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THE DELINEATION OF CENSUS URBAN AREAS
BY COMPUTER-ASSISTED MAPPING AND REMOTE SENSING

by

(C) Kenneth Dean Korporal

A thesis submitted to
the Faculty of Graduate Studies and Research
in partial fulfilment of
the requirements for the degree of
Master of Arts
in Geography

Department of Geography

Carleton University

Ottawa, Ontario

December 6, 1985

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"THE DELINEATION OF CENSUS URBAN AREAS BY COMPUTER-ASSISTED
MAPPING AND REMOTE SENSING"

submitted by KENNETH DEAN KORPORAL
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ABSTRACT

At Statistics Canada, the delineation of census urban areas is currently a manual process that is based on definitions, methods and technologies largely unchanged in over 25 years. Evaluation of the urban area concept and definition concludes that statistical criteria, such as derived population density data calculated and displayed by enumeration area, can be manipulated and classified using methodologies and techniques of computer-assisted mapping and geographic information systems. Furthermore, the integration of various data sources, including street network files and classified remotely sensed imagery, provides supplementary visual information for the delineation process. Developments include the transfer of remotely sensed data from the Canada Centre for Remote Sensing to a geographic information and mapping system at Statistics Canada, utilizing the Standard Data Transfer Format. Recommendations for further study and future research are presented.

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The preparation of a thesis or major research paper is often a long, seemingly-never-ending process that requires significant interaction with many people. It would be difficult to mention everyone who has assisted in one manner or another, but it is necessary to credit those who have offered special levels of support. In particular, this author is indebted to three groups of individuals who have contributed to specific aspects of the study through involvement of their institution or agency: Carleton University, Statistics Canada and the Canada Centre for Remote Sensing. The nature and scope of this research required considerable cooperation amongst the participating groups; the willingness and individual concern encountered at almost all levels of interaction necessitates a somewhat lengthy, but well deserved acknowledgement to those who have been most generous in their support.

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CHAPTER I

INTRODUCTION

1.1 Background

The delineation of urban areas, as practised at Statistics Canada, is based on definitions, methods and technologies largely unchanged since at least 1961. This process of identifying and delineating the urban area boundary is currently a manual operation. Population counts, population density calculations, and various supporting tools and decision criteria are utilized within the delineation process. In turn, these population counts, calculations and decisions are derived from statistics and documents compiled from and based upon data from the previous Census of Canada. The actual urban area delineation procedure takes place sometime before the next census year; thus there is a continual gap between the acquisition of statistics and the use of those statistics in the urban area delineation process. For example, an urban area as defined for the 1986 Census, might be delineated in 1984 based upon data collected in 1981. Therefore, when the census data are publicly released in 1987, at the earliest, they will be based on an urban area definition at least 6 years out of date. High growth areas, such as new suburbs, are especially affected.

In addition to the time-lag problem, there is also question of the accuracy, speed and cost of the present delineation methodology. It is desirable, therefore, to seek new methods of delineation that are more timely and more accurate to represent current characteristics and conditions more realistically. It is also necessary to design a methodology that produces delineations more quickly and with comparable or lower production costs as compared to the existing methods.

This study will endeavour to derive such a methodology by integrating existing systems and programs where available, and by developing new programs and techniques as necessary. Computer-assisted geographic information and mapping systems will form the backbone of the procedure, while the use of remote sensing techniques and data will also be proposed and implemented for use in appropriate situations. With the sensible introduction of appropriate automated techniques, there is a high probability that the objective of completing urban area delineations with greater accuracy, with improved productivity, and, hopefully, at equal or lower costs, can be realized.

1.2 Goals and Objectives

The major goal of this study is to demonstrate the benefits that can be derived by using updated methodologies, including computer-assisted mapping and remote sensing systems, for the delineation of urban area boundaries. Three major objectives are identified in support of this goal:

- 1) To demonstrate the effectiveness of using computer-assisted

mapping methodologies as a supplement to existing urban area delineation procedures. In support of this objective, two demonstration urban areas will be selected and subsequently used for the testing, evaluation, comparison, and analysis of the new methodologies, techniques, and systems.

- 2) To develop the methodologies, techniques and systems required to update the urban area delineation process and to integrate the remotely sensed data, via the Standard Data Transfer Format, with a geographic information and mapping system.
- 3) To demonstrate the application of using remotely sensed data, in conjunction with revised mapping methodologies, as a timely and accurate data source for the updating of urban areas.

1.3 Methodologies and Organization

In order to facilitate an understanding of the urban area (UA) concept, a chapter will be devoted to a discussion of its origins, use and boundary derivation at Statistics Canada, use in other countries, and the current delineation methodologies. With this understanding of the UA concept, this study will next focus on the automation of the UA delineation process beginning with methodological updating via a geographic information and mapping system (GIS), then proceed to developments of a remote sensing nature.

With the implementation of the two complementary systems, the following stage of the study will integrate the GIS and remote sensing functions to create an analytical package to support the urban area

delineation process specifically, as well as producing a system that can have many other potential applications.

The final chapters of this study will examine, compare and evaluate the trial delineations and methodologies in terms of timeliness, accuracy, speed and production costs with both the existing techniques and those of another alternative using the Procom system (see Section 1.4). Recommendations for future work and research directions will be proposed, with an emphasis on further development of related applications, and for the use of the Aries image analysis system recently acquired by Statistics Canada.

1.4 Selection of Study Areas

Recent studies initiated by the Geography Division, Statistics Canada, have demonstrated the ability to discern urban/non-urban areas from remotely sensed Landsat data. One study, contracted to Gregory Geoscience Ltd. (Moore, et al, 1983) by the Geography Division, examined the potential of using a zoom-transferscope type of device known as the Procom system, to update existing urban area 1:50,000 scale maps with transparencies produced from remotely sensed Landsat multispectral scanner (MSS) imagery. Although the results were acceptable, it is this author's contention that the technology and techniques are available to further automate the map updating procedure. For example, if geocoded remotely sensed data were transferred to an existing computer mapping system, they could be integrated with digital boundary files and used as a supplementary visual information source. Although not within the

scope of this study, future research projects could compare and contrast these digital files with the results derived from the Procom system. For this reason, it is desirable to select areas that can be compared and contrasted with the various techniques.

The existing urban delineation process is, of course, used for the delineation of all Canadian urban areas. The Gregory study involved the classification of land-use changes in five urban areas. This study will select two of the Gregory sites for trial delineation purposes. The chosen sites should be representative of a 'typical' urban area in Canada, yet should also pose certain problems in order to effect a 'real' delineation. Two areas with varied urban characteristics, different terrain in the urban fringe areas, and with suitable Landsat MSS imagery for the required time period, were selected: Brampton, Ontario and Kelowna, British Columbia.

Brampton and Kelowna will be used throughout the study as examples in the trial delineations of both the proposed computer-assisted system and the remote sensing applications. Chapter 5 further discusses the urban characteristics and delineation problems presented by each site.

CHAPTER II

THE URBAN AREA CONCEPT

2.1 Geographic Units of the Canadian Census

Statistics Canada supports and maintains some 12 levels of geographic areas ranging from the basic data collection units, the enumeration areas, to very large dissemination units such as provinces. These spatial units can be defined and categorized into conceptual areas used mainly for statistical purposes or areas used primarily for administrative functions. Figure 2.1 depicts the interdependencies and hierarchical structure of these standard geostatistical areas as defined for the 1981 Census.

It is clear, from Figure 2.1, that the building unit of the entire geostatistical hierarchy is the enumeration area (EA). Both statistical and administrative units can be derived from, or rolled-back to, the basic building blocks composed of enumeration areas. It is further evident that the geostatistical unit of most specific interest to this study, the urban area (UA), is a distinct entity that is not necessarily required to respect geostatistical units other than the enumeration areas from which it is derived. This statement is somewhat of a paradox, however, because enumeration areas, in theory, respect urban

Figure 2.1: Hierarchy of Geographic Units for the 1981 Census
 (Source: Statistics Canada, 1982a)

areas, even though EAs are used as the delineating unit for UAs. Nonetheless, and whenever possible, the delineation process does endeavor to respect other geostatistical units. The delineation criteria are discussed further in Section 2.5.

Given a basic background of the structure and interdependences of the various geostatistical census units, this chapter will further examine the evolution of the urban area. It begins with a brief historical review of the concept and a detailed definition of the urban area, a summary of urban concepts as used in census programs in other countries, the importance of the urban unit, and will conclude with an overview of the delineation process used to determine the urban area boundaries.

2.2 History of the Canadian Urban Area Concept

Beginning with the Census of 1871, the Canadian census has classified the population into urban and rural categories. The concept of the urban area has not altered significantly since its first use, although the specific definition used for the urban boundary delineation process has undergone progressive modification in response to the changing demographic and social situation over the one-hundred-and-ten year plus period. The consistency of the UA concept makes it possible to compare and contrast urban data with the confidence that the data collection and dissemination continuity is very high. This historical continuity of urban level data is, in itself, an important factor for justifying the retention of the urban classification. The importance of

the UA unit is discussed further in section 2.4.

An outline and summary of the urban definition, from its introduction in 1871 to the definition to be used in the 1986 Census, is shown in Table 2.1. As evident in the table, the evolving trend of the urban definition has been from one of a very restrictive administrative definition to a more statistical type of definition, where the delineation data are derived from the previous census.

Ricour-Singh and Parenteau (1973) have identified two main approaches for classifying urban concentrations: (1) the administrative classification, based on an area's status and boundaries; and (2) the agglomeration classification, based on limits of defined clusters. Although these two classifications are well defined and differentiated, it is found that most countries employ secondary criteria, and often, elements of both approaches in their urban definition.

Prior to 1976, Canada's definition of urban was classed as a complex type in the administrative category, as are those of France and the United States (Ricour-Singh and Parenteau, 1973). By the 1976 Census, however, Canada began to base its urban definition, and emphasis, on agglomeration criteria (population and population density) without having regard to the administrative status of the area.

Until 1951, it was relatively easy to identify an urban area because the definition required that the area be incorporated. The urban area boundary would therefore correspond to the incorporated limits of the municipality. On the other hand, the period 1951 to 1971

<u>Census Period</u>	<u>Definition</u>
1871 - 1941	incorporated cities, towns and villages
1951	cities, towns and villages with a population of 1,000 and over, incorporated or not
1956	as for 1951, with the addition of suburban areas in major urban areas
1961 - 1971	as for 1956, with the addition of built-up areas in all towns and villages
1976	all areas with a population concentration of 1,000 or more and a population density of 1,000 or more per square mile (386 per square kilometre)
1981 - 1986	all areas with a population concentration of 1,000 or more and a population density of 400 or more per square kilometre

Table 2.1: Canadian Census Definitions of Urban, 1871-1986
(adapted and updated from Kralt, 1976)

had a somewhat more complicated definition which required many criteria in order to classify and delineate the boundary. That twenty year period corresponded to very rapid changes in the urban/rural demographic and social structure and, subsequently, the census definition of the urban area was modified more frequently (Statistics Canada, 1984b). Many of the changes were introduced in order to account for large population shifts, including the establishment of many urban fringe areas, such as subdivisions outside of the official municipal limits, as well as the corresponding decreases in the rural population. The most recent major modification, introduced for the 1976 Census, simplifies the definition by requiring only a minimum population and population density to achieve an urban classification. The 1976 definition completes the trend away from total reliance upon the administrative status of an area to that of a statistical status. The nature of the current statistical definition has an additional benefit in that it is also ideally suited to automation of the delineation process.

2.3 Other Urban Definitions

It is thought that the trends and changes experienced in Canada's approach to classifying urban may also have occurred in other countries, especially those countries which have urban characteristics and development patterns similar to those of Canada. The United States shares many of these same qualities; therefore it should be examined and contrasted more thoroughly.

2.3.1 United States

The American definition of urban is considerably more complicated than the current Canadian definition. In fact, it can still be classed as a complex type in the administrative category, like that of Canada prior to 1976. Nonetheless, there are parallels and the basic urban area concept has a similar objective: to identify all population concentrations having urban characteristics.

The U.S. Bureau of the Census first introduced the concept of urban in its 1850 Census. Like the Canadian definition, the U.S. version has undergone progressive modification in response to the changing urban situation. The 1980 U.S. Census definition of urban required that for each UA, at least one incorporated place must have a minimum population of 50,000 and, for delineating continuously built-up fringe areas, places outside of the city must have a population of 2,500 or more (U.S. Bureau of the Census, 1985). This definition is not unlike the 1971 Canadian definition.

The urbanized area concept seems to have greater importance to the U.S. Census program than is the case in Canada. For example, U.S. urban area boundaries are often used as the main criterion for the funding of federal programs, including General Revenue Sharing, Urban Mass Transit, and the Federal Highway Act. Due in part to the significance attached to the UA concept and in response to considerable criticism of the present definition and the resulting delineations, a thorough re-examination of the concept is underway for the 1990 Census and beyond. Preliminary discussion indicates strong support for a statistical

approach, similar to Canada's, based on a minimum population and population density (U.S. Bureau of the Census, 1984). It is recognized that an ideal urban area definition will be very difficult, if not impossible, to achieve. The delineation difficulties imposed by a complicated definition must also be taken into consideration.

2.3.2 Other Countries

The United Nations Department of International Economic and Social Affairs (United Nations, 1985) publishes yearly demographic statistics on urban population. The definitions of urban, as compiled by the U.N., indicate that there is wide variability in the definition and application of the urban concept. Therefore, international comparability of urban data is difficult and often inaccurate. It is generally accepted that no single standard definition is possible in an international context (U.S. Bureau of the Census, 1984). Detailed discussion of the background and issues related to an international definition is beyond the scope of this study; however, the reader is referred to Shryock and Siegel (1971), Goldstein (1976) and Ricour-Singh and Parenteau (1973) for thorough coverage of this subject area.

The United Nations has divided the various global definitions into five major categories used for deriving the urban area: (1) administrative areas; (2) population size/density; (3) local government areas; (4) urban characteristics; and (5) predominant economic activity (Shryock and Siegel, 1971: 153-154). In one form or another, population size is the criterion used most frequently, by

almost all countries, in at least part of the urban delineation process.

The Canadian definition of urban is similar to several of the European definitions. The U.N. compilation of urban definitions (United Nations, 1985) serves to highlight the diverse range of definitions in use around the world. It is immediately obvious that 'urban' can, and is, defined as just about anything that the particular country wishes it to be. This causes problems in international comparability of urban population percentages, although this is not of great concern to most countries because they define urban primarily for their own internal purposes. Canadian census users, like those in the United States and other countries, recognize that no single definition is fully adequate for their own country, still less applicable on a global scale. Nonetheless, the initiative for any re-definition will come from specialists within Statistics Canada after consultation and study with data users and specialists in Canada and abroad. The results of new delineation methodologies, which will be proposed later in this study, will supplement the existing techniques, and may also contribute to further modifications of the existing definition.

2.4 Importance of the Urban Area Concept

The UA is an important concept for two main reasons: (1) urban data allow comparison of urban trends between the provinces as well as other countries (even though there are problems with the UA definition), and; (2) government programs, policy and grants are often based on the distribution and urbanization of the population (Parenteau, 1978). The UA also provides a picture of the urbanized parts of the country and can

be used to depict trends in urban and rural growth or decline. The concept also permits historical comparisons, as noted earlier.

It should be noted that the remaining population and areas not classified as urban are, by default, classified as rural. The rural population count is calculated by simply subtracting the urban population from the total population. This urban/rural split, although strictly delimited in the census definition, is not at all distinct in today's reality. Rural society, in particular, has undergone great change in the last few decades resulting in fewer differences between the urban and rural ways of life. Kralt (1976), identifies the communication and transportation revolutions, and the influences of the automobile, television, and telephone as especially important in narrowing the distinction between the urban and rural segments.

As a result of the on-going changes occurring in Canada's demographic patterns and the stated need for a more accurate urban definition, several studies were undertaken by Statistics Canada in order to determine whether or not the urban definition, and its default rural companion, require modification (Kralt, 1976; Ricour-Singh and Parenteau, 1973; Parenteau, 1978 and 1979). Although suggestions and proposals to change the urban definition have been advanced, no major revisions have yet occurred. As mentioned earlier, the U.S. Bureau of the Census is in the process of performing a major review of many of their geostatistical definitions. As part of that process, a 1990 Census planning conference was held in April 1984 (U.S. Bureau of the

Census, 1984) with the participation of census geographers, academics, demographers, urban planners, etc. Working groups were established to assess the present definitions and to make recommendations to be implemented for the 1990 Census. Several of the recommendations pertaining to urban areas may have application in a Canadian context. Chapter 7 will further discuss their feasibility and application in the proposed automated delineation system.

2.5 The Delineation Process

The delineation process designed for the 1986 Census is based on the following definition of an urban area: "an area having a population concentration of 1,000 or more and a population density of 400 or more per square kilometre" (Statistics Canada, 1982a). The definition of an urban area is relatively simple and straightforward as compared to the criteria established for the delineation of the UA boundary. Prior to each census, Statistics Canada prepares the appropriate guidelines required to produce accurate and consistent delineations for all of the geostatistical boundaries. For urban areas, the procedures are outlined in an internal document, the "Delineation Guide And Rules Of Application Of The Urban Concept For The 1986 Census" (Dubuissan, 1983a).

The UA delineation procedure begins by procuring a large number of materials, including: various administrative forms; topographic and census modified G-12 series topographic maps; several census publications including "1981 Population And Dwelling Counts", "Population: Geographic Distributions" and "Enumeration Area Reference Lists"; interim change lists for municipal boundaries, status, and

names; and finally, scaled rules for calculating areas.

Using the above listed tools and materials, the delineation is begun by following the procedures in the delineation guide. The delineation document lists 15 main steps (rules of application) which need to be considered throughout the procedure. Many of these steps can be bypassed, however, because they are special rules that are only applied in certain circumstances or situations. For example, rules have been established to account for areas that meet the basic population and population density criteria, yet are separated by areas that do not meet the minimum population or density criteria; in this instance, if the distance is less than 2 kilometres the area will be defined as one urban concentration. The application rules are again consulted to select the correct name for the newly derived urban area. Other application criteria are used for partly urban incorporated municipalities, the crossing of administrative and statistical boundaries, urban number coding and Indian Reserves.

It is difficult to derive estimates for delineating an 'average' urban area. Municipalities with a relatively small population and large area are more difficult to delineate, for example, than a similarly sized area with a denser population. More complex delineations will also result when the special application rules must be consulted for urban areas which have rural enumeration areas or adjoining municipalities.

When the delineation rules are basically unchanged, as they have

been since 1976, the delineation procedure should proceed more rapidly because only the urban fringe areas will need re-assessment with the 'new' census data. This, of course, assumes that no significant population decrease has occurred in the core area of the previous UA. The number of enumeration areas which require population and density calculations to be performed is therefore significantly reduced, along with the amount of time required to delineate each urban area. Problems can arise, however, because this practice of assuming the previous delineation of the core areas can lead to the perpetuation of previously incorrect boundary definitions (as will be seen in Chapter 6).

CHAPTER III

AUTOMATION OF THE URBAN AREA DELINEATION PROCESS

3.1 Background,

The previous chapter outlined the methodology and techniques presently used to delineate the boundary of an urban area. In this chapter, a system is developed for a computer-assisted delineation procedure which will have application in most large urban centres. The proposed system primarily incorporates existing software and digital data files originally developed for other applications. The advantages of using available components are readily apparent; however, many limitations are imposed by the incompatibilities of multi-purpose applications software and the use of data files not intended for manipulation in diverse topological situations.

A general overview of the major production steps is outlined in the flow chart in Figure 3.1. In order to understand the automation process, and its advantages and limitations, an overview of the various digital geographic boundary and statistical data files is required. A brief summary of the system components, followed by an examination of each of the major elements, should provide an appropriate background and understanding of the workings of the system.

Figure 3.1: Production Steps for the Computer-Assisted Generation and Delineation of Urban Areas

3.2 Boundary File Processing

3.2.1 Area Master Files

The Area Master File (AMF) is an integral component of the Statistics Canada Geographically Referenced Data Storage and Retrieval (GRDSR) System. The GRDSR is a system developed to enable the extraction of data for small, non-standard areas within the larger urban municipalities of Canada. For example, statistical data can be obtained for areas from as small as a city block-face, when strict confidentiality requirements are met, to larger units such as traffic zones, school districts, and the like. The retrieval system is based on geocoding techniques that assign each data collection unit, such as a household, a coordinate number identifying its geographic location. These units are then assembled into the larger block-face unit for data extraction purposes (Statistics Canada, 1972).

The AMF is the component of GRDSR that contains the geocoded spatial information in computer readable form. Large urban areas with a population of 50,000 or more are included in the AMF coverage. An AMF references each street, address range, block-face centroid, and many geographic features including rivers, water bodies, municipal boundaries, enumeration area boundaries and railroad tracks. Of these features, the enumeration area boundaries and the street network files are of particular value to the methodology proposed in this study.

At present, AMFs are available for about 200 municipalities (see Table 3.1), most of which are part of census metropolitan areas (CMAs). For example, the 1981 Toronto CMA is composed of 20 municipalities,

Province/ Territory	# of Municipalities			1981 Population		
	Total	in AMFs	%	Total	in AMFs	%
Newfoundland	403	2	.49	567,681	84,996	14.97
P.E.I.	112	0	0	122,506	0	0
Nova Scotia	113	2	1.76	847,442	176,871	20.87
New Brunswick	285	9	3.15	696,403	188,917	27.12
Quebec	1619	59	3.64	6,438,403	3,229,611	50.16
Ontario	932	78	8.36	8,625,107	6,148,035	71.28
Manitoba	282	2	.70	1,026,241	564,914	55.04
Saskatchewan	889	3	.33	968,313	318,126	32.85
Alberta	416	3	.72	2,237,724	1,179,061	52.69
B.C.	580	46	7.93	2,744,467	1,594,388	58.09
N.W.T.	9	0	0	45,741	0	0
Yukon	70	0	0	23,153	0	0
Canada	5710	204	3.57	24,343,181	13,484,919	55.39

Table 3.1: Area Master File Coverage by Province, 1985
(source: Yan and Parker, 1985)

including one of the study regions, Brampton. Given that there were 946 urban areas delineated in 1981, and assuming that the AMF is an integral component of the proposed delineation system, it is evident that there is a major deficiency in the effectiveness of the system with regards to the hundreds of other urban areas. This is, perhaps, the largest single limitation of the proposed system. Nonetheless, if the street network files are excluded as a non-essential component, the sole requirement of the AMF would be to provide the enumeration area boundaries. Alternatives to the AMF will be discussed later in this study.

3.2.2 Enumeration Area Files

The enumeration area (EA) is a spatial unit used by the census for defining the area of coverage of one census enumerator. Normally, the EA is the smallest geostatistical unit for which census data are disseminated in published or digital (i.e. computer tape) form. An EA is defined on the basis of two main criteria: (1) number of households (maximum of 375 in large urban areas, 125 in rural areas); and (2) limits of any other geostatistical units (an EA cannot cross other units). In addition, an EA will respect major features such as streets, railways, rivers and lakes, in order that an enumerator can locate the EA without difficulty.

Although the AMF codes EA boundaries in a digital form, the EAs are perceived as a product of the AMF rather than a standard digital geostatistical product. Most other geostatistical boundaries including census tracts, census divisions and federal electoral districts, are available in a digital form from Statistics Canada. Therefore, digital

coverage of EAs is presently restricted to AMP centres. As stated earlier, the major limitation of a computer-assisted urban area delineation system is the absence of digital EA files for all of Canada. The many potential applications if country-wide digital EA boundary files were available, in addition to their utility in the automation of other geostatistical boundary delineations, should justify their creation.

Statistics Canada has a system which is used for the extraction of geographic information for any geostatistical area. Known as the Census Geographic Master File, or CGMF, all information is geocoded in a computer coded format and has two main purposes: "(1) to provide a central computer data base of the geographic information for the census; and (2) to quality assure the geographic data to ensure the correct aggregation and presentation of census data" (Statistics Canada, 1982c). Information available through the CGMF includes boundaries for all geostatistical areas (except the enumeration areas as noted above) and attribute data such as names, land area and population by geostatistical area. If expansion of the digital EA coverage occurs, it is likely that the CGMF will be the source data base.

Within Statistics Canada, there are presently three sources of digital EA files. They are: (1) the AMP, although there are technical restrictions preventing their general use until further software developments are completed; (2) an extraction procedure available through the User Services Unit of STC's Geography Division; and (3) the

CGMP data base. It should be noted that the three sources for EA files have identical coverage areas (AMP coverage) and are derived from the same digitized base. The CGMP source was used for the retrieval of digital EA files in this study.

3.2.3 Extraction and Transfer of Files

The extraction of the EA files is a straightforward operation involving the submission of a standard request for the boundaries of any available municipality (see Table 3.1). The request is processed by the Geographic Digital Datafile Unit (Geography Division, Statistics Canada) with the files written to tape in a standard 29 byte record interfile format. The CGMP data base resides on Statistics Canada's main Amdahl computer; therefore the extraction procedure is also carried out on that system. Upon receipt of the tape, all subsequent processing is performed at the VAX computer site in the Geocartographics Subdivision. Standard foreign tape read procedures are used to copy the tape information to a VAX disk file. The AMALGAM program (see next section) then transforms and formats the data for use in the GIMMS mapping program (Section 3.3).

3.2.4 AMALGAM

AMALGAM is a software system developed for the purpose of integrating a number of existing utility programs. Since its inception several years ago, the AMALGAM system has expanded to include new applications software developed in-house. Some of the capabilities include: projection transformations, file input and output in a variety of formats, file editing and manipulative functions. New features and

functions are developed and added as necessary.

AMALGAM is used for several functions in the system designed for urban area delineations. First, AMALGAM is used to convert the EA boundary file from that of an interfile format to a GIMMS data input format. It is also used to edit the EA names because of limitations in label lengths imposed by the GIMMS system. Secondly, AMALGAM performs a similar function in converting and editing the street network files (discussed further in Section 3.5). Lastly, it outputs a command file giving UTM map sheet coordinates, the correct scale factor for a 1:50,000 plot and the correct origin coordinates.

3.3 GIMMS Input and Mapping

The GIMMS program (Geographic Information Manipulation and Mapping System) was developed in the 1970's at the University of Edinburgh (Waugh and McCalden, 1983). GIMMS is best known for its mapping module which produces medium to high quality maps and supplemental graphics at virtually any scale or size, limited mainly by the capabilities of the output device. There are also modules to perform sophisticated geographic manipulations such as searches, a powerful graphics module, arithmetic functions, polygon creations, data formatting, etc. Cartographic enhancements are an integral part of the program, enabling the addition of titles and other textual features, legends, north arrows, shielding, overlays, offsets, many text fonts, and multi-map sheets. User-specified black and white or colour shading and dot patterns are available for the effective presentation of data.

GIMMS is used for all mapping applications used in the delineation procedure, and, in addition, it is used for the presentation of the remotely sensed data and geographic file overlays (see Chapter 4). The real strength of GIMMS is its thematic mapping capabilities which it performs as well as, if not better than, any system currently available.

One of the AMALGAM outputs is a formatted GIMMS input file. This file is then processed by GIMMS and a segment line file is derived, which, when drawn (Figure 3.2), maps the segments as encountered in the raw data file.

In order to perform most thematic mapping functions, the digital boundary files must again be processed by GIMMS in order to create closed polygon files. Polygon or area type files differ from the segment files in that a complete 'closed' boundary description is required where the start and end points for each polygon are identical. The boundary file processing is now complete and the files can be used, in conjunction with the appropriate statistical data, for any GIMMS thematic mapping application.

3.4 Statistical Data

The only statistical data required for the urban area delineation process are the most recent population data by enumeration area. Normally, this data will be derived from the most recent census; for example, all data used in this demonstration originated from the 1981 Census. Population data at the EA level are usually collected and disseminated only by the census. Therefore, data more recent than that

Figure 3.2: Plot of a GIMMS Segment File, Brampton, 1981 Enumeration Areas

of the last census are not available.

The statistical data can be acquired from existing data bases, including the CGMP maintained by the Geography Division at Statistics Canada, and the CANSIM data base which is also accessible to the public. The CGMP is the appropriate source because the EA boundaries are also being extracted from that base. Using the CGMP only one extraction request is required and, further, it is expected that fewer extraction errors will result. As an alternative, the data can be entered manually from the appropriate census publication, but this, of course, defeats the purpose of an automated system.

Once the data are on tape, or on disk, the VAX 11/780 mini-computer is used for all subsequent GIMMS processing. The data may require further formatting, however, depending on its origin and file structure. Either AMALGAM or GIMMS is capable of this function. It may also be necessary to sort and match the data with the boundary file in order to ensure that there are no missing data values in the statistical file and no missing enumeration areas in the boundary file. Finally, the statistical data are processed by GIMMS and formatted in an internal GIMMS format. The statistical data can now be used for most thematic mapping tasks.

Further processing of the statistical data is necessary in order to derive the population density and related information including the EA code number, area of the EA in square metres, X and Y centroid values, area of the EA in square kilometres, and the calculated population

density (i.e. EA population divided by the EA land area). Table 3.2 lists a portion of the output extracted from the Brampton calculations. It is interesting to note that this output, including the data in Table 3.2, is derived via GIMMS calculations using only the boundary and statistical data files. Figure 3.3 is a GIMMS thematic map created from the population density data.

3.5 Street Network Files

One of the developments initiated by this study has resulted in a capability to extract AMF street network files from the AMF digital data set. The street networks provide an additional overlay which can be used by the delineator to supplement his/her knowledge about the area. For example, residential areas are often visually discernible because of their street patterns and street density. Given that the manual delineation methodology uses the NTS topographic sheets for their base, the more current AMF street network will more accurately depict recent street developments. The street patterns are usually good indicators of land use, especially in more recently developed areas. For example, Figure 3.4 illustrates a portion of a street network file for the Brampton urban area. The residential areas tend to have random, relatively dense street networks which are readily discernible throughout the plot. It is expected that the street files will also have relevance to other tasks including the delineation of enumeration areas, census tracts and population ecumenes. As well, the street files can be used as a supplementary data source in conjunction with files derived from remote sensing.

Pop.	EA #	Sq. Metres	X Cent.	Y Cent.	Sq.Km.	Popden
17	030001	2386301.50	609184.94	4843473.50	2.39	7
1	030002	1279317.50	607934.38	4842060.50	1.28	1
14	030003	4576714.00	606206.00	4839667.00	4.58	3
1408	030004	1111625.50	605654.75	4840619.00	1.11	1267
1335	030006	415031.50	604959.63	4841137.00	0.42	3217
1356	030007	296745.00	605117.88	4840651.00	0.30	4570
1450	030008	256330.00	604676.75	4840706.00	0.26	5657
1195	030009	1186254.00	604681.63	4839418.50	1.19	1007
1131	030010	219578.00	604503.56	4840482.00	0.22	5151
1374	030011	355575.50	604495.00	4840046.50	0.36	3864
859	030012	226183.50	604115.44	4840260.00	0.23	3798
1208	030013	327316.00	603818.94	4839826.50	0.33	3691
1238	030014	387266.00	604168.63	4842425.00	0.39	3197
945	030015	151933.00	604261.06	4842424.00	0.15	6220
923	030016	490751.00	604447.81	4841852.50	0.49	1881
1278	030017	282084.00	604268.25	4841428.00	0.28	4531
1149	030018	162570.00	603994.75	4841303.50	0.16	7068
1338	030019	237144.50	603709.06	4841884.50	0.24	5642
281	030020	39691.00	603739.56	4842063.50	0.04	7080
450	030021	23182.50	603503.31	4841777.00	0.02	19411
1235	030022	396609.50	603854.00	4840901.50	0.40	3114
1464	030023	480313.00	603451.75	4840490.00	0.48	3048
892	030024	146692.00	603264.81	4840103.50	0.15	6081
915	030025	337696.50	605135.31	4841723.50	0.34	2710
1072	030051	241047.00	603782.56	4842738.50	0.24	4447

Pop. = 1981 population
 EA # = enumeration area number code
 Sq. Metres = EA area in square metres
 X Cent. = EA X centroid value
 Y Cent. = EA Y centroid value
 Sq.Km. = EA area in square kilometres
 Popden = EA population density (per square kilometre)

Table 3.2: Example of a Listing Depicting the Output of Calculations and File Extractions for 25 Brampton Enumeration Areas, 1981 Data

Figure 3.3: Population Density by Enumeration Area, Brampton, 1981 Data

Figure 3.4: Portion of a Street Network File, Brampton, 1985

An overview of the flows and methodology for extracting and transferring AMF street networks is outlined in Appendix 1. It should be noted that this is a prototype system developed specifically for this study. Several modifications are in the process of being incorporated in order to improve efficiency of the transfer process and to eliminate the 'rectangular boxes' (as seen in Figure 3.5) which occur because of file size limitations associated with the AMF data extraction routines. These boxes actually delineate the 'window' or outer boundary of the area that is extracted (each extraction creates a file; the Brampton street network, for example, had to be extracted in four files). These software modifications will enable a direct transfer of the AMF features (not necessarily limited to street networks) without file size restrictions.

Urban applications of the street network are evident in the Brampton overlay file (Figure 3.5), especially in places where residential type street patterns are obvious in enumeration areas having a low population density. There are also large areas within some high density EAs that have few, if any, residential type streets, thus implying that the EA has a mix of residential and rural and/or commercial/industrial qualities. Figure 3.6 is an enlarged plot of an area in Brampton that better depicts residential streets in overly large EAs that have large areas without any road network. Questions concerning the EA delineation itself can therefore be advanced; however, it must be remembered that the street network file is at least five years more recent than the EA file. The main advantage of the street

Figure 3.5: Population Density by Enumeration Area and Street Network File Overlay, Brampton, 1981 Data

Figure 3.6: Plot of Enumeration Areas and Overlay Street Networks of a Portion of Brampton

network overlay appears to be in its use as a timely, visual supplementary reference source for supporting questionable or problem delineations. An evaluation of the application, advantages and limitations of the street network file process is reviewed in Chapter 6.

3.6 System Overview

A perspective understanding of the automated procedures, and the systems and techniques developed and integrated, can be derived from the flow chart in Figure 3.7. The techniques and methodologies outlined in this chapter have application to areas that: (1) have digital EA coverage (some 200 municipalities); and, optionally, (2) have street network file coverage. Complete application of the system requires that the digital EA coverage be expanded to include all of Canada and, optionally, that street network coverage also be expanded to include all of the country. If that were the case, computer-assisted urban area delineation could be performed, initially, on very large areas, perhaps up to the size of a province. An assessment of the ensuing plot would pin-point areas that meet the UA criteria. These areas could then be individually evaluated and delineated. Chapter 5 illustrates the delineations derived from the system shown in Figure 3.7, while Chapter 6 evaluates the delineation accuracies and cost-effectiveness.

Figure 3.7: Major Data Sources and Systems Used for the Computer-Assisted Delineation of Urban Areas

CHAPTER IV

REMOTE SENSING METHODOLOGY AND DEVELOPMENTS

4.1 Remotely Sensed Data

Recent studies initiated by the Geography Division, Statistics Canada, including the Gregory Geoscience study (Moore, et al, 1983), have demonstrated the ability to discern urban/non-urban areas from Landsat multispectral scanner (MSS) remotely sensed data. Although the techniques utilized in the Gregory Geoscience study required high levels of manual intervention by trained image interpreters and analysts, techniques and the technology are available to further automate this process. For example, the Gregory study used a standard Canada Centre for Remote Sensing (CCRS) product, enhanced colour transparencies derived from Landsat MSS digital data, as their test data source. An objective of this study is to demonstrate that MSS digital data, which can be purchased on magnetic tape, can generate similar results without having to convert to an analogue data form such as transparencies. The subsequent processing and analysis will allow the data to remain in a digital form and permit its use in automated and computer-assisted analysis systems. Furthermore, if the Landsat data are geocoded, they can be used in conjunction with geographic data coded in a similar

fashion.

Given the above, it is thought that the addition of remotely sensed data to the interpretation and decision making stages of the delineation process, be it manual or automated, could result in more timely and realistic delineations. For this purpose, the digital data can be used in two ways: (1) as a supplementary information source used in association with visual image interpretation techniques; and (2) as a complementary data source using classified imagery. The use of Landsat MSS data may be a limiting factor, to one or both of the above applications, because of the relatively coarse resolution of the data and the subsequent image classification.

This chapter will begin with a review of literature and classification techniques, followed by discussions concerning the remote sensing methodologies, the transfer of the classified image data to a geographic information system, and the subsequent mapping and overlay capabilities. The following discussions concerning the remote sensing procedures and methodologies are presented as a general, non-technical overview. For further information on specific remote sensing details or topics, the reader is referred to the cited references or the general titles listed in the bibliography.

4.2 Review of Literature and Classification Techniques

The remote sensing community has, in general, concentrated on applications in the natural resources field including agriculture, forestry, geology, land use, etc. There has not been comparable

research into urban applications of remote sensing. This disparity has been justified on several fronts, but mainly involves that of priorities and money. Natural resource applications have the need, political support and the major corporations to provide the necessary impetus. It is also commonly held that the resolution of the Landsat MSS imagery is too coarse for use in complex interpretation and classification situations such as those encountered in most urban areas. The recent higher resolution sensors, such as the Thematic Mapper (TM) on Landsats 4 and 5, have re-generated interest in peripheral applications including urban analysis. Nonetheless, the amount and variety of literature indicate that the major research orientation is still geared towards those in the natural resources applications.

Before a review of literature is begun, it is important to establish the remote sensing parameters which affect the design and application of this project. For example, this study is limited to the use of Landsat MSS data. The major reasons for this restriction include: (1) 1981 (census year) data are required (higher-resolution thematic mapper (TM) data were not available until 1982); (2) the comparisons to the Procom methodology which used MSS data transparencies; and (3) for a simple urban/non-urban, or similar, classification requirement, it is thought that MSS data should provide sufficient resolution and spectral separability. The review of literature is therefore concentrated on, although not restricted to, MSS applications.

The urban/remote sensing research appears to be most intensive in

the United States, with Great Britain and Australia following with several researchers active in the application. There are scattered papers and articles by remote sensing scientists from other parts of the world, but they tend to be few and far between. Another interesting observation of the literature reveals that the majority of the papers are very technically oriented versus that of an analytical applications nature. This can be explained by the fact that many of the authors are remote sensing specialists, not applications specialists.

Most 'urban' type literature is directed toward urban change detection or urban/agriculture fringe analysis. Of the U.S. researchers, several, including Friedman (1981), Toll and Wharton (1980), Toll et al (1980), Landini and McLeod (1979), Friedman and Angelici (1979), Davis and Friedman (1979), Christenson (1976), and Colner (1976), have dealt specifically with census urban area delineation problems. Because of the specific census urban area application of this study, the groundwork established by the researchers involved with the U.S. census applications will be reviewed.

In the mid 1970's, the U.S. Bureau of the Census became very interested in the potential use of Landsat MSS data to delineate urban areas. This, of course, is exactly the same application under examination in this study. A number of research contracts were let with private and semi-private organizations in order to have expert representation on the remote sensing technical side. These organizations included; the Jet Propulsion Laboratory, NASA, General

Electric Company and Computer Sciences Corporation (Davis and Friedman, 1979). A number of studies were conducted between 1976 and 1981. The results of studies were mixed, but generally successful. Nonetheless, the decision was made by the U.S. Bureau to abandon the Landsat/urban area delineation research for the time being. The main reason for this decision was a lack of resources due to the general restraint program imposed by the government and by the re-assignment of resources to a system known as TIGER, which is a very large effort involving the automation of virtually all geographic aspects of the 1990 Census. In personal conversation with several of the persons involved in the research, their feelings are reserved with regards to the use of MSS data, but very positive towards application of the higher resolution sensors. The U.S. Bureau expects to resume research in this area sometime before 1990. The completion of the TIGER system, incidentally, should prove to be advantageous to the use of remotely sensed data because of the emphasis on geocoding and common formats to be in place throughout the system.

The methodology employed by the U.S. Bureau in their delineation attempts takes the same basic approach as proposed in this study, i.e. an integration of remote sensing and geographic information systems. The major difference lies in the type of geographic information system (GIS) being used. The U.S. studies used a raster based system known as IBIS (developed by the Jet Propulsion Laboratory), whereas this study will use a vector based GIS system (GIMMS). IBIS has an advantage in that there is less processing required of the Landsat data because they

are already in a raster form. The cartographic data (census tracts), however, must be converted from their vector format to a raster format. The GIMMS GIS requires the reverse: the Landsat data must be converted from raster to vector. Vector to raster processing is generally more efficient and accurate than the reverse, although recent conversion developments are minimizing this problem.

Another difference between the system methodologies results from the level of geostatistical unit selected for the GIS thematic map input. In the case of the U.S. it is the census tract, while the smaller (larger scale) enumeration area unit has been selected for this study.

MSS band 5 is acknowledged as the best single channel for depicting boundaries between cultural features and natural features (Jensen, et. al, 1983). Visual interpretations are normally performed with a false colour composite wherein the urban areas are enhanced in a steel-blue colour. The U.S. Bureau of the Census, meanwhile, used both manual delineation (visual interpretation) and a digital feature-space partitioning algorithm where bands 5 and 7 were interactively partitioned using a scattergram (Friedman and Angelici, 1979).

4.3 Selection of Standard Procedures and Techniques

This study has not attempted to define or modify established techniques for classifying Landsat MSS data. Rather, commonly practised techniques and procedures will be implemented, where possible, given the restrictions of the image analysis hardware and software, the CCRS Image

Analysis System (CIAS).

A series of classification tests were tried with the Brampton scene. First, a 256 X 256 pixel sub-scene encompassing the visually developed area of the Brampton scene was selected. Next, various classification algorithms, including both supervised and unsupervised classification techniques, were applied to the sub-scene. For the supervised classifications, training areas were selected based on visual interpretations confirmed by consultations with a NTS 1:50,000 map. The supervised algorithms and techniques included Feature-space partitioning and maximum likelihood texture transformations. The results of these initial tests were not very encouraging. Assessments of the resulting classifications, at this stage, were based upon visual verification with the NTS map sheet. The unsupervised classification technique and most of the supervised techniques did not produce satisfactory results. The most promising was the feature-space partitioning in combination with the maximum likelihood algorithm. Also, the inclusion of a generated texture transformation included as a channel within the classification program produced good results. It was also apparent that a visual classification could produce comparable or better results in a very short period of time. The texture transformation, when displayed on the monitor, further improved the visual interpretation of the data.

Given the results of the tests and the resolution of the MSS data, it was decided that two techniques would be utilized for both the Brampton and Kelowna study areas: (1) manual delineation via visual interpretation of the on-screen image; and (2) the combination feature-

space partitioning (using on-screen histogram slicing) and maximum likelihood including texture transformation. The objective of the classification process is to differentiate the urban and non-urban (rural) areas. It was decided that because of the different textural patterns and distinct signatures of commercial/industrial areas and residential areas, a simple two level (binary) classification could be derived. Water, because of its unique spectral properties and easy classification, will also be classified for geographic reference purposes. A summary of the processing steps is outlined in Figure 4.1. The procedures used in the data transfer process are described in the following sections.

4.4 Data Transfer

Many of the techniques and developments associated with the transfer of remotely sensed classified data from CCRS to Statistics Canada have evolved over a three year period. The transfer attempts were begun during the course of a graduate research tutorial which examined relationships between computer cartography and remote sensing as they existed in 1982 (Korporal and Manore, 1982). The following sections were first documented in a paper written and presented by this author at the Sixth International Symposium on Automated Cartography and subsequently selected for publication in an "Auto-Carto Six: Selected Papers" issue of Cartographica (Korporal, 1983).

4.4.1 The Standard Data Transfer Format

In 1979, an ad-hoc group of federal government departments, the

( ) CIAS PROGRAM

Figure 4.1: Summary of Processing Steps for Generating Theme Classifications on the CIAS

Spatial Data Transfer Committee (SDTC), developed a standard format for transferring spatial data polygon files (Goodenough, et al, 1979). Although the Standard Data Transfer Format (SDTF) was accepted by the SDTC member agencies, its adoption was limited primarily to the published record of the standard. No agency, to our knowledge in 1982, had successfully completed a data exchange using the format. The SDTF was, in fact, only a 'paper' standard because the software programs necessary to use the SDTF were left to each user agency to develop, within the SDTF framework, based upon that agency's individual requirements. The net result was considerable interest in the standard, but no users. It was therefore thought that a demonstration transfer would speed the implementation and usage of the SDTF, not only among the member SDTC agencies, but also by other departments and provincial organizations. In addition, it was well known that one of the large voids existing in the digital data users' community was one of data exchangeability. The lack of a transfer mechanism for remotely sensed data into geographic information and mapping systems, and vice versa, was especially prevalent and added to the impetus for further research and development. The SDTF provided a structure to connect these systems.

The Canada Centre for Remote Sensing (CCRS) initiated and provided much of the impetus for the creation of the Standard Data Transfer Format. In order to promote the SDTF and encourage its use at other agencies, CCRS was also the first agency to write SDTF software and to begin in-depth experimentation. The Lands Directorate of Environment

Canada also agreed to work with CCRS and to write SDTF software interfaces to their Automap system. Goodenough, et al (1983) have documented the procedures, successes and problems associated with the SDTF and the experimental transfers to the Lands Directorate. To date, however, only limited success has been achieved because it is not yet possible to use the transferred data to produce thematic maps at the Lands Directorate. The problems encountered mostly relate to the topological errors created by the raster to vector conversion programs, rather than problems with the SDTF definition. The Statistics Canada transfers, on the other hand, produced satisfactory thematic maps because of less stringent and fewer topological restraints required by the GIMMS system (Waugh and McCalden, 1984), detailed in Chapter 5.

4.4.2 Structure of the SDTF

The basic structure of the SDTF is based on polygon chains. Conforming to the standards derived for Computer Compatible Tape (CCT), the SDTF also provides for general geographic, spatial and descriptive information. The design of the structure incorporates properties suitable for present and future digital data applications, including machine and language independence, generality, expandability, and, self-definition (Goodenough, et al, 1979). The format is presently undergoing review and modification to also incorporate line and point data.

Spatial data in the SDTF are composed of three files: the Volume Directory File, the Master Header File and the Geographic Detail File (Figure 4.2). It is the latter, the Geographic Detail File, that

Figure 4.2: Standard Data Transfer Format File Organization
(from Goodenough, et al., 1979)

contains the detailed polygon chain information which is the essential geocoded data needed for thematic mapping purposes. Included in the file are X and Y chain coordinates, chain numbers, left and right polygon descriptors, left and right polygon numbers, number of points in the chain, and left and right polygon areas (Goodenough, et al, 1979).

4.5 Processing at the Canada Centre for Remote Sensing

Normal procedures and software programs are used in the classification process of the remotely sensed data on the CCRS Image Analysis System (CIAS). All SDTF processing is performed after the classified image files are created. As described earlier in this study, classified LANDSAT Multispectral Scanner (MSS) data were used in the analysis and subsequent classifications. The remotely sensed data used for SDTF transfer purposes requires minimal special processing other than the final formatting and transfer to tape. The process flows are outlined in Figure 4.3.

Some theme manipulation is required to remove single or small groups of scattered pixels causing 'speckle' in the image classifications. Although this filtering is not absolutely necessary, it is highly desirable for several reasons, including: (1) cartographic generalization for thematic mapping, (2) the need to avoid excessively large vector data files and storage requirements, and (3) to reduce the computing time, and costs, during vector file processing. Generalization of thematic data into contiguous classes may improve map readability and perhaps better represent real conditions. If, however,

Figure 4.3: Processing at the Canada Centre for Remote Sensing

patterns produced by 'spurious' pixels are important, then such theme manipulation may not be beneficial.

After completion of the theme manipulation and processing, the thematic data are vectorized using raster to polygon software implemented for SDTF purposes. The final step at CCRS requires writing the vectorized data to tape using software which converts the data to the SDTF description. A more detailed outline of the processes and the SDTF software is described by Goodenough, et al (1983).

4.6 Processing at Statistics Canada

Before processing of the remotely sensed data at Statistics Canada could be undertaken, SDTF software development was required in order to read and format the data from the tape generated at CCRS. This SDTF software resides on a VAX 11/780 mini-computer located in the Geocartographics Subdivision at Statistics Canada. The geographic information and mapping system, GIMMS, which is subsequently used to process the data also resides on the same VAX computer.

The processing can be divided into four major operations:

- 1) reading of the SDTF tape;
- 2) converting and formatting the digital files;
- 3) line and polygon file creation; and
- 4) thematic mapping, graphics and GIS functions.

Figure 4.4 illustrates these major steps and processing flows at Statistics Canada.

Figure 4.4: Processing at Statistics Canada

4.6.1 SDTF Tape Reading

Reading of the formatted tape is a relatively straightforward process using standard VAX VMS system foreign tape mount procedures. Normally, the SDTF tape is composed of three files giving volume, header and segment information. Details essential for accurate tape reading, such as record lengths, number of records, and some general geographic information including projection, scale, etc. are on the first two files. A program called SDTREAD was developed to convert these two files from mixed ASCII and BINARY to ASCII only files. The third file, the Geographic Detail File, is processed separately because of its complexity and reliance on information contained in the volume and header files.

4.6.2 File Conversion and Formatting

Reading, converting to ASCII, and formatting of the Geographic Detail File presented the most difficult and time consuming developments involved in the data transfers. The program created at Statistics Canada to perform this task, CONVERT, has undergone several modifications over a three year period. The current version of CONVERT enables the user not only to perform standard formatting, but also to select the SDTF features to be transformed. For example, the user can choose to process either the thematic classification of the data, or the polygon numbers, to create the formatted data file for the polygon creation stage. Modifications to CONVERT also resulted from minor changes to the SDTF definition, as well as in response to problems encountered at later stages of the processing.

Many of the difficulties encountered in developing and modifying the format software were a result of qualitative uncertainties inherent in each step of the transfer process. As an example, when spurious lines would appear in a file during the thematic mapping stage, it was difficult to determine if the problem was related to GIMMS, to the conversion program CONVERT, to incorrect information on the SDTP tape data files, or even further back to the raster to vector conversion programs or the version of the SDTP software at CCRS. The net result was a significant amount of time spent in tracing problems to the source, several software corrections at CCRS, long delays, and further modifications to CONVERT.

In its present form, CONVERT creates two output files. The first is a formatted GIMMS input segment file with segment labels, coordinate pairs and unique GIMMS command identifiers. These data are then used to create a line segment file, and optionally, a topologically correct polygon file for thematic mapping. The second output file contains formatted and sorted data composed of classification values and polygon labels, also in GIMMS input format specifications. This data file is used for thematic mapping and GIS manipulation.

4.6.3 Line and Polygon File Creation

Upon completion of CONVERT processing, the segment data file is ready for GIMMS processing to create two more output files and, later, merge with the data classification file to produce thematic maps.

Using the CONVERT generated segment data file, GIMMS creates a

segment line file which, when drawn, maps the segments as encountered in the raw data file (Figure 3.2). In the context of thematic mapping, the main purpose of this file is to provide the input for creation of a polygon descriptor file. As described in Chapter 3, polygon or area type files differ from the segment file in that a complete 'closed' boundary description is required where the start and end points for each polygon are identical. The polygon file is required for most thematic mapping purposes where shading or dot patterns are wanted. The very large size of the data files generated from remotely sensed data, combined with the many small areas described by small groups of pixels, puts great demands on GIMMS whose usual mapping application is for much larger areas such as those of political or census type boundaries. GIMMS has the capability to allow the easy upgrading of 'normal' program limits for unusual or unique application such as those encountered in this study.

An important feature of GIMMS is that a check can be made on the segment data to test for errors such as polygon closure, at much lower processing costs than required for creating the polygon data files. This check is recommended if errors are anticipated in the segment file description. Newer updates of the SDTF software, presently under development at CCRS, should make this check redundant. In addition, a generalization function can be introduced into the polygon file creation process to reduce the number of points associated with the mapping component.

4.6.4 Thematic Mapping

The classification values, contained in the classified data file, the second output file from CONVERT, are required at the thematic mapping phase. These are the thematic data which will be represented by the selected symbolism and on which the graphics and user specified manipulations are based. The GIMMS file can also be manipulated and used to derive geographic information including area calculations, density and other mathematical functions, geographic searches, merging with other files, centroid calculations, etc.

An example of one of the first classified Landsat MSS data files to successfully complete the SDTF transfer and subsequent conversion and processing to that of a GIMMS polygon file and thematic map is shown in Figure 4.5. In addition, many of the cartographic enhancements discussed in Chapter 3.3 may be incorporated. Figure 4.6 displays a thematic map with the addition of an automatically calculated frequency histogram.

Figure 4.5: GIMMS Thematic Map Produced from Landsat Classified Data Transferred via the Standard Data Transfer Format (from Korporal, 1983)

**Figure 4.6: GIMMS Thematic Map and Frequency Histogram from Landsat
Classified Data Transferred via the Standard Data Transfer
Format
(from Korporel, 1983)**

CHAPTER V

TRIAL DELINEATIONS

5.1 Background

The methodologies employed in these trial delineations were outlined in Chapter 3, for the computer-assisted delineations, and in Chapter 4, for the remote sensing components. However, as time, experience, new developments and trial and error attempts progressed, limitations associated with the procedures and problems relating to data acquisition, data quality and changes in format specifications became apparent. When possible, these problems were circumvented or resolved by means that would not affect the overall design of the study nor unfairly bias the results. If the problem could not be resolved within the context and time constraints of this project, suggestions for eliminating or overcoming the problem and how it might be incorporated into future research projects are presented. These recommendations are discussed in Chapter 7.

The delineations presented here, especially the remote sensing components, should be viewed as a first look and a beginning of longer term analysis of the applications. These are discussed more thoroughly in the final chapter.

5.2 Study Sites

5.2.1 Brampton

Brampton is a rapidly growing city situated thirty minutes, by freeway, from downtown Toronto. Located in the urban and industrial heartland of Ontario, Brampton is a medium-large city with a 1981 population of over 149,000. It is within one day's trucking of the largest consumer market in Canada and has excellent access to the huge American population. The surrounding territory includes small farms, scattered industrial complexes, less densely settled patches of homes and light industry, and abandoned agricultural land. The city itself is large in area, has a high population density and well defined residential/commercial/industrial areas bordering the low density rural lands.

In many ways Brampton is an ideal site for evaluating various urban delineation techniques. For instance, the city has experienced very high growth, including a doubling of the population from 1971 to 1981. The subsequent infringement of residential suburbs into the rural areas presents opportunities for the testing of applications for change detection procedures at relatively frequent intervals. Furthermore, a transition from a suburban bedroom community to that of an important manufacturing and industrial centre has taken place. The major industrial parks and the residential districts are fairly homogeneous and are easily discriminated visually on most types of imagery, including Landsat MSS data displayed on a high-resolution monitor. A glance at a street map (such as the street network overlay in Figure

3.5) clearly exhibits the strong rectangular grid structure of the road networks. These road patterns present recognizable landmarks in addition to performing a more subtle function: that of providing a framework for new development. For remote sensing purposes, these features combine to yield what should be an appropriate municipality for the testing and evaluation of the urban area delineation and remote sensing applications.

5.2.2 Kelowna

Kelowna, with a 1981 population of over 59,000, presents many contrasts, in addition to size, with the city of Brampton. The physical location and layout, the environs, and the city's economic base all contribute to these differences and their effect on the urban area delineation.

Kelowna is located in the warm, sunny Okanagan Valley in south-central British Columbia. The moderate climate of the valley and the warm waters of Okanagan Lake combine to elevate the tourism industry to one of the prominent economic businesses in the region. Other industries including forestry, fruit orchards, fruit processing, vineyards, and cattle are also of major importance. Manufacturing is of considerably less importance than in Brampton.

Of interest to the urban delineation process, is the separation of the residential, commercial and industrial areas. In Kelowna, these are not as distinct as in Brampton. The presence of orchards scattered throughout the city and its surroundings, and a generally less

systematic development pattern and road network, make it more difficult to distinguish between the various areas within the city, or to determine visually, the urban/non-urban aerial extent. The surrounding territory includes forests, forest cutovers, orchards, small farms, very dry terrain on some of the hillsides with scrub and brush land as well as unvegetated desert-like areas. These elements give the spectral reflectances a more complex spatial pattern than found in the Brampton area; thus, Kelowna is a challenging area to test the remote sensing components.

5.3 Computer-Assisted Delineations

Following the delineation procedures outlined in Chapter 3 (Figure 3.1), automated population density maps were produced for Brampton (Figure 3.3) and Kelowna (Figure 5.1). It should be noted that the thematic maps produced for these trial delineations are designed to be directly overlaid on the G-12 (NTS 1:50,000) series of reference maps modified by the Geography Division. The actual working scale is therefore much larger than is evident from the maps portrayed in this document.

Most of the city of Brampton is located on NTS map sheet 30 H/12, while Kelowna is mostly covered by 82 E/14. At the 1:50,000 scale, these population density maps are plotted on a transparent or semi-transparent material to enable the base G-12 map information to be read underneath.

The statistical break-points (Figures 3.3 and 5.1) used to

Figure 5.1: Population Density by Enumeration Area, Kelowna, 1981 Data

differentiate the different population densities, are based on the definition of urban: "an area having a population concentration of 1,000 or more and a population density of 400 or more per square kilometre." (Dubuisson, 1983a). As the value of the population density at or above the threshold of 400 is automatically considered urban, at the enumeration area level, a thematic map displaying only that range can be produced. Assuming that the 400 or more population density EAs also have a total population of 1,000 or more (the remaining part of the UA definition: in practice, the population criteria would be determined before calculating the population densities), then the urban area boundary would be represented by the outer line of the displayed enumeration areas. Figures 5.2 and 5.3 identify the Brampton and Kelowna EAs that meet these definition criteria.

Although the urban areas depicted in Figures 5.2 and 5.3 conform to the published UA definition, several concerns must be addressed before the delineation can be accepted. First, the UA definition does not state that the population density is based on EAs, or any other unit. The delineation guide (Dubuisson, 1983a), however, is clear in that the population density is calculated by EA for each municipality (steps 3, 4, 5 and 6). The delineation criteria are less clear, and not consistent with the UA definition, for many of the rules of application found throughout the delineation document (see Chapter 2.5). These rules are the second major concern, because it must be determined which rules have effect on the delineations.

Figure 5.2: Brampton Enumeration Areas Conforming to the UA Definition, 1981 Data

Figure 5.3: Kelowna Enumeration Areas Conforming to the Urban Area Definition, 1981 Data

Examination of the two urban area delineations shows that there are 'islands' of isolated EAs which do not share at least one common border with most of the urban area. In Brampton, there is one occurrence of this phenomenon, while Kelowna contains three such 'islands', one of them very large and distant from the other two. It is conceivable that the inverse could occur in some delineations (i.e. a 'pocket' area could be surrounded by EAs conforming to the definition criteria). The rules of application should therefore be consulted in order to determine the steps to be taken in this situation. The rule that seems applicable in this circumstance is the 2km distance rule which states that "if the distance between two urban concentrations is greater than 2km they will be made into two separate concentrations with different urban code." (Dubuisson, 1983a). This rule, as currently written, is difficult to apply and subject to various interpretations, unless its intention is to refer to whole municipalities, rather than to individual EAs. Given the vague interpretations of this and other special rules, it is perhaps best not to try and use them in a computer-assisted delineation; instead, an examination of other methodologies may be more appropriate.

First, it is necessary to keep in mind the goal of the delineation process which is to identify all population concentrations that conform to the UA definition. This has been accomplished in these first two trial delineations. The delineations, however, should go beyond the strict limitations of the definition to try and include an interpretation of the UA concept.

One of the problems of the UA definition (with any such definition)

is the arbitrariness of the population density criteria. Enumeration areas, especially those with a large area, can be excluded from the delineation because of a population count which may be out by as few as one or two people. As well, the delineation by EA does not account for sub-EA populations; therefore concentrations such as recent suburbs can be found in EAs that have a very large area, much of it non-urban, and the subsequent population density falls below 400.

A population density map that contains finer break-points may alleviate some of the more glaring problem areas. Figures 5.4 and 5.5 illustrate the urban area made up of the EAs that conform to the 400 persons per square kilometre definition, plus all EAs that are close to this arbitrary number. In both Brampton and Kelowna, the added areas have bridged the stray 'islands', except in the case of the two very large concentrations in Kelowna. If all areas displayed are classified as urban, the delineations can be considered as differing, perhaps substantially, from the UA definition. Another problem with this approach is the rigidity imposed by the EAs themselves; the question then is whether or not the urban area be delimited by the confines of EAs, or, should the delineation be permitted to follow the true extent of the portions of the concentration that conform to the urban area definition and concept. In addition, the question of the resulting maps representing the 'true' urban concentration is still difficult to answer. The use of other information sources may also have application in areas that require standardized decisions. It will be necessary, therefore, to introduce supplemental information sources into the

Figure 5.4: Brampton Urban Area and High Population Density Enumeration Areas

Figure 5.5: Kelowna Urban Area and High Population Density Enumeration Areas

delineation toolbox.

5.4 Integration of Supplementary Information

As seen in the computer-assisted delineations, the boundary of an urban area is determined by the extent of enumeration areas meeting the definition criteria. The two supplementary information types already discussed are street network files and remotely sensed classified imagery. It is thought that both of these information sources can provide timely, cost-effective, accurate and appropriate additional information that are suitable in a digital delineation process.

5.4.1 Street Networks

The procedures and techniques for integrating the AMF street network files were discussed in Chapter 3. An appreciation of the "rectangular box" problem, also discussed in Chapter 3, is necessary while examining the street network overlays in the following figures.

When the street networks are overlaid on the high population density enumeration areas, some very interesting results are apparent (Figures 5.6 and 5.7). First, pockets of what appear to be residential areas are scattered throughout the plots in places not classified as high density urban. These may be accounted for because the street network files are of a more recent origin (1985) than are the EAs and the population density data (1981). Secondly, typical residential street patterns are not evident in some large EAs that meet the density criteria. Possible reasons for this are the inclusion within the of what are termed "special EAs". These special EAs are sub-block face

Figure 5.6: Brampton Urban Area and Street Network Overlay

Figure 5.7: Kelowna Urban Area and Street Network Overlay

sized areas such as hospitals, old-age homes, large apartment buildings, etc. Their presence can cause a skewing of the population data in a 'mother' EA that would not meet the criteria. Further implications of these special EAs and the street network files are discussed in the concluding chapter.

Although a delineation based on the street network input will not be undertaken within the context of this study, it is apparent that the streets provide another source of information in situations where the EA is borderline in conforming to the definition criteria. It would also be necessary that the UA definition and the UA delineation criteria allow for the use of this supplementary data source.

5.4.2 Remote Sensing

The procedures used for the classification of the remotely sensed imagery, their conversion and transfer from CCRS to Statistics Canada, and their subsequent processing and formatting for use and output in the GIMMS geographic information and mapping system were described in Chapter 4. The Landsat MSS data selected for use in this study required the following characteristics: (1) the date of imagery had to be as close as possible to the 1981 Census day (June 3); (2) the study sites had to be relatively cloud free; and (3) output had to be in a geocoded format by the Digital Image Correction System (DICS). The selected scene for the Brampton area was imaged on August 19, 1981; the Kelowna scene was imaged on August 13, 1981.

The classified imagery, as discussed in Chapter 4, was generated

from standard classification algorithms and by means of visual interpretation of the urban, commercial and industrial areas. The resulting classifications were judged suitable for transfer by SDTP, and for use as one of the supplemental information sources, on the basis of a rapid visual confirmation. The results of the transfer process, however, have been variable, and the Kelowna classifications have not yet been successfully transferred. Therefore, only the Brampton classifications and transfers will be used to demonstrate the use and application of the remotely sensed data.

Figure 5.8 is a GIMMS thematic map of Brampton using data derived from a visual interpretation and classification of the digital display on the colour screen. This plot is also overlaid with the Brampton enumeration area file. Figure 5.9 depicts a maximum-likelihood classification, also with an EA overlay. Note that the selected scene does not extend to all areas covered by the Brampton AMF; however, most of the urban fringe areas do fall within the scene limits.

A visual evaluation of Figures 5.8 and 5.9 shows considerable promise for the use of classified remotely sensed data as a supplementary data source. The correspondence along many of the linear enumeration area boundaries (which also happen to be roads) are a good indicator of the quality and accuracy of the classifications. The addition of street networks overlaid on the classifications provides another visual check for quality of the data (Figures 5.10 and 5.11). Throughout these maps, the streets are seen to define borders between

Figure 5.8: Manual Classification (Visual Interpretation) from Landsat MSS Data, Brampton, August 1981

Figure 5.9: Maximum-Likelihood Classification from Landsat MSS Data, Brampton, August 1981

urban and non-urban areas; the correspondence between these features provides a further confirmation of the overall classification quality. The following chapters will further discuss the accuracy and application considerations that are required before adoption of classified imagery can be used as an operational information source.

Figure 5.10: Manual Classification and Street Network Overlay

Figure 5.11: Maximum-Likelihood Classification and Street Network Overlay

CHAPTER VI

EVALUATION OF PROCEDURES

6.1 Comparison of Methods

A comparison of delineation methods can be based on an examination of various factors, including an assessment of accuracy, timeliness, speed and cost of the delineations. It is also necessary to analyze other components of the UA delineation process, including a determination of how well the procedures regard the design and intentions of the UA concept. This chapter will discuss these factors, compare the manual and computer-assisted delineations, examine the supplementary data sources (street network files and classified remotely sensed data), and present an overview of the results.

6.2 Accuracy Assessment

The analysis of comparative accuracies of the different approaches and methodologies to delineating urban areas should involve an objective analysis of the resulting delineation products. Normally, such a comparison requires an evaluation against a 'standard', that is, a delineation that is known to be accurate. The standard, in the case of urban area boundaries, should be the delineation as derived from the existing operational delineation techniques. There are, however, many

questions concerning the accuracy of the urban area boundaries that are delineated by the present manual methods. These delineations, therefore, must not be used as the standard. The question concerning what other means are available to assess accuracy of the methodologies still requires further investigation.

One possibility, is to assume that the computer-assisted delineations are accurate and that they represent the best possible result given the restrictive parameters of the UA definition. The evaluation of the delineations will, therefore, compare the manually derived boundaries with the assumed standard, the computer-assisted delineations.

6.2.1 Evaluation of Delineations

Figures 6.1 and 6.2 illustrate urban area delineations as derived from the traditional manual techniques as well as the proposed computer-assisted methodology. It is obvious that the delineations differ in many respects, especially in the size of area classified as urban; in both study sites, the manual delineations are significantly larger. Many EAs have been included in the urban area even though minimum population density criterion has not been reached. Although the enumeration areas are not overlaid on these delineations (in order to better distinguish the two boundaries), analysis reveals instances where the manual delineation cuts through EAs. For example, in an area in the north-western region of Brampton, the manual boundary was based on EAs that were incorrectly transposed from a larger scaled base map; the resulting

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Figure 6.1: Manual and Computer-Assisted Delineations, Brampton, 1981 Data

Figure 6.2: Manual and Computer-Assisted Delineations, Kelowna, 1981 Data

is presented in Kelowna because the 'standard' divides the city into two major population concentrations. This type of situation requires consultation with the UA delineation guide, as discussed in Chapter 5. In this instance, the two kilometre distance rule could be applied in order to create a single concentration (for the computer delineation) because the distance between the closest points in each concentration is under two kilometres. The problem remains as to which EAs should be incorporated in order to derive the single concentration, if, in fact, that is the necessary approach in order to conform to the UA definition. The UA delineation guideline does not adequately resolve this problem.

Figures 6.3 and 6.4 illustrate the population density by EA with the manual delineation of the urban areas also indicated. Many of the problems discussed above are more evident on these maps. Those EAs that were classed as urban, yet have a very low population density, serve to highlight the incompatibility of the urban area definitions and the rules for delineation.

Although not evident in the previous illustrations, the manually delineated urban area boundaries are also prone to various interpretation errors. Furthermore, although only two of the over 900 urban areas have been evaluated, the nature of the problems uncovered in Brampton and Kelowna suggests that many, if not most, of the manual delineations would exhibit similar problems. The errors can be classed as follows:

- 1) Repetitive/historical: delineations that have been duplicated

Figure 6.3: Population Density and Manual Urban Area Delineations, Brampton

Figure 6.4: Population Density and Manual Urban Area Delineation, Kelowna

over ²several census periods. It is the practice of the delineators to examine, if possible, only those enumeration areas which surround the previous UA delineation to determine whether or not they now meet the delineation criteria. Errors created in previous delineations are therefore perpetuated in the more recent boundaries.

- 2) Procedural errors and miscalculations: the routine of extracting statistics from publications, calculating areas by measuring the distance between the farthest points and squaring, and calculating the population density from the first two extractions, is certain to create computational errors. Whether the errors are significant is difficult to ascertain. Certainly, areas that are close to break-points, such as those just under or over the 400 persons per square kilometre threshold, may be incorrectly classified.
- 3) Application of rules: several of the special rules of application, including the 10 kilometre squared rule for partly urban areas, could be misinterpreted or subject to delineation bias. In addition, several of the rules of application seem to be inconsistent with the definition of urban. For example, urban concentrations with a 50 square kilometre area and no farms are automatically considered urban. This rule may override the definition criteria in instances where the concentration would not otherwise be classified as urban. In

addition, the vagueness and different interpretations of these rules contributes to potential inconsistencies in the delineations.

Another check on the accuracy of the two delineations can be performed by adding the street network overlay and analyzing areas of contention. Figures 6.5 and 6.6 help to confirm many of the previously mentioned problems with the manual delineations. For instance, in the area of Brampton where the enumeration areas were incised, the street patterns confirm the computer-assisted version of the delineation. The street networks are very useful in this regard. They provide a timely, accurate source of ancillary information which, when correctly interpreted, assist the delineator in the confirmation and/or resolution of many delineation problems.

6.2.2 Evaluation of Remote Sensing Components

In order to assess the digital classifications, a systematic evaluation should be undertaken to ascertain their relative accuracies. Once again, a source or 'standard' classification is required for an evaluation of each method and to make comparisons. There are several ways to approach this task; a common method involves the creation of a source ('standard') map which is output at the same scale as the delineations being compared. Normally, such a source document is derived from an intensive analysis, perhaps using aerial photographs, ground surveys, or other reliable information. The next step would result in the compilation of a confusion or error matrix where each method is compared to the 'standard' and errors of omission and

Figure 6.5: Urban Area Delineations and Street Networks, Brampton

Figure 6.6: Urban Area Delineations and Street Networks, Kelowna

commission are calculated.

An approach and evaluation, such as that suggested above, is not possible within the context and scope of this study. The remotely sensed data have, nonetheless, application as a supplementary visual information source for use in a manner similar to that of the street networks; a more detailed evaluation will be the focal point of future studies.

6.3 Time and Cost Assessment

Estimates of the time and costs required to effect delineations by manual or computer-assisted means are relatively easy to derive. Time and speed evaluations of each methodology are, however, considerably more difficult to compare. Contributing factors include:

- 1) The UA manual delineations are an established procedure which, in turn, are only a part of a much larger geostatistical delineation process; therefore, many of the preliminary operations (such as producing the enumeration area maps) are not included as part of the UA delineation procedure.
- 2) Time estimates for the manual procedure are very general and account only for the total elapsed time; the individual production steps are not adequately accounted for. Unlike the manual process, the computer-assisted delineations time each program to the second, if desired. It is expected that the elapsed times will be greater in the automated approach because

the acquisition of basic materials (such as EA boundaries via the extraction process) should be included in the estimates. In a true production environment, however, the EA files would already reside in the data base. Subsequently, the elapsed time associated with these extractions would be substantially reduced or eliminated.

- 3) Processing time (and costs) in an automated system are variable depending on the time of day, number of computer users and, of course, the nature of the processing (including size of area, complexity of the digital boundaries and complexity and number of calculations).
- 4) In the computer-assisted process, longer elapsed times are anticipated, but the actual processing time might only be a fraction of the elapsed time requirements.

Therefore, in order to make reliable time comparisons, several parameters will be eliminated from the estimates: (1) the calculated times do not include the organization and acquisition of materials for the manual procedure; (2) the automated process will not take into account the elapsed time required for EA boundary and data extraction; and (3) the administrative details, such as completion of various forms, are not included for either process.

The estimates in Table 6.1 were derived in the following manner: (1) a manual re-delineation of the Brampton and Kelowna test sites was performed, and timed, by an experienced member of the urban area

MANUAL DELINEATIONS

- 1) locate area
- 2) copy old UA delineation
- 3) locate and identify EAs
- 4) calculate area and population density
- 5) delineate new boundary

SUB-TOTALS

Brampton 90 minutes (personnel)
= \$22.50

Kelowna 50 minutes (personnel)
= \$12.50

TOTALS

= \$35.00

COMPUTER-ASSISTED DELINEATIONS

- 1) run CRAMAL and CRSORT
10 minutes, \$2.50
- 2) run CRAREA
5 minutes, \$1.50
- 3) run CRPOPDEN
3 minutes, \$2.00
- 4) run CRMAP
3 minutes, \$2.00
- 5) plot on Versatec plotter
2 minutes, \$3.00

SUB-TOTALS

Brampton 23 minutes (processing)
= \$11.00
20 minutes (personnel)
= \$5.00

Kelowna 23 minutes (processing)
= \$11.00
20 minutes (personnel)
= \$5.00

TOTALS

= \$32.00

-
- Notes:
- 1) personnel time calculated at \$15.00 per hour
  - 2) setup and material costs for the manual delineations were not considered (i.e., mylar EA maps); as well, the elapsed time and data extraction costs for the computer-assisted delineations were not included (i.e., CGMF EA and population data)
  - 3) all times and dollar values are approximations (rounded-up) based upon current interactive computer processing charges
-

Table 6.1: Summary of Approximate Time and Costs to Delineate the Urban Area Boundaries for Brampton and Kelowna

delineation team; (2) the computer-assisted delineations were derived from standard command files created, submitted and monitored by the author.

As stated earlier, the time estimates for the manual process are only general approximations. These estimations will, of course, vary from delineation to delineation. Though many factors affect the time estimates, the size of the urban concentration and the number of EAs are the major determinants in either delineation method. A time analysis of a manual procedure should also take into account the biases introduced by the individual performing the task. Factors such as training, experience and abilities will influence the outcome, especially when the delineation area is more complex. Error rates can also be expected to increase in a manual process when the number of individual calculations is increased, for example when estimating EA area or performing population density calculations. In a computer-assisted process, complexity may add to processing time, but the likelihood of error is no greater than for a simple process, assuming that the program logic and data files are error-free.

The costs are calculated by simply multiplying the personnel or machine time by the applicable rate. It is assumed that the same manpower level and category could carry out either delineation technique. Based on these charges, the costs associated with the two delineation methods are comparable.

6.4 Analysis of Results

The computer-assisted delineation of urban areas should be utilized wherever and whenever possible. Given the current urban area definition and delineation criteria, these trial delineations are accurate and consistent in their application. The time and cost efficiency of the automated process appears to be comparable between the two methodologies. Timeliness, although mentioned at the start of this chapter, does not enter into the delineations until supplementary information, such as street networks or remotely sensed data, is added. With appropriate planning and the development of a digital EA data base, many of the up-front costs associated with the computer-assisted process would be eliminated. The per UA delineation cost would subsequently be less than the current manual delineation costs. Perhaps the issue of cost/benefit is best summarized with the asking of a question: what, if any, price is too high for ensuring accuracy and consistency?

CHAPTER VII

CONCLUSIONS

7.1 Summary

Three major research objectives were identified at the beginning of this report. With reference to those objectives, this study has demonstrated the following:

- 1) Computer-assisted mapping methodologies can be effectively used to delineate urban areas.
- 2) The Standard Data Transfer Format and related system developments and methodologies are a viable transfer mechanism for the inter-agency exchange of spatial polygon data.
- 3) Remotely sensed data have application as a timely, supplementary data source.

The computer-assisted mapping methodologies produced accurate, consistent, quick-to-execute, and cost-effective urban area delineations. The manual delineations, however, were shown to be inconsistent in quality and application of delineation criteria. The reference guidelines prepared for the delineation process have a number of contradictions and inconsistencies with respect to the census urban area definition. A re-writing of the delineation criteria is required

to both improve the quality of the manual delineations and to provide a document that works equally well for the automated approach.

A number of new developments, as well as the integration of existing techniques, were implemented and incorporated into the methodologies. Perhaps the most important was the integration of the various digital data files which are resident on different data bases, which in turn, are located on different computers. For example, the CGMF data base provided the EA boundary descriptions and the statistical population data. These files were then extracted, transferred to another computer, formatted, processed and output as overlay population density maps. As well, the results obtained from using Area Master File street networks demonstrate considerable promise for use in the urban area delineation process, as well as for other applications.

Most of the remote sensing components and developments are associated with the transfer mechanisms of the Standard Data Transfer Format. Although a number of technical problems were encountered, the classification of image data is, nonetheless, potentially an important tool for use in the delineation process. The forthcoming version of the SDTF software at CCRS should resolve the technical problems so that more substantial cooperative research projects can be undertaken.

In an operational context, the computer-assisted delineation developments are ready and available for further, more comprehensive testing. A volume production test would be an appropriate next step. The system components include documented procedures and instructions and

a series of ready-to-use command files that, with minimal additional effort, can be further integrated into a 'user-friendly' prompt-and-reply production system. Several caveats, however, must be mentioned: (1) the proposed automated system is applicable only to urban concentrations that have digital EA coverage (AMF areas); (2) that the census urban area definition remains a statistical type based upon population densities or similar numerical manipulations; (3) that delineation guidelines conform to both the UA definition and the urban area concept, and are structured in a manner suitable for any delineation technique (manual and/or automated); and (4) that a better methodology be developed to handle 'special' EAs (the provision of a digital description for all EAs, which is preferred, or else an automatic system to aggregate the population data of the 'special' EAs with their 'mother' EAs).

This study should be viewed as a first attempt to introduce automated techniques for the delineation of urban areas. Several avenues are possible given the present state of technology and the likelihood of several new developments. Specific recommendations related to the adoption of the proposed techniques are offered below, as are suggested future directions for related research projects.

7.2 Recommendations for Future Research

These recommendations are presented with the assumption that an automated urban area delineation process is preferable, where appropriate, to the traditional techniques, and that the automated system is based on existing, or soon to be available, technologies and

developments within Statistics Canada. Furthermore, the medium-term objective is to incorporate automated techniques, where possible, into the urban area delineation process that will be used for the 1991 Census. The recommendations are summarized below:

- 1) Resources should be allocated for the volume production testing of the computer-assisted delineation process. Although the delineations for the 1986 Census are complete, the proposed techniques should be volume tested using the 1986 delineation data to ensure that operational problems can be resolved before the 1991 Census production begins.
- 2) An extensive review of the urban area concept, definition and delineation criteria ought to be undertaken. With the U.S. Bureau of the Census undergoing a similar process, and considering the developmental efforts of the TIGER system, close cooperation and sharing of information with appropriate U.S. colleagues is desirable.
- 3) A review of the base delineation unit (i.e., the enumeration area) is necessary. The notion of extending digital EA coverage to the whole of the country, the provision of digital descriptions for all EAs (elimination of 'specials'), and the potential establishment of a permanent EA or similarly sized unit should be reviewed.
- 4) Continue the testing of applications of remote sensing to the

delineation of urban areas. The evaluation should utilize the recently acquired Statistics Canada Aries III image analysis system, rather than the CCRS system. The utilization of higher resolution satellite data, such as TM and SPOT, could provide more accurate and reliable classifications of urban area land-use (Anuta, et al, 1984; Colwell and Poulton, 1985; Dolan, Martin and Warnick, 1985; Schmidt and Naugle, 1985; and, Toll, 1984). As well, an examination of change detection procedures and applications could further increase the use and efficiency of the image data (Angelici, Nevin and Friedman, 1977; Christenson, et al, 1979; Estes, Stow and Jensen, 1982; Howarth and Wickware, 1981; Howarth and Boasson, 1983; Jensen, 1981; Jensen and Toll, 1981; Maxwell and Riordan, 1980; Riordan, 1980; and Toll, Royal and Davis, 1984). As analysis procedures are adopted for the UA delineation process, more sophisticated and automated techniques should be investigated, including: classification methodologies; the use of masks for large, densely populated urban areas; and, the integration of digital cartographic data files as overlays on the Aries image data display. The base information and data derived for the Brampton and Kelowna study sites can be incorporated into the design of such studies. Comparisons with a visual system, such as Procom, could also be investigated to determine what benefits are derived from a non-digital data source in a computer-assisted mapping and analysis environment.

- 5) There will always be the requirement to exchange data among various users and between systems; therefore, it is desirable to continue testing and evaluating the data transfer process. A recently updated version of the Standard Data Transfer Format software is now available for testing. These SDTF developments will permit the exchange of data amongst a number of systems including the CIAS, ARIES, GIMMS, ARC/INFO, and Intergraph.
- 6) Investigate the feasibility of Canada-wide street network coverage (AMF). Any study of this nature would have to look at the much larger implications of using blocks and block faces as the collection unit, in addition to expansion of coverage to all urban and rural areas.
- 7) For significant reductions in data acquisition timeframes and better inter-file compatibility, consideration must be given to amalgamation of the files on a common computer, preferably the same processor that networks the geographic information and Aries systems. The files could be controlled from a cartographic library similar to the existing CARTLIB digital data file library or the CGMF data base. This development is necessary for all digital geostatistical units including enumeration areas.

APPENDIX 1: Overview of Flows and Methodology for Transferring Street Networks

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