, and bodies of water too small to show on the maps.

0 ORGANIC SOILS (Not placed in capability classes).

SUBCLASSES

Excepting Class 1, the classes are divided into subclasses on the basis of kinds of limitation. The subclasses are as follows:

SUBCLASS C: adverse climate — The main limitation is low temperature or low or poor distribution of rainfall during the cropping season, or a combination of these.

* SUBCLASS E: erosion damage — Past damage from erosion limits agricultural use of the land.

SUBCLASS I: inundation — Flooding by streams or lakes limits agricultural use.

SUBCLASS P: stoniness — Stones interfere with tillage, planting, and harvesting.

SUBCLASS R: shallowness to solid bedrock — Solid bedrock is less than three feet from the surface.

SUBCLASS S: soil limitations — Limitations include one or more of the following undesirable structure, low permeability, a restricted rooting zone because of soil characteristics, low natural fertility, low moisture-holding capacity, salinity.

SUBCLASS T: adverse topography — Either steepness or the pattern of slopes limits agricultural use.

SUBCLASS W: excess water — Excess water other than from flooding limits use for agriculture. The excess water may be due to poor drainage, a high water table, seepage or runoff from surrounding areas.

* SUBCLASS X: Soils having a moderate limitation caused by the cumulative effect of two or more adverse characteristics which singly are not serious enough to affect the class rating.

CONVENTIONS

Large arabic numerals denote capability classes.
Small arabic numerals placed after a class numeral give the approximate proportion of the class out of a total of 10. Letters placed after class numerals denote the subclasses, i.e. limitations.

*Denotes class or subclass not present on this map.

EXAMPLES

An area of Class 4 land with topography and stoniness limitations is shown thus: 4^{T}_{P}

An area of Class 2, with topographic limitation, and Class 4 with stoniness limitation, in the proportions of 7:3 is shown thus: $2^{7}_{T}4^{3}_{P}$

SOURCE: Canada Land Inventory, Simcoe Map 31d.

SOIL CAPABILITY CLASSIFICATION FOR FORESTRY

CLASS 1 LANDS HAVING NO IMPORTANT LIMITATIONS TO THE GROWTH OF COMMERCIAL FORESTS.

Soils are deep, permeable, of medium texture, moderately well-drained to imperfectly drained, have good water-holding capacity and are naturally high in fertility. Their topographic position is such that they frequently receive seepage and nutrients from adjacent areas. They are not subject to extremes of temperature or evapotranspiration. Productivity will usually be greater than 111 cubic feet per acre per year.

When required this class may be subdivided on the basis of productivity into classes 1 (111 to 130), 1a (131 to 150), 1b (151 to 170), 1c (171 to 190), 1d (191 to 210), and by 20 cubic foot classes thereafter, as necessary.

CLASS 2 LANDS HAVING SLIGHT LIMITATIONS TO THE GROWTH OF COMMERCIAL FORESTS.

Soils are deep, well-drained to moderately well-drained, of medium to fine texture and have good water-holding capacity.

The most common limitations (all of a relatively slight nature) are: adverse climate, soil moisture deficiency, restricted rooting depth, somewhat low fertility, and the cumulative effects of several minor adverse soil characteristics.

Productivity will usually be from 90 to 110 cubic feet per acre per year.

CLASS 3 LANDS HAVING MODERATE LIMITATIONS TO THE GROWTH OF COMMERCIAL FORESTS.

Soils may be deep to somewhat shallow, well to imperfectly drained, of medium to fine texture with moderate to good water-holding capacity. They may be slightly low in fertility or suffer from periodic moisture imbalances.

The most common limitations are: adverse climate, restricted rooting depth, moderate deficiency or excess of soil moisture, somewhat low fertility, impeded soil drainage, exposure (in maritime areas) and occasional inundation.

Productivity will usually be from 71 to 90 cubic feet per acre per year.

CLASS 4 LANDS HAVING MODERATELY SEVERE LIMITATIONS TO THE GROWTH OF COMMERCIAL FORESTS.

Soils may vary from deep to moderately shallow, from excessive through imperfect to poor drainage, from coarse through fine texture, from good to poor moisture holding capacity, from good to poor structure and from good to low natural fertility.

The most common limitations are: moisture deficiency or excess, adverse climate, restricted rooting depth, poor structure, excessive carbonates, exposure, or low fertility.

Productivity will usually be from 51 to 70 cubic feet per acre per year.

CLASS 5 LANDS HAVING SEVERE LIMITATIONS TO THE GROWTH OF COMMERCIAL FORESTS.

Soils are frequently shallow to bedrock, stoney, excessively or poorly drained of coarse or fine texture, may have poor moisture holding capacity and be low in natural fertility.

The most common limitations (often in combination) are: moisture deficiency or excess, shallowness to bedrock, adverse regional or local climate, low natural fertility, exposure particularly in maritime areas, excessive stoniness and high levels of carbonates.

Productivity will usually be from 31 to 50 cubic feet per acre per year.

CLASS 6 LANDS HAVING SEVERE LIMITATIONS TO THE GROWTH OF COMMERCIAL FORESTS.

The mineral soils are frequently shallow, stoney, excessively drained, of coarse texture and low in fertility. A large percentage of the land in this class is composed of poorly drained organic soils.

The most common limitations (frequently in combination) are: shallowness to bedrock, deficiency or excess of soil moisture, high levels of soluble salts, low natural fertility, exposure, inundation and stoniness.

Productivity will usually be from 11 to 30 cubic feet per acre per year.

CLASS 7 LANDS HAVING SEVERE LIMITATIONS WHICH PRECLUDE THE GROWTH OF COMMERCIAL FORESTS.

Mineral soils are usually extremely shallow to bedrock, subject to regular flooding, or contain toxic levels of soluble salts. Actively eroding or extremely dry soils may also be placed in this class. A large percentage of the land is very poorly drained organic soils.

The most common limitations are: shallowness to bedrock, excessive soil moisture, frequent inundation, active erosion, toxic levels of soluble salts, and extremes of climate or exposure.

Productivity will usually be less than 10 cubic feet per acre per year.

SUBCLASSES

Except for Class 1, subclasses indicate the kind of limitation for each class. The subclasses are as follows:

CLIMATE

Denotes a significant adverse departure from what is considered the median climate of the region, that is, a limitation as a result of local climate; adverse regional climate will be expressed by the class level.

SUBCLASS A – droughty or arid conditions as a result of climate.

SUBCLASS C – a combination of more than one climatic factor or when it is not possible to decide which of two or more features of climate is significant.

SUBCLASS H – low temperatures, that is too cold.

SUBCLASS U – exposure.

SOIL MOISTURE

Denotes a soil moisture condition less than optimum for the growth of commercial forests but not including inundation.

SUBCLASS M – soil moisture deficiency

SUBCLASS W – soil moisture excess.

SUBCLASS X – a pattern of "M" and "W" too intimately associated to map separately.

SUBCLASS Z – a pattern of wet organic soils and bedrock too intimately associated to map separately.

PERMEABILITY AND DEPTH OF ROOTING ZONE

Denotes limitations of soil permeability or physical limitation to rooting depth.

SUBCLASS D – physical restriction to rooting by dense or consolidated layers, other than bedrock.

SUBCLASS R – restriction of rooting zone by bedrock.

SUBCLASS Y – intimate pattern of shallowness and compaction or other restricting layers.

OTHER SOIL FACTORS

Denote factors of the soil which, individually or in combination, adversely affect growth.

SUBCLASS E – actively eroding soils.

SUBCLASS F – low fertility.

SUBCLASS I – soils periodically inundated by streams or lakes.

SUBCLASS K – presence of perennially frozen material.

SUBCLASS L – nutritional problems associated with high levels of carbonates.

SUBCLASS N – excessive levels of toxic elements such as soluble salts.

SUBCLASS P – stoniness which affects forest density or growth.

SUBCLASS S – a combination of soil factors, none of which, by themselves would affect the class level but cumulatively lower the capability class.

TREE SPECIES INDICATORS

The species which can be expected to yield the volume associated with each class are shown as part of the symbol. Only indigenous species adapted to the region and land are shown. Where only one species indicator is shown in a complex it applies to all classes.

yB................. Yellow Birch
tL..................... Tamarack
hM................. Hard Maple
rM................... Red Maple
rO...................... Red Oak
rP..................... Red Pine
ewP.......... Eastern White Pine
bS................. Black Spruce
wS................. White Spruce

CONVENTIONS

Large arabic numerals denote capability classes.

Small arabic numerals placed after a class numeral give the approximate proportion of the class out of a total of 10. Letters placed after class numerals denote the subclasses, i.e., limitations. Letters placed below large arabic numerals denote tree name abbreviations.

*Denotes class not present on this map.

EXAMPLES

An area of Class 4 land with soil moisture deficiency and white spruce indicator species: $\underset{wS}{4_M}$

An area of Class 4, with moisture deficiency and Class 5 with a soil depth limitation, in the proportion of 8:2 and white spruce and $\underset{wS}{4^8_M}\underset{tA}{5^2_R}$

SOURCE: Canada Land Inventory, Simcoe Map 31d.

Soil Capability for Recreation, Waste Disposal and Urbanization

As has been mentioned, capability classifications were devised originally by soil taxonomists to predict the potential of various soils or landscapes for agricultural, wildlife, recreational and forestry uses. These classifications are described in detail in Report Numbers 2, 3, and 4 of the Department of Regional Economic Expansion, Ottawa. The classifications for recreation, waste disposal and urbanization described in the following pages use many of the same principles found in the Canada Land Inventory classifications, yet they differ in many respects.

First of all, there are 5 classes rather than 7 class systems. Class 1 is best and class 5 is poorest for a particular use. The classes are subdivided into subclasses which indicate the *kind* of limitation (wetness, slope, depth to bedrock, depth to water table, stoniness, etc.) The classes indicate the *degree* of the limitation.

The interpretation of soils or landscapes into classes and subclasses provides an evaluation of "productivity," and a means of estimating the inputs needed to prepare a site for a specific use. For example, soils developed on gravelly materials are often placed in class 3 for waste disposal, in spite of the fact they are excellent filters. That is because gravel materials are also excellent aquifers, and so permeable, that the residence time of waste products may be too short for biodegradation to take place. On such gravelly sites, water pollution can occur unless proper precautions are taken. The costs (inputs) of preparation are higher on class 3 sites than on class 1.

Any area, no matter in what class it has been placed, can be used for the purpose stated. However, the carrying capacity (productivity) decreases and the costs of reclamation increase as the class changes from 1 to 5. Some sites are considered unsuitable for certain uses because the costs of reclamation could be excessive. Unsuitable sites include organic deposits and places where the bedrock is at or near the surface.

Capability classifications do not indicate best use, nor can they be used to determine expected income. They merely indicate that the physical characteristics of one soil or landscape provide a better or poorer site for a specific use than another. The limitations are also given.

TABLE 16

SOIL CAPABILITY FOR RECREATION

Soil and Site Factors	Subclass Symbols	Capability Classes 1	2	3	4	5
Landscape-slope	L	3–30%	3–30%	>30%	0–2%	0–2%
variability		high	moderate	high–moderate	low	low
Drainage	W	good	moderate	rapid	poor	very poor
Fertility	F	high–medium	high–medium	low	high–low	high–low
Texture	A	loams silt loams	sandy loams silty clay loams clay loams	loamy sands gravels fine sandy loams clays	silts very fine sands	all textures of wet locations
Stoniness	P	classes 0, 1	classes 0, 1	class 2	class 3	class 4
Flooding interval	I	none	occasional (> 10 weeks)	frequent (6–10 weeks)	very frequent (3–5 weeks)	very frequent (> 2 weeks)
Depth to impermeable layer	Y	none	one or more > 3′ deep	one or more 2–3′ deep	one or more 1–2′ deep	one or more < 1′ deep
Depth to bedrock	R	> 5′	> 5′	> 5′	> 5′	< 5′
Erosion	E	none	none	none to slight	moderate	severe

SOURCE: Hoffman and Acton (1974), p. 71).

SOIL CAPABILITY FOR RECREATION, WASTE DISPOSAL AND URBANIZATION - Continued

TABLE 17

SOIL CAPABILITY FOR WASTE DISPOSAL

Soil and Site Factors	Subclass Symbols	Capability Classes				
		1	2	3	4	5
Depth to bedrock	R	> 5′	> 5′	> 5′	> 5′	> 5′
Depth to water table	B	> 6′	> 6′	4–6′	3–4′	< 3′
Slope — percent	T	0–2%	3–5%	6–9%–D	6–9%–d	> 9%
— pattern		Aa, Bb				
Stoniness	P	classes 0, 1	classes 0, 1	class 2	class 3	class 4
Natural drainage	W	good	moderate	imperfect	poor and rapid	very poor
Texture	A	loams clay loams	fine sandy loams sandy loams clays	loamy sands gravels silt loams	very fine sands, silts	any texture with high water table
Structure	D	strongly granular or blocky; porous; water stable	moderately strong granular or blocky; porous; water stable	weakly granular	structureless	structureless, unstable
Depth to impermeable layers	Y	none	one or more 3′ deep	one or more 2–3′ deep	one or more 1–2′ deep	one or more < 1′ deep

TABLE 18

SOIL CAPABILITY FOR URBANIZATION

Soil and Site Factors	Subclass Symbols	Capability Classes				
		1	2	3	4	5
Depth to bedrock	R	> 20′	8–20′	0–8′	0–8′	0–8′
Depth to water table	B	> 20′	> 20′	8–20′	0–8′	0–8′
Slope — percent	T	0–5–	6–9%–Dd	10–15%–Ee	16–30%–Ff	> 30%
— pattern		Aa, Bb, Cc				
Stoniness	P	classes 0, 1	classes 0, 1	class 2	class 3	class 4
Natural drainage	W	good	moderate	imperfect	poor	very poor
Texture	A	loams clay loams sandy loams	fine sandy loams clays	loamy sands gravels silt loams	silts very fine sands	any texture with high water table
Structure	D	strong, granular blocky; porous; water stable	moderately strong granular or blocky; porous; water stable	weak granular or blocky	structureless	structureless, unstable
Impermeable layers	Y	none	one or more > 3′ deep	one or more 2–3′ deep	one or more 1–2′ deep	one or more < 1′ deep

SOURCE: Hoffman and Acton (1974), pp 73 and 76 respectively.

APPENDIX B

CRITERIA FOR LAND-USE CLASSIFICATION

BY AIR PHOTOGRAPHIC INTERPRETATION

I URBAN

1. Residential

Size: 0.2-2.0 ha or 30.5 m frontage; relatively small lot.
Association: adjacent county road with relatively short access; surrounding farmland obviously associated with a farm homestead.

2. Sand and Gravel Pits

Size: 1-2 ha.
Shape: irregular outline; depressional; steep, perpendicular edges.
Association: access road; related structures.
Tone: highly reflective, very light.

II AGRICULTURAL LANDS

1. Structures

Size and Shape: usually larger and older appearance than non-farm buildings.
Pattern: often cluster of structures representing farm homestead; also solitary barn structures.
Associations: with surrouding farmland includes barnyards, crop and pasture land, livestock and machinery paths.

2. Cropland

Size and Shape: relatively smaller, well-defined recatangular fields.
Patterns: "patchwork" spatial arrangement of fields; characteristic planting, plowing and harvesting patterns indicating active land use.
Tone: even but varying field to field, light or dark; indication of little or no relief variations.
Texture: usually smooth; corn appears carpet-like

3. Improved Pasture

Size and Shape: relatively larger, well-defined irregular fields.
Patterns: perhaps plowing but no indications of cropping.
Tone: medium even, with some variation in reflectance due to slightly irregular relief.
Texture: medium smooth; patchiness may indicate areas trampled or eaten by livestock.
Association: excavated, round water holes; paths to farm buildings; animals; perhaps fencing.

4. Rough Pasture

Size and Shape: large, relatively poorly-defined irregular

fields.
Patterns: no regular internal patterns.
Tone: darker, irregular, variations indicating a usually rugged relief.
Texture: rough, weedy nature; blotchy appearance indicating livestock grazing; may be scrubby.
Association: paths to farm buildings; worn, eaten patches; animals; silos, fodder cropland and other indications of a related livestock operation.

5. Inactive
Size and Shape: variable; often large groupings of relatively well-defined, rectangular or irregular fields.
Patterns: lattice-like appearance of deteriorating field deliniations (trees, stones, wooden fences).
Tone: light, even, with little varuation in reflectance due to level relief and non-use.
Texture: smooth, but weedy, slightly-scrubby.
Association: no evidence of use at present but appearing to have been used in past; inactive farm structures; building ruins; stone piles and lines; some evidence of a lack of erosion control (sand patches, eroded steep slopes and river banks).

III FOREST LANDS

1. Woodland
Size and Shape: varying sizes of wooded areas; well-defined irregular outline of stands; usually full-grown trees.
Pattern: natural, random growth and packing of tree crowns.
Tone: medium to dark variations of individual tree crowns, indicating heterogeneous stands.
Texture: rough, dense with closely packed, circular tree crowns; density over 75% maesured using comparative stereograms (Avery, p.197).
Association: often adjacent to wildlands and/or plantations; stream courses, wetlands.

2. Scrubland
Size and Shape: varying size; poorly-defined, irregular boundaries.
Pattern: natural random but sporadic distribution of trees, bushes and low-level growth.
Tone: medium to dark variations of vegetation and exposed soil, depending on growth density and relief.
Texture: rough; variable density of vegetative growth with respect to exposed soil surface; density between 25 and 75% measured using Avery.
Association: rolling land; sparsely vegetated wetlands; wildlands showing no photographic evidence of grazing or other agricultural land use.

3. Plantation
Size and Shape: varying size; well-defined boundaries, rectangular plots.
Patterns: very regular, straight-row or countour planting.
Tone: Dark; even, indicating homogeneous stands.
Texture: rough; density a function of stand age; recent planting, individuals identifiable as "specks" in rows; mature stand, very dense, smooth.
Association: natural woodland; sandy or inactive lands.

V UNPRODUCTIVE LAND

1. Sand

Size: variable, between 1 and 15 ha.
Shape: "blowouts", large, smoothly rounded or irregular features; convex or concave; "blotches", poorly-defined patches; associated linear features such as gullies and stream courses; irregular, meandering.
Tone: very light, highly reflective.
Texture: smooth to slightly rough.
Associayion: little or no vegetative cover; enclosing rectangular plots of inactive land, highly dominated by erosional features; dry stream courses; steep slopes.

APPENDIX C

UNITS

Metric

100 centimeters (cm) = 1 meter (m)

1000 meters = 1 kilometer (km)

1 square kilometer (km^2) = 100,000 square meters (m^2)

= 100 hectares (ha)

Conversion

1 cm = 0.394 inch

1 m = 3.281 feet

1 km = 0.621 miles

1 km^2 = 0.386 square miles

1 ha = 2.471 acres

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