USING LANDSAT DATA TO ASSESS LAND USE CONVERSION IMPACTS ARISING FROM URBANIZATION: THE CANADIAN CONTEXT

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ABSTRACT:

While Canada ranks second in the world in terms of national land area, its most productive arable land is limited in extent. These lands are also under pressure due to rapid urbanization, especially in the high growth areas of southern Ontario, the Calgary-Edmonton corridor and the lower Fraser River valley of British Columbia. Currently, a program is underway in the Earth Sciences Sector of Natural Resources Canada to quantify urban transportation sustainability in support of energy policy-makers. This work includes the creation of the Canadian Urban Land Use Survey (CUrLUS), a series of land-cover/land-use (LCLU) maps, derived in part from Landsat Thematic Mapper imagery, for all Canadian cities with populations in excess of 200,000. These LCLU maps have potential application beyond transportation issues. To study land conversion impacts during the period 1966-2001, it has been necessary to assimilate this information with historic land use sources from other federal initiatives including the Canada Land Use Mapping (CLUMP) program and the Canada Land Inventory (CLI). This paper addresses assimilation issues through an assessment of the consistency of these information sources leading to a rationalization of their class legends and spatial resolution differences.

1. INTRODUCTION

In recent decades, Canadian cities have experienced unprecedented growth, and in parallel, increasing automobile dependence with its associated detrimental impacts (increased energy consumption and greenhouse gas emissions as well as eco and human health-related problems). To better understand the relationship between transport and urbanization and the long-term sustainability of current urban growth patterns, a project is being undertaken within the Earth Sciences Sector of Natural Resources Canada to quantify a series of indicators that have been identified by policy and decision-makers as being relevant to transport-related energy sustainability. Sustainability can best be understood through a time series assessment since it's historic trends provide valuable insight and needed information to evaluate alternative strategies of future growth. In the Canadian context, a 30-40 year historic record is desirable since this time period encompasses the country's most significant urbanization 'era'. A major challenge is in the assembly or assimilation of information from diverse historical land-use sources into a temporally and spatial consistent information set. In our case, Landsat Thematic Mapper (TM) images have been used to generate lcirca 2000 and mid 1980's products. The output of this activity will hereafter be referred to as the Canadian Urban Land Use Survey (CUrLUS). For the time period 1966 to 1986 we are utilizing information from two Environment Canada initiatives, namely, the Canada Land Use Monitoring Program (CLUMP) and the Canada Land Inventory (CLI). These land-use sources can be further sub-divided into two self-consistent components that will hereafter be referred to as the CLUMP-CLI (1966-1976) and CLUMP-II (1981-1986) urban LULC maps.

Information or data assimilation is among the key pre-processes for maximizing information/data utility from available resources acquired or developed by various parties. There are assimilation methodologies developed to meet various challenges such as inconsistency in categorization (e.g. Feng and Flewelling, 2003; Schmullius and Herold, 2004) or in spatial/temporal domains (e.g. Buehner, 2002). Spatial processing efforts encompass a broad range of activities including spatial co-registration and compensation for differences in spatial resolution. From the thematic information side, inconsistencies can arise from differences in source data (e.g. aerial photography for CLUMP/CLI versus satellite data for our later epochs), mapping methodologies and categorization systems (i.e. class legends). The latter reflect different goals or motivations for the LULC mapping projects in question. For example, our goal is the study of transportation energy and hence sub-division of urban built-up areas into 'residential' and 'commercial/industrial' classes is important since work and shopping are important travel components. The CLUMP/CLI programs, on the other hand, were motivated by the need to map general land-use and land capability.

In this paper we outline the steps utilized in our assimilation process.

2. SOURCES OF LULC INFORMATION

Although all of these LULC sources have arisen from mapping (sub)projects that addressed urban issues, their specific motivation or goals were different. Our urban project supplies contemporary information that is tailored to addressing the

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relationship between urbanization and transportation, while the focus of CLUMP was on land-use changes in the rural-urban fringe of cities. These mapping objectives are reflected in differences in class legends. CLUMP-CLI has a simple land cover legend, CLUMP-II provides the most detailed and complex legend, while the CUrLUS legend, being urban transport-oriented, emphasizes urban land-use and urban form. Since our goal is to employ CLUMP products within the context of an urban-transportation study, our data assimilation efforts are directed at rationalizing (i.e. cross-walking) the CLUMP thematic information to the CUrLUS legend.

A second assimilation consideration arises from differences in source data and mapping methodologies. The CLUMP efforts relied on human interpretation of aerial photography (black and white and color for CLUMP-CLI and CLUMP-II respectively) while CUrLUS products were generated from a combination of automatic and manual pixel-level classification of Landsat data and subsequent integration with 1:50,000 scale topographic information. This results in differences in minimum mapping unit, i.e. the spatial resolution of the map information, although the map spatial scale (30m vs. 1:50,000) is compatible. In addition, the CLUMP time series products were generated through a map update procedure while each satellite-based product has been generated independently.

2.1 CUrLUS (Canadian Urban Land Use Survey)

The Canadian Urban Land Use Survey consists of digital LCLU products based on classification of Landsat Thematic Mapper images. To date, the survey database is complete for Landsat 7 scenes acquired during the 1999-2001 timeframe. Currently we are augmenting CUrLUS with products generated from Landsat 4 and 5 images acquired in the mid 1980s. A new methodology has been developed for this purpose that combines pixel-based and segment-based classifications to exploit both spectral and spatial information (Guindon et al., 2004). These information layers have then been integrated with other federal sources including road networks, additional digital topographic classes and demography from the 2001 census.

2.2 CLUMP

The Canada Land Use Monitoring Program was established in 1978 by the Lands Directorate of Environment Canada. One of its major components is a series of products based on Urban-Centered Regions (UCR). The rationale behind the UCR initiative was to examine land-use in the rural-urban fringe of major Canadian urban centers. As mentioned above, mapping was based on interpretation of aerial photographs augmented with field checks and supplementary information sources such as municipal planning maps, street maps and satellite images. The CLUMP UCR program operated from 1966 through to 1986 on a 5-year update cycle corresponding to Canada's census years. There were two distinct data collections and, as a result, the UCR program had two distinct sub-programs; the CLUMP 1966-1976 cycle (CLUMP-CLI) and the CLUMP 1981-1986 cycle (CLUMP-II). The first part of CLUMP complemented the land capability and land use surveys of the Canada Land Inventory. CLUMP-CLI had the same land class category as CLI, but was compiled at a higher level of detail (1:50,000 versus 1:100,000). The 1966 mapping is based on CLI Present Land Use manuscripts but it was modified by the CLUMP team to more closely reflect land-use and land-cover conditions in 1966 and to correct errors on the original material. The 1966 mapping served as the "base year" for subsequent mapping in the 1966-1976 cycle. The 1971 mapping was compiled from land- use change overlays that were applied to the 1966 base year. Similarly, a 1976 land-use change overlay was applied to the 1971 derived results to produce the final 1976 mapping. Within the constraints of the CLI land-use coding, these maps represent current land-use and land-cover conditions in their respective years. Further information and the datasets can be found on the GeoGratis website (www.geogratis.ca).

CLUMP-II products were generated for 1981 and 1986. In 1981 the original CLI based land-use classification was discarded in favor of a more comprehensive land-use and land-cover classification scheme (Giermam, 1981). The spatial resolution of CLUMP-II maps was also substantially improved.

3. COMPATIBILITY ASSESSMENT

The success of assimilation depends on the compatibility of the independent information sources. In our work, categorical and spatial compatibility were investigated. The level of category compatibility is assessed based on a ‘cross-walk’ analysis of mapping legend schemes. Spatial compatibility analyses were undertaken to assess how much urban information can be

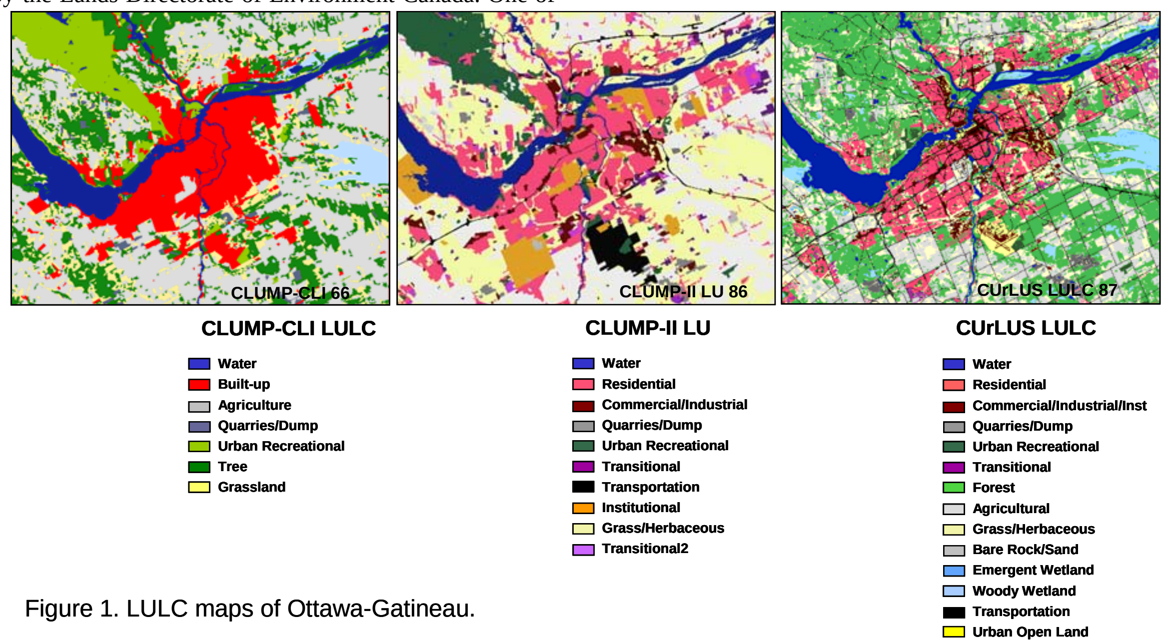

Figure 1. LULC maps of Ottawa-Gatineau.

recovered from maps with the lowest spatial resolution. Because urban transportation is our prime application, we have focused on relevant urban land classes, namely, residential (R), urban open-land, commercial/industrial/institutional (C/I/I) and urban recreational (i.e. parks, school yards, etc.).

Before LULC information integration, it is necessary to assess the consistency and compatibility of the CLUMP sources relative to the CUrLUS. It is difficult to undertake assimilation between CLUMP and CurLUS using the circa 2000 Landsat-based product. Instead, we have generated CurLUS products using Landsat TM data acquired in the mid 1980s thereby establishing a temporal link between the two information sources, i.e. this Landsat product and the 1986 CLUMP products are then representations of the same ground conditions. To illustrate these information sources, Figure 1 shows three maps of Ottawa-Gatineau, 1966 CLUMP-CLI (left), 1986 CLUMP-II (centre) and 1987 CurLUS (right). Cursory inspection of these maps reveals the improvement in urban spatial resolution (i.e. delineation and internal detail) from left to right. There is an obvious legend incompatibility in the thematic legend of CLUMP-CLI since its urban definition (shown in red) is based upon only one class, i.e. an 'urban' mask. In other words, CLUMP-CLI provides no information about the internal structure of the urban areas.

We have undertaken urban class legend compatibility assessment at two levels of thematic detail, namely, 'urban' (i.e. all urban classes are aggregated), and for specific 'built-up' classes.

3.1 Overall Urban Level

In this case, we assume that ideal compatibility between CUrLUS and the 1986 CLUMP-II should result in the same area coverages. Test results indicate that large percentage of the CUrLUS urban area is also defined as urban in the CLUMP urban layer. Comparison with the 1966 CLUMP-CLI is more difficult because of temporal differences. However, if we make the reasonable assumption that the process of urbanization is irreversible, then the 1966 CLUMP-CLI urban mask should ideally be a subset of the CUrLUS mask. Comparison results show that high percentage of the early mask meets this criterion.

3.2 Built-Up Classes

The CLUMP-CLI products do not include any detailed urban classes and therefore further assessment of it is precluded. On the other hand, the CUrLUS product includes five urban classes, 'residential', 'commercial/industrial', 'open-land', 'recreational' and 'transitional', the first two of which constitute the built-up portion of a city. CLUMP-II includes three built-up classes, 'dwellings', 'commercial/manufacturing' and 'institutional'. For comparison purposes, we will refer to the first as 'residential' and combine the latter two into a 'commercial/industrial/institutional' (C/I/I) category since the CUrLUS commercial/industrial class includes institutional buildings.

For the residential class, excellent agreement has been found, namely, 94.3% of CUrLUS residential pixels have the same class label in the CLUMP-II product. In the case of the C/I/I class, a significantly lower level of agreement, 61.5%, has been found. This discrepancy results in part from the fact that the CLUMP-II product is less detailed (see Figure 1) and hence numerous small patches of C/I/I pixels in the CUrLUS product are omitted from the CLUMP-II product.

Comparison of the CLUMP-II and CUrLUS information, reveals that potentially the most contentious classes in terms achieving category assimilation are 'urban open-land' (CUrLUS) and 'institutional' (CLUMP-II). 'Open-land' encompasses herbaceous land patches within an urban area such as portions of large residential housing lots dominated by lawns, school yards, open grassland around airports and hospitals and vacant lands available for future in-fill, etc. The spatial distribution and density of urban open-land pixels provides information about building density or impervious land density. In low-density residential and C/I/I areas, i.e. where open-land constitutes a high percentage of urban pixels, the spatial similarity between CLUMP-II and CUrLUS is low. However, we can further study the class 'urban open-land' by comparing its coincidence with three CLUMP-II urban classes residential, commercial/industrial and institutional.

The second major issue relates to areas classed as C/I/I in CLUMP-II. These are generally distributed in large patches and encompass both buildings and surrounding grassy areas. In CUrLUS, on the other hand, pixels classed as commercial/industrial are those dominated by impervious surfaces such as building roofs and parking lots. Surrounding grassy areas, are classed as open-land. These differences are reflected in the greater spatial detail of CUrLUS depicted in Figure 1. These differences we believe account for the low level of agreement for the C/I/I class as noted above. If, however, we combine openland with the building classes of CUrLUS and compare these to the CLUMP-II 'built-up' classes (including all residential, commercial/industrial, institutional, urban transportation land), the levels of agreement rises dramatically for C/I/I to 94.5%.

In summary, the richness in spatial information in LULC maps increases from early years to later years. The CLUMP-II maps have a high compatibility of urban structure information with CUrLUS maps if it is recognized that the CLUMP-II built-up classes are constituted both by buildings and surrounding herbaceous land.

4. DERIVATION OF TIME SERIES INFORMATION

The urban LULC information integration involves two steps, legend assimilation as described above and inference of urban

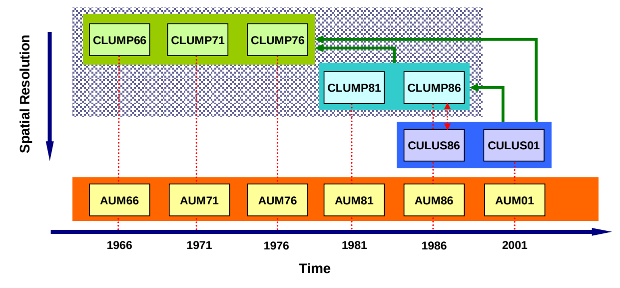

Figure 2. Strategy for generation of assimilated urban maps (AUM series).

Figure 2. Strategy for generation of assimilated urban LULC maps.

detail that is missing from the earlier CLUMP sources. Figure 2 illustrates the strategy of information inference. An inference can be made based on the following assumptions:

a. Canadian urbanization can be regarded as irreversible during the period of interest.
b. Once urbanization has occurred, conversion between residential and C/I/I land is rare.

The above assumptions allow us to recover urban form information by using the spatially detailed urban information from CUrLUS products that exist under the CLUMP urban masks for the 'epochs' of CLUMP-CLI (i.e. 1966-1976).

4. EXAMPLE RESULTS

The LULC change map of Ottawa-Gatineau map shown in Figure 3 is an example of results from the LULC information assimilation. (Note: the road networks is the contemporary overlay). The urban spatial structure of the early years, especially of 1966, 1971 and 1976, have been retrieved. In a similar vein, Figure 4 presents information on the absolute and normalized growth patterns for three cities, Ottawa-Gatineau, Toronto and Calgary. A major concern regarding urbanization in the Canadian context is the loss of valuable agricultural and eco-sensitive lands. These impacts can be quantified by assessing the areas of various rural land classes and land capability conversions to urban through the temporal sequence of urban mask expansion from 1966 to 2001.

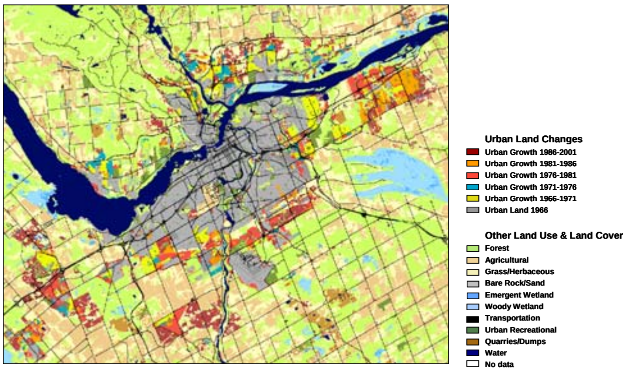

Figure 3. Integrated LULC change map of Ottawa-Gatineau.

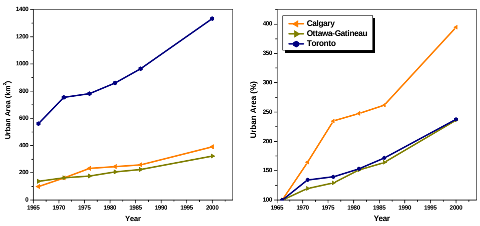

Figure 4. The absolute (left) and normalized (right) urban growth of Ottawa-Gatineau, Toronto and Calgary from 1966 to 2001.

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