LAND USE CHANGE IN THE MCINTOSH RUN WATERSHED

SPRYFIELD, NOVA SCOTIA

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Submitted in partial fulfillment
of the requirements for the degree of
Bachelor of Science Honours in Earth Sciences

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Dalhousie University
Halifax, Nova Scotia
April 2016

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Abstract

Many of the world's watersheds are under constant pressures from land use change and urban sprawl, increasing potential flood risk. Studying and increasing our understanding of land change in these environments helps in mitigating environmental degradation. Nirupama and Simonovic (2006) studied the Thames River in London, Ontario and established that increasing urbanized area correlated with an increase in the magnitude and number of annual flood peaks. This study seeks to classify and quantify land use change over the past century within the McIntosh Run Watershed located southwest of Halifax, NS, using high-resolution historical air photos and satellite imagery. By classifying land into six classes (forest, barrens, water, wetland, high density urban and low density urban), I have established a timeline of urbanization within the watershed. Since 1931, the watershed has transformed from a largely forested environment with some scattered agricultural use, to forest with no agriculture, and considerable low and high density urban development. These changes will increase surface runoff, resulting in more pronounced and regular flood peaks within the McIntosh Run Watershed.

McIntosh Run; Watershed; Land Change Analysis; Land Use Change; Hydrology; Remote Sensing; Spryfield; Long Lake

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Acknowledgements

My supervisors, Charlie Walls and Lawrence Plug cannot be thanked enough for the time, patience, and energy they gave as I completed this project. Their support made my thesis possible. Thank you to the Scotia Research Fund for the funding they provided, without which the scope of this project would not have been possible. The Dalhousie GIS Centre who provided me with access for datasets which were helpful in my analysis. My thanks to the McIntosh Run Watershed Association which provided information and data, I wish them all the best in protecting a watershed I have enjoyed every moment learning about.

Chapter 1: Introduction

Study and Problem

Watersheds globally are increasingly being pressured by expanding urbanization, resulting in their transformation from natural land covers to high and low density urban land covers. This change causes concern of increased flooding in urban areas due to decreased infiltration.

The McIntosh Run watershed is located between Bayers Lake and Herring Cove, Nova Scotia, southwest of the Halifax Peninsula within the Halifax Regional Municipality. The watershed is 30 km^2, extending from northwest of Long Lake, southeast to the mouth of McIntosh Run near Herring Cove (Figure 1). The watershed has undergone significant changes in land surface largely due to anthropogenic influences over the past 200 years, as the city of Halifax has expanded. The watershed has transitioned from mixed forest and granite barrens, to sparse agricultural use through the 1800's and early 1900's, to moderate density residential and commercial development in the late 20th century through to present. However, large areas of the watershed remain undeveloped.

My study seeks to establish a historic timeline of land use change within boundaries of the McIntosh Run Watershed, and quantify how the hydrology of the watershed has been affected as land use has shifted towards a more urban environment.

The use of remotely sensed data has been used to determine global land use change from a wide variety of causes. These causes range from anthropogenic changes such as development and construction, or natural causes such as vegetation lost due to fires, flooding, and climate change.

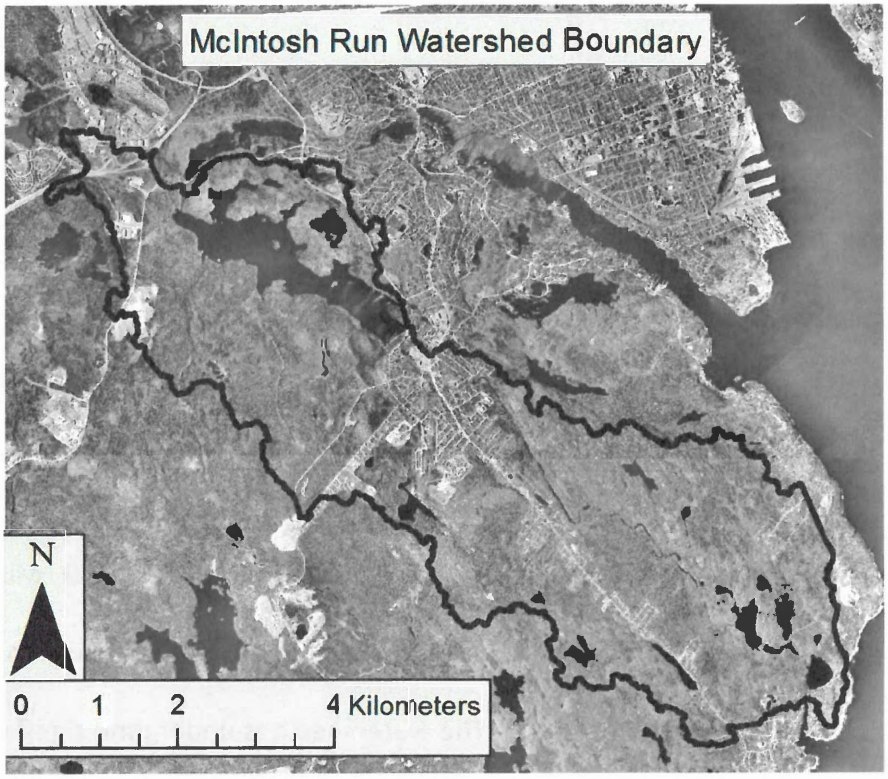


Figure 1: Boundary of the McIntosh Run Watershed. Image is 2006 Air photo.

A Remote Sensing investigation into the McIntosh Run provides an opportunity to further our knowledge and understanding of how historical land use changes have affected the health of the watershed, and how contemporary changes continue to alter its behaviour into the future. Through the use of various air photos spanning back to 1931, multispectral satellite data, and elevation maps of the region, the project will attempt to determine how the history has changed over the past century as urbanization in the region has increased.

The availability of a digital elevation map is crucial for taking this study beyond land use change. In 2007 in response to concerns over sea level change (Halifax Regional Municipality, 2007), HRM flew LiDAR over much of the city. This coverage included McIntosh Run watershed.

Climate and Physiography

Halifax has a mild and wet climate typical of Maritime cities on the coast of the Atlantic Ocean. An average of data from 1960 through 1979 shows annual precipitation totalling 1339.2mm, and a mean annual temperature of 7.2°C. January average temperature is -4.1C, and June average temperature is 14.5°C (See appendix 2.3) (Environment Canada, 2015).

Geologically, the upper extents of McIntosh Run are firmly on the granitic rocks of the South Mountain Batholith (SMB). Based on interpretation from geologic maps, the river loosely follows along a boundary between the leucomonzogranite and monzogranitic rocks to the south (MacDonald & Horne, 1987), before reaching its mouth in Herring Cove and the Atlantic Ocean.

Chapter 2: Background

Background Theory

Change detection through remote sensing methods uses a series of images collected over time, to show how a given region has changed due to urbanisation, natural disasters, industrial development, environmental factors, or other causes. Commonly referred to as 'land cover change' or 'land use change', it can be used in any region where there is historical coverage by aerial photographs or satellite images, and can also be used in a limited capacity using accurate historical maps, including topographic (USGS, 1999).

A number of land cover classification systems are used in practice. This project elected to use a modified version of the *U.S. Geological Survey Land Use/Land Cover Classification System for Use with Remote Sensor Data* (Anderson, Hardy, Roach, & Witmer, 1976). Despite the 1930's imagery being of lower quality in resolution compared to all other aerial photos, it was still more than sufficient to produce meaningful and confident classifications and allowed for the establishing of a baseline dataset. Much of the aerial photography used was black and white, or panchromatic single band imagery, and image classification can be accomplished using a single band, albeit not as robustly as in a multispectral image.

Multispectral data captures portions of the spectrum that are missed by methods that only capture visible light, such as colour or black and white air photos. This extra spectral detail can be used to determine vegetation health, make distinctions on species of vegetation, and allow for greatly improved analysis. These sensors are most typically found aboard satellite platforms, and are greatly beneficial in analysis where operator knowledge of the study area is marginal, as the extra spectral data allows for improved computerized classification.

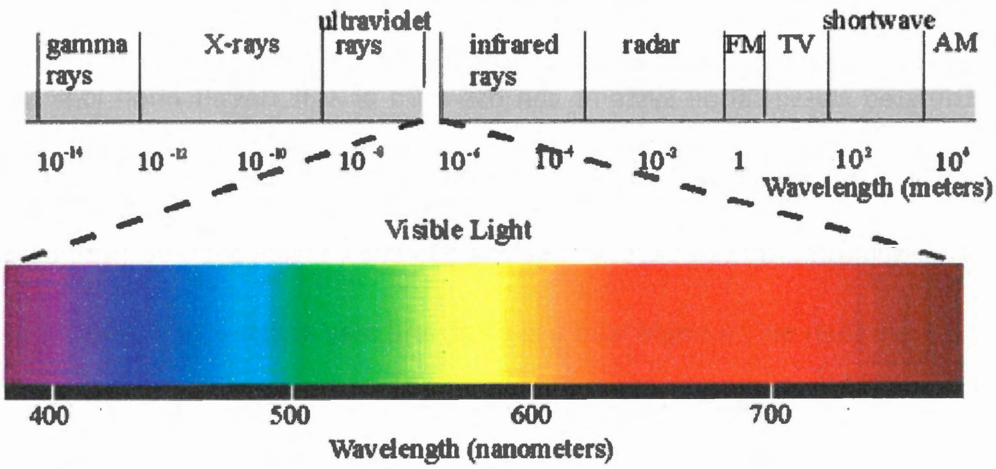


Figure 2: Wavelenghts of the spectrum, showing the restricted range of visible light. (Satellite Imaging Corp, 2016)

Two major categories of image classification, supervised classification and unsupervised classification, can be utilized in image analysis, allowing for the comparison of how each classification system produces differing results. Within this, there are hard, and soft or fuzzy classification logics.

Supervised Classification requires the GIS or Remote Sensing software to be taught through the use of training sites, where the operator manually defines a class location in the images. The software learns spectral values of pixels, and uses this information in determining land classification (Lillesand, Kiefer, & Chipman, 2015). By training a number of map areas, the software is then able to complete classification on its own. This requires the user to have prior knowledge of the area.

With unsupervised classification systems, the GIS software will use statistics to determine bounds for a set number of different classes, and does not require pre-existing knowledge about ground cover in the study area.

A third system, involves a form of artificial intelligence through the programing of a learning neural network, and is beyond the scope of this project.

Automated classification systems can use hard or soft classification logic. Hard logic is where the system applies a single class to each pixel, and disregards the possibility of a pixel not being 100% agricultural, or 100% water. Soft classification logic opens up the possibility that a pixel can be more than only a single land use class, and may assign a pixel a percentage value of various classes that the pixel represents, such as 10% soil, 10% water, 80% forest. This soft classification can produce data that is more precise for pixels that have considerably varied composition, or mixed pixels. This is not relevant to my study as an assumption is being made that the mixed pixel problem is overcome by the sub-metre resolution of the air photos and commercial satellite imagery.

It is important to note that no one classification system is superior to others. There is weakness in all systems that make them appropriate for certain sets of data, and less appropriate for others.

A manual classification increases the risk of human error in the classification process, but if the same individual is classifying imagery with an established and consistent criterion for each land class may provide excellent results. This is useful when there are insufficient spectral depth to use any type of band ratio or multiple spectral signatures to assign to a feature. Without multispectral data, manual classification is the most reliable and consistent means to classify land usage with meaningful results.

In the McIntosh Run region, we can see a historical event that has been captured through remote sensing platforms. In 2009 a forest fire burned much of the vegetation within the southern portion of the watershed and is preserved through aerial photography which was captured in 2009 after the fire. Datasets from prior to 2009, including the 2005 QuickBird satellite imagery and 2006 aerial photography, show the watershed prior to the damage dealt by the fire. Historically, the older air photos may capture old events that are not widely known, such as natural disasters, but the primary expectation is that change analysis will show significant conversion to urban environments.

Similar Studies of Other Watersheds

London, Ontario

Nirupama and Simonovic (2006) used remote sensing analysis and historical gauge data to determine how urbanization and forest clearing in London Ontario affected the Thames River. They found that between 1974 and 2000, land use change in the area included major deforestation. Urbanized area increased from 10% to 22% of the watershed, Agricultural land decreased from 83% to 73%, and open water decreased from 3.65% to 2.73%. Their hydrologic analysis determined that peak flow in 1970 was 350 m^3/s when total precipitation was 400mm, and by 1997, 200mm of total precipitation resulted in peak flows of 800 m^3/s. They concluded that an increase in impervious area results increased magnitude and occurrence of peak flood events, and enhanced river flows.

The study had four major components, 1) land use classification of satellite imagery, 2) remote sensing data analysis, 3) hydrologic data analysis, and 4) integration of remote sensing images with hydrologic data.

Image classification in Nirupama and Simonovic (2006) used a maximum likelihood method, which depends on mean, variance, and covariance matrices of spectral signatures to estimate the probability that a given pixel belongs to a class. The method calculates the level of correlation between bands for each class. Bayes Theorem is central to the method, where the class probability density $P(x|C_i)$ is multiplied by the prior probability $P(C_i)$, the product of that is then divided by the feature probability density $P(x)$ according to

Equation 1

$$P(x|C_i) = \frac{P(x|C_i)P(C_i)}{P(x)}.$$

A major issue with the maximum likelihood method is that it does not consider variability seen within a class. However, as mentioned it excels in considering class variability through the covariance matrix.

The land classification system used in the Thames River study was one developed by the Upper Thames River Conservation Authority (Nirupama & Simonovic, 2006), and relied solely on LandSat for the remote sensing component, which in 1973 provided 60m pixel resolution. The McIntosh Run project will utilize aerial photography of sub-metre resolution with temporal depth to 1931, and some modern commercial satellite imaging which is of 50cm pansharpened pixel resolution.

Cleveland, Ohio

Clapham (2003) investigated the challenges of using remotely sensed images for land use/land cover classification purposes in Cleveland, Ohio, finding that classification is generally robust in rural settings, but encountered mixed pixel problems from the heterogeneous character of urban areas. The problem is increased when using LandSat images due to coarse spatial resolution. Commercial platforms like QuickBird (0.61m), Ikonons (1m), Pleiades (0.5m), Worldview(0.31m), offer far superior resolution, but are not freely provided. Coarse LandSat pixels result in the spectral values being a composite of the various land covers when they are present in a given pixel.

Clapham (2003) utilized a classification technique that differed from the London, ON project. *Continuum-based classification* is a type of unsupervised classification that forms statistical clusters based on spectral bands. The continua being considered in the analysis are chosen based on factors which vary from a minimum to maximum among all pixels to be analyzed. Each statistical cluster is associated with a specific continua position chosen, and the results are field-checked to determine validity. Thus, Land Cover images are thematic, and continuum analysis images are continuous (Clapham, 2003).

The SPOT series of satellites are of medium resolution, and offer resolution ranging from 10m pansharpened for SPOT 1 and 1.5m pansharpened for SPOT 6 and 7. Commercial satellites achieve resolution on the order on 40cm-1m, and allow more precise discrimination of land cover. As more of this high-resolution data is accessible over a spread of time, the capabilities of remote sensing analysis will become much more powerful. The McIntosh Run project is limited to historical single band visible light air photos for historical data, and some modern high-resolution satellite imagery. The advent of truly high-resolution remote sensing platforms in the sub-metre resolution scale with IKONOS in the 2000s will make a major change in future studies, when historical datasets can consist of high resolution multispectral data.

Clapham sought to characterize the increase in impervious land cover, and the decrease in canopy cover in Cleveland. The study does not break out individual land cover classes, but rather broadly characterizes regions in terms of the permeability as a whole.

Changes in the six watersheds

	Doan Brook	Mill Creek	Salt Run	West Branch	Tinker's Creek	Yellow Creek
Increase in impervious land, %	1.63	5.13	1.30	0.34	6.19	3.60
Increase in impervious land, ha	41.37	268.85	9.43	31.05	1536.29	290.20
Decrease in canopy cover, %	9.22	8.41	16.76	6.15	13.83	9.02
Decrease in canopy cover, ha	233.46	440.71	121.80	568.44	3434.87	728.16

Table 1: Results from Clapham (2003) on the six watersheds in the Cleveland Study, showing the percent change in impervious land cover for the six watersheds.

Studies such as those undertaken in Cleveland and London detected urbanization over approximately 30 years in large watersheds. However, in my study, I aim to establish a longer timeline of almost 100 years, and for a smaller watershed of about 30 km^2, or 3000 Ha which experienced land use change at scales too fine to resolve with the modest resolution of LandSat imagery. Hence my imagery includes aerial photographs, satellite data, and a different classification approach in order to maintain consistency across the variable imagery.

Earth Observing Satellites

In deciding on what satellite platform to obtain data from, factors such as spectral resolution, pixel resolution, and cost must be assessed. Nirupama & Simonovic used LandSat which is freely accessible though the USGS, but has much lower image resolution than commercial satellites. Due to the ~5800 km^2 size of the Thames river watershed, this coarse resolution is not a major issue, as land use change is not being assessed at a very fine scale. Clapham utilized SPOT which must be purchased from an image retailer, but has improved resolution over LandSat.

Image resolution for earth observing satellite platforms has changed considerably since early LandSat images in 1973. LandSat 1 produced images with 60m pixel resolution on 4 spectral bands from the Multi Spectral Scanner (MSS), which remained the standard through LandSat 2 and 3, until 1982 when both SPOT 1 and LandSat 4 were launched. LandSat 4 captured 30m pixel resolution across 7 spectral bands, using the Thematic Mapper (TM) sensor. SPOT 1 produced 20m multispectral images from the High Resolution Visible (HRV) sensor, but had a 10m panchromatic band, which allowed for the coarser multispectral bands to be pansharpened, producing more detailed multispectral imagery. It captured, Green, Red, and Near Infrared (NIR) spectral data. LandSat 5 was a virtual twin of LandSat 4, launching in 1984 and operating for 28 years (USGS, 2015). Spot 2 was launched in 1990, and had the same spectral and pixel resolution as SPOT 1, as did SPOT 3 which was launched in 1993. SPOT 4 was launched in 1998, still carried identical pixel resolution of the prior SPOT satellites, but carried an upgraded HRV Infrared (HRVIR), allowing for improved capture of infrared data and improving the return time for recapture.

After the launch failure of LandSat 6, LandSat 7 was launched in 1999 and remains active today. It is the first LandSat satellite to have a panchromatic band, part of the Enhanced Thematic Mapper + system, (ETM+), allowing for 30m multispectral images to be pansharpened to 15m. SPOT 5 introduced improved pixel resolution on the High Resolution Geometrical (HRG) and High

Resolution Stereoscopic (HRS) sensors, with band ranging from 2.5-5m for the panchromatic, and 10m for multispectral sensors, a marked improvement over previous iterations. SPOT 6 and 7 share the same design, and carry the New AstroSat Optical Modular Instrument (NAOMI), and were launched in 2012 and 2014 respectively with pixel resolution equal to SPOT 5. LandSat 8, operational as of 2013, carries a new Operation Land Imager (OLI) and the Thermal Infrared Sensor (TIRS), and has the same 30m pixel resolution for multispectral data, with pansharpening to 15m. It has increased spectral resolution compared to any previous LandSat Satellite, capturing 10 spectral bands, plus the panchromatic band (USGS, 2015).

The Pleiades satellites were launched by Astrium, now owned by Airbus, and was the source of the 2015 image used in this project. It is considered to be a very-high-resolution (VHR) satellite, and captures 2m multispectral pixel resolution, and 0.5m or 50cm panchromatic (Satellite Imaging Corporation, 2015). It is ideally suited for land change detection at a small scale such as the McIntosh Run Watershed.

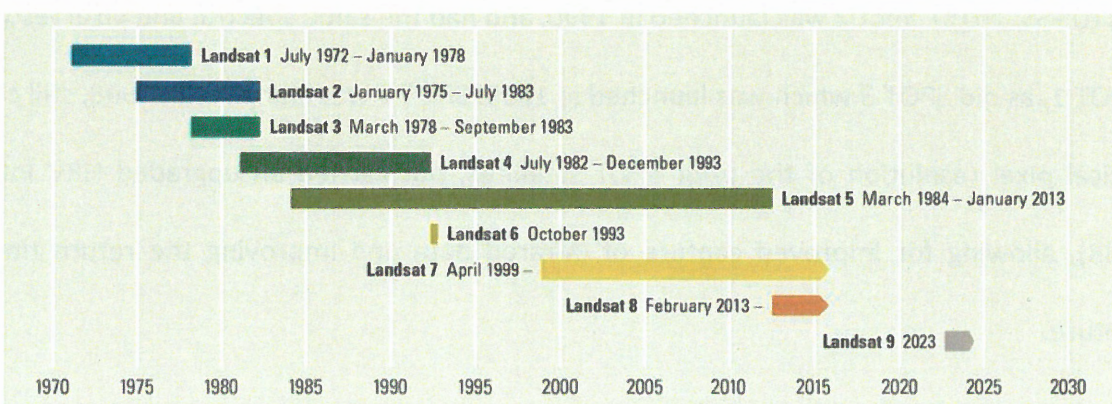


Figure 3: Timeline of LandSat program (USGS, 2015)

Most imagery used in this project was sources from aerial photos which until recently used film, so pixel resolution cannot be compared with satellite platforms, however, sub-metre features can generally be discerned. These images can be expensive to obtain for large areas due to spatial coverage of a single image being quite small, resulting in large numbers of images needing to be purchased for effective coverage.

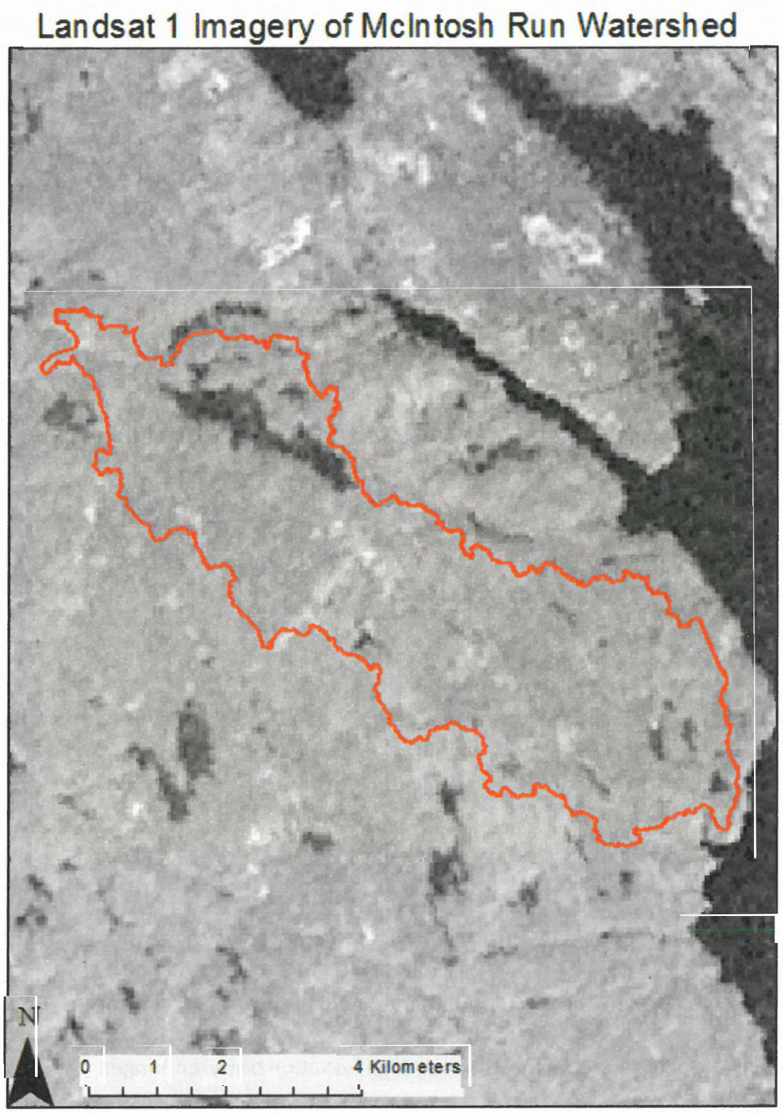


Figure 4: LandSat 1 Image of McIntosh Run Watershed, illustrating the challenge of working with early multispectral data and diminished resolution in comparison to Aerial Photography. See figures on pages 2, 23 and 24 to compare image quality.

Chapter 3: Methodology

Air photos were acquired from the Federal and Provincial Governments (Nova Scotia Geomatic Centre, 2015), and a satellite image acquired from the Pleiades satellites at 50cm pansharpened resolution. A major difference between my project and the previous works discussed above is the lack of multispectral data used for automated image classification. Our McIntosh Run imagery included single-band monochrome air photos that captured visible light spectrum, with select 3-band (R-G-B Colour) of more modern imagery.

2015 imagery is a 50cm pansharpened multispectral scene from Pleiades-1A, and could have been classified using supervised and/or unsupervised methods. I used a manual approach for all imagery, as varying methods between different data sets will result in data which cannot be reliably compared with meaningful results.

Imagery Used in Study

Year	Acquisition	Source	Type	Scale/Resolution	Bands
1931	June 22-25	NAPL	B/W	1:15,000	1
1947	November 3	NAPL	B/W	1:35,000	1
1954	June 20	NAPL	B/W	1:15,000	1
1966	June 3	NS Gov	B/W	1:16,500*	1
1973	June 4	NS Gov	Colour	1:15,840	3
1981	August 14	NS Gov	Colour	1:10,000	3
1992	July 25	NS Gov	Colour	1:10,000	3
2006	May 8	Dal GIS	B/W	1:40,000	1
2015	May 6; June 15	AIRBUS	Multispectral	50cm	4

* Indicates approximate scale, slight variation between images

Figure 5: Comparison of datasets used in this project. All imagery captured between May-August (exception 1947)

Processing

Defining the Watershed

Watershed delineation was completing using ArcGIS and the included suite of Hydrology Tools using a Digital Elevation Model (DEM) from 2007 provided by the Dalhousie GIS Centre through HRM's Open Data initiative. The LiDAR data for the DEM was captured by PHB Lasermap for the Halifax Regional Municipality, and processed by the Applied Geomatics Research Group at Nova Scotia Community College in 2012 (Halifax Regional Municipality, 2013). The data was processed to 1m accuracy. The workflow of the watershed delineation process can be seen in Figure 6. Initially the *Fill* tool was utilized, which uses the DEM as an input and corrects elevations errors or local pits that are inherent in DEM datasets. I used the *Flow Direction* tool, which calculates the direction of downslope from any given pixel in the steepest direction, creating a raster dataset where cell values indicate the direction water would run if it was to fall in any given cell. From the output of *Flow Direction*, *Flow Accumulation* determines how many cells flow into, or accumulate in any cell, and assigns each cell a value which represents this. High value cells represent concentrated flows, likely representing streams and river systems, while zero represents areas which do not accumulate at all, such as high peaks and ridgelines. This allows for the determination of regions which are storing and transporting water. This accumulation raster is *Snapped to Pour Point*, or the cell within a set distance for which the highest flow accumulation data exists. This represents the mouth of the river or stream system.

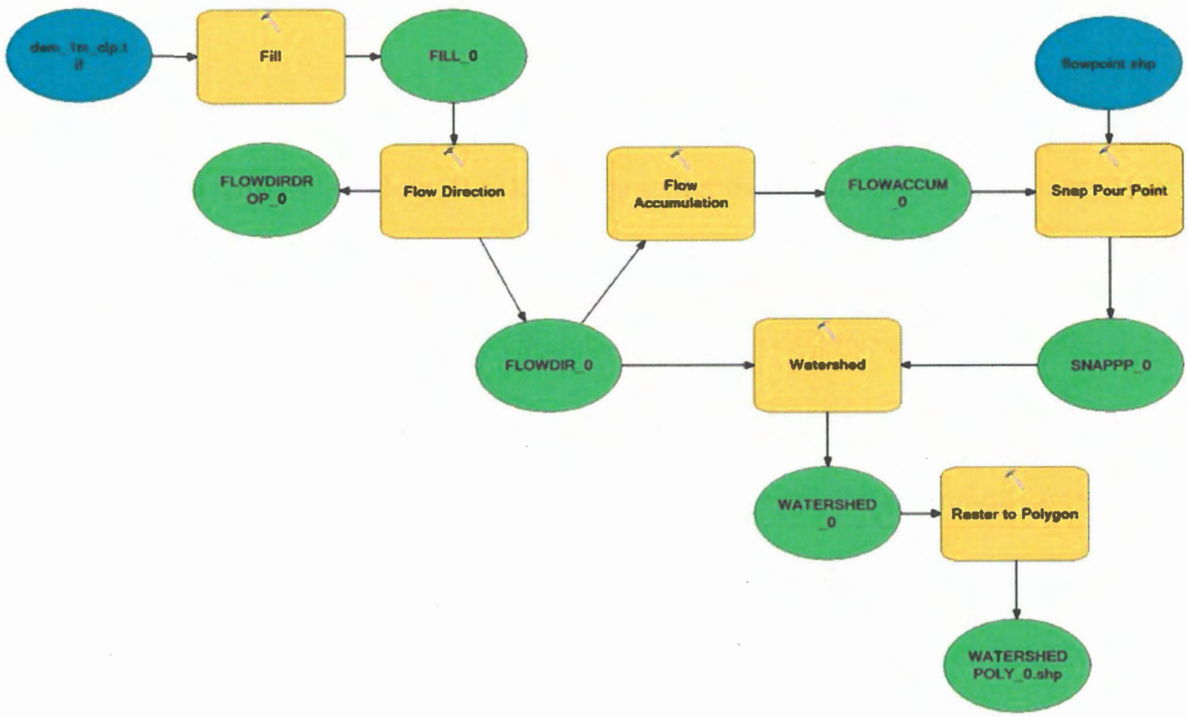


Figure 6: Model for delineation of the boundary for the McIntosh Run Watershed, from ArcGIS ModelBuilder.

The *Snap Pour Point* output raster is used along with the previously created *Flow Direction* raster within the *Watershed* tool to create boundaries as seen in Figure 1 on page 2. Finally, Raster to Polygon produces a vector polygon, which sets the study boundary for the project.

Using this watershed boundary, air photos were chosen to provide cost effective coverage of the watershed. Images were acquired from the National Air Photo Library (NAPL) division of Natural Resources Canada, The Nova Scotia Provincial government, and the Dalhousie University GIS Centre in approximately one-decade intervals. Pre-1960 images are archived with the NAPL in Ottawa, while images post 1960 are available from the Province of Nova Scotia. The most recent image was purchased from an image retailer, captured by Airbus Defense's Pleiades-1A commercial imaging platform.

Georeferencing

All aerial photographic images were obtained without spatial reference on approximately one-decade intervals from 1931 through 1992. The 1931 air photos were scanned at a lower resolution of 1200 DPI due to scanning limitations of the original film rolls and produced a 9017 x 11360 pixel image. Imagery from 1947 to 1954 were scanned from film to produce a 2032 DPI TIFF image file containing 17968 x 18149 pixels.

1931		1947		1954	
Roll #	Photo #	Roll #	Photo #	Roll #	Photo #
A3525	29	A11767	65	A14195	38
A3525	30	A11767	66	A14195	39
A3525	65	A11767	76	A14195	41
A3525	67	A11767	77	A14195	79
A3554	22	A11767	78	A14195	81
A3554	24			A14195	82
A3560	24			A14291	20
A3560	25			A14291	22
A3561	22				

Table 2: Aerial Photos acquired through the National Air Photo Library (NAPL) (NRCan)

Air photos were obtained from 1966, 1973, 1981, and 1992 from the Provincial Government of Nova Scotia as 16860 x 16859 TIFF images without spatial reference. This is comparable in quality to the 1947 and 1954 NAPL data.

1966

Roll #	Photo #
19576	016
19576	017
19599	107
19599	108
19599	018
19599	019
19599	038

1973

Roll #	Photo #
30675	071
30675	029
30675	028
30675	027
30675	021
30675	022

1981

Roll #	Photo #
81321	115
81321	116
81321	086
81321	087
81321	088
81321	049
81321	050
81321	013
81321	034
81321	038
81321	083
81321	085
81321	090
81321	112
81321	114
81327	032
81327	034

1992

Roll #	Photo #
92350	062
92349	199
92349	150
92349	151
92349	101
92349	102
92349	103
92347	185
92350	060
92350	064
92349	099
92349	148
92349	182
92349	154
92349	195
92349	197
92347	183

Table 3: Aerial Photos acquired through the Province of Nova Scotia (DNR)

Georeferencing was completed in ArcGIS ArcMap 10.2.2 using an airphoto index to arrange the imagery, in combination with unique features to precisely reference images including exposed bedrock, water features, and identifiable buildings and infrastructure including St. Michael's Catholic Church, the Community Centre, and High School. Road intersections can also be used but are considered an undesirable georeferencing feature due to changes in road infrastructure from the 1930's to present day. All datasets were projected into UTM Zone 20 using a NAD 1983 CSRS datum. The 2006 digital air photos were provided with a pre-existing spatial reference; all imagery without spatial reference were georeferenced relative to the 2006 images. Pleiades satellite data was purchased as raw data without spatial reference, and was georeferenced using decimal degrees coordinates provided in the metadata.

Mosaic Datasets

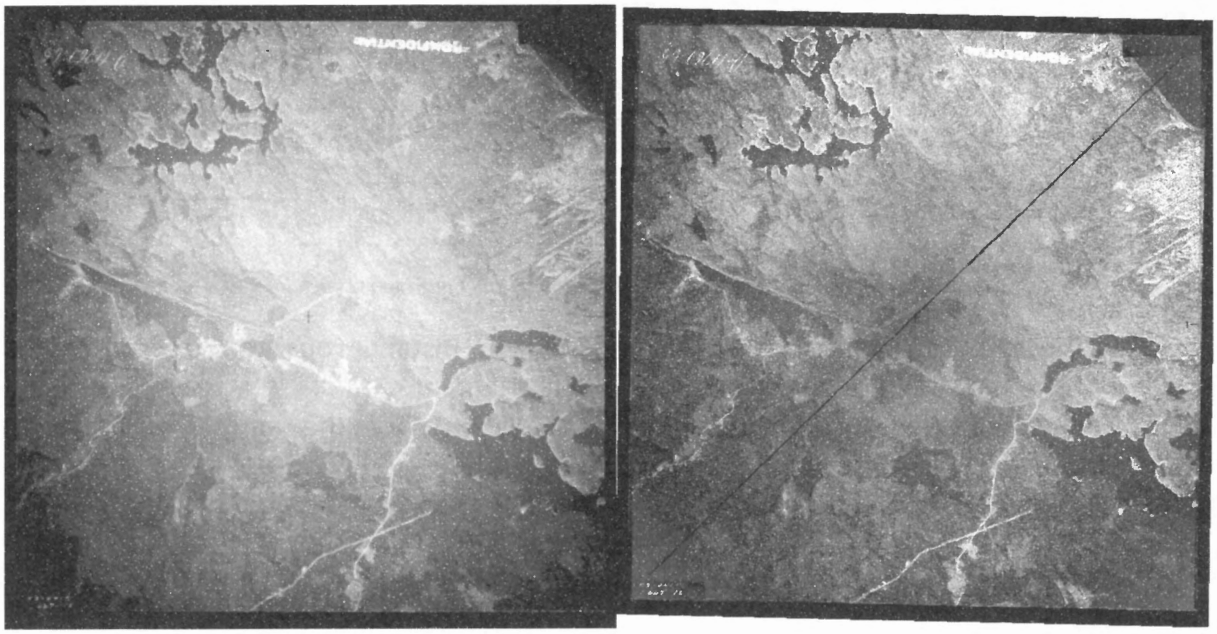


Figure 7: Left - Uncorrected air photo with vignette present; Right - same air photo after the correction process. Line shows direction of profile graph which was used to produce the correction factor.

Prior to the classification, mosaic datasets were produced to gain a single large image which was a composite of the dataset for each decade. The 1947 and 1954 datasets had a very noticeable vignette, or change in brightness value in a radiating pattern from a point on the image. This may have been caused by an artifact introduced in the scanning or exposure process, and made it difficult to view the images clearly, creating inconsistent greyscale values for similar land cover at different locations. This was corrected by first calculating the centroid for each image of the two datasets, marked by a single point. For 1931 the centroid model was not used, and the Euclidean distance point was placed manually due to the offset center point of the vignette.

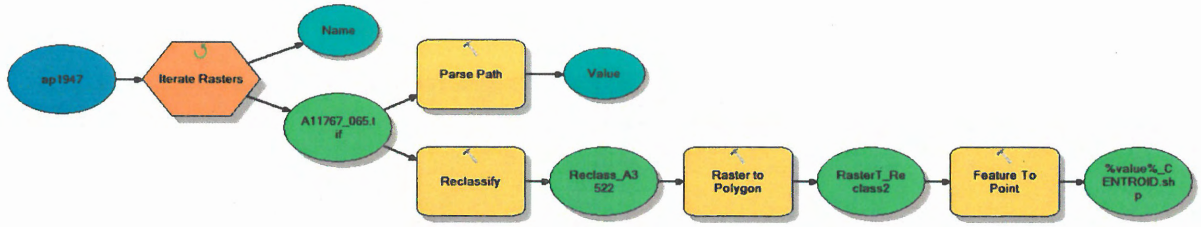


Figure 8: Reclassifying georeferenced Air Photos for the Centroid for each image.

This became the point from which a Euclidean Distance operator was calculated, producing a raster dataset where values increase with distance from the centroid, limited by the extent of the image. Using ArcGIS 3D Analyst, a profile graph was generated for each image of the dataset, and an average correction factor was calculated and applied to each image of the dataset. Raster Calculator was then used to multiply the Euclidean distance output by the correction factor, creating a raster that is referred to as the Mask.

Equation 2

$$Correction\ Factor = \frac{Max\ Brightness - Min\ Brightness}{Max\ Distance}$$

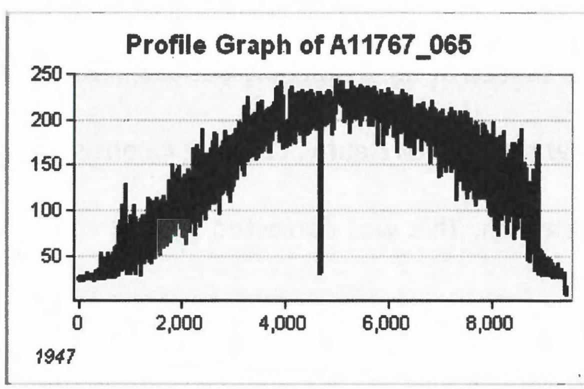


Figure 9: Profile Graph of an Air Photo that required Vignette Correction.

Since all images in the given dataset suffered from the vignette problem, it was assumed that each image was affected by the same amount, based on visual inspection. Automated classification systems had they been used would have had difficulty with the radial brightness value shift across images, as spectral values of land covers would vary wildly based on where they were located on an image. Many other methods could be pursued to remove the vignette, and would likely be equally suitable. The resulting correction factor mask raster was then added to the original air photo to produce the vignette corrected image, as seen in Figure 7.

Removal of Borders

With the exception of the most recent digital datasets, all imagery had thick black borders, a result of the film scanning process. These were removed in order to produce a seamless mosaic. A model was created in ArcGIS's ModelBuilder, which would iterate through all the images for a given dataset, store the filename as a variable and create a mosaic dataset within a file geodatabase. Then the model added a single raster to the new mosaic, creating a mosaic dataset consisting of a single image. Finally, it builds footprints, which includes a "Shrink Distance" variable which cuts a set number of pixels off of the edge of the mosaic, removing the black borders. This tool must be run twice due to an error in ArcGIS where the model does not recognize a geodatabase that the tool itself creates, prior to the model being run.

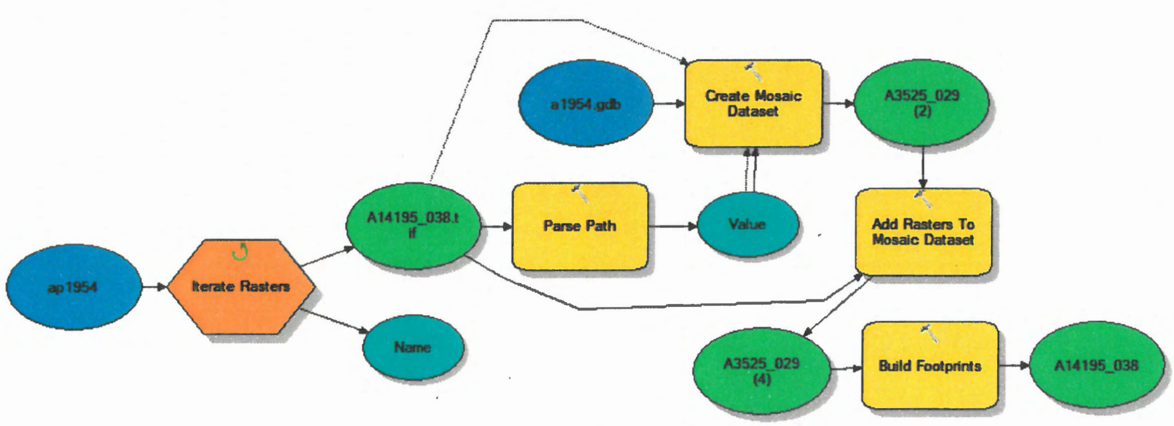


Figure 10: Iterative Model which removes image borders from film negatives

Each of these single image mosaics was exported back to a borderless TIFF image, and added to a new, complete mosaic dataset for all images in a given year. All of the mosaics can be found in appendix 4. A selection of the mosaic images can be seen in the following figures.

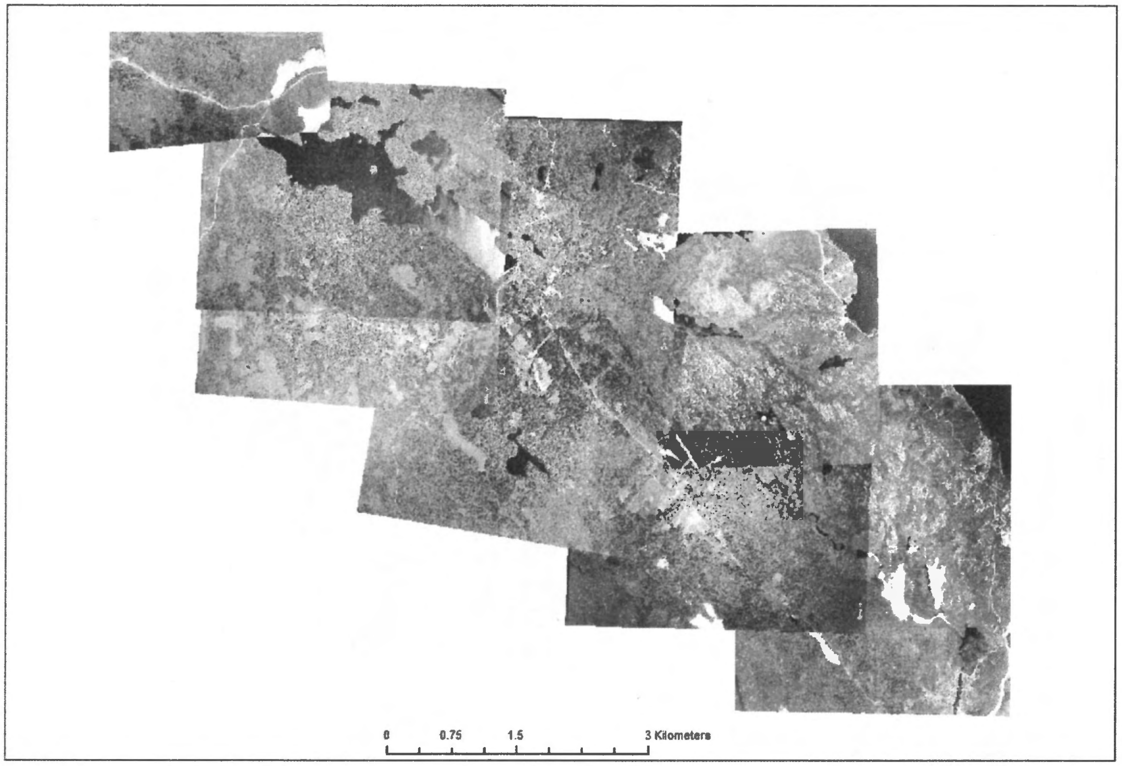


Figure 11: 1931 Mosaic Dataset, single band black/white imagery.

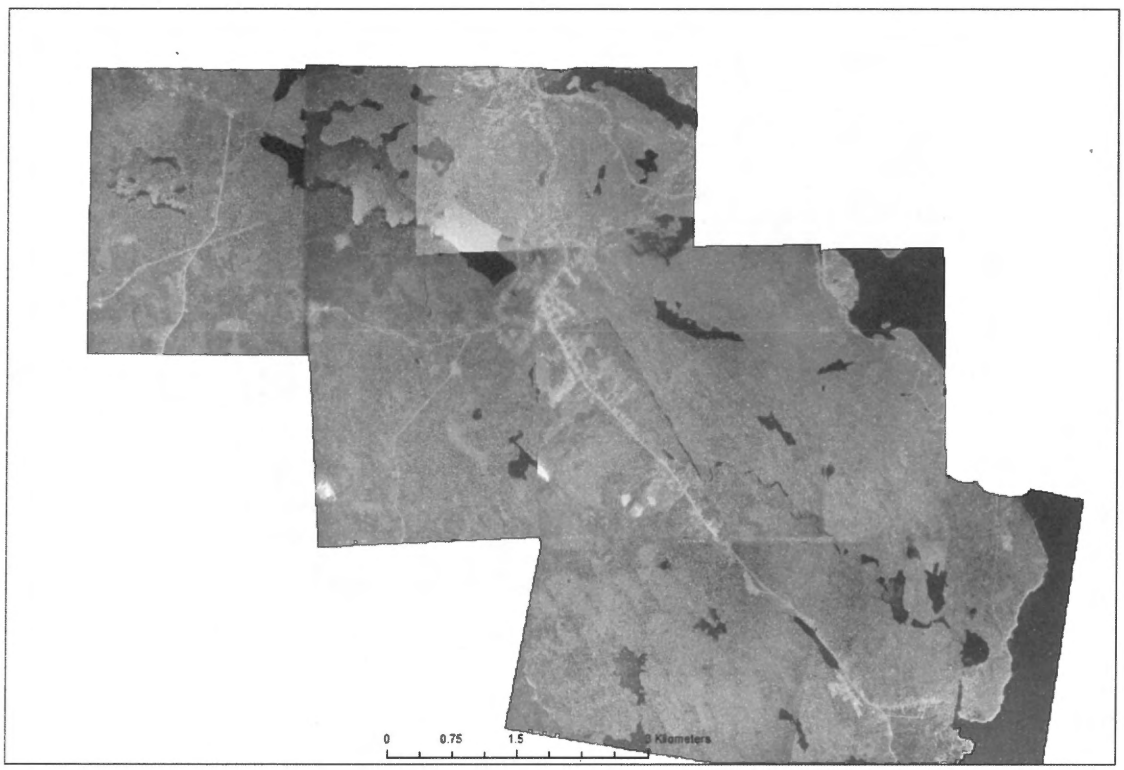


Figure 12: 1954 Mosaic Dataset, single band black/white imagery.

Figure 13: 1973 Mosaic Dataset, multi-band colour imagery.

Figure 14: 1981 Mosaic Dataset, multi-band colour imagery.

Image Classification Process

An attempt was made to use unsupervised classification using the *iso cluster* method, but due to variation in exposure, sun reflection, and a variety of other factors, the results was unusable in the single-band black and white imagery. While the automated classification could reliably identify road networks and granite barrens, it misidentified all other features. For example, open water was classified into all classes due to varying reflectance and angle of incident light. Automated or unsupervised classification was abandoned in favour of manual classification.

Land Classses

Starting in the 1930's, land usage within parts of the watershed, notably south of Long Lake has shifted from a dominantly forested environment with some agricultural activity, to a densely populated urban community. Six land use classifications were chosen to differentiate water infiltration, categorizing how "flashy" a location would be. Flashy refers to the degree of imperviousness of a land surface, and how likely it is to produce flash flood style events. In a non-flash land surface, infiltration and permeability is high. The land surface can absorb water, which decreases the running surface water. These six classes were based on a modification of the *U.S. Geological Survey Land Use/Land Cover Classification System for Use with Remote Sensor Data* (Anderson, Hardy, Roach, & Witmer, 1976). The modifications were the division of *urban* into *high density urban* and *low density urban*, the inclusion of *agricultural land* with the *low density* urban, and the omitting of *perennial snow/ice*, *Tundra*, and *Rangeland* as they are not relevant to the McIntosh Run Watershed. The six classes of land use that were chosen are:

1) Barrens - defined as areas of undeveloped land that had a concentration of outcropping granitic rocks. There are three notable areas of barrens within the watershed, and they are assumed to exhibit a somewhat flashy behaviour in relation to hydrology and infiltration rates.

2) *Forested* areas consist of undeveloped vegetated lands, or land that was once in usage but has now been returned to a wild state. This land class includes recovering vegetated areas that were destroyed in the 2009 wildfire.

3) *Wetlands* were classified based on visual inspection of high resolution colour imagery, and could be differentiated by a marked colour change from green of the forests to orange/yellow wetlands. If uncertainty existed in determining if the wetland did or did not exist in black and white historical imagery, it was assumed the wetland is there, and no change was recorded.

4) *Open water* consists of all lakes, rivers, and streams within the McIntosh Run Watershed.

5) *Low density urban* was classified as all roads, residential neighbourhoods, and development that did not consist of extreme levels of paving, concrete, and roofing structures. In the earliest air photos, notably 1931, this land class also included agricultural lands.

6) *High density urban* consists of any urban areas that were not covered by the low density urban class. This consisted mostly of developments such as Bayers Lake, the shopping center in Spryfield, some larger community buildings, and any parking lots. These types of development would have the least infiltration of all the land classifications, and result in the flashiest behaviour.

Using the manual classification method, in order to avoid "No Data" regions it was initially assumed that everything within the watershed was a forest polygon. From this, polygons of other land cover types were drawn over the imagery, and polygons were then erased from each other, leaving no overlap in the final classification image for a consistent total area. Failure to erase features results in double-counting of polygon areas, and erroneous inconsistent total areas of the watershed. This was done using Model Builder within ArcGIS to eliminate human error.

Images were classified beginning with the most recent imagery from 2015. This was done due to the method in which the Low Density Urban polygons were created. Using the shapefiles available within the CanVec digital topographic maps available from the Government of Canada through GeoGratis (Natural Resources Canada, 2015), the Roads shapefile was isolated, and brought into ArcGIS with the 2015 satellite imagery. Additional roads from recent development in the watershed that CanVec was missing were manually drawn. With this updated 2015 road polyline, a buffer operation created a set of polygons extending 45m, or roughly the depth of a plot of land, around the roads polyline. For 1931 through 1953 the buffer was set to 15m, a smaller value to account for the lack of development along the roads. It was assumed that this is an accurate representation of development along roads in the area. Any major light density urban areas that were unaccounted for were identified and manually drawn.

Next, the rivers and lakes shapefiles were isolated from the CanVec dataset and compared to the datasets to confirm all bodies of water were accounted for and all rivers and streams had been correctly identified. After this, a 5m buffer was placed on the rivers polyline in much the same manner as the roads and light urban shapefile. The Rivers and the Lakes shapefiles were then merged to produce the Open Water polygons consisting of connected rivers, streams, and lakes.

Classification Process

High Density Urban polygons were all drawn manually, and consisted of large shopping areas, parking lots, schools, and any other area that consisted of large developed areas which were almost entirely paved or roofed, indicating significant changes to the infiltration in the watershed. This was identified as an area that would be very flashy and have a more hydrologically negative impact on the area, relative to a residential district or barrens.

The granite barrens of the McIntosh Run Watershed were also manually classified, and were defined as areas of significant exposed granite at the surface. Smaller areas with one or two small outcrops were excluded from this class. The most significant barren lies on the east side of the McIntosh Run, with a second west of Herring Cove Road. The exposed barrens have areas of bog-type vegetation between outcrops, but for the purpose of this study these regions were included as granite barrens. The barrens are considered to still be flashy relative to a forest or wetland land class.

Wetland polygons were identified based from image interpretation of the colour datasets, where a notable orange/brown colour of the wetland areas made them easy to classify. These regions were then compared to the older datasets and a decision was made if the wetland did or did not exist in the past. Wetland are not considered to be a flashy land class.

Once all areas were satisfactorily identified, the process of erasing polygon overlap began to eliminate the double-counting of areas, as each area could only be classified as one of the six classes. Following this, all polygons were clipped to the watershed polygon, as the focus of the study is only in areas strictly within the boundaries of the watershed as defined in Figure 1. As each class for each dataset was a separate polygon at this point, they were merged to produce a single polygon for each year where an attribute identified the land use. From this, the area of each class for each year was then calculated.

Data was exported from ArcGIS (as seen in Appendix 2.1) into Microsoft Excel. Here it was prepared into the format seen in Appendix 2.2, 2.3 which was used to produce charts and graphs of the Land Use Change within the McIntosh Run Watershed presented in the following section.

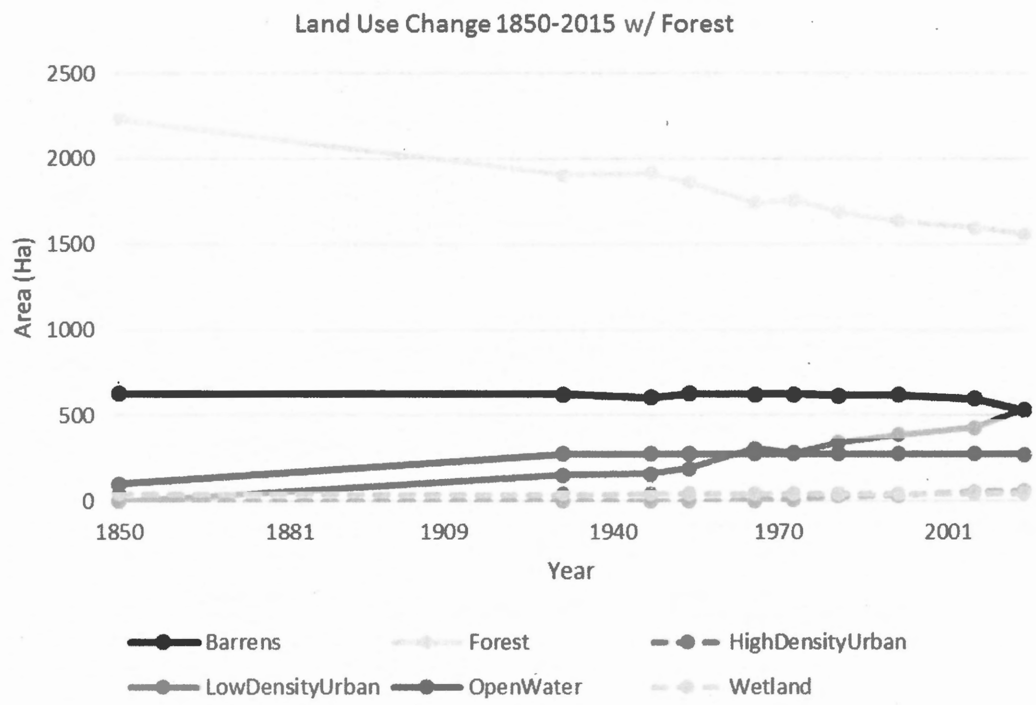
Chapter 4: Data Analysis & Discussion

Land Use Change

The change analysis shows significant land use change within the ~3000 hectare (Ha) McIntosh Run Watershed (Table 4 and Table 5). With the exception of the damming of Long Lake, almost all change in land cover within the watershed is due to urbanization with a secondary effect from clearing of woodland for agricultural uses, which is considered as low density urban in the classification system. The majority of this development occurs in the northern part of the watershed, where Bayers Lake was constructed, as well as south of Long Lake where the town of Spryfield has developed. Other low density urban development has occurred along Herring Cove Road.

Baseline-1931

Beginning with the damming of Long Lake in 1848 and the advent of farming in the region, a major shift in land use within the watershed began. From 1800 baseline to 1931, land change included the loss of approximately 14.5% (324.6 Ha) of forested land. Low density urban reached 152.2 Ha by 1931, 5.1% of the watershed. Open water increased by 178.5% (177.4 Ha) from 99.4 Ha to 276.8 Ha. This observed change should, however, be taken as a maximum; without data on pre-Long Lake land cover we assumed it to be forest. Cocked Head Lake once existed beneath what is now Long Lake (McIntosh Run Watershed Association, 2004), though most flooded area was likely wetland or forest. It is unlikely any barrens were lost to Long Lake, because none are in the area and barrens occur in the uplands elsewhere in the watershed.



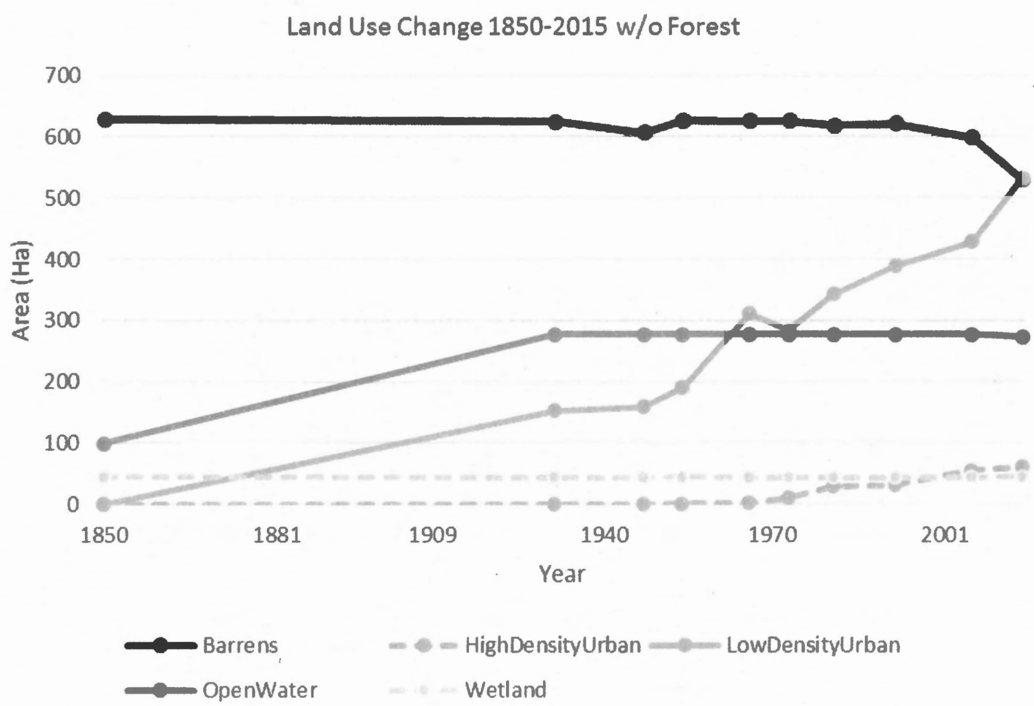


Figure 15: (Top) Graph showing all six land use classification, 1800 through 2015.
(Bottom) Land Use Change omitting Forest class, to bring attention to the lower area land usages.

By 1931, a road network had been established which included what is now Herring Cove Road and Purcell's Cove Road, and secondary roads which led to various agricultural plots. With the exception of some residential building in Herring Cove in the southern limits of the watershed, land change is restricted to farming activity scattered along Herring Cove Road and west of Long Lake.

1931-1954

By 1954, land use is beginning to shift from agricultural to low density urban and residential developments. Light urban land usage increased by 46.8% (50.75 Ha). At this time, we now see the first high density urban developments, in some large buildings which are 0.69 Ha. 23.6 Ha, or 1.2% of the forested area was cleared to accommodate this urban growth. Barrens decreased in area by 3.4%, (20 Ha).

Through the classified 1947 air photos, we can determine significant changes in the urbanization of Spryfield and the watershed in this 16-year span. By 1947, the shift from agricultural use to urban environment is well underway, with major urban development beginning at the south end of Long Lake. By 1954, most farmland appears to be abandoned as forests begin to encroach the fields, or are redeveloped into residential neighbourhoods.

1954-1973

Over the following two decades, agricultural use is fully abandoned and the watershed now hosts major residential areas. More land was converted from forest, with a loss of 169.3 Ha (8.7%) of the remaining forest area cleared for developments. High density urban grew significantly and expanded by 1337.7%, expanding from 0.686 Ha to 9.9 Ha by 1973. Low density urban doubled with an increase of 163.3 Ha (102.6%). The 1966 air photos shows much or the growth in urban land classes had already occurred by that time. This indicated very rapid land use change between 1954-1966.

1973-1981

In the 8 years separating these datasets, the most significant change is the continuing growth in high density urban developments. This land class increased by a further 195.8%, growing by 19.4 Ha as a result of shopping and other large building being constructed. Urban developments that were low density increase increased by 59.1 Ha (20.9%) as residential neighbourhoods continued to expand. This expansion resulted in the conversion of 91.1 Ha of forest and 7.6 Ha of barrens to urban usage.

1981-2006

In the next 25 years, there was further low density residential expansions around the community of Spryfield as this land class increased by 85.6 Ha (25%). 25.8 Ha of high density urban development occurred mostly in the Bayers Lake area representing 88.3% growth. This resulted in the clearing of 92 Ha of forested land. Bayers Lake in particular, though largely outside of the watershed boundary, would be a major factor in reducing infiltration and increasing flood peaks in the region, and the large parking lots and buildings cause increased surface runoff.

During construction of the Bayers Lake commercial and light industrial park a portion of the Chain Lakes watershed was linked with the McIntosh Run Watershed by a diversion dam upstream of Long Lake (See appendix 4.1) (Halifax Water, 2013). Water that would otherwise have flowed into the Chain Lakes, instead diverted to Long Lake and the McIntosh Run

Watershed. This diversion, which persists to the present, was to avoid contamination of the Chain Lakes by acidic runoff generated by arsenic bearing-rocks in the Bayers Lake region which (McIntosh Run Watershed Association, 2004). When exposed by blasting and construction, these rocks leached acidic runoff. A result is an decreased water quality, increased area of the watershed, and higher flow volume in the McIntosh Run.

2006-2015

From 2006 to the present day, 11.5% (68.9 Ha) of the barrens along with 2.3% (37.3 Ha) of forest was converted to urban development. This grew the total area of low density urban by 104 Ha, an increase of 24.3%, caused by new residential developments in the region. There was no change recorded for the high density urban class. Much of this new expansion is directly alongside the McIntosh run itself.

At the Governor's Brook development on the east side of the McIntosh Run, development is occurring with a minimum buffer of approximately 40m of the Run, with storm sewer boulder lined channels discharging directly into the run (Rideout, 2012). This meets the 20m vegetated buffer requirement of the Halifax Regional Municipality, which storm infrastructure is exempted from (Rideout, 2012). As part of urbanization and land development in the region, water was diverted from its original flow path from Colpitt Lake, outside of the eastern boundary of the watershed, into the McIntosh Run Watershed. (Nova Scotia Utility Review Board, 2004). This serves to both decrease the volume of water into the Colpitt Lake Watershed, and to increase the volume of water in the McIntosh Run Watershed (McIntosh Run Watershed Association, 2004). This increased runoff would be probably largest during spring melts and significant rain events, due to decreased infiltration flood events within the watershed.

Figure 16: (Top) Standing near McIntosh Run at Governor's Brook Development; Storm water drainage channel directly into McIntosh Run. (Bottom) Storm Drainage channel into McIntosh Run.

Baseline-2015

Overall, between 1800 baseline and 2015, 141 Ha (23.2%) of barrens and 625.1 Ha (27.8%) of forest was lost to the Long Lake Dam project, which flooded sections of forest, and growing urban developments along Herring Cove Road and through Spryfield.

Total land use in Ha

	1850	1931	1947	1954	1966	1973	1981	1992	2006	2015
Barrens	629.13	624.78	606.95	626.57	625.79	625.79	618.17	621.30	598.21	529.32
Forest	2228.10	1903.55	1914.60	1862.00	1741.05	1761.22	1690.13	1638.27	1598.15	1560.87
HighDensityUrban	0.00	0.00	0.00	0.69	2.18	9.86	29.17	31.62	54.92	60.70
LowDensityUrban	0.00	152.17	158.91	190.62	311.20	283.62	342.80	388.52	428.43	532.44
OpenWater	99.39	276.79	276.77	276.77	276.77	276.77	276.77	277.33	277.33	272.93
Wetland	44.40	43.74	43.80	44.37	44.03	43.77	44.03	44.03	44.03	44.83

Table 4: Total Area in Hectares (Ha) of each land classification by year

Net change in Land Class (Ha)

	1850-1931	1931-1947	1947-1954	1954-1966	1966-1973	1973-1981	1981-1992	1992-2006	2006-2015	1850-2015	1931-2015
Barrens	-4.35	-17.83	19.62	-0.78	0.00	-7.62	3.13	-23.09	-68.89	-99.81	-95.46
Forest	-324.56	11.05	-52.59	-120.95	20.17	-71.09	-51.85	-40.12	-37.28	-667.24	-342.68
HighDensityUrban	0.00	0.00	0.69	1.50	7.68	19.31	2.45	23.31	5.77	60.70	60.70
LowDensityUrban	152.17	6.74	31.71	120.58	-27.58	59.18	45.72	39.91	104.01	532.44	380.27
OpenWater	177.40	-0.02	0.00	0.00	0.00	0.00	0.55	0.00	-4.40	173.53	-3.87
Wetland	-0.67	0.06	0.57	-0.34	-0.27	0.27	0.00	0.00	0.79	0.42	1.09

Table 5: Land Use Change in Hectares (Ha) between datasets

Percent change between Datasets

	1850-1931	1931-1947	1947-1954	1954-1966	1966-1973	1973-1981	1981-1992	1992-2006	2006-2015	1850-2015	1931-2015
Barrens	-0.69%	-2.85%	3.23%	-0.13%	0.00%	-1.22%	0.51%	-3.72%	-11.52%	-15.86%	-15.28%
Forest	-14.57%	0.58%	-2.75%	-6.50%	1.16%	-4.04%	-3.07%	-2.45%	-2.33%	-29.95%	-18.00%
HighDensityUrban	-	-	-	218.32%	351.66%	195.84%	8.40%	73.71%	10.51%	-	-
LowDensityUrban	-	4.43%	19.96%	63.26%	-8.86%	20.86%	13.34%	10.27%	24.28%	-	249.89%
OpenWater	178.49%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.20%	0.00%	-1.59%	174.60%	-1.40%
Wetland	-1.51%	0.15%	1.31%	-0.77%	-0.61%	0.61%	0.00%	0.00%	1.80%	0.95%	2.50%

Table 6: Percent change between given years

Other notable changes to the watershed include the damming of Long Lake, which occurred in the 1848 (McIntosh Run Watershed Association, 2004), flooding a smaller lake and lifted water levels 8-metres. (Nova Scotia Department of Natural Resources, 2008). While beyond the scope of this project, in terms of watershed habitat health the Long Lake Dam lacks a fish ladder and is a hard barrier for access to spawning grounds. Wildlife activity can be observed in the 2015 satellite image as new open water is formed in the eastern part of the watershed barrens, a result of beavers damming a section of a stream that feeds the McIntosh Run.

To summarize, between 1800-2015, 100 Ha of barrens were converted into low density residential developments, 667 Ha of forest was converted into low and high density urban, and also into open water by the damming of Long Lake. High Density urban now totals 60.7 Ha, while the majority of urban growth has occurred in Low Density urban, which now accounts for 532 Ha. Open Water increased as a result of the Long Lake Dam and the activity of beavers in 2015, for a total increase of 174 Ha. Finally, wetlands saw no substantial change in area, which is expected due to the difficulties of draining a wetland for construction, compared to simply building on plentiful stable and dry land elsewhere.

Chapter 5: Conclusions and Further Work

Conclusions

I have established a historical dataset and a baseline of land use change in the McIntosh Run Watershed that serves to quantify land use change, and may serve as a baseline for future monitoring within the watershed.

In the Mcintosh Run Watershed, forest and granite barrens have been converted into urban developments. Beginning with the damming of Long Lake and the advent of farming in the region a major shift in the land usage within the watershed was set in motion. We see a gradual shift from farmland towards residential homes. By the 1960's, most farms have been converted to urban or abandoned to forest regrowth.

Between 1973 and 1981 the Bayers Lake shopping district, which is partially within the watershed, was developed resulting in diversion of the Chain Lakes watershed to the McIntosh Run Watershed. This converted an area in the north of the watershed to concrete and asphalt, which significantly decreased infiltration and absorption capacities for that portion of the watershed and increased flashy behaviour. While this development is a distance away from the run itself, it is nevertheless part of the watershed that feeds Long Lake and eventually the McIntosh Run. Overdevelopment and urbanization in the north of the watershed may lead to further decreasing infiltration. This will result in increasing flow and flashy behaviour during heavy precipitation events, and the potential overtopping of Long Lake Dam. Currently the upper watershed is protected by Long Lake Provincial Park, this is key to protecting the infiltration capacity of the upper watershed and maintaining the health of the watershed.

Through the remainder of the datasets, we see continuous and steady expansion of residential areas with the 2015 dataset showing a new low-density residential development converting a portion of the exposed barrens. The clearing and construction for the Governors Brook residential development, along with a second new development of some 50 hectares are occurring in direct proximity to the McIntosh Run. Developments this close to the river give little buffering distance to allow the remaining infiltration capacity to absorb surface water. This will cause increased surface runoff, and higher flood peaks during peak flood events within the McIntosh Run Watershed.

Further Work

The McIntosh Run provides a wealth of future research possibilities, including but not limited to the modelling of hydrology within the watershed based using software such as GreenKenue. This software can input historical rainfall data in combination with infiltration estimates for each land cover classification to simulate the watershed under variables and conditions which the user sets as model parameters. This would provide a further level of understanding to understand how the land use changes has changed the watershed hydrology.

The continued monitoring of the watershed through remote sensing provides the opportunity to monitor land change into the future in combination with the historical dataset created here. The installation and monitoring of stream gauges would also be valuable in beginning a true flow record of the McIntosh Run which would benefit future work. As the newest development is happening directly on the banks of the McIntosh Run, which would be very interesting to study how these developments affect the watershed with data from before and after. Hydrochemistry or water quality analysis would be extremely useful in determining the health of the watershed, and if that is limiting factor or has a significant impact on the biodiversity of life within the McIntosh Run.

The next logical step for this project if it was to be expanded upon is to monitor the McIntosh Run for a period of years to establish a small hydrology dataset, produce hydrographs, and compare them to modeled flow values from GreenKenue. Through adjusting variables, we can match the curves of the modeled and actual hydrographs, which will allow for much more accurate historical modelling of the McIntosh Run Watershed, and for future predictions.

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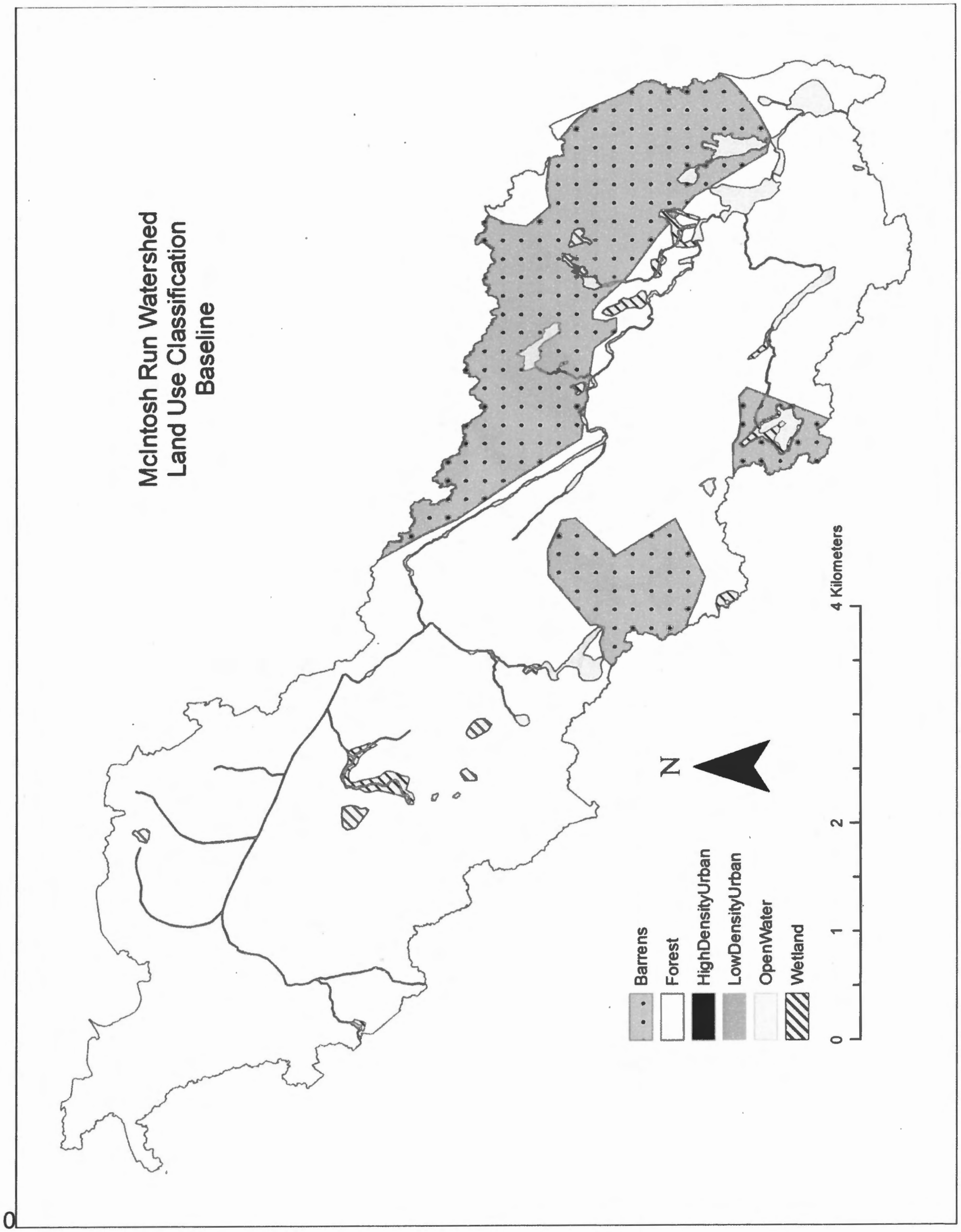
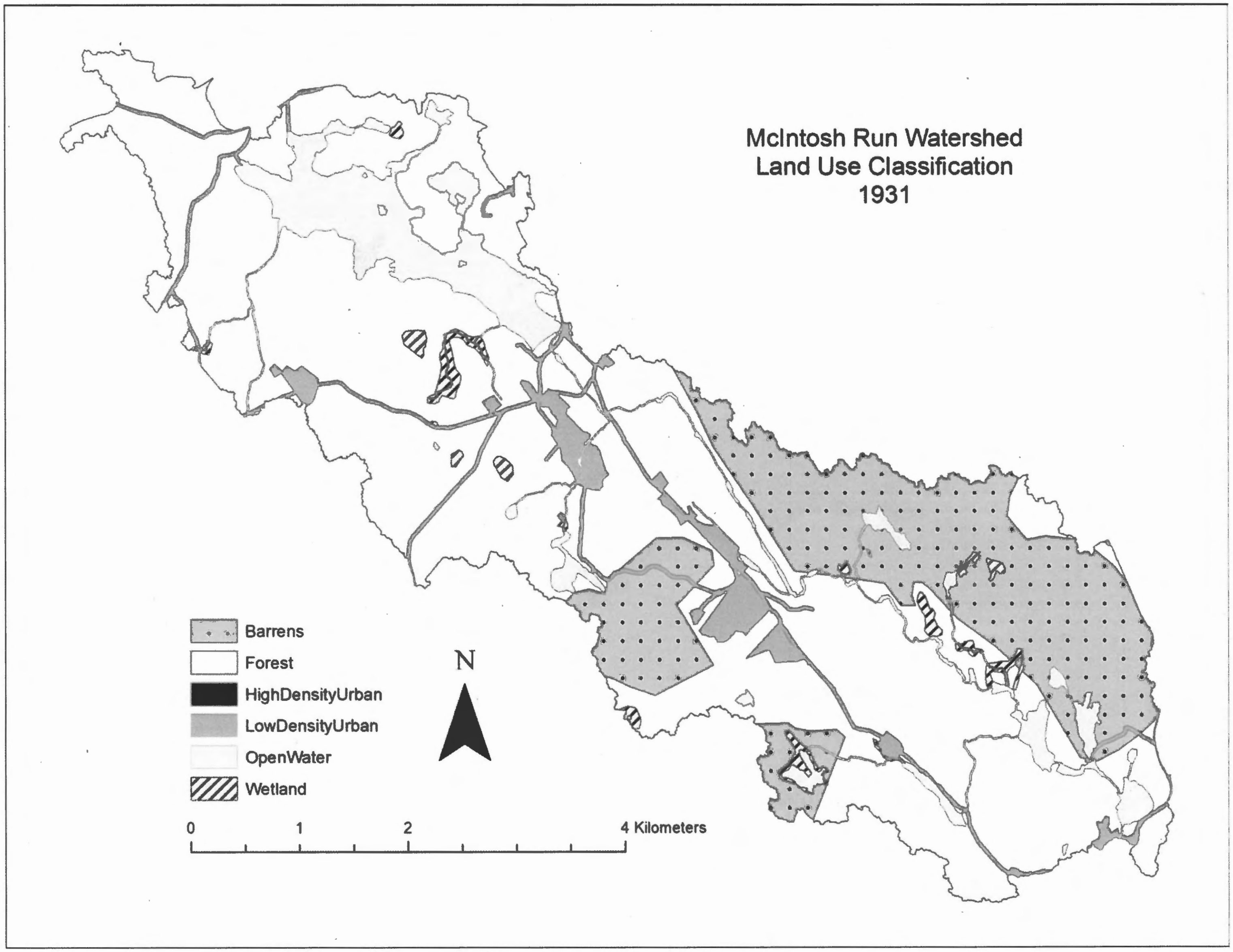
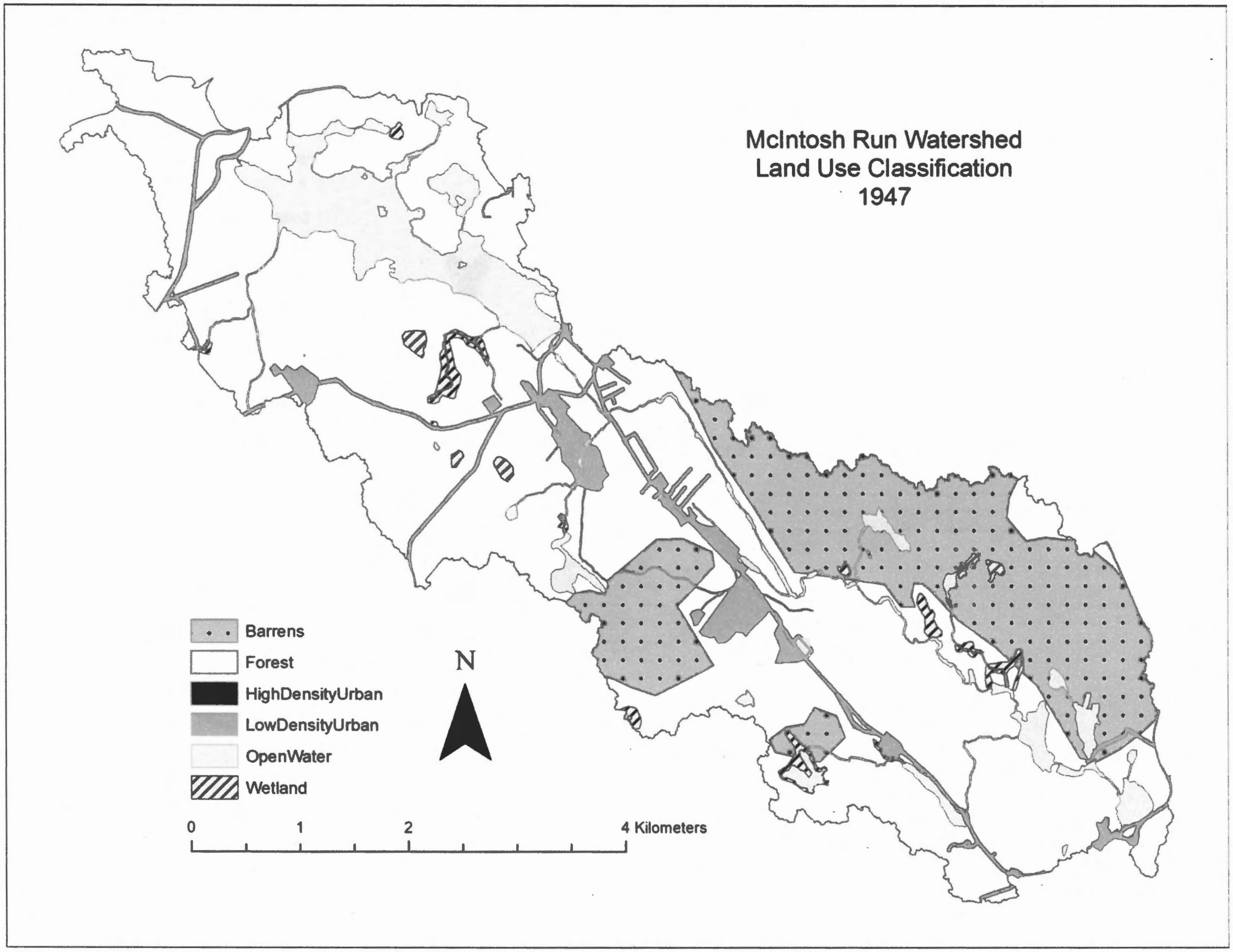
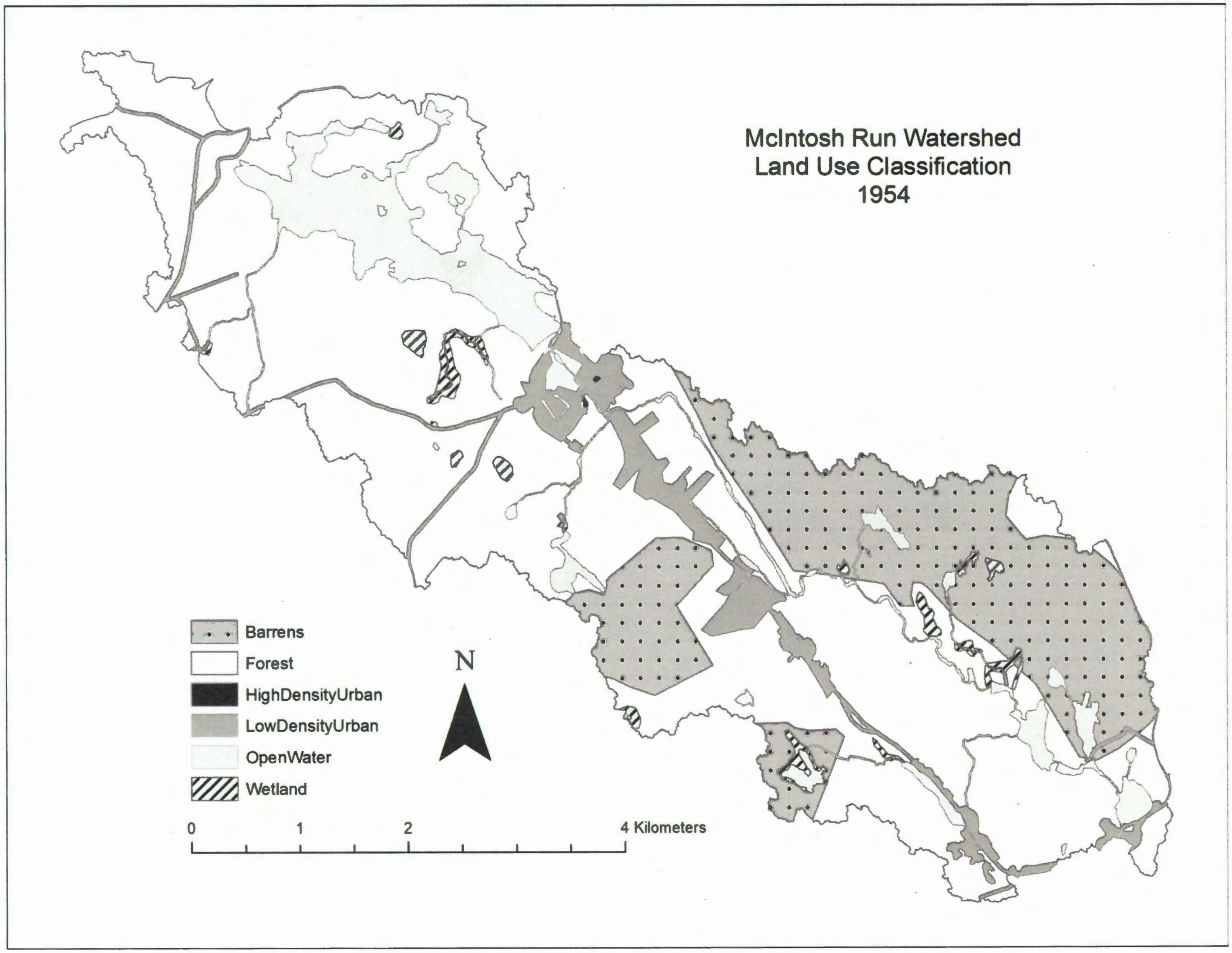
Appendix

Appendix 1: Classification Maps

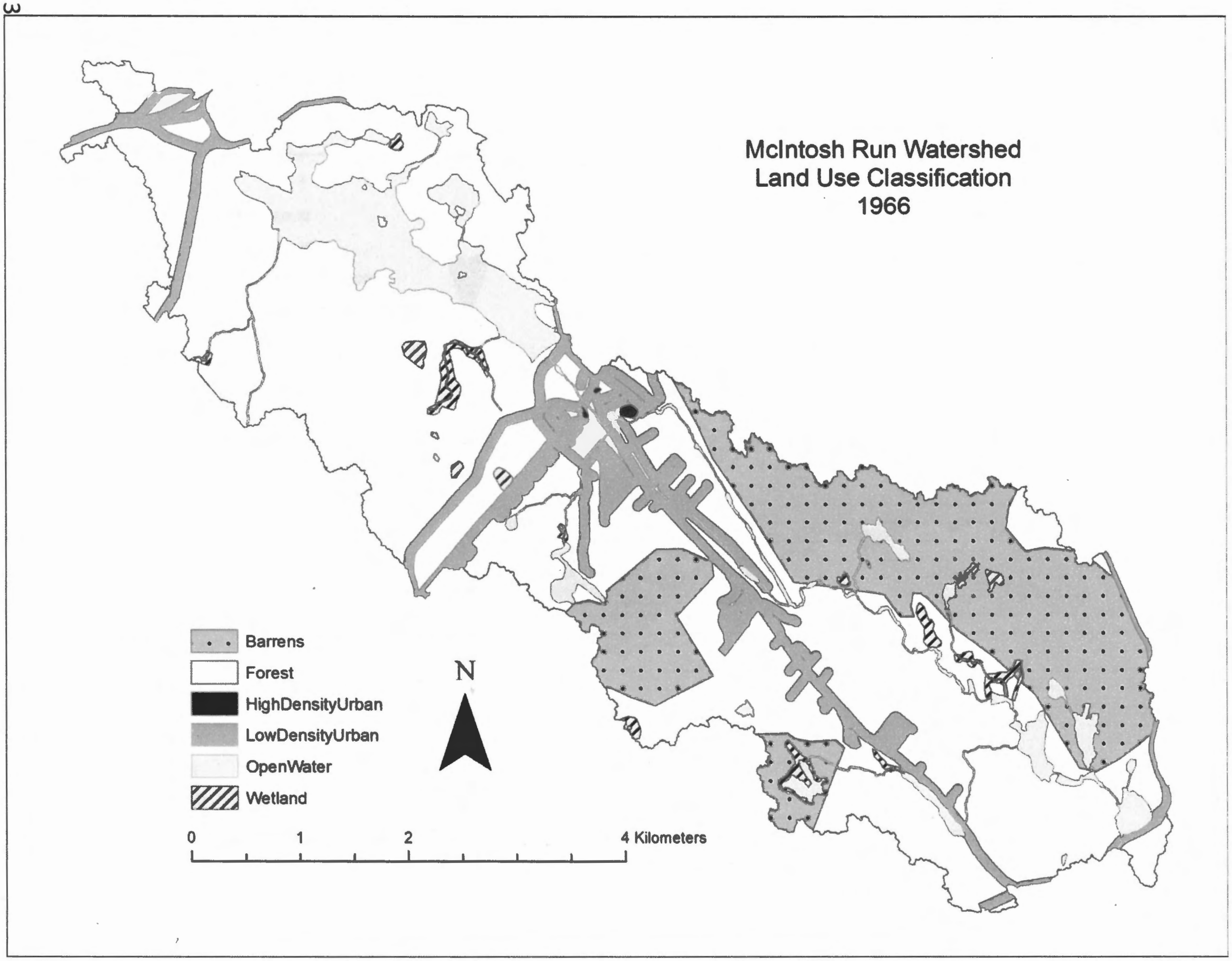


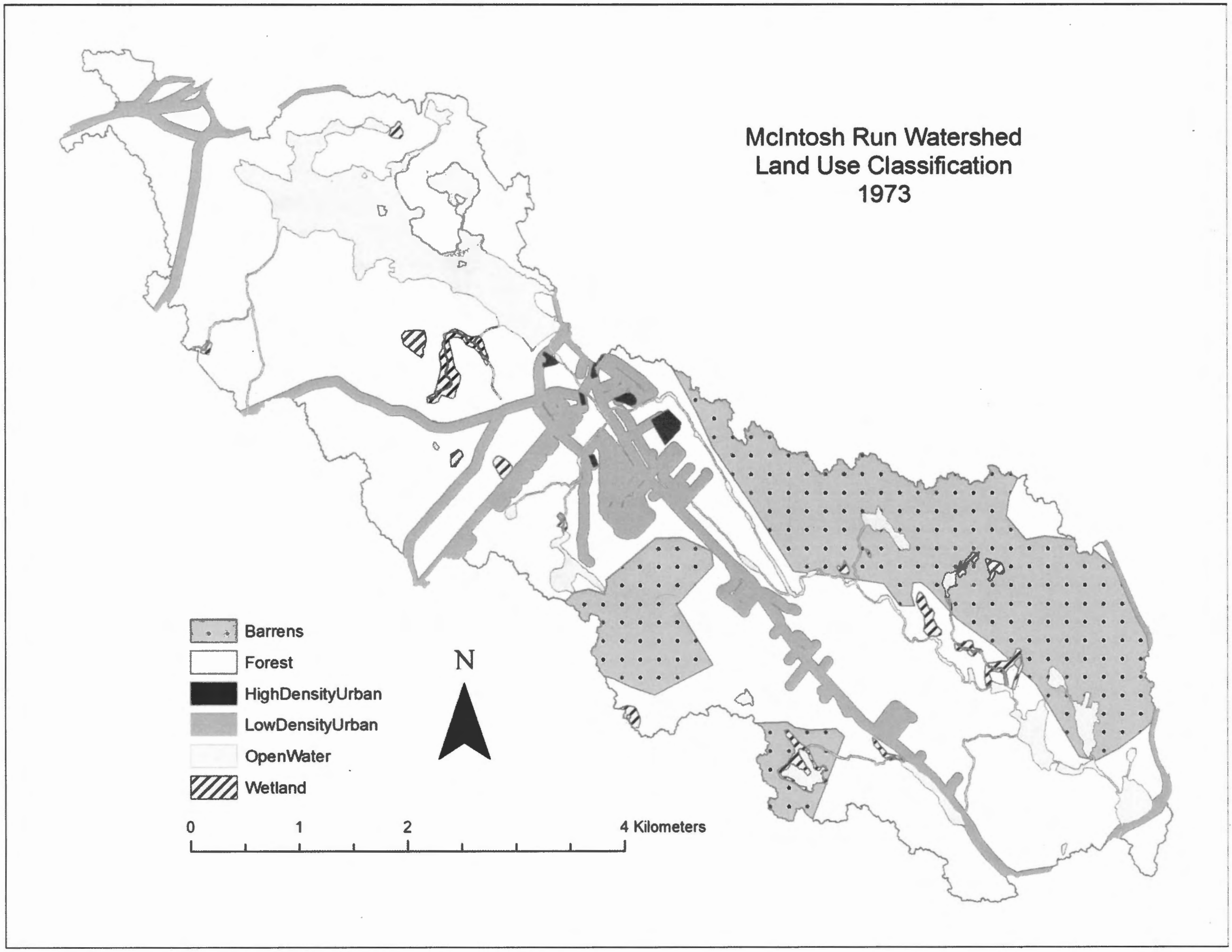

McIntosh Run Watershed
Land Use Classification
1931
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers

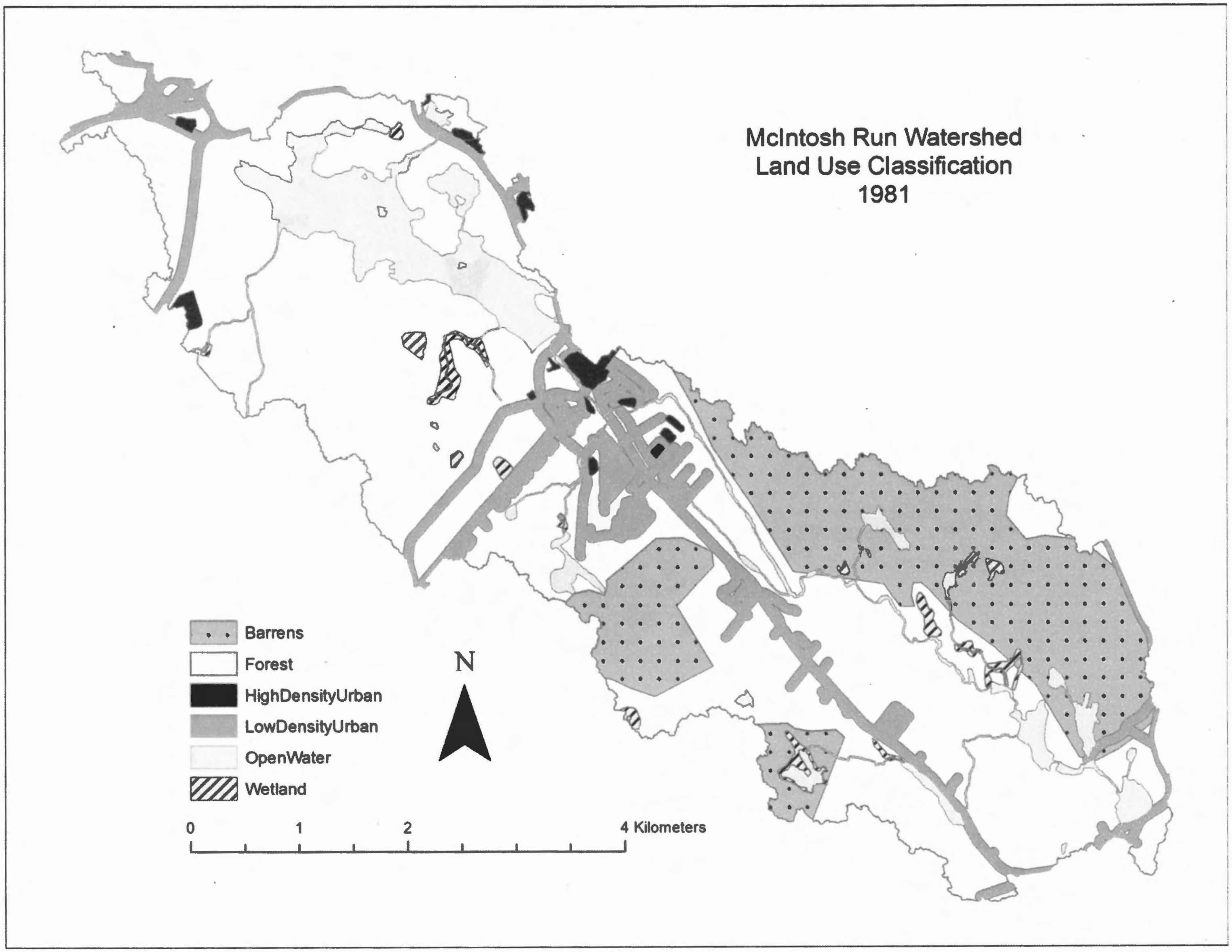

McIntosh Run Watershed
Land Use Classification
1947
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers

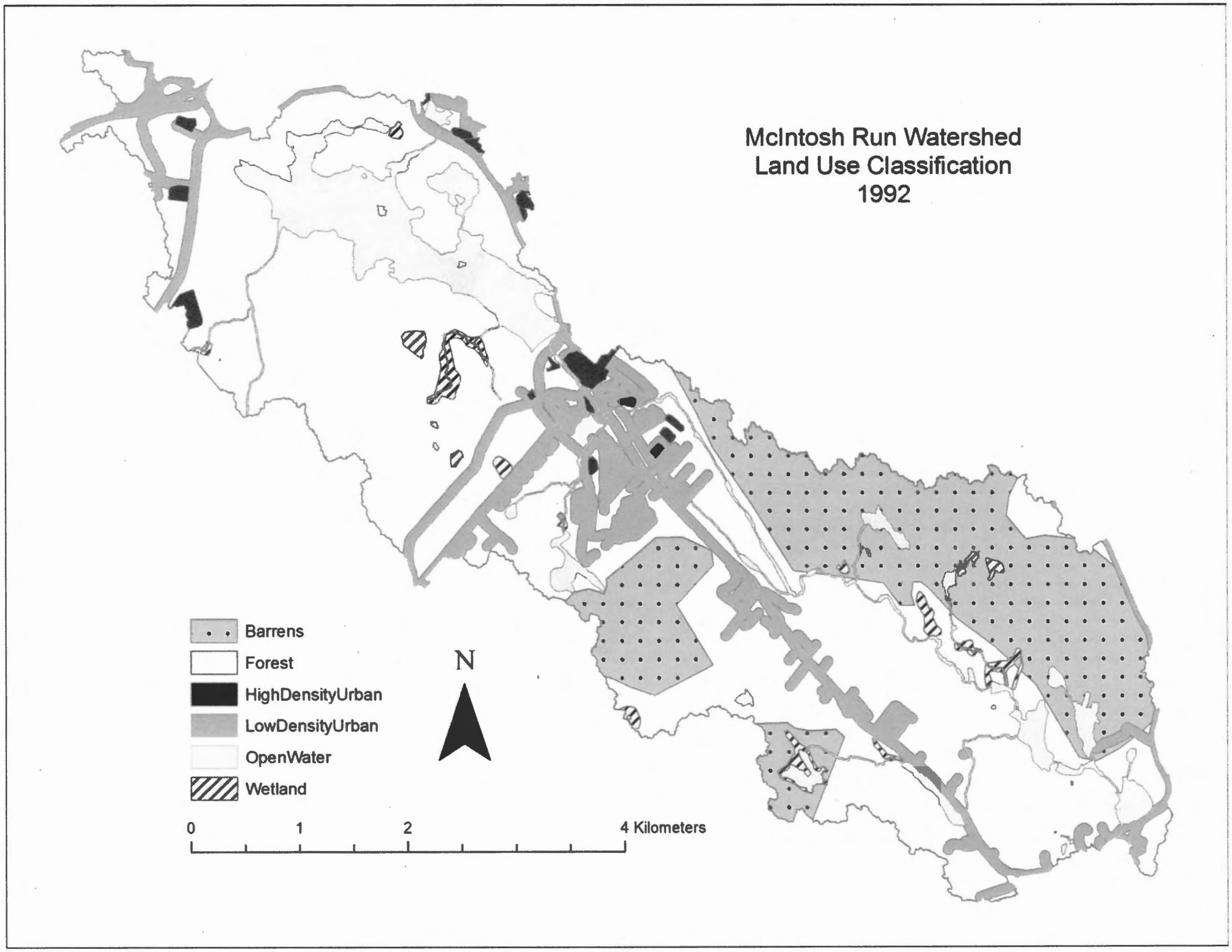

McIntosh Run Watershed
Land Use Classification
1954
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers

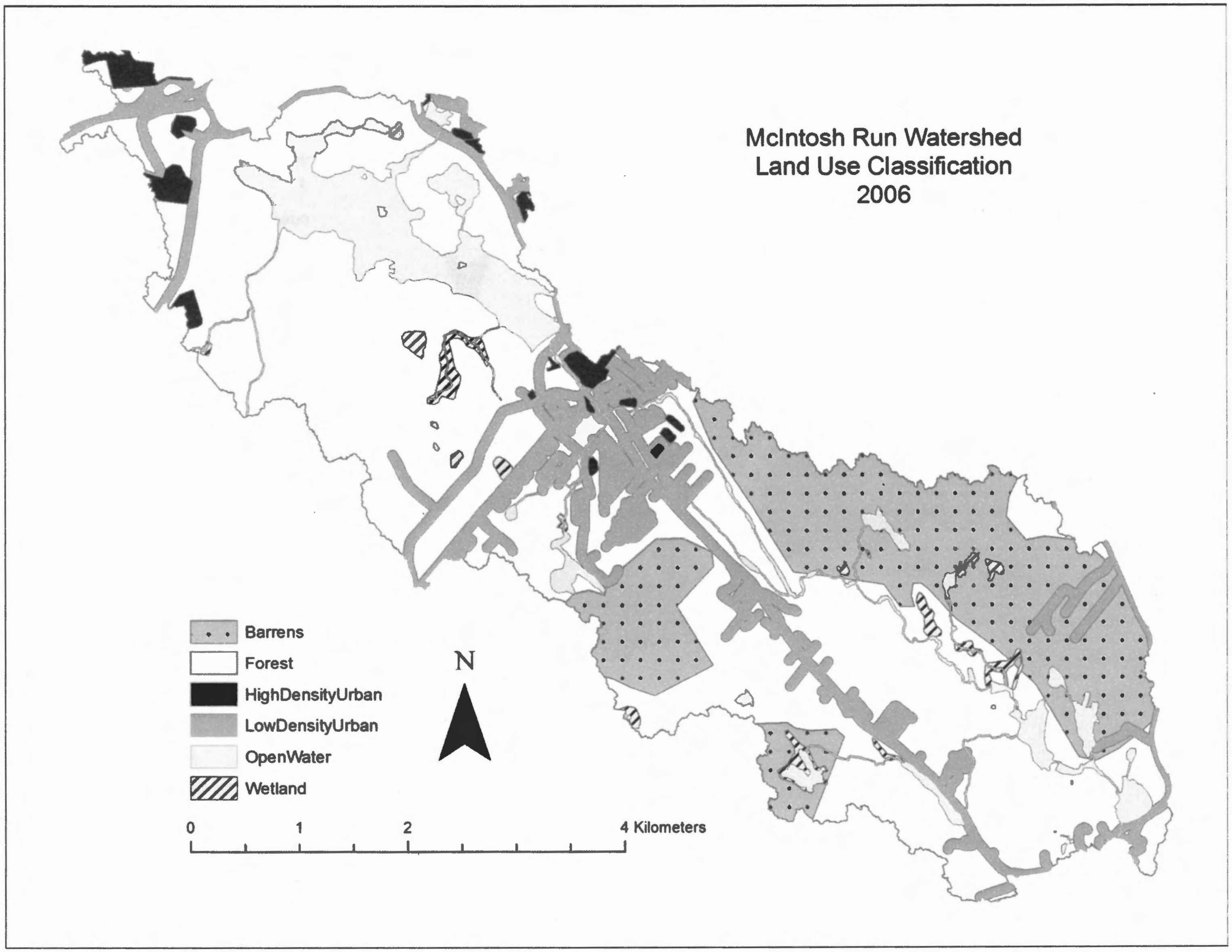
3

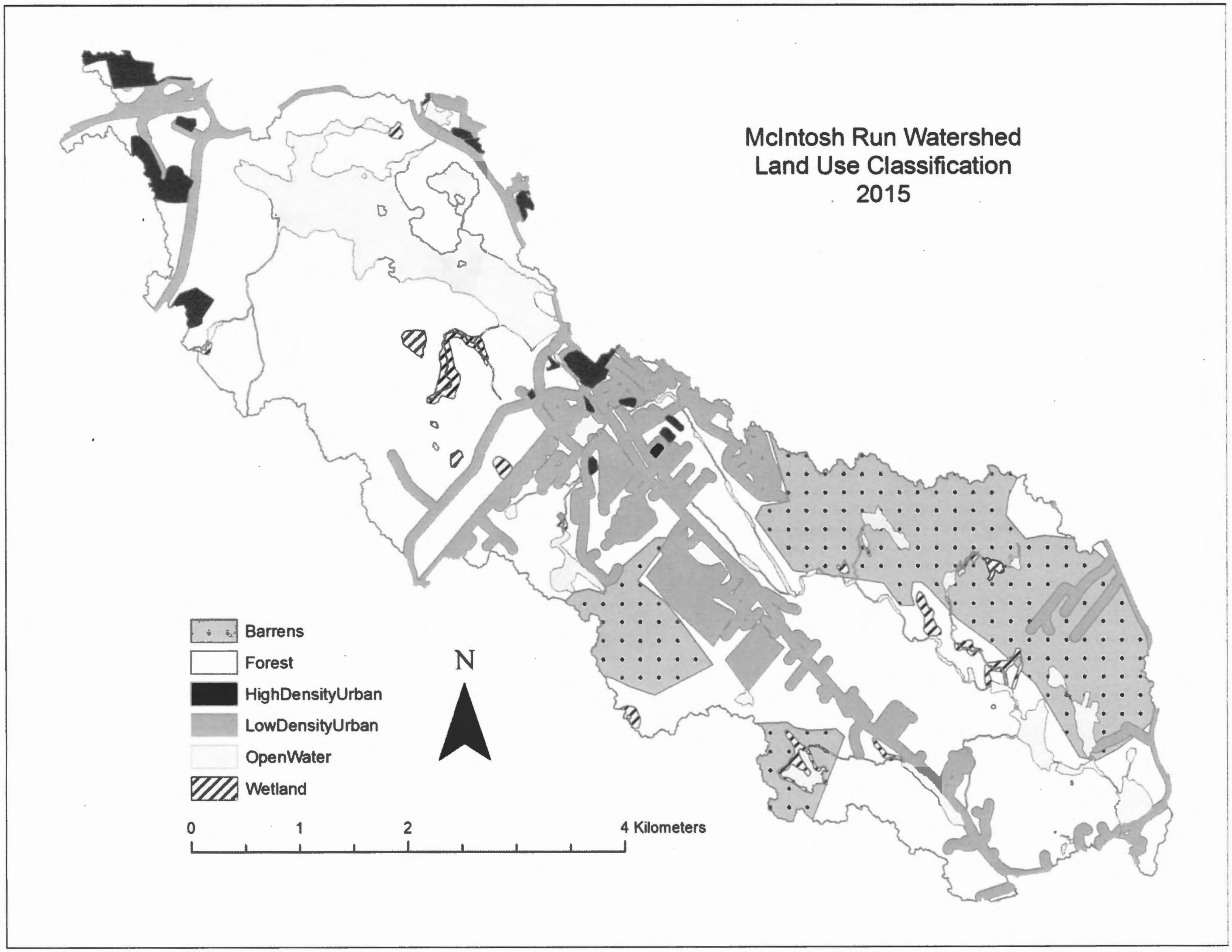

McIntosh Run Watershed
Land Use Classification
1966
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Land Use Classification
1973
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Land Use Classification
1981
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Land Use Classification
1992
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Land Use Classification
2006
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Land Use Classification
2015
Barrens
Forest
HighDensityUrban
LowDensityUrban
OpenWater
Wetland
N
0
1
2
4 Kilometers

Appendix 2: Selected Tables

2.1 - Land Use values in Hectares (Ha)

Year	OID	Type	Count_Type	Area_Ha	Year	OID	Type	Count_Type	Area_Ha
2015	0	Barrens	3	529.318263	1966	0	Barrens	3	625.789476
	1	Forest	1	1560.868194		1	Forest	1	1741.050107
	2	HighDensityUrban	17	60.695765		2	HighDensityUr	3	2.182771
	3	LowDensityUrban	1	532.440624		3	LowDensityUr	1	311.200289
	4	OpenWater	1	272.92503		4	OpenWater	1	276.774202
	5	Wetland	20	44.82727		5	Wetland	20	44.03335
2006	0	Barrens	3	598.212398	1954	0	Barrens	3	626.572918
	1	Forest	1	1598.148257		1	Forest	2	1862.002676
	2	HighDensityUrban	17	54.922548		2	HighDensityUr	2	0.685714
	3	LowDensityUrban	1	428.430228		3	LowDensityUr	1	190.62128
	4	OpenWater	1	277.328378		4	OpenWater	1	276.774202
	5	Wetland	20	44.03335		5	Wetland	20	44.373386
1992	0	Barrens	3	621.304107	1947	0	Barrens	3	606.949131
	1	Forest	2	1638.272593		1	Forest	2	1914.597665
	2	HighDensityUrban	16	31.61712		2	HighDensityUr	0	0
	3	LowDensityUrban	1	388.519633		3	LowDensityUr	1	158.909384
	4	OpenWater	1	277.328378		4	OpenWater	1	276.774202
	5	Wetland	20	44.03335		5	Wetland	20	43.799776
1981	0	Barrens	3	618.173904	1931	0	Barrens	3	624.779903
	1	Forest	2	1690.125771		1	Forest	2	1903.548307
	2	HighDensityUrban	15	29.166342		2	HighDensityUr	0	0
	3	LowDensityUrban	1	342.801632		3	LowDensityUr	1	152.171915
	4	OpenWater	1	276.774202		4	OpenWater	1	276.7947
	5	Wetland	20	44.033349		5	Wetland	20	43.735319
1973	0	Barrens	3	625.789481	1800	0	Barrens	3	629.128961
	1	Forest	2	1761.218047		1	Forest	2	2228.104979
	2	HighDensityUrban	6	9.858671		2	HighDensityUr	0	0
	3	LowDensityUrban	1	283.623687		3	LowDensityUr	0	0
	4	OpenWater	1	276.774202		4	OpenWater	1	99.391461
	5	Wetland	20	43.765994		5	Wetland	20	44.404769

Total Area of the McIntosh Run Watershed: 3001 Ha

Total land use in Ha

	1850	1931	1947	1954	1966	1973	1981	1992	2006	2015
Barrens	629.13	624.78	606.95	626.57	625.79	625.79	618.17	621.30	598.21	529.32
Forest	2228.10	1903.55	1914.60	1862.00	1741.05	1761.22	1690.13	1638.27	1598.15	1560.87
HighDensityUrban	0.00	0.00	0.00	0.69	2.18	9.86	29.17	31.62	54.92	60.70
LowDensityUrban	0.00	152.17	158.91	190.62	311.20	283.62	342.80	388.52	428.43	532.44
OpenWater	99.39	276.79	276.77	276.77	276.77	276.77	276.77	277.33	277.33	272.93
Wetland	44.40	43.74	43.80	44.37	44.03	43.77	44.03	44.03	44.03	44.83
Totals:	3001.03	3001.03	3001.03	3001.03	3001.03	3001.03	3001.08	3001.08	3001.08	3001.08

Land Class as a Percentage of the Total Watershed Area (3001 Ha)

	1850	1931	1947	1954	1966	1973	1981	1992	2006	2015
Barrens	20.96%	20.82%	20.22%	20.88%	20.85%	20.85%	20.60%	20.70%	19.93%	17.64%
Forest	74.25%	63.43%	63.80%	62.05%	58.02%	58.69%	56.32%	54.59%	53.25%	52.01%
HighDensityUrban	0.00%	0.00%	0.00%	0.02%	0.07%	0.33%	0.97%	1.05%	1.83%	2.02%
LowDensityUrban	0.00%	5.07%	5.30%	6.35%	10.37%	9.45%	11.42%	12.95%	14.28%	17.74%
OpenWater	3.31%	9.22%	9.22%	9.22%	9.22%	9.22%	9.22%	9.24%	9.24%	9.09%
Wetland	1.48%	1.46%	1.46%	1.48%	1.47%	1.46%	1.47%	1.47%	1.47%	1.49%

Land Class relative to Total area change for the entire watershed [Net difference of percentages]

	1850-1931	1931-1947	1947-1954	1954-1966	1966-1973	1973-1981	1981-1992	1992-2006	2006-2015	1850-2015	1931-2015
Barrens	-0.14%	-0.59%	0.65%	-0.03%	0.00%	-0.25%	0.10%	-0.77%	-2.30%	-3.33%	-3.18%
Forest	-10.81%	0.37%	-1.75%	-4.03%	0.67%	-2.37%	-1.73%	-1.34%	-1.24%	-22.23%	-11.42%
HighDensityUrban	0.00%	0.00%	0.02%	0.05%	0.26%	0.64%	0.08%	0.78%	0.19%	2.02%	2.02%
LowDensityUrban	5.07%	0.22%	1.06%	4.02%	-0.92%	1.97%	1.52%	1.33%	3.47%	17.74%	12.67%
OpenWater	5.91%	0.00%	0.00%	0.00%	0.00%	0.00%	0.02%	0.00%	-0.15%	5.78%	-0.13%
Wetland	-0.02%	0.00%	0.02%	-0.01%	-0.01%	0.01%	0.00%	0.00%	0.03%	0.01%	0.04%

2.2 Cont'd - Selected Land Use Classification calculations

Net change in Land Class (Ha)

	1850-1931	1931-1947	1947-1954	1954-1966	1966-1973	1973-1981	1981-1992	1992-2006	2006-2015	1850-2015	1931-2015
Barrens	-4.35	-17.83	19.62	-0.78	0.00	-7.62	3.13	-23.09	-68.89	-99.81	-95.46
Forest	-324.56	11.05	-52.59	-120.95	20.17	-71.09	-51.85	-40.12	-37.28	-667.24	-342.68
HighDensityUrban	0.00	0.00	0.69	1.50	7.68	19.31	2.45	23.31	5.77	60.70	60.70
LowDensityUrban	152.17	6.74	31.71	120.58	-27.58	59.18	45.72	39.91	104.01	532.44	380.27
OpenWater	177.40	-0.02	0.00	0.00	0.00	0.00	0.55	0.00	-4.40	173.53	-3.87
Wetland	-0.67	0.06	0.57	-0.34	-0.27	0.27	0.00	0.00	0.79	0.42	1.09

Percent change from previous year

	1850-1931	1931-1947	1947-1954	1954-1966	1966-1973	1973-1981	1981-1992	1992-2006	2006-2015	1850-2015	1931-2015
Barrens	-0.69%	-2.85%	3.23%	-0.13%	0.00%	-1.22%	0.51%	-3.72%	-11.52%	-15.86%	-15.28%
Forest	-14.57%	0.58%	-2.75%	-6.50%	1.16%	-4.04%	-3.07%	-2.45%	-2.33%	-29.95%	-18.00%
HighDensityUrban	-	-	-	218.32%	351.66%	195.84%	8.40%	73.71%	10.51%	-	-
LowDensityUrban	-	4.43%	19.96%	63.26%	-8.86%	20.86%	13.34%	10.27%	24.28%	-	249.89%
OpenWater	178.49%	-0.01%	0.00%	0.00%	0.00%	0.00%	0.20%	0.00%	-1.59%	174.60%	-1.40%
Wetland	-1.51%	0.15%	1.31%	-0.77%	-0.61%	0.61%	0.00%	0.00%	1.80%	0.95%	2.50%

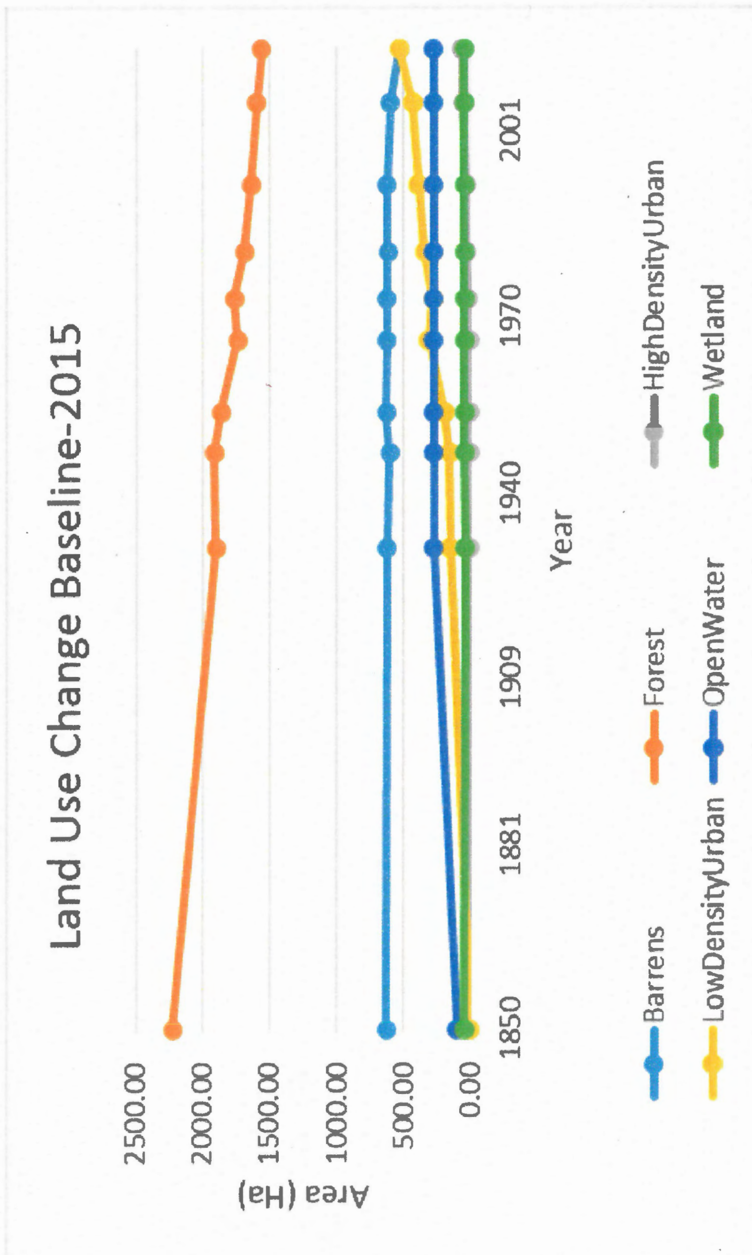
2.3 - Historical Precipitation data for Halifax.

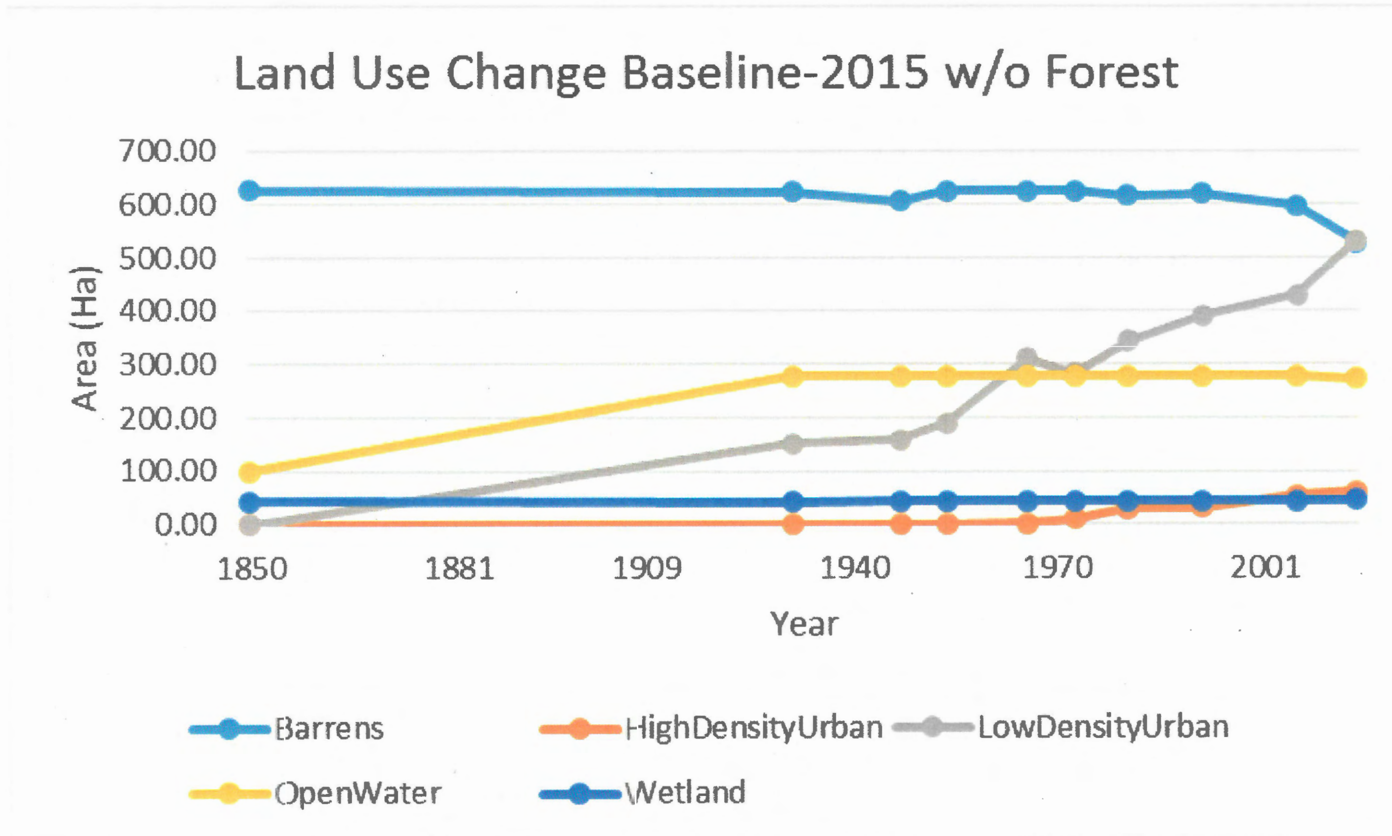
Year	Annual Precip	Mean Annual Temp	Mean Temp (Jan)	Mean Temp (June)
1960	1084.8	8.2	-3.3	15.9
1961	NODATA	7.4	-5.6	14.5
1962	1494.5	6.8	-3.6	14.2
1963	1339.4	7	-0.9	14.8
1964	1401.6	7.1	-3.1	13.4
1965	933.5	6.7	-4.8	14.8
1966	928.9	7.8	-2	14.2
1967	1588.6	7	-1.7	15.1
1968	1066.9	7.5	-5.5	14
1969	1132.7	8.3	-1.7	16
1970	1125.5	7.2	-6.7	14.6
1971	1497.6	7.5	-5.6	14.6
1972	1538.5	6.7	-3.2	13.9
1973	1220.8	7.8	-3.3	15.5
1974	1265.5	6.3	-4.7	15.1
1975	1451.2	6.7	-8.2	9.6
1976	1587	7	-4.8	16.9
1977	1574.7	7.2	-6.2	13.5
1978	1265.5	6.5	-4.1	14.3
1979	1946.7	7.4	-2.5	15.5
MEAN	**1339.2**	**7.2**	**-4.1**	**14.5**

Source: (Environment Canada, 2015)

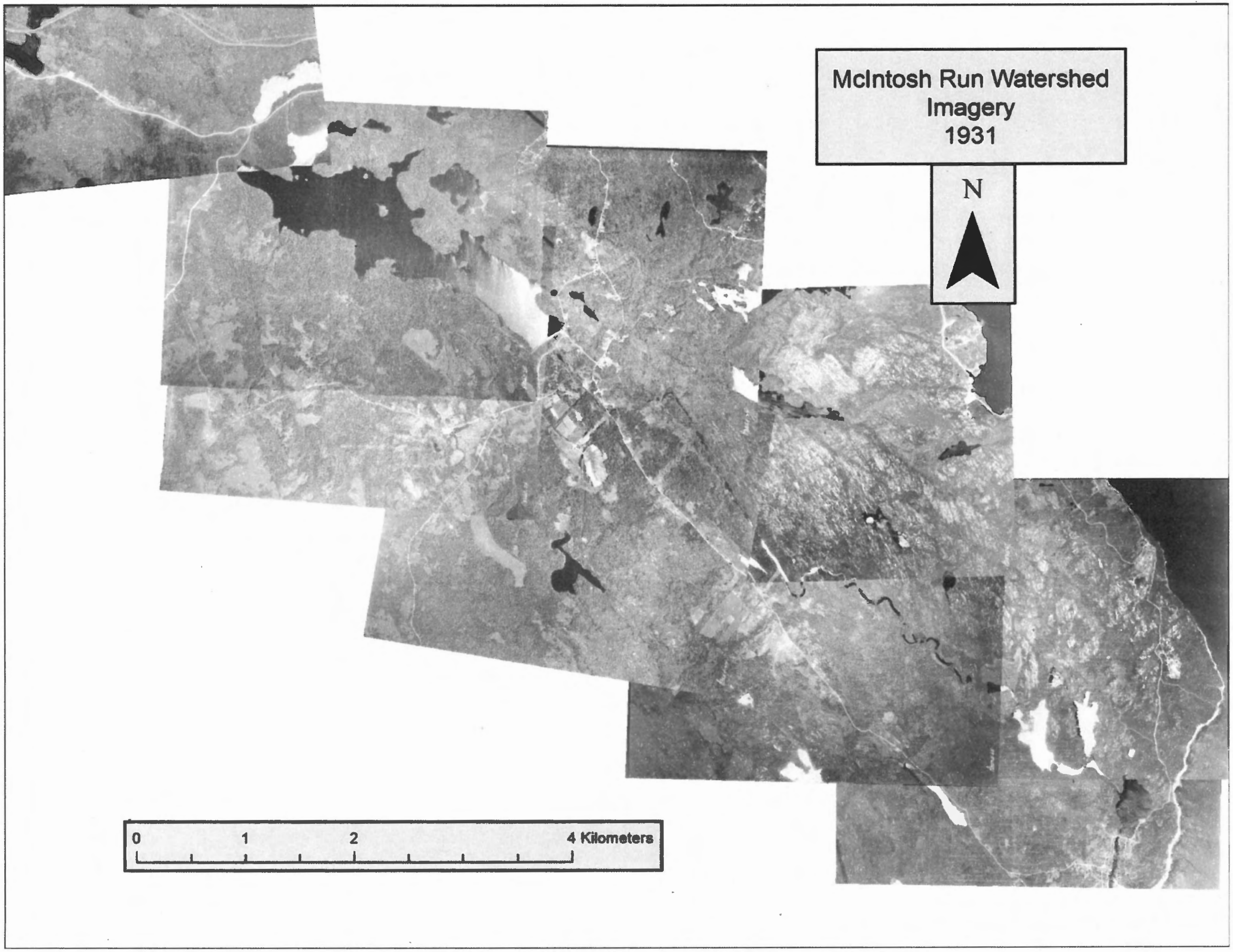
Appendix 3: Graphs

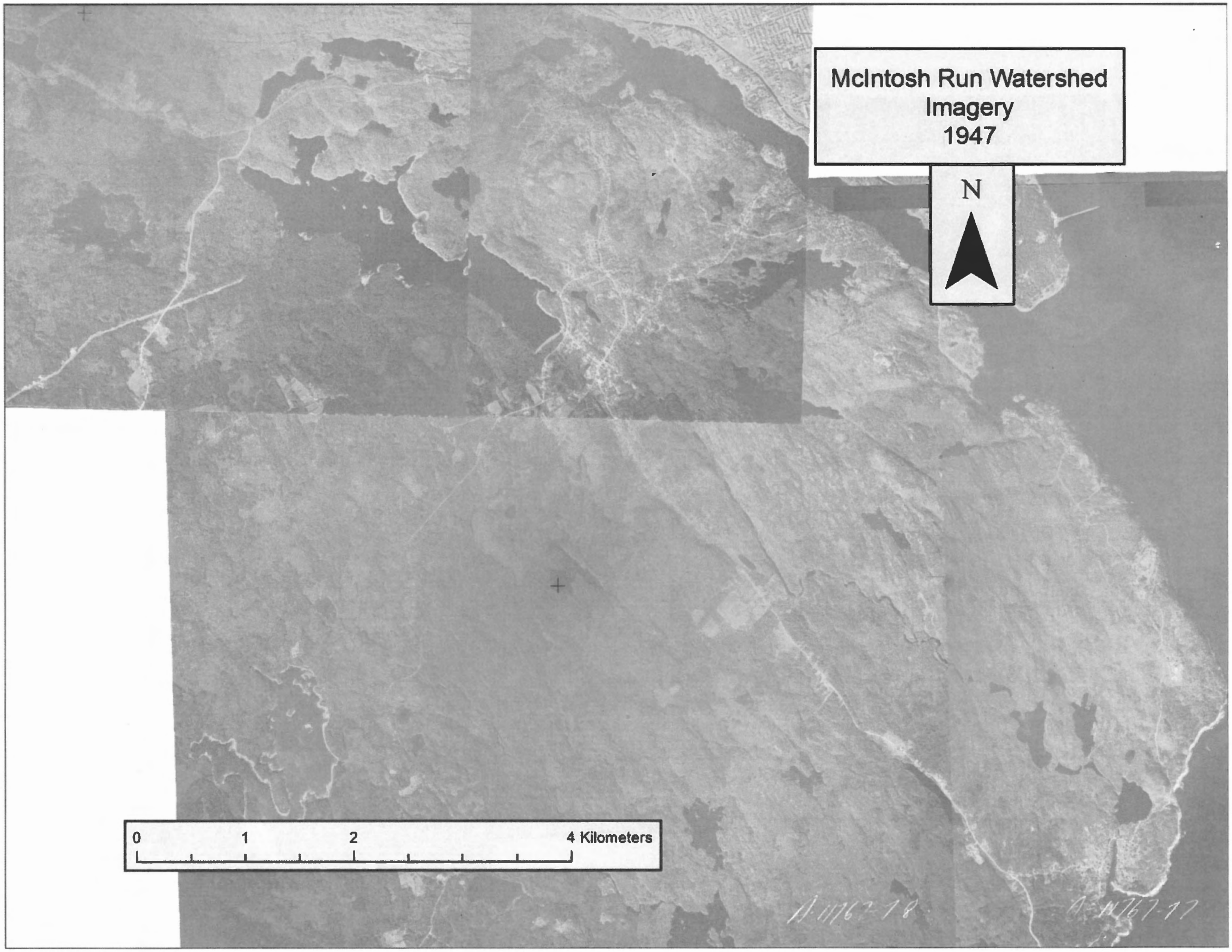
3.1 – Land use change 1800-2015

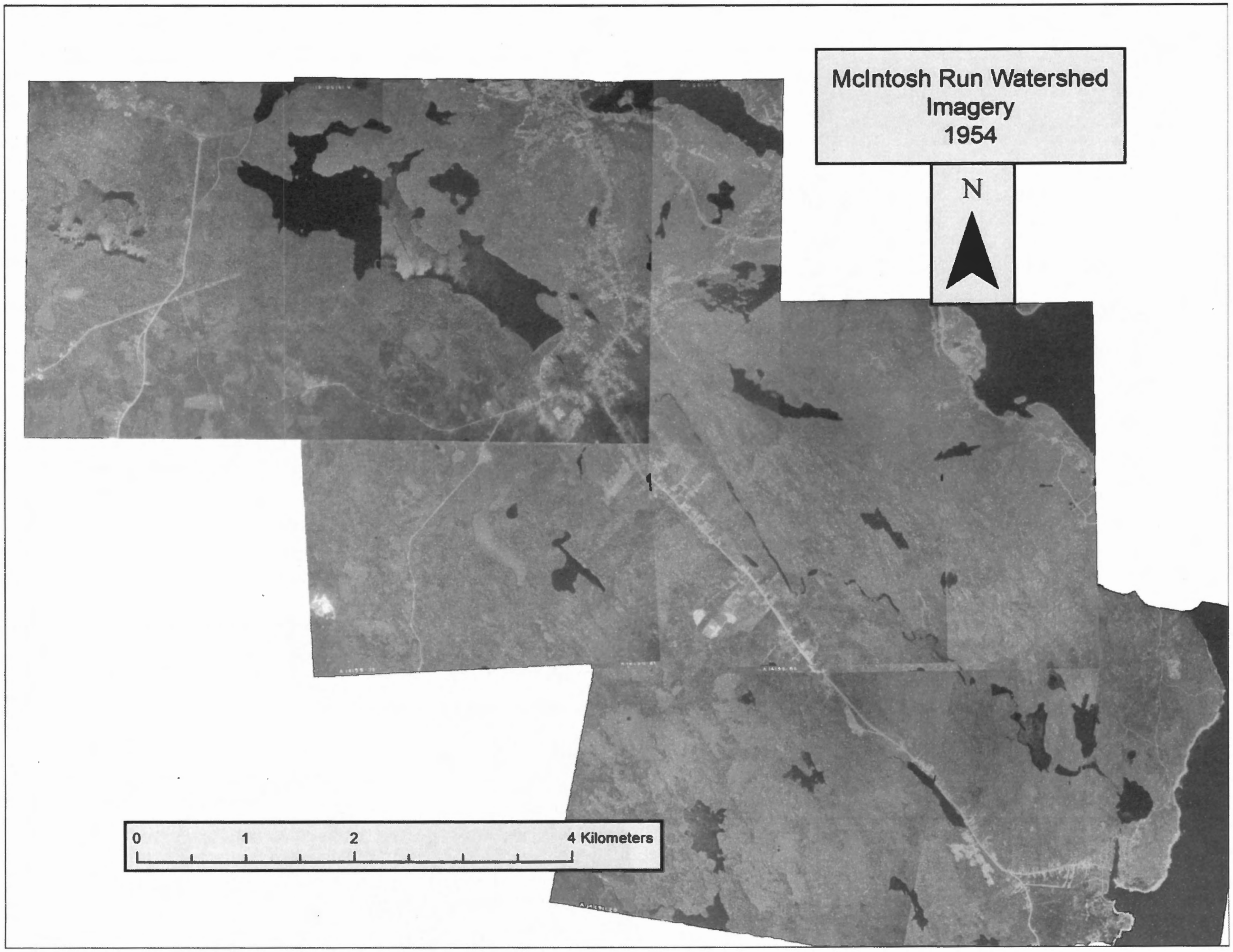


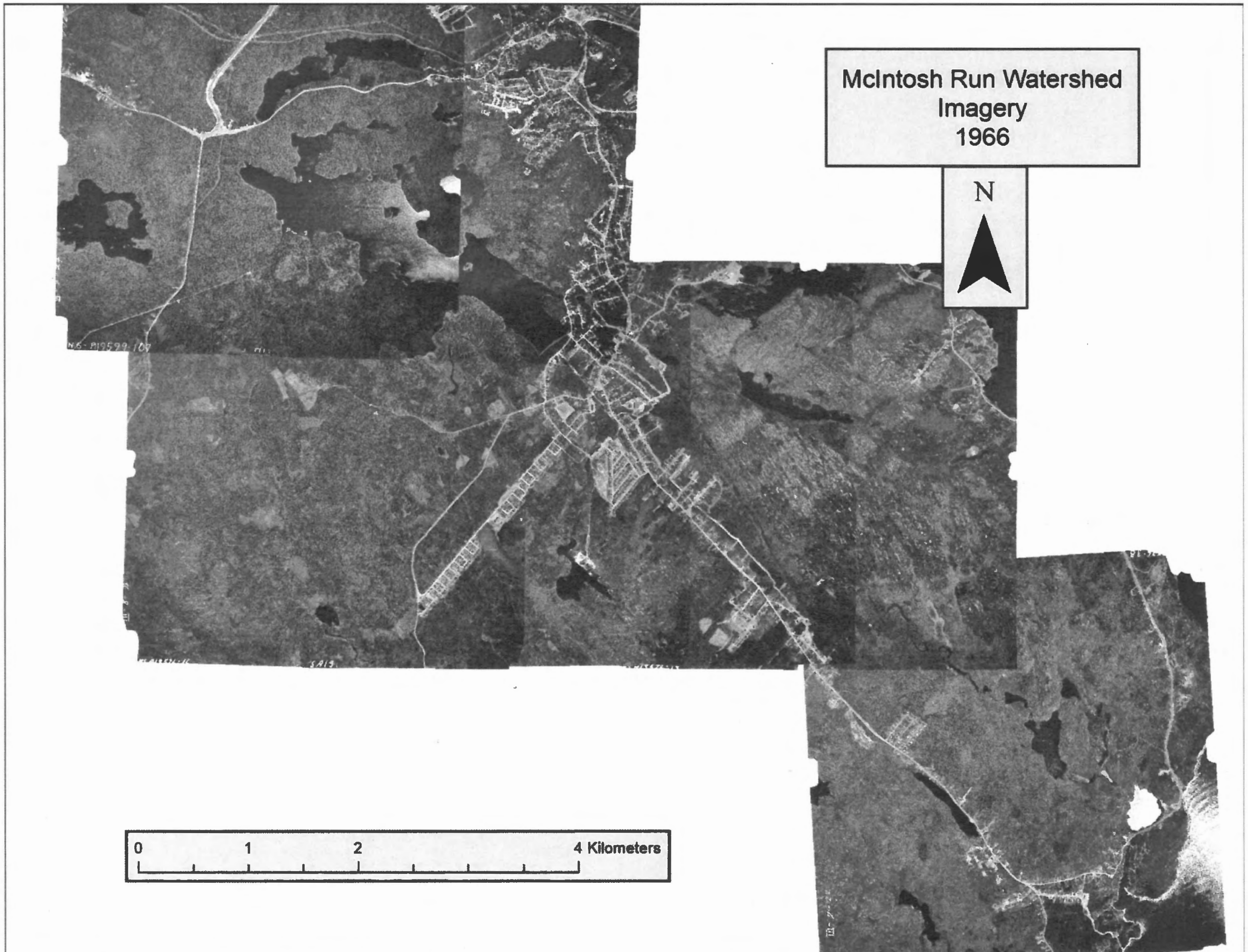


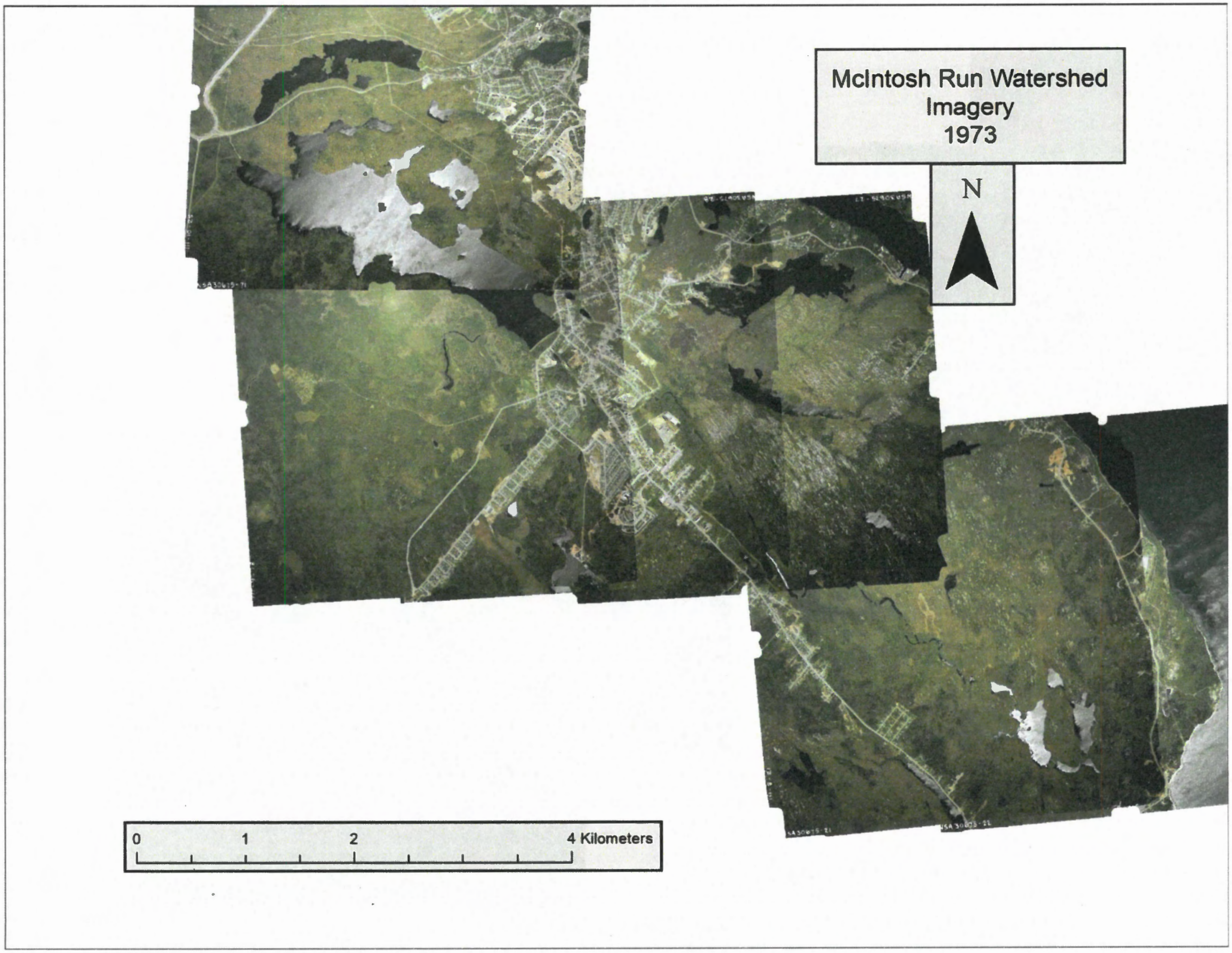
3.2 – Land Use Change 1800-2015 excluding forest area

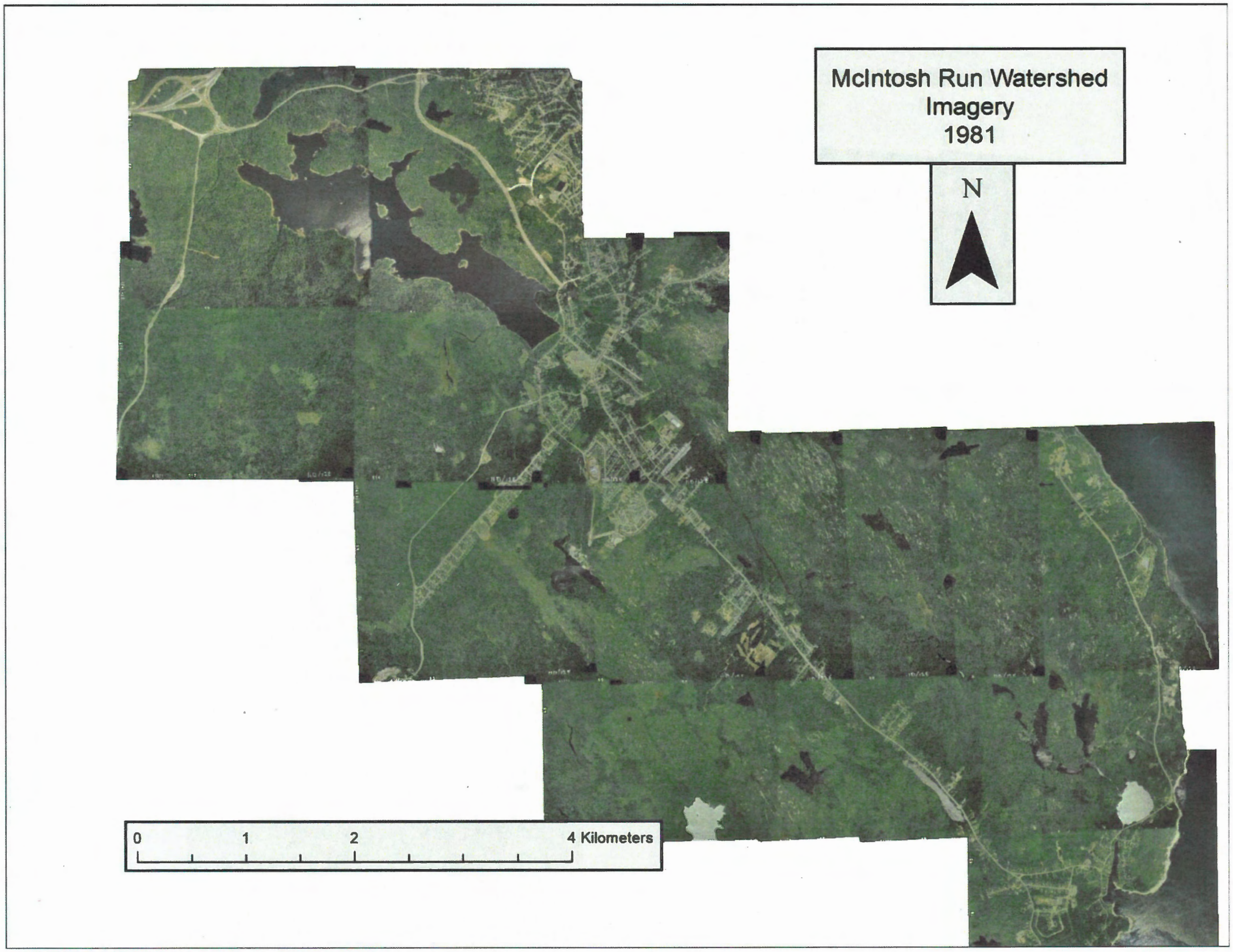

McIntosh Run Watershed
Imagery
1931
N
0
1
2
4 Kilometers

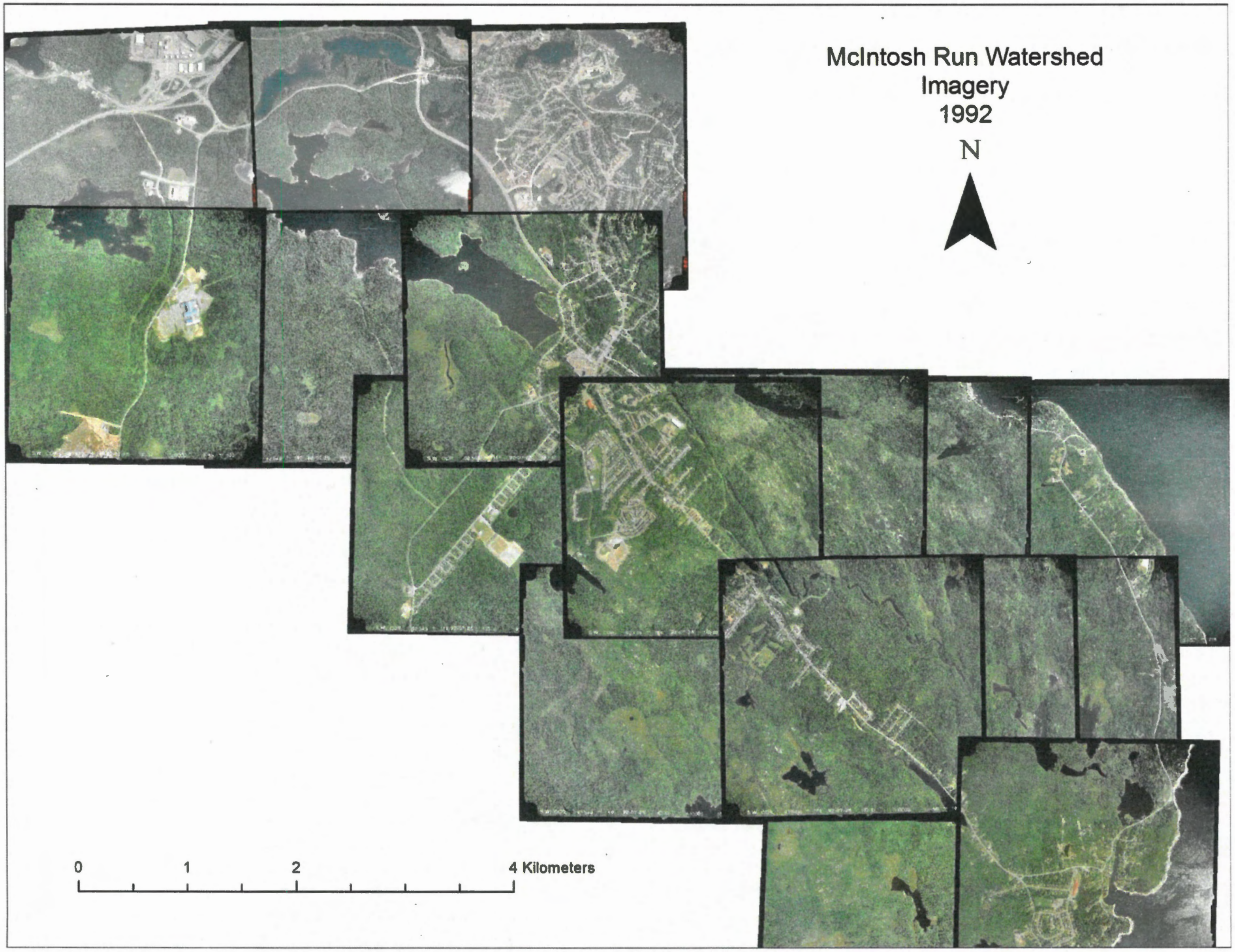

McIntosh Run Watershed
Imagery
1947
N
0
1
2
4 Kilometers

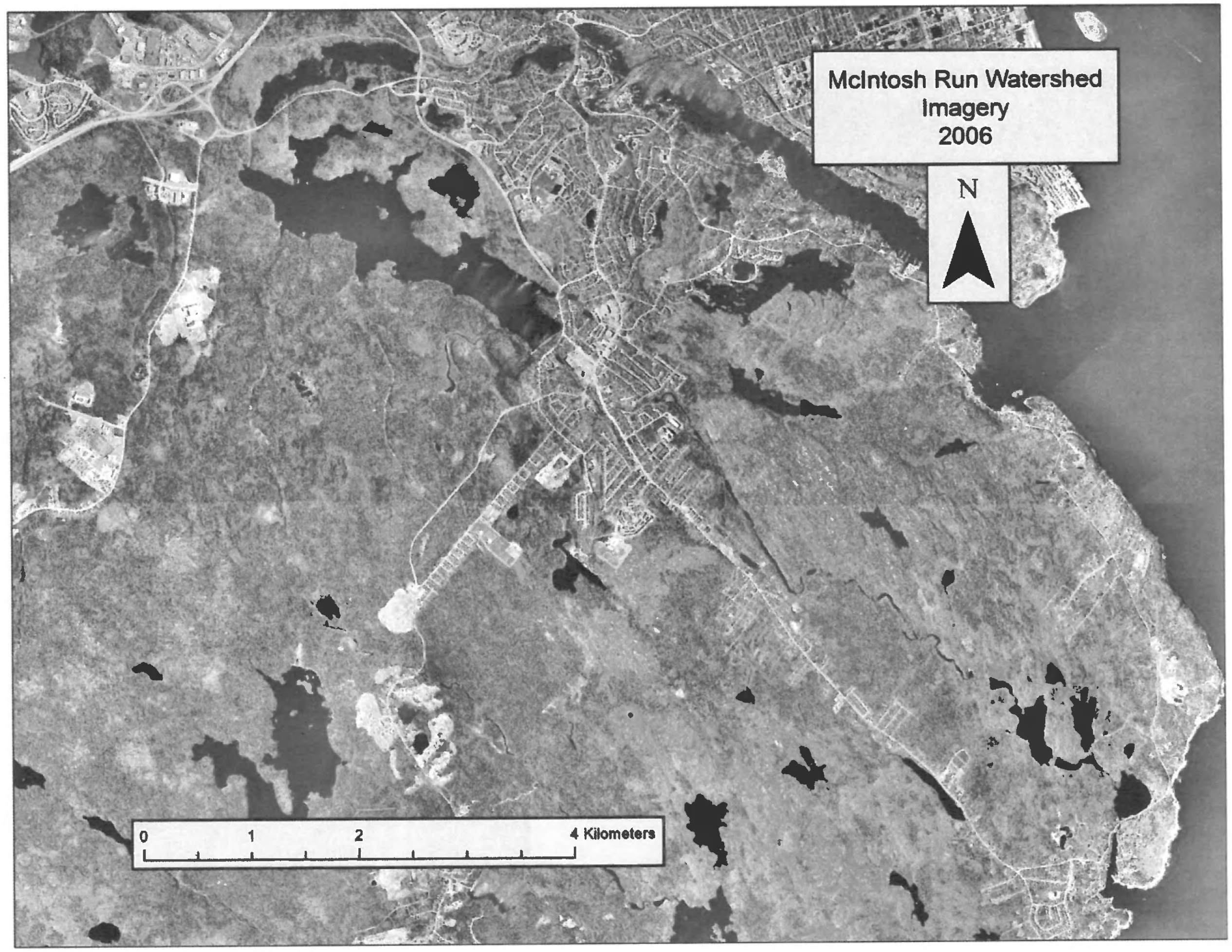

McIntosh Run Watershed
Imagery
1954
N
0
1
2
4 Kilometers

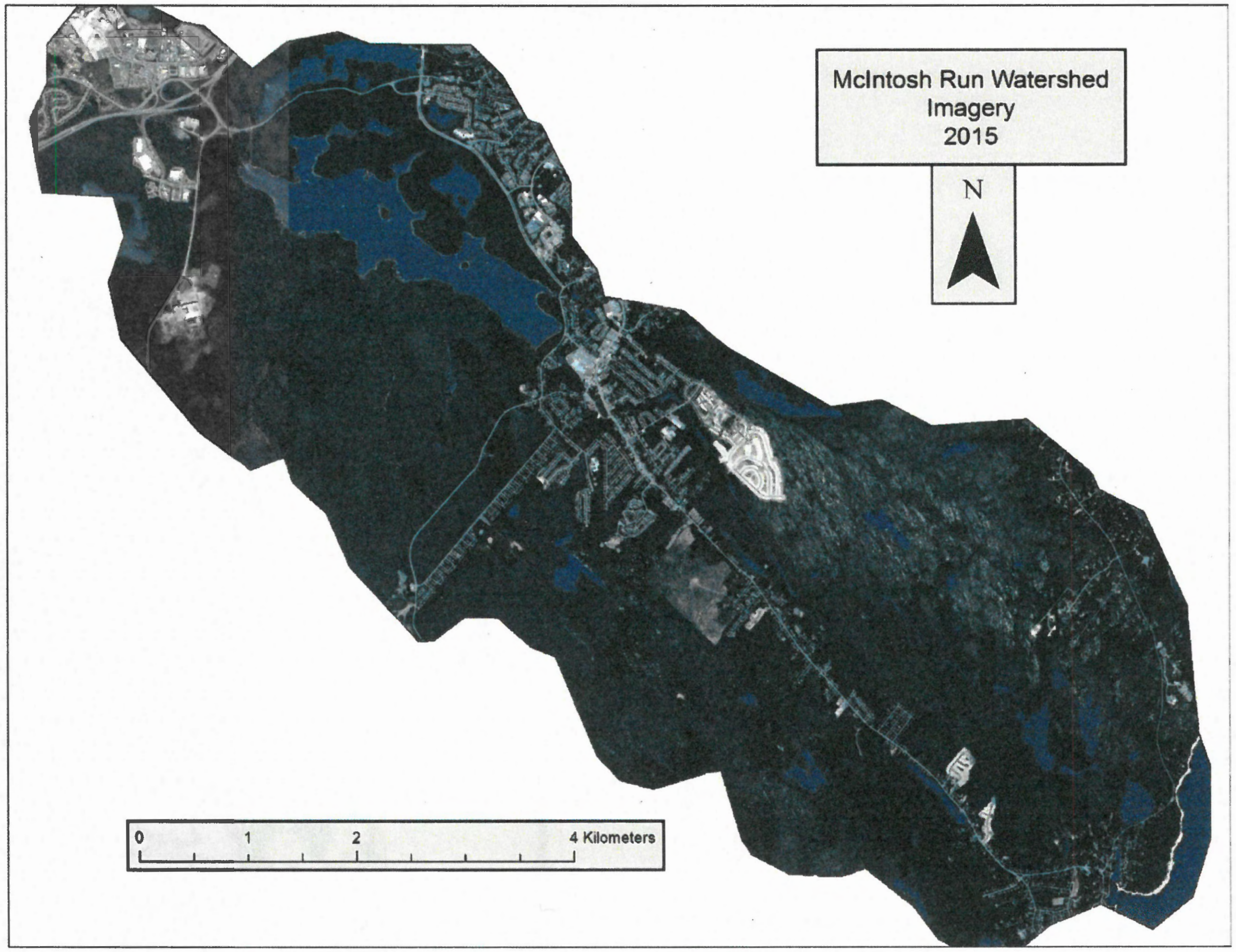

McIntosh Run Watershed
Imagery
1966
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Imagery
1973
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Imagery
1981
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Imagery
1992
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Imagery
2006
N
0
1
2
4 Kilometers


McIntosh Run Watershed
Imagery
2015
N
0
1
2
4 Kilometers

Appendix 5: Figures

4.1 - Bayers Lake Industrial proximity to the McIntosh Run Watershed
(Steeghs, Zuck, & Davis, 1994)