DEVELOPMENT OF AN URBAN LAND INFORMATION BASE FROM DIGITAL SATELLITE IMAGERY

Pilot Study

of the

Ottawa-Hull Census Metropolitan Area

Spatial Analysis and Geomatics Applications
Agriculture Division
Statistics Canada

and

State of the Environment Reporting
Environment Canada

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EXECUTIVE SUMMARY

Some of the most actively changing areas in Canada are located in and around heavily populated urban regions. Monitoring of land-use change in these areas is essential to reporting on the state of Canada's environment and for sound resource management. Informed decisions concerning the use and protection of Canada's environment can only be made with the benefit of credible, consistent and compatible time-series data and indicators based on land-use.

The *State of Canada's Environment* report revealed a lack of nationally consistent and up-to-date land-use statistics for the built-up portion (core urban area) of Canada's urban centres. Green space data (especially wooded) areas were also singled out as an information gap. Although many municipalities collect land-use (land-activity and land-cover) data, the information varies in coverage, time period, classification used and method of storage, and thus cannot be aggregated or compared. Information derived from high-resolution digital remotely-sensed satellite imagery can help to fill some of these data gaps.

It was agreed that Statistics Canada and Environment Canada would participate in a pilot study to analyze imagery with the aim to develop a standardized, nationally consistent approach to gathering land-use information. The Ottawa-Hull Census Metropolitan Area (CMA) was selected as the pilot study region. This centre was chosen because of its close proximity for conducting field work if necessary, the 'local knowledge' of the region, and because of the availability of additional historical imagery and ancillary information.

The primary 1991 data source is Landsat TM digital satellite imagery which covers all of the Ottawa-Hull CMA. To determine the land-use change between 1986 and 1991 it was necessary to have a 1986 reference base-year. The project team agreed that 1986 Canada Land Use Monitoring Program (CLUMP) files for the Ottawa-Hull urban area would be used for the base-year.

The methodological objectives were to 1) use the digital satellite imagery as the primary source to derive 1991 urban land classes, 2) relate this information to 1986 CLUMP data, and 3) develop a methodology that could be applied operationally to other CMAs. The end-to-end digital processing was to be as automated and objective as possible. Broad land-activity and land-cover classes were defined and delineation decision rules for their classification were established. These classes are:

Land-Activity
- Residential
- Commercial / Industrial / Institutional
- Transportation / Communications
- Recreation
- Other / Unknown

Land-Cover
- Water
- Wooded Vegetation
- Non-Wooded Vegetation
- Non-Vegetated Surfaces

A series of statistical tables and maps were produced to display examples of the results and potential applications for the derived data. The information were produced at a city level for Ottawa (Census Subdivision), for the Ottawa-Hull Urban Area and for the Census Metropolitan Area of Ottawa-Hull.

The pilot study concludes that:

1) Development of an urban land information base from digital remotely-sensed satellite imagery is practical and feasible;

2) Urban land information generated from remotely sensed imagery has proven to be reasonably accurate;

3) The urban land-activity and land-cover information generated from remote sensing for the Ottawa-Hull pilot study, including rural-urban land conversion information, fills an important data gap in state of the environment reporting information;

4) Urban land information generated from an end-to-end digital process has many advantages for further applications. Transfer of the spatial data between GIS systems, such as ESRI ARC/INFO and Intera-Tydac SPANS, can pose technical problems that have to be resolved;

5) The linkage of urban land information based on remote sensing to earlier land-activity and land-cover information generated from fieldwork and airphoto interpretation, through the CLUMP program, has proven feasible and will facilitate trend analysis of land-use change;

6) The urban land information generated in the Ottawa-Hull pilot study has the potential for many diverse analytical and reporting applications by both national and local agencies. The information can be used for the development of environmental indicators and in state of the environment reporting.

7) The development of a national urban land information base, should prove to be reasonably cost-effective in comparison to: (1) previous urban land data collection based on a different process and technology; and, (2) similar kinds of data monitoring based on remote sensing. Nevertheless, development of the data base will be relatively costly and requires careful consideration; and,

8) Innovative, multi-agency partnerships will likely be necessary to ensure continuation of the development of a national urban land information base over both the near-term and the long-term, and to maximize the use of this information base. Options for implementation will have to be developed and explored.

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ACKNOWLEDGEMENTS

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DEVELOPMENT OF AN URBAN LAND INFORMATION BASE FROM DIGITAL SATELLITE IMAGERY

Pilot Study of the Ottawa-Hull Census Metropolitan Area

1. INTRODUCTION

Urban Land Change In Canada

Some of the most actively changing areas in Canada are located in and around heavily populated urban regions. Monitoring of land-use change in these areas is essential to reporting on the state of Canada's environment and for sound resource management. Informed decisions concerning the use and protection of Canada's environment can only be made with the benefit of credible, consistent and compatible time-series data and indicators based on land-use.

In the past, land monitoring activities in Canada were initiated when time-series data were required to meet specific objectives. The Canada Land Use Monitoring Program (CLUMP) was established in 1978 by the Lands Directorate of Environment Canada. CLUMP provided statistical and geographic information on the amount, type and location of land-use change enabling assessments of the significance of this change from national and sustainable resource perspectives. A key operational aspect of the CLUMP program was the collection and analysis of data on the conversion of rural land to urban use (1966-1986) at 5 year intervals for 70 urban centred regions of 25,000 population or more. Since Lands Directorate was disbanded in 1988, this rural-urban land conversion database has not been updated. Nevertheless, monitoring of land-use change is important for current program needs and an opportunity therefore exists to build on this data for future monitoring and reporting.

Environmental reporting is a major objective of Canada's Green Plan. The *State of Canada's Environment* report (1991) discussed the urbanization of rural land and featured the rural-urban conversion statistics (to 1986) in the Land, Urban and Agriculture chapters. The *Report on Canada's Progress Towards a National Set of Environmental Indicators* (1991) contained an urbanization indicator based on the same rural to urban land conversion database (to 1986). This particular indicator has evoked strong interest from many groups. Therefore, there is a need and an interest to maintain rural to urban land-use monitoring in an accurate and cost-effective way.

Data Gaps - The Urban Environment

The *State of Canada's Environment* report revealed a lack of nationally consistent and up-to-date land-use statistics for the built-up portion (core urban area) of Canada's urban centres. Green space data (especially treed) areas were also singled out as an information gap. Although many municipalities collect land-use (land-activity and land-cover) data, the information varies in coverage, time period, classification used and method of storage, and thus cannot be aggregated or compared.

Information derived from remote sensing can help fill certain data gaps. Remotely sensed data can provide standardized, timely and relatively inexpensive information on land-use and land-use change. A recent report, *Remotely Sensed Data for Environmental Reporting* (Intera, 1992) completed on behalf of Environment Canada and Statistics Canada, indicates that remotely sensed data can provide i) information for various Environment Canada and Statistics Canada (STC) environmental reporting activities, and ii) options for filling some data gaps, particularly those related to agriculture and forestry.

Project Goals And Objectives

A 1986 Memorandum of Understanding states that "Environment Canada and Statistics Canada have the primary responsibility for developing the State of the Environment Reporting System for the Government of Canada". In January 1992, Spatial Analysis and Geomatics Applications (SAGA) in the Agriculture Division, Statistics Canada and State of the Environment Reporting (SOER), Environment Canada, signed a letter of agreement for the development of authoritative national information relating to the state of urban and urban-rural fringe environments. To take advantage of the 5-year census cycle (as did CLUMP) and the ensuing datasets, SOER provided funding for SAGA to acquire high-resolution 1991 digital satellite imagery for the major Census Metropolitan Areas (CMAs) in Canada. It was agreed that SAGA and SOER would participate in a pilot study to analyze imagery with the aim to develop a standardized, nationally consistent approach to gathering land-use information.

A pilot study for a selected Census Metropolitan Area (CMA), proposed to:

- develop and assess 1991 satellite imagery compatibility with 1986 CLUMP data;
- develop and assess a standardized image classification methodology;
- compare, where possible, the accuracy, timeliness and costs of the methodology to that of the CLUMP program;
- evaluate the applicability of the methodology for other CMAs; and,
- prepare resource estimates for applying the methodology to other CMAs to monitor land-use change in Canada's major urban areas cyclically over five year intervals.

The pilot study will produce various statistics and map products of land-use and land-use change in the CMA, including:

- a quantification of the amount and distribution of land-activity and land-cover for 1991;
- a quantification of the amount and distribution of rural to urban land-use change between 1986 and 1991;
- development of a methodology and measures of urban green space.

2. METHODOLOGY

Study Area

The Ottawa-Hull Census Metropolitan Area (CMA) was selected as the pilot study region (see Map 1). This centre was chosen because of its close proximity for conducting field work if necessary, the 'local knowledge' of the region, and because of the availability of additional historical imagery and ancillary information. In addition, Ottawa-Hull has many characteristics that provide a challenging test of the methodology: relatively high-growth areas, diverse land-activity, varied land-cover and many layers of governmental jurisdiction. The layers of governmental jurisdiction have another advantage in that they are potential sources of data for verification and, in the longer term, potential users of the outputs from this study.

Data Sources

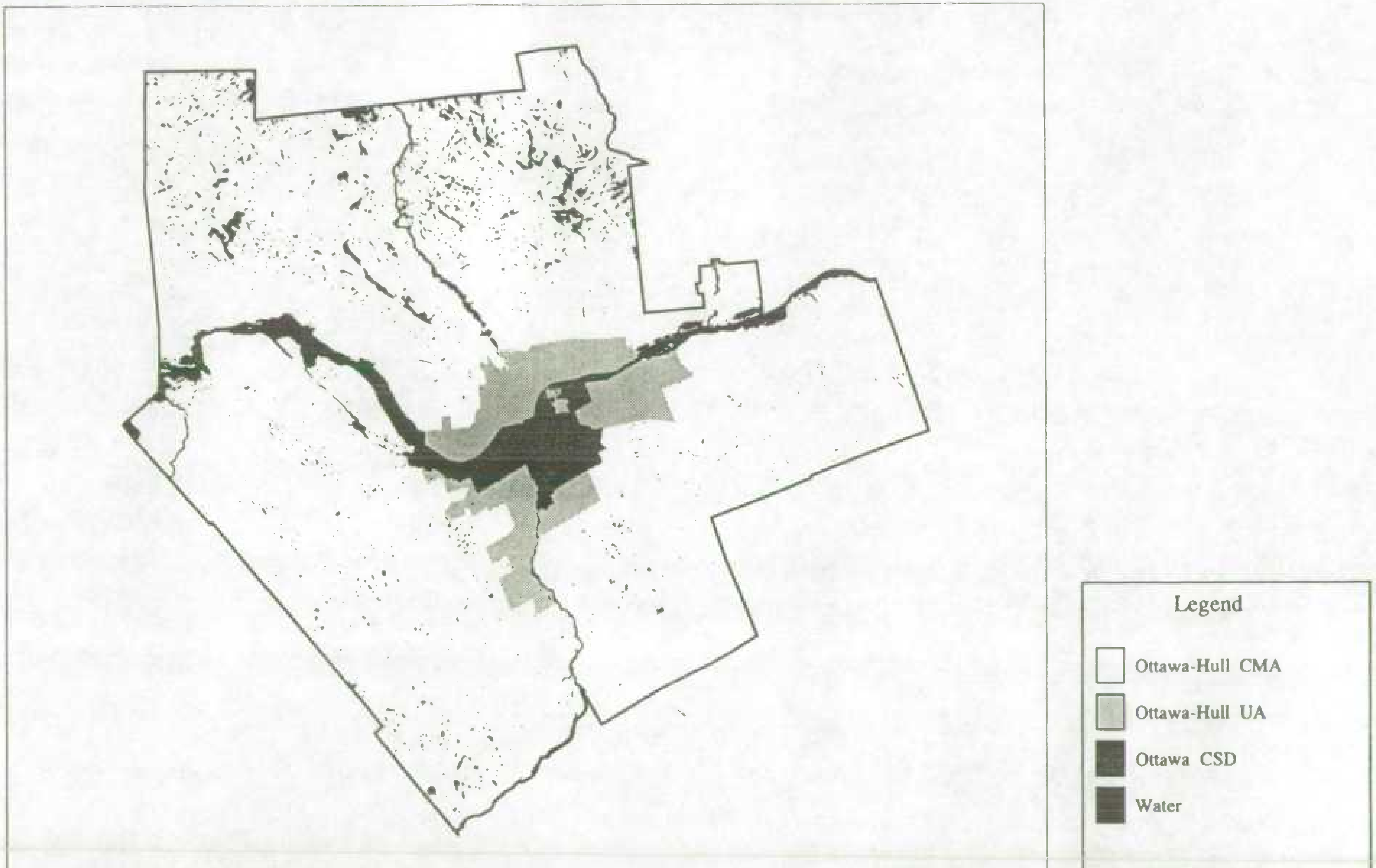
The primary 1991 data source is Landsat TM digital satellite imagery, bands 3, 4 and 5, acquired on May 18, 1991 (see Map 2). The full Landsat scene (Track 16, Frame 28) covers all of the Ottawa-Hull CMA.

Before acquiring any imagery for the land-use change program, SAGA conducted a study to determine the optimal geometric and radiometric properties required to achieve the objectives of a national land-use monitoring program. As satellite data acquisition costs are a major factor, consideration had to be given to the cost/benefit of using 3-band versus 7-band Landsat TM data. Additionally, the trade-offs of using the lower-resolution/larger areal coverage of Landsat TM multi-spectral imagery (30 metre resolution and 185 km^2 coverage) versus SPOT imagery with higher-resolution/smaller areal coverage (20 metre resolution and 60 km^2 coverage) had to be factored. The evaluation concluded that Landsat TM bands 3, 4 and 5 provided the best combination of geometric resolution and radiometric information at the lowest cost for the large CMA areas and the land-use information required for the proposed program.

To determine the change between 1986 and 1991 it was necessary to have a 'best' source of data for the 1986 base-year. The project team agreed that 1986 CLUMP files for the Ottawa-Hull urban area would be used for the base-year. SOER has maintained the historical CLUMP databases that now reside in the Canadian Geographic Information System (CGIS).

Several other sources of ancillary data were available to assist in the classification process of the 1991 satellite imagery. These included 1:50 000 NTS maps, digital geostatistical boundary files (Census Metropolitan Areas, Urban Areas, Census Sub-Divisions, and Enumeration Areas), various name correspondence and aggregation files from Statistics Canada, and an urban road and street name map published by Allmaps Canada Ltd.

Map 1: 1991 Study Region, Ottawa-Hull Census Metropolitan Area



Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Map 2: Landsat Satellite Image, City of Ottawa

Source: Landsat TM
Satellite Image
May 18, 1991

Legend
Ottawa CSD Boundary

Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Methodological Overview

The methodology was jointly developed by SAGA and SOER. It was determined that the pilot study could be broken into a number of component steps and phases, several of which could be conducted concurrently. The methodological objectives were to 1) use the digital satellite imagery as the primary source to derive 1991 urban land classes, 2) relate this information to 1986 CLUMP data, and 3) develop a methodology that could be applied operationally to other CMAs. The end-to-end digital processing was to be as automated and objective as possible.

The primary processing was conducted at Statistics Canada using the SAGA image analysis and geographic information processing facilities. Preparation of the 1986 CLUMP files was completed by SOER using an Intera-Tydac SPANS geographic information system.

The first step was to obtain the required digital datasets and integrate the data into the SAGA spatial analysis systems. Depending on the source of the data and the type of pre-processing required, the data were imported either into the PCI EASI/PACE image analysis system or the ESRI ARC/INFO geographic information system. The Landsat data and the CLUMP files were processed in the PCI environment, while the geostatistical files were processed using ARC/INFO. All data were eventually transferred into ARC/INFO where the database was maintained and spatial and statistical analysis performed.

Two approaches to image classification were developed. The land-cover classes were obtained primarily using automated digital classification techniques, while the land-activity classes were based on visual interpretation of the imagery.

Urban Land Classes

Considerable discussion was given to determining the appropriate classes that could be realistically obtained from the satellite imagery. The limitations of the data source had to be balanced with the needs and requirements planned by the SOER end-users. As well, consideration had to be given to requirements that might not have been identified at this stage and to anticipate other potential applications for the data. For example, there are many other potential users of the database including federal departments and agencies, provincial departments, municipal governments, researchers and consultants.

The SOER team determined the broad land-activity and land-cover classes required for their immediate needs. Essentially, there are two separate classifications for the Ottawa-Hull CMA. These classes and their definitions are listed below. See Appendix A for more detail on the aggregated CLUMP classes and their conversions.

1. Land-Activity

   - Residential (including rural residential estates and rural villages)
     Includes all land where dwelling occurs either as a permanent, as a temporary, or as a seasonal activity. This includes houses, apartments, rural estate development, rural villages, trailer parks, cottages and retirement homes. This class also

includes road networks and municipal parks contained within these activity areas except as defined in the Transportation and Communications class.

- Commercial / Industrial / Institutional
  Includes industrial uses (including pits and quarries), commercial stores, offices, restaurants, etc., manufacturing, storage, waste treatment and disposal sites (eg. sewage lagoon), institutional sites. This class also includes road networks contained within these activity areas except as defined in the Transportation and Communications class.

- Transportation / Communications
  Includes major facilities only such as freeways, airports, railways, harbours and hydro stations.

- Recreation
  Includes golf courses, provincial and federal parks.

- Other / Unknown
  Includes any activity not defined by the above classes. Some major examples are agriculture and forestry. Also includes land that has no perceived activity.

2. Land-Cover

- Water
  Includes lakes, rivers, canals, open reservoirs, water in sewage lagoons and other artificial water surfaces.

- Wooded Vegetation
  Includes areas dominated by dense, mature and immature woody vegetation. Includes deciduous, coniferous and mixed forest, and orchards of sufficient density. May include some shrub area.

- Non-Wooded Vegetation
  Includes all other non-wooded vegetation, grasses, sedges, reeds, mosses, lichens and other non-woody plants and cultivated crops. May include some shrub areas. Agricultural fields (both cropped and bare) and urban parks are included.

- Non-Vegetated Surfaces
  Includes rock, paved, concrete, snow and ice and any other non-vegetated surface, except bare agricultural fields and water.

Decision Rules

After considerable testing, SOER and SAGA agreed that the above classes were feasible and achievable in the context of the pilot study. This was an iterative process resulting in the following observations and decision rules:

Land-Activity

- A single land-activity polygon could have one or more, or all, land-cover classes associated with it;

- The 1986 CLUMP file was considered the 'master' source. Therefore, errors in that coverage were not corrected in order to ensure that the change statistics do not indicate 'false' change.

- Residential areas under development, for example where only the street networks exist, were classified as residential;

- Rural villages have been classified as entirely residential even though a small number of other land-activities are sometimes located there as well. Although every effort has been made to do so, it is quite likely that some rural residential estate areas have not been captured in the classification;

- There was a need to combine commercial, industrial and institutional activities into one land-activity class since these activities are difficult to distinguish separately using remotely sensed imagery;

- Extraction activities have been included in the industrial, institutional and commercial class.

Land-Cover

- With the wide variety of land-covers involved, wetlands cannot be reliably identified using an automated classification process and is therefore not shown as a separate class. Wetlands may be found in the forest, vegetation and water classes;

- Many agricultural fields did not have discernable vegetation cover because of the early date of the imagery (May 18). These bare soil fields were nonetheless classified as having vegetation;

- Due to the wide variety of land-covers, agricultural activities cannot be individually distinguished using automated classification. As a result, agricultural activities are included in the 'Non-Wooded Vegetation' class.

- The 'Non-Vegetated Surfaces' classification includes covers such as urban residential areas (except those with large tracts of land between the houses such as found in rural estate developments), commercial areas, gravel pits, and concrete and asphalt cover (roads, urban cores);

- Any land-activity can be combined with any vegetated surface (wooded or non-wooded), within the urban core areas, to equal "green space";

- Areas of one pixel (30m X 30m) were reassigned to the closest dominant class.

3. SPATIAL PROCESSING

Image Analysis

The Landsat imagery were loaded onto the PCI image analysis system that is hosted by a dedicated HP 720 Unix workstation with a 24-bit colour display and graphics accelerator. Routine pre-processing procedures were performed including UTM correction and image enhancement. Enhancements are done to sharpen the image, provide better contrast between features of interest, and to reduce atmospheric effects such as localized haze. Some of the geostatistical boundary files were also loaded into PCI in order to provide overlay and classification limits for the various municipalities in the study region. As discussed in a following section on Data Integration and Geographic Information Processing, it was found necessary to subdivide the imagery into smaller parts for the ARC/INFO GIS integration processing.

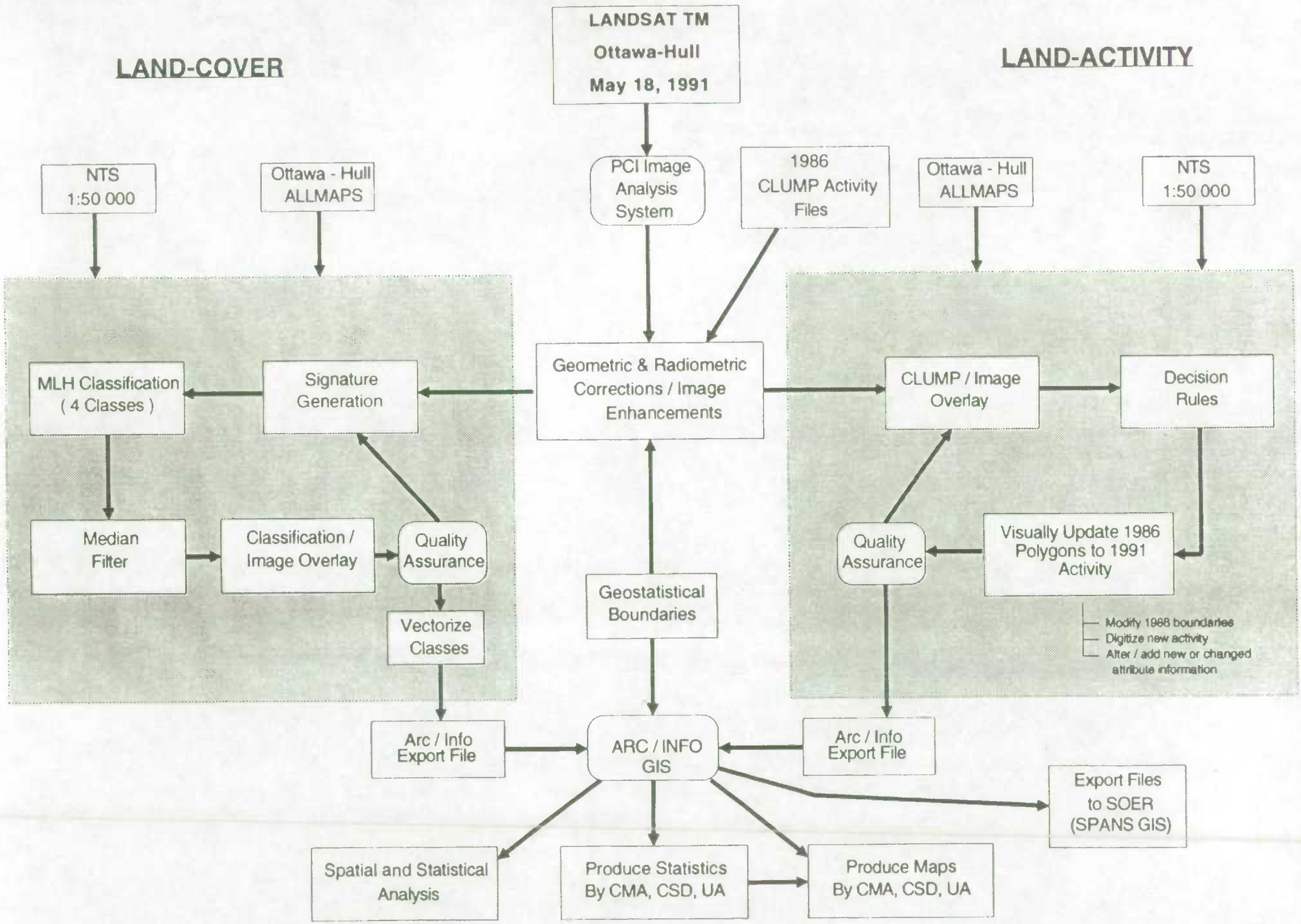
The 1986 CLUMP base files were also processed using the PCI image analysis system. These files originated in the SOER Intera/Tydac SPANS GIS. The variables required for this study were extracted by the SOER, projected to UTM output in PCI format and copied to high-density diskettes using compression software. In the SAGA facilities, the files were decompressed and loaded on to the PCI system. Although these data were in the UTM projection, the correct coordinate information was not associated with each pixel. A procedure had to be developed to calculate the correct line/pixel coordinates to offset the CLUMP files so that they would overlay precisely on the imagery. As the SPANS files are in a raster format, the pixel 'grey' values had to be associated with the land-activity classes.

The classification of the imagery was based on the two approaches previously mentioned: automated classification for the land-cover and visual classification for the land-activity classes. Figure 1 provides a summary of the major spatial processing steps.

Land-Activity Classification

The approach to generate the land-activity classes was largely a visual process. The methodology requires a 'best available' base source which is used to determine the change between the 1991 imagery and that base source. It was determined that the 1986 CLUMP data would be the base source for this demonstration project. A 1991 Ottawa-Hull and environs road and street name map, from Allmaps Canada Ltd., was also used as a reference source for the urbanized areas. The CLUMP polygons were displayed over top of the enhanced 1991 Landsat imagery. As mentioned earlier, one of the important working assumptions was that the 1986 land-activity boundaries were considered correct, unless a major error was noted and verified from other external sources.

Figure 1: Summary of Major Spatial Processing Steps



The classification procedure requires that the analyst divide the CMA into much smaller working units. For each of these subdivided areas the analyst decides if any polygons from the 1986 land-activity classes appear to have a different activity. Using the NTS and Allmaps maps as additional reference information, it is determined what the 1991 activity should be. The 1986 polygons are then updated by outlining the area of change using an on-screen manual digitizing program with the imagery displayed as a backdrop on the monitor. In effect, a digital copy of the 1986 activity classes is updated to produce the 1991 classes.

The above procedure works well in the urban areas and rural areas where there are 1986 activity data. The 1991 Ottawa-Hull CMA is larger than the area classed in 1986. Therefore, for those new regions, the land-activity had to be determined solely from visual analysis of the 1991 imagery and all classes were newly generated. This land-activity classification will form a 1991 baseline from which future change may be monitored.

There were several questions and concerns that arose in the course of classifying the imagery. For example, in the 1986 CLUMP file, Gatineau Park was classified as recreation. This land-activity class could not be extended to the 1991 CMA limits because of uncertainty of the park boundaries. Therefore, the CSDs that contain parts of Gatineau Park do not have a recreation activity and were therefore classified as 'Other / Unknown'.

This visual approach requires significant image interpretation skills. Steps, such as the decision rules mentioned earlier, were taken to make the process as objective as possible. Nonetheless, it is recognized that two image analysts could produce slightly different interpretations. Consistency in the decision-making process and application of the decision rules is very important. It should also be noted that quality image interpretation requires considerable knowledge of digital image processing and enhancement, visual image analysis and extreme attention to detail.

After the entire CMA is updated, the file is output in ARC/INFO format. There is a restriction in the PCI to ARC/INFO output format, in that the type and amount of attribute information is limited to one variable per polygon. For the purpose of this study, the most important variable was the land-activity.

Land-Cover Classification

The methodology to derive the land-cover classes is based on the standard supervised maximum-likelihood classification algorithm. This approach requires accurate ground-truth information to create representative signature files for each land-type being classified. The most recent 1:50 000 NTS maps and the 1991 Allmaps map, along with visual interpretation of obvious features, were used for this purpose.

Some features, such as water and forest, are relatively easy to classify. Other features, especially vegetated surfaces, are quite complex because of the number of different types of vegetated surfaces that exist in an area as large as Ottawa-Hull. Over 20 separate spectral signatures had to be created in this instance. The vegetated surfaces include a wide range of crops, short cut grass, open natural and abandoned fields, and grasses and crops in many stages of growth.

The maximum-likelihood classification can produce many small, spurious polygons. For the forest and vegetated surfaces, a post-classification 3 X 3 median filter was applied to generate larger contiguous areas. The resulting classes were then merged and overlaid on the imagery to verify the classification accuracy. The entire process, including regeneration of the signature files, may be repeated several times for complex feature classes.

The classified pixels, in raster format, are assigned to the land-cover classes and the polygon outlines are vectorized. The final step is to output the classified files in a format that can be imported into ARC/INFO. Once again, care must be taken when producing the output files because of the limitations in the type and amount of information that can be carried over as attribute data. This attribute was the assigned land-cover class.

Data Integration and Geographic Information Processing

The ARC/INFO geographic information system was used to integrate the various datasets. The SAGA ARC/INFO licenses reside on dedicated networked Unix workstations including SUN Sparc 2s and an HP 720. In the ARC/INFO environment, the datasets were projected to UTM and manipulated so that the data, generated with different resolutions, could be used transparently for the spatial analysis and statistics generation.

Many problems were encountered in trying to create ARC/INFO coverages from the extremely large image classifications. Currently, ARC/INFO has a limitation in that a polygon cannot have more than 10,000 arcs. In a vector file generated from a complex raster classification, such as the forest classification, it is easy to have many times that number of arcs in a polygon. This limitation caused considerable problems in trying to bring in the forest classification. After many attempts and consultations, it was determined that the best way to get around this problem would be to cut the PCI classification into smaller areas. This method had time and cost implications which were considered before implementation. The Census Subdivision (CSD) file was used to generate these coverages that were then brought into ARC/INFO. It should be noted that the forest classification alone, for example, required over 80 megabytes of disk space and could take over 10 hours to process using a dedicated Sun workstation! So the trial-and-error process was quite time-consuming.

After creating the topologically correct ARC/INFO files, the data were organized into two coverages, land-activity and land-cover.

Spatial Analysis and Statistics Generation

One of the goals of the pilot project was to setup the spatial database so that the process of generating detailed statistics or performing spatial queries could be accomplished without complex programming or the need to have an ARC/INFO expert do the work. To this end, it was decided to use a related ARC/INFO product, called ArcView, to provide a spatial 'window' into the database. ArcView allows a user, with minimal training, to perform relatively complex queries of these data. The ArcView software is available for many computer platforms including PCs and Unix workstations. SAGA currently has both a Sun version and a PC version residing

on a 486 level PC. Demos using this software have been created and many of the following examples were generated using this system.

Although the ArcView front-end to the database is relatively easy to use, the back-end setup and ARC/INFO manipulation are very complex. The size of the datasets, combined with the number of classes and many potential units for analysis all combine and add to the complexity. The ARC/INFO Macro Language (AML) was used to create programs to perform the initial data integration, data extractions and statistics generation.

Both the land-activity and the land-cover statistics were calculated using three geostatistical boundary files: i) Census Metropolitan Area (CMA) of Ottawa-Hull ii) Urban Areas (UAs), and, iii) Census Subdivisions (CSDs). The Geography Division at Statistics Canada delineates these boundaries using standardized criteria. Geography Division is also responsible for digitizing and maintaining the ARC/INFO digital versions of these boundaries. There are 23 CSDs and 5 UAs within the Ottawa-Hull CMA.

It should be noted that the CSD and UA published areas (Statistics Canada, 1993) differ somewhat from the areas calculated for this study. There are likely several reasons for these differences: i) the published area estimates were derived manually by tracing the outlines of the boundaries; and, ii) the published estimates exclude all water bodies. The statistics generated in this study include water and are precisely calculated by the ARC/INFO software.

Two main ARC/INFO coverages were created for use in the statistics and analysis process:

1) The first coverage contains the 1986 and 1991 land-activity information only. This coverage is used to calculate land-activity change. Errors in the original CLUMP file were not corrected in order to prevent 'false change' statistics. It is important to note that these errors were usually small and infrequent. Also, this coverage only includes information based on the 1986 boundaries which were much smaller in area than the 1991 Ottawa-Hull CMA. Nevertheless, the 1986 boundaries include the contiguous built-up urban area and the adjacent rural-urban fringe where much of the change occurs. Some rural residential estate developments that were more distant from the built-up area were possibly missed.

2) The second coverage contains the new 1991 land-activity combined with the 1991 land-cover. Errors in the 1986 CLUMP land-activity classes were corrected and the information was expanded to include the whole 1991 Ottawa-Hull CMA. It is intended that this file will be the base for determining all future change for both land-activity and land-cover. It should be noted that polygons with an area less than 1,250 square metres (approximately equal to one Landsat TM pixel) were eliminated from the calculations and statistics generation. These very small areas are generally 'slivers' that occur in the overlay of the raster and vector data files.

Both the land-activity and land-cover information reside in ARC/INFO databases. Statistics and map products can be generated by the software, as can export files to transfer the data to other GIS systems such as SPANS. The following results section provides examples of various outputs at different levels of geographic detail.

4. RESULTS

This section provides examples of typical statistical outputs and maps that can be derived from the land-activity and land-cover databases. The series of tables and maps are depicted at three levels of geographic detail: 1) the City of Ottawa, 2) the Ottawa-Hull Urban Area, and 3) the CMA of Ottawa-Hull. Each geographic level has four tables:

1. 1991 Land-Activity
2. 1991 Land-Cover
3. 1991 Land-Activity / Cover Matrix
4. 1986 to 1991 Land-Activity Comparison

The four tables are followed by map and graphic outputs appropriate to the geographic level. For example, each level has land-activity, land-cover and land-activity change maps. In addition, maps showing the derived green space were produced for the City of Ottawa and the Ottawa-Hull Urban Area. These maps also have a histogram that shows the distribution of the green space polygons by their size in hectares.

Land-Activity and Land-Cover, 1991

Land-Activity and land-cover (1991) vary dramatically according to the geographic level of inquiry in the Ottawa-Hull CMA. If the focus is on the inner city (City of Ottawa), built-up area predominates with nearly 65% of the area recorded as non-vegetated surfaces (Table 2 and Map 4). Similarly, residential use is a dominant activity (over 46%) while commercial, industrial and institutional uses together are also very significant at over 23% (Table 1 and Map 3).

At the level of the Urban Area which comprises the cities of Ottawa and Hull, as well as all of the contiguous suburban municipalities, the built-up area (non-vegetated surfaces) remains prominent at nearly 48% of the total land area. Areas of grassland and shrubbery, however, are listed at nearly 30% (Table 6 and Map 8). Correspondingly, residential and commercial activities are significant uses at 37% and 12% of the urban area respectively. Rural and farm uses in the rural-urban fringe, and major water bodies such as the Ottawa river, encompass 43% of the total area (Other / Unknown in Table 5 and Map 7).

For the CMA as a whole, the broadest level of inquiry includes expanses of rural area and small villages near to Ottawa-Hull in which residents are oriented to the urbanized core for work and shopping. The results show that the built-up area is only 12.5% with vegetated areas covering over 80% of the total landscape, divided almost equally between wooded and non-wooded cover (Table 10 and Map 12). In the Ottawa-Hull CMA as a whole, residential, commercial and transportation activities account for under 10% of the surface area, while agriculture, forestry and other rural uses encompass nearly 87% of the total CMA area (Table 9 and Map 11).

Land-Activity Comparison, 1986-1991

For the City of Ottawa, which comprises the built-up inner city with the commercial core, land-

use change included a 4% increase in residential area and a 10% rise in commercial, industrial, institutional area, largely derived from the "other" category, particularly in southeast Ottawa (Table 4). These increases in built-up area are modest, but significant in view of the fact that the City of Ottawa is largely developed.

At the geographic level of the Urban Area, including all Ottawa-Hull suburban municipalities, increases in residential area are substantial (11.4%) over the five-year period, but outstripped by the growth in commercial, industrial and institutional uses (Table 8). The location of new residential areas are found largely on the periphery of the urban area, but widely dispersed. By contrast, the commercial, industrial and institutional growth, in part, is more centrally located, representing infilling of open space in institutional precincts and industrial parks.

Expansion of residential activity (1986-1991) at the Ottawa CMA level has been truly dramatic at 23.1% (5,950 ha) with much of it focused in the rural and urban fringe beyond the contiguous built-up area (Table 12). Some of this expansion reflects a strong trend toward rural estate development and development adjacent to small villages near to Ottawa-Hull. At the CMA level, expansion of commercial land-use is also significant, but more focussed within the built-up area.

Green Space, 1991

Urban green space is depicted for the City of Ottawa (Map 5) and the Ottawa-Hull Urban Area (Map 9). Both the city and the UA as a whole are well endowed with formal and informal green space, owing to the parkways, the greenbelt, the southern portion of Gátineau Park, the Experimental Farm and other features. Perhaps equally important for the access of residents to nearby green space is that there are large numbers of small green spaces throughout the urban area which complement the relatively fewer, large community and regional green spaces (histograms in Maps 5 and 9).

Table 1: 1991 Land-Activity, City of Ottawa (hectares)

Activity	1991 Area	% of Total Area
Residential	6,151	46.60
Commercial / Industrial / Institutional	3,051	23.12
Transportation / Communications	549	4.16
Recreation	485	3.68
Other / Unknown	2,961	22.44
Total - City of Ottawa	13,197	100.00

Table 2: 1991 Land-Cover, City of Ottawa (hectares)

Cover	1991 Area	% of Total Area
Water	1,199	9.09
Wooded Vegetation	594	4.50
Non-Wooded Vegetation	2,853	21.62
Non-Vegetated Surfaces	8,551	64.79
Total - City of Ottawa	13,197	100.00

Table 3: 1991 Land-Activity / Cover Matrix, City of Ottawa (hectares) *

1991 Activity	Water	Wooded Vegetation	Non-Wooded Vegetation	Non-Vegetated Surfaces	Total
Residential	17	92	523	5,519	6,151
Commercial / Industrial / Institutional	28	121	967	1,935	3,051
Transportation / Communications	7	16	228	298	549
Recreation	20	56	228	181	485
Other / Unknown	1,127	309	907	618	2,961
Total - City of Ottawa	1,199	594	2,853	8,551	13,197

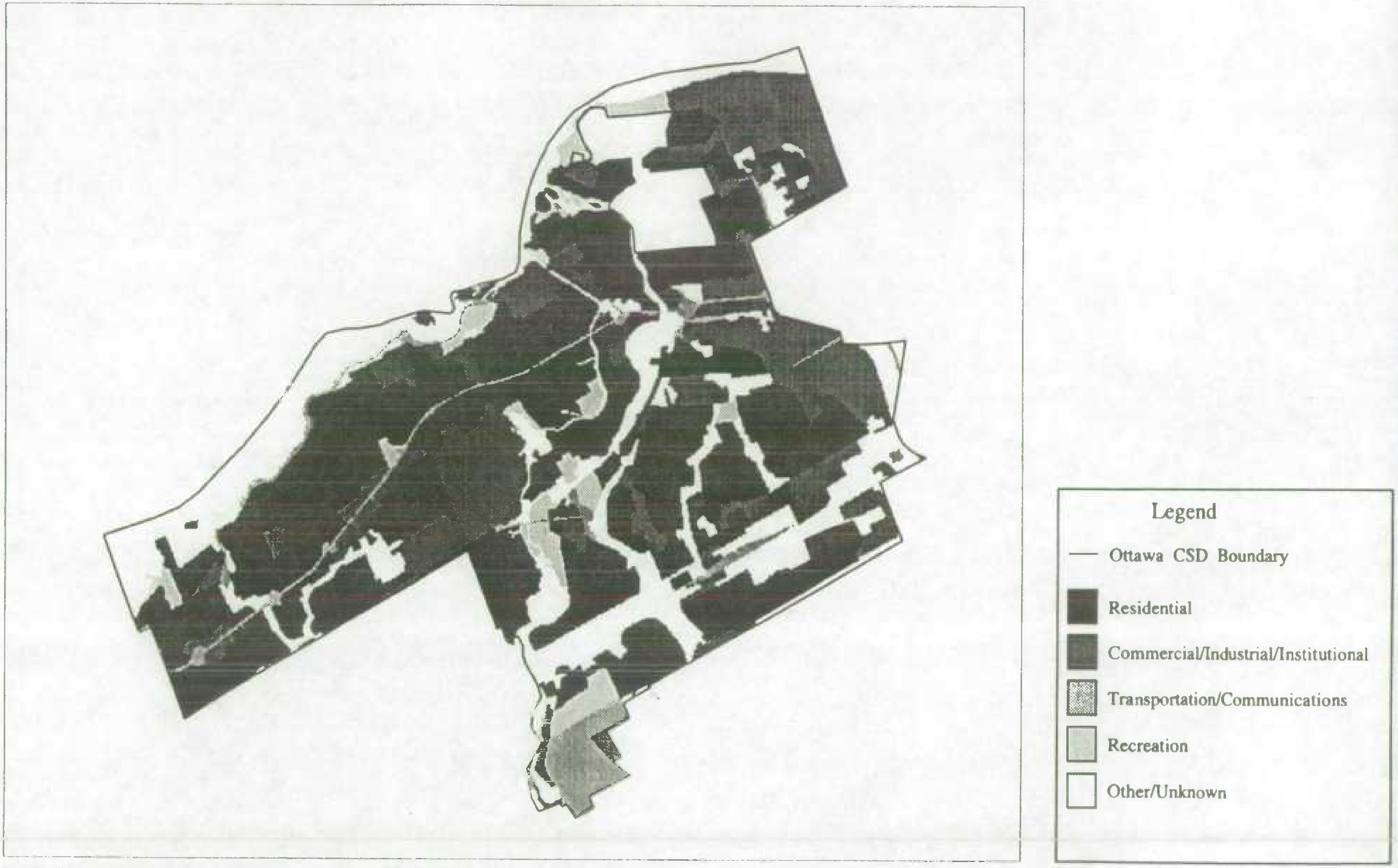
* <u>Note:</u> See Appendix B for example descriptions of this matrix.

Table 4: 1986 to 1991 Land-Activity Comparison, City of Ottawa (hectares)

Activity	1986 Area	1991 Area **	Change	Percent Change
Residential	5,977	6,202	225	3.8
Commercial / Industrial / Institutional	2,742	3,027	285	10.4
Transportation / Communications	551	549	-2	-0.4
Recreation	492	485	-7	-1.4
Other / Unknown	3,435	2,934	-501	-14.6
Total - City of Ottawa	13,197	13,197		

** <u>Note:</u>
In order to prevent the calculation of 'false change' statistics, these 1991 areas are based on the 1986 CLUMP coverage area (including offset errors) and unrevised 1986 city boundaries. See the previous section on **Spatial Analysis and Statistics Generation** for further information.

Map 3: 1991 Land-Activity, City of Ottawa

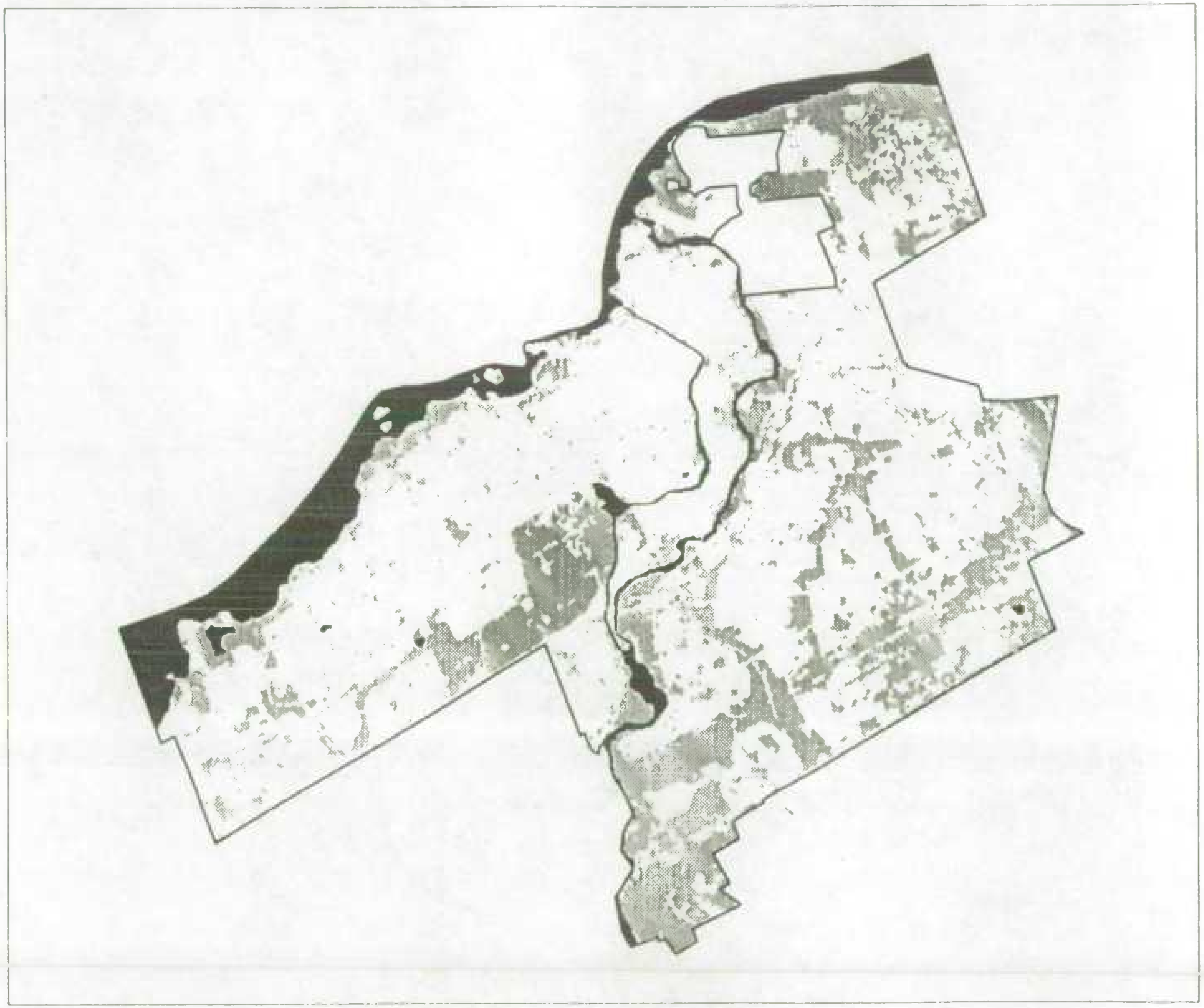


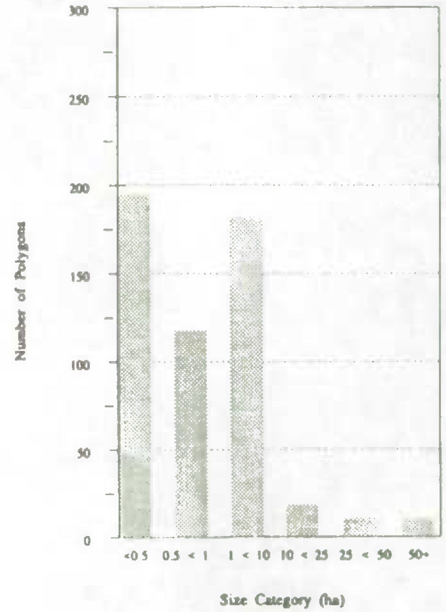
Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Map 4: 1991 Land-Cover, City of Ottawa

Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

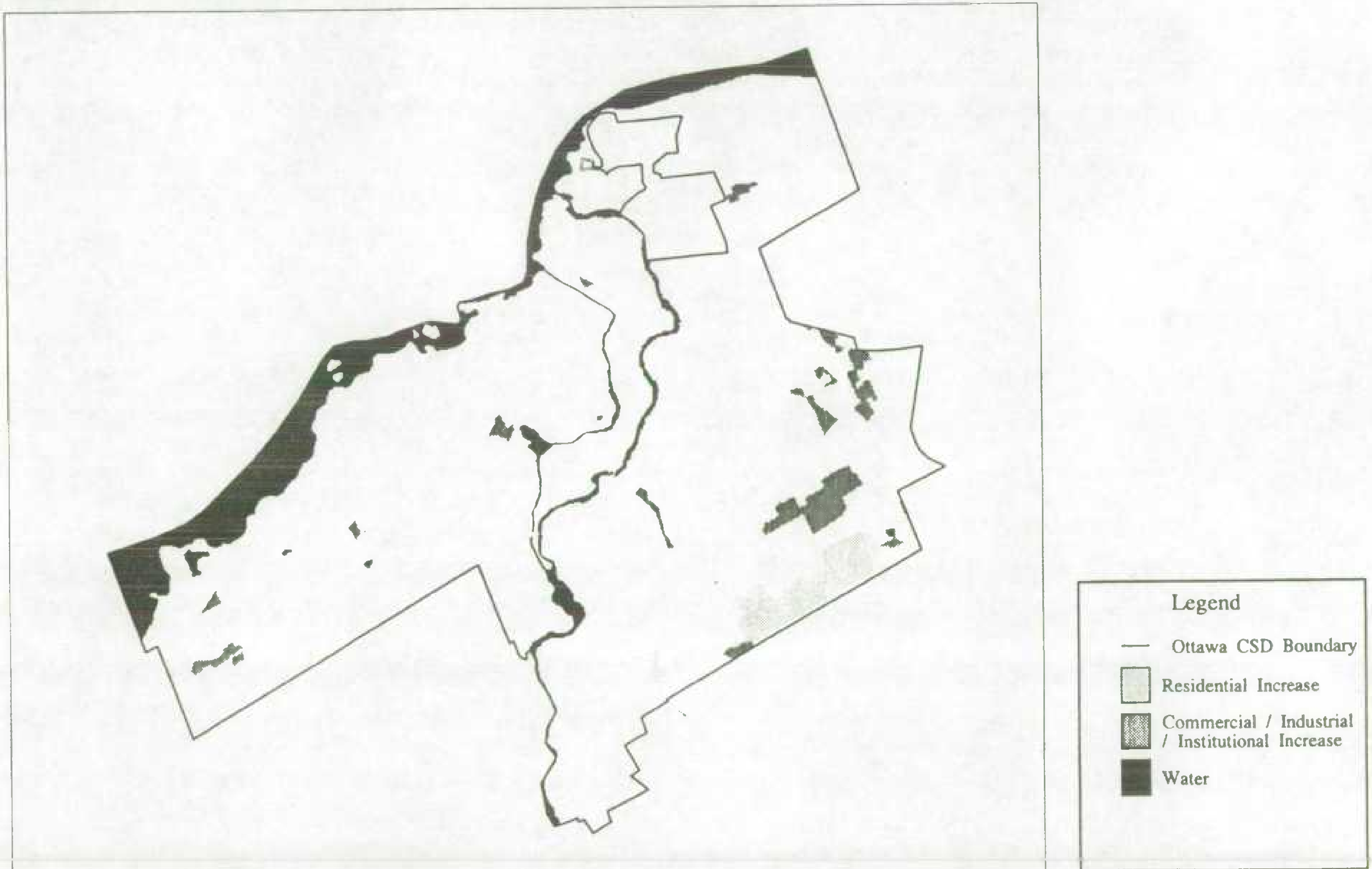
Map 5: 1991 Green Space, City of Ottawa





Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Map 6: 1986 to 1991 Land-Activity Change, City of Ottawa



Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Table 5: 1991 Land-Activity, Ottawa-Hull Urban Area (hectares)

Activity	1991 Area	% of Total Area
Residential	18,714	36.85
Commercial / Industrial / Institutional	6,190	12.19
Transportation / Communications	2,034	4.01
Recreation	1,970	3.88
Other / Unknown	21,875	43.07
Total - Ottawa-Hull UA	50,783	100.00

Table 6: 1991 Land-Cover, Ottawa-Hull Urban Area (hectares)

Cover	1991 Area	% of Total Area
Water	5,545	10.92
Wooded Vegetation	6,024	11.86
Non-Wooded Vegetation	15,108	29.75
Non-Vegetated Surfaces	24,106	47.47
Total - Ottawa-Hull UA	50,783	100.00

Table 7: 1991 Land-Activity / Cover Matrix, Ottawa-Hull Urban Area (hectares) *

1991 Activity	Water	Wooded Vegetation	Non-Wooded Vegetation	Non-Vegetated Surfaces	Total
Residential	67	517	2,323	15,807	18,714
Commercial / Industrial / Institutional	54	306	2,037	3,793	6,190
Transportation / Communications	7	247	939	841	2,034
Recreation	37	559	873	502	1,970
Other / Unknown	5,381	4,395	8,936	3,163	21,875
Total - Ottawa-Hull UA	5,545	6,024	15,108	24,106	50,783

* Note: See Appendix B for example descriptions of this matrix.

Table 8: 1986 to 1991 Land-Activity Comparison, Ottawa-Hull Urban Area (hectares)

Activity	1986 Area	1991 Area **	Change	Percent Change
Residential	16,755	18,661	1,906	11.4
Commercial / Industrial / Institutional	5,221	6,109	888	17.0
Transportation / Communications	2,038	2,034	-4	-0.2
Recreation	1,940	1,922	-18	-0.9
Other / Unknown	24,444	21,672	-2,772	-11.3
Total - Ottawa-Hull UA	50,397	50,397		

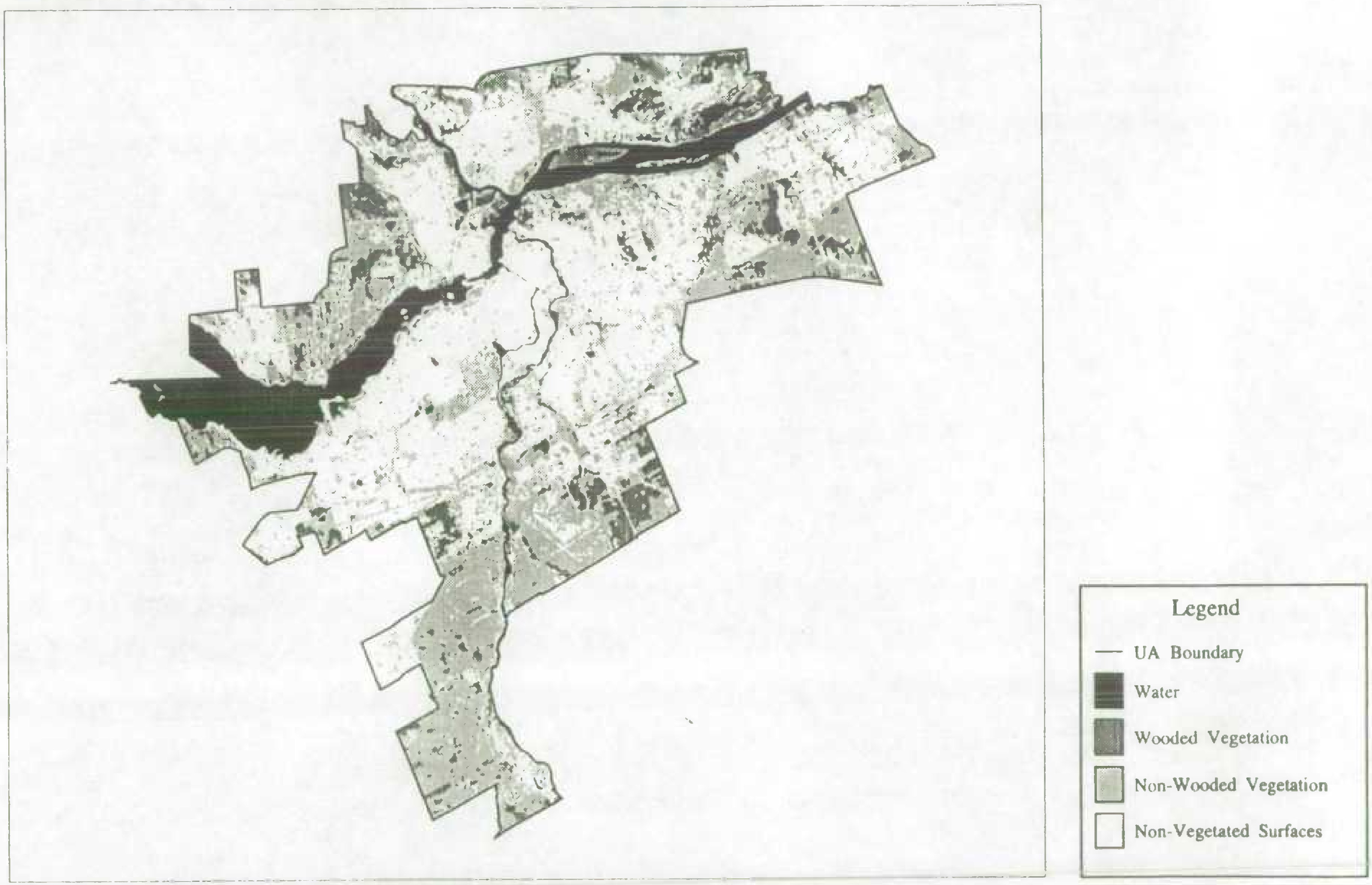
** Note:

- In order to prevent the calculation of 'false change' statistics, these 1991 areas are based on the 1986 CLUMP coverage area (including offset errors). See the previous section on **Spatial Analysis and Statistics Generation** for further information.

Map 7: 1991 Land-Activity, Ottawa-Hull Urban Area

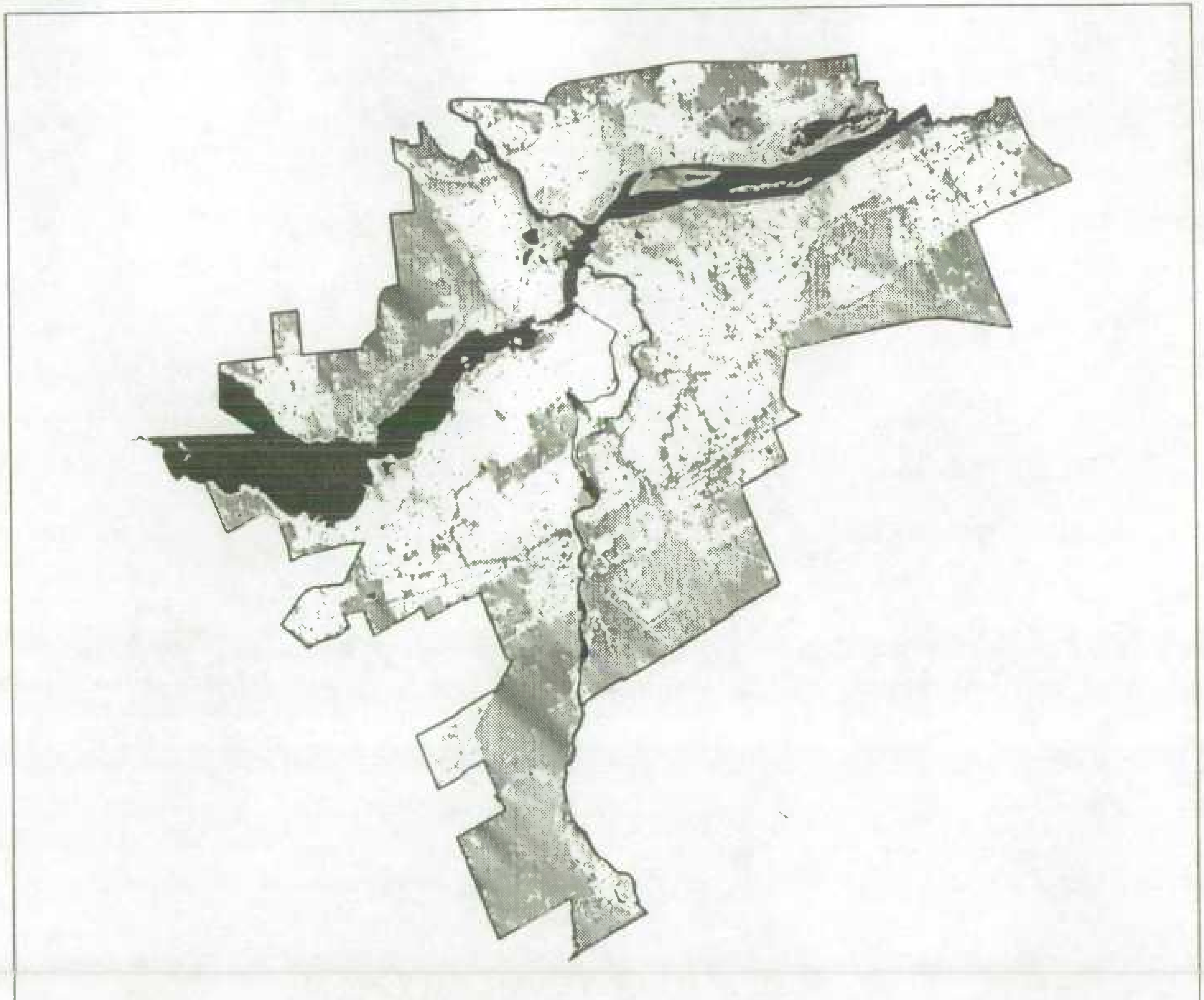
Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

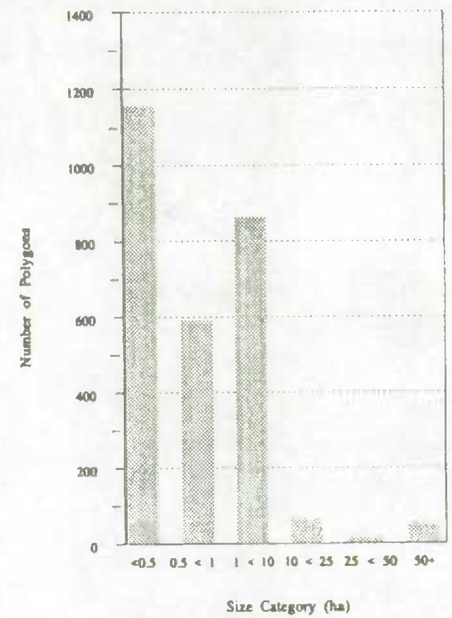
Map 8: 1991 Land-Cover, Ottawa-Hull Urban Area



Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

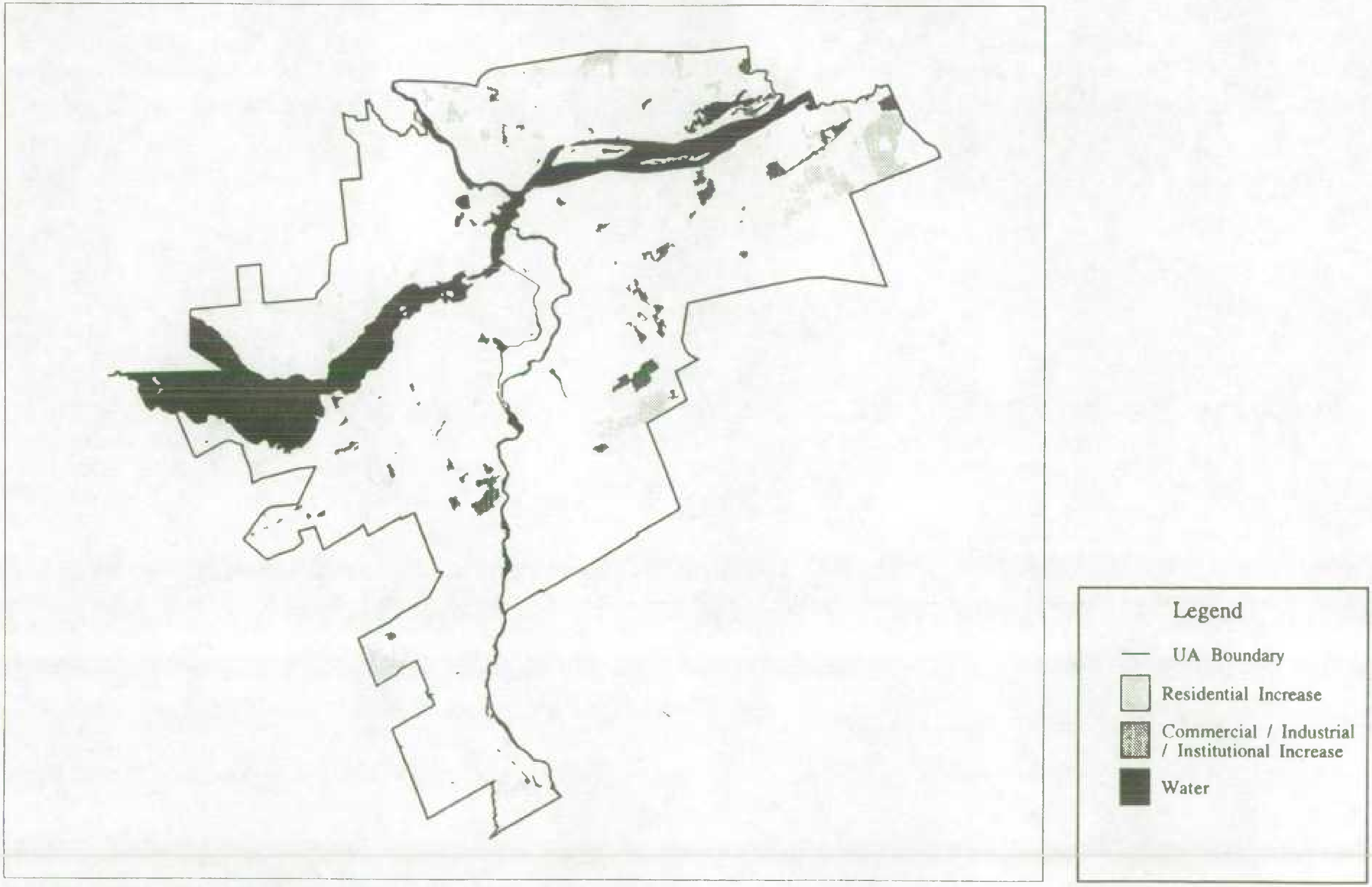
Map 9: 1991 Green Space, Ottawa-Hull Urban Area





Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Map 10: 1986 to 1991 Land-Activity Change, Ottawa-Hull Urban Area



Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Table 9: 1991 Land-Activity, Ottawa-Hull CMA (hectares)

Activity	1991 Area	% of Total Area
Residential	36,362	6.68
Commercial / Industrial / Institutional	13,471	2.48
Transportation / Communications	3,755	0.69
Recreation	18,332	3.37
Other / Unknown	472,195	86.78
Total - Ottawa-Hull CMA	544,114	100.00

Table 10: 1991 Land-Cover, Ottawa-Hull CMA (hectares)

Cover	1991 Area	% of Total Area
Water	32,342	5.94
Wooded Vegetation	229,758	42.23
Non-Wooded Vegetation	214,262	39.38
Non-Vegetated Surfaces	67,752	12.45
Total - Ottawa-Hull CMA	544,114	100.00

Table 11: 1991 Land-Activity / Cover Matrix, Ottawa-Hull CMA (hectares) *

1991 Activity	Water	Wooded Vegetation	Non-Wooded Vegetation	Non-Vegetated Surfaces	Total
Residential	345	4,456	8,845	22,715	36,362
Commercial / Industrial / Institutional	372	1,056	6,547	5,495	13,471
Transportation / Communications	18	526	1,849	1,361	3,755
Recreation	246	13,966	2,981	1,140	18,332
Other / Unknown	31,360	209,753	194,040	37,042	472,195
Total - Ottawa-Hull CMA	32,342	229,758	214,262	67,752	544,114

* Note: See Appendix B for example descriptions of this matrix.

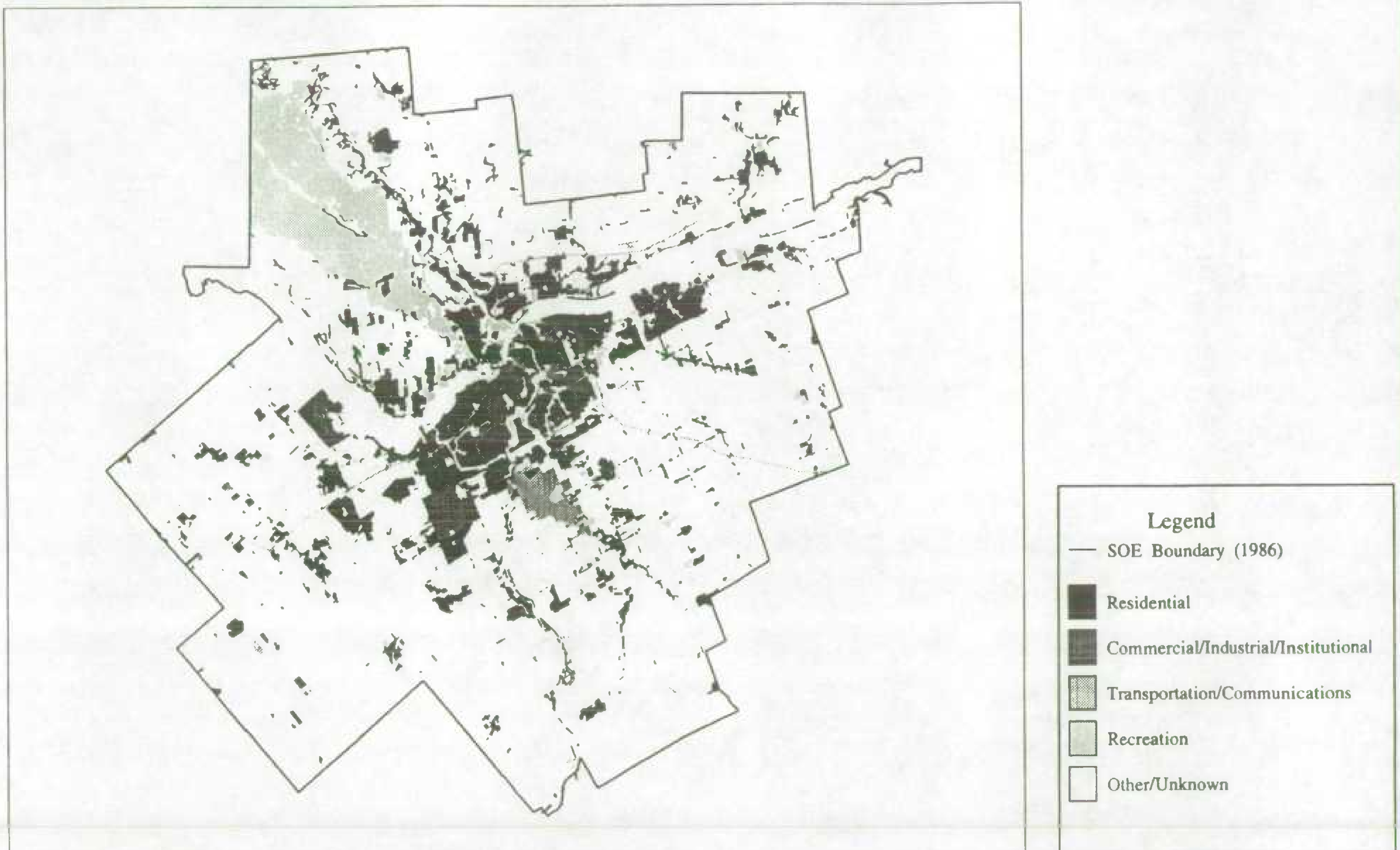
Table 12: 1986 to 1991 Land-Activity Comparison, Ottawa-Hull CMA (hectares)

Activity	1986 Area	1991 Area **	Change	Percent Change
Residential	25,738	31,688	5,950	23.1
Commercial / Industrial / Institutional	11,880	13,023	1,143	9.6
Transportation / Communications	3,700	3,689	-11	-0.3
Recreation	17,838	18,040	202	1.1
Other / Unknown	231,778	224,494	-7,284	-3.1
Total - Ottawa-Hull CMA	290,934	290,934		

** Note:

In order to prevent the calculation of 'false change' statistics, these 1991 areas are based on the 1986 CLUMP coverage area (including offset errors). See the previous section on **Spatial Analysis and Statistics Generation** for further information.

Map 11: 1991 Land-Activity, Ottawa-Hull Census Metropolitan Area



Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Map 12: 1991 Land-Cover, Ottawa-Hull Census Metropolitan Area

Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

Map 13: 1986 to 1991 Land-Activity Change, Ottawa-Hull CMA

Produced by: Spatial Analysis and Geomatics Applications, Agriculture Division, Statistics Canada, 1993

5. DISCUSSION

This section will assess and evaluate the pilot study results, discuss the remaining technical and methodological issues and provide an indication of the costs associated with the study. In addition, an estimate of resources and costs will be given to operationally produce similar products, using similar methods, for the remaining CMAs for which 1991 imagery has been acquired.

Results Assessment

An evaluation of the classification processing should include a measure of accuracy as compared to reliable 'ground-truth' information. This quantifiable accuracy measurement is usually displayed in a matrix that compares the classification results to the known land-activity or land-cover. For this study, there was no allocation of resources to conduct and collect detailed ground-truth data. In fact, this study was initiated on the premise that the remote sensing approach would provide levels of accuracy comparable to that of other large-scale land-use programs such as CLUMP, for selected land-activity and land-cover classes. This assumption was made based on the experience and expertise of the SAGA and SOER personnel, and on reviews of many studies cited in remote sensing literature.

This study has also assumed that the historical CLUMP data are of sufficient accuracy and resolution to serve as base-information for the land-activity updating approach and subsequent change calculations. Following completion of the classifications by SAGA, a visual verification of the results was conducted by SOER. This process involved spot-checking of random areas throughout the classification and comparing the result to the various ancillary information sources available (NTS maps, AllMaps map, CLUMP files, etc.). The members of the study team are confident that the anticipated levels of accuracy have been achieved. Nonetheless, it is recommended that an independent review of the results be conducted. This is discussed further in the conclusions section of this report.

Although quantifiable comparisons are not possible, general observations can be made in comparison to the CLUMP data files used in this pilot study:

- Spatial accuracy is believed to be better. For example, the CLUMP files had obvious, although relatively minor, registration problems that caused classification errors. Recent advances in precision geocoding enable the remotely-sensed and other data to be accurately geometrically corrected to the best available map data source (in this case NTS 1 : 50 000 scale base maps).

- Although there are several technical and methodological issues that still require resolution and testing (see the following section), the basic approach has been demonstrated to be effective for obtaining timely, accurate and appropriately aggregated urban land information.

- The CLUMP program derived considerably more information for urban and rural areas. Nonetheless, this remotely-sensed approach produces sufficiently detailed key

information that closes the data gap and provides answers to many of today's needs and important issues.

A comparison of rural to urban land-use change for the Ottawa-Hull CMA since 1976 shows that the amount of change identified for the 1986-1991 timeframe is reasonable (Table 13). Over 7,000 hectares of new urban area were delineated and measured for the 1986-1991 period. This is over twice the area of change found in the 1981-1986 period. This significant increase can be attributed to a number of factors:

- Rapid population growth and high levels of housing development during the 1986-1991 period;
- An increase in the proportion of low density rural "estate" development which uses large land parcels ;
- Up until 1991, land-use changes were interpreted from aerial photography, from which "land in transition" was distinguishable from actual built-up land. Using Landsat imagery, these classes often appear similar. Therefore, there may be a slight adjustment due to the new technique.

When the above factors are taken into account, the level of urbanization appears reasonable. However, a detailed verification procedure would serve to confirm the accuracy of the interpretation technique and the land-use change measured.

Table 13: Rural to Urban Change for the Ottawa-Hull CMA, 1971 - 1991 (hectares)

Time Period	Built-Up Area	Built-Up Change (%)	Population	Population Change (%)
1976	51,763		693,288	
1976 - 1981		4,179 (8.1)		(3.4)
1981	55,942		717,263	
1981 - 1986		3,588 (5.7)		(14.2)
1986	59,156		819,263	
1986 - 1991		7,284 (12.3)		(12.4)
1991	66,440		920,857	

Technical and Methodological Issues

The major limitation and analysis bottleneck with the current technology and methodology lies with the ARC/INFO 10,000 arcs in a polygon restriction. Discussions have been ongoing with ESRI, the developers of ARC/INFO, concerning short-term workarounds and the longer-term resolution of this problem. SAGA has been informed that the 10,000 arc restriction will be resolved in the next release of the software. Although a release date has not yet been announced, it is expected that a beta version could be acquired by the fall of 1993.

There are several other methodological changes that should also be tested. It is thought that these processes could improve production throughput and help to reduce the limitation imposed by the 10,000 arcs problem. Another benefit resulting from these proposed changes would be a more efficient database design for statistics generation and spatial queries. These processes were not tested in the pilot study because of tight timeframes and resource issues. The major suggested changes are:

1) The classifications were transferred from the image analysis system to ARC/INFO as separate coverages. The coverages (water, forest, vegetation, etc.) were then merged, in ARC/INFO, as one coverage. It is likely that the inevitable overlaps that occur in such merging were responsible for a portion of the 10,000 arcs problem. It is recommended that future classified coverages be merged and cleaned at the image analysis stage and then brought into ARC/INFO. This will significantly reduce the problems and amount of time required for ARC/INFO processing.

2) Working with the entire Landsat image area creates extremely large file sizes. It is recommended that the image and classifications be clipped by the vector CSD boundaries, in the image analysis system, rather than in ARC/INFO. Once again, this process should result in time savings and a further reduction in the impact of the 10,000 arcs problem. Once in ARC/INFO, the CSD files can be 'tiled' (spatially indexed) for efficient database access.

3) There should be an evaluation to determine if generating the statistics and performing spatial queries using raster-based systems could provide time/cost savings. It is recommended that the raster processing module, GRID, in ARC/INFO be evaluated for this purpose, as should the Intera/Tydac SPANS system at SOER.

Cost Evaluation and Estimates

One of the objectives of this study is to compare, where possible, the accuracy, timeliness and costs of the methodology to that of the CLUMP program. Unfortunately, records of CLUMP costs have not been retained; therefore, a direct comparison is not possible. Nonetheless, discussions with former administrators and principals involved with CLUMP have consistently indicated that resource and non-salary costs of CLUMP, to produce this same level of information, would be significantly higher than the approach proposed in this study. The cost of producing information using this approach must therefore stand on its own.

Another purpose of the pilot study is to use the process as a learning tool and an opportunity to try new techniques and methodologies. Often there are, and were, 'false' starts, dead-ends and many obstacles for which solutions had to be developed. The process can be, and was, very time consuming! The pilot study is therefore not an accurate measure of resources and costs that would be incurred in the production environment of an operational program. The study, however, does provide indicators that can be used to estimate and extrapolate costs for analyzing the remaining CMAs.

The pilot study required about 75 days of technical resources to complete. Although this number seems rather high, it does provide an indication of the problems and limitations that were encountered. It should be noted that the 75 days do not include time spent producing the statistics, maps and writing of this document.

It is difficult to estimate the time and costs to analyze the remaining CMAs for which imagery has been acquired. The biggest problem is that the CMAs have considerable variance in size and complexity. For example, Toronto requires 2 images to cover the entire CMA, while both Vancouver and Victoria are covered by the same image. Some CMAs should be straightforward to classify (such as Regina), while it is anticipated that others will be more difficult (such as Edmonton). Nonetheless, it is thought that Ottawa-Hull is representative of an 'average' CMA. Table 14 ranks the degree of difficulty that is anticipated to analyze the major cities for which imagery has been acquired. This ranking must be viewed as a 'best guess' based on the Ottawa-Hull experience and preliminary knowledge of the size and complexity of the CMAs, urban fringe activity, typical land use, and concerns such as the impact of UTM zone overlap.

From Table 14, the difficulty in analyzing the remaining cities averages a rank of 3. The assumption that Ottawa-Hull is representative of the other cities appears to be true. Therefore, it can be extrapolated that the estimated production time to process Ottawa-Hull, in an operational manner, would be the average for the remaining cities. This also assumes that the harder and the easier-to-analyze cities would average out to be the same.

The estimated time to process Ottawa-Hull in an operational manner is a maximum of 25 days. Therefore, the processing of the remaining 23 cities could require up to 575 person days, or about 2.7 person years. It should be stressed that this is a maximum anticipated amount of time, but subsequent funding proposals should nonetheless be based on this amount.

The above time estimates deal only with the data preparation and integration, image and GIS processing, database setup, quality assurance, documentation, and production management. It is also assumed that the remaining technical and methodological issues, discussed in the previous section, will have been resolved. This is especially true for the 10,000 arcs in a polygon problem. Furthermore, any subsequent analysis of the data and the production of value-added products, such as maps or statistics, would require time and non-salary resources over and above these person-day estimates. A formal agreement(s) would also have to be established to cover responsibilities and issues such as database access, database maintenance, distribution of information, revenue generation and sharing, and so on.

Table 14: Estimated Ranking of Difficulty to Analyze the Proposed CMAs

CITY	easier 1	2	average 3	4	harder 5
St. John's, NFLD	•				
Charlottetown, PEI	•				
Halifax, NS			•		
Saint John, NB				•	
Montréal, QUE					•
Québec, QUE			•		
Hamilton, ONT			•		
Kitchener, ONT			•		
London, ONT			•		
Ottawa-Hull, ONT / QUE			***		
St. Catherines, Niagara, ONT				•	
Toronto, ONT					•
Windsor, ONT			•		
Winnipeg, MAN			•		
Regina, SASK	•				
Saskatoon, SASK	•				
Calgary, ALTA					•
Edmonton, ALTA					•
Kelowna, BC		•			
Vancouver, BC					•
Victoria, BC				•	
Red Deer, ALTA		•			
Oshawa, ONT		•			
Moncton, NB	•				
Total For Each Ranking	5	3	7	3	5

6. CONCLUSIONS

1) **Development of an urban land information base from digital remotely-sensed satellite imagery is practical and feasible.**

   The Ottawa-Hull pilot study has demonstrated that an urban land information base can be developed from digital high-resolution remotely-sensed satellite imagery. The methodology uses the best aspects of visual and digital classification techniques, both with sets of rules that would ensure comparable results produced by any qualified image analyst.

2) **Urban land information generated from remotely sensed imagery has proven to be reasonably accurate.**

   Preliminary accuracy assessments have been conducted on the Ottawa-Hull pilot study area. A more detailed accuracy assessment needs to be undertaken by a third party. The pilot has further demonstrated that a 1991 base-year for urban land information can be established in an accurate and cost and time effective manner. As the related technologies continue to improve, it should become even more cost-effective to update the 1991 base-year on a five year cycle corresponding to the Census. It is also anticipated that information with greater detail and higher accuracies will be possible in the future.

3) **The urban land-activity and land-cover information generated from remote sensing for the Ottawa-Hull pilot study, including rural-urban land conversion information, fills an important data gap in state of the environment reporting information.**

   Unlike air quality and water use statistics, there is no national coverage of consistently defined and collected land-use change information available for Canadian urban centres over time. Rural-urban land conversion statistics are available, 1966-1986, for large urban centres, from the CLUMP program, which no longer exists. If the collection system developed for the Ottawa-Hull pilot study were applied to large Canadian urban centres at regular intervals, this data gap could be filled and analysis linking urban land statistics to other urban environmental data sets could be undertaken.

4) **Urban land information generated from an end-to-end digital process has many advantages for further applications. Transfer of the spatial data between GIS systems, such as ESRI ARC/INFO and Intera-Tydac SPANS, can pose technical problems that have to be resolved.**

   The most obvious advantage is that the data available in a digital form can be incorporated into a variety of spatial analysis systems. For example, it is relatively straight-forward to setup a user-friendly map query and statistical database using some of the new mapview type of software recently developed. Both ARC/INFO and SPANS now have such software.

Another important advantage is the ability to integrate these data with other environmental and socio-economic data sources. This process is possible because all of the data are geocoded and can be re-compiled into standard or customized geostatistical units. For example, the land-activity classes can be aggregated at the Enumeration Area or Census Tract level and tabulated with economic variables available from the Census of Population, also at the EA or CT level. Or, the database could be overlaid with custom boundaries such as urban ecozones, re-aggregated and integrated with ecozone data available from Environment Canada sources.

It will be necessary to export PCI files of the classified remotely-sensed imagery for Ottawa-Hull to the Environment Canada SPANS system where additional statistical summaries could be undertaken. Results should be compared to ARC/INFO summaries with respect to statistical accuracy, cost and efficiency and ease of linkage between the two GIS systems.

5) **The linkage of urban land information based on remote sensing to earlier land-activity and land-cover information generated from fieldwork and airphoto interpretation, through the CLUMP program, has proven feasible and will facilitate trend analysis of land-use change.**

The Ottawa-Hull pilot study has shown that the land-activity and land-cover categories interpretable through analysis of digital remotely-sensed satellite imagery can be linked in a consistent and accurate way to the land-activity and land-cover categories of the earlier CLUMP program. Some land information is lost, however. Most notably, detailed agricultural land-use and the wetlands land-cover cannot be readily distinguished using this methodology. Nonetheless, additional analytical techniques could likely be developed to derive some of this information.

The 1986 CLUMP land-cover information should be included for the remaining urban centres and also be added to the data derived for the Ottawa-Hull CMA. These data would increase application potential by enabling calculation of former cover types of changed land.

6) **The urban land information generated in the Ottawa-Hull pilot study has the potential for many diverse analytical and reporting applications by both national and local agencies. The information can be used for the development of environmental indicators and in state of the environment reporting. The significant range of potential applications are highlighted in the following section.**

7) **The development of a national urban land information base, should prove to be reasonably cost-effective in comparison to: (1) previous urban land data collection based on a different process and technology; and, (2) similar kinds of data monitoring based on remote sensing. Nevertheless, development of the data base will be relatively costly and requires careful consideration.**

8) **Innovative, multi-agency partnerships will likely be necessary to ensure continuation of the development of a national urban land information base over both the near-term and the long-term, and to maximize the use of this information base. Options for implementation will have to be developed and explored.**

Potential Applications

A broad range of analytical and reporting applications, at both the national and local level, are feasible from the kind of urban land information generated in the Ottawa-Hull pilot study. Examples of the range of applications are highlighted below.

1) Many types of statistical products can be generated from the GIS files, including:

   - area of 1991 land-activity class by 1991 land-cover class;
   - area of rural to urban conversion, 1986 to 1991;
   - former (1986) cover and activity classes of urbanized rural land, 1986 to 1991;
   - size spectrum and location of contiguous green space (forest and other vegetated classes) within the urbanized core.

2) The urban land information can be linked to other land-based or socio-economic information to produce value-added GIS or statistical products. Some examples are:

   - agricultural capability of land urbanized between 1986 and 1991;
   - spatial variations in population density or age of neighbourhood (housing stock) compared with the distribution of urban green space, 1991;
   - spatial variation in average household income level compared with the distribution of urban green space, 1991, which helps to integrate the environmental and socio-economic dimensions.

3) Timeseries analysis of rural-urban land conversion, 1966-1991, and other related statistics, through linkage of the CLUMP data base and the urban land information base.

4) If the urban land information base developed in the Ottawa-Hull pilot study is extended to the full set of major urban areas in Canada (the 25 Census Metropolitan Areas), it would become a key piece of information for national state of the environment reporting products, including urban environmental indicators (urban green space, rural to urban conversion), the national SOE report, Human Activity and the

Environment publication, fact sheets and a data base for the Environmental Information Network (EIN) and the Environmental Information System (EIS).

5) The urban land information data base should also prove useful to local and regional municipalities since:

   - it can be produced for each Census Tract, municipality or group of municipalities within the CMA, thus facilitating community or neighbourhood analysis;

   - it has the potential to be linked with other local GIS data bases in municipalities (transportation networks, infrastructure, zoning, ecologically significant areas), thus adding another key component to analysis;

   - it can be a useful data base for developing, monitoring and evaluating urban land-use plans;

   - it can be incorporated into municipal state of environment reporting activities;

   - it can facilitate comparative analysis between municipalities or be used to set the local municipality within the regional or national context.

6) At the international scale, a Canadian urban land information base could facilitate international comparisons and monitoring as well as facilitate Canadian responses to requests for information from organizations such as the Organization for Economic Cooperation and Development (OECD) and the United Nations Environment Program (UNEP).

These are but some of the potential applications possible from the development of a national-level urban land information base. More applications will be identified as discussions with potential partners and users of the information are consulted.

APPENDIX A

Table 15: CLUMP Class Aggregations for Land-Activity and Land-Cover

Aggregated Class	CLUMP Mapping Code	CLUMP Definition
Land-Activity		
Residential	D0	Dwelling Activities
Commercial / Industrial / Institutional	M1 M2 J0 E0	Commercial, Manufacturing and Storing Treating and Disposal of Wastes Providing Institutional Services Extraction Activities
Transportation / Communication	H0	Transportation and Communication
Recreation	R1 R2	Land Dependent Recreational Activities Indoor and Outdoor Recreational and Cultural Site Activities
Other / Unknown	A1 A2 A3 A4 B1 B2 B3 F1 F2 G1 G2 L0 N0 O7 O8 & O9	Annual Tillage Crops, Forage and Grazing Fruit, Berry and Nut Production Other Agriculture Productive Land Agriculture Site Activities Former Agricultural Activity Former Forestry Activity Other Former Activities Productive-Land Forestry Activities Site Forestry Activities Productive-Land Wildlife and Fisheries Wildlife and Fisheries Related Activities Land in Transition No Perceived Activities Urban Undifferentiated Unclassified
Land-Cover		
Water	Z0	Water
Wooded Vegetation	W1	Trees
Non-Wooded Vegetation	W2 V1 V2 V3 V4	Shrubs, Bushes and Vines Row Crops Close Grown Crops Improved Grasses, Legumes Unimproved Grass Lands, Reeds, Hedges, Mosses, and Other Non-Woody Plants
Non-Vegetated Surfaces	O7 X0 Y0	Urban Undifferentiated Denuded Surfaces Constructed Cover

Mapping Codes and Definitions are from Gierman (1981).

APPENDIX B

1991 Land-Activity / Cover Matrix Description

1) Residential / Water
Commercial, Industrial, Institutional / Water
Transportation, Communications / Water
Recreation / Water
Other, Unknown / Water

Could describe any pond, lake, river or ravine within specific activity boundaries. For example, a residential neighbourhood will often have ravines and small ponds within its limits. Lakes in recreational areas, such as large parks, would be in this class combination.

2) Residential / Wooded Vegetation
Commercial, Industrial, Institutional / Wooded Vegetation
Transportation, Communications / Wooded Vegetation
Recreation / Wooded Vegetation
Other, Unknown / Wooded Vegetation

Could describe any forested area within specific activity boundaries. A wooded area on the grounds of a hospital or a wooded park in a residential neighbourhood are examples of this activity/cover combination. This would also include forests in recreational areas.

3) Residential / Non-Wooded Vegetation
Commercial, Industrial, Institutional / Non-Wooded Vegetation
Transportation, Communications / Non-Wooded Vegetation
Recreation / Non-Wooded Vegetation
Other, Unknown / Non-Wooded Vegetation

Could describe any open field within specific activity boundaries. Open fields within institutional areas or a soccer field within a residential neighbourhood are examples of this combination.

4) Residential / Non-Vegetated Surfaces
Commercial, Industrial, Institutional / Non-Vegetated Surfaces
Transportation, Communications / Non-Vegetated Surfaces
Recreation / Non-Vegetated Surfaces
Other, Unknown / Non-Vegetated Surfaces

Could describe any built-up area (pavement, concrete) within specific activity boundaries. For example, a large portion of residential neighbourhoods within the urban area are dense enough (with the combination of roads and houses) to be considered non-vegetated surfaces. Other examples include shopping malls and industrial areas for the commercial/industrial/institutional combination.

GLOSSARY

ARC/INFO

See ESRI ARC/INFO.

Census Agglomeration (CA)

The general concept of a census agglomeration (CA) is one of a large **urban area**, together with adjacent **urban** and **rural areas** which have a high degree of economic and social integration with that urban area. A CA is delineated around an urban area (called the urbanized core and having a population of at least 10,000, based on the previous census). Once a CA attains an urbanized core population of at least 100,000, based on the previous census, it becomes a census metropolitan area (CMA).

Census Metropolitan Area (CMA)

The general concept of a census metropolitan area (CMA) is one of a very large **urban area**, together with adjacent **urban** and **rural areas** which have a high degree of economic and social integration with that urban area. A CMA is delineated around an urban area (called the urbanized core and having a population of at least 100,000, based on the previous census). Once an area becomes a CMA, it is retained in the program even if its population subsequently declines.

Census Subdivision (CSD)

Refers to the general term applying to municipalities (as determined by provincial legislation) or their equivalent, e.g., Indian reserves, Indian settlements and unorganized territories. In Newfoundland, Nova Scotia and British Columbia, the term also describes geographic areas that have been created by Statistics Canada in cooperation with the provinces as equivalents for municipalities.

Census Tract (CT)

The general concept of a census tract (CT) is that of a permanent, small urban neighbourhood-like or rural community-like area established in large urban-centered regions with the help of local specialists interested in urban and social science research.

Canada Land Use Monitoring Program (CLUMP)

CLUMP refers to the Canada Land Use Monitoring Program of the former Lands Directorate of Environment Canada. One of the major activities under CLUMP was the "Urban Centred Regions" project which monitored land-use change among Canada's largest urban regions at 5 year intervals, the last cycle ending in 1986. For ease of understanding, the more widely known term CLUMP has been used in this report to refer specifically to the "Urban Centred Regions" project, although many other types of monitoring activities took place under that program.

CMA / CA Parts

The concept of CMA / CA parts distinguishes between central and peripheral **urban** and **rural areas** within a **census metropolitan area (CMA)** or a **census agglomeration (CA)**. There are three CMA / CA parts: urbanized core, urban fringe and rural fringe:

Urbanized core:	A large urban area around which a CMA or CA is delineated. The urbanized core must have a population (based on the previous census of at least 100,000 in the case of a CMA, or between 10,000 and 99,999 in the case of a CA.
Urban fringe:	An urban area within a CMA or CA, but outside the urbanized core.
Rural fringe:	All territory within a CMA or CA lying outside urban areas.

Core Urban Area

The physical limits of contiguous urban land use of the major urban centre(s) contained within the CMA or CA.

Coverage

A coverage is a digital representation of an analog map. A coverage contains map features such as arcs, nodes, polygons and label points.

Enumeration Area (EA)

An enumeration area (EA) is the geographic area canvassed by one census representative.

ESRI ARC/INFO

Environmental Systems Research Institute, Inc. (ESRI) are the developers of the ARC/INFO geographic information system. ARC/INFO has a powerful arc-node topological data structure and fully integrated relational database capabilities.

Geographic Information System (GIS)

A geographic information system (GIS) is an organized collection of computer hardware, software, geographic data, and personnel designed to efficiently capture, store, update, manipulate, analyze, and display all forms of geographically referenced information.

Green-Space

All vegetated land-cover surfaces within the Urban Area. In this study, green space is comprise of wooded vegetation and non-wooded vegetation land-cover classes.

Image Analysis System

An image analysis system is a sophisticated computer system, comprised of hardware, software and peripheral devices, which enable the processing and analysis of digital remotely sensed data.

Image Processing and Image Analysis

Image processing and image analysis encompasses digital image operations including image compression, enhancement, classification, spatial filtering, geometric and radiometric corrections

Intera-Tydac SPANS

A commercially available geographic information system (GIS) based on a variable raster data storage structure.

Land-Activity

The active use humans make of the land.

Land-Cover

The vegetation and artificial construction covering the land surface.

Landsat Satellite

The Landsat series of earth-observation satellites was first launched in 1975 by NASA in the USA. The current satellite, Landsat-5, records data in 7 radiometric channels (or bands) and has a ground resolution of about 30 metres with each image encompassing an area of 180 km^2.

Land-Use

The term used to describe both land-activity and land-cover.

Median Filter

Median filtering is a spatial operation used to smooth and remove spurious pixels from the classified digital imagery. A filter window, such as one of 3 X 3 pixels, is applied to the imagery and moved throughout the image one pixel at a time. The filtered pixels are re-assigned to the larger dominant class.

PCI EASI/PACE

PCI Inc. are the developers of the EASI/PACE digital image analysis system.

Rural Area

The general concept of a rural area is that of a sparsely populated area. Statistics Canada defined rural areas as those areas of Canada lying outside **urban areas**.

Urban Area (UA)

The general concept of an urban area (UA) is that of an area containing a dense concentration of population. Statistics Canada defines an urban area as an area which has attained a population concentration of at least 1,000, and a population density of at least 400 per square kilometre, at the previous census. All territory lying outside urban areas is considered **rural**. Together, urban and rural areas cover all of Canada. Urban areas separated by gaps of less than two kilometres are combined to form a single urban area.

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