A comparative analysis using change detection to monitor urban growth and its influences on public transportation in St. Catharines & Thorold, Ontario

[2000-2013]

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Project Overview

Remote Transportation Technologies, or RTT, is a company dedicated to monitoring public transportation services across metropolitans globally. Aided by remote sensing technologies, RTT is committed to ensuring sustainability, efficiency and data accuracy of the highest degree in all of our consultations. Comparing urban and transportation expansion collected from satellite imagery, RTT is capable of gaining state of the art analyses, understanding and forecasting for the future of public transit. The cities of St. Catharines and Thorold, Ontario, Canada, have hired our firm to monitor the change of the land-use/land cover in the city from 2000-2013. Addressing the recent urban developments, our team is dedicated to determining if the St. Catharines public transit system currently operates in an efficient manner, meeting the needs of potential transit users across both cities.

1. Introduction

The form cities take have major impacts on the lifestyle choices of their residents. The well being, "of growing and expanding urban metropolitan regions is intimately connected to the provision of adequate and appropriate transportation services" (Murray, Davis, Stimson & Ferreira, 1998, 319). Thus consideration on the efficiency of public transportation is essential in combating automobile dependence. Modern urban development continually sprawls outward from downtown centres. As a result, urban and transportation planners are required to meet these demands. Stretching transportation corridors across greater distances. This developmental pattern is visible across the North American continent. Consequentially, an increase in urban growth creates both environmental degradation and traffic congestion across transportation networks in cities (Schrank & Lomax, 2004). These land changes, "commonly referred to as urban sprawl [are] associated with rapid expansion of low density suburbs into formerly rural areas [having] ramifications for both the environmental and socioeconomic sustainability of communities" (Yuan, Sawaya, Loeffelholz & Bauer, 2005, 317). Sprawling growth generates difficulties for transportation engineers, urban planners and citizens within cities. Therefore, it is crucial to understand the interconnectedness between both urban development and the transportation network. More importantly, understanding the interconnectedness between urban infrastructure and public transit participation.

If increases in public transit membership are going to occur, adequate policy and infrastructure need to be in place. This can only be achieved, "if the service quality of public transit is considerably improved and simultaneously the use of the private vehicle is substantially limited 'i.e. parking supply restraints'" (Kirchhoff, 1995, 3). As cities continually push for economic, environmental and civic success, it is essential to ensure public transit is of the highest degree. Transportation is not limited to the mobility of people; rather what people carry with them. For instance, public transit allows cities to thrive via the mobility of capital and culture. The question arises, how adequate is the St. Catharines transit system? Is it currently operating in a fashion that meets the demands of the St. Catharines and Thorold residents it intends to serve? The St. Catharines Transit Commission (SCTC) claims their purpose is to, "provide a safe, courteous and reliable transit service which responds to the needs of our community" (St. Catharines Transit Commission, 2013). The SCTC is a shared service by both local residents and members of the Brock University community. With thousands of people relying on public transit as their primary means of mobility through both cities, an analysis between urban growth and public transportation networks is principal.

Using change-detection and image-to-image comparison, allows RTT to assess, (1) urban growth and (2) how urban growth influences public transit, which provides multiple advantages. Advantages from using a change-detection method are firstly that, the ability to analyze change with multiple images increases the ability to detect change over a studied area (Shahtahmassebi *et al.*, 2012). Satellite, "remote sensing has the potential to provide accurate and timely geospatial information describing changes in land-use/land-cover of metropolitan regions" (Yuan *et al*., 2004, pg. 317). The use of remotely sensed imagery allows for an easy means of gathering data on temporal trends and spatial distribution within the image. However, despite advantages several limitations are recognized. First, urban areas usually have features that are smaller than the spatial resolution of most satellites. The satellites in our study have a 30m spatial resolution. This means any urban features that are less than 30m will be generalized and could be removed if the majority of the pixel is not urban features (Shahtahmassebi *et al.*, 2012). Finally, the most common approach is classifying urban features into specific categories such as industrial, commercial residential, roads, etc. However, using this approach can have limitations. First, most urban features are not spectrally different which will cause the classification to place features in the wrong classes. Finally, buildings are made up of different materials resulting in the same class having different spectral signatures making classified images bias (Powell *et al*., 2007).

2. Background

As of 2008, "more than half of the world's human population has resided in urban areas; and by 2030, urban inhabitants will account for approximately 60 % of the world's population" (Waibel, 1995).

Therefore, careful monitoring of urban and transportation expansion is principal in a continually urbanizing world. Urban-land use information is of growing importance for planners, geographers and environmental scientists. Current, "practical processes for updating urban land-use/land-cover maps in municipal governments mainly rely on aerial photo interpretation and field surveys" (Hu and Wang, 2013, 790). Hu and Wang (2013) emphasize, "with continued changes in the urban environment…the process of updating land-use/land-cover [especially with greater frequency] has become a routine assignment for municipal administrators" (2013, 791). Thus understanding the importance of urban environments is not only beneficial, but also crucial for cities to maintain vitality. Urban travel patterns are directly connected to the urban infrastructure [or lack of urban infrastructure] surrounding an individual. Thus Baslington (2008) indicates the benefits of reduced automobile use [replaced by alternatives modes of transportation, such as public transit] are both applied to the environment and an individual's health.

There is a complex relationship between transportation and urban development; urban growth strongly dictates the form of urban spatial structures (Aljoufie, Zuidgee, Brussel and Van Maarseveen, 2013). Aljoufie et al. (2013), reveal that, urban growth is strongly connected to transportation's mutual cause and effects... by monitoring the rapid growth of cities and their populations, [we notice an] increase [of] urban traffic (Cervero, 2003 and Millot 2004), traffic congestion, and infrastructural pressures (Allen and Lu, 2003, Bhatta 2010 and Brueckner, 2000). As Wang, Lu and Peng, (2008) state, the urban transportation system is molded from geographical, social, economic and environmental factors. Similar to Meyer and Miller's understanding of the transportation network; they argue that transportation systems provide the, "mobility for people and goods influence patterns of growth and levels of economic activity through land accessibility" (2001, 450). In order to plan and manage urban spaces effectively, Klosterman (1999) highlights the importance of knowing underlying driving forces, and the combination of the chronology and impacts of urbanization. Ultimately, "city planners, economists and resource managers…need advanced methods and a comprehensive knowledge of the cities under their jurisdiction to make the informed decisions necessary to guide sustainable development" (Pham, Yamaguchi and Bui, 2011, 223). Thus, the incorporation of remotely sensed imagery in urban regions provides greater coverage over a large area with both high spatial and temporal frequency, which is beneficial for studying historical time series (Jensen and Cowen, 1999).

Although attempting to reverse urbanization would be extremely problematic, efforts can be made to ensure future growth is of a sustainable nature. There has been, "increased efforts within the Canadian federal government to better align its science activities with policy…one priority concern is urbanization" (Guindon and Zhang, 2006, 276). Guindon et al., continue to explain that, "the rapid suburbanization of major Canadian cities has potentially detrimental effects including loss of valuable agricultural and eco-sensitive (i.e. wetlands, forests) lands and amplified energy consumption, greenhouse gas emissions and air pollution increasing from private vehicle use" (2006, 149). Sustainable planning requires the cautious use of resources and the management of the processes of landscape change (i.e. via remotely sensed imagery).

3. Study Area

The area of interest includes the City of St. Catharines along with a portion of its neighbour to the south, the City of Thorold (Figure 1). The study area resides within the Niagara Region, just south of Lake Ontario, and 19 km from the U.S.A border. The area consists of a total study area of 137.484 km^2 while the ground area is 97.221 km^2 leaving 40.263 km^2 of the study area to water bodies. Although the study area does not cover all of the two neighbouring cities, these cities have a combined population of 149,331 in 2011, down from 150,213 in 2006, with a low in 2001 of 144,215 according to Statistics Canada

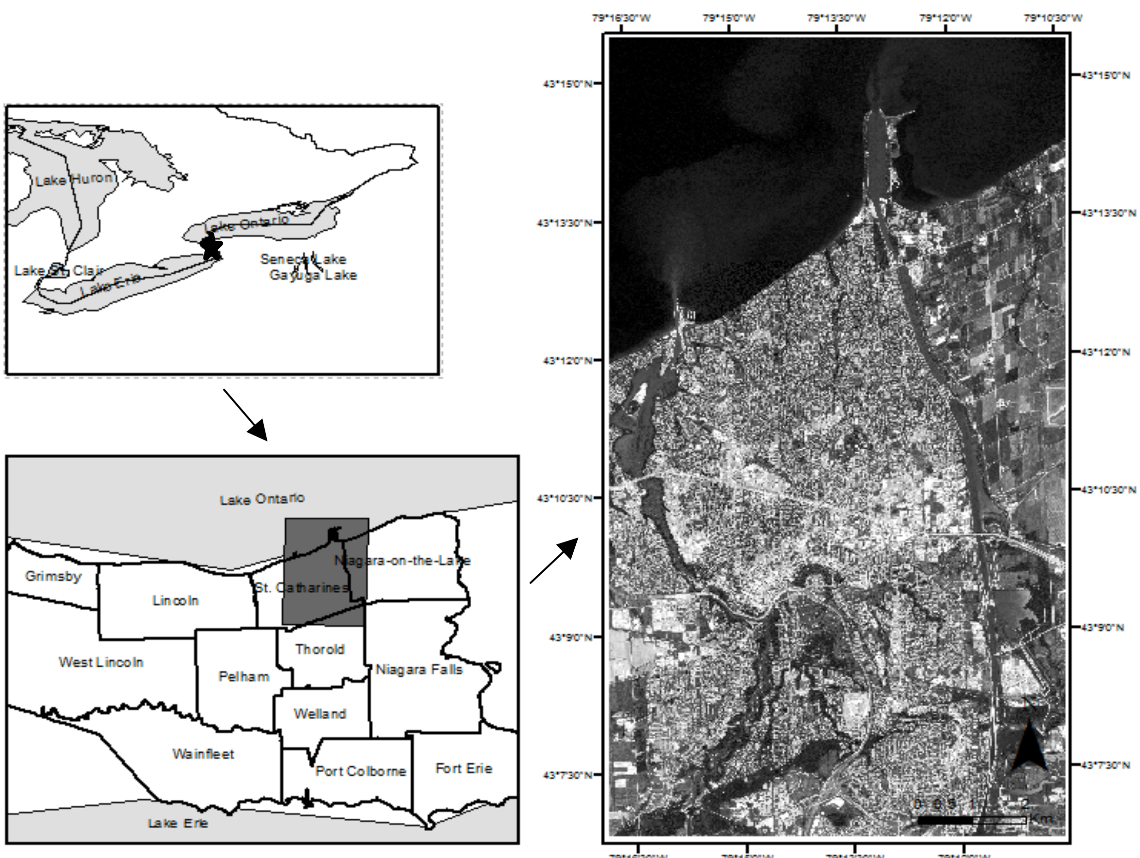


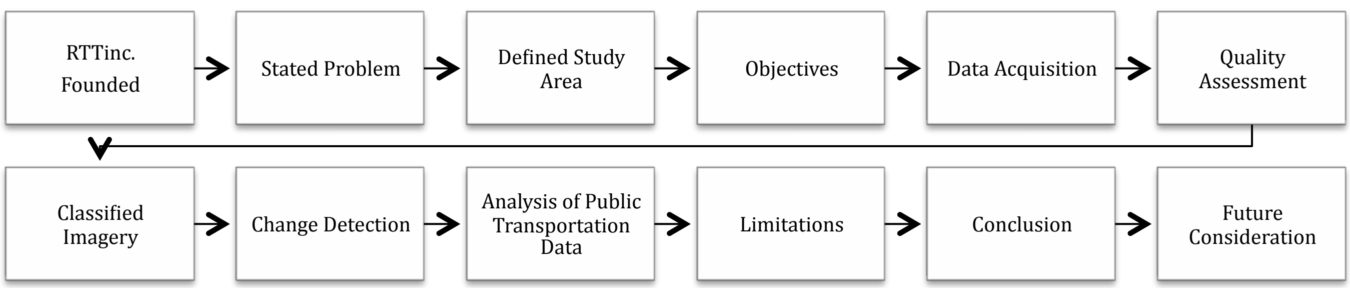
Figure 1 - Study Area

(Statistics Canada). St. Catharines is home to Brock University, which is a continuously growing University with an enrolment of over 18,000 students during the 2012-2013 school term, a rise from the 11,916 students that were enrolled in the 2001-2002 school term, an increase of 52.65%. During these ten years, the population of the combined cities has risen only 3.55 (Brock University, Statistics Canada).

4. Methodology

4.0 Project Development

The following diagram below is an outline of the project development stages that RTT inc. applied throughout the research process.



4.1 Reference Data & Data Collection

The purpose of this research project is to assess the growth in the St. Catharines and Thorold, Ontario area through remote sensing, followed by reviewing how the public transit system has adapted around such growth from 2000 to 2013. Historical remotely sensed images were acquired in September of 2000, September of 2005, both from Landsat7 ETM+ and from July 2009 from GeoEYE-1. All three images acquired are multispectral images, with four bands being used throughout the study (Band 1 – Blue, Band 2 – Green, Band 3 – Red, and Band 4 – NIR). All four bands were used as they all facilitate to differentiating the six classified land-use/land-cover regions. Blue is used to differentiate between urban and bare soil, while green shows the change between vegetation and urbanized land. Red distinguishes the turbid water to deep water, and the red and NIR (near-infrared) distinguishes the vegetation to urbanized land to water, each all having significantly unique reflectance values from band to band allowing to be differentiated (figures 3, 4, 5). The Landsat7 ETM+ images contain an 18-day temporal resolution (2000. 2005) while the GeoEYE-1 image from 2009 contains a 2-8-day temporal resolution (GeoEYE-1, 2009). Images from multiple years are needed in order to conduct a change detection analysis within the region for a desired timeframe. To maximize the information gathered form these remotely sensed images, data quality analyses were conducted prior to obtaining images and again once obtained. The analysis showed that there is no cloud cover within the GeoEye-1 2009 image, and limited coverage on the previous two dates. Quality checking data ensures that no data contained anomalies that could pose an effect within the study.

4.2 Data Preprocessing

In order to achieve the best results possible the data were calibrated both geometrically and radiometrically. Due to the three different images coming from two different sensors, the data needed to be geometrically corrected to 30m. This was due to the 2000 and 2005 images had a spatial resolution of 30m and the 2009 image originated in a 0.5m resolution. Pseudo-invariant features (such as the bridges crossing the cannel, and the peak of the entrance to from Lake Ontario to the Welland Cannel) and used as Ground Control Points (GCP's) to geographically verify the location and geometry of the features projected. Since the original 2009 image had already gone through basic corrections, it was assumed that the image was geometrically correct. From the fifteen GCP's that were obtained from the 2009 and used as a reference to geometrically correct the 2000 and 2005 images. An RMS error was calculated to be 0.463 for the rectification of the 2005 image through the 2009 image, while a RMS error was calculated to be 0.428 for the 2001 image being rectified to the 2009 image. The 2000 and 2005 image however is in 8-bit radiometric resolution, while the 2009 image is in 16-bit resolution, this could not be corrected, but was taken into account during analysis.

In this study, supervised classifications were used in order to produce land-use/land-cover maps of the study area. These maps were "the essential tool used for extracting quantitative information from remotely sensed image data (Richards, 1993). Once these maps were produced, a post-classification analysis took place using change detection methods from 2000-2005, 2005-2009, 2000-2009. 4.3 Classification

4.3 Data Processing/Image Analysis

4.3.1 Supervised classification

Using the Region of Interest (ROI) tool, a range from 10n to 100n pixels (n being the number of bands used; 4, with a minimum selection being 40 pixels) (Lillesand et al., 2008). These ROI's were used for the maximum-likelihood algorithm in ESRI 5.0 classic, three quantitative land-use/land-cover maps were produced, one for each of the three years (Appendix: Map 1 - 2000, Map 2 - 2005, Map 3 – 2009).

Initinally we considered classes such as roads, commercial buildings, mixed forest, agricultural land, grassland, and water, to maximize our results for this particular study. However, during classification it was determined that some of these classes had spectral signatures similar to others (Appendix: Figure 3, 4, 5). This resulted in a more generalized classification approach, combining similar classes to create an end total of six classes. Image classifications are summarized in Table 1 for further understanding. All stats were obtained through the maximum-likelihood classification images; once this process was completed, a mode filter was implemented to all the images.

A 3x3 mode filter was applied to the classified data. This filter uses a 'moving window' to pass over the classified image and each pixel's value is determined by the most reoccurring value within the window (Watson,C). The mode filter was used within both the urban and water classes for the 2000 and 2009 image. However, the 2005 image had a mode filter applied to the urban, bare soil and water classes. The filters were applied to increase the aesthetic appeal of the output maps. The mode filter reduces noise within the image.

Table 1 – Land-use/Land-cover Classifications

Class	Description
Agriculture	Any type of crop, grassland, that is outside that of forest.
Bare Soil	Any land-cover that is not covered by any type of agriculture or urban setting. Includes gravel pits, aggregated fields, and dirt roads.
Mixed Forest	Land-cover consisting of large trees; coniferous and deciduous.
Turbid Water	Water consisting of minimal depths, can contain turbid soils.
Urban	Developed land, from commercial buildings, to roads and residential areas.
Water	Water that contains great depths, such as large lakes.

4.3.2 Change detection

Once the data was obtained, corrected and classified, post-classification methods were used to analyze the urban growth within the three different images. Change detection was conducted for 2000-2005, 2005-2009, and an overall change detection from 2000-2009. This produced statistic values, allowing for further examination of the urban growth that the St. Catharines and Thorold have witnessed through the 2000's. The trends of change were then compared to the public transit bus system trends within the study period to gather a better understanding of how these two cities have changed.

4.4 Accuracy Assessment

Through the procedure of accuracy assessment, the data went through a set of statistical tests that were found to be quantifiable by literature values. A confusion matrix (Table 2) was produced, showing the quality of reliability of the data. These values were produced by the gathering of sample units assigned to each class and comparing them to the actual pixels verified on the ground (Congalton, 1991). With this method, one can quantify the probability of a reference pixel being classified correctly within the classification resultant, which can be seen through overall accuracy, the Kappa Coefficient of Agreement and errors of omission and commission (Congalton, 1991). With all the appropriate information presented, the confusion matrix can now be used as a starting point for a basis of descriptive and analytical statistical techniques (Congalton, 1991).

Furthermore, ROI's were used to generate specific land-use/land-cover classifications. After the classifications were completed, the user and the producer were tested through all six classes for quality and accuracy, showing very good accuracy, by evaluating the spectral signatures of each classification to the appropriate ROI's collected (Figure 3, 4, 5).

In order to assess the accuracy of ROIs, errors of omission and commission were produced. An error of omission is the product of dividing the total number of correct pixels by the total numbers of pixels within that class (Congalton, 1991). This measure of accuracy can also be called the producer's accuracy as it indicates the probability of a reference pixel being classified correctly (Congalton, 1991).

An error of commission however, is calculated by dividing the number of correctly classified pixels in a class by the total number of pixels within that class (Congalton, 1991). These errors of commission, therefore gives a measure of user's accuracy, which reveals the probability of the pixels classified, that actually represents the classes on the ground (Congalton, 1991). Therefore, we can see through the analysis of Table 3 that there are indeed various ways in which an image can be considered 'accurate.'

4.5 Bus route production

The 2009 St. Catharines transit bus route was obtained through the Brock University Maps Data, and GIS library. This offered a geographic location for each bus stop for each route within the transit system. From this, a model builder was produced using ArcGIS to convert the points obtained from the Maps Data and GIS library into shapefile polylines. Once these points were converted into a shapefile, each route lines were analyzed using a paper copy along with a street map layer to ensure accuracy.

These steps produced the 2009 bus route lines. From here a paper copy of bus routes from 2001 and 2013 were obtained. These two maps were visually analyzed for difference per route line. From these differences the changes from years were recorded, and produced into their own shapefile. After having 3 available years route lines, GIS analysis took place to overlay their differences throughout the year, this is shown in Map 4.

5. Results and Discussion

In the both the cities of St. Catharines and Thorold, Ontario, urban development has been affected by transportation infrastructure. This relationship was investigated by first monitoring the change of urban pixels in all three images (2000, 2005, and 2009), and second, then overlaying the St. Catharines Transit Commission's bus routes from 2000 – 2013 atop the three images, allowing for statistical and visual analyses to be conducted. This section will analyze the land-use/land-cover types of each image, the changed results and lastly, commentary in regards to the public transit routes and their impact on urban development.

5.1 Supervised Classification Accuracy

Confusion matrices were used to access the accuracy of the maximum likelihood supervised and is represented in Table 2. The overall accuracies for 2000, 2005 and 2009 were, respectively, 98.68%, 96.84% and 93.66% with Kappa coefficient percentage of 95.82%, 95.97%, and 91.66%. Therefore there was a strong relationship between the number of pixels classified correctly and the number of reference (test-site) pixels within each image. The overall strong accuracy of these classification results can be attributed to the amount of training sites chosen and that these training sites were scattered throughout the entire image. These techniques improved the spectral differentiation and variance of classes.

Accuracy Assessments were completed to determine the users and producer's accuracy; this is evident in table 3. The producer's accuracy is relatively high with values ranging from 88.02% to 100%. The user's accuracy was relatively high with an average of 91.66%. However, there are some low values in user's accuracy they are, 52.86% in 2000 for the agriculture class, 70.33% in 2009 for the bare soil class and 75.38% in 2009 for the mixed forest class. The results of the confusion matrix show why the user's accuracies for these specific classes are relatively low. The user's accuracy for agriculture in 2000 is low because 66 out of the 140 in the region of interests were placed in the mixed forest class. This is a usual occurrence in remote sensing because agriculture and mixed forest have very similar spectral signatures shown in Figure 3. In 2009, the bare soil and mixed forest class had relatively low user's accuracy as well. 53 of the 182 pixels in the region of interests were placed in the urban class, resulting in this low user's accuracy. This is a common error in remote sensing classifications as the spectral signatures for bare soil and urban are very similar (Figure 5). The mixed forest class has the same error as the agriculture class in 2000 however it is vice versa. Out of the 195 pixels in the region of interests for the mixed forest class 39 of them were placed in the agriculture class. As stated above agriculture and mixed forest have similar spectral signatures and explains why the user's accuracy is low. Accuracy is relatively high overall resulting in a study that has a lower bias then a study with a relatively low accuracy (Congalton, & Green, 2008).

5.2 Land-use/land-cover Types in 2000

In 2000, the largest land-use/land-cover type was agricultural land (29.47%); agriculture land consists of grassland and agricultural crops (Table 4). The agricultural land-use/land-cover type was mostly spread out in the western, northern, and southeastern parts of the study area. The second most dominant land-use/land-cover type was water and turbid water (27.745% combined). The Lake Ontario shoreline has been increasing every year resulting in an increase in water percentage each year. Urban land is the focus of this study and is the third largest land-use/land-cover type in the study area (21.362%) Urban land consists of residential areas, commercial areas, transportation networks (roads and highways) and Industrial areas. This land-use/land-cover is dominant in the centre of the study area growing along the Queen Elizabeth Parkway (QEW). The fourth largest land-use/land-cover type in the study area is bare soil (10.787%). Bare soil is an area that is covered in soil or a crop that has been harvested. The majority of bare soil is found in the east of the Welland Canal, this is an area that consists of a lot of agricultural fields. The amount of bare soil plots east of the Welland Canal would increase when harvesting occurs. The last land-use/land-cover type is mixed forest. The percentage of mixed forest is the study area is 10.635% (Table 4). The mixed forested area is found along the Twelve Mile Creek. As well as, mixed forested areas are found on the Niagara Escarpment where land is not feasible for construction, as the slope is very high. This is all evident in Table 4 and Map 1-3.

5.3 Land-use/land-cover Types in 2005

In 2005, the largest land-use/land-cover type was still agricultural land, with a tendency for relative continuity (28.483%) even with a 1% decrease. The urban land-use/land-cover type grew by roughly 5% during the five-year span. The second largest land-use/land-cover type is water and turbid water (28.947% combined). This is an increase of roughly 1% from 2000. This results in a decrease of land-use/land-cover by roughly 1%. The urban land-use/land-cover is the third highest land-use/land-cover type (26.221%). The urban land is still situated along the QEW. However, it also expanded into the western area of St. Catharines and into Thorold, the southern area of the study area. The fourth largest land-use/land-cover type is mixed forest (8.257%). Mixed forest is still found along the Twelve Mile Creek and the southwest corner of the study area. However, mixed forest has decreased by roughly 2% from 2000. The last land-use/land-cover type is bare soil. This land-use/land-cover type covers 8.092% of the study area. This is the smallest land-use/land-cover type in the study area and is mostly found east of the Welland Canal. However, bare soil was found in small portions within the urban center. These stats are highlighted in Table 4. These areas were most likely misclassified though as the spectral signatures between urban and bare soil is very similar (Figure 4).

The built-up urban area expanded primarily in the centre of the study area. Development followed along the QEW, the main transportation route through St. Catharines. The St. Catharines urban development grew in a diagonal pattern towards the Twelve Mile Creek from the Welland Canal. The area of Thorold (the southern area of the study area) and the area of West St. Catharines have also increased. Agricultural land, bare soil and mixed forest have all decreased in the study area. These land-use/land-covers lost 8,333,100m^2 of land (Table 4). The Urban class gained 7,126,200m^2 of land (Table 4). It can be assumed that the agricultural land, bare soil and mixed forest decreased mainly because of the expansion of the urban area.

5.4 Land-use/land-cover Types in 2009

In 2009, the largest land-use/land-cover type was water and turbid water combined (29.285% combined). The percentage of water in the study area increased another 0.3% from 2005 to 2009. The second largest land-use/land-cover type is now urban areas (27.862%). This is an increase of 1.641% from 2005 to 2009. The majority of urban growth has occurred in the northern area of St. Catharines however we also see growth in west St. Catharines and Thorold as well. The third largest land-use/land-cover type is agriculture (24.728%). Agriculture had a large reduction in area as it decreased roughly 4% from 2005. A large result of this is the starting construction of the new hospital in west St. Catharines. This area was a large agricultural field in 2005 and became a construction area in 2009. The other two land-use/land-covers are mixed forest and bare soil with a percentage of 12.136% and 5.988%, respectively. This is evident in Table 4 and Figure 5. Bare soil decreased on the east side of the Welland Canal resulting in a much lower percentage from 2005. This is most likely a result of temporal factors as the 2005 image was taken in September while the 2009 image was taken in July (Geoeye, 2009; Landsat -

7 Imagery, 2005). September crops are being harvested or have already been harvested and July is a growing month for vegetation. Mixed forest has increased along the Twelve Mile Creek.

The built-up urban area expanded primarily north of the QEW, the major highway through St. Catharines. The area of Thorold has major infill of urban development. This urban development could be in relation to the Brock Enrollment has increased every year (Brock Facts, 2001, 2006, 2011). Infilling also occurred in West St. Catharines, as more houses were needed for the growing student population. Agricultural land was the majority land-use/land-cover type used to build up the urban form. This can be determined as from 2005 to 2009 the agriculture land-use/land-cover decreased by 5,161,500m^2 (Table 4). From 2005 to 2009 the urban land-use/land-cover increased by 1,810,800m^2 (Table 4). The reduction in agriculture also, resulted in an increase in the mixed forest land-use/land-cover by 5,333,400m^2 (Table 4).

5.5 Change Detection between 2000 and 2005

From 2000 to 2005, multiple changes to land-use/land-cover types have been seen through analyzing remotely sensed images and their statistics. A change detection matrix was derived to show the change between these two images. The change detection matrix shows the increase in the urban land-use/land-cover and how this increase has occurred over time. The urban class gained an area 7,126,200m^2 of land between 2000 and 2005, which is an increase of 4.859%. Through the confusion matrix it can be determined that 10.9% of the increase in Urban came from agriculture pixels, 16.3% came from bare soil pixels, 1.6% came from mixed forest pixels, and 5.7% came from turbid water and water pixels combined (Table 4). This is important to acknowledge as it determines which land-use/land-covers are being used for development. Furthermore, it can be determined where growth occurred by analyzing the remotely sensed images created.

The visual aspect of change detection is an easy way to determine change. Studying Table 4 it can be seen that the majority of urban change from 2000 to 2005 occurred in the centre of the study area, along the QEW. The growth around the QEW is logical as it is a main transportation network into major cities such as Hamilton and Toronto. In addition, commercial facilities desire a close proximity off major transportation networks and the majority of jobs in the manufacturing sector are built along the QEW in St. Catharines so, they have access to a major transportation network. This would result in the majority of urban development occurring around the QEW. North of the QEW has also seen urban development. The area of Port Dalhousie and areas along Lake Ontario have been development. These developments would not be directly related to the QEW access. This development is most likely a result of Lake Ontario and having access to Lake Ontario.

Three other areas in the study had a large increase in urban development. These areas include Thorold, west St. Catharines and the Pen Centre/Oakdale area; this can be visually seen in Figure 2 comparing the 2000 image to the 2005 image. The urban area of Thorold infill of urban development can easily be seen through the images. This infill was not created directly from a population increase as the population of Thorold only increased by 140 people from 2001 to 2006 (Statistics Canada, 2001, 2006. However, this infill could be a result of the cities proximity to Brock University. As from 2001 to 2006 the enrollment at Brock University increased from 11,916 to 17,453, an increase of 5,537 students (Brock Facts 2001, 2006). These students need a place to reside during the school semesters and could be a major reason why this urban development infill occurred in Thorold from 2000 to 2005. West St. Catharines has had a major increase in urban development between 2000 and 2005. The development of the Fourth Avenue plaza and the increase of commercial stores along Fourth Avenue have increased the urban development of this area. This commercial cluster could also attract residents to live in the area as they would be in close proximity to this commercial cluster. Brock University's enrollment may also have an effect on the urban development of west St. Catharines as it is in close proximity to Brock University and has a bus route to support the student population, which will be analyzed in a section below. From 2000 to 2005 an increase in urban development can be seen near the Pen Centre and Oakdale area. This area has a large student population and has the commercial strip along Hartzel road.

5.6 Change Detection between 2005 and 2009

From 2005 to 2009, infill of urban development has occurred. Urban development did increase from 2005 to 2009 but was not as large of a change as seen in 2000 to 2005. The urban land-use/land-cover saw a growth of 1,810,800m^2 from 2005 to 2009, which is an increase of 1.641% (Table 4). A confusion matrix for change detection between 2005 and 2009 was also derived. The class that decreased the most from the increase in urban was the agriculture class. 21.5% of the agriculture class from 2005 changed to urban in 2009, 9.6% of the mixed forest class from 2005 changed to urban in 2009, 7.3% of the bare soil class from 2005 changed to urban in 2009 and 2.4% of turbid water and water class combined changed to urban in 2009. It can be determined that these classes decreased in order for urban development to occur (Table 5). The major change from 2005 to 2009 was the decrease in agriculture by 5,161,500m^2 or a decrease of 3.755% (Table 4). Through visual interpretation it can be determined what areas have been affected by change.

Analyzing the 2005 and 2009 images created it can be determined that change was much less than the change from 2000 to 2005. Change has occurred north of the QEW, in Thorold and in West St. Catharines however the change isn't that large, this can visually be seen while studying the 2005 image and 2009 image in Figure 2. The urban development between 2005 and 2009 was not as large of a change between 2000 and 2005 as the population from 2006 to 2011 in St. Catharines and Thorold actually decreased. The population in St. Catharines and Thorold combined was 150,213 and the population in 2011 was 149,331 (Statistics Canada, 2006, 2011). This decrease was largely affected by the closing of manufacturing plants (St. Catharines City Council, 2007). This can determine why the urban change detection was less from 2005 to 2009 then it was from 2000-2005. On the other hand, urban development may have increased in student areas as the Brock Enrollment continues to rise (Brock Facts, 2001, 2006, 2011). Hence, this is why it can be seen that the Thorold and west St. Catharines area continue to grow. These are two areas in St. Catharines that are heavily populated by students. A major construction project that can be seen in the 2009 is the development of the new hospital in west St. Catharines. This is the large bare soil area on the west side of the 2009 image (Map 3). The construction of this hospital caused an increase in bare soil and a decrease in agriculture. The reason infill of urban development north of the QEW is unknown. However, it is probably due to the growth of the city and citizens moving away from the central business district and into subdivision areas.

Another change that can be seen in the 2009 image is that the east side of the image has less bare soil then the 2005 image. The reason for this is the temporal change. The 2005 image was taken in September, which is past harvesting season for most crops (Landsat-7 Imagery, 2005). The 2009 image was taken in July, which is part of the growing season for most crops (GeoEye, 2009). This is the reason for the very low bare soil percentage recorded for the 2009 image.

5.7 Change Detection between 2000 and 2009

Using change detection to analyze the 2000 and 2009 images it can be determined that two major land changes have occurred within the study area. The first land-use/land-cover change is the significant increase in urban development and the second is the significant reduction in agriculture land. The urban land-use/land-cover class gained 6.5% or 8,937,000m^2 of land from 2000 to 2009. While the agricultural land-use/land-cover class decreased by 4.743% or 6,520,500m^2 (Table 4). A confusion matrix for change detection was created for the images from 2000 and 2009. The image difference value for urban is 30.4% and for agriculture it is -16.1% (Table 5). Therefore, it further emphasizes the loss of agriculture and the gain of urban land.

The majority of change detection can be determined by analyzing the 2000 and 2009 images. The majority of change occurs in the same areas stated in the change detection between 2000 and 2005. However, the changes between 2000 and 2009 are more noticeable. Urban development can be seen easily within the areas of Thorold, west St. Catharines and North St. Catharines (Figure 2).

5.8 Urban Development and its influence on Public Transportation

After analyzing urban development RTT Inc. needed to determine how urban development affects public transportation. To accomplish this three years of bus routes were analyzed. The years were 2001, 2009 and 2013.

5.8.1 2001 Bus Route

The bus route in 2001 was focused on the residences of St. Catharines rather than the students in St. Catharines. The majority of buses are focused around north St. Catharines. The bus routes in heavily populated student areas such as west St. Catharines, Thorold and near the Pen Centre have very little bus routes or poor bus frequency. To travel from Brock University to west St. Catharines requires you to take two buses. Bus users travelling from Brock University to west St. Catharines have to take the 116 to

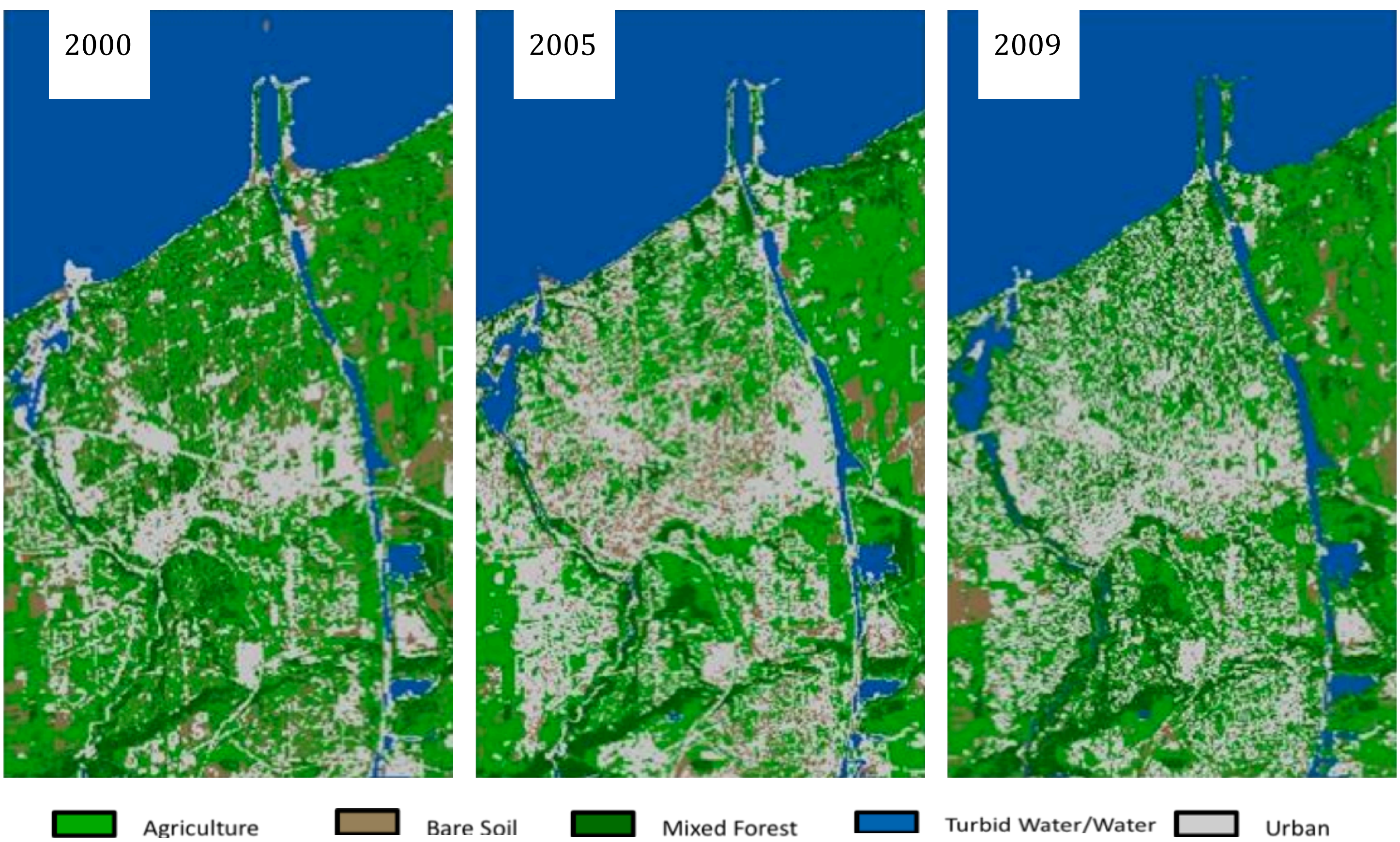


Figure 2 - Land-use/Land-cover maps [2000, 2005, and 2009]

Glendale and Glenridge and then transfer to the 115 to travel to their destination in West St. Catharines. Bus users at Brock University students wanting to travel to Thorold from Brock University have to take the 21 that runs every 60 minutes. Travelling to the Pen Centre from Brock University students have to take the 122, this bus runs every 30 minutes. However, it does not run Saturday or Sunday making it very difficult for students to travel to the Pen Centre on weekends (St. Catharines Transit Commission, 2001).

5.8.2 Bus Route changes 2001 to 2009

The route changes that occurred in 2009 from 2001 were based around students and student living areas. The implementation of the West Brock Commuter allowed students to travel from Brock University to West St. Catharines via one bus instead of two. This allowed students to travel faster since they do not have to wait to transfer buses. Furthermore, The West Brock Commuter bus covers all of the urban infill area and not just Louth Street which the 115 in 2001 travels along; this is shown in Map 4 on the west side of the image in red. The 104 bus travelling to the Oakdale area has also increased the area it covers in 2009; this can be seen in Map 4 in red. An addition to the Thorold bussing allowed for infill to occur in the Thorold area. The addition was the Tupper Extra bus. This bus runs through Confederation Heights in Thorold and runs every 30 minutes (St. Catharines Transit Commission, 2013). This bus was a very important feature in building Thorold's student population, as before this bus there was no bus that entered Confederation Heights.

5.8.3 Bus Route changes 2013

The route changes that occurred in 2013 were focused around students and student living areas as well. New bus routes were focused around Thorold and bus frequency was increased on multiple buses. Multiple buses were added and changed in Thorold, the Tupper Extra bus was removed but three new Thorold buses were created. The buses created were the 28 traveling from Brock to towpath, the 29 traveling from Brock through Confederation Heights and the 30 travelling from Brock to Sullivan (St. Catharines Transit Commission, 2013). These buses can be seen in Map 4 in the southeastern corner of the image in yellow. The increases in these buses allow the majority of Thorold to be reached through buses. However, for the most part, there were minimal increases of new public transit routes over this 12-year duration. The majority of change observed with public transportation occurred with the frequency of bus stops.

Public transit routes travelling to Thorold from Brock University in 2001 required a 60-minute wait and there was only one bus to take. In 2013, there are four buses students can take to reach Thorold from Brock University and the majority of them run every 30 minutes. The second change is to the 116-bus route. This route runs every 15 minutes from 6:45am to 6:15pm Monday to Friday in 2013. In 2001, this bus route ran every 15 minutes from 6:45am until 12:15pm and then ran every 30 minutes from 12:15 to 3:15pm and then every 15 minutes till 6:15pm. In addition, the Saturday bus in 2013 runs till 11:15pm. However, the 2001 bus on Saturday only ran till 6:15pm. Another large change in frequency is the West St. Catharines bus. The West St. Catharines bus ran every 30 minutes from 6:30am to 6:00pm however the bus ran every 60 minutes from 6:15pm to 11:15pm in 2001. In addition, students had to take the 116 to take the West St. Catharines bus. In 2013, there is a bus that travels from Brock University directly to West St. Catharines. Furthermore, this bus runs every 30 minutes from 7:20am to 10:30pmMonday to Friday. The last major update in public transit from 2001 to 2013 is the implantation of the 122 – Brock to Pen Centre bus and the 124 – Brock – Glendale – Pen Centre. Before these buses were created there was no direct route from Brock University to the Pen Centre. The 122 and 124 run every 30 minutes Monday to Friday (St. Catharines Transit Commission, 2013; St. Catharines Transit Commission 2001).

5.9 Limitations

The assessment of growth in St. Catharines and Thorold, Ontario has contained several limitations. The first limitation identified was the quality of the data. The spatial resolution for all three images was 30m, resulting in the generalization or grouping of several classes (i.e. in the instance of the urban class). Furthermore, 'mixels' (mixed pixels) were encountered during the classification process. For example, urban and bare soil pixels were located within Lake Ontario and bare soil pixels were located within urban areas. Thus, when examining the change detection results the percentage of certain classes may not be 100% accurate. For visual purposes a smoothing majority filter was implemented on the image.

The second limitation was cost. Increases in funds could have provided RTT inc. with images containing greater spatial and radiometric resolutions. In addition, more funding would allow RTT Inc. to purchase additional images within the time period of 2000 to 2013; increasing the amount of datasets to choose from, ultimately resulting in higher levels of accuracy.

The third limitation was temporal. Two images were acquired in September and one was acquired in July. Temporal changes can affect the accuracy of change detection. For instance, July is a growing season for agriculture and September is a harvesting season. This results in class changes over non-urbanized areas. Analyzing Images with the same temporal frequency removes this error.

7. Conclusions and Recommendations

7.1 Conclusions

All together, the following research intended to understand the link between urban growth and the public transportation network in St. Catharines and Thorold, Ontario. RTT Inc. monitored land-use/land-cover changes within the study area by means of remotely sensed imagery and the use of change detection, in addition to the analyses of public transit routes, ultimately with the goal of understanding the relationship between public transportation and urban development. The following conclusions have been determined based upon the coinciding research: (1) using change detection RTT Inc. discovered there was minimal urban sprawl development between 2000 to 2009. However, urban infill tended to be the developmental pattern of the urban fabric within the study area. (2) There were minimal increases in new public transportation routes over the 14-year duration (2000 to 2013) in St. Catharines, although Thorold contained the majority of new transportation routes. (3) The majority of change observed within public transportation occurred via the frequency of bus services. Despite minimal expansion of new bus routes in St. Catharines specifically, bus frequencies continually increased from 2000 to 2013. (4) The adequacy of the St. Catharines Transit Commission cannot be fully understood without having a standard to compare it to.

7.2 Recommendations

Moving forward, RTT Inc. has suggested several improvements that could benefit future assessments. Firstly, eliminating the limitations listed above would lead to increases in accuracy and precision in future consultations. Second, comparisons between a city of similar size to our study area would allow for a greater understanding of the degree of adequacy that the St. Catharines Transit Commission (SCTC) is currently operating in. The final improvement suggested would be the collection of qualitative and quantitative data from transit users from varying routes within the defined study area. The implementation of these improvements would increase the effectiveness of RTT Inc.'s research capabilities. All together, the future implications of RTT Inc.'s research are critical in a rapidly urbanizing world. Thus, the incorporation of remotely sensed technologies is extremely beneficial for municipalities today; remote sensing will lead to better decision-making models for future land use development, provides accurate chronology of urban development and lastly, improved public transportation planning, ensuring all residents are situated within reasonable proximity to public transit. Resulting in economic, environmental and social success for all municipalities.

8. Appendix

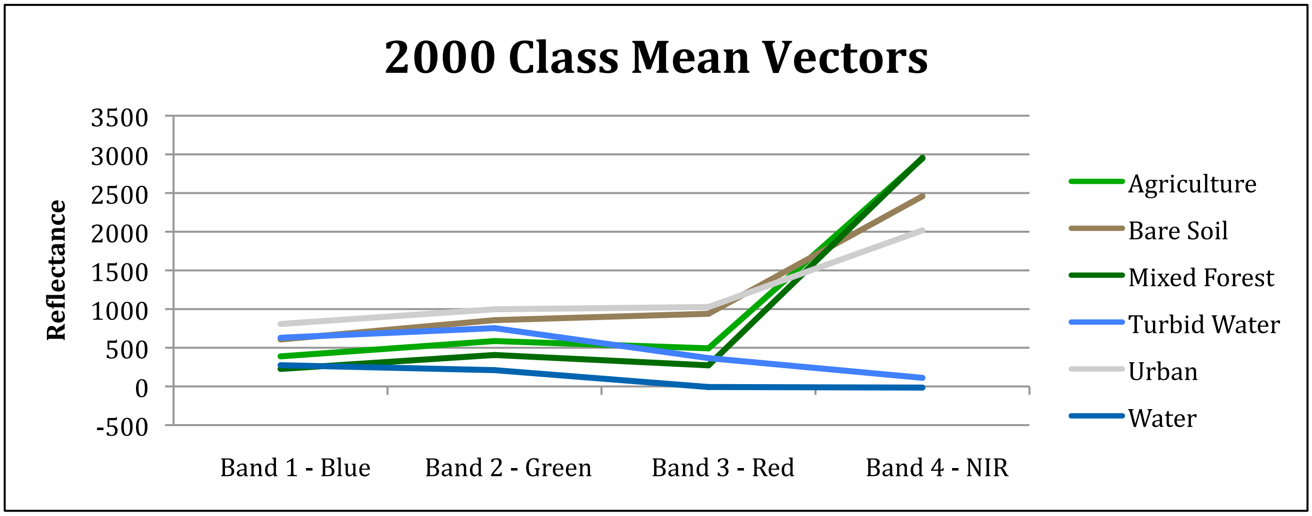


Figure 3 - 2000 Spectral Reflectance Signatures

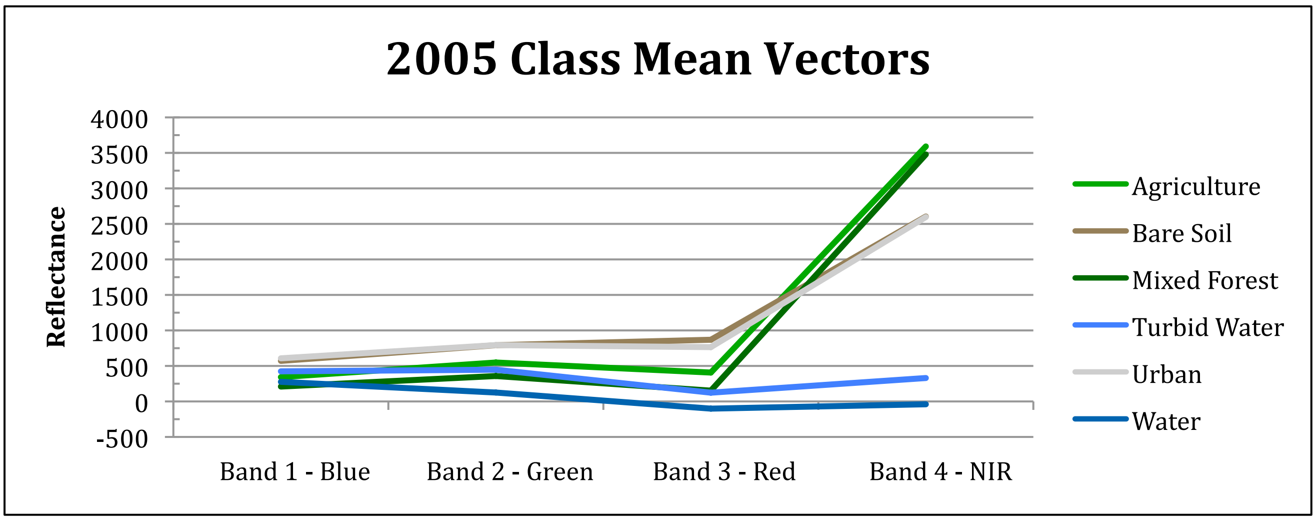


Figure 4 - 2005 Spectral Reflectance Signatures

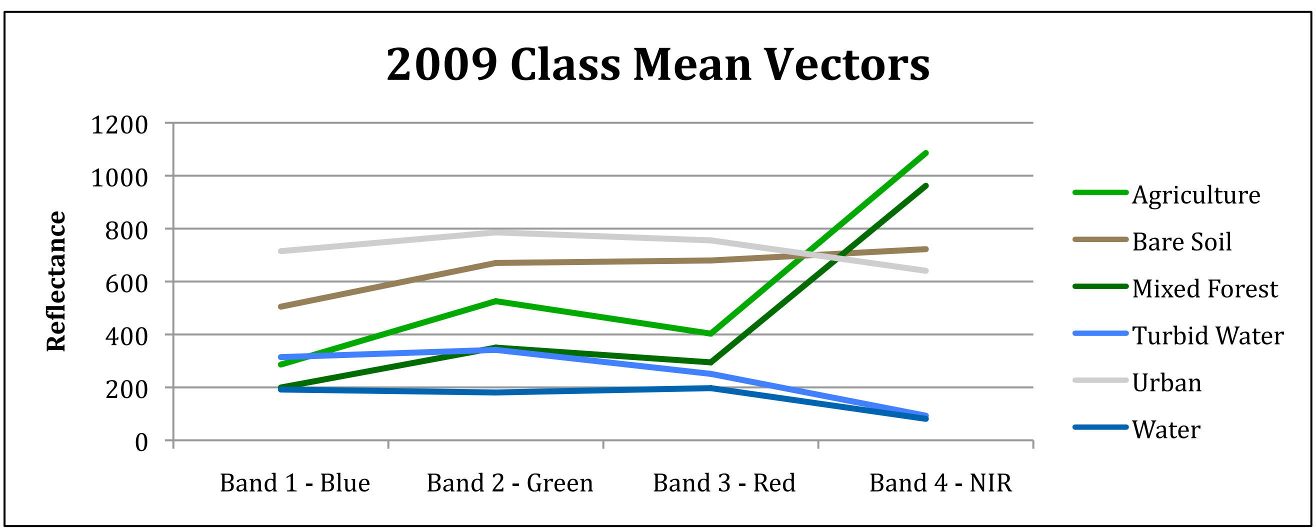


Figure 5 - 2009 Spectral Reflectance Signatures

Table 2 - Confusion Matrix by Pixels [2000, 2005, 2009]

2000

Class	Agriculture	Bare Soil	Mixed Forest	Turbid Water	Urban	Water	Total
Agriculture	**74**	0	66	0	0	0	140
Bare Soil	0	**101**	0	0	1	0	102
Mixed Forest	10	0	**261**	0	0	0	271
Turbid Water	0	0	0	**437**	0	0	437
Urban	0	2	0	1	**139**	1	143
Water	0	0	0	0	0	**5023**	5023
Total	84	103	327	438	140	5024	6116
	Overall Accuracy	0.98675605	98.68%				
	Kappa Coefficient	0.9582					

2005

Class	Agriculture	Bare Soil	Mixed Forest	Turbid Water	Urban	Water	Total
Agriculture	**259**	0	0	0	0	0	259
Bare Soil	0	**158**	0	0	22	0	180
Mixed Forest	5	0	**57**	0	0	0	62
Turbid Water	0	0	0	**100**	0	0	100
Urban	0	4	0	1	**306**	0	311
Water	0	0	0	0	0	**102**	102
Total	264	162	57	101	328	102	1014
	Overall Accuracy	0.968441815	96.84%	`			
	Kappa Coefficient	0.9597					

2009

Class	Agriculture	Bare Soil	Mixed Forest	Turbid Water	Urban	Water	Total
Agriculture	**296**	2	17	0	36	0	351
Bare Soil	1	**128**	0	0	53	0	182
Mixed Forest	39	0	**147**	1	8	0	195
Turbid Water	0	0	2	**330**	0	11	343
Urban	4	2	1	2	**871**	0	880
Water	0	0	0	0	0	**873**	873
Total	340	132	167	333	968	884	2824
	Overall Accuracy	0.936614731	93.66%				
	Kappa Coefficient	0.9166					

Table 3 - Accuracy Assessment

Class	Producer's Accuracy (%)	Omission Error (%)	User's Accuracy (%)	Commission Error (%)
		2000		
Agriculture	88.1	11.9	52.86	47.14
Bare Soil	98.06	1.94	99.02	0.98
Mixed Forest	79.82	20.18	96.31	3.96
Turbid Water	99.77	0.23	100	0
Urban	99.29	0.71	97.2	2.8
Water	99.98	0.02	100	0
		2005		
Agriculture	98.11	0	100	0
Bare Soil	97.53	0.99	87.78	12.22
Mixed Forest	100	2.47	91.94	8.06
Turbid Water	99.01	6.71	100	0
Urban	93.29	1.89	98.39	1.61
Water	100	0	100	0
		2009		
Agriculture	87.06	12.94	84.33	15.67
Bare Soil	96.97	3.03	70.33	29.67
Mixed Forest	88.02	11.98	75.38	24.62
Turbid Water	99.1	0.9	96.21	3.79
Urban	89.98	10.02	98.98	1.02
Water	98.76	1.24	100	0

Table 4 - Change Detection [2000, 2005, 2009, and Absolute Change]

	2000		*2005*		*Absolute Change, 2000-2005*	
Land-use/Land-cover	m^2	%	m^2	%	m^2	%
Agriculture	40,518,000	29.471	39,159,000	28.483	-1359000	-0.988
Bare Soil	14,830,200	10.787	11,125,800	8.092	-3,704,400	-2.695
Mixed Forest	14,621,400	10.635	11,351,700	8.257	-3,269,700	-2.378
Turbid Water	3,437,100	2.5	8,389,800	6.102	4,952,700	3.602
Water	34,708,500	25.245	31,408,200	22.845	-3,300,300	-2.4
Urban	29,368,800	21.362	36,495,000	26.221	7,126,200	4.859

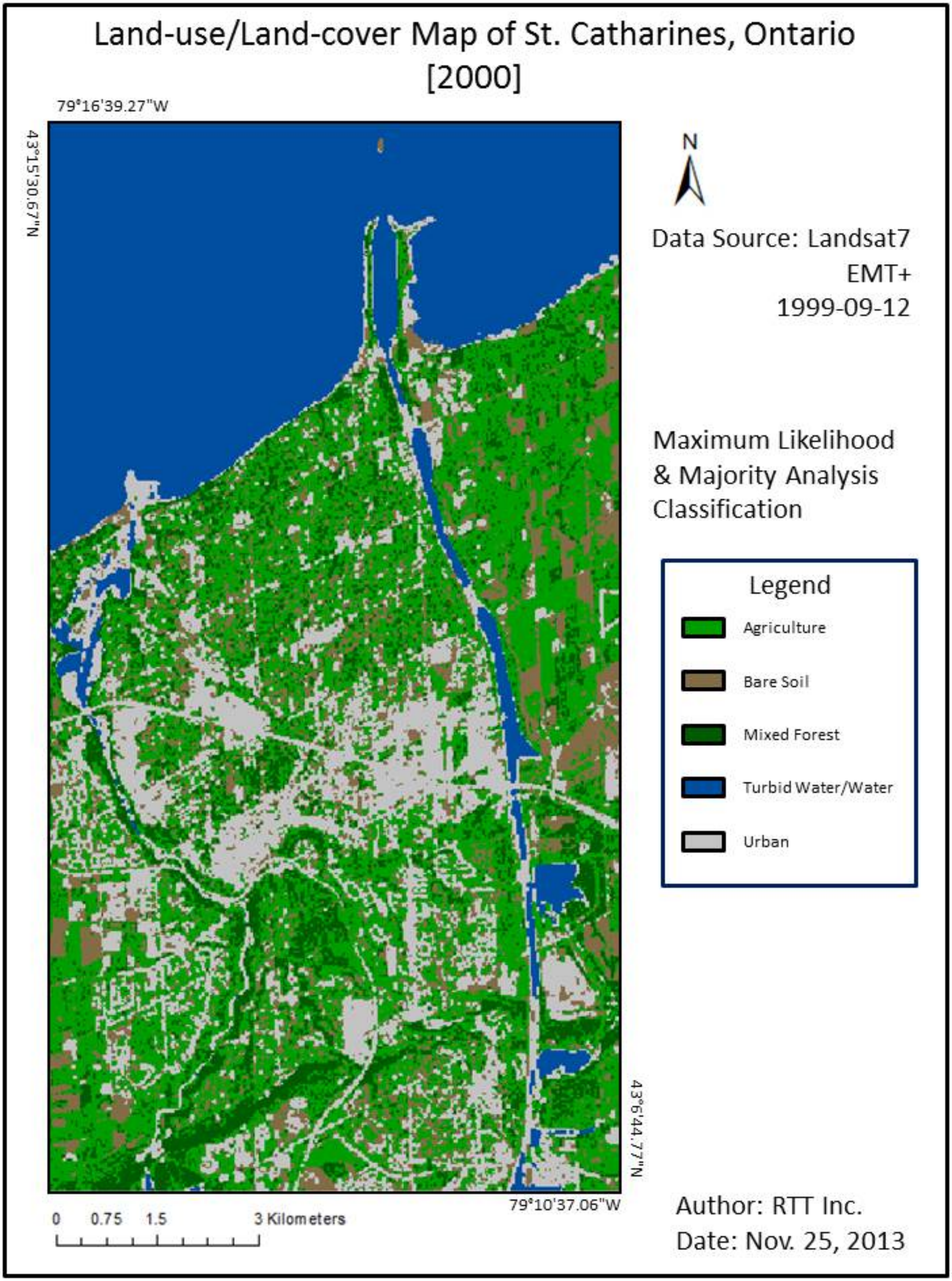
	2005		*2009*		*Absolute Change, 2005-2009*	
Land-use/Land-cover	m^2	%	m^2	%	m^2	%
Agriculture	39,159,000	28.483	33,997,500	24.728	-5,161,500	-3.755
Bare Soil	11,125,800	8.092	8,233,200	5.988	-2,892,600	-2.104
Mixed Forest	11,351,700	8.257	16,685,100	12.136	5,333,400	3.879
Turbid Water	8,389,800	6.102	30,013,200	21.83	21,623,400	15.728
Water	31,408,200	22.845	10,249,200	7.455	-21,159,000	-15.39
Urban	36,495,000	26.221	38,305,800	27.862	1,810,800	1.641

	2000		*2009*		*Absolute Change, 2000-2009*	
Land-use/Land-cover	m^2	%	m^2	%	m^2	%
Agriculture	40,518,000	29.471	33,997,500	24.728	-6,520,500	-4.743
Bare Soil	14,830,200	10.787	8,233,200	5.988	-6,597,000	-4.799
Mixed Forest	14,621,400	10.635	16,685,100	12.136	2,063,700	1.501
Turbid Water	34,37,100	2.5	30,013,200	21.83	26,576,100	19.33
Water	34,708,500	25.245	10,249,200	7.455	-24,459,300	-23.79
Urban	29,368,800	21.362	38,305,800	27.862	8,937,000	6.5

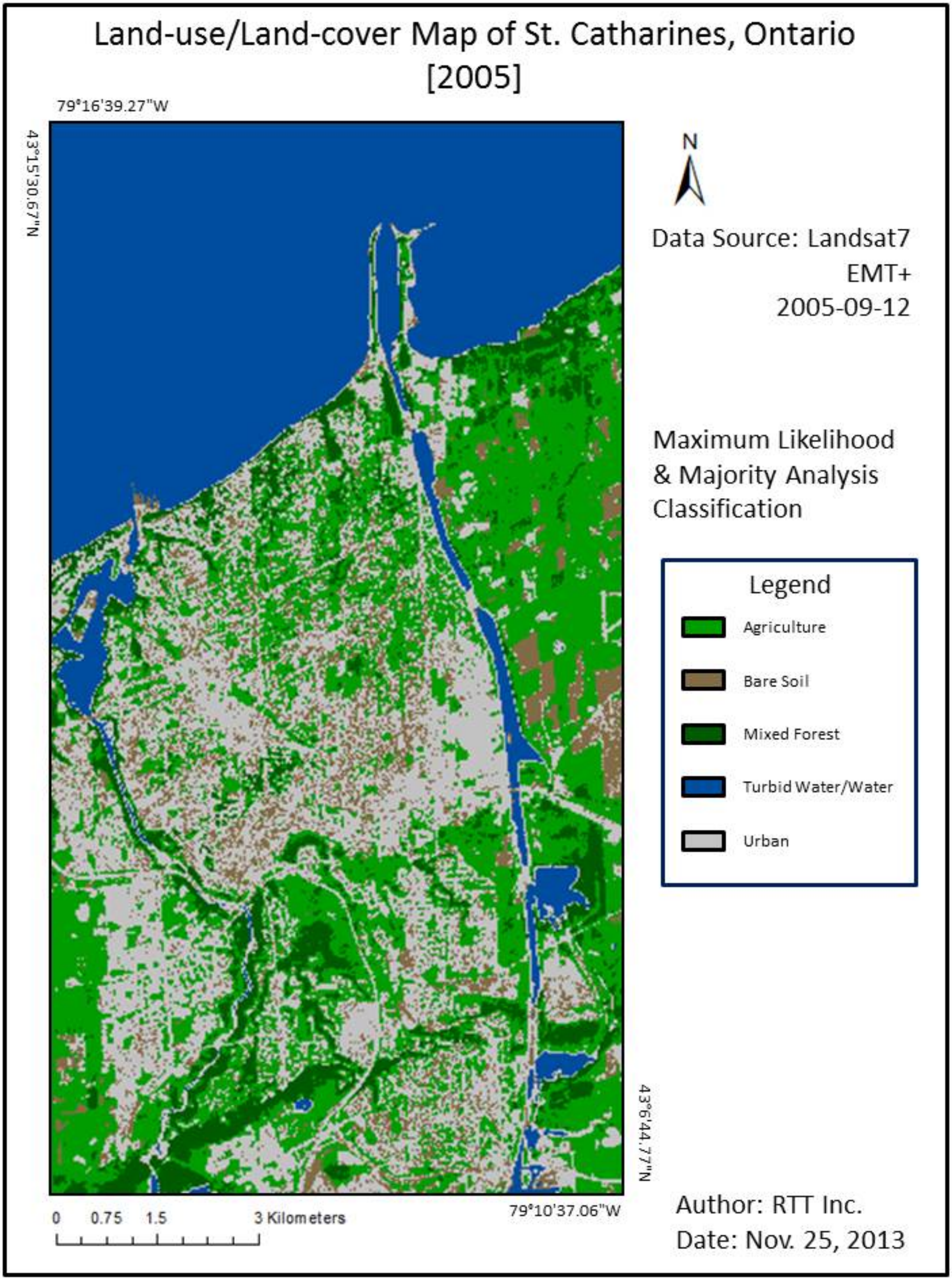
Table 5 – Change Detection by Percent: Class to Class comparison

			2000-2005			
Class	Agriculture	Bare Soil	Mixed Forest	Turbid Water	Urban	Water
Agriculture	**60.1**	39.9	38.7	0.7	10.9	0.0
Bare Soil	7.1	**19.4**	3.7	1.5	16.3	0.0
Mixed Forest	10.5	1.8	**43.4**	0.7	1.6	0.0
Turbid Water	0.5	1.4	0.5	**90.5**	5.2	9.9
Urban	22.2	37.5	13.7	6.2	**65.7**	0.1
Water	0.0	0.1	0.0	0.5	0.5	**90.0**
Total	100	100	100	100	100	100
Class Changes	39.9	80.6	56.6	9.5	34.4	10.0
Image Difference	-3.4	-25.0	-22.4	144.1	22.7	-9.5
			2005-2009			
Class	Agriculture	Bare Soil	Mixed Forest	Turbid Water	Urban	Water
Agriculture	**51.2**	26.1	27.4	1.8	21.5	0.0
Bare Soil	10.1	**11.7**	2.9	0.5	7.3	0.0
Mixed Forest	14.9	7.2	**55.5**	3.0	9.6	0.0
Turbid Water	0.2	1.5	1.3	**87.6**	2.4	68.1
Urban	23.6	53.4	13.0	3.6	**59.1**	0.1
Water	0.0	0.1	0.0	3.4	0.0	**31.7**
Total	100	100	100	100	100	100
Class Changes	88.3	48.8	44.5	12.4	40.9	68.3
Image Difference	-26.0	-13.2	47.0	257.7	6.3	-67.4
			2000-2009			
Class	Agriculture	Bare Soil	Mixed Forest	Turbid Water	Urban	Water
Agriculture	**45.4**	37.6	33.5	1.7	17.3	0.1
Bare Soil	8.8	**12.2**	4.4	0.5	7.5	0.0
Mixed Forest	17.3	7.8	**2.3**	2.3	6.9	0.1
Turbid Water	0.4	1.5	0.5	**92.0**	6.9	70.3
Urban	28.2	40.9	18.0	3.5	**61.3**	0.2
Water	0.0	0.0	0.0	0.0	0.2	**29.4**
Total	100.0	100.0	100.0	100.0	100.0	100.0
Class Changes	54.6	87.8	56.4	8.0	38.7	70.6
Image Difference	-16.1	-44.5	14.1	73.2	30.4	-70.5

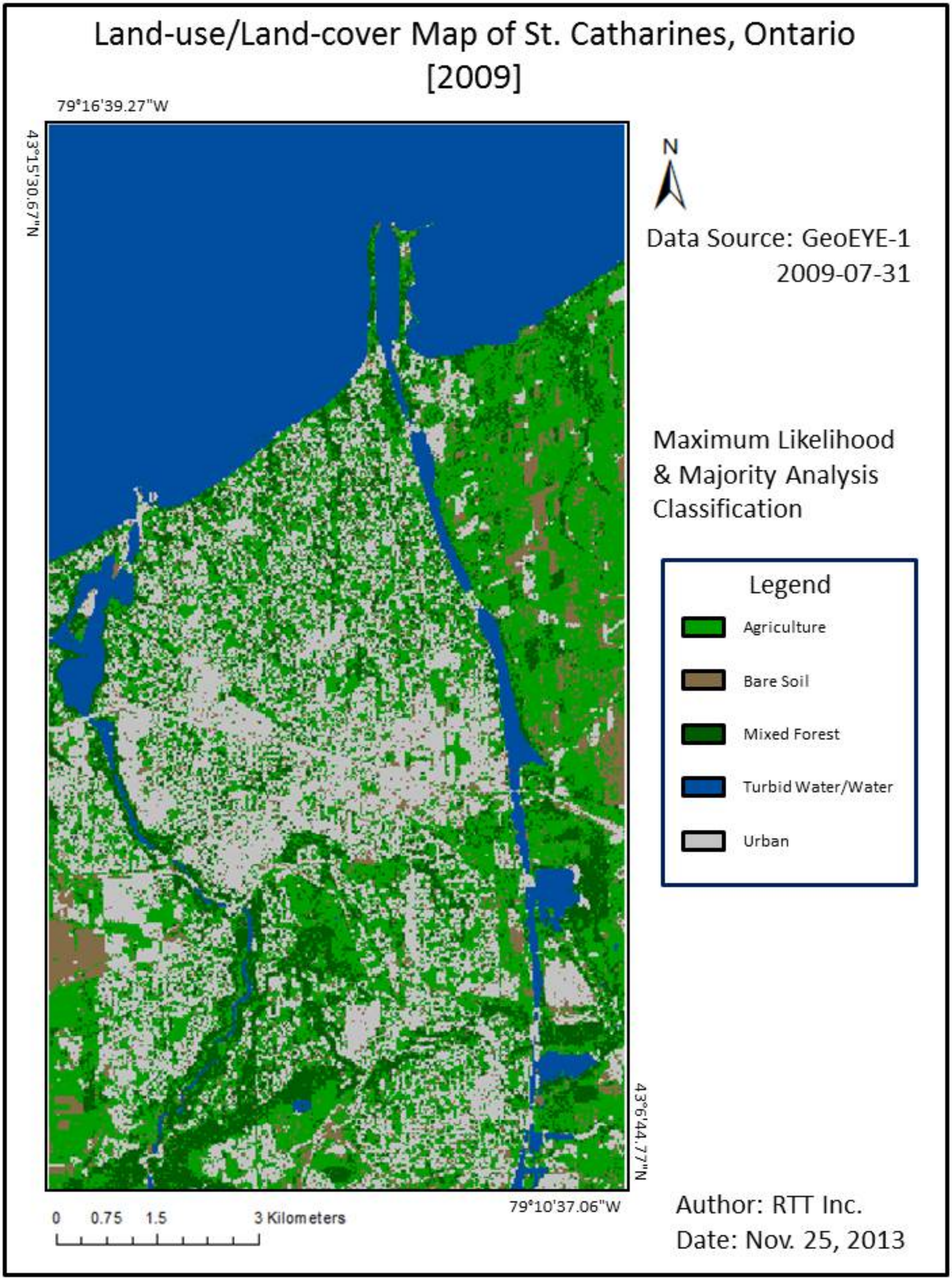
Map 1 - Land-use/Land-cover: 2000



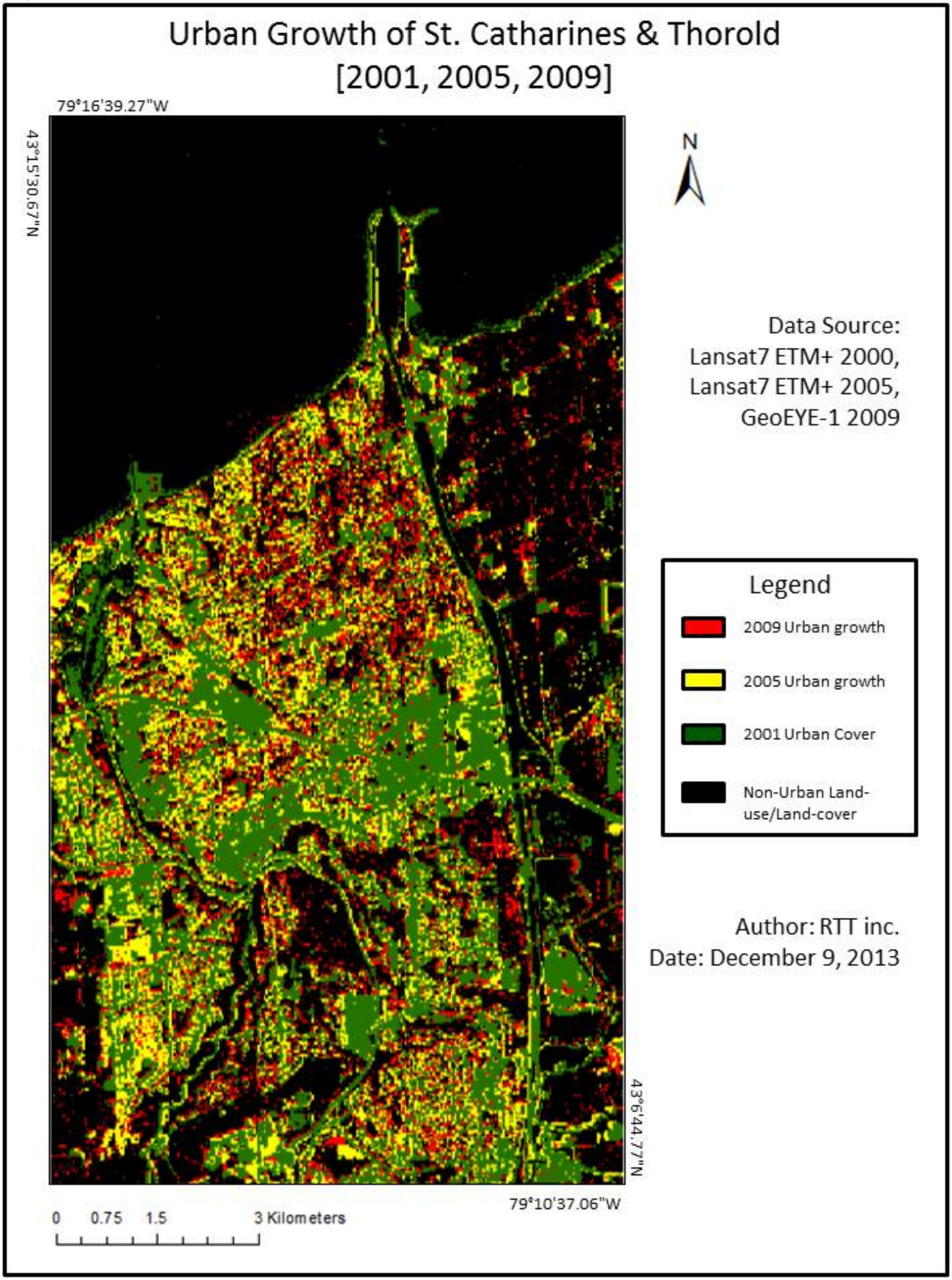
Map 2 - Land-use/Land-cover: 2005



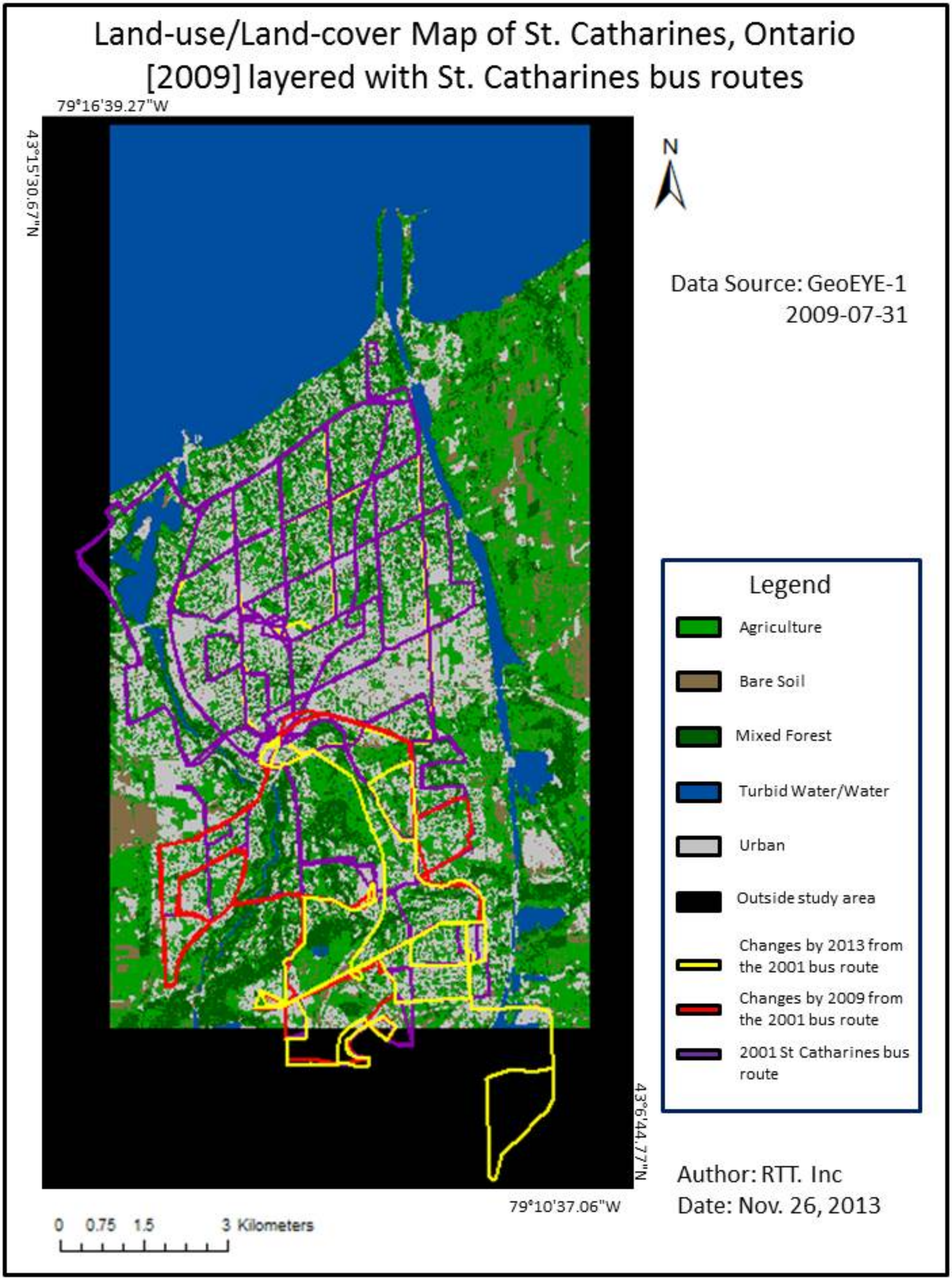
Map 3 - Land-use/Land-cover: 2009



Map 4 - Urban Growth from 2001 to 2013



Map 5 – St. Catharines Transit Bus route: 2001, 2009, 2013



9. References

Allen, J., & Lu, K. (2003). Modeling and prediction of future urban growth in the Charleston region of South Carolina: A GIS-based integrated approach. *Conservation Ecology, 8(2), 2.*

Aljoufie, M., Zuidgee M., Brussel Mark., & Van Maarseveen, M. (2013). Spatial-temporal analysis of urban growth and transporation in Jeddah City, Saudi Arabia. Cities, 31: 57-68

Baslington H. (2007)*. Healthy travel and child socialisation: Policy implications for social and cultural change. Forthcoming Ph.D. thesis, Institute for Transport Studies, University of Leeds, Leeds, England.*

Bhatta, B. (2010). *Analysis of urban growth and sprawl from remote sensing data.* Heidelberg: Springer-Verlag.

Brock University (2001). Brock Facts.

Brock University (2006). Brock Facts.

Brock University (2011). Brock Facts.

Brueckner, J. (2000). Urban sprawl: Diagnosis and remedies. *International Regional Science Review, 23(2), 160–171.*

Cervero, R. (2003). Road expansion, urban growth, and induced travel: A path analysis. Journal of the American Planning Association, 69(2), 145–163.

Congalton, R.G., & Green, K. (2008). Assessing the Accuracy of Remotely Sensed Data: Principles and Practices. Boca Raton, FL: Tayler & Francis Group.

GeoEye. GeoEye-1 scene 2009073116134721603031606123, Standard Geometrically Corrected, Pansharpened, DRA-off. Aurora, CO: eMap International, July 31, 2009.

Guindon, B., and Zhang, Y. (2006). Using satellite remote sensing to survey transport-related urban sustainability – Part II of a Canadian urban assessment. *Canada Centre for Remote Sensing: International Journal of Applied Earth Observation and Geoinformation: 9: 276 – 293.*

Guindon, B., and Zhang, Y. (2006). Using satellite remote sensing to survey transport-related urban sustainability – Part II of a Canadian urban assessment. *Canada Centre for Remote Sensing: International Journal of Applied Earth Observation and Geoinformation: 9: 276 – 293.*

Hu, S., and Wang, L. (2013). Automated urban land-use classification with remote sensing. *International Journal of Remote Sensing, 34(3), 790-803*

Jensen, J.R., Cowen, D.C., (1999). Remote sensing of urban/suburban infrastructure and socio-economic attributes. *Photogrammetry Engineering Remote Sensing, 65, 611–622.*

KARUGA, J.G. (1993). Actions towards a better Nairobi: report and recommendations of the Nairobi City Convention, July 1993, City Hall, Nairobi.

Kirchhoff, P. (1995). Public Transit Research-And-Development in Germany. *Transportation Research.* **29(1):** 1 -7

Klosterman, R.E., (1999). The Whati f? Collaborative planning support system. *Environmental Planning. B 26, 393–408.*

Landsat-7 Imagery [computer file]. (2000). Ottawa, ON: Canada Centre for Remote Sensing. Available: Brock University Map Library Controlled Access S:\Maplibrary\DATA\MNR\Landsat 7\1730\1730_fuse.sid (October 10, 2013).

Landsat-7 Imagery [computer file]. (2005). Landsat-7 p017r030_7dx20050912, Standard Geometrically Corrected, Ottawa, ON: Canada Centre for Remote Sensing. Available: University of Maryland, Global Earth Land Cover Facility: Earth Science Data Interface, http://glcfapp.glcf.umd.edu:8080/esdi/ftp?id=273245 (October 10, 2013).

Lillesand, T.M., &Kiefer, R. W. (1999). Remote sensing and interpretation/ Thonas M.

Lillesand, Ralph W. Keifer. New York:John Wiley & Sons, 1999.

Lunetta, R.S., Cogalton, R.G., Fenstermaker, L.K, Jensen, J.R., McGuire, K.C, &Tinney, L.R.(1991). Remote sensing and geographic information systems data integration: error sources and research issues. Photogrammetric Enginering & Remote Sensing. 57(6), 677-687.

Murrary, A. T., Davis, R., Stimson, R. J., & Ferreira, Luis. (1998). Public Transportation Access. *Pergamon.* Ellsvier Science Ltd., **3**:319-324

Pham, H., Yamaguchi, Y., & Bui, T. (2010). A case study on the relation between city planning and urban remote sensing and spatial metrics. *Landscape and Urban Planning, 100, 223-230.*

Powell, R.L., Roberts, D.A., Dennison, P.E., Hess, L.L., 2007. Sub-pixel mapping of urban land cover using multiple endmember spectral mixture analysis. *Remote Sensing of Environment*, **106**(2):253-267.

Richards, J. A, (1993). Remote sensing digital interpretation analysis: an introduction.

Schrank, D. & Lomax, T. (2004) The 2004 Urban Mobility Report. *Texas Transportation Institute*. <http://mobility.tamu.edu>(accessed September 23, 2013).

Shahtahmassebi, A., Yu, Z., Xu, H., Deng, J., Li, J., Luo, R., Wu, J., Moore, N., (2012). Monitoring rapid urban expansion using a multi-temporal RGB-impervious surface model. *Applied physics & Engineering,* **13**(2):146-158

Statistics Canada. (2011). Community profiles – St Catharines, Ontario. Government of Canada, Ottawa.

Statistics Canada. (2006). Community profiles – St. Catharines, Ontario. Government of Canada, Ottawa.

Statistics Canada. (2001). Community profiles – St. Catharines, Ontario. Government of Canada, Ottawa.

St. Catharines Transit Commission. (2013). Your community, Your bus. < http://www.yourbus.com/>

St. Catharines Transit Commission. (2001). Bus Routes.

Study Area [map]. 1:100,000. Data Layers: Ontario_poly_2003-08-28, Lakes, Municipality (Statistics Canada, 2006), GeoEye-1 scene2009073116134721603031606123 [computer files]. Place of publication: Josh Valenti, December 4, 2013. Using: ArcMap 10.1. ESri Inc. 1999-2012.

Waibel, M. (1995). Drawn and quartered–Hanoi's ancient centre is feeling the pressure from outside and in, So what can architects and officials do to stop the rot? Vietnam Econ. Times., 24–25.

Wang, J., Lu, H., & Peng, H. (2008). System dynamics model of urban transportation system and its application. *Journal of Transportation Systems Engineering and Information Technology, 8(3), 83–89.*

Wang, R.Y., Storey, V.C., & Firth, C., P. (1995). A framework analysis of data quality research.Transactions on Knowledge and Data Engineering, 7(4), 620-640.

Watson, C. *Liner filtering*. The University of Washington. Retrieved from: < http://www.cs.washington.edu/research/metip/tutor/tutor.Filtering.html>

Yuan, F., Sawaya, K.E., Loeffelholz, B.C., Bauer, M.E., (2005). Land cover classification and change analysis of the Twin Cities (Minnesota) Metropolitan Area by multitemporal Landsat remote sensing. *Remote Sensing of Environment,* **98**:317-328