URBAN SPRAWL INTO THE NIAGARA REGION:

THE EFFECT OF URBAN ENCROACHMENT ON AGRICULTURE SEEN THROUGH THE USE OF REMOTE SENSING APPLICATIONS AND LANDSCAPE METRICS

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Abstract

Urban sprawl into the Niagara Region: the effect of urban encroachment on agriculture seen through the use of remote sensing applications and landscape metrics

Master of Applied Science, 2017
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The Niagara Region contains land that is ideal for agricultural practices. This thesis strives to illuminate whether or not urban growth in the Niagara Region is a detriment to agricultural land use. Using Landsat 5 TM and 8 OLI-TIRS satellite imagery, spatial statistics, called landscape metrics, will be utilized to determine growth and loss of urban and agriculture land uses. Satellite imagery will be classified based on researched methods in order to create land class maps. These maps will then be utilized for landscape metrics using the Patch Analyst extension for ArcMap. Change detection methods will also be observed. The above methods will be done for the overall landscape of the Niagara Region. This study will find that agriculture in the Niagara Region is changing and endeavors to highlight how urban sprawl is part of the cause. Fragmentation will be discussed as part of the issues due to urban sprawl.

Acknowledgements

I would like to sincerely thank my supervisor, Dr. Eric de Noronha Vaz, for continually showing me support and providing expert guidance throughout the long thesis writing process. I would also like to thank my family for never giving up hope that I would complete this thesis. Last, I would like to thank my lab mates for staying late with me on countless nights and keeping me sane when approaching the completion of this thesis and during a looming deadline.

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List of Abbreviations

AAFC: Agriculture and Agri-Foods Canada

CMA: Census Metropolitan Area

UNESCO: United Nations Educational, Scientific, and Cultural Organization

MaB: Man and the Biosphere Programme

NEPDA: Niagara Escarpment Planning and Development Act

NEC: Niagara Escarpment Commission

NEP: Niagara Escarpment Plan

LPA: Landscape Pattern Analysis

USGS: United States Geological Survey

TM: Thematic Mapper

OLI: Operational Land Imager

TIRS: Thermal Infrared Sensor

.shp: Shapefile

ESA: Environmentally Significant Area, or Environmentally Sensitive Area

NDVI: Normalized Difference Vegetation Index

PCA: Principal Component Analysis

RGB: Red, Green, and Blue

MPAR: Mean Perimeter-Area Ratio

MPE: Mean Patch Edge

MedPS: Median Patch Size

AWMPFD: Area Weighted Mean Patch Fractal Demention

AWMSI: Area Weighted Mean Shape Index

CA: Class Area, or Core Area

CACOV: Core Area Coefficient of Variance

CAD: Core Area Density

CASD: Core Area Standard Deviation

ED: Edge Density

MCA: Mean Core Area

MPFD: Mean Patch Fractal Dimension

MPS: Mean Patch Size

MSI: Mean Shape Index

NUMP: Number of Patches

PSCOV: Patch Size Coefficient of Variance

PSSD: Patch Size Standard Deviation

TCAI: Total Core Area Index

TE: Total Edge

TLA: Total Landscape Area

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1. Introduction

The Niagara Region is an area made up of pristine ecosystems and prime farmland. Even though the land is so valuable, development projects are prominent. The study area involved in this thesis incorporates a small portion of the Niagara Escarpment, and therefore, it is important to understand the laws and regulations that surround development along the Escarpment area. The Niagara Escarpment is a mostly protected zone, and yet housing expansions and industry/commercial developments are dotting the landscape. This thesis will strive to show whether or not urban expansion into the Niagara Region is affecting agriculture. Urban sprawl is when larger cities continue to grow. It is defined as low-density expansion of larger urban areas that manifest in a physical pattern due to certain market conditions. This expansion is often found to overtake some agricultural spaces. Sprawl is dangerous as it is synonymous with development which is not well planned, or planned at all, and development which occurs incrementally (EEA, 2006). Once the population can no longer be contained within the city limits, housing on the outskirts of the city centre must be created. This development expands the city limits and the pattern continues outward if there is no policy and management in place. As city centres grow, they need building material which are sourced from the surrounding rural areas, or shipped in from elsewhere. Not only do cities expand outwards in the physical sense, but the growth of a city can be seen in the boom of industry in the surrounding rural areas which supply many resources. To observe whether or not urban sprawl is having any effect on the Niagara Region, landscape metrics will be utilized. Spatial analysis involving landscape metrics in ArcGIS will disclose whether there have been significant changes over time in agricultural land. Remote sensing software will allow for land use to be shown using specific land use classifications. Land use change will be shown over time.

The dates chosen span a thirty-year period from 1985 to 2015. This ensures that change detection can be completed by comparing and contrasting satellite imagery from those years. Following will be a comprehensive literature review that includes aspects of policy, geologic composition, and settlement in the Region.

The urban-rural fringe is a particularly sensitive zone for agriculture. Exurbia, or the urban-rural fringe, is one of the fastest changing landscapes today (Shaker and Ehlinger, 2007). As cities push out of their boundaries, agricultural land is developed into low-density residential neighbourhoods. This poses a problem called fragmentation. While fragmentation can occur naturally, most research as of late discusses human imposed fragmentation. Fragmentation along the urban-rural fringe is an important consideration in planning processes (Petrov and Sugumaran, 2009). The research in this thesis focuses on the loss of agricultural lands throughout the Niagara Region with the expansion of many urban populations. The Niagara Region was chosen for the study due to the area's distinct agricultural possibilities. The territory has some of the best farmland in all of Ontario, and urban sprawl is encroaching, which has and will continue to cause many issues. These issues include the size of farmland, fragmentation, soil erosion, and the loss of agricultural zones entirely. Farmland loss needs to be monitored for a number of reasons. Farmland has an effect on the economy of the Region, it varies the landscape providing enjoyment for those that live in rural communities and for those touring the Niagara Region and Escarpment, and it provides habitat for a number of species, including birds, fish, and other wildlife. Perhaps one of the most important aspects of farmland is that it provides food for human consumption. Due to the importance of these issues to the environment and humans, this study will determine if urban sprawl is affecting agriculture in the Niagara Region. The population of the Regional Municipality of Niagara as of

2011 was 431,346. This is up from 403,554 in 1996 and continues to climb steadily with the advent of new housing plots (Niagara Region, 2011).

The study zone for this thesis extends north to south from Lake Ontario to Lake Erie and east to west from Niagara Falls to Hamilton, but does not include Hamilton. This is effectively known as the Niagara Peninsula, or the Regional Municipality of Niagara. The study area is portrayed in Figure 1. There are twelve municipalities within the region. From west to east these include Grimsby, West Lincoln, Wainfleet, Lincoln, Pelham, St. Catharines, Thorold, Welland, Port Colborne, Niagara-on-the-Lake, Niagara Falls, and Fort Erie.

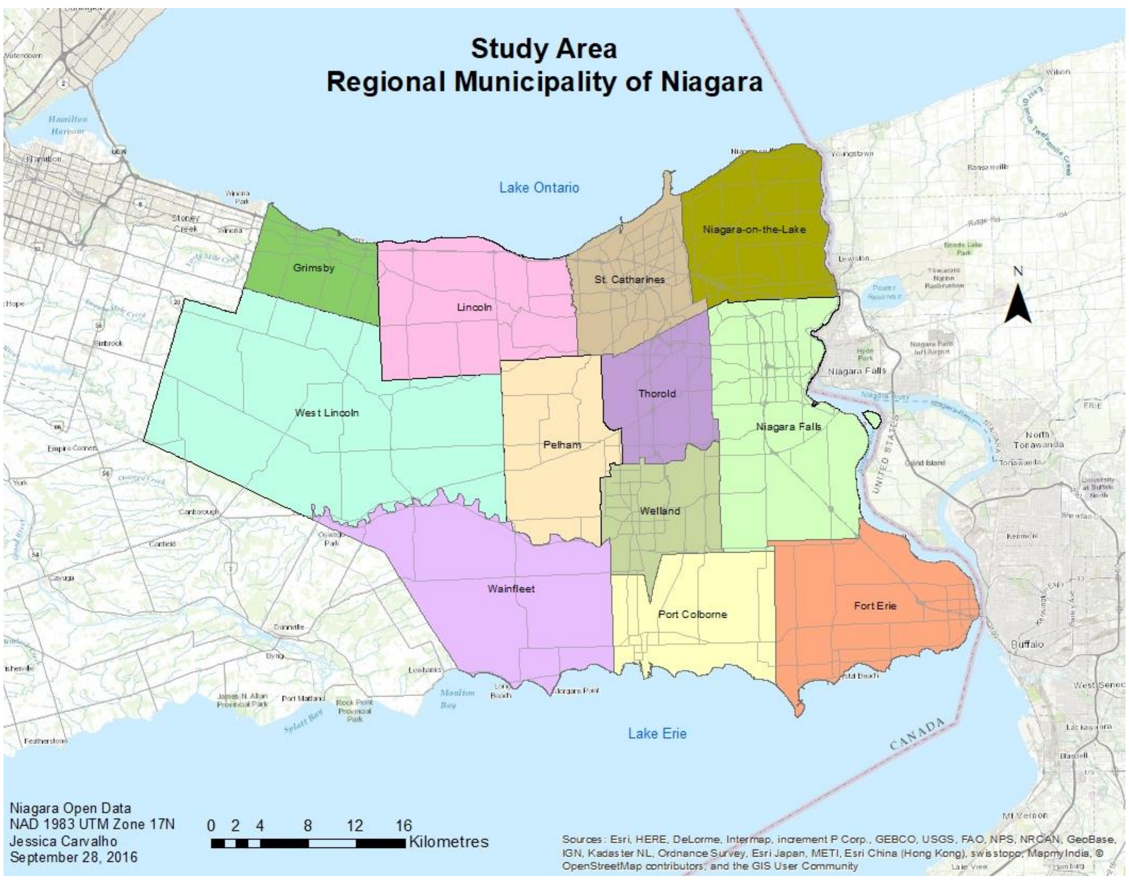


Figure 1 Thesis Study Area

Table 1 details the population of each town in the Niagara Region in the years 1996, 2001, 2006, 2011, and 2016. It is evident that there has been an increase in population from 1996 to 2016 throughout the majority of the municipalities, with the exception of Port Colborne where there is

Table 1 Niagara Region Population 1996 - 2016 (Statistics Canada, 2012-2017)

	Niagara Region Population						
Town	**1996**	**2001**	**2006**	**2011**	**2016**	**Difference (1996-2016)**	**Change (%)**
Grimsby	19585	21295	23937	25325	27314	7729	39.46
West Lincoln	11513	12265	13167	13837	14500	2987	25.94
Wainfleet	6253	6260	6601	6356	6372	119	1.90
Lincoln	18801	20610	21722	22487	23787	4986	26.52
Pelham	14393	15275	16155	16598	17110	2717	18.88
St. Catharines	130926	129170	131989	131400	133113	2187	1.67
Thorold	17883	18045	18224	17931	18801	918	5.13
Welland	48411	48405	50331	50631	52293	3882	8.02
Port Colborne	18451	18450	18599	18424	18306	-145	-0.79
Niagara-on-the-Lake	13238	13840	14587	15400	17511	4273	32.28
Niagara Falls	76917	78815	82184	82997	88071	11154	14.50
Fort Erie	27183	28140	29925	29960	30710	3527	12.98
Total	**403554**	**410570**	**427421**	**431346**	**447888**	**44334**	**10.99**

Table 2 Niagara Region Population Change (%) Between 1996 and 2016

Town	**Change (%)**
Grimsby	39.46
West Lincoln	25.94
Wainfleet	1.90
Lincoln	26.52
Pelham	18.88
St. Catharines	1.67
Thorold	5.13
Welland	8.02
Port Colborne	-0.79
Niagara-on-the-Lake	32.28
Niagara Falls	14.50
Fort Erie	12.98
Total	**10.99**

a recorded decrease of approximately 145 people. Though Niagara Falls saw the greatest increase in residents by 2016, the actual growth was much larger in Grimsby. Niagara Falls showed a growth in those 20 years by 14.50%, but Grimsby showed an incredible increase of 39.46%. West Lincoln and Lincoln townships are not that far behind with the increased growth trend, showing both 25.94% and 26.52% respectively. It could be conceivable to state that this is due to these municipality's spatial approximation to Hamilton, which is a rather large census metropolitan area (CMA) with approximately three quarters of a million residents. Another reason for the growth could be the proposed expansion of Metrolinx GO train and bus services. The expansion from Burlington straight through to Niagara Falls for their train services is expected to be completed by 2023, but bus routes run every hour every day. The expansion of public transport makes it easier for those working in a CMA to commute, which means that the less expensive housing outside of those CMAs will likely be more popular. St. Catharines is the largest city in the Regional Municipality of Niagara, but growth is slow at 1.67% change in 20 years.

Figure 2 depicts the population growth as whole for the Region. In the last twenty years, there has been a slow and steady climb in population with a slight plateau between 2006 and 2011. That small lag was left behind with the new population numbers of 2016, showing that the Region's population is now 447888. This trend is likely to continue as development is always present.

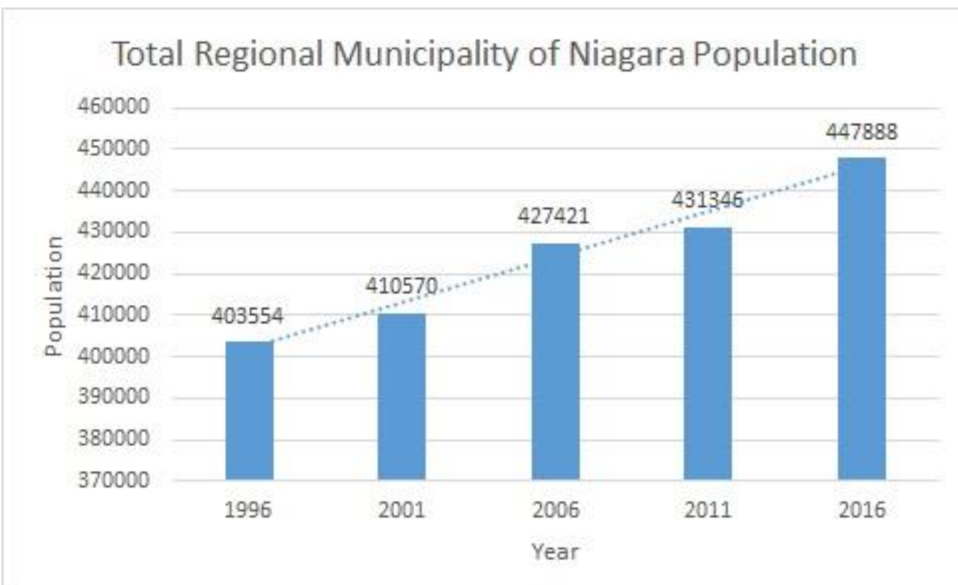


Figure 2 Niagara Region Population Growth (Statistics Canada, 2012 - 2017)

Figure 3 takes the overall population and breaks it down by municipality as stated in Figure 1. Here, it is easier to see the increases (or decreases) of population for each section of this study. As was stated above, it is clear that St. Catharines is the largest city, followed by Niagara Falls and Niagara-on-the-Lake, but what is truly pertinent is the amount of growth that occurred over the 20-year period, which is not as easily understood in this graph. It is also evident that Wainfleet, Thorold, and Port Colborne have remained relatively stationary in the realm of population growth. Port Colborne was the only municipality with an overall decrease between the 20-year period; however, other municipalities recorded decreases along the way. Those include St. Catharines with a decrease in both 2001 and 2011, Wainfleet in 2011, Thorold in 2011, and Welland in 2001. This proves that populations do fluctuate visually, but compared alongside Table 2, the growth percentage in this 20-year period illuminate the changes the Region has actually observed. Table 2 simply restates the growth percentage so that it is easily comparable directly with the municipality population graph.

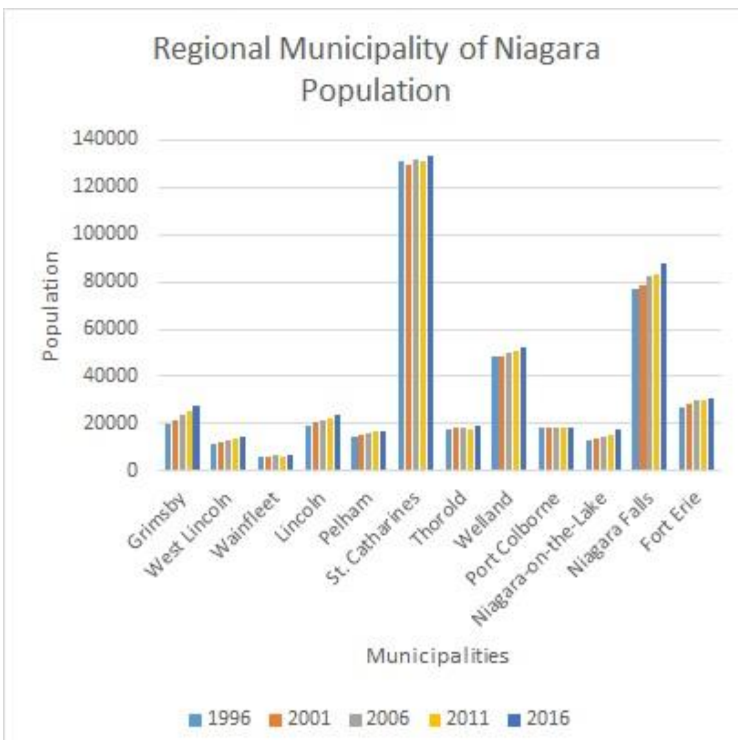


Figure 3 Population by Municipality 1996 - 2016 (Statistics Canada, 2012-2017)

This part of Southern Ontario contains what is known as the Niagara Fruit Belt. Within the fruit belt, tender fruit is grown. These tender fruits include plums, peaches, nectarines, pears, cherries, and grapes. Grapes and peaches from the area are popular across Canada; grapes especially from vineyards for wine. Organizations such as the Ontario Tender Fruit Growers have pledged to help boost the Ontario economy, as well as the economy of Niagara, by initiating a pilot project where approximately 500 acres of tender fruit trees will be planted in the spring of 2016. This will cost the organization $400,000, but after approximately four years, there is a projection of about $4 million into Ontario's economy (OTFG, 2015). Figure 4 indicates the tender fruit growing areas of the Niagara Region as the purple areas. The tender fruit agricultural zones fall within the north of the Region which is located at the base of the Niagara Escarpment and along the shores of Lake Ontario. This combination provides excellent soil high in nutrients allowing this business to prosper. 40% of this land has been lost to urbanization since World War II (Gayler, 2010).

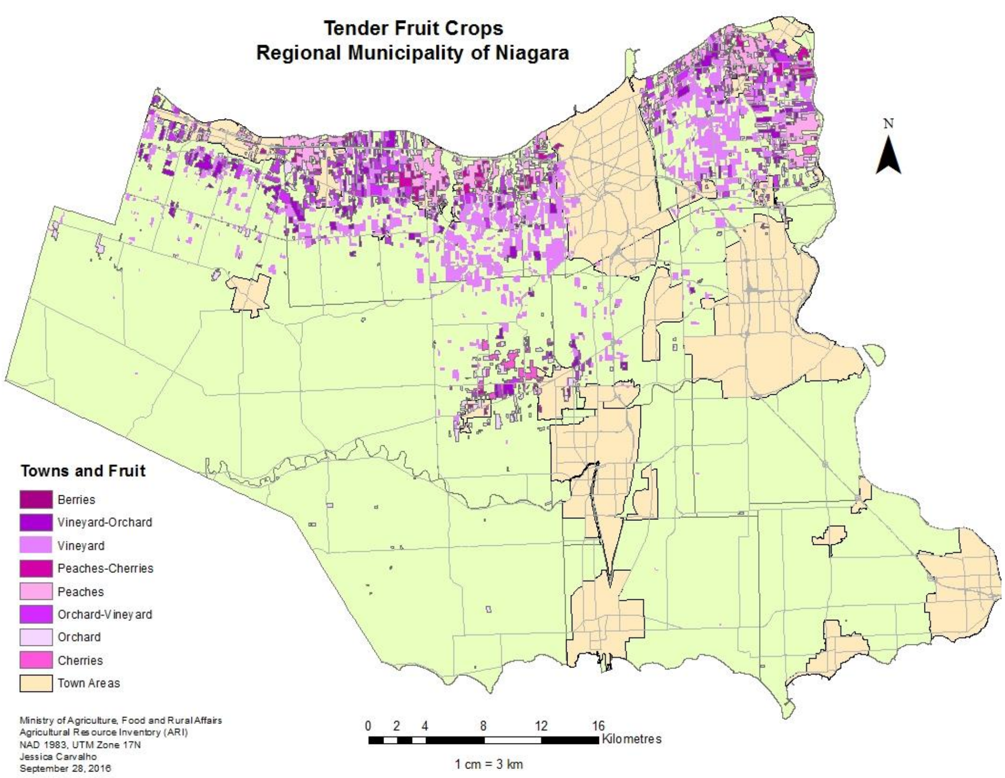


Figure 4 Niagara Region Fruit Belt

As of 2016, 1827 farms were reported for the Census of Agriculture. In 2011, there were 2014 farms reported. This shows a decline of 187 farms in a five-year period. The area coverage of these farms can be seen in table 3. It is interesting to note that while most farms of varying size have decreased, there have been minor increases in the farms that are 72.84 ha to 96.71 ha, 161.78 ha to 226.21 ha and 307.56 ha to 452.84 ha specifically.

Table 3 Niagara Region Farm Area (ha) (Statistics Canada, 2017)

Total Farm Area

Hectare (ha)	**2011**	**2016**
under 4	385	359
4 - 27.99	1001	858
28 - 52.20	237	228
52.60 - 72.43	100	90
72.84 - 96.71	71	79
97.12 - 161.47	108	97
161.87 - 226.21	44	46
226.62 - 307.15	23	22
307.56 - 452.84	17	23
453.24 - 647.09	12	7
647.49 - 906.09	8	9
906.49 - 1165.09	5	6
1165.49 - 1424.08	0	0
over 1424.49	3	3

1.1 Goals and Objectives

Much work has been accomplished using landscape metrics and remote sensing; however, there has been little work conducted on the agricultural and urban landscape relationship in the Niagara Region using these tools. This study seeks to understand whether or not these tools are effective methods in observing this relationship and if the policies of the Region have been effective for the past thirty years. Therefore, this thesis seeks to understand if urban sprawl is altering the rural landscape of the Niagara Region

2. Literature Review

2.1 Geological Composition

It is crucial to understand why the Niagara Region and, contained therein, Niagara Escarpment, are such unique areas. This section outlines the historic constituents that took place in order for the land to end up the way that is has, creating such prime agricultural lands. Escarpment is a term that means a ridge composed of gently dipping rock strata with a long, gradual slope on one side and a relatively steep cliff on the other (Park Planning Branch, 1976). The Niagara Escarpment extends from Queenston on the Niagara River to the islands off of Tobermory on the Bruce Peninsula in Ontario (Ontario's Niagara Escarpment, 2015a). There is no other land like the Niagara Escarpment throughout all of Canada. It is geologically and ecologically unique, plus it boasts many natural rivers and streams that provide some of the best recreational opportunities in all of Ontario (MNRaF, 2014). The Niagara Escarpment is found to have a Paleozoic bedrock that was built upon during the late Quaternary by glacial, interglacial, and fluvial sediments. These layers have shown the variations in environmental conditions throughout that period. The rocks found in this area consist of shales, dolostones, limestones, and sandstones. The Laurentian Channel formed valleys by eroding the rock of the Paleozoic era right before the deposits from the Quaternary period occurred. This helped form the Great Lakes region. The Laurentide ice sheet went through many episodes of advancing and receding during the Quaternary period and into the Wisconsin. This helped move many sediments, shaping the land as it is seen today and it aided in filling the Great Lakes Basin (Meyer and Eyles, 2007). These sediments have created soils unrivaled throughout the rest of Canada. The people that first began cultivating the rich land in the Niagara Region provide some insight on how this area became so well known for its agricultural potential.

2.2 Settlement

Ontario's Southern Woodland Natives began experimenting with horticulture around 700 AD. This began a new, sedentary way of life. The day of nomads in what is now Southern Ontario slowly phased out. Iroquois Natives that lived near the Niagara Escarpment began burning patches of forest in order to grow corn. By 1350, beans and squash were being cultivated. These were known as the Three Sisters Crops due to their relationship with one another. The corn stalks provided support for the growing beans, while the squash remained near the soil, effectively preventing weeds from growing and retaining soil moisture. Beans also provide nitrogen for the soil, which acts as a fertilizer (Dickason, 2010).

Settlements along the Great Lakes expanded. The Great Lakes were important for trade and supplies, which is why settlements sprouted here primarily. Once covered in vast forests, the land was cleared to make way for farming operations, mills, and settlements. More and more movement in the area led to ox-cart trails being developed, which eventually led to dirt roads, making it easier for neighbouring communities to become one larger community (Keough, 1990). This is when communities around mills became popular. Ball's Falls in Vineland was once a prosperous grist mill (i.e. grist being grains that are ground to make flour). It has now been transformed into a Conservation Area that boasts historical knowledge, which is another reason why agriculture is so important in the Region. Communities would form around mill sites as mills offered jobs. In the early 1900s, industry and population was booming causing large cities to form. Any concern for the environment fell by the wayside as the turnaround of the economy was what mattered. However, by 1960, environmental concern was finally realized. Driving throughout the Niagara Escarpment, one once would have seen holes blasted for mining and quarrying operations. In 1886 in fact, the Forks of the Credit Mine was the first to start mining for limestone blocks used to help build the City of Toronto. This practice was occurring rapidly in the 1960s. Growth of larger cities and the end of the war meant that there was a population boom, meaning that more housing was desperately needed. But the concern for the picturesque landscape won, and protection plans were put into place.

2.3 Protection Groups and Policies

Here, it is important to note what environmentally significant areas are. ESAs, sometimes known as environmentally sensitive areas, are areas of agricultural land that need protection due to their unique landscape or wildlife. Historical value of this land often plays a role in whether or not it is classified as an environmentally significant area. Throughout the Niagara Region and especially the Niagara Escarpment, there are numerous ESAs indicated, with varying levels of protection. In Furberg and Ban's (2012) report of the Greater Toronto Area, they found that in 1985 and 1995 there was a significant overlap between sprawling urban zones and ESAs. 1985 showed a 2.5 percent overlap and 1995 showed a 6.1 percent overlap. Between those ten years, there was an increase of 3.6 percent overlap. The period between 1995 and 2005; however, only showed an increase of 0.3 percent overlap. This makes sense as protection of these areas has become a much more recent issue. The protection levels within the confines of the Escarpment are much higher, but this region also offers many valuable resources, and so, sometimes, protection can be considered lax. Even though these ESAs are generally well protected, urban expansion can occur around their borders. This effectively disassociates one ESA from another, meaning that ecosystems may be disrupted by the urban settings between two ESAs.

2.3.1 Niagara Escarpment Biosphere Reserve

A United Nations Educational, Scientific, and Cultural Organization (UNESCO) biosphere reserve is created by first recognizing that the residents in the area want this area to be considered a biosphere reserve. That decision is then ratified by a national committee, and finally designated by UNESCO. The purpose of a biosphere reserve is to help humans live and work in conjunction with nature (Parks Canada, 2005). In February of 1990, UNESCO and the Man and the Biosphere Programme (MaB) named the Niagara Escarpment as one of the world biosphere reserves (MNRaF, 2014). MaB is an intergovernmental scientific plan launched in 1971 that urges better relationships between people and their environments. It uses people from a wide variety of backgrounds, such as the natural and social sciences, economics, and education, to provide innovative ways of increasing economic growth, but in a manner that is both culturally and environmentally sustainable (UNESCO, 2014). There are a total of sixteen Biosphere Reserves in Canada and the Niagara Escarpment is included on that list (The Canadian Commission for UNESCO, 2015). The protected zone covers approximately 183,000 hectares stretching from Niagara Falls to just outside of the Bruce Peninsula. This is a 725 kilometre stretch of land that changes drastically throughout. Valleys, hills, waterfalls, and caves are just some of the intricate details that can be found here. The Niagara Escarpment houses over 300 bird species, 39 species of reptiles and amphibians, 53 species of mammals, 90 fish species, and approximately 1800 plant species that include some only found in Canada, such as specific orchid flower varieties (Foster, 2000). Not only is it home to this wide variety of life, but it caters to diverse human livelihoods, mostly in the form of agriculture. Others include the tourism industry, forestry, and mineral resource mining. The Niagara Escarpment Biosphere Reserve instituted by UNESCO is financed provincially, but typically run municipally. This means that organizations, such as the Niagara

Escarpment Commission, whose purpose is to ensure that the regulations set forth in the Niagara Escarpment Plan are adhered to, must work with each municipality separately and come to a consensus on all issues (Foster, 2000). This also means that the Niagara Escarpment Commission is subject to provincial cutbacks, which will be discussed in the Niagara Escarpment Commission section of this study.

2.3.2 Niagara Escarpment Planning and Development Act (NEPDA)

The Niagara Escarpment Planning and Development Act was approved by the Ontario Legislature in June of 1973 and has been revised as recently as 2012. The purpose of the NEPDA is "to provide for the maintenance of the Niagara Escarpment and land in its vicinity substantially as a continuous natural environment and to ensure only such development occurs as is compatible with that natural environment (NEPDA, 2012)."

2.3.3 Niagara Escarpment Commission (NEC)

The Niagara Escarpment Commission is composed of seventeen members that are appointed by the Lieutenant Governor in Council. The first nine members are people that have been appointed to represent the public. The remaining eight members are chosen by each municipality making a list of people they think would be suitable. One member is then picked from each compiled list. Those on the lists must be an employee of the municipal government (Ontario's Niagara Escarpment, 2015b). Many people that live within the boundaries of the Niagara Escarpment are unaware of the level of protection that the area faces. It is understood that protection exists and many community-based protection groups believe that this protection is full proof. This means that they believe that development is not allowed in any sense and this often leads to misunderstandings and local backlash when a proposal for development has been accepted. Many people fail to realize that there are limiting factors affecting the Commission's ability to enforce proper policies. These include funding cutbacks from the Provincial government. Cutbacks have made it extremely difficult for the Commission to respond to questionable development proposals and to initiate educational opportunities. There have also been a number of people on the Commission that do not support the protection of the Escarpment as strongly as some of the other environmentally forward political commissioners. They have spoken outwardly about the need to expand the area for economic purposes, thus many proposals often make it through the cracks of protection (Preston, 2001). This is why local governments and citizens must also play a vital role in ensuring the protection of this ecologically important area.

2.3.4 Niagara Escarpment Plan (NEP)

The Niagara Escarpment Plan is used to indicate how land within the Plan boundaries can be used and managed. The Plan also contains information on how development can proceed within the area. Policies are outlined for the Niagara Escarpment Parks and Open Space System as well. It is set by the Ministry of Natural Resources and Forestry and enforced by the Niagara Escarpment Commission. This Plan was established from the NEPDA as a "framework of objectives and policies to strike a balance between development, preservation and the enjoyment of this important resource" (MNRaF, 2014). The objectives of the Plan include the protection of the unique ecological and historical areas of the Escarpment, the enhancement of the water supply and natural streams, to ensure that outdoor recreation is not hindered, to preserve the natural landscape by instituting compatible farming or forestry operations, making sure that any development complies with the purposes of the Plan, to provide access to the public, and to aid municipalities in the installation of future planning following the NEPDA outline (MNRaF, 2014). The accumulation of protective action taken along the Escarpment has resulted in many conservation areas and parks, which has aided in lessening the impact of development; however, even with the continued outpouring of development proposals, the majority of the Escarpment is privately owned land (Preston, 2001). The outer boundary distinguished within the Plan is fixed and inflexible and can only be changed by a Plan amendment. The Plan outlines seven land use designations and Appendix A illustrates a map of each of these land uses for the section of the Niagara Escarpment that is found in the Niagara Region. The seven land use designations include (MNRaF, 2014):

1. Escarpment Natural Area

   Stream valleys, wetlands and forests, plant and animal habitats, geological features, and cultural heritage features are all included in this land classification. The permitted uses of this land include existing agricultural operations, home occupations and cottage industries, forest, and wildlife and fisheries management, etc.

2. Escarpment Protection Area

   These areas are considered visually prominent and therefore of environmental significance. The areas included in this classification are agriculture or residential development and buffer zones for Escarpment Natural Areas. These ranges are used to promote agriculture and recreation. The Escarpment Protection Areas can be used for wineries, nature reserves, or farm vacation homes, etc.

3. Escarpment Rural Area

   They provide a buffer to extremely sensitive ecological zones throughout the Escarpment. These areas aim to maintain the scenic value of the lands, but also provide zones for new Mineral Resource Extraction Areas, but only if they are accompanied with an amendment. If an amendment has been placed to change Escarpment Rural Areas into Mineral Resource Extraction Areas, then many issues must be considered. These include the protection of the natural and cultural environment, the plan to rehabilitate the land, the maintenance of the natural area and its further enhancement, and the ability for the land to be used in agricultural operations after rehabilitation.

4. Minor Urban Centre

   Rural settlements, villages, and hamlets are all part of this land classification within the Niagara Escarpment. These existing areas are used to pinpoint where further growth may develop. New lots are not permitted to extend into the Escarpment Natural Areas.

5. Urban Area

   Some parts of the Escarpment are still largely undeveloped, but surrounded by developed cities, such as Hamilton, and then there are other areas that have been encroached upon by development. This land use designation is used to protect the Escarpment from further urban growth and to minimize the impact of current urban sites. For growth of these Urban Areas to occur, they must not impede on Escarpment Natural or Protection Areas. They can also not encroach on areas that grow specialty crops (i.e. peanuts).

6. Escarpment Recreation Area

   This section outlines areas that could become or already are recreational areas. Recreational areas can include seasonal and permanent allocations. The goal is to minimize any adverse effects on the Escarpment caused by recreational facilities and to ensure that the Escarpment can always be used for this enjoyment factor. This area can be used for new ski resorts and Bruce Trail activities as an example.

7. Mineral Resource Extraction Area

   This section includes pits and quarries that are in pursuit of aggregates under the Aggregate Resource Act and other areas that could contain mineral resource extraction. The goal of this land use designation is to minimize the effect that quarries will have on the surrounding environment of the Escarpment and to establish areas where quarries can possibly exist. The idea is that the rehabilitation of the quarried land will be returned to its most natural state and become part of the Niagara Escarpment Parks and Open Space System. If a new Mineral Resource Extraction Area is proposed and will be used to extract less than 20,000 tonnes of aggregate per year, then an amendment is not needed to the Plan. If more than 20,000 tonnes of aggregate per year would be mined in a New Mineral Resource Extraction Area, then an amendment to the Niagara Escarpment Plan would need to be constructed. These new Mineral Resource Extraction Areas can only take place within a designated Escarpment Rural Area.

2.3.5 Greenbelt Act/ Plan

The Greenbelt Act of 2005 enabled the creation of the Greenbelt Plan. This was instituted to protect approximately 1.8 million acres of environmentally sensitive and agricultural land. This land was established within the Golden Horseshoe and the Greenbelt Plan helps to protect this area from urban sprawl and development. The Greenbelt Plan builds on the already existing protection of the Niagara Escarpment Plan and includes many more environmentally significant areas, such as the Oak Ridges Moraine. A Council exists for various reasons, such as the administration of the Greenbelt and also to help with the implementation of the plan. The Greenbelt Plan helps support the policies found within the Niagara Escarpment Plan (The Greenbelt Act, 2013).

2.3.6 Neptis

Neptis is a nonpartisan, privately capitalized foundation that is located in Toronto, Ontario. The organization aims to improve policy and decision making regarding urban growth and management by conducting research and in depth analysis of Canadian urban regions. Research that has been conducted by Neptis in the Niagara Region indicated the level of protection the landscape faces. Table 4 shows the level of protection that is found in the Niagara Region for specific greenlands. Neptis defines greenlands as environmental elements that have been recognized as ecologically significant by municipal or provincial governments, or by conservation authorities (Fraser and Neary, 2004). Neptis has established that protection level one indicates that an area is fully protected, level two indicates generally protected areas, level three indicates partially protected areas, and level four indicates areas that are not protected. Figure 5 shows what Table 4 eludes to (Neptis Foundation, 2014). Dark green shows category one protection all the way to yellow, which shows no protection (category four).

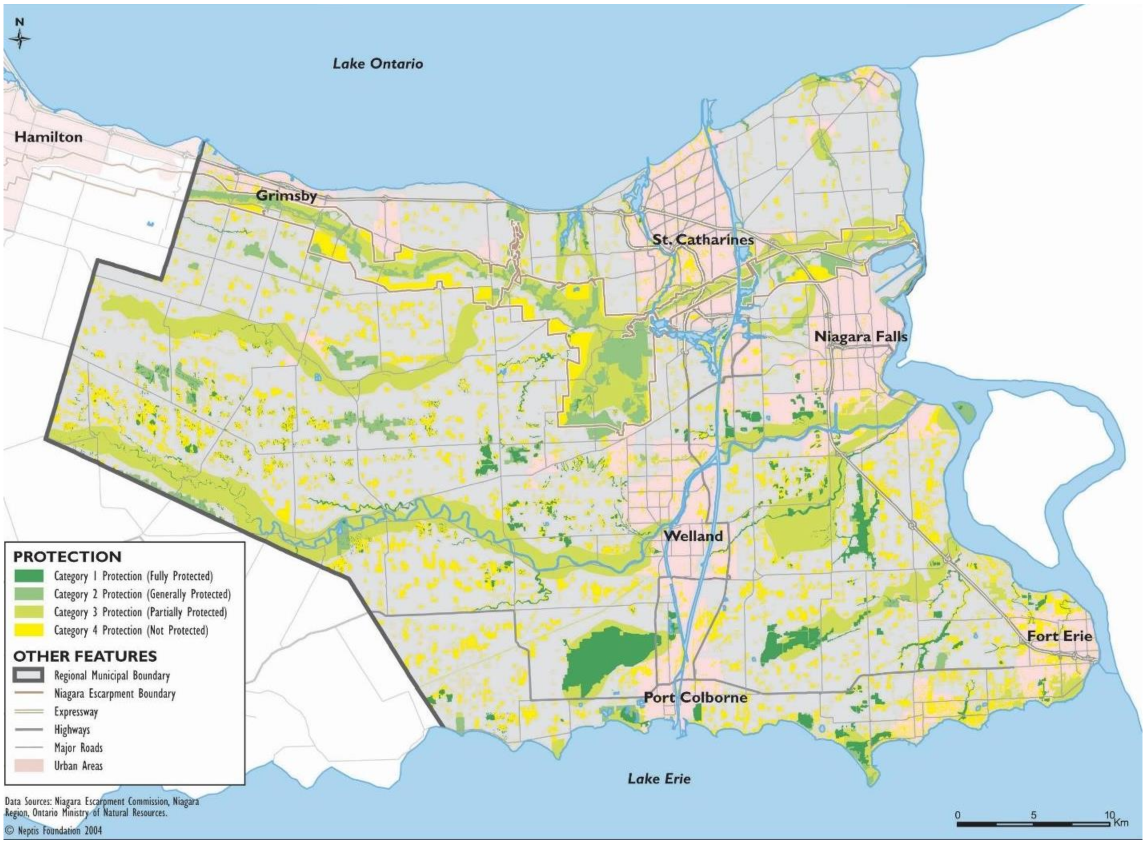


Figure 5 Neptis Protection Projection for the Niagara Region

Table 4 Niagara Escarpment Protection Levels by Neptis

Table 7: Levels of Greenlands Protection for the Region of Niagara

Level of Protection	1	2	3	4
PROTECTION	FULLY PROTECTED	GENERALLY PROTECTED	PARTIALLY PROTECTED	NOT PROTECTED
Environmentally Sensitive Areas				
1. Significant Woodlands (PPS)			x	
2. Significant Wildlife Habitat (PPS)			x	
Significant portions of the habitat of endangered and threatened species (MNR) (PPS)	x			
Provincially Significant Wetland (MNR) (PPS)	x			
Locally Significant Wetland (MNR)		x (NEP)	x	
Unevaluated Cartographic Wetland				x
Fish Habitat (PPS) (not mapped)		x		
Other Woodlands				x
Conservation Area		x		
Provincial Park, Nature Reserve		x		
Significant Wildlife Habitat			x	
NEP Escarpment Natural Areas				
1. Significant Valleylands		x (NEP)		
2. Provincially Significant Life Science ANSI (PPS)		x (NEP)		
3. Earth Science ANSI (MNR)		x (NEP)		
NEP Protection Areas				
1. Regionally Significant Life Science ANSI (MNR)			x (NEP)	
2. Woodlands			x (NEP)	

Region of Niagara Official Plan, 2000.

It is clear in Figure 5 that the most partially protected (Category 3) areas in the Niagara Region are along water sources. Fully protected (Category 1) areas are those such as the Wainfleet Bog, which is the largest dark green mass in the image above, and Humberstone Marsh in Port Colborne, which is directly to the east of the Wainfleet Bog. Generally protected (Category 2) areas are those areas such as Short Hills Provincial Park, which is in Thorold. This is the light green area located in the centre of the map toward the north, just to the west of St. Catharines. From Neptis' map above, it is also clear that the strip of land that is meant to be the protected Escarpment Zone, is essentially only rated as generally to partially protected (Category 1 and 2). See Appendix A for a map that depicts the study zone portion of the Niagara Escarpment Plan.

2.4 Defining Landscape

Landscapes are features of the earth's surface that change continuously, both naturally and anthropogenically. These changes can be thought of as either a deterioration or an improvement; however, what constitutes as deterioration or improvement varies depending on a person's perspective (Antrop, 1998). Forman and Godron (1981) define a landscape as "a kilometer[sic]-wide area where a cluster of interacting stands or ecosystems is repeated in similar form." It is stated that a landscape is formed by geomorphological processes and disturbances that function simultaneously within the landscape boundary (Antrop, 2014). A landscape disturbance is defined as any disruption from an event, no matter how small, that alters the availability of substrate or the physical environment and its resources that ultimately have an effect on the ecosystem, community, or population (Pickett and White, 1985). Disturbances can lead to new landscapes on any scale depending on the amount of disturbance involved. This may also lead to landscape fragmentation. Studies of spatial heterogeneity emerged in the 1980s as landscape ecology became more developed with easier access to data and analysis methods. Spatial heterogeneity simply refers to the abiotic and biotic relationships found in a system and how this will affect its ecology (Turner, 2005a). The term landscape ecology was first introduced by Carl Troll, a German biogeographer in 1939, who studied regional geography and vegetation science, but was aided by the newly launched perspective of aerial imaging in the 1950s (Turner, 2005b). In Europe, landscape ecology was mainly focused on human activities and used for land use planning. In North America and Australia, there is a more complex approach that observes the spatial patterns at varying scales depending on the organism (Costanza et al., 2007). Agroecosystems consist of the biologic, economic, and social elements of a landscape. This means that both living and non-living components of the landscape are important for functionality and spatial study (Hietala-Koivu, 2002). In studies of sustainability, focus has largely been on the relationship between complex human and environmental systems (Shaker, 2015). Due to the various scales mentioned above, the definition of a landscape is rather difficult to ascertain. The definition depends strongly on the particular study. For example, landscapes can be as small as a homeowner's garden, since the biotic and abiotic relationships can be studied for spatial heterogeneity. In contrast, an entire region can be observed for similar abiotic and biotic components, but at a scale that makes sense for such a large scope, such as urban sprawl and agricultural lands. It is important to note that for this study, changes in small landscape ecological patterns like those found in a garden would not be observed through satellite imagery and therefore no change would be discerned. This study aims to observe a much larger scope of landscape.

In order to observe changes in landscape and landscape ecology, landscape pattern analysis (LPA) must be undertaken. This will aid in establishing the relationship between spatial patterns and ecological processes that occur in a landscape (Oyana, Johnson, and Wang, 2014). Landscape metrics allow for the measurement, analysis, and interpretation of spatial patterns and are used frequently in landscape ecology oriented studies (Turner, 2005a). Turner (2005b) notes that in order to understand the spatiotemporal changes of a landscape, the human uses of land must be acknowledged. Antrop (1998) suggests that in order to study changing landscapes, four questions should be considered. These include:

1. Change of what?,
2. How frequent are the changes?,
3. At what scale do the changes take places?, and
4. What time period for change is being observed?

This study looks at the overall change of the Niagara Region's urban landscape and whether or not this is affecting the agricultural landscape. Magnitude of change can be observed between the years that are being portrayed as a direct comparison between each decade as well as an overall comparison between 1985 and 2015, which is a thirty-year period. Spatial patterns can be defined by two aspects. One being the spatial units. These are referred to in the literature often as the area, region, patch, or zone. The second being the boundaries between the different features of the landscapes. This leaves landscapes open to change via many varying avenues.

The Patch-Corridor-Matrix model is a useful tool to aid in understanding what comprises a landscape. The matrix is the overall theme of an area of study. For example, land use that is predominantly forested area, with a few burn sites, would be considered a matrix of forested area, with patches of burn area. Corridors are strips of land that are between patches and matrices that contain aspects of the matrix directly adjacent. Corridors can fall into four categories. These include line corridors, strip corridors, stream corridors, and networks. Line corridors are those such as pathways or roadways, perhaps even hedges. Strip corridors are wider than the line corridors and may even include patches of their own that allow for migration between other patches and matrices. Stream corridors run along waterways. Networks are those corridors that intersect and cause a loop somewhere in the matrix (Lausch et al., 2015). Often, line corridors are human made interceptions amongst patches. While some corridors allow for easy movement from patch to patch, human made corridors can pose risks to the species that reside in those patches and rely on movement between patches for nutrients. This can be for animal or plant matter. Corridors have an alternate affect in that they can help eliminate the movement of unwanted species or pollutants toward the natural inhabitants of a patch. For example, streams can prevent nutrient runoff from dirtying the water through a process called siltation, which allows sediments to remain suspended in the water (Devi, et al. 2008). With the varying components to landscape mosaics, it is only fair to state that natural movements will constantly occur between patches, corridors, and matrices. These movements can be referred to as flow or flux and the amount of flow or flux between and within the patch-corridor-matrix model is heavily dependent upon the boundaries found within this model (Kindlmann, et al., 2005).

3. Data Overview

3.1 Satellite Imagery

The United States Geological Survey (USGS) provides an excellent website entitled Earth Explorer. This allows for the user to search for an area and find satellite images that coordinate. When searching for an area, it is important to make sure that the appropriate dates are in place. In the beginning of this study, two images were chosen for each year of 1985, 1995, 2005, and 2015. Originally, one image was from the beginning to the middle of the growing season and the second image was from the middle to the end of the growing season. This means that all of the images would have been captured between May and October of their respective years. It is also important to ensure that all of the images are from the same time period, otherwise there would be obvious differences depending on the season that would compromise the legitimacy of the study. This means that eight images were originally requested for download; 1985, 1995, 2005, and 2015. Requesting images can take a little while for approval to download. It depends on what the images are to be used for. Landsat imagery was chosen for this study because it is a North American satellite series developed by NASA, which is world renowned. Specifically, for the 1985, 1995, and 2005 images, Landsat 5 was used, and for the 2015 images, Landsat 8 was used. Landsat 6 was a failed satellite and Landsat 7 is very commonly used. Landsat 8 is relatively new and thus it was chosen for the final two images for this study. The Landsat series of satellites cover the entirety of the globe, not only the Niagara Region. There are more than forty years of land use change that can be seen with Landsat. The large scope applications of these satellites is astounding. The images acquired were:

Table 5 Study Data

Datasets - Landsat Satellite Imagery					
Acquisition Date	**Satellite & Sensor**	**Spatial Resolution**	**Path**	**Row**	**Projection**
1985-05-24	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
1985-09-20	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
1995-05-20	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
1995-07-30	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
2005-07-02	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
2005-09-11	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
2015-06-03	8, OLI-TIRS	30 m	017	030	NAD 1983 UTM Zone 17N
2015-09-16	8, OLI-TIRS	30 m	017	030	NAD 1983 UTM Zone 17N

For the earlier six images, Landsat Thematic Mapper images were used. These images consist of seven bands. The first five bands and the seventh band have a resolution of 30 metres. The sixth band has a resolution of 120 metres because this is the thermal infrared band. It is not useful for the classification of these images as the resolution is not strong enough. The Multispectral Scanner System (MSS) has a much lower spatial resolution of approximately 78 metres, and therefore is not used for this study. The OLI-TIRS sensor system used for the final two images are actually instruments that are onboard the Landsat 8 satellite. The Operational Land Imager (OLI) sensor has added two new bands to the satellite. One being a deep blue specifically designed for water features. The second is a new infrared band which helps capture cirrus clouds. The TIRS (Thermal Infrared Sensor) add two new thermal bands to the captured images (United States Geological Survey, 2015).

To obtain the exact shape of the Region, a boundary shapefile was created using data gathered from the Regional Municipality of Niagara open data website. It was exported into PCI Geomatica and the satellite images were clipped to this boundary once the NDVI (discussed below) equation had been added.

4. Methods

4.1 Methods Overview

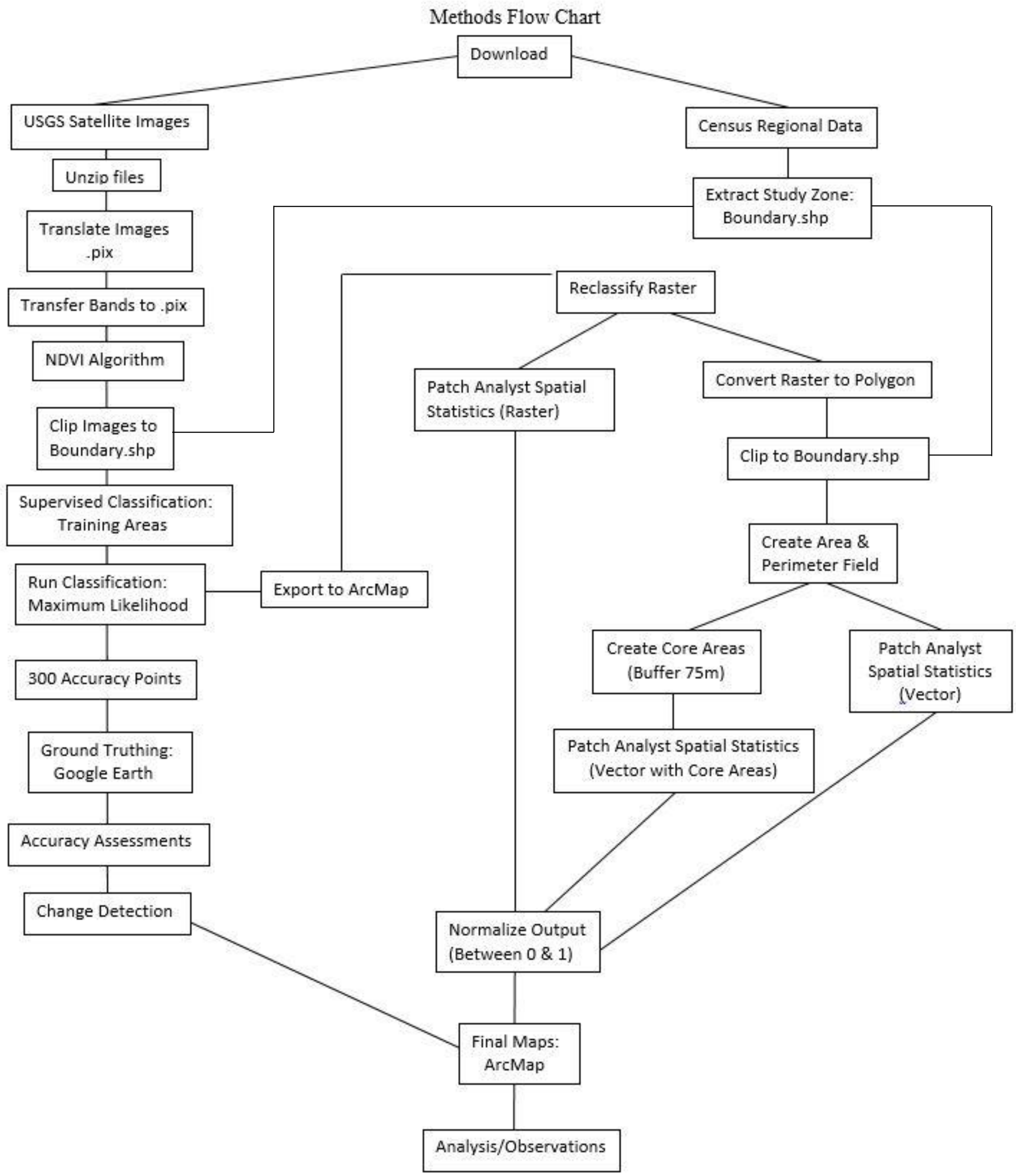


Figure 6 Methods Flow Chart

Figure 6 depicts the work progress flow chart for this study. The study compares supervised classifications done with satellite imagery throughout at thirty-year period with that of land use data analyzed through the use of landscape metrics. Figure 6 outlines how both of those methods were undertaken. Both will be described in great detail to follow.

4.1.1 Remote Sensing and Landscape Metric Studies

There are a number of research endeavours that have utilized similar methods to those found in this study; however, none have conducted studies in the Regional Municipality of Niagara for the same thirty-year time period. This time period is significant as it directly corresponds with the initialization of the above mentioned Niagara Escarpment protection policies. Studying whether these policies had any effect at a regional level on urban growth is an interesting use of landscape metrics in this Region. Following is a very brief glimpse at some work conducted in recent years that observe many of the techniques used in this paper.

In the Greater Toronto Area, urban areas have grown by 20% between 1985 and 2005. It was found that low density urban areas (i.e. suburbs) have increased substantially between the aforementioned time frame and mostly at the cost of agricultural land. This study was done using remotely sensed images of the Greater Toronto Area which had been classified for land use purposes. Images were collected using Landsat satellites from the years 1985, 1995, and 2005 (Ferberg and Ban, 2012). In Calgary, urban sprawl had been an increasing concern. Entropy had increased greatly over time and was found to be much higher than that of other cities, further concluding that sprawl was an issue. In order to determine this, satellite imagery for 1985, 1990, 1992, 1999, 2000, and 2001 were classified using specialized software. This allowed for predictions of future urban growth to be made and for policies to be advocated (Sun, et al. 2007). In Petrov and Sugumaran's (2009) study of Iowa's agricultural loss, they use similar methods that will be covered in this paper. In Iowa's Polk County (urban settlement), they found that cropland agriculture declined between 1984 and 2000 by 6930 hectares and that this could mostly be linked to the increase in impervious areas – almost a 60% rise. Based on their study, it is expected that the most change in agricultural land in this study should be seen around city edges. Agricultural loss can also be found when forestry or other natural environment (ex. wetland) growth has occurred, which is the case in Iowa due to conservation efforts. It is most commonly found that the most intense changes occur nearer city limits and lessen further into rural territory. The agricultural lands of the Algarve in Portugal have been under tremendous strain due to the increased tourism and industrial sector. Using landscape metrics, it could be seen that an increase of urbanization occurred in the Algarve by 50.2% between 1990 and 2006, while agriculture had significantly decreased by 94.88%, which can harm the heritage of the area and disturb the equilibrium of the environment (Vaz, et al. 2014). For a more in depth review of studies that utilize landscape metrics, it is suggested that Uuemaa et al.'s work be read. Here, a study of all papers that utilized landscape metrics, landscape indexes, and landscape indices were combed through to observe in what category these studies were conducted (Uuemaa, et al., 2013).

4.2 Remote Sensing

Updates in satellite image receptors have allowed for much clearer accuracy when observing land use changes over periods of time (Vaz, et al., 2011). This has proven to be helpful in areas that have previously not been intensively mapped.

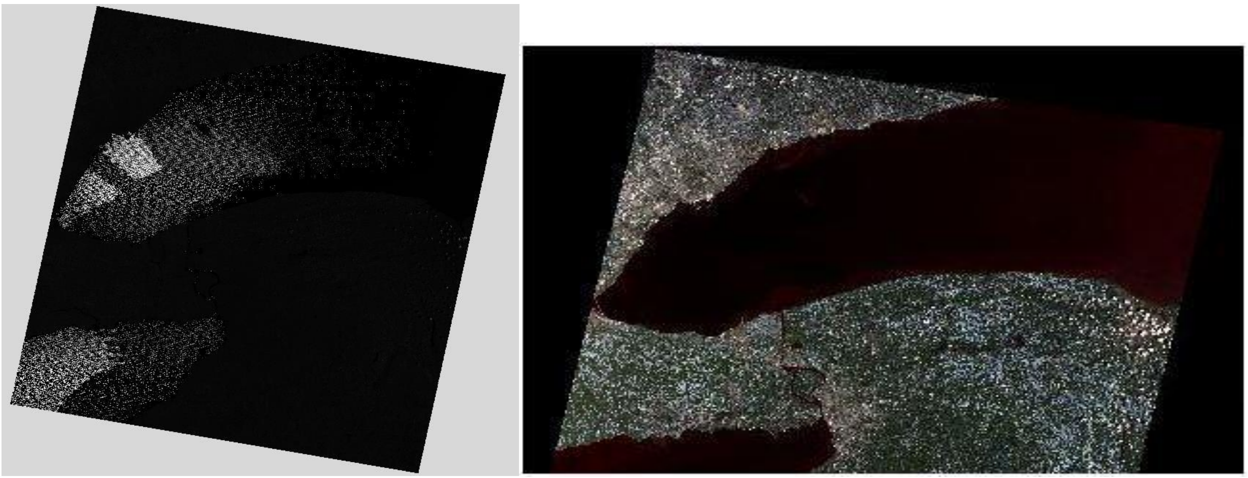


Figure 7 i) Band of Satellite Image **ii)** True Colour Satellite Image

Figure 7i shows what a downloaded satellite image looks like. This is only one band of the image. Satellite images are broken into bands to capture different light wavelengths. Each band can be used to show different objects on Earth more sharply. In order to utilize the bands, they must all be compiled into one image and an algorithm can be used to enhance those bands. Figure 7ii shows what the compiled bands would look like. It has been converted to true colours, so that it most closely reflects the colours of the surface of the Earth.

Once the composite image has been created, the Normalized Difference Vegetation Index (NDVI) algorithm was applied. This equation allows for the green aspects of each image to be better visualized. This means that all plant matter would have the opportunity to be more easily visible for the classification portion of the process. Chlorophyll is what causes the greenness of a plant's leaves. This pigment absorbs visible light to a high extent in order to activate photosynthesis; however, the cell structures of the same leaves reflect near-infrared light to a high extent. The more infrared light that is reflected back to the satellite's sensor, the more vegetation there will be in that area. If a larger portion of visible light is reflected, then the land is most likely to be barren (Weier and Herring, 2000). Therefore, the formula for calculating NDVI is a simple differencing formula:

$$NDVI = (NIR - VIS) / (NIR + VIS)$$

The Normalized Difference Vegetation Index equals the near infrared radiation minus the visible radiation divided by the near infrared radiation plus the visible radiation. For the Landsat 5 imagery, this meant:

$$(\text{Band 4 (NIR)} - \text{Band 3 (visible)}) / (\text{Band 4 (NIR)} + \text{Band 3 (visible)})$$

For the Landsat 8 imagery this meant:

$$(\text{Band 5 (NIR)} - \text{Band 4 (visible)}) / (\text{Band 5 (NIR)} + \text{Band 4 (visible)})$$

Once the NDVI was applied to aid in vegetation enhancement, the images needed to be clipped to the study area as the images are much larger than needed, including the majority of Lake Ontario and into the United States. A boundary layer was created using Niagara Region open data in ArcMap and imported to PCI Geomatica. The option to clip the images based on coordinates or a clip layer was present. The boundary shapefile used was created to specifically encapsulate the entirety of the study area and therefore was the suitable option.

Image classification is a process that is used to classify pixels in the image and make all the pixels that match that pixel one colour. This is done either through a supervised or an unsupervised classification. In this study, a supervised classification method was utilized, which means that each pixel will be converted to the appropriate class manually. In order to complete a classification, a classification scheme must be chosen. For this study, it is imperative to show the difference been urban and agricultural land. The USGS developed a paper in which guidelines for best practices in remote sensing classification are outlined. Upon review of the different land classes and uses that can occur in any one remotely sensed image, and upon review of the study area, it was deemed that for initial classification, nine classes would be utilized. These nine classes included Tree Cover/ Forest, Water, Orchard/ Vineyard, Cropland/ Pasture, Other Agriculture, Industrial/ Quarry, Commercial, Residential, and Other. The other category includes only the void space where the original imagery was cropped to the study area boundary. According to the standardization of classes set forth by the USGS in their paper, the classes of Agriculture and Urban Land are considered Level 1 Category classes; they are broader class titles. Level 2 Category classes would include components that make up differing agricultural land use or different urban land use. For example, Orchard/ Vineyard and Cropland/ Pasture are still types of agriculture; however, slightly more specific. These can be broken in to Level 3 Categories as well, but to differentiate cropland from pasture would require a much higher resolution image. As it stands, a supervised classification using level 2 categories for the images chosen proved quite difficult, and was therefore only done on the initial images to fully understand how accurate those images could be once classified. Urban or Built-up Land is defined as areas that are used intensively and the surface is mostly covered by structures. For this study, the Level 2 Category classes were used in the beginning. This included a residential class, which included low density to high density housing. Houses that are not in a typical residential neighbourhood, such as those which are located on farmland, become difficult to classify as residential, and therefore, many of those establishments are amalgamated as agriculture. Commercial land cover is typically considered areas in which there are sales of products or services. The types of agriculture that were included in the agricultural classification include orchards, vineyards, pastures, fields, etc. Over time, some agricultural lands may have changed from fields to greenhouses. Greenhouses are still considered agriculture, but will not be seen that way in this study. Figure 8 shows a supervised classification of the September 16, 2015 Landsat 8 image using the Category 2 classification scheme. This study strives to visualize the difference between the urban and agricultural areas over time. Once this supervised classification was completed, it was apparent that the resolution of the imagery would not be enough to undertake a Category 2 classification scheme for all images. Thus, Category 1 classification schemes were utilized. Category 1 allows for more blatant classification titles. For example, Commercial, Agriculture, Residential, etc. This meant that orchard, vineyard, pasture, etc., would be under the agriculture umbrella, simplifying the classification process. Figure 9 shows a Category 1 classification using the June 3, 2015 Landsat 8 imagery. Here, the same aspects of the landscape are highlighted (i.e. residential) without the confusion of multiple classes. In the northern corner of the imagery in Figure 8, it is clear that agriculture is confused between orchard/vineyard and pasture/open land. With the resolution of Landsat 8 imagery, it is very difficult to be accurate that that classification is correct. Figure 9 reduces this confusion by enabling an agriculture class as a whole.

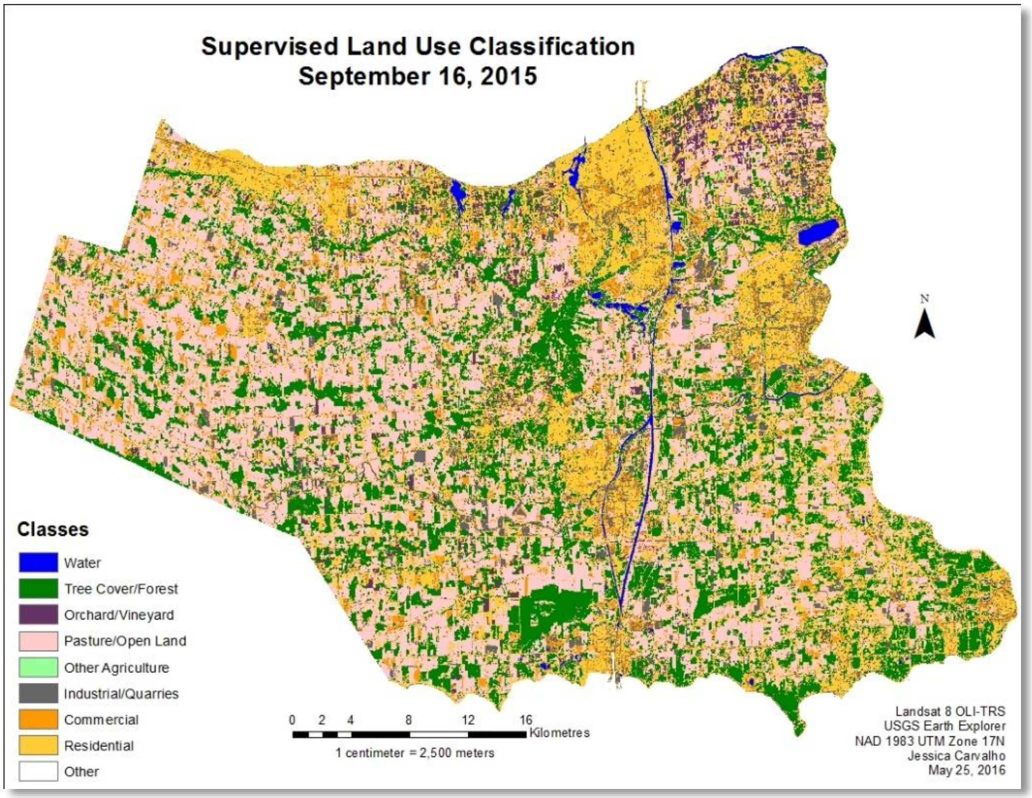


Figure 8 Category 2 Classification Scheme

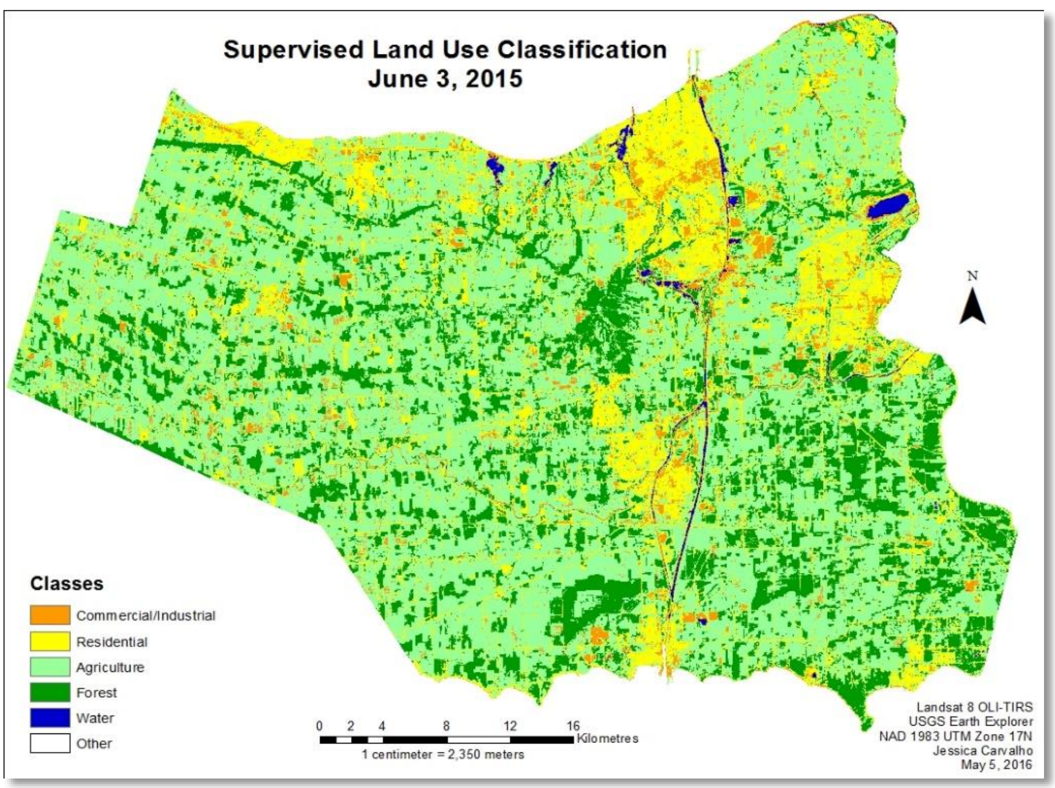


Figure 9 Category 1 Classification Scheme

Once the classification scheme was clear through trial and error, supervised classifications could be done for all of the images. This was done by creating training sites for each class. The class was selected and training sites could be drawn directly on the image being classified. Once all of the training areas were completed, the classification was run. For the supervised classifications in this study, the maximum likelihood method was chosen, which simply means that if there was a controversy between pixel prioritization, then the pixel would be assigned a class that makes the most sense based on those pixels surrounding it. Once the classifications had been run, a colourized image was presented, such as those in Figure 8 and Figure 9.

Once the classifications were completed, 300 accuracy points were used to ensure the classifications were done as well as possible. When using accuracy points, there is the potential to use another image to match the classes in the image. The author used the original image for reference as well as Google Earth for ground truthing purposes. To ensure that the pixels being observed were being converted to the appropriate class, ground truthing techniques were applied. Ground truthing for this study can be completed in two different ways. The first being to use a true picture of the area being classified. This will give an indication of which classification each pixel in the area will correspond with. The other alternative is to be present in the location of the study area. Google Earth was the most useful for this study and has been a method utilized by the author in previous studies. Ground truthing using Google Earth is a widely accepted practice throughout the literature. Numerous examples of peer reviewed articles can be found that have used this method to observe vegetation (Taylor and Lovell, 2012; Vega, Craig, and Lindo, 2011; and Duhl, Guenther, and Helmig, 2011).

Once the accuracy was completed it became evident through visual interpretation that there was no need for eight overall image classifications. The images from the same year, but separate ends of the growing season, showed little to no differences. Four images, one from each year of the study, were chosen. The four images were those with the best quality. This meant no cloud cover and no impurities in the original imaging. The images chosen to continue the study were:

Table 6 Final Study Data

Datasets - Landsat Satellite Imagery					
Acquisition Date	**Satellite & Sensor**	**Spatial Resolution**	**Path**	**Row**	**Projection**
1985-05-24	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
1995-05-20	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
2005-07-02	5, TM	30 m	017	030	NAD 1983 UTM Zone 17N
2015-09-16	8, OLI-TIRS	30 m	017	030	NAD 1983 UTM Zone 17N

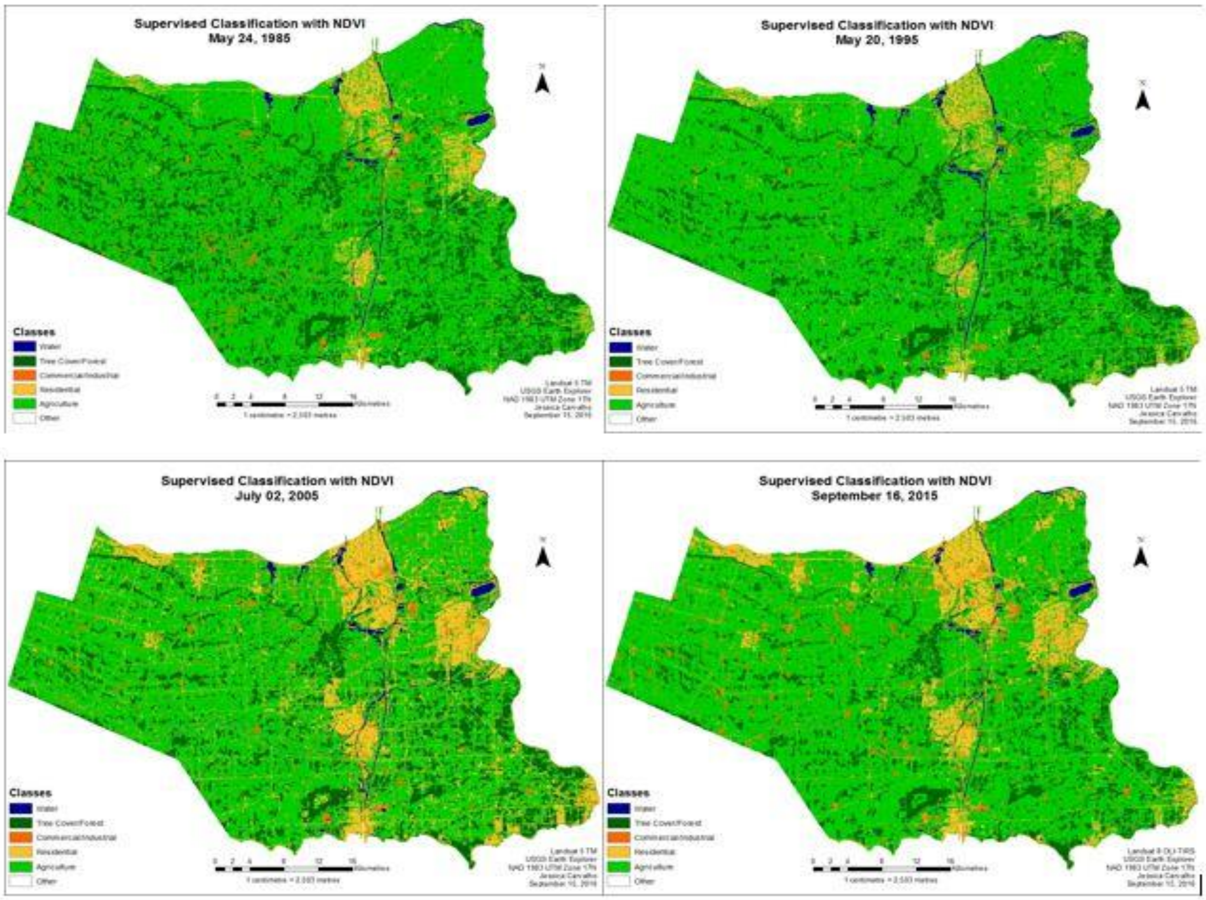


Figure 8 Completed Supervised Classifications

Figure 10 shows the completed supervised classification with the NDVI enhancement and after completing the 300 accuracy points. The accuracy reports will be discussed further in the results portion of this thesis. The initial output of Error Matrices and Accuracy Reports from PCI Geomatica can be seen in Appendix B. From left to right the images are 1985, 1995, 2005, and 2015. It is fairly easy to see by eye that there has been an increase in the yellow areas over the 30-year period. The yellow portion is the residential class for each classified image. Residential and commercial (includes industrial) are considered the urban portion of this study. From west to east, the towns with the increasing residential areas are Grimsby, St. Catharines, Welland, Wainfleet, Niagara Falls, and Fort Erie. St. Catharines is the largest residential block on each map, which corresponds with the population data mentioned in the introduction of this thesis. Also, Grimsby becoming prominent in the past 30 years is accurate compared to the overwhelming 39.46% growth shown in the population data from the introduction portion.

Classifications formed in PCI Geomatica are easily exportable to ArcMap. The above completed classifications were visualized in ArcMap. Figure 11 shows the final four classifications reclassified. In ArcMap this is a tool that is particularly useful in allowing the user to showcase only the important aspects of the landscape pertaining to the particular study. In this case, the six classes were reclassified into only three. Those being Other (includes class other, water, and tree cover/forest), Urban (includes residential and commercial/industrial), and Agriculture. It is important to note that agriculture includes open land. This is land which may not necessarily be for agricultural use, but is part of the rural landscape. From left to right, the newly reclassified images are less contorted than in the previous images and analysis of the truly important aspects becomes easier. Here, testing for the urban growth in the Niagara Region becomes simpler. The reclassify tool is utilized in such a way that the pixels in each class are assigned to a new class chosen arbitrarily by the user. In this case, the author chose class numbers of one, two, and three. One pertained to all those that were not pertinent to this study, such as tree cover and forest, water, and the other category. This class can be seen in Figure 11 as the light grey. Unfortunately, in a raster model from satellite imagery, the background is part of this other category, which mean that it is part of the classification. This can jeopardize the analysis, so it was important to capture this part of the classification in the new 'Other' category and run no further analysis on these component. Class number 2 captured the urban land uses in the previous classifications. This included commercial/industrial and residential and is noted as the pale peach colouring. Class number 3 captured all agricultural land and open land usages; essentially everything considered rural. These newly reclassified images will come into use in the Landscape Metrics portion of this thesis.

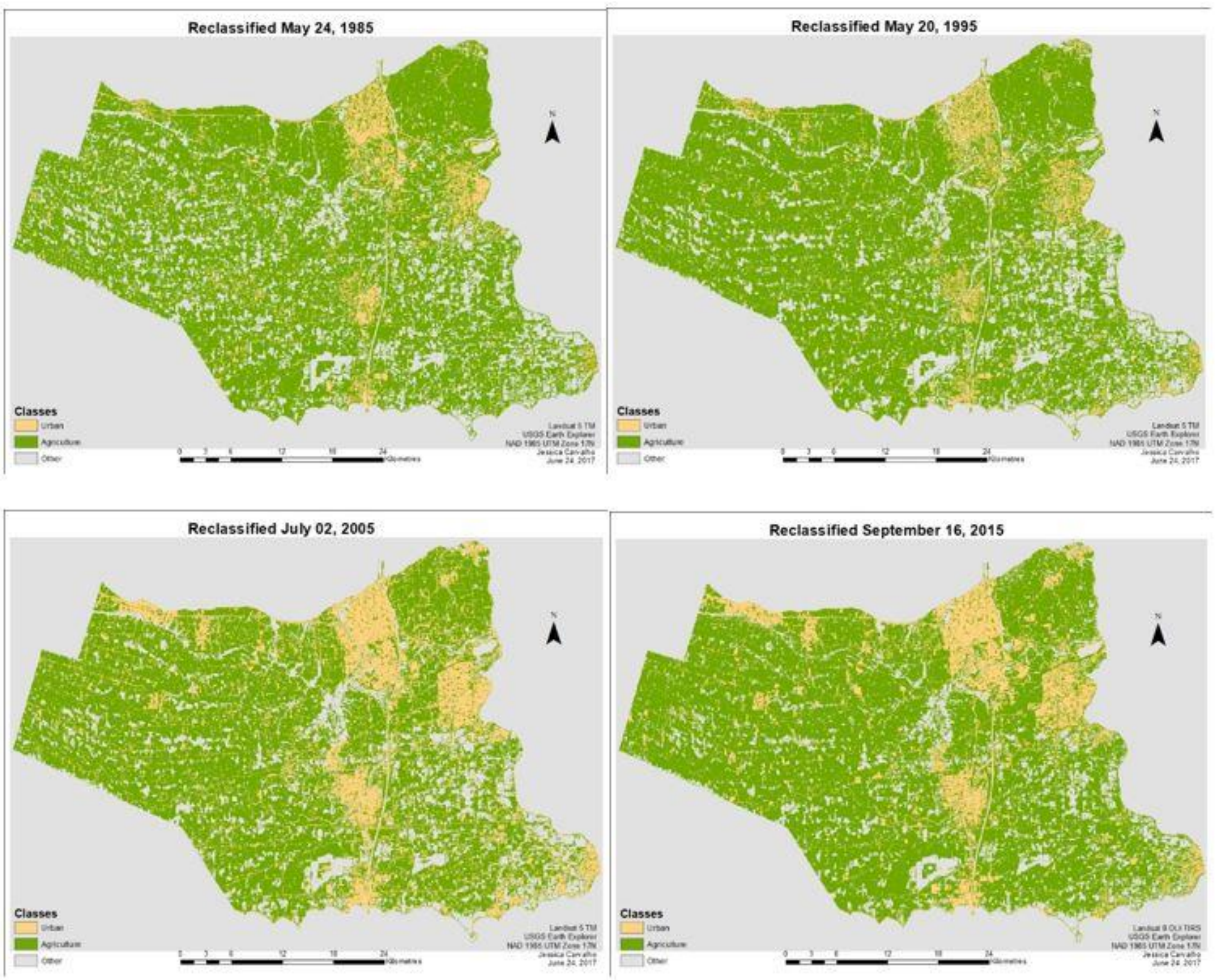


Figure 9 Reclassified Raster Land Use Classes

Finally, change detection methods were utilized in order to gain insight into the actual visual difference in urban land from 1985 to 2015. In PCI Geomatica, this process is relatively simple and can be done in a number of ways. The method chosen for this study was image differencing which can take a number of forms. Three trials were done for this study to ascertain the best image differencing results possible. First, the final classified maps were used within the image difference application. This subtracts the prior year from the next year in the series (ex. difference image = (1995 final classification – 1985 final classification)). The subtraction of the images from one another occurs pixel by pixel and a third image is created which includes all of the differences found (Ridd and Liu, 1998). The second trial utilized band 1 to observe changes. In this trial, for example, difference image = (1995 band 1- 1985 band 1). The only difference was for the comparison between 2005 and 2015 and the comparison between 1985 and 2015. The equations were difference image = (2015 band 2 – 2005 band 1), and difference image = (2015 band 2 – 1985 band 1). The reason for the difference in the equation lies in the 2015 Landsat image. This was a Landsat 8 image, whereas the other three images were from Landsat 5. The band designations are slightly different, but the same bands still exist. Table 6 and 7 highlight the different band designations for Landsat 5 and Landsat 8 images below, as well as their wavelengths and what each band is best used for. These are important for the other image differencing options conducted for this study. The tables below allowed for a deeper understanding of what the individual bands in the Landsat imagery portrayed. Due to the nature of this study being about the growth or decline in the agriculture land use of the Niagara Region, certain bands can be chosen from each satellite image to conduct other image differencing-styled change detections. As mentioned above, band 1 was used for initial image differencing between the years; band 2 for the

2015 Landsat 8 image. This band was chosen for initial analysis due to its ability to distinguish soil from vegetation.

The third and final round of trials used band 2; band 3 for the 2015 Landsat 8 image. Band 2 was chosen due to its ability to accentuate vegetation. Band 2/band 3 (Landsat 8) for image differencing was also utilized in a similar urban land use analysis conducted by Forsythe and Waters (2006). In their study, they were experimenting with different applications to enhance urban change detection in Calgary, Canada and utilized band 2 in their final change detection analysis. The applications that Forsythe and Waters (2006) studied were those of image texture, but their study also included principal component analysis (PCA) and NDVI. The study conducted in this thesis utilizes NDVI, but not image texture. Principal component analysis was tested for this thesis, but ultimately not used in the final four classified images that are shown above. While this study is looking for growth in urban land use, it can also be accomplished by looking for a loss of agriculture in the analysis.

Table 7 Landsat 5 TM Bands (USGS, 2017)

Landsat 5 Thematic Mapper Band Designation		
Band	**Wavelength**	**Useful for Mapping**
Band 1 - Blue	0.45 - 0.52	Bathymetric mapping Difference between soil and vegetation Difference between deciduous and coniferous vegetation
Band 2 - Green	0.52 - 0.60	Accentuates peak vegetation
Band 3 - Red	0.63 - 0.69	“Discriminates vegetation slopes”
Band 4 - Near Infrared	0.77 - 0.90	Biomass content and shorelines are accentuated
Band 5 - Short-wave Infrared	1.55 - 1.75	Difference between moisture content of soil and vegetation Infiltrates thin clouds
Band 6 - Thermal Infrared	10.40 - 12.50	Thermal mapping and estimated soil moisture
Band 7 - Short-wave Infrared	2.09 - 2.35	“Hydrothermally altered rocks associated with mineral deposits”

Table 8 Landsat 8 OLI-TIRS Bands (USGS, 2017)

Landsat 8 Operational Land Imager and Thermal Infrared Sensor		
Band	**Wavelength**	**Useful for Mapping**
Band 1 - Coastal Aerosol	0.43 - 0.45	Coastal and aerosol studies
Band 2 - Blue	0.45 - 0.51	Bathymetric mapping Difference between soil and vegetation Difference between deciduous and coniferous vegetation
Band 3 - Green	0.53 - 0.59	Accentuates peak vegetation
Band 4 - Red	0.64 - 0.67	"Discriminates vegetation slopes"
Band 5 - Near Infrared	0.85 - 0.88	Biomass content and shorelines are accentuated
Band 6 - Short-wave Infrared 1	1.57 - 1.65	Difference between moisture content of soil and vegetation Infiltrates thin clouds
Band 7 - Short-wave Infrared 2	2.11 - 2.29	Improved difference between moisture content of soil and vegetation Infiltrates thin clouds
Band 8 - Panchromatic	0.50 - 0.68	"15metre resolution Sharper image definition"
Band 9 - Cirrus	1.36 - 1.38	Detects cirrus clouds
Band 10 - TIRS 1	10.60 - 11.19	"100 metre resolution Thermal mapping and estimated soil moisture"
Band 11 - TIRS 2	11.50 - 12.51	"100 metre resolution Improved thermal mapping and estimated soil moisture"

Depending on the gradient chosen, the outcome of the image differencing equations can be read in a few different ways. Initially, it was thought that the RGB gradient would be the most usefully utilized output. This method would show positive changes in the landscape as ranging from gray to bright red. Negative changes would be shown on a blue scale. Gray being the most neutral (i.e., little to no change in that section) to bright blue for the largest negative changes. Upon further reading, the PCI Geomatics change detection tutorial suggested that pseudocolour be used for the output (PCI Geomatics, 2015). Due to the use of the PCI Geomatics software, this was the first output chosen for all of the change detection image differences. It was soon discovered that once the output is opened in ArcMap, it is automatically converted to grayscale. It could be changed back to pseudocolour, but the grayscale seemed like a more software-friendly option since it occurred in both PCI Geomatica and ArcMap much more easily. Therefore, the grayscale method is what can be seen here. If the land appeared whiter in the difference image, this meant that less 'greeness' could be detected once the years were subtracted from one another. This lead to what could be considered an increase in some urban areas; however, it also meant that some farmland may have been harvested or recently plowed. From the differenced images and direct comparison with the original Landsat images, this seemed to occur frequently. This poses a problem for further statistical analysis as urban land and harvested cropland appeared too similarly. The darker the area in the differenced image, the more 'greeness' could be detected. This often meant that more forested or tree cover area was detected. Any gray colouring is considered neutral, which means that little to no change occurred between the two dates being observed.

Overall, twenty-four change detection images were created. There were six differenced images for each decade, plus six more for the overall time period between 1985 and 2015. The first three in each decade were done in pseudocolour utilizing the three separate trials listed above (final classifications, band 1, and band 2/3 respectively). The other three in each decade were grayscale, which were ultimately used for further analysis. The twelve total grayscale differenced images were compared and contrasted against the corresponding original satellite imagery of the same years that were part of the difference image. This lead to the realization that the change detection visualized in the classified images was not ideal. These images did not display nicely and were difficult and confusing to read. There were only minor differences between the band 1 and band 2 differenced images; however, the band 2 images had cleaner colourization. This meant that there seemed to be fewer grey areas, which allowed for a better understanding of what type of change had occurred. Therefore, the final four images chosen for the change detection model were those that utilized band 2 image differencing equations.

In Figure 12, the four final image differencing maps were created and show cased. From left to right, the changes captured are 1985 to 1995, 1995 to 2005, 2005 to 2015, and 1985 to 2015. It is important to note that image differencing does not only show urban growth or loss. It is showing all differences apparent throughout the classifications of the images. As mentioned previously, the use of NDVI allows for the greenness of the landscape to reflect to the satellite sensor much more sharply. In image differencing, that greenness is key in establishing the differences seen over time. Other methods can be utilized to help boost the greenness and sharpness of a satellite image, such as the tasseled cap correction.

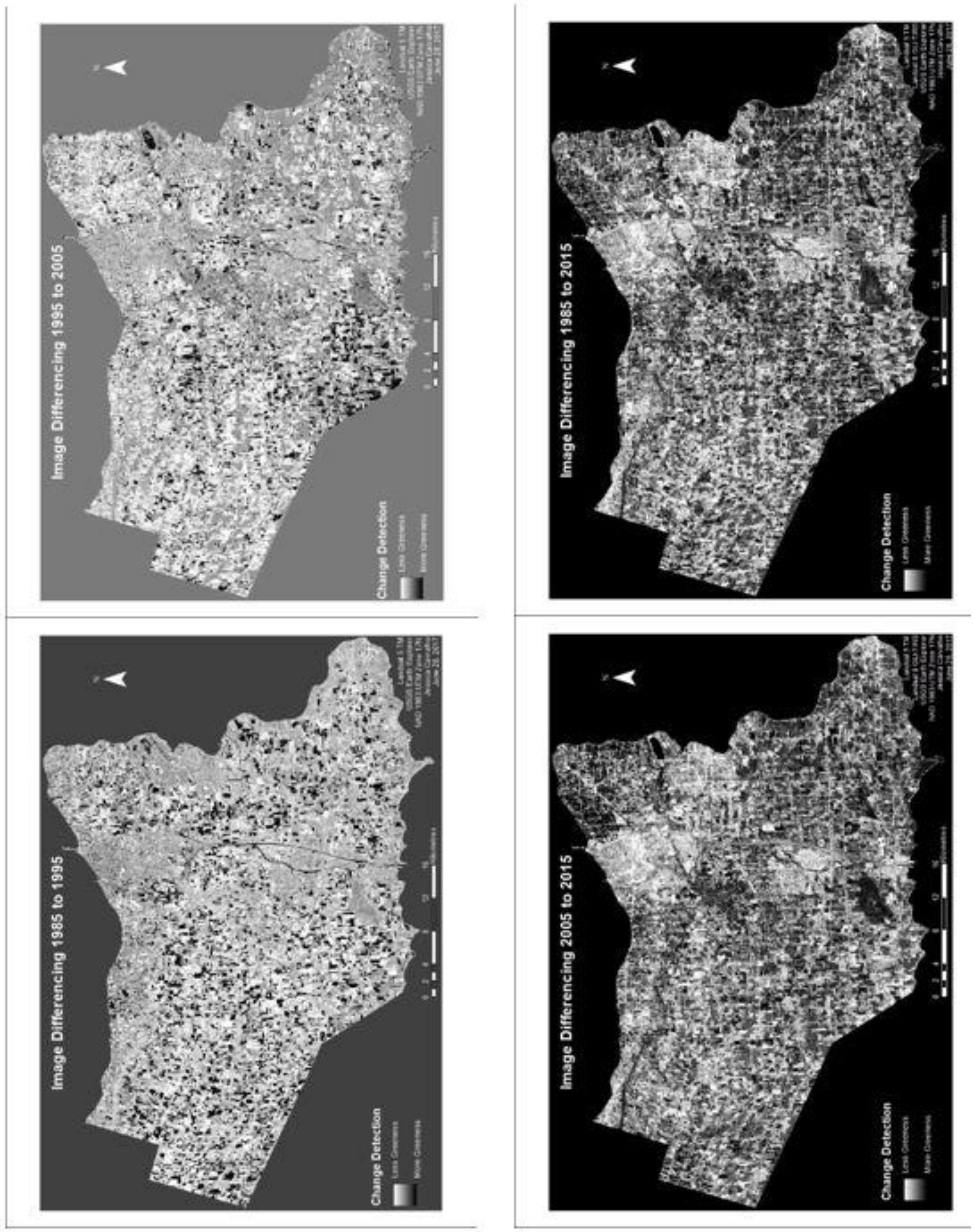


Figure 10 Change Detection using Image Differencing Equations

4.3 Landscape Metrics

Landscape metrics are a method which include a series of quantitative indices that are used to describe the patterns of different categorical data (Turner, 2005b; and McGarigal, 2015). This analysis will aid in forming a functional mosaic of land use so that assessment of quantifiable patterns of the landscape can be undertaken. Landscape metrics are useful especially when considering where administrative boundaries lay in comparison to policy changes over time and socioeconomic growth or decline (Vaz, et al., 2014). Landscape metrics will provide a better understanding of the overall fragmentation of the different land uses and this study will pay particular attention to the variation of urban growth and rural disturbances (Vaz, 2014). Some of the most popular metrics can be seen in Table 9 (Herold, et al., 2002). A few examples include the fractal dimension, which measures the perimeter of landscape versus the entire area. Values in this metric range from one to two. If the landscape is less fragmented, it will have a value closer to one. The larger each perimeter becomes in accordance to the entirety of the area, the closer the value will be to two. This would indicate a greatly fragmented landscape (Herold, et al., 2002). Patch density describes the number of patches within a certain landscape. The size of patches as

Table 9 List of Popular Landscape Metrics

Metric	Variable	Category	Measure
Area	Area	Area/Density/Edge	Landscape Composition
Number of Patches	NP		Fragmentation
Largest Patch Index	LPI		Dominance
Landscape Shape Index	LSI		Aggregation
Normalized LSI	NLSI		Aggregation
Total Core Area	TCA	Core Area	Landscape Composition
Number of Disjunct Core Areas	NDCA		Spatial Contiguity
Percentage of Like Adjacencies	PLADJ	Contagion/Interspersion	Aggregation
Interspersion & Juxtaposition Index	IJI		Intermixing of classes
Clumpiness	CLUMP		Adjacency
Landscape Division	DIV		Diversity
Splitting Index	SPLIT		Fragmentation
Effective Mesh Size	MESH		Homogeneity
Perimeter-Area Fractal Dimension	PAFRAC	Shape	Shape Complexity
Patch Cohesion Index	COHE	Connectivity	Connectedness

well as their density can be useful in describing the configuration of the landscape. Patch size is an indicator of species within and on the edge of a given patch and fragmentation amongst patches can affect those species (Gergel and Turner, 2002). In Vaz's (2014) study of Mumbai's mangroves, a number of metrics were used that will also be utilized for this analysis. The reason for this close similarity is due to the nature of the Mumbai mangrove study. In that study, loss and gain of mangroves was the main focus and proponent as mangroves play a large role in biodiversity and overall ecological health of that particular region. In this study, loss and gain of agriculture is the main focus, which also holds a large role in ecological health of the Niagara Region. The loss or gain of agriculture will be ascertained by discerning the growth of the urban landscape. Hence, similar metrics will be utilized as they have been tested in similar literature. It is important to note at which level the metrics are studied. This could mean that metrics are run on a class level, which would include the different classes of the study level (i.e., agriculture, commercial, forest, etc.). This means that metrics would be computed for the whole of the landscape, but by class and not as one overall image. Metrics can also be utilized to look at the overarching landscape. The entirety of the landscape would be visualized in the statistical computations at this level. This would give a broader interpretation of the changes that might be expected (McGarigal, 2015). Appendix C showcases two examples of what the Patch Analyst spatial statistics output appears as in ArcMap.

The spatial statistics in Appendix C that will not actually be used in this study are as follows:

1. MPAR (Mean Perimeter-Area Ratio): helps describe the shape complexity.

   MPAR = the sum of each perimeter-area ratio / NUMP

2. MPE (Mean Patch Edge): is the average amount of edge for each patch.

   MPE = TE / NUMP

3. MedPS (Median Patch Size): is the middle patch size, or the 50^{th} percentile.

The rest of the statistics that will be used in this study from Appendix C and those based on Vaz's 2014 study of Mumbai's mangroves are seen below (McGarigal, 2015, Elkie et al., 1999, and Vaz, 2014):

AWMPFD is the Area Weighted Mean Patch Fractal Dimension. This adds individual weighting to patch areas of each patch. This can be used to determine shape complexity without depending upon the patch's size.

$$\mathbf{AWMPFD} = \sum_{j=1}^{n}\left[\left(\frac{2\ln(.25p_{ij})}{\ln a_{ij}}\right)\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$$

Where:

j = 1 is the number of patches

p_{ij} is the perimeter (m) of the patch.

a_{ij} is the area (m^2) of the patch.

The Area Weighted Mean Shape Index (AWMSI) will display a number of one when the patch is a perfect circle. This number will increase when there is greater shape irregularity. Larger patches will weigh more than smaller patches and this is due to the added patch area weighting.

$$AWMSI = \sum_{j=1}^{n}\left[\left(\frac{.25p_{ij}}{\sqrt{a_{ij}}}\right)\left(\frac{a_{ij}}{\sum_{j=1}^{n} a_{ij}}\right)\right]$$

The Class Area (CA) is simply the sum of all of the patches in each class. Therefore:

$$CA = \sum_{j=1}^{n} a_{ij}\left(\frac{1}{10,000}\right)$$

CACOV, or the Core Area Coefficient of Variance, allows for the display of the variability in the amount of consistency of core areas in relation to the average core area.

$$CACV2 = \frac{CASD2}{MCA2}(100)$$

The Core Area Density (CAD) is the number of isolated core patches relative to the total landscape area.

$$DCAD = \frac{\sum_{j=1}^{n} n_{ij}^{c}}{A}(10,000)(100)$$

Where:

n_{ij}^{c} is the disjunct core areas determined by the buffer size.

The Core Area Standard Deviation (CASD) is the measure of patchiness in the core area size. It is the standard deviation of isolated core areas.

$$\text{CASD1} = \sqrt{\frac{\sum_{j=1}^{n}\left[a_{ij}^{c} - \left(\frac{\sum_{j=1}^{n} a_{ij}^{c}}{n_i}\right)\right]^2}{n_i}}\left(\frac{1}{10{,}000}\right)$$

Where:

n_i is the total number of patches in the class.

ED (Edge Density) is the amount of perimeter in relation to the landscape area.

$$\text{ED} = \frac{\sum_{k=1}^{m} e_{ik}}{A}(10{,}000)$$

Where:

e_{ik} is the total length (m) of the perimeter between patches in the landscape.

k = 1 is the number of classes in the landscape.

The MCA (Mean Core Area) is the average size of the isolated core patches.

$$\text{MCA1} = \frac{\sum_{j=1}^{n} a_{ij}^{c}}{n_i}\left(\frac{1}{10{,}000}\right)$$

Where:

a_{ij}^{c} is the core area (m^2) of each patch determined by the buffer size.

The MPFD, or the Mean Patch Fractal Dimension, aids in distinguishing patch complexity. The number will be closer to one when the perimeter of the patch is simpler and will approach two when more complexity is shown.

$$MPFD = \frac{\sum_{j=1}^{n}\left(\frac{2\ln(.25p_{ij})}{\ln a_{ij}}\right)}{n_i}$$

The Mean Patch Size (MPS) is the average size of patches.

$$MPS = \frac{\sum_{j=1}^{n} a_{ij}}{n_i}\left(\frac{1}{10{,}000}\right)$$

The Mean Shape Index (MSI) aids in identifying shape complexity. If the patch is a circle (for vector data) then the number will be one and it will increase with patch shape irregularity.

$$MSI = \frac{\sum_{j=1}^{n}\left(\frac{.25p_{ij}}{\sqrt{a_{ij}}}\right)}{n_i}$$

NumP, or Number of Patches, is the total number of patches for the class level statistics or the total number of patches for the landscape level statistics. This depends on what was chosen in the Patch Analyst interface.

$$NP = n_i$$

PSCOV, which is the Patch Size Coefficient of Variance, measures the variability amongst the patches.

$$PSCV = \frac{PSSD}{MPS}(100)$$

Patch Size Standard Deviation (PSSD) is the standard deviation of the patch areas.

$$\mathrm{PSSD} = \sqrt{\frac{\sum_{j=1}^{n}\left[a_{ij} - \left(\frac{\sum_{j=1}^{n} a_{ij}}{n_i}\right)\right]^2}{n_i}}\left(\frac{1}{10{,}000}\right)$$

TCAI is the abbreviation for the Total Core Area Index. This explains the amount of core area for the Total Landscape Area. "Total core area index is a proportion of core area in the entire landscape and is equal to zero when no patches in the landscape contain core and approaches one as the relative proportion of core area in the landscape increases (Elkie, et al., 1999)."

$$\mathrm{TCAI} = \frac{\sum_{j=1}^{n} a_{ij}^{c}}{\sum_{j=1}^{n} a_{ij}}(100)$$

Total Edge (TE) is the perimeter of all of the patches.

$$\mathrm{TE} = \sum_{k=1}^{m} e_{ik}$$

Finally, the Total Landscape Area (TLA) is the sum of the areas for each patch in the landscape, not only for each class.

$$\mathrm{TA} = A\left(\frac{1}{10{,}000}\right)$$

The abbreviations for these metrics were taken from the Patch Analyst extension, and not from McGarigal so that they would be easier to understand with the output seen in this study. These statistics can be grouped in a particular fashion that allows them to be more easily analyzed. First, they can be grouped by the level at which they are observed. This means that they can be observed at the patch, class, or landscape level. Class level is utilized for this study. The statistics are aspects of pattern and can be found in metric categories such as area and edge, shape, core area, contrast, aggregation, subdivision, isolation, and diversity (McGarigal, 2015). The difference between patch and class level is that the class level observes each patch by its specified class.

The Patch Analyst tool in ArcMap allows for spatial analysis to be conducted on either vector or raster classifications. For this study, both options were undertaken to ascertain which returned the more accurate data. Raster data is easier to run through Patch Analyst as core areas do not need to be separately created. Since raster data is made of cells, the centre most areas of a patch are more easily discerned. The process of running the spatial statistics for vector data is slightly more complicated in that there are more steps to completion. First, the reclassified raster data is converted through the raster to polygon tool in ArcMap. This will initiate the vector data. From here, the vector model can be clipped to the boundary shapefile so that the background data from the original satellite imagery can be removed. Once this has been removed, adding the area and perimeter to the attribute table is a necessary step. Next, core areas need to be created. It is important to note that spatial statistics can be created without using core areas; however, core areas allow for the measurement of the most centre area of the patch as well as allow for a better understanding of the edge of the patch and whether or not that patch may contribute to fragmentation of the landscape. These are just a few reasons that core areas were created.

Unfortunately, due to the smooth nature of vector data, creating core areas takes a little more time than seems logical. Using a 75 metre buffer, each of the four vector classifications were eventually given core areas. Once core areas are completed, the landscape metrics can be run. Similar indices were chosen as those above; however, the core area coefficient of variance (CACOV), mean core area (MCA), and core area standard deviation (CASD) are not metric options that can be chosen in the Patch Analyst interface for vector data. The output tables were recreated in Microsoft Excel in order for maximum readability to be reached. The output in ArcMap is shown in the attribute table and makes direct analysis between multiple years difficult as the attribute table only shows the land use of the year being observed. The original output can be observed in Appendix E.

5. Results

5.1 Satellite Image Classification

Appendix C shows the Error Matrices (or Confusion Matrices) for the completed classifications. These are the outcome of the 300 accuracy points mentioned above. In the tables, the classes used in the classifications are the first column. The accuracy points are generated at random on the classified image and then, utilizing the Google Earth ground truthing methods, each of the 300 points is assigned a class. The columns of the error matrix indicate where each point fell based on the outcome of the ground truthing. For example, in the 1985 error matrix, it can be seen that for the tree cover class, thirty-three points were indeed assigned as tree cover, while eight points were assigned as agriculture. This happens when the classification is not completely accurate. Human error and satellite imagery resolution limitations must be taken into account. While ground truthing, it was found that those eight points were not actually tree cover, but were in fact agriculture. This reduces the rate of the accuracy reports, which can be seen in Appendix D.

Appendix D includes the aforementioned accuracy reports for each completed supervised classification. When undertaking supervised classifications, it is widely accepted that 80% accuracy is the absolute lowest for a study to be deemed applicable. Anything less than 85% tends to becomes cause for scrutiny, even if the analysis is well done (Bakillah et al., 2014). The way the accuracy is read is on a diagonal. For example, one would start with the water class and find the corresponding water column. From this point diagonally downward to the right corner, each column should match up with the same class name in it's row. The numbers in this diagonal stretch should be the largest numbers for each class. The higher these numbers, with fewer in incorrect columns, the higher the accuracy will be. The other columns are Producer's Accuracy and User's Accuracy. Producer's accuracy is calculated using the proportion of correctly indicated sample points relative to ground truthing. It measures the level of omission for the final maps. The user's accuracy measures the level of commission in the final maps. This means that those two categories can state whether any of the classes have been over or under emphasized (Unger, et al., 2014).

In the May 24, 1985 accuracy statistics table, it is stated that the overall accuracy for this supervised classification was approximately 91.66%. The Kappa statistic reads 0.87. The Kappa statistic is a less biased view of the overall accuracy as it reflects the difference between the overall accuracy and the accuracy that could have occurred by chance. The overall accuracy is only a partial story. The Kappa Coefficient computation can be seen in the following equation.

$$K = \frac{M\sum_{i=1}^{r} x_{ii} - \sum_{i=1}^{r} x_{i+}x_{+i}}{M^2 - \sum_{i=1}^{r} x_{i+}x_{+i}}$$

Where:

r = is the number of rows in the error matrix,

x_{ii} = is the number of observations in row i and column i,

x_{i+} and x_{+i} = the totals of row i and column i,

M = total number of observations ((Ridd and Liu, 1998).

The overall accuracy reads as 88.66% for 1995, with the Kappa statistic being 0.82. The accuracy for 2005 was 94% with a Kappa statistic of 0.90 and for 2015 the overall accuracy was 93.33% with a Kappa statistic of 0.89. It is sometimes difficult to determine between commercial land use and residential land use as they both can reflect back to the sensor on the satellite as a bright white spot on the earth. This is one of the reasons for some of the errors in those class categories. Roads were meant to be part of the urban classes, but at a 30 metre resolution it is difficult to capture such a minute aspect of the landscape. With that being said, there were many instances where what should have been placed in the commercial/residential class was actually thought to be agriculture.

5.2 Change Detection

The following images are the change detections done through image differencing in PCI Geomatica. The detected change areas were extracted using the EXPOLRAS algorithm and saved as shapefiles. This allowed the user to visualize the changed areas in ArcMap. Figure 13 and 14 showcase extracted change areas between 1985 and 1995. Figure 15 and 16 show the extracted change areas between 1995 and 2005. Figure 17 and 18 show the extracted change areas between 2005 and 2015. Most importantly, Figure 19 and 20 show the extracted change areas between 1985 and 2015. The first set of maps in each series show the change areas on the image differencing layout, while the second set of maps in each series shows the changes on the original satellite image.

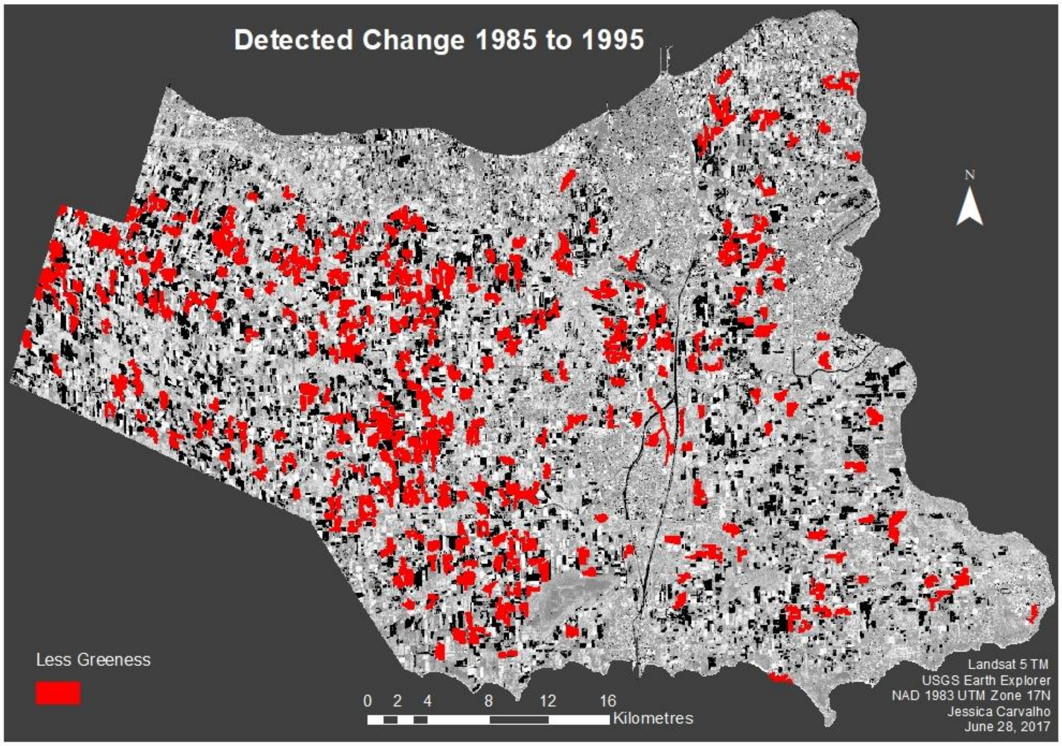


Figure 11 Change Detection with EXPOLRAS change shapefiles on 1985 – 1995 image differencing map

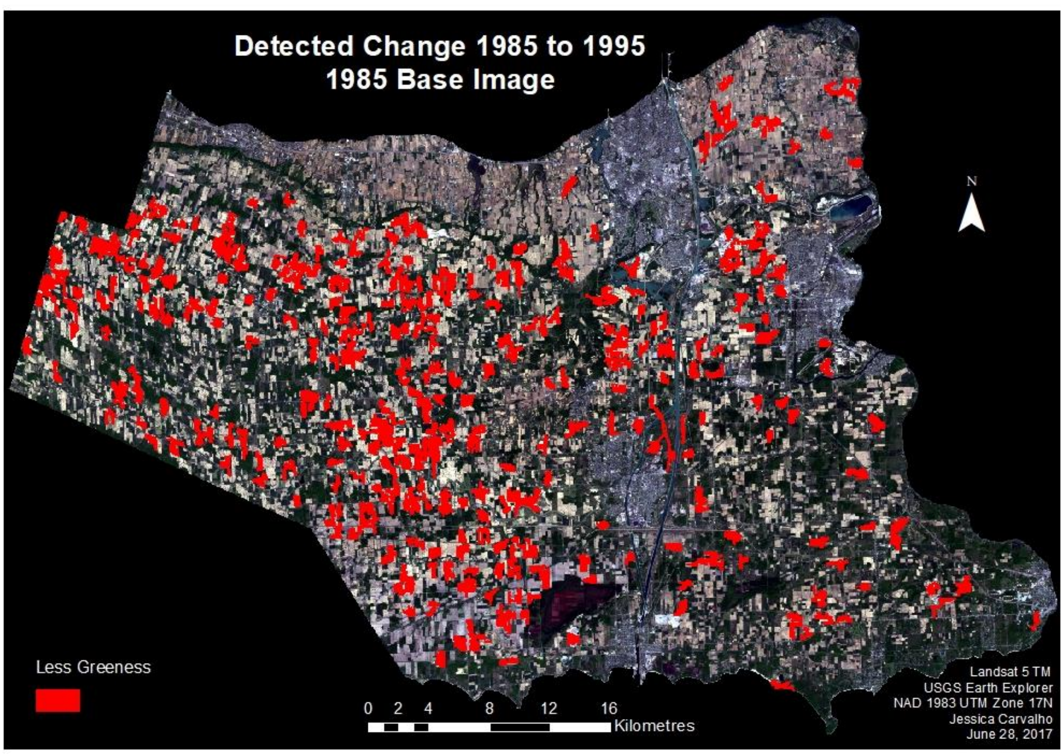


Figure 12 Change Detection with EXPOLRAS change shapefiles on 1985 Satellite Image

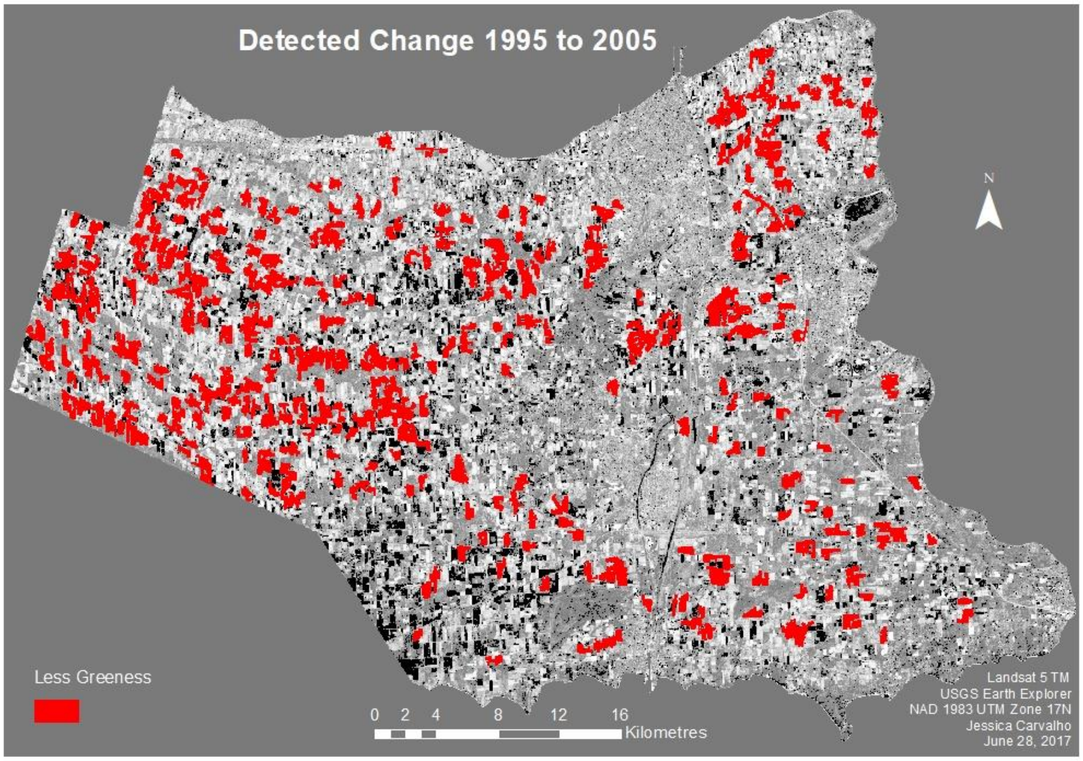


Figure 13 Change Detection with EXPOLRAS change shapefiles on 1995 - 2005 image differencing map

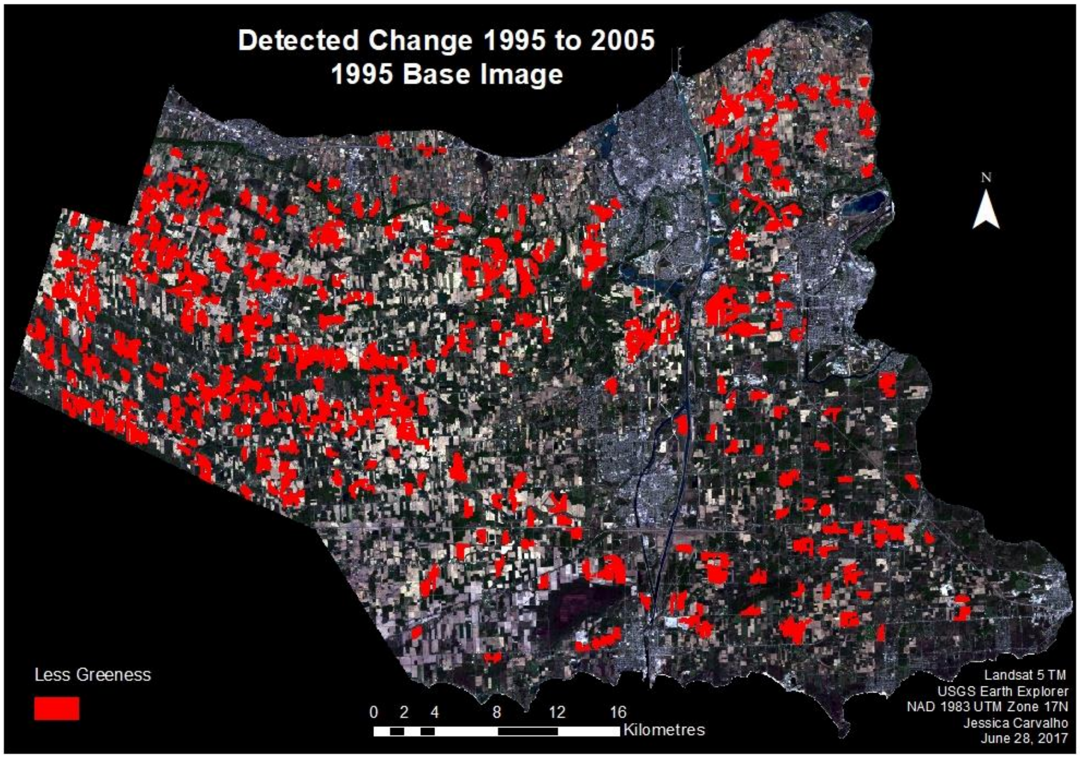


Figure 14 Change Detection with EXPOLRAS change shapefiles on 1995 Satellite Image

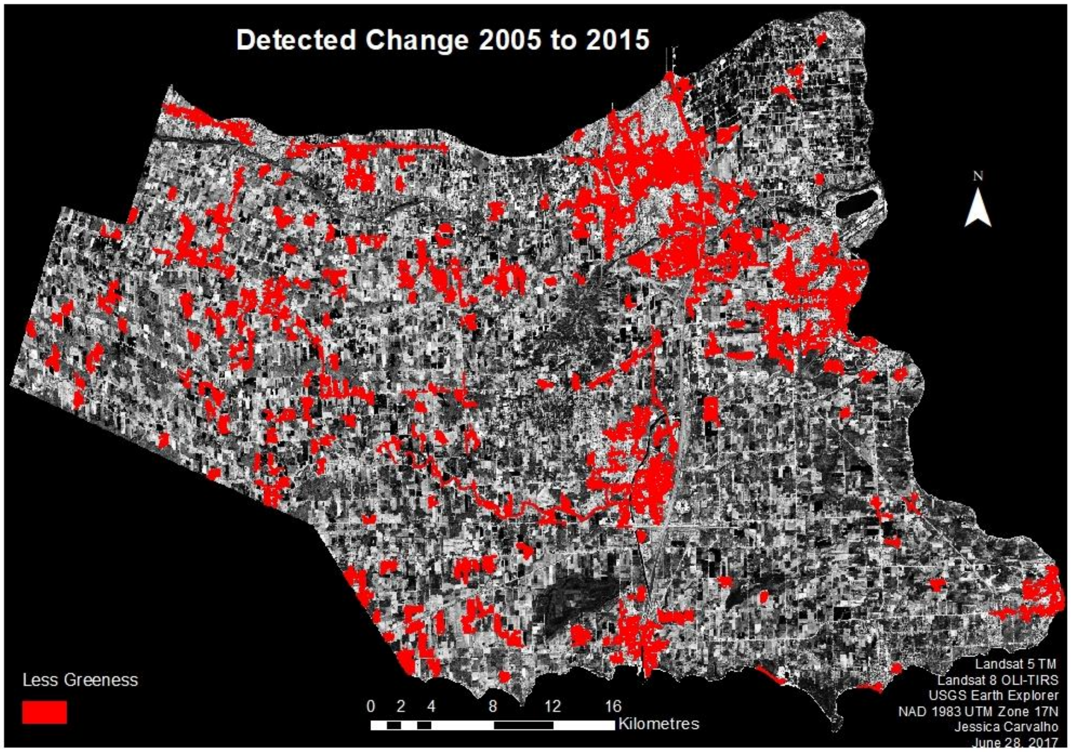


Figure 15 Change Detection with EXPOLRAS change shapefiles on 2005 - 2015 image differencing map

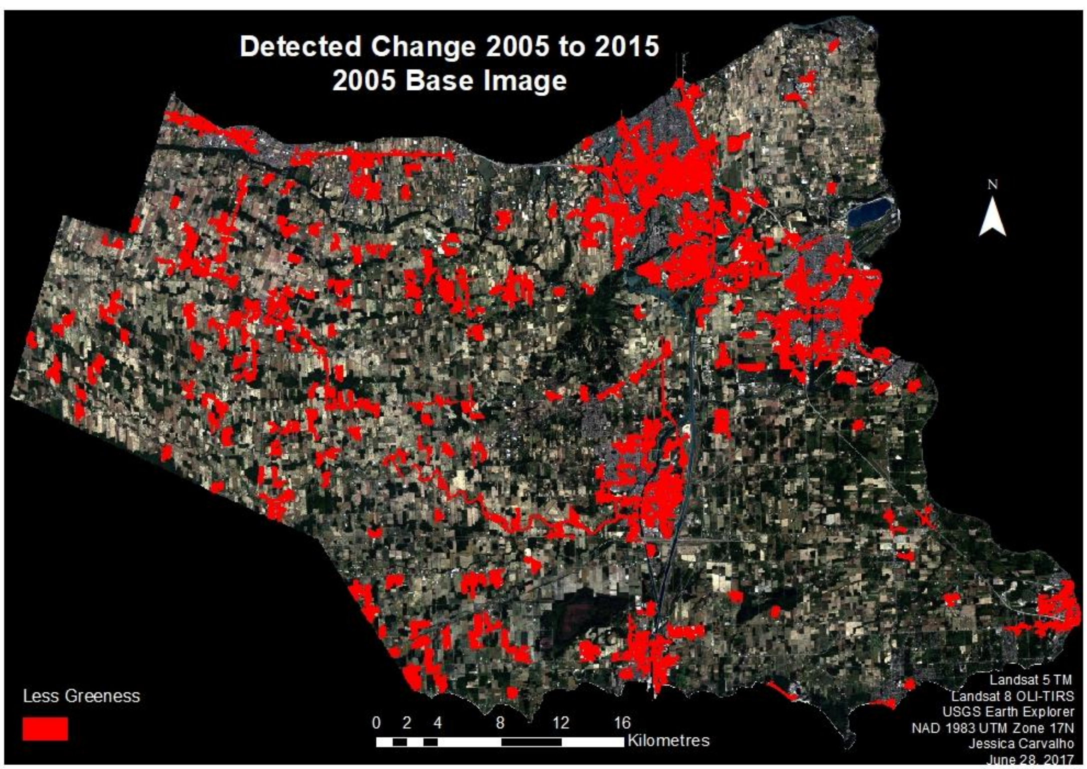


Figure 16 Change Detection with EXPOLRAS change shapefiles on 2005 Satellite Image

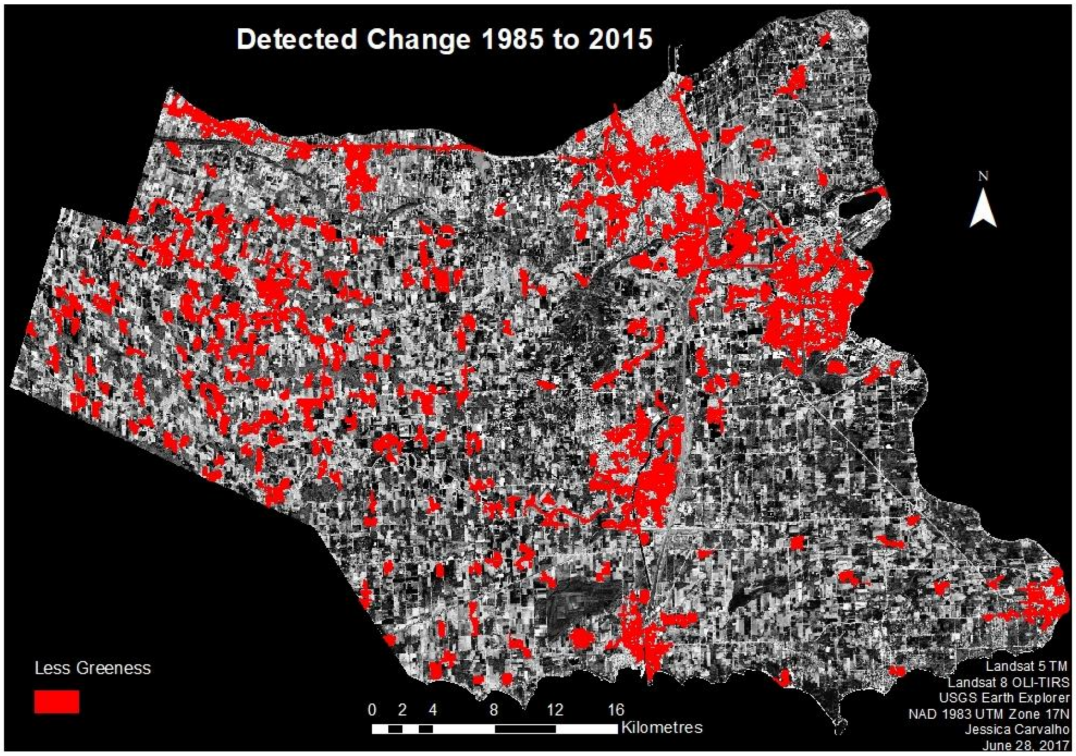


Figure 17 Change Detection with EXPOLRAS change shapefiles on 1985 - 2015 image differencing map

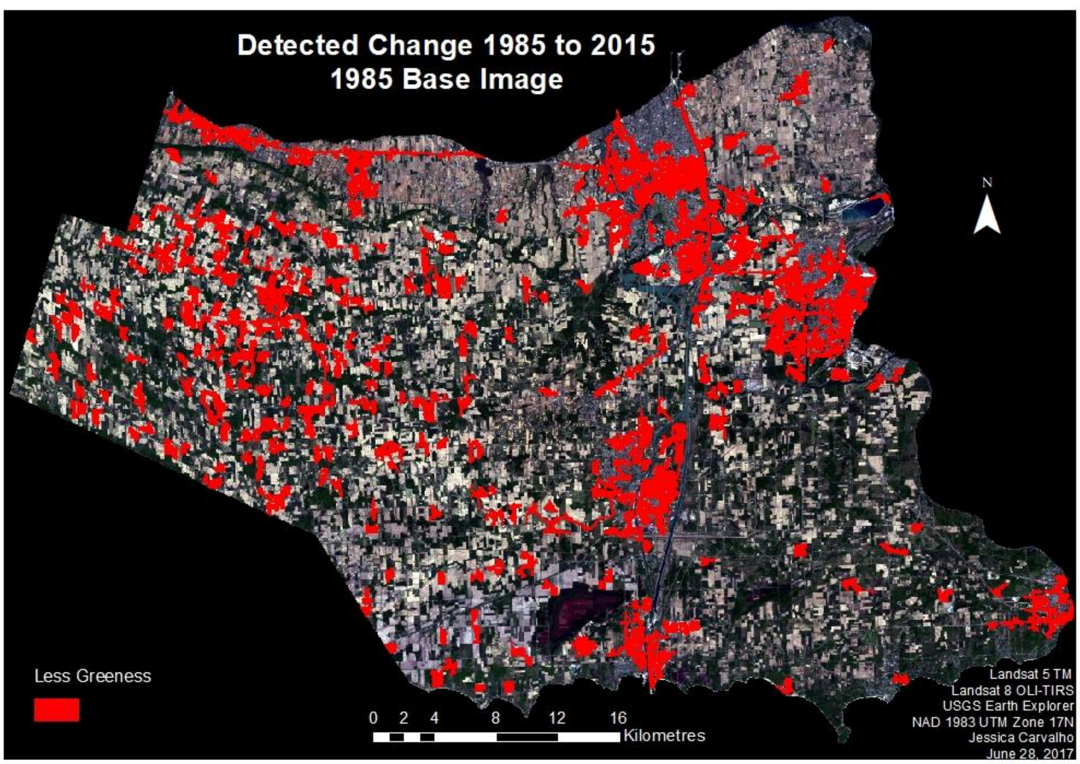


Figure 18 Change Detection with EXPOLRAS change shapefiles on 1985 Satellite Image

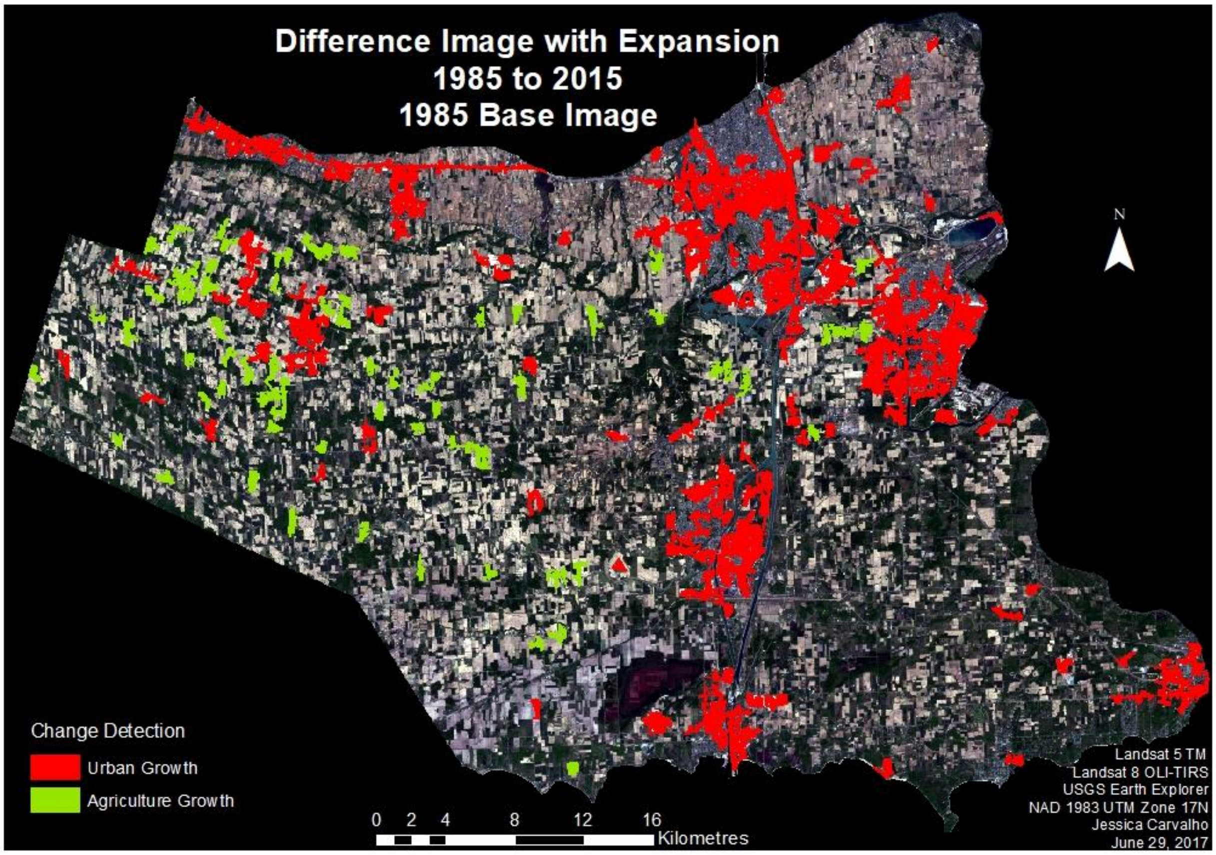


Figure 19 Final Change Detection between 1985 - 2015 with EXPOLRAS shapefiles on 1985 satellite image

Figure 21 is the final map in the series of change detection trials that were completed. This map highlights the change that has occurred in the thirty-year period being observed by this study. The attribute table for the EXPOLRAS shapefile for this image differencing map was combed through number by number. Each field id was highlighted and the user chose whether or not that change was urban growth, agricultural growth, or no change. The map above shows the urban growth in red and the agricultural growth as green. It is clear to see that the vast majority of cities and townships within the Niagara Region have expanded outward over this thirty-year period.

5.3 Landscape Metrics

Once the chosen landscape metrics have been computed, the output can be reorganized and analyzed. Table 10 and 11 highlight the raw metrics output from Patch Analyst for the raster data. Table 10 illustrates the values for the urban class and table 11 is for the agriculture class. Here, all of the landscape metrics mentioned previously are enlisted.

Table 10 Raw Raster Metrics – Urban

Landscape Metrics for Urban Rasters (Value)									
Year	**CACOV**	**MCA**	**CASD**	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**
1985	3108.34	1.23	38.08	31.47	1.23	18.63	1.24	1.04	1.26
1995	2342.52	0.73	17.03	20.55	1.32	15.49	1.21	1.04	1.26
2005	4984.44	2.23	110.93	40.05	2.01	22.76	1.27	1.04	1.28
2015	4946.92	3.21	159.01	47.67	1.29	39.47	1.25	1.04	1.32
Year	**TE**	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**	
1985	7380840.00	21.64	1.09	15013.00	3958.70	43.16	341098.56	16368.84	
1995	9198540.00	26.97	0.71	22449.00	3081.28	21.79	341098.56	15873.84	
2005	15370560.00	45.06	1.25	30338.00	6499.41	81.50	341098.56	38044.26	
2015	9509160.00	27.88	1.95	15249.00	7292.51	142.30	341098.56	29755.80	

Table 11 Raw Raster Metrics – Agriculture

Landscape Metrics for Agriculture Rasters (Value)									
Year	**CACOV**	**MCA**	**CASD**	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**
1985	5688.69	14.90	847.36	72.67	1.84	71.98	1.25	1.04	1.42
1995	5764.72	14.97	862.98	73.81	1.93	62.55	1.27	1.04	1.41
2005	6003.58	10.00	600.26	67.42	2.28	62.89	1.29	1.04	1.40
2015	5201.86	16.63	864.84	75.17	1.71	52.60	1.26	1.04	1.39
Year	**TE**	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**	
1985	16790700.00	49.23	25.53	5027.00	4979.75	1271.22	341098.56	128328.48	
1995	17492580.00	51.28	19.50	6836.00	5568.11	1085.53	341098.56	133271.73	
2005	19615980.00	57.51	10.28	11226.00	6659.49	684.64	341098.56	115411.14	
2015	16471260.00	48.29	13.47	9581.00	6287.85	847.06	341098.56	129069.36	

Table 12 and table 13 indicate the landscape metrics created for the vector data with core areas based on their 'Gridcode', which is the arbitrary raster number (1, 2, or 3, stated previously) that was assigned in the reclassify process. Table 12 shows the urban land use and Table 13 shows the agricultural land use. Again, this is the raw data output.

Table 12 Raw Vector Metrics with Core Areas – Urban

Landscape Metrics for Urban Core Areas (Gridcode)									
Year	**CACOV**	**MCA**	**CASD**	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**
1985				9.16	0.35	2.00	1.59	1.52	1.33
1995				2.59	0.21	1.67	1.55	1.55	1.34
2005				25.20	0.84	4.14	1.66	1.50	1.38
2015				21.75	0.87	3.81	1.65	1.50	1.36
Year	**TE**	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**	
1985	266337	4.56	1.47	615	333.20	4.90	58293.50	905.61	
1995	96161.9	1.60	0.65	355	297.44	1.95	59810.80	232.83	
2005	1037380	21.61	3.29	1371	636.62	20.95	47985.30	4513.71	
2015	1004960	15.35	2.87	1480	778.48	22.39	65459.50	4256.98	

Table 13 Raw Vector Metrics with Core Areas – Agriculture

Landscape Metrics for Agriculture Core Areas (Gridcode)									
Year	**CACOV**	**MCA**	**CASD**	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**
1985				38.49	2.47	6.16	1.76	1.49	1.38
1995				41.83	2.31	10.16	1.74	1.51	1.42
2005				35.31	2.74	4.62	1.71	1.50	1.38
2015				49.14	1.69	7.61	1.76	1.49	1.39
Year	**TE**	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**	
1985	6635050	113.82	11.22	4255	875.23	98.26	58293.50	47773.20	
1995	6772250	113.22	13.28	3880	1183.71	157.27	59810.80	51552.40	
2005	5664360	118.04	7.96	4439	627.24	49.98	47985.30	35370.60	
2015	6215080	94.94	19.86	2862	846.36	168.13	65459.50	56856.20	

Table 14 and table 15 were added components to observe the difference between the landscape metrics of the vector data with and without added core areas. Again, the same indices as the previous vector data are missing clearly from these two tables; however, two other indices are also no longer a part of the table. This exclusion now includes total core area index (TCAI) and core area density (CAD) since no core areas were created for this vector data from the outset. This is the raw data output from Patch Analyst into the attribute tables of the vector layers for each year of the study.

Table 14 Raw Vector Metrics without Core Areas – Urban

Landscape Metrics for Urban (Gridcode)									
Year	CACOV	MCA	CASD	TCAI	CAD	AWMSI	MSI	MPFD	AWMPFD
1985						9.72	1.34	1.43	1.43
1995						8.86	1.31	1.43	1.44
2005						14.57	1.34	1.43	1.44
2015						22.69	1.34	1.42	1.45
Year	TE	ED	MPS	NUMP	PSCOV	PSSD	TLA	CA	
1985	6370460	33.85	0.76	20437	2972.90	22.87	188185	15727.10	
1995	8177230	43.45	0.47	31845	2873.75	13.69	188185	15177.80	
2005	13454400	74.49	0.82	44501	6792.21	56.30	188185	36889.20	
2015	8285120	44.02	1.31	22272	7113.70	93.44	188185	29255.20	

Table 15 Raw Vector Metrics without Core Areas – Agriculture

Landscape Metrics for Agriculture (Gridcode)									
Year	CACOV	MCA	CASD	TCAI	CAD	AWMSI	MSI	MPFD	AWMPFD
1985						52.42	1.35	1.43	1.51
1995						51.43	1.35	1.43	1.51
2005						52.02	1.34	1.43	1.51
2015						41.05	1.34	1.43	1.49
Year	TE	ED	MPS	NUMP	PSCOV	PSSD	TLA	CA	
1985	14162900	75.26	12.73	10167	6360.86	809.91	188185	129454.00	
1995	15116700	80.32	8.81	15265	8137.89	717.28	188185	134548.00	
2005	16992800	90.29	5.35	21769	9043.76	484.27	188185	116569.00	
2015	14078700	74.81	7.26	17870	8214.33	596.85	188185	129843.00	

The above tables were normalized to exist between zero and one, which can be seen in the tables below. The equation to accomplish this was executed in Excel and appears as:

$$z = \frac{x - \min(x)}{\max(x) - \min(x)}$$

This allows for easier and more accurate comparison amongst the metrics calculated (Vaz, 2014). A spider graph was created for each normalized table so that the statistics would be more visually attainable and understandable.

Table 16 Normalized Raster – Urban

Normalized Landscape Metrics for Urban Rasters									
Year	**CACOV**	**MCA**	**CASD**	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**
1985	0.289873	0.201613	0.148260	0.402655	0.000000	0.130942	0.500000	1.000000	0.000000
1995	0.000000	0.000000	0.000000	0.000000	0.115385	0.000000	0.000000	0.000000	0.000000
2005	1.000000	0.604839	0.661361	0.719027	1.000000	0.303169	1.000000	1.000000	0.333333
2015	0.985798	1.000000	1.000000	1.000000	0.076923	1.000000	0.666667	1.000000	1.000000
Year	**TE**	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**	
1985	0.000000	0.000000	0.306452	0.000000	0.208352	0.177330	0.000000	0.022327	
1995	0.227505	0.227583	0.000000	0.485220	0.000000	0.000000	0.000000	0.000000	
2005	1.000000	1.000000	0.435484	1.000000	0.811670	0.495478	0.000000	1.000000	
2015	0.266382	0.266439	1.000000	0.015400	1.000000	1.000000	0.000000	0.626148	

Table 17 Normalized Raster – Agriculture

Normalized Landscape Metrics for Agriculture Rasters									
Year	**CACOV**	**MCA**	**CASD**	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**
1985	0.607232	0.739065	0.933933	0.677419	0.228070	1.000000	0.000000	0.000000	1.000000
1995	0.702066	0.749623	0.992970	0.824516	0.385965	0.513416	0.500000	0.000000	0.666667
2005	1.000000	0.000000	0.000000	0.000000	1.000000	0.530960	1.000000	0.000000	0.333333
2015	0.000000	1.000000	1.000000	1.000000	0.000000	0.000000	0.250000	0.000000	0.000000
Year	**TE**	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**	
1985	0.101580	0.101952	1.000000	0.000000	0.000000	1.000000	0.000000	0.723231	
1995	0.324773	0.324295	0.604590	0.291821	0.350268	0.683436	0.000000	1.000000	
2005	1.000000	1.000000	0.000000	1.000000	1.000000	0.000000	0.000000	0.000000	
2015	0.000000	0.000000	0.209180	0.734635	0.778751	0.276893	0.000000	0.764713	

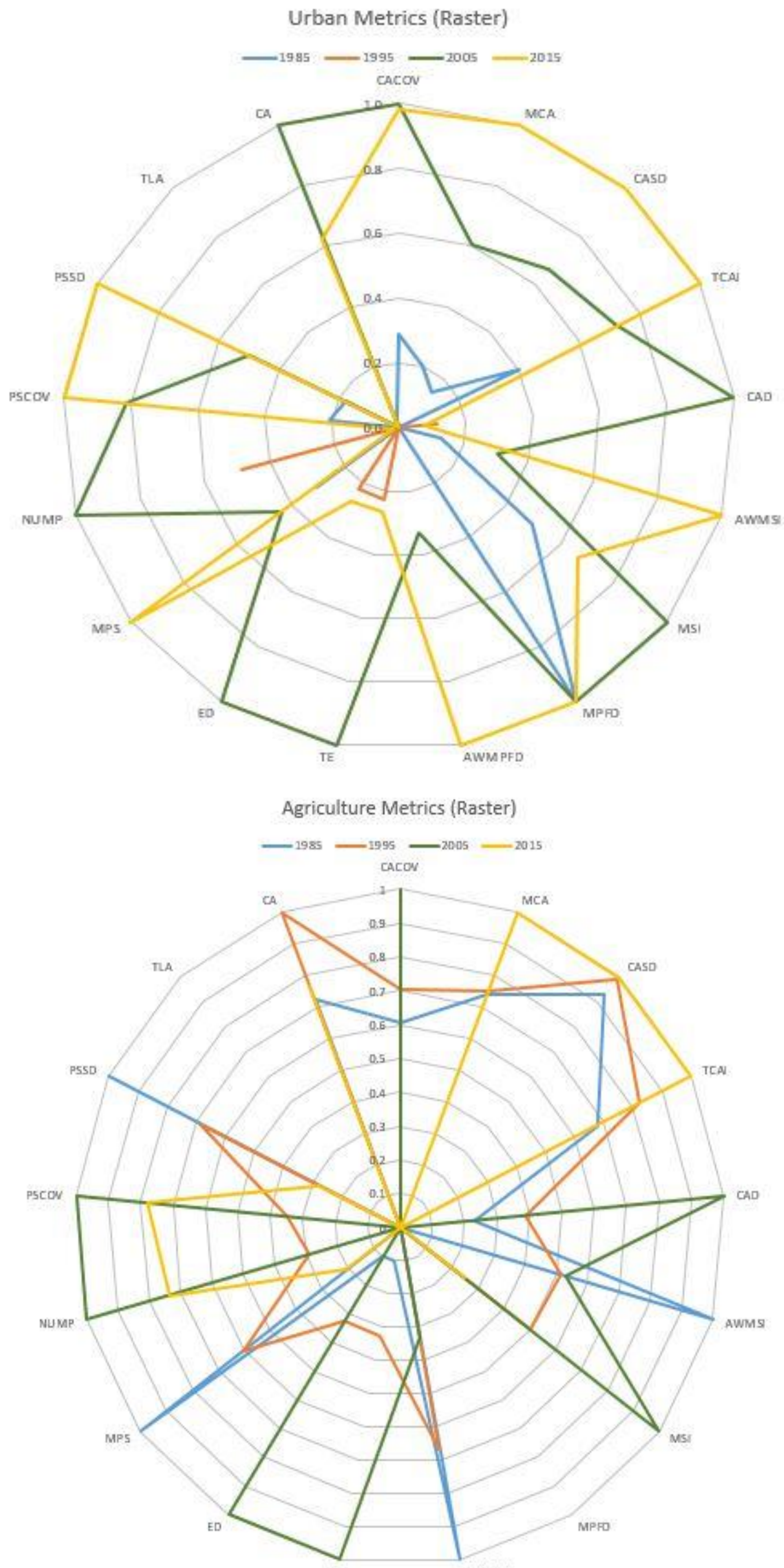


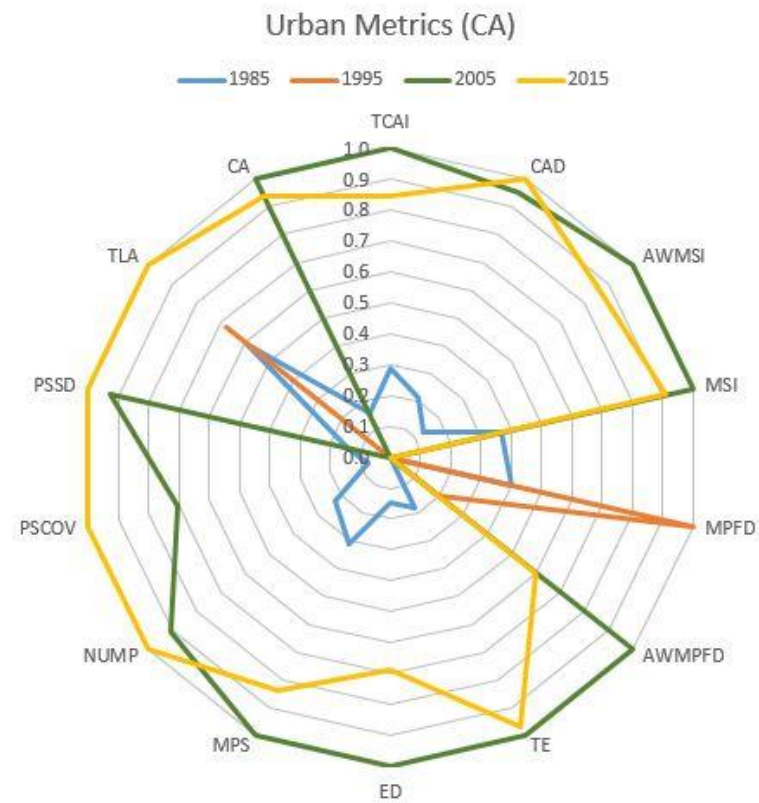
Figure 20 Normalized Raster Urban and Agriculture Spider Graphs

Table 18 Normalized Vector with Core Areas - Urban

Normalized Landscape Metrics for Urban Core Areas							
Year	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**	**TE**
1985	0.290579	0.212121	0.133603	0.363636	0.400000	0.000000	0.180803
1995	0.000000	0.000000	0.000000	0.000000	1.000000	0.200000	0.000000
2005	1.000000	0.954545	1.000000	1.000000	0.000000	1.000000	1.000000
2015	0.847413	1.000000	0.866397	0.909091	0.000000	0.600000	0.965555
Year	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**
1985	0.147926	0.310606	0.231111	0.074339	0.144325	0.589910	0.157159
1995	0.000000	0.000000	0.000000	0.000000	0.000000	0.676741	0.000000
2005	1.000000	1.000000	0.903111	0.705097	0.929550	0.000000	1.000000
2015	0.687156	0.840909	1.000000	1.000000	1.000000	1.000000	0.940029

Table 19 Normalized Vector with Core Areas - Agriculture

Normalized Metrics for Agriculture Core Areas							
Year	**TCAI**	**CAD**	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**	**TE**
1985	0.229935	0.742857	0.277978	1.000000	0.000000	0.000000	0.876161
1995	0.471439	0.590476	1.000000	0.600000	1.000000	1.000000	1.000000
2005	0.000000	1.000000	0.000000	0.000000	0.500000	0.000000	0.000000
2015	1.000000	0.000000	0.539711	1.000000	0.000000	0.250000	0.497089
Year	**ED**	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**
1985	0.817316	0.273950	0.883323	0.445648	0.408633	0.589910	0.577252
1995	0.791342	0.447059	0.645529	1.000000	0.908083	0.676741	0.753146
2005	1.000000	0.000000	1.000000	0.000000	0.000000	0.000000	0.000000
2015	0.000000	1.000000	0.000000	0.393768	1.000000	1.000000	1.000000



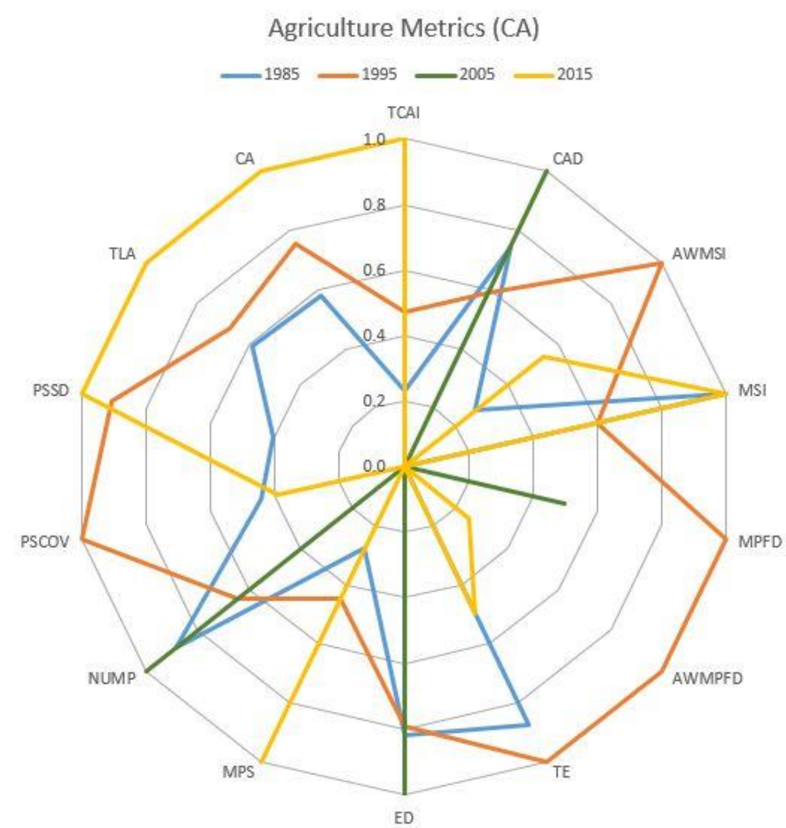


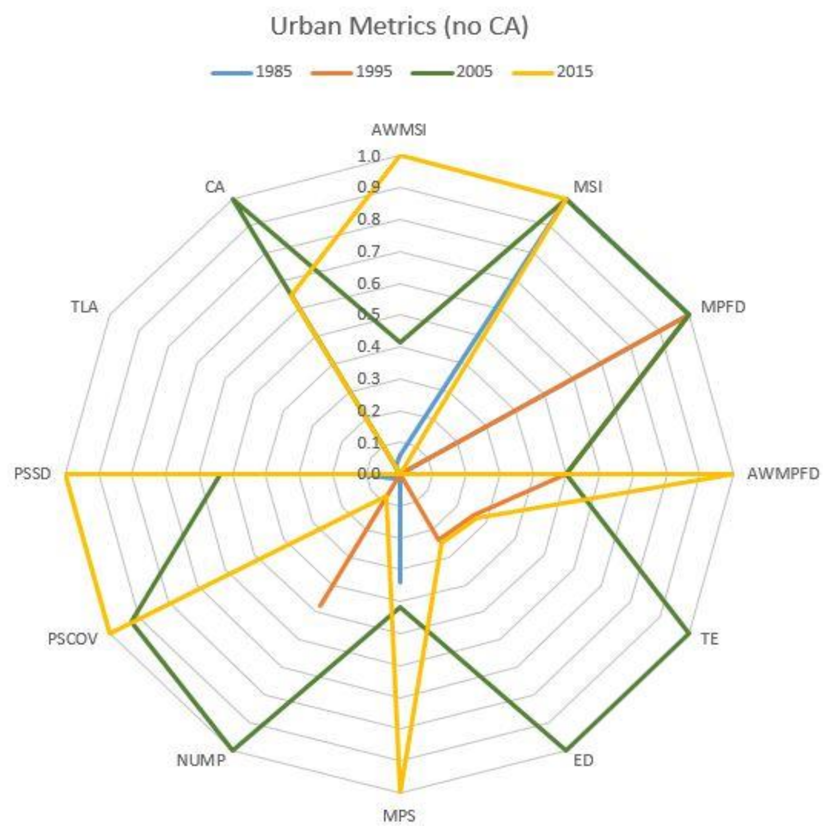
Figure 21 Normalized Vector Urban (CA) and Agriculture (CA) Spider Graphs

Table 20 Normalized Vector without Core Areas - Urban

Normalized Metrics for Urban no Core Areas						
Year	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**	**TE**	**ED**
1985	0.062184	1.000000	1.000000	0.000000	0.000000	0.000000
1995	0.000000	0.000000	1.000000	0.500000	0.255052	0.236220
2005	0.412871	1.000000	1.000000	0.500000	1.000000	1.000000
2015	1.000000	1.000000	0.000000	1.000000	0.270282	0.250246
Year	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**
1985	0.340000	0.000000	0.023385	0.115110	0.000000	0.025300
1995	0.000000	0.474069	0.000000	0.000000	0.000000	0.000000
2005	0.416667	1.000000	0.924176	0.534295	0.000000	1.000000
2015	1.000000	0.076255	1.000000	1.000000	0.000000	0.648387

Table 21 Normalized Vector without Core Areas - Agriculture

Normalized Metrics for Agriculture no Core Areas						
Year	**AWMSI**	**MSI**	**MPFD**	**AWMPFD**	**TE**	**ED**
1985	1.000000	1.000000	0.000000	1.000000	0.028894	0.029070
1995	0.912929	1.000000	0.000000	1.000000	0.356199	0.355943
2005	0.964820	0.000000	0.000000	1.000000	1.000000	1.000000
2015	0.000000	0.000000	0.000000	0.000000	0.000000	0.000000
Year	**MPS**	**NUMP**	**PSCOV**	**PSSD**	**TLA**	**CA**
1985	1.000000	0.000000	0.000000	1.000000	0.000000	0.716669
1995	0.468835	0.439407	0.662354	0.715545	0.000000	1.000000
2005	0.000000	1.000000	1.000000	0.000000	0.000000	0.000000
2015	0.258808	0.663937	0.690846	0.345719	0.000000	0.738306


Urban Metrics (no CA)
1985
1995
2005
2015
AWMSI
MSI
MPFD
AWMPFD
TE
ED
MPS
NUMP
PSCOV
PSSD
TLA
CA
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

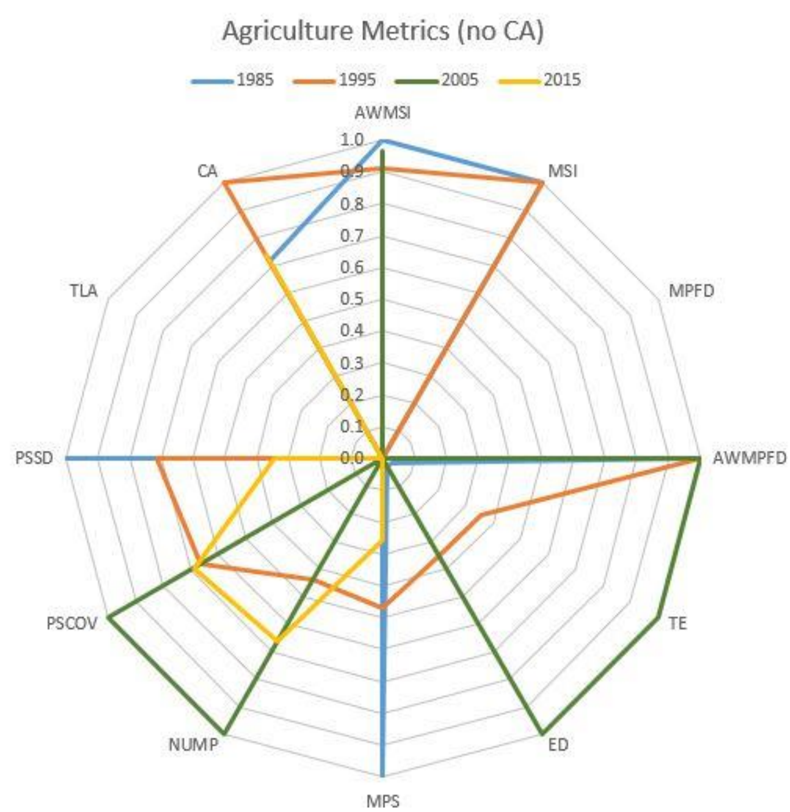

Agriculture Metrics (no CA)
1985
1995
2005
2015
AWMSI
MSI
MPFD
AWMPFD
TE
ED
MPS
NUMP
PSCOV
PSSD
TLA
CA
1.0
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1
0.0

Figure 22 Normalized Vector Urban (no CA) and Agriculture (no CA) Spider Graphs

5.4 Analysis

The raster data is the data that will be analyzed here, since it included all of the statistics that originally were to be included in this study. The raster data was also not transformed to vector data, meaning that the data would be less distorted and truer to the original satellite images.

NUMP for the urban landscape shows that urban patchiness was on the rise for the 1985, 1995, and 2005 data ($NUMP_{1985}^{urban}$ = 15013, $NUMP_{1995}^{urban}$ = 22449, $NUMP_{2005}^{urban}$ = 30338). This could indicate that while the urban landscape is becoming patchier, it may also be expanding into more rural settings. Meaning that in rural settings, more subdivisions may be incorporated, or smaller stores to cater to the new subdivisions. The patchiness of the agricultural landscape throughout the same three study years showed similar patterns. In 2005 alone, the number of patches for agricultural land use almost doubled from 6836 in 1995 to 11226. This sharp increase in patches indicates that there were a greater number of disturbances to the agricultural landscape in that ten-year period. This could be accounted for by the increased NUMP of urban patches for the same year (NUMP = 30338). By 2015 the number of patches for agriculture had decreased to 9581. In order to confirm what NUMP is showing, CA was observed. In 2005, when the NUMP was at its peak, the CA for urban was 38044.26 ha. This was the largest observed CA for the urban landscape, which confirms that the urban landscape had indeed grown, but more sporadically. The CA for agriculture land use for 2005 was also at its lowest at 115,411.14 ha, indicating that along with more patches, there was less agricultural area. By 2015, the CA for agriculture had only grown to 129,069.36 ha. The overall change between 1985 and 2015 for the urban landscape was a growth by approximately 81.79%. Agriculture increased by approximately only 0.57% for the thirty-year study period.

The ED refers to the border that occurs between urban and non-urban classes, or agriculture and non-agriculture classes. Here, the total amount of edge is divided by the TLA in order to aid in the understanding of fragmentation. In 1985, ED for urban settings was 21.64 m/ha, by 2015 this number had risen to 27.88 m/ha. More edge corresponds directly with a higher NUMP between these two years. For agriculture, ED in 1985 was 49.23 m/ha, dropping to 48.29 m/ha in 2015. TLA was the same for every year for both classes because the landscape occupied the same space throughout the study, only certain patches changed. The statistics were calculated at the class level and not the landscape level. Agriculture TE has decreased slightly in the thirty-year time period (TE_{1985}^{agri} = 16790700 m, TE_{1995}^{agri} = 17492580 m, TE_{2005}^{agri} = 19615980 m, and TE_{2015}^{agri} = 16471260 m). The urban TE has increased quite a bit in the same time period (TE_{1985}^{urban} = 7380840 m, TE_{1995}^{urban} = 9198540 m, TE_{2005}^{urban} = 15370560 m, and TE_{2015}^{urban} = 9509160 m).

The AWMSI for urban indicated that there had been a significant increase of shape irregularity amongst the patches over the thirty years studied. This would suggest that urban is indeed sprawling throughout the region and perhaps not in a well-planned manner. This is an alarming thought considering how valuable the land is. For agriculture, the AWMSI showed that shape irregularity was relatively high in 1985 and had decreased by approximately the same amount that urban had increased by. This would suggest a direct decrease in agricultural land due to urbanization. Another key index was the MPS. The normalized figures for urban landscapes show steady growth throughout the study period, whereas the MPS for agricultural patches confirm a decline in patch size, contributing to greater fragmentation. The smaller the average size of a patch, the more complex the matrix will be. There are likely to be more patches and corridors in the matrix in this case. This concisely iterates that urban landscapes are growing and allowing for an overall patchier landscape. This speaks to the level of development policy in effect in the Region. While certain aspects of the land are highly protected, this ideology does not apply to the entirety of the Niagara Region.

The PSCOV helps to explain the variability about the mean. In the case of urban patches for 1985, the PSCOV was approximately 39% while in 2015, the PSCOV was approximately 72%. For agricultural patches in 1985, PSCOV showed a value of roughly 49% and in 2015 this value had reach approximately 62%. This shows that there is a greater amount of inconsistency in the urban patches to maintain their size and shape throughout the study period. Agriculture, which shows the variability as increasing, but more slowly than urban, is still showing an increase, which is worrisome as this means that the patches are changing more frequently than they once were.

MPS might be the single most conclusive metric in this study. In 1985, an urban patch was averaged at 1.09 ha, but by 2015, this had increased to 1.95 ha. This is almost double the size in 30 years. The MPS of an agriculture patch in 1985 was averaged at 25.53 ha, but has significantly reduced to only 13.47 ha in the same amount of time. This is more than half the size of what the patches were originally in 1985, suggesting steady and significant decline in the amount and connectivity of patches. The spider graphs in figure 22 illustrate this sharp contrast well. It is clear to see the growth of the urban patch areas, while the agriculture patch areas wane. There is greater fragmentation of agricultural patches.

6. Discussion

While agriculture has grown slightly (0.57% in the study period), there is clearly much more fragmentation. The greater fragmentation observed through the use of these metrics is cause for concern. Fragmentation allows for isolated parcels of land that maintain habitats, but with greater barriers of urbanized land surrounding them. Agriculture requires large amounts of land in order to operate successfully depending on the agricultural practice. With increased urbanization, farms become increasingly fragmented, meaning that these operations are smaller and become more difficult. This can be caused by road ways or by the outward sprawl of rural towns steadily growing. This has become such an issue recently that the Alberta Agriculture and Forestry government sector recognized this pattern of decreased agriculture and conducted a study to help determine where there was greater fragmentation in their own province. Fragmentation not only affects the land's production capacity, but also has an impact on the scenic qualities that the Niagara Region boasts. The parcelization of farm land poses problems such as monitoring crop growth or pest infestations (Brabec and Smith, 2002).

The Greenbelt Act of 2005 added about 4046.856 ha of provincial protection to Niagara's tender fruit crop area in an effort to curb dangerous urban sprawl habits. Urban growth is necessary in order for the Region to prosper economically. The Greenbelt Act in collaboration with the NEP has put forth stringent regulations in order to ensure that the growth does not impede on the agriculture and rural landscapes (NEP, 2017). Agriculture is the most common land use type throughout the Region (Pond, 2009b). Expansion into rural areas is inevitable as the Region continues to grow. The goal of the Greenbelt Plan and the Places to Grow Act are to slow the spread of low-density residential housing throughout the Niagara Region as well as the rest of the

Greater Golden Horseshoe area. Since low-density residential growth is often the cause of most urban sprawl, this is a necessary step in order to alleviate the pressures of expansion on rural landscapes (Pond, 2009a). As of July 2017, the NEP and the Greenbelt Act have both been reviewed and updated to further enhance these regulations and ensure their protective qualities. Arguably, these policies have been effective, as can be seen by the actual small growth that agriculture land has seen. Between 1985, which is shortly after the NEPDA was launched, and 2015, which is ten years after the Greenbelt Plan was introduced, agriculture has seen a growth of approximately 0.57%. With a projected population increase of 40,800 people between 2011 and 2031, these policies will become crucial. This is a potential 9.3% growth rate in a twenty-year period, which is actually a slower growth rate than the rest of Ontario (Niagara Region, 2014; Metrolinx, 2015), however; considering that the growth rate for the thirty-year period in this study was very similar (10.99%), the projected population is one that is growing much faster than previously for the Region. This will add the need for greater infrastructure, which must also follow the policies set forth by the Greenbelt Plan and the NEP.

Part of the Niagara Region's plan to garner population growth is to introduce greater public transportation, which is also a key factor in the Places to Grow Act (OMoMA, 2017). Late into 2016, efforts were made via air travel to reduce the time it took to travel from Toronto to Niagara Falls from two hours to only fifteen minutes. While this seemed like an exciting leap into better public transportation options for the region, in reality it was not feasible for the majority of the population. Unless an individual is able to afford the $149 round-trip ticket daily, it is not possible. Not to mention each flight holds only eight people (Smith, 2016). Currently, there are GO buses available daily that run from Burlington to Niagara Falls. There is a GO train that can be taken from Toronto to the Burlington GO bus. This service is provided by Metrolinx. By 2023, the train line is scheduled to be extended for daily trips from Toronto to Niagara Falls with stops in between. These are great options, but are the immediate future. It is important to recognize that this Region will continue to grow and need better and improving options. High-speed rail is already in existence throughout the majority of Europe and in China. These have had an effect on time-space shrinkages, especially in China. High-speed rail has created new high-speed rail towns in China that do not follow a sustainable development plan, so if high-speed rail were to be added to Niagara the sustainable development of urban lands needs to be maintained (Chen, Zhu, and Zeng, 2016). These are all options that could happen in a more immediate time frame. However, in planning for the future, it is necessary to think about what could exist for the Region thirty or more years into the future. The addition of hyperloop technology to the Region could be a possible next step within the next thirty to forty years. Hyperloop is a train-like mode of transportation; however, it uses near-vacuum tubes to move pods along a track. This new transportation system can move faster than commercial airlines, up to speeds of 970km/h (Ryerson University, 2017). Transportation methods are a major consideration when discussing the urban land use expansion into the Region, as this can have an impact on agricultural lands as well as other natural landscapes.

7. Limitations

There are a number of issues that can arise when constructing a study such as this thesis. All of which can affect the validity and efficiency of the final outcome. In particular, satellite imagery for an analysis of this level can be quite difficult. It is imperative to utilize high quality imagery. This means imagery that was taken from an appropriate time (ex. time of day, time of year) and without any imperfections such as cloud cover or band flares. Most studies of this nature utilize high-resolution imagery; 10m or less has been cited as the most effective. However, since this study was to give a general sense of the entire landscape and not specific aspects of the urban landscape, the 30m resolution of the Landsat imagery was sufficient. The imagery chosen from July 02, 2005 was the most difficult imagery to work with. It was initially thought that due to the time period being in direct alignment with a high crop yields time period, it would be exceptionally effective in communicating agricultural land use. This was not the case; however, due to the harvesting of the majority of low lying crops. This left many farm plots empty, which allowed them to reflect to the satellite sensor as bright white. It made classification difficult due to these plot's similarity with the urban class's bright white reflection as well.

The vectorization of the raster data was decidedly not analyzed in the discussion portion of this study due to possible representation inaccuracy. The process of converting raster data to vector data can dissolve boundaries which may allow for an increase in patch size or a change in the patches shape. This will then have an effect on the spatial relationships amongst all patches in the landscape (Corry and Nassauer, 2005). Many indices are sensitive to the spatial resolution of the data presented as well as the scope of the study area (Turner, 2005a). It is also apparent that many metrics are synonymous, and therefore, special consideration and understanding of the study and metrics being chosen is needed (McGarigal, 2015). This problem lends itself to human error. In a study of this nature, human limitation is abundant. From the satellite images chosen, to the classifications, and the metrics involved and their interpretation, the outcomes can vary. Thus, there was a trial and error period when all data was tested and inspected for accuracy and understanding.

Access to data was the final limitation of this study. While Landsat satellite images are readily available, many have slight imperfections which make them difficult to work with. These imperfections can be cloud cover, which is not inherently the problem of the satellite, but with the conditions of the atmosphere on the day the image was taken, or they could be errors such as sensor flares. Other than this, immediate use of satellite imagery is also not always possible. There can sometimes be a waiting period for the images from the USGS. This period is often not long, but needs to be considered in the time span of a study. Land use analysis conducted on vector data that was not converted from raster satellite images would have been another aspect to this study that would have been beneficial. A small scope study of land use change over a thirty-year period of individual cities within the Niagara Region would have been the next step. This was not conducted entirely as open data with land use was not available at the time of initial data collection for that time period. DMTI Spatial provides land use data for the entirety of Canada for the previous ten to fifteen years, but it was difficult to obtain anything prior to 2002. This could show immediate changes that have occurred, but would not speak to the nature of historical change in the Region. Land use data was found for Southern Ontario land use for 1966, but because it was created by a different company, the land use classes were not the same. DMTI Spatial also does not provide a specific ‘agriculture’ category, but an ‘open area’ class, which incorporates agriculture as well as all other rural aspects of the land. However, this would still have been suitable because the satellite images used in this study also deemed agriculture and open area as one and the same. The DMTI Spatial data also separated urban classes sufficiently enough that the study would have been conducted had the appropriate years been accumulated by the author.

8. Conclusions

The trend toward greater growth will prove to be one of an undying nature. With less expensive housing outside of city centres and easier transit options, urban sprawl is a very likely outcome. Sprawl occurs when there are not rigid growth plans in place for smaller towns that are starting to develop more heavily. Though the Niagara Escarpment has heavy protections in place to ensure the pristine landscape remains intact, these protections do not necessarily cascade into the regional planning of Niagara cities and townships, where the escarpment does not extend. The Greenbelt Plan does have some effect on the non-escarpment areas. Of the twelve towns, townships, and cities found in the Niagara Region, Grimsby and Lincoln have shown the most growth, which is likely due to their closer proximity to large cities such as the City of Hamilton, and only slightly further, the City of Toronto.

The use of satellite image classifications in this study proved to be beneficial as land use was easily obtained at a 30 m resolution. A 30 m resolution was adequate in order to garner an overall understanding of land use change in the Region, which means that a category two classification scheme was not undertaken. A more general sense of the land use coverage was all that was needed and, therefore, category one was obtained relatively easily. A coarser perspective, although not necessarily entirely representative of the exact surface of the Earth, allows for rapid calculations and understanding of the changes that are happening. The four images that were utilized for further analysis were classified using a supervised classification with an NDVI component. This allowed for the greenness in the image to be more prominent. The finished classifications allowed for change detection practices utilizing image differencing to occur. Here, it was clear that urban change had occurred quite heavily in areas that were directly adjacent to the towns or cities of the Region. The image differencing change confirmation encouraged the use of landscape metrics to further analyze the amount of change that had occurred in the thirty-year study period.

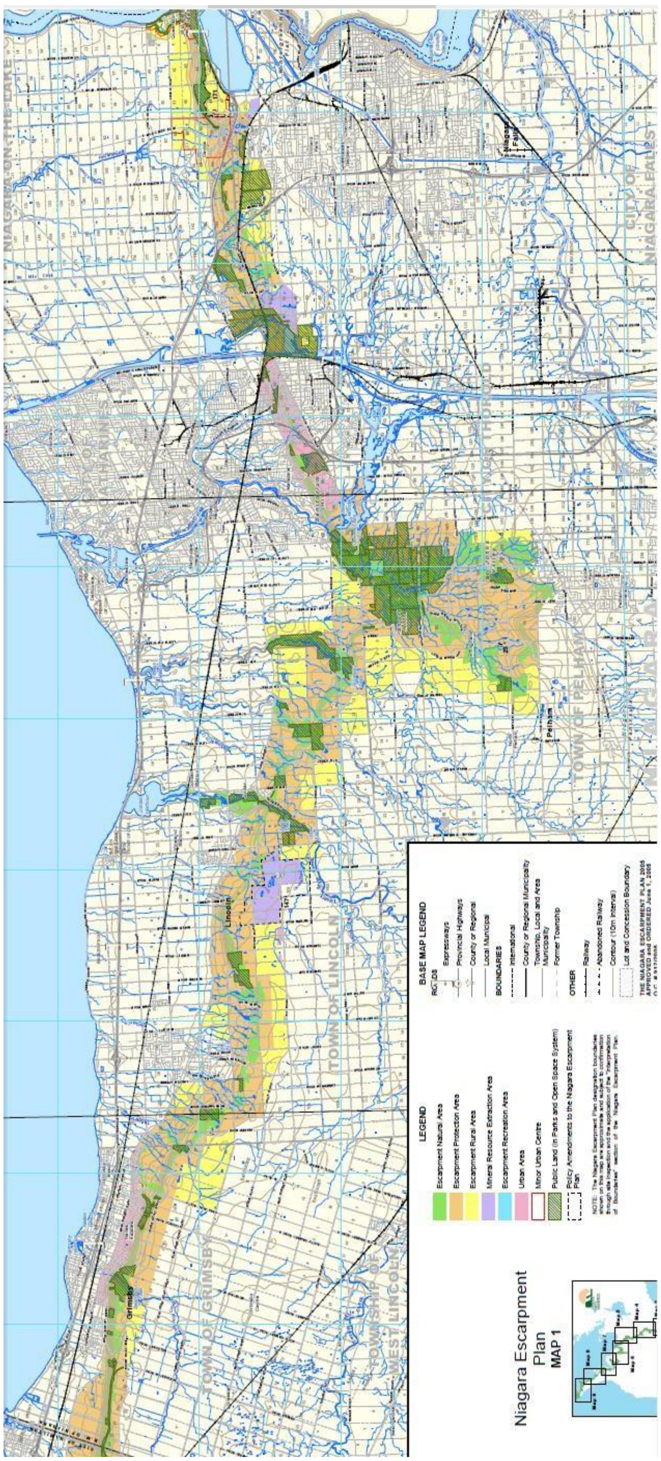
The patch analyst extension for ArcMap has made the application of landscape metrics rather simple. This extension allows for both vector and raster data to be observed, as was completed in this study. The raster data was chosen as the final set of data to continue the analysis as it would be the data that had undergone the least amount of transformation, therefore allowing for a more spatially accurate analysis. Once the indices had been chosen for the study, based on research and methods used in previous literature, they could be computed through the extension. Here, it was observed that some indices are only available when the raster data is being computed. The landscape metrics confirmed that urban growth in the Niagara Region has been steadily increasing for the past thirty years at the expense of the agricultural landscape within the region. Farms in the Region had reduced to 1827 in 2016 from 2014 in 2011 alone. That shows a difference of 187 farms in only a five-year period.

Landscape metrics are an excellent tool in assessing land cover change and ecology of a specific area. This study can be used as an example for a greater need for strict enforcement of regional planning policies and where they need to be implemented. These metrics show that growth in the urban nature of the region will not be lessening over time and will only increase. As can be observed by this study, the mean patch size of agriculture has steadily decreased by almost half in the last thirty years, while the number of patches has increased from 5027 to 9581. The use of GIS and remote sensing applications, allows for predictions of future change and makes it easier to monitor current conditions (Shaker and Ehlinger, 2007). This decrease in size, but increase in patches is indicative of fragmentation and is a crucial motivator for increased policy awareness in the Regional Municipality of Niagara.

Appendices

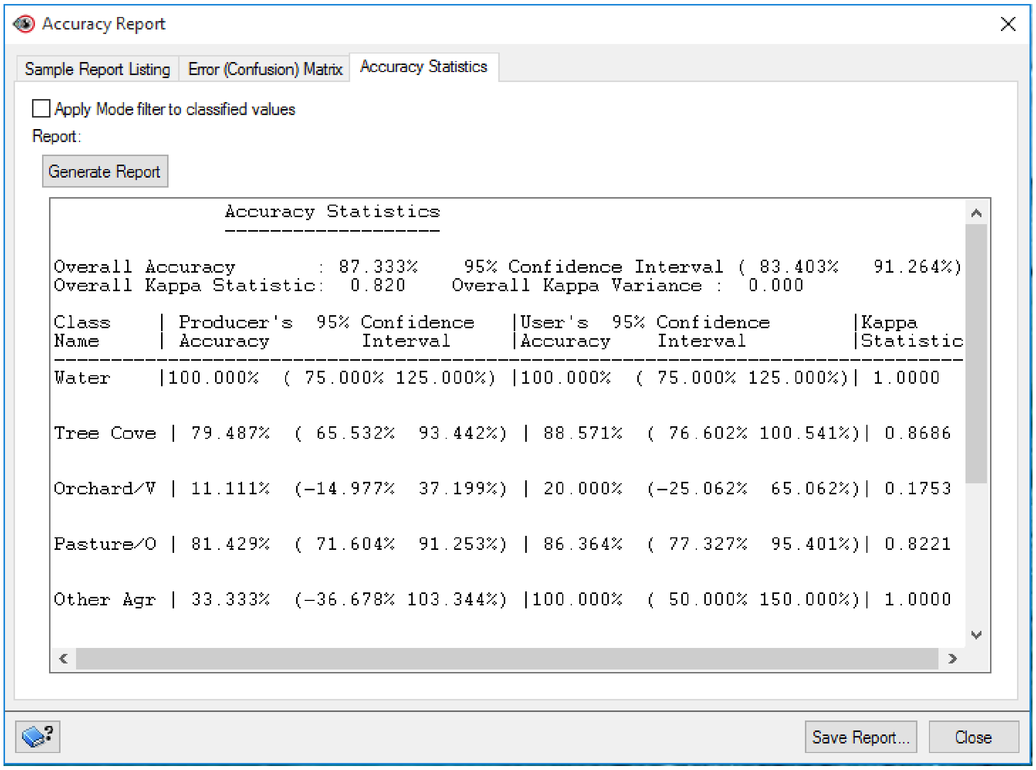
Appendix A

NEP Land Use Designation's for the Niagara Region



Appendix B

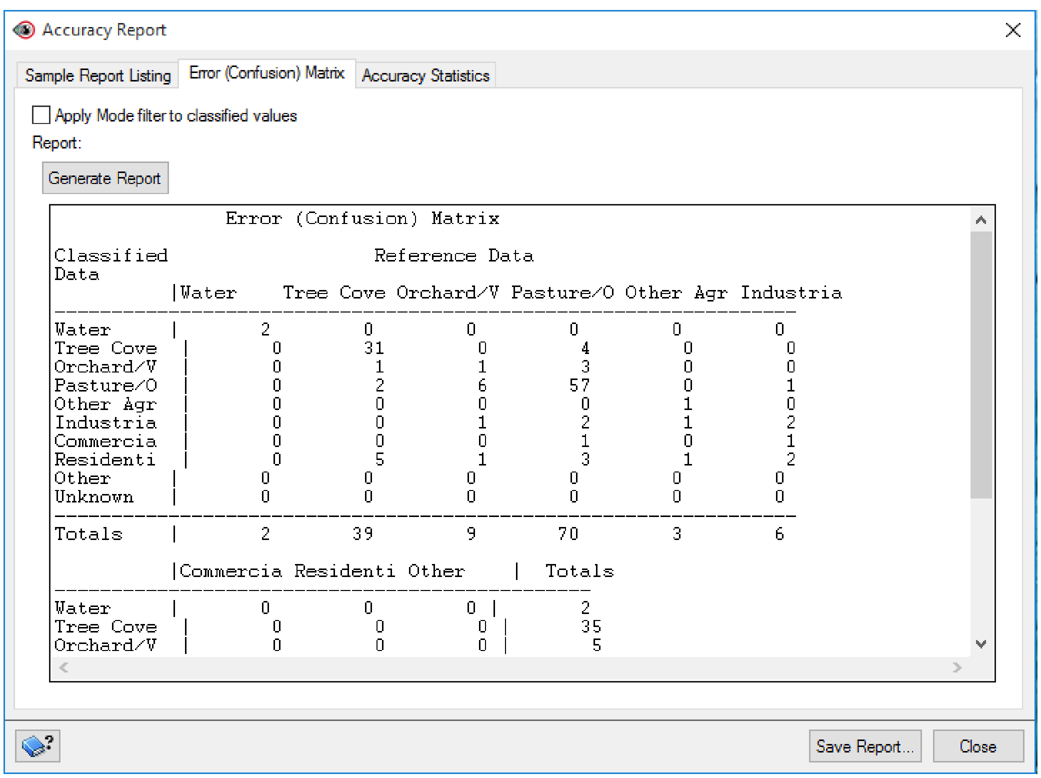
How Accuracy Statistics and Error Matrices appear at Initial Output



Accuracy Statistics

Overall Accuracy : 87.333% 95% Confidence Interval (83.403% 91.264%)
Overall Kappa Statistic: 0.820 Overall Kappa Variance : 0.000

Class Name	Producer's Accuracy	95% Confidence Interval	User's Accuracy	95% Confidence Interval	Kappa Statistic
Water	100.000%	(75.000% 125.000%)	100.000%	(75.000% 125.000%)	1.0000
Tree Cove	79.487%	(65.532% 93.442%)	88.571%	(76.602% 100.541%)	0.8686
Orchard/V	11.111%	(-14.977% 37.199%)	20.000%	(-25.062% 65.062%)	0.1753
Pasture/O	81.429%	(71.604% 91.253%)	86.364%	(77.327% 95.401%)	0.8221
Other Agr	33.333%	(-36.678% 103.344%)	100.000%	(50.000% 150.000%)	1.0000



Error (Confusion) Matrix

Classified Data	Water	Tree Cove	Orchard/V	Pasture/O	Other Agr	Industria
Water	2	0	0	0	0	0
Tree Cove	0	31	0	4	0	0
Orchard/V	0	1	1	3	0	0
Pasture/O	0	2	6	57	0	1
Other Agr	0	0	0	0	1	0
Industria	0	0	1	2	1	2
Commercia	0	0	0	1	0	1
Residenti	0	5	1	3	1	2
Other	0	0	0	0	0	0
Unknown	0	0	0	0	0	0
Totals	2	39	9	70	3	6

Reference Data

	Commercia	Residenti	Other	Totals
Water	0	0	0	2
Tree Cove	0	0	0	35
Orchard/V	0	0	0	5

Appendix C

Error (Confusion) Matrices for Supervised Classifications

Error (Confusion) Matrix							
Classified Data	**Water**	**Tree Cover**	**Commercial**	**Residential**	**Agriculture**	**Other**	**Totals**
Water	4	0	0	0	0	0	**4**
Tree Cover	0	33	0	0	8	0	**41**
Commercial	0	0	4	0	3	0	**7**
Residential	0	0	1	11	1	0	**13**
Agriculture	0	9	0	3	97	0	**109**
Other	0	0	0	0	0	126	**126**
Totals	**4**	**42**	**5**	**14**	**109**	**126**	**300**

Matrix 1 - May 24, 1985

Error (Confusion) Matrix							
Classified Data	**Water**	**Tree Cover**	**Commercial**	**Residential**	**Agriculture**	**Other**	**Totals**
Water	1	0	0	0	0	0	**1**
Tree Cover	0	34	0	0	7	0	**41**
Commercial	0	0	2	1	2	0	**5**
Residential	0	1	1	5	2	0	**9**
Agriculture	1	9	1	8	98	0	**117**
Other	0	0	0	0	1	126	**127**
Totals	**2**	**44**	**4**	**14**	**110**	**126**	**300**

Matrix 2 - May 20, 1995

Error (Confusion) Matrix							
Classified Data	**Water**	**Tree Cover**	**Commercial**	**Residential**	**Agriculture**	**Other**	**Totals**
Water	136	0	0	0	0	0	**136**
Tree Cover	0	18	0	0	3	0	**21**
Commercial	1	0	0	0	0	0	**1**
Residential	0	0	2	17	3	0	**22**
Agriculture	0	2	2	5	111	0	**120**
Other	0	0	0	0	0	0	**0**
Totals	**137**	**20**	**4**	**22**	**117**	**0**	**300**

Matrix 3 - July 02, 2005

Error (Confusion) Matrix							
Classified Data	**Water**	**Tree Cover**	**Commercial**	**Residential**	**Agriculture**	**Other**	**Totals**
Water	1	0	0	0	0	0	**1**
Tree Cover	0	22	0	1	2	0	**25**
Commercial	0	0	2	0	5	0	**7**
Residential	0	0	0	17	2	0	**19**
Agriculture	0	8	0	2	102	0	**112**
Other	0	0	0	0	0	136	**136**
Totals	**1**	**30**	**2**	**20**	**111**	**136**	**300**

Matrix 4 - September 16, 2015

Appendix D

Accuracy Statistics for Supervised Classifications

Accuracy Statistics			
Class Name	Producer's Accuracy (%)	User's Accuracy (%)	Kappa Statistic
Water	100.00	100.00	1.00
Tree Cover	78.57	80.48	0.77
Commercial	80.00	57.14	0.56
Residential	78.57	84.61	0.83
Agriculture	88.99	88.99	0.82
Other	100.00	100.00	1.00
Overall Accuracy (%)	91.66		
Overall Kappa Statistic	0.87		

Accuracy 1 - May 24, 1985

Accuracy Statistics			
Class Name	Producer's Accuracy (%)	User's Accuracy (%)	Kappa Statistic
Water	50.00	100.00	1.00
Tree Cover	77.27	82.92	0.79
Commercial	50.00	40.00	0.39
Residential	35.71	55.55	0.53
Agriculture	89.09	83.76	0.74
Other	100.00	99.21	0.98
Overall Accuracy (%)	88.66		
Overall Kappa Statistic	0.82		

Accuracy 2 - May 20, 1995

Accuracy Statistics			
Class Name	Producer's Accuracy (%)	User's Accuracy (%)	Kappa Statistic
Water	99.27	100.00	1.00
Tree Cover	90.00	85.71	0.84
Commercial	0.00	0.00	-0.01
Residential	77.27	77.27	0.75
Agriculture	94.87	92.50	0.87
Other	0.00	0.00	0.00
Overall Accuracy (%)	94.00		
Overall Kappa Statistic	0.90		

Accuracy 3 - July, 02, 2005

Accuracy Statistics			
Class Name	Producer's Accuracy (%)	User's Accuracy (%)	Kappa Statistic
Water	100.00	100.00	1.00
Tree Cover	73.33	88.00	0.86
Commercial	100.00	28.57	0.28
Residential	85.00	89.47	0.88
Agriculture	91.89	91.07	0.85
Other	100.00	100.00	1.00
Overall Accuracy	93.33		
Overall Kappa Statistic	0.89		

Accuracy 4 - September 16, 2015

Appendix E

How Patch Analyst Spatial Statistics appear at Initial Output

spatialstats(75)

OID	Name	RunDate	Run	Class	TCAI	CAD	AWMSI	MSI	MPFD	AWMPFD	TE	ED	MPS	NumP	PSCoV	PSSD	TLA	CA
2	reclassifiedCA	6/22/2017 6:28:38 PM	1	3	38.4989	2.47609	6.16048	1.76056	1.4971	1.38982	6635050	113.821	11.2275	4255	875.239	98.2678	58293.5	47773.2
0	reclassifiedCA	6/22/2017 6:28:38 PM	1	2	9.16781	0.357884	2.00008	1.59656	1.52408	1.33789	266337	4.5689	1.47254	615	333.2	4.90651	58293.5	905.613
1	reclassifiedCA	6/22/2017 6:28:38 PM	1	1	30.12	1.49613	1.94041	1.62531	1.45113	1.31258	1907540	32.723	3.73964	2571	366.551	13.7077	58293.5	9614.63

1966_Patch_Analyst_Report

OID	Name	RunDate	Run	Class	AWMSI	MSI	MPAR	MPFD	AWMPFD	TE	ED	MPE	MPS	NumP	MedPS	PSCoV	PSSD	TLA	CA
0	clip1966	2016-09-30 8:22:53 AM	1	Improved pasture and forage crops - 50.0	11.0213	1.71512	1738.68	1	1	49.9403	240.153	0.088547	0.000181	564	0.000009	820.438	0.001489	0.207952	0.102338
1	clip1966	2016-09-30 8:22:54 AM	1	Unimproved pasture and range land	2.42442	1.53684	1983.99	1	1	33.4587	160.896	0.024476	0.000022	1367	0.000008	231.871	0.000051	0.207952	0.030352
2	clip1966	2016-09-30 8:22:55 AM	1	Productive woodland	1.86977	1.40656	1825.8	1	1	23.6156	113.563	0.019946	0.000017	1184	0.000009	166.065	0.000029	0.207952	0.020555
3	clip1966	2016-09-30 8:22:55 AM	1	Horticulture	1.47233	1.28977	2210.39	1	1	5.1356	24.6961	0.011189	0.000006	459	0.000004	112.799	0.000007	0.207952	0.002891
4	clip1966	2016-09-30 8:22:56 AM	1	Urban built-up area	3.71328	1.6573	1990.2	1	1	12.2731	59.0189	0.035678	0.000052	344	0.000007	522.668	0.00027	0.207952	0.017743
5	clip1966	2016-09-30 8:22:56 AM	1	Non-productive woodland	1.72837	1.4612	2007.29	1	1	7.22402	34.7389	0.017159	0.000012	421	0.000008	172.663	0.000021	0.207952	0.005115
6	clip1966	2016-09-30 8:22:57 AM	1	Swamp, marsh or bog	2.31375	1.96386	2399.81	1	1	1.37328	6.60382	0.032697	0.000049	42	0.000009	462.466	0.000224	0.207952	0.002038
7	clip1966	2016-09-30 8:22:57 AM	1	Orchards and vineyards	5.54106	1.45999	1952.24	1	1	21.1122	101.524	0.029282	0.000034	721	0.000005	678.996	0.00023	0.207952	0.024384
8	clip1966	2016-09-30 8:22:57 AM	1	Outdoor recreation	1.45869	1.32189	1377.43	1	1	0.46956	2.25802	0.023478	0.000036	20	0.000013	163.485	0.000058	0.207952	0.000711
9	clip1966	2016-09-30 8:22:58 AM	1	Improved pasture and forage crops - 95.0	1.18758	1.17447	2679.29	1	1	0.01354	0.065113	0.00677	0.000003	2	0.000003	40.362	0.000001	0.207952	0.000005
10	clip1966	2016-09-30 8:22:58 AM	1	Mines, quarries, sand and gravel pits	1.47423	1.30199	1870.51	1	1	0.157477	0.757276	0.014316	0.000011	11	0.000005	132.414	0.000015	0.207952	0.000123
11	clip1966	2016-09-30 8:22:58 AM	1	Unproductive land - rock	3.35889	2.88884	10293.1	1	1	0.150702	0.724698	0.018838	0.000004	8	0.000002	83.279	0.000003	0.207952	0.000028
12	clip1966	2016-09-30 8:22:59 AM	1	Water area	7.34215	3.17099	2582.86	1	1	2.64911	12.7391	0.101889	0.000061	26	0.000026	192.192	0.000116	0.207952	0.001574
13	clip1966	2016-09-30 8:22:59 AM	1	Unproductive land - sand	5.30314	4.64812	6498.15	1	1	0.537259	2.58357	0.048842	0.000008	11	0.000008	55.5337	0.000005	0.207952	0.000093

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