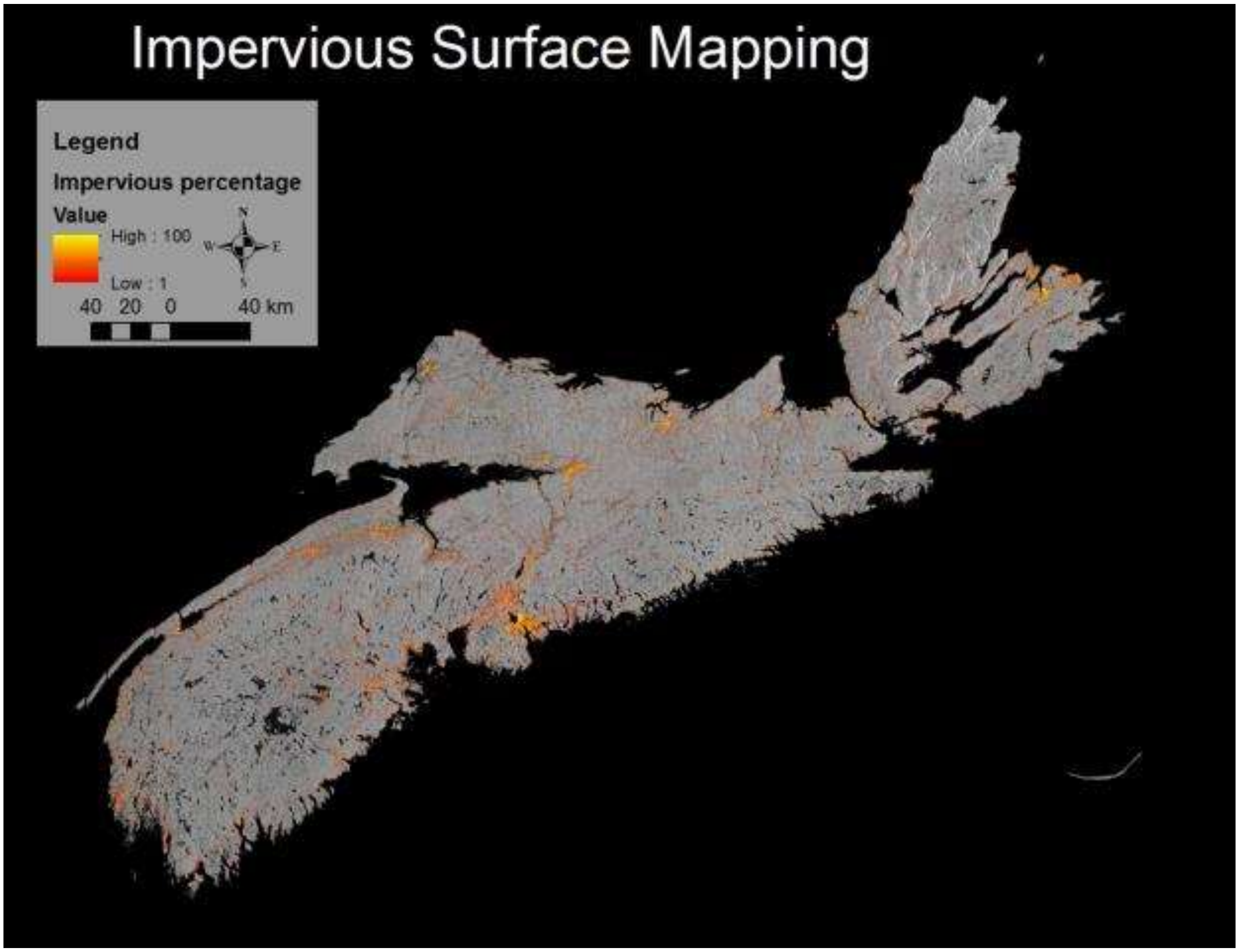
Impervious Surface Mapping for Nova Scotia



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Submitted to

Environment Canada
Dartmouth, NS
March 2014

Executive Summary

The amount of impervious surface in a given watershed affects how much precipitation will be absorbed or will runoff of the land surface because impervious surfaces prevent water from infiltrating into the ground and promote runoff. These surfaces are typically associated with developed areas and are composed of materials such as asphalt and concrete. With increased amounts of impervious surface area in a watershed, there is an increased risk of contaminants draining into rivers and coastal waters, thus degrading the ecosystem. No maps exist depicting the amount of impervious surface around the Gulf of Maine and Bay of Fundy in Nova Scotia. As part of Canada's commitment to protecting and enhancing marine habitat in the Bay of Fundy, Environment Canada commissioned this study to develop a method and map these impervious areas using satellite imagery.

We collaborated with the United States Geological Survey (USGS) to develop a method of using a combination of high resolution satellite data ca. 1-4 m and freely available Landsat imagery ca. 30 m to map impervious surfaces for the entire province of Nova Scotia with special emphasis on the watersheds surrounding the Bay of Fundy. Small representative areas (2 km X 2 km) were extracted from the high resolution imagery (Ikonos, Quickbird and World View-2 satellite data) and were classified to map the developed areas. These maps were then used to calculate the percentage of impervious area within a 30 m pixel representing the broader Landsat image resolution. The signatures of the developed areas were then applied to the entire Landsat scene to map all the developed areas and the percentage of impervious material in each pixel. This map then needed to be refined to eliminate fallow agricultural fields and forest clear cuts that may appear as developed areas on the Landsat image. Existing maps of urban areas that are mapped in the provincial forest cover GIS layer and the road network were used to develop a methodology to clean up the results of the Landsat classification of percent impervious area. The production of a map that spatially details the amount of impervious surface material for the Nova Scotia watersheds provides the basis for the assessment of the potential amount of runoff into rivers and coast waters from the uplands. This information can be used to assess the risk of contaminants effecting aquatic ecosystems and help protect critical habitat. Along with the methodology, the project also delivered a series of GIS maps that can be used as a baseline to compare to future developments to track the amount of impervious surface area. A series of layered PDF maps were also developed that allows non-GIS users the ability to toggle layers on and off when inspecting the impervious areas.

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1. Introduction

As the landscape becomes more developed and cities and towns expand, the amount of impervious surface material increases and promotes surface water to runoff rather than infiltrate into the land. These impervious surfaces are typically associated with urban developed areas and are composed of materials such as asphalt and concrete. With increased amounts of impervious surface area in a watershed, there is an increased risk of contaminants draining into rivers and coastal waters, thus degrading the ecosystems. The spatial extent and distribution of impervious surfaces impact urban climate by altering sensible and latent heat fluxes within the urban surface and boundary layers; impervious surfaces also increases the frequency and intensity of downstream runoff and decreases water quality (Yang et al. 2007). The presence of impervious surfaces have adverse impacts on local flora, faunal, avian and aquatic species affects, in addition to modifying hydrology and behavior of the watershed (e.g. more flashy discharge and flooding after precipitation events). The issues of expanding impervious surface area degrading ecosystems and habitat is not new; Oxley and Fenton (1976) tackled the issue of expanding road systems damaging nearby animal and plant populations, and the environment as a whole. Animals and plants living in previously remote spaces soon begin to feel the effects of this improved access and as a result, the amount of road kill dramatically increases (Oxley & Fenton, 1976) and may affect the conservation status of certain species. Percent impervious surface area has emerged as a key factor to explain and generally predict the degree of impact severity to streams and watersheds (Bauer et al., 2007). Yuan and Bauer (2006) documented a strong relationship between the amount of impervious surface area and land surface temperatures or the urban heat island effect. It follows that impervious surface information is fundamental for watershed planning and management and for urban planning and policy.

No maps exist depicting the amount of impervious surfaces around the Bay of Fundy or the province of Nova Scotia. As part of Canada's commitment to protecting and enhancing marine habitat in the Bay of Fundy, Environment Canada commissioned the Applied Geomatics Research Group (AGRG) at the Nova Scotia Community College (NSCC) to develop a method and map these areas using satellite imagery. The Nova Scotia Watershed Assessment Program (NSWAP) was initiated to increase our knowledge on the current state of watersheds in Nova Scotia (Garroway ret al., 2012). Leading up to the launch of the "Water For Life Water Resource Management Strategy" a knowledge gap on the pattern of watershed issues faced in the Province was identified. Several parameters were examined in the construction of a

GIS database to analyze the risk and state of the watersheds within Nova Scotia during this study (Garroway ret al., 2012). However, no information on the amount of impervious surface material was available for thier study and the results of this current project can be used for further risk assessment of watersheds.

The purpose of this study was to examine a previous project in New Brunswick in 2009 where members of the New Brunswick Community College (NBCC) worked with the United States Geological Survey (USGS) to map impervious surfaces across the Maine-NB board and the rest of NB. Unfortunately the people who worked on this project were no longer at the NBCC and a report of the methodology and project was never completed. In fact, no one was sure where the actual digital maps were located and thus made it challenging to build on their efforts. After several communications with members of NS Environment, and different government departments in NB it appeared these data and the methods used to construct them were not going to be available for this study.

As a result of this, a literature review was undertaken to assess the various methods used by other researchers to classify the degree of impervious surface area. Since the formulation by Ridd (1995) of a conceptual model of urban landscapes as a spectral mixture of vegetation, impervious surfaces and soil, a growing number of researchers have used Landsat data to map impervious surface area. Bauer et al. (2004) have shown that Landsat remote sensing has the potential for mapping and monitoring impervious surface area. Yang et al. (2003) developed an approach to quantify urban impervious surfaces as a continuous variable by using multi-sensor and multi-source datasets. Subpixel percent impervious surfaces at 30-metre resolution were mapped using a regression tree model. They used a combination of high resolution satellite data for classifying developed areas and used it for training to classify the Landsat imagery. Bauer et al. (2007) described a method where they treat the impervious areas as a continuous variable, thus the errors associated with assigning a mixed pixel to a single nominal class with a range of impervious amounts or in assigning an average impervious value to each land cover/use class were avoided. Yuan, Wu and Bauer (2008) compared spectral analysis techniques for estimating impervious surface area using Landsat. In their study they used high resolution imagery as reference for the percentage of impervious surface area within a 30 m pixel. They then used high resolution multispectral imagery for classification of developed areas and training for the Landsat imagery. They compared regression the modelling approach used by Bauer et al. (2004, 2007), a regression tree approach used by Yang et al. (2003), and the normalized spectral mixture analysis used by Yuan and Bauer (2007). They also developed scatter plots of percentage of impervious area (% ISA) and the tasseled cap greenness index and showed a correlation of 0.91. The regression tree model has been adopted by the USGS as part of their National Land Cover Data classification. Homer et al. (2007) described the various products that are generated from remotely sensed data including %ISA. They utilize a commercial regression tree software package known as Cubist (http://caret.r-forge.r-project.org/Model_Tree.html) and describe their methods in broad terms. Estimates for imperviousness were created on all pixels, with a subsequent masking strategy employed to reduce errors of commission on estimate areas with spectrally similar features difficult to discriminate accurately (e.g. bare agriculture fields for imperviousness). Imperviousness masks were produced by combining GIS layers of road density buffers, city lights, spectral classifications, and image segmentation-based classifications. Completed masks were hand-edited to ensure an accurate inclusion of urban areas.

With Yuan, Wu and Bauer (2008) demonstrating that the greenness index is highly correlated to the amount of impervious surface material in a Landsat pixel, we decided to further explore this approach in this study. Another method to assess the greenness or amount of healthy vegetation from remotely sensed data is to calculate the Normalized Difference Vegetation Index (NDVI) which involves the ratio of the difference over the sum of the Landsat TM red and near-infrared bands. Most of the studies of mapping %ISA dealt with the problem of calculating a percentage of impervious area within the 30 m by 30 m Landsat pixel. They all made use of high resolution satellite data to first classify developed areas, or 100 percent impervious surfaces, and then used different approaches to scale and translate this information to the coarser Landsat imagery using a variety of methods. As a result, we began to compile various high resolution (HR) multispectral images that had been previously purchased for other studies throughout the province by AGRG-NSCC. These data included imagery from the Ikonos, Quick Bird and most recent World View-2 satellites. Experiments were carried out where the HR imagery was classified as developed and compared through regression analysis to the greenness index and the NDVI data derived from the Landsat imagery. A higher inverse correlation was observed between the %ISA and NDVI than between the %ISA and greenness index.

During this phase of literature review and methodology development, we continued to attempt to track down the previous NB GIS data on %ISA and the appropriate contacts at the USGS. Mr. Reid McLean of NB Department of Local Government was contacted and recently provided the final GIS layer that was developed for %ISA for NB. This layer was examined and modified (cleaned and reclassified) to represent a map that had been provided as a PDF file at the onset of our study. These NB %ISA GIS layers are included in the deliverables of this project. Various communications with different members of the USGS where explored until finally the person who was involved in the collaboration with NBCC was tracked down and contacted. Mr. Jon Dewitz, a National Land Cover Data (NLCD) Quality Supervisor with the USGS Earth Resources Observation and Science Center (EROS), Sioux Falls, South Dakota, provided researchers at AGRG with a webinar where he outlined the methodology that the USGS uses and provided us with the NLCD add on tool to Erdas (MDA, 2012). The same methodology apparently was presented to the staff of NBCC. A combination of utilizing the Erdas IMAGINE image analysis system (ver 2011) and the Cubist regression tree software (free source code download, http://rulequest.com/cubist-info.html) were utilized for the project. A similar methodology as described by Homer et al. (2007) was developed for this project, although after the classification of the Landsat imagery, there is a significant amount of refinement and cleaning to remove erroneous features such as bare soil agriculture land and clear cuts that are not part of the developed impervious outputs of the USGS. The methods developed for the refinement and cleaning are specific to this project and are dependent on what type of ancillary GIS data are available and the results of the initial %ISA classification process.

1.1. Study Area

Given the delays in establishing the contract, the project deliverables were scaled back to include impervious surface mapping only for the Nova Scotia watersheds that drain into the Bay of Fundy and if possible to finish the NB project. Since it took so long to actually acquire the NB data, this component of the project was not accomplished. However, after we finally did make contact with Mr. Dewitz of the USGS and understood the methodology the USGS employs, we began work on the Nova Scotia study area. In preparation for the project, several Landsat satellite images for the province were downloaded, inspected and available for use. The NB project made use of Landsat imagery from 2005 and that was the year of imagery requested for this study to ensure consistency of a measure of the amount of impervious surface area around the Bay. Landsat Thematic Mapper (TM), Landsat Enhanced Thematic Mapper Plus (ETM+) and Landsat 8 imagery for the study area were obtained from the United States Geological Survey (USGS) Earth Explorer website (http://earthexplorer.usgs.gov/). A suite of Landsat images were downloaded and examined for quality, which consisted of evaluating them for cloud, haze and seasonal effects (Figure 1-1).

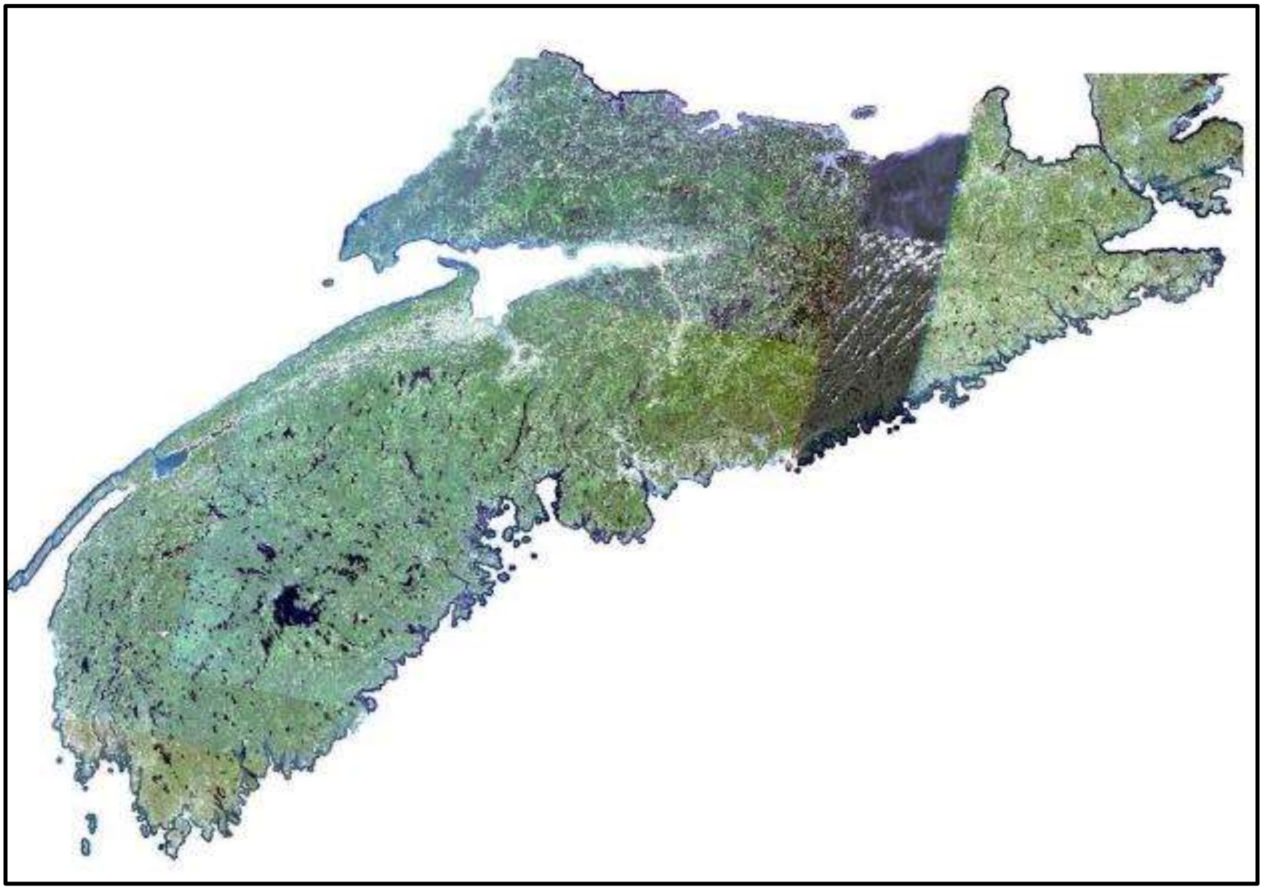

Figure 1-1 Multiple scenes of Landsat imagery for mainland Nova Scotia from 2005. Images were selected with the least amount of cloud cover.

As can be seen from figure 1.1 some of the imagery still contains cloud cover in central Nova Scotia. Although the deliverables for this project were for impervious surface mapping for the watersheds surrounding the Bay of Fundy for Nova Scotia, a complete analysis for the entire province was requested and agreed upon if time permitted. As a result, imagery was downloaded for Cape Breton Island in anticipation of completing the analysis for the entire province (Figure 1-2).

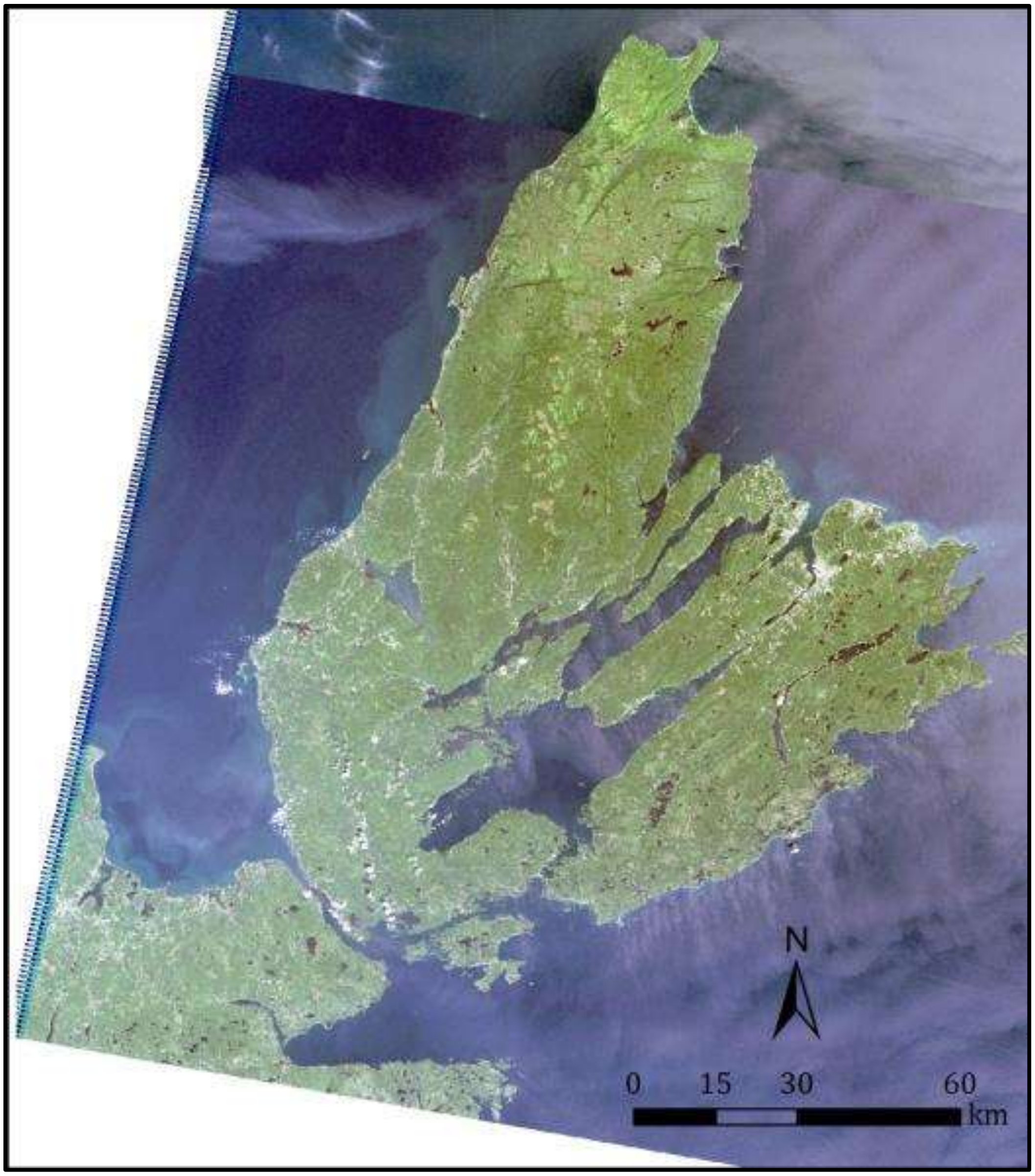

Figure 1-2 Two Landsat scenes were selected for use in Cape Breton Island for the impervious surface classification. The northern tip of the island is from 2005 and the main section of the island is from 2007.

When utilizing Landsat imagery to classify impervious surfaces, clouds and their associated shadows cause a problem for the classification algorithms and thus scenes were selected to attempt to avoid these conditions. Landsat scenes from 2006 and 2007 had to be selected for use in the central part of the province and most of Cape Breton (Figure 1-3). The months when the images were acquired consisted mostly of July and August with the area around Antigonish requiring a September scene (Figure 1-3). In total eight scenes were used in the classification process.

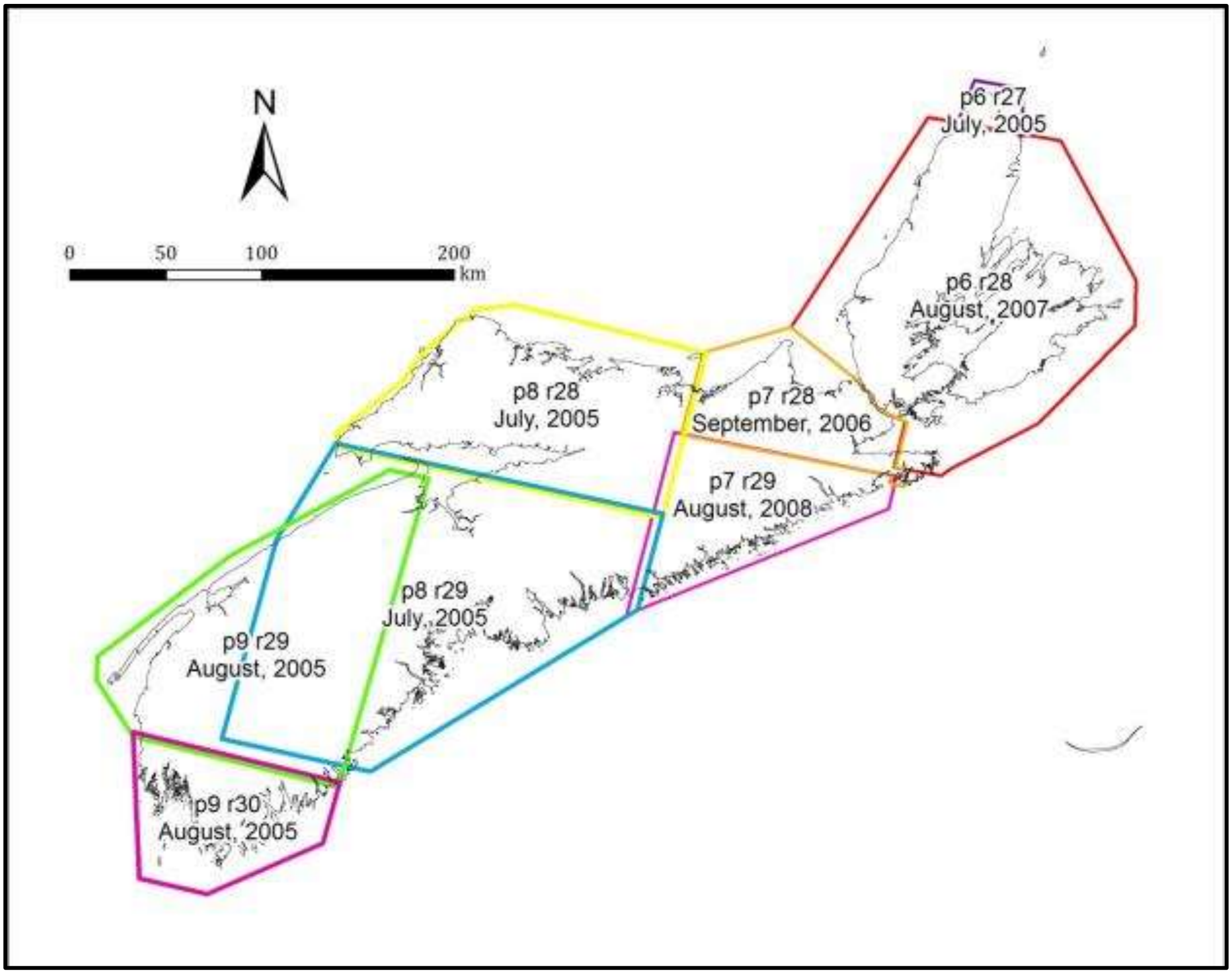

Figure 1-3 Map depicting the dates of the Landsat scenes that were used for the impervious surface classification mapping.

2. Methods

2.1. High level overview of the process

A high level overview of the process used in this project is as follows:

1) Classify the high resolution imagery (1 m or 4) into developed or not, 1 bit binary output.
2) Use a 29x29 pixel at 1 m focal sum window to count the number of pixels of the developed class.
3) This produces a raster image of the count of developed cells per 29x29 pixel window.
4) This image (step 3) gets resampled to a 30 m pixel to be used with the Landsat data (cubic convolution resampling).
5) This image (step 4) is used as the training area along with Landsat bands (2,3,4,5 – visible, near-infrared and mid-infrared) to be passed to the Cubist software for the regression tree analysis.
6) Cubist determines the rules that best describe the impervious percentages from the training data and Landsat bands.
7) These rules are translated from Cubist into Erdas IMAGINE to be used for classifying the entire Landsat scene.
8) This process (step 7) results in a classification 0-100% of impervious surface areas (may require scaling of individual scenes).
9) The classification is inspected and modified (remove agricultural land, clear cuts (bare soil) etc. that have a similar spectral signature as developed areas in the Landsat data).
10) Final classification is a map of the percent (1-100%) for the study area.

2.2. High resolution imagery for classifying developed areas and training

The methodology to utilize 30 m Landsat imagery into percent impervious surface area (%ISA) requires detailed mapping at the 1-4 m resolution of developed areas where materials such as asphalt and concrete are delineated. No current GIS database exists that has that level of detail. As a result, high resolution (HR) satellite or airborne imagery is required to generate these maps. Ideally the imagery consists of multispectral information to improve the classification process of developed areas. Although Landsat imagery is freely available for download, HR imagery is only available commercially and typically costs ca. $25 per sqkm. Fortunately, AGRG has acquired a variety of HR images over the years as part of their research program and these data were utilized to aid in mapping the developed areas. Table 2-1 summarizes the Landsat scenes and dates and locations and dates of HR imagery used for training areas.

Table 2-1 List of Landsat scenes used and the dates and location of HR imagery and training areas.

Path	**Row**	**Landsat ID**	**Landsat Imagery Date**	**Training Data Date**	**Training Area**
6	27	LT50060272005202GNC	7/21/2005	2014	Sydney
6	28	LT50060282007224GNC	8/12/2007	2014	Sydney
7	28	LT50070282006260GNC	9/17/2006	2014	Antigonish
7	29	LT50070292008234GNC	8/21/2008	May, 2008	Halifax
8	28	L5008028_0282005070	7/3/2005	Aug, 2008	Amherst
8	29	L5008029_0292005070	7/3/2005	May, 2008	Halifax
9	29	L5009029_0292005082	8/27/2005	Oct, 2006	Middleton
9	30	L5009030_0302005082	8/27/2005	Oct, 2012	Wedgeport

2.3. Example of the process of classifying %ISA and refinement

To demonstrate how the process works, an example of datasets used have been extracted for the Amherst area at the head of the Bay of Fundy. Landsat scenes are divided into path and rows, where each scene is approximately 185km x 185km. The Landsat scene, path 8 row 28, covering the upper Bay of Fundy including Amherst was acquired July 3, 2005 (Figure 2-1).

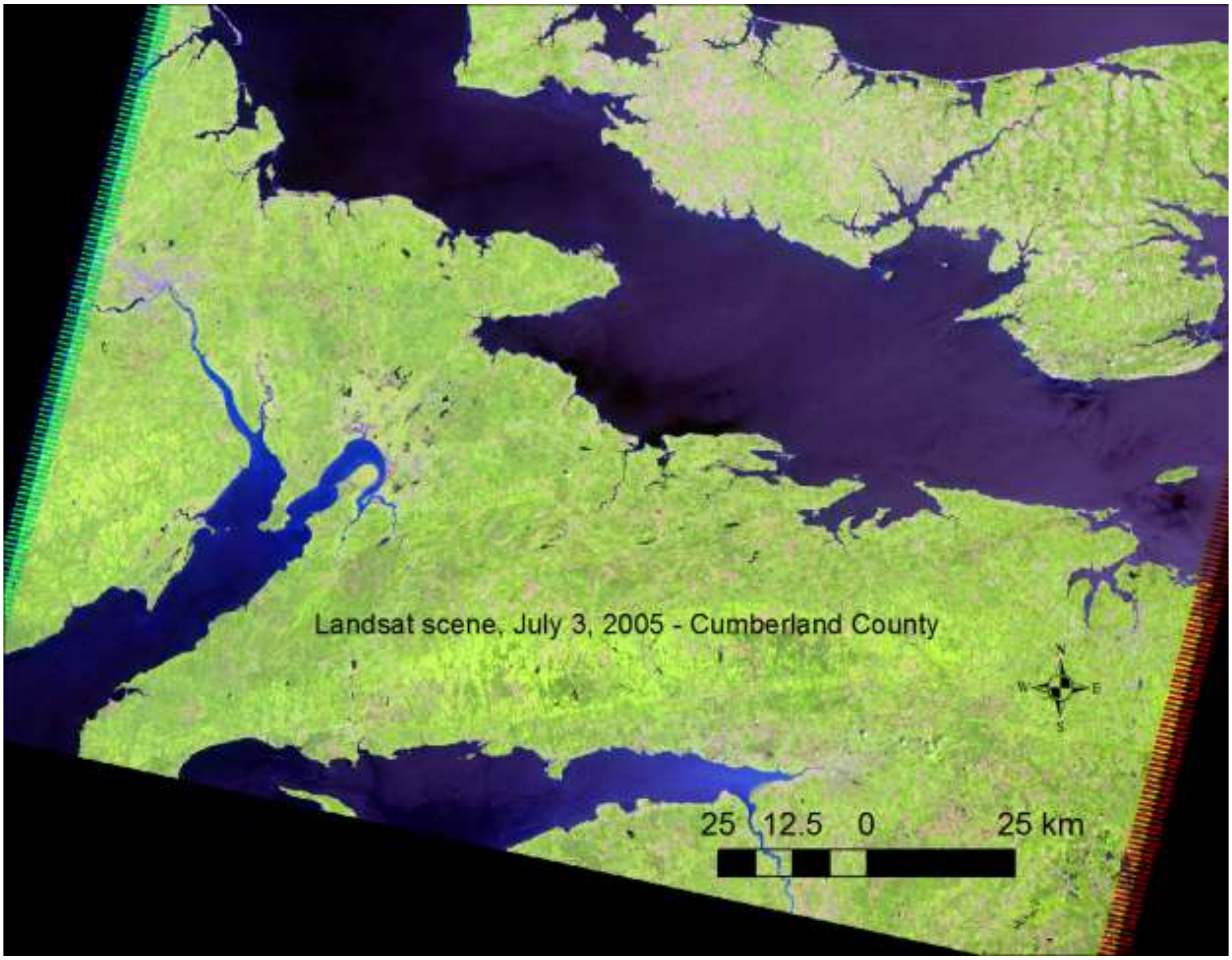

Figure 2-1 Landsat scene of northeast (Cumberland County, plus others) Nova Scotia. Amherst is located at the head of the upper Bay of Fundy Map.

A close up of Amherst in the Landsat scene reveals how the urban developed area is fuzzy and not well defined as a result of the 30 m pixel resolution (Figure 2-2).

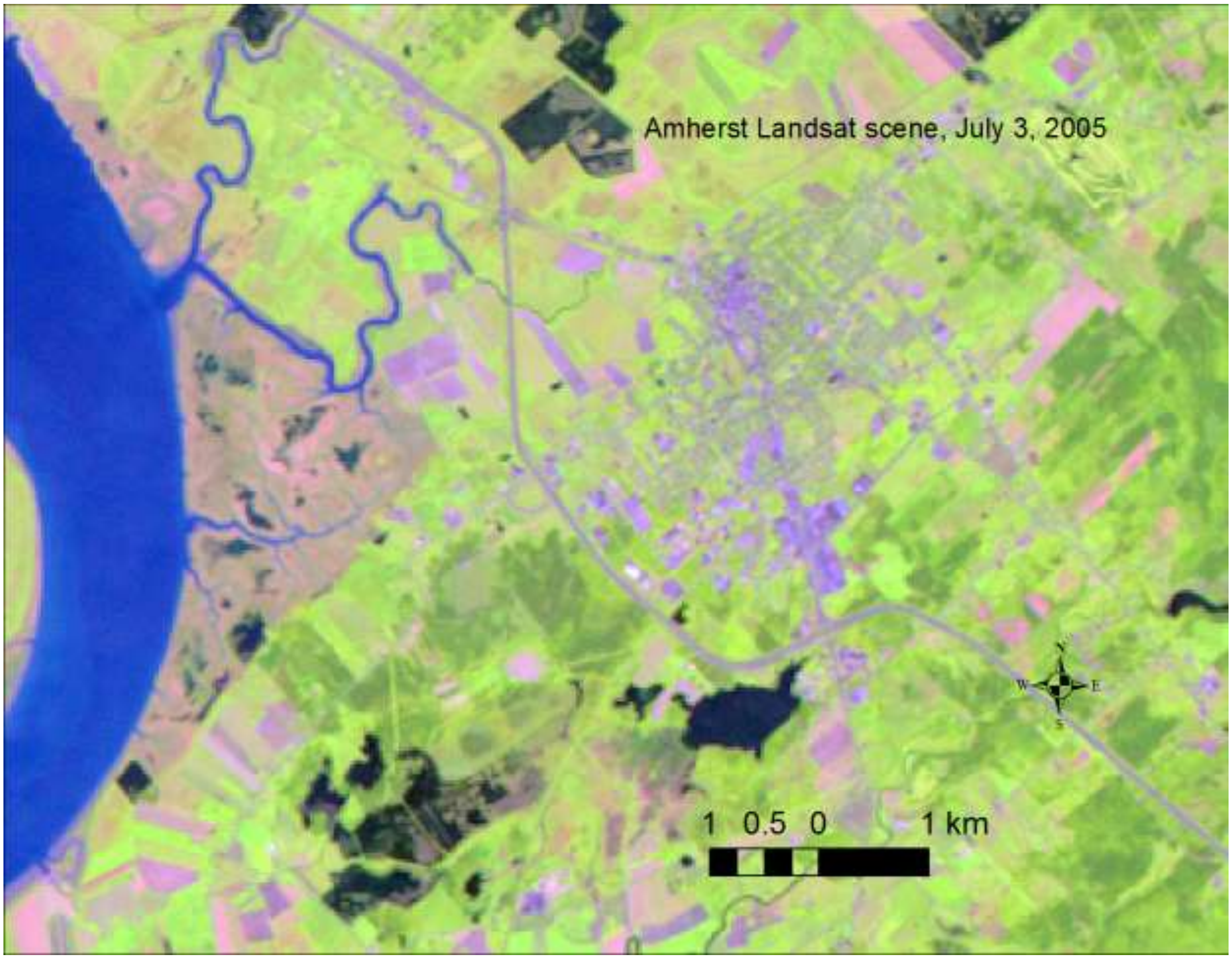

Figure 2-2 Close up of the Amherst area in the Landsat scene false colour composite. Highway 104 is visible on the true colour composite image. The town of Amherst appears in a blue hue similar to agricultural fields with bare soil. Areas of salt marsh, cleared areas (agriculture or clear cuts) appear as pink and fresh water bodies are black.

The detail of the Quickbird HR satellite image is demonstrated as compared to the Landsat image (Figure 2-3). The Quickbird HR image was acquired on August 21, 2008 and provided a much higher resolution to differentiate the developed areas around Amherst. Examining the areas at an ever larger scale (closer view) shows that the HR image provides the detail of the most developed downtown section of Amherst as compared to the suburbs surrounding it (Figure 2-4). It is this variation in the amount of impervious surface that is the challenge to map with the coarser resolution Landsat and requires the input of the HR imagery.

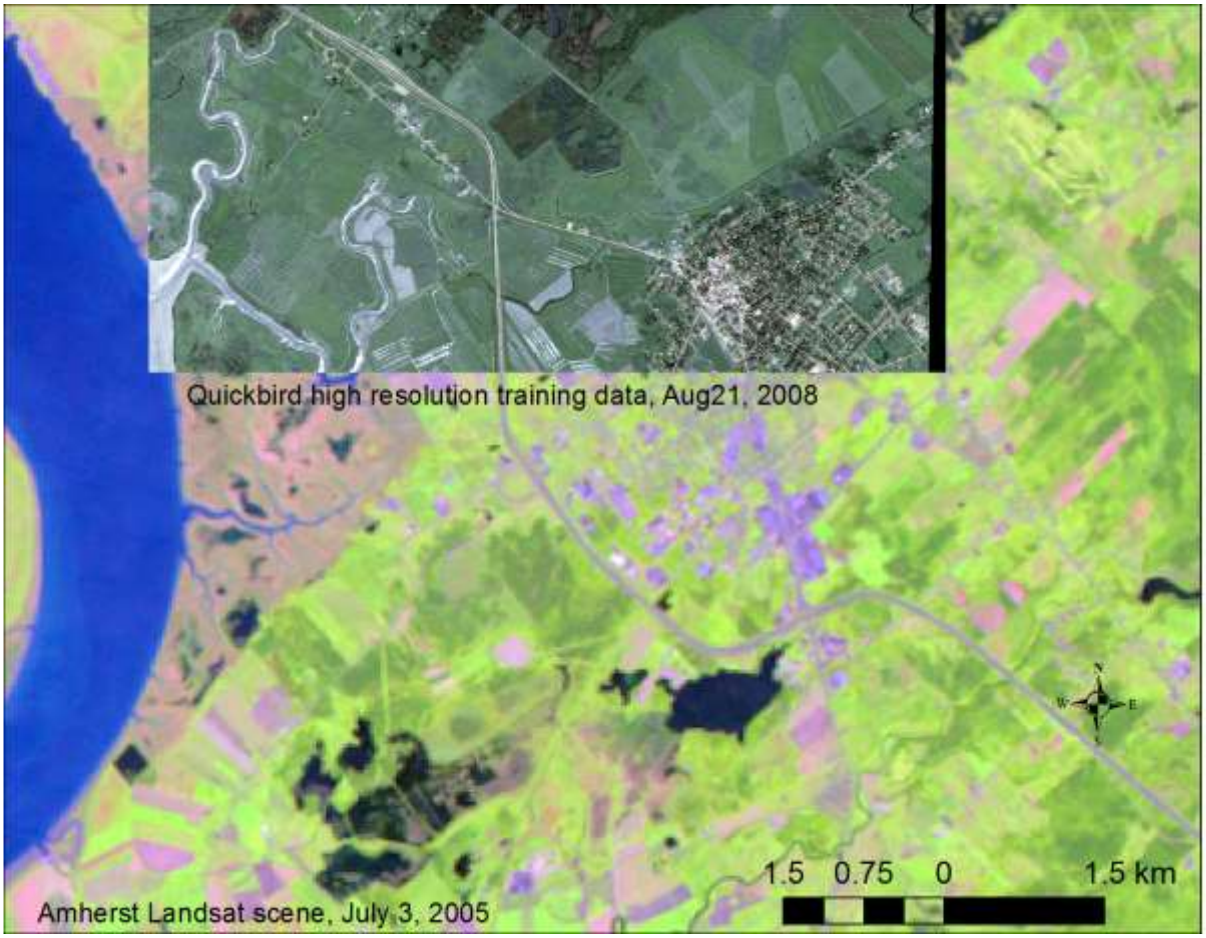

Figure 2-3 Landsat and Quickbird (dark green) satellite images for the Amherst area.

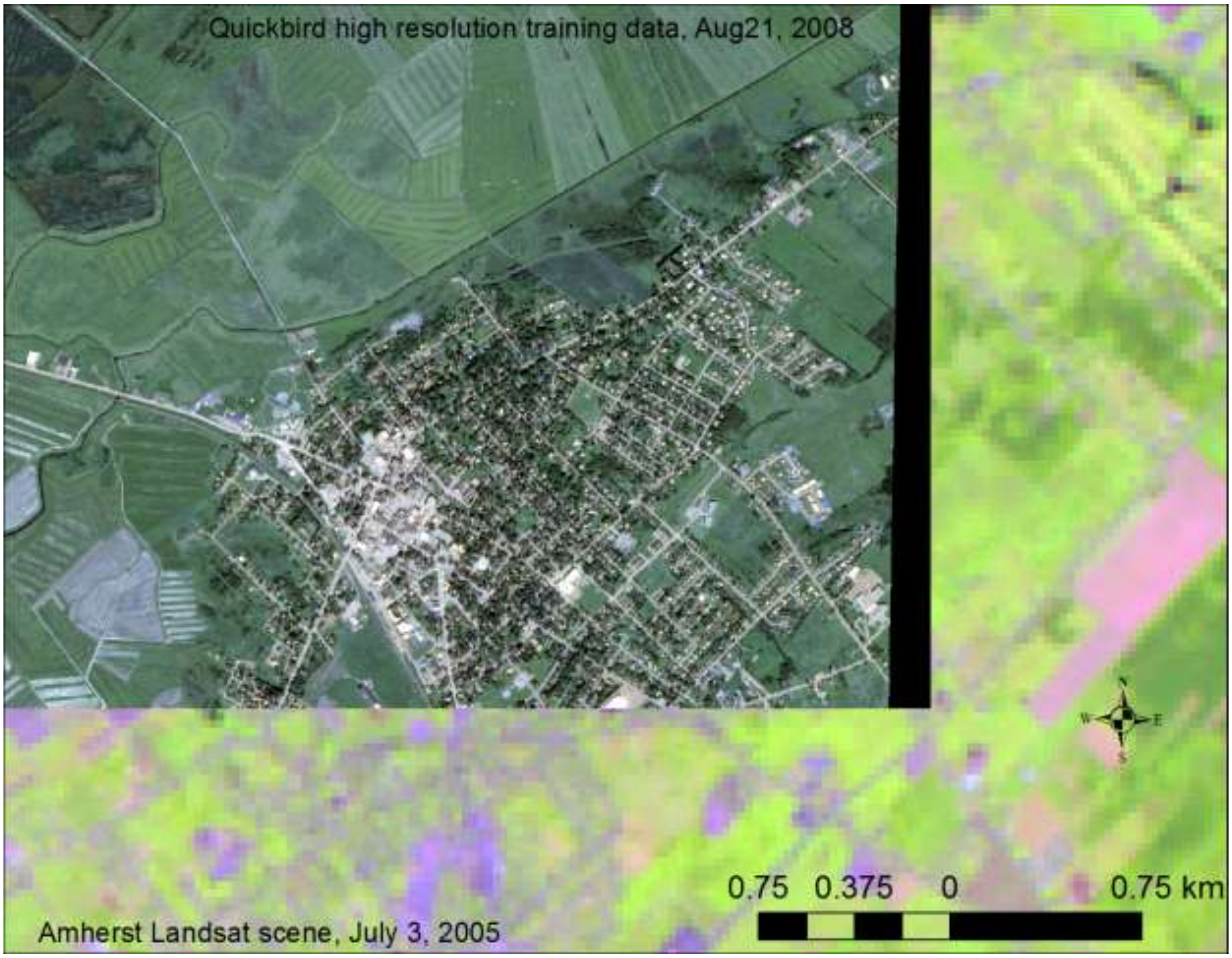

Figure 2-4 Close-up view of the town of Amherst. The downtown area appears more white-grey as a result of the increased amount of impervious surface as compared to the suburbs where for trees and vegetation are visible.

The Quickbird image bands are used to classify the different types of impervious surface materials using a combination of traditional unsupervised and supervised image classification methods (Figure 2-5). The types of materials are loosely grouped into lighter (roads and buildings) and darker objects (mostly building roofs) along with other cover types including vegetation.

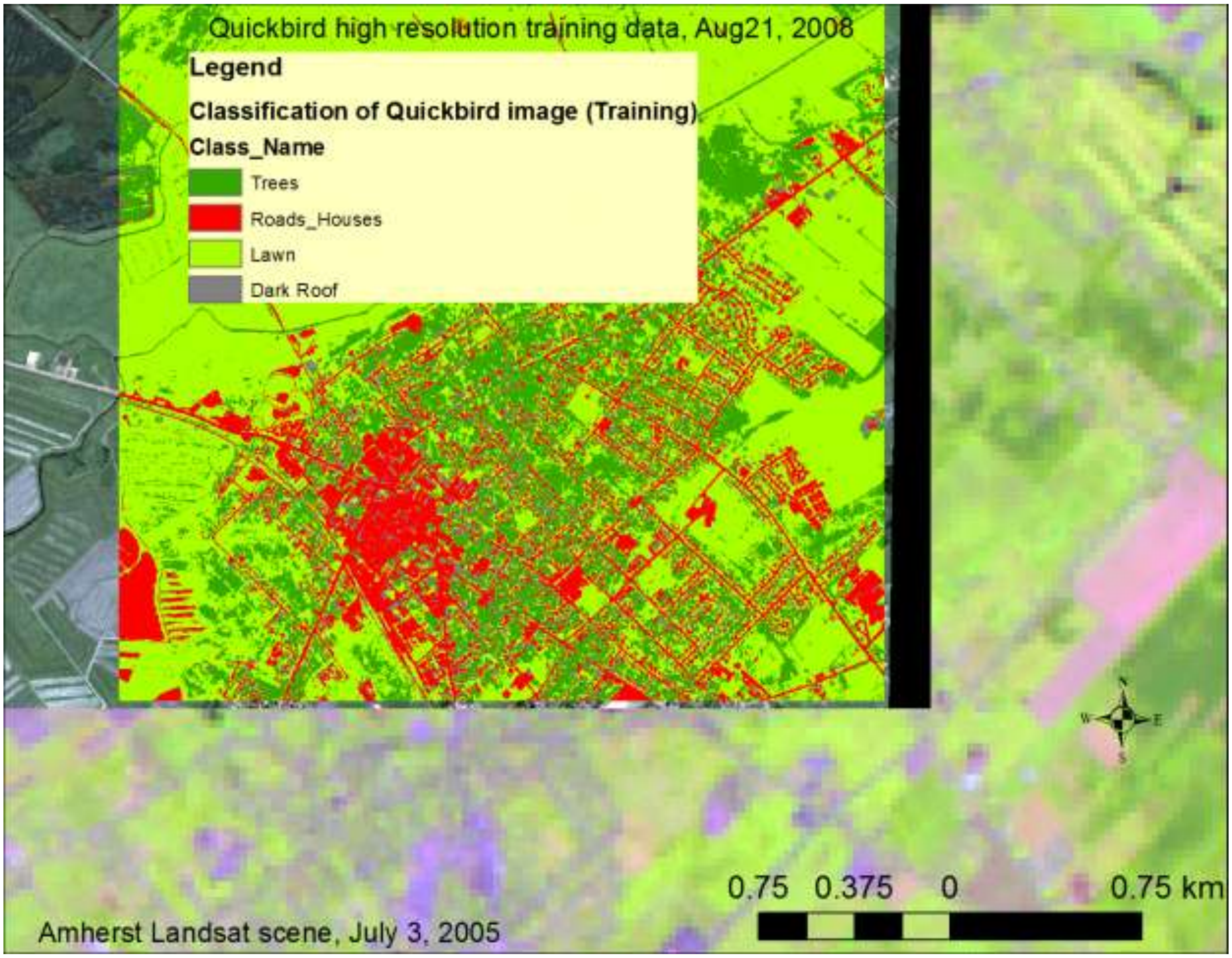

Figure 2-5 Result of classifying the land cover in the Quickbird image into different types of impervious material as well as types of vegetation.

The classified image is then re-classified into a binary class representing developed areas (Figure 2-6).

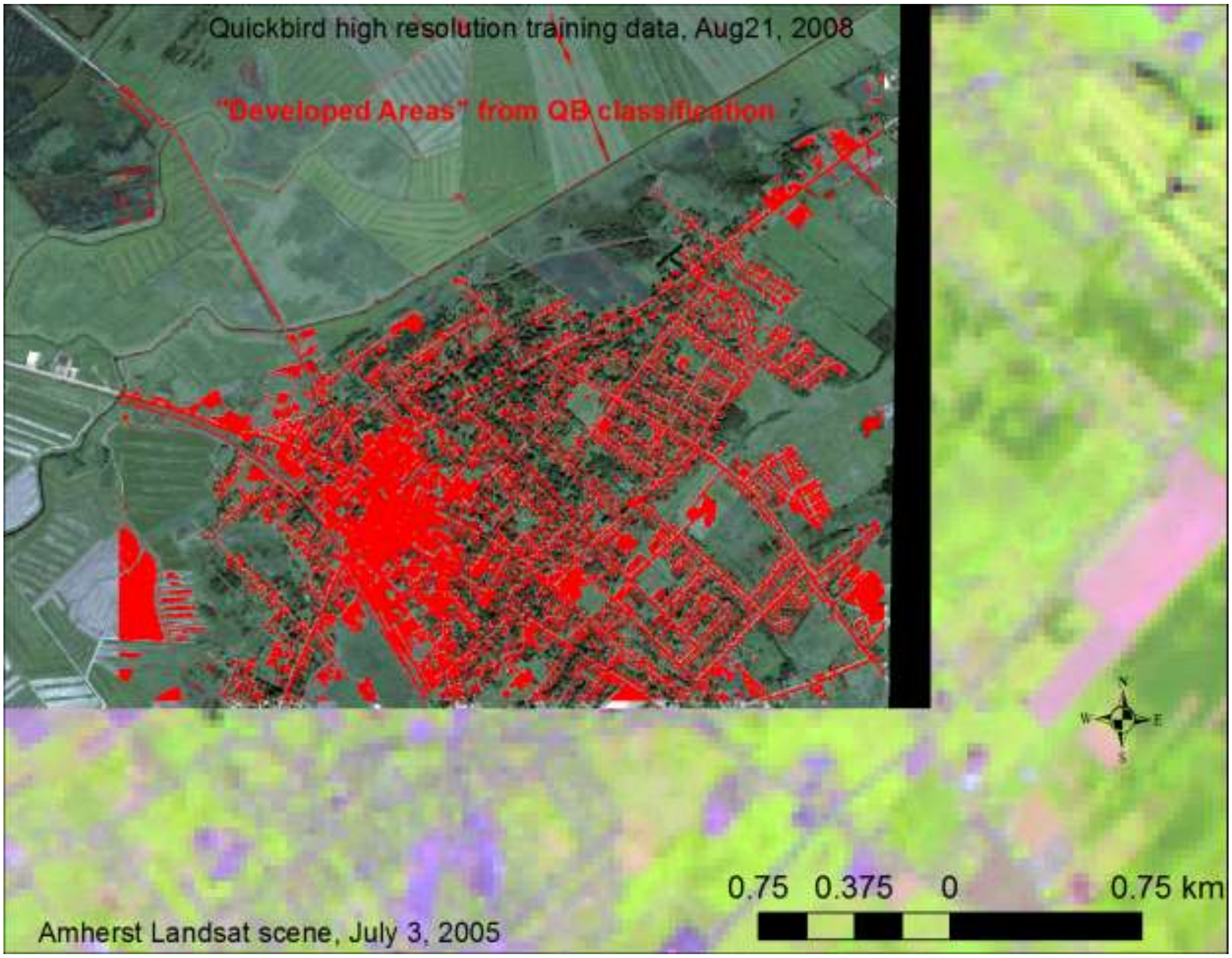

Figure 2-6 The previous classified image is re-classified into a binary image representing the developed area which consists dominantly of impervious materials.

This image is then subjected to a 29 x 29 pixel kernel that applies a focal sum operator to the image, where the number of developed pixels are counted (summed) within the kernel (Figure 2-7). The kernel is moved pixel by pixel throughout the image and results in a new image that represents the amount or percentage of developed areas within a 29 x 29 pixel area, which is approximately the same area as the Landsat pixels (Figure 2-7).

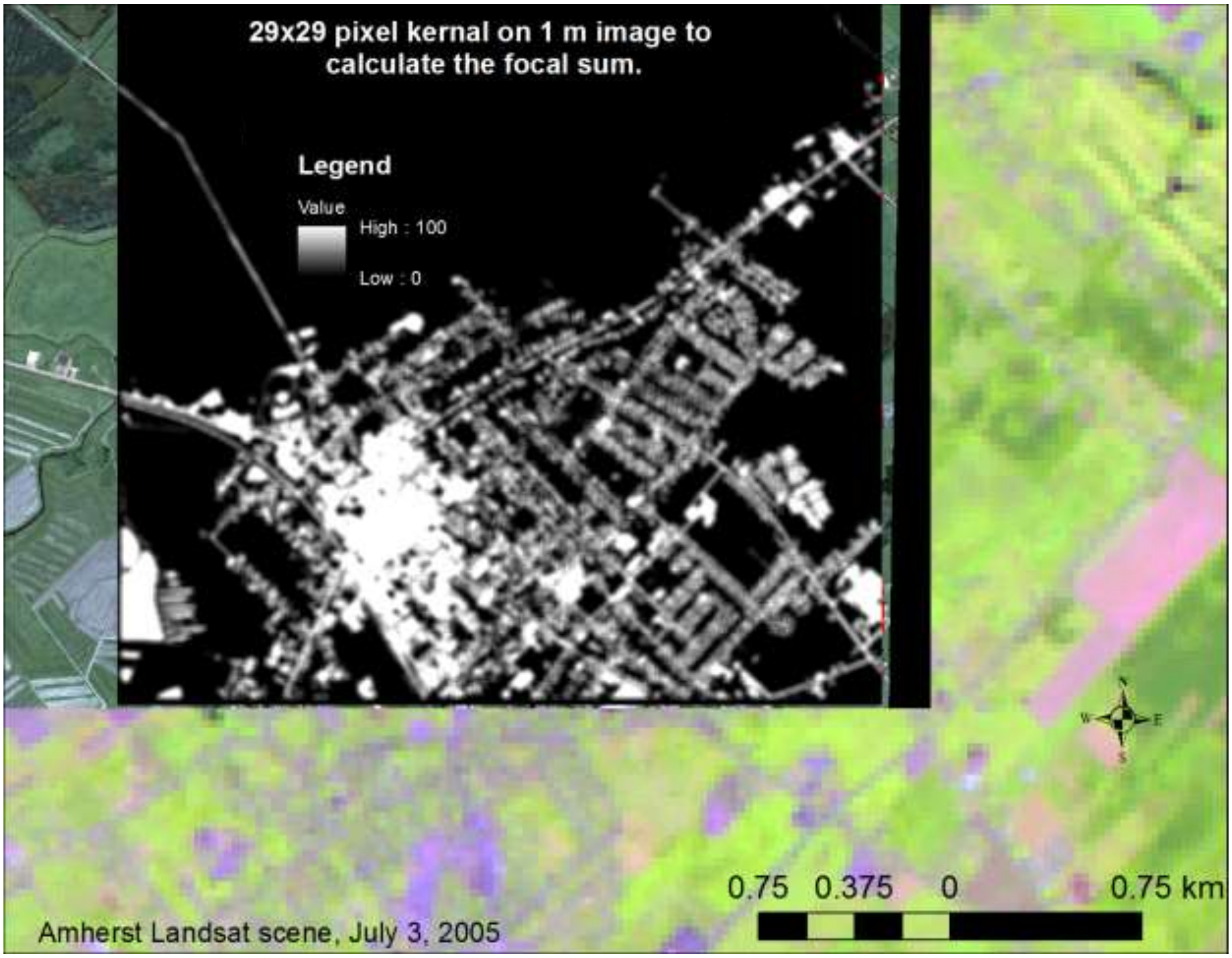

Figure 2-7 Resultant image of the 29 x 29 pixel kernel focal sum operator applied to the classified image of developed areas.

The HR focal sum image is then resampled to a 30 m pixel to match the Landsat imagery using the cubic convolution resampling method to ensure the continuous nature of the image is maintained (Figure 2-8). Note the difference in the resolution in the %ISA of the images at 1 m compared to 30 m. The resultant image now represents the %ISA for the 30 m Landsat image and can be used as training data to classify the entire image.

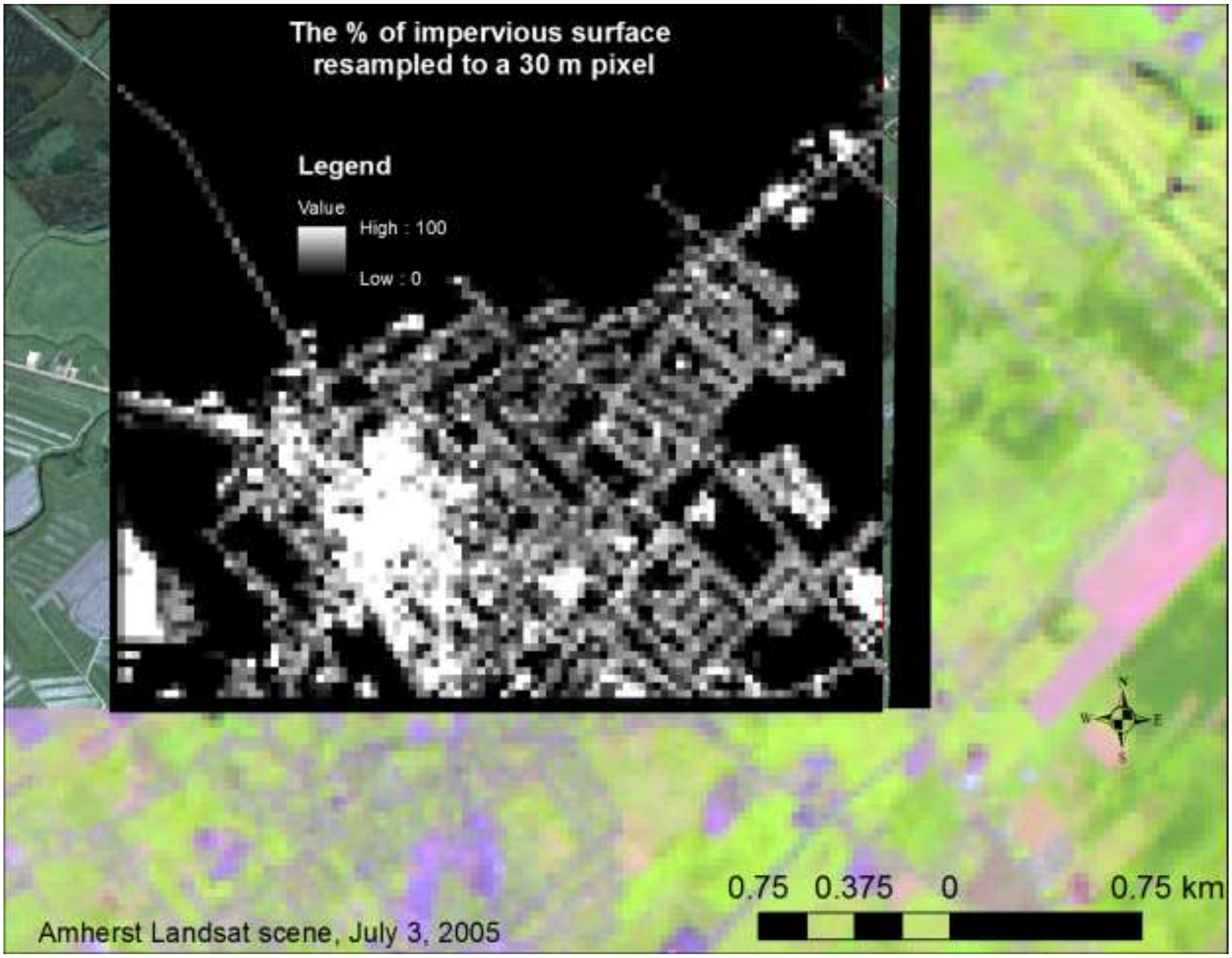

Figure 2-8 Focal sum image resampled to 30 m pixels to match the Landsat imagery.

The 30 m training image (from the resampled focal sum) is used to analyze the Landsat bands 2,3,4 and 5 and classify the image into %ISA (Figure 2-9). Note that the resultant image has both omission and commission errors. An example of the omission error is that not all of the roads have been correctly classified in the Landsat image (north of the town of Amherst) and a commission error is that some of the agricultural fields have been classified as %ISA.

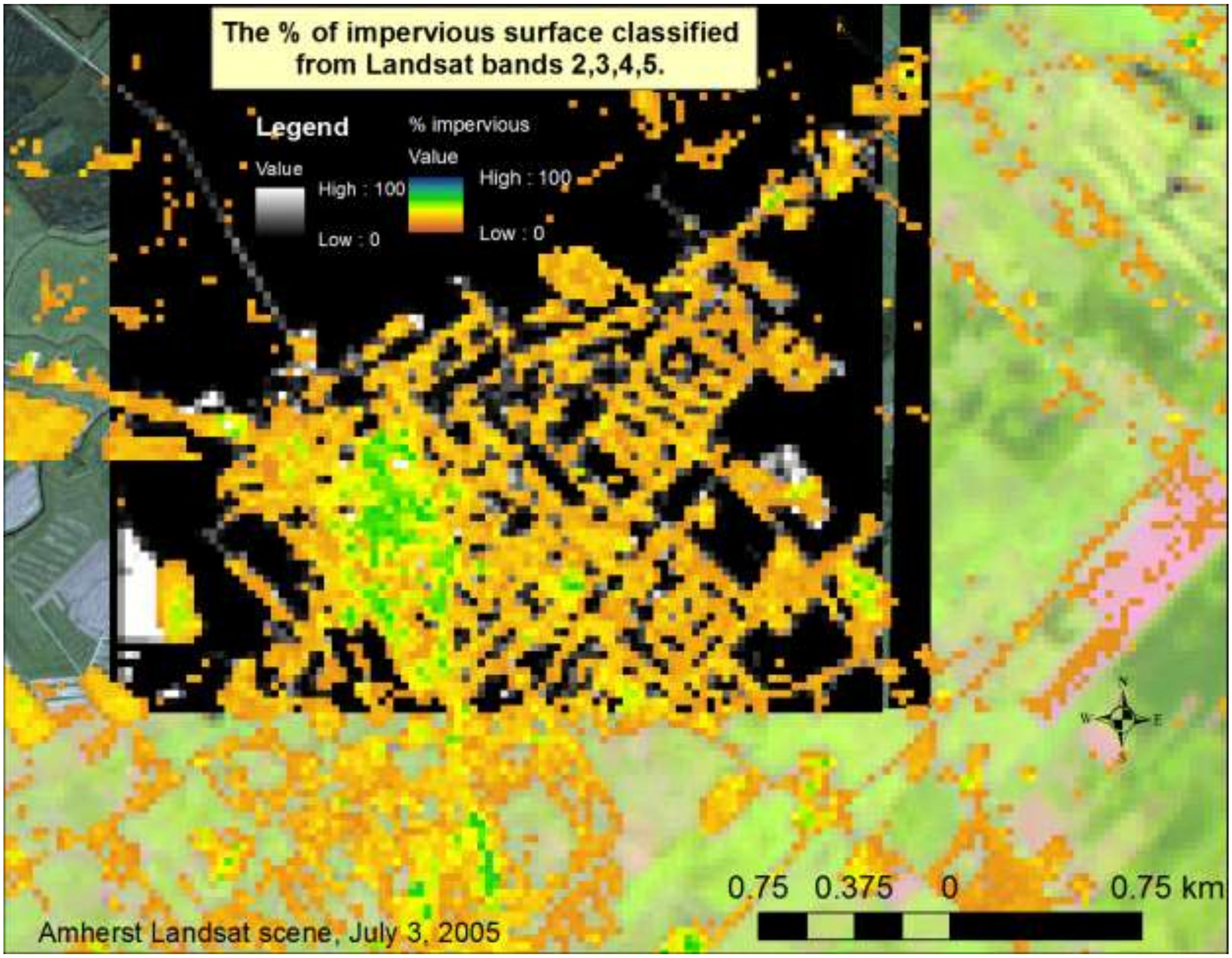

Figure 2-9 Classified %ISA of the Landsat image (orange to green scale) overlaid on the training image (grey scale) and original Landsat composite (background image).

The resultant %ISA classification must be refined and the omission and commission errors resolved (Figure 2-10).

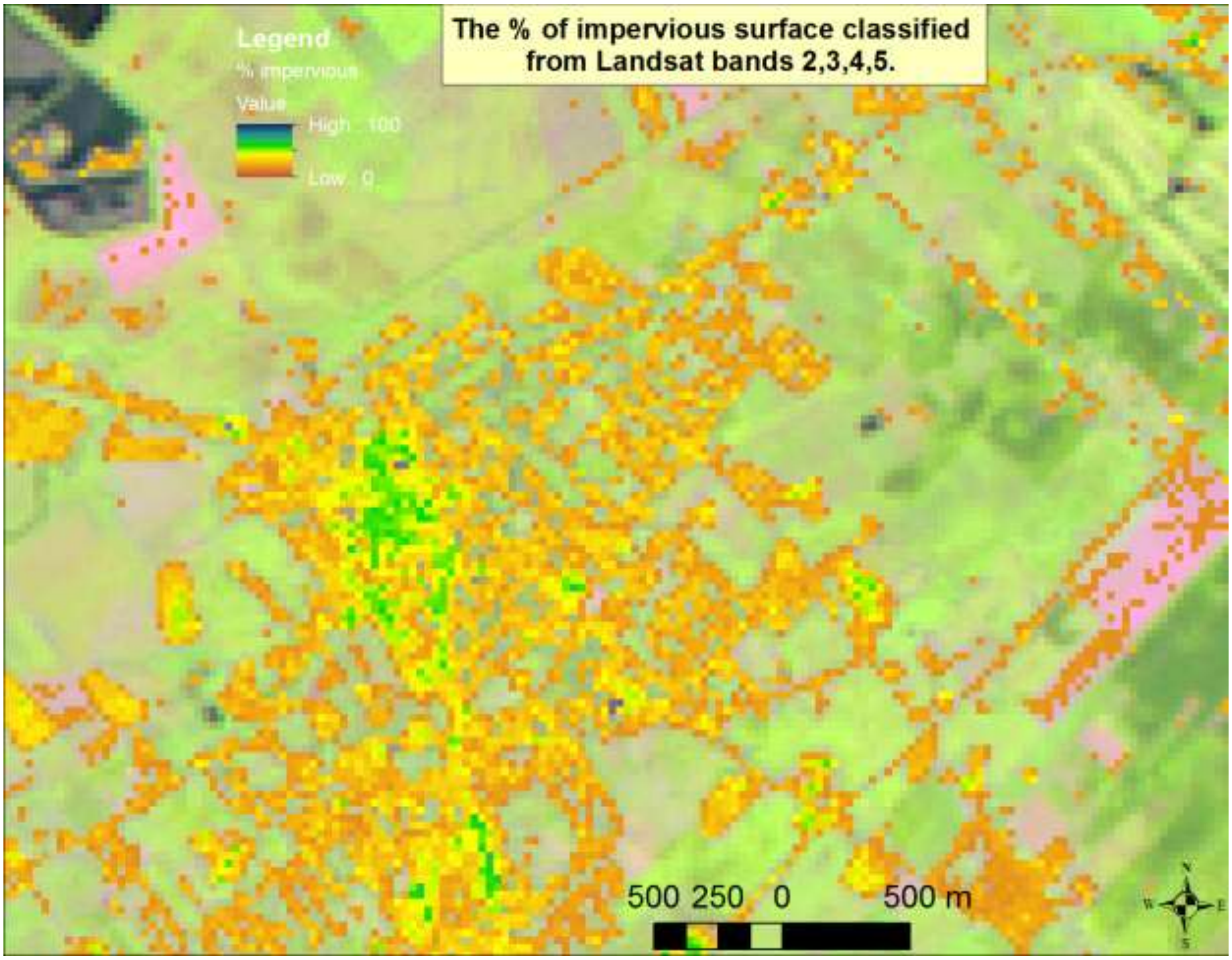

Figure 2-10 Result of the classification process of Landsat bands 2,3,4,5 to map %ISA.

To fix the classification errors associated with the %ISA Landsat image, different GIS databases were examined. The 1:10,000 scale forest inventory data from NS Department of Natural Resources (DNR) delineates urban areas with a polygon that surrounds the towns and developed areas along many of the roads. However this database does not include all of the roads which were obtained from the 1:10,000 scale Nova Scotia Topographic Database (NSTDB). This GIS database has most of the roads and they are coded based on their material (ie. gravel or paved). The urban polygon from the NS DNR forest layer was used along with the roads layer from the NSTDB to refine the classification (Figure 2-11).

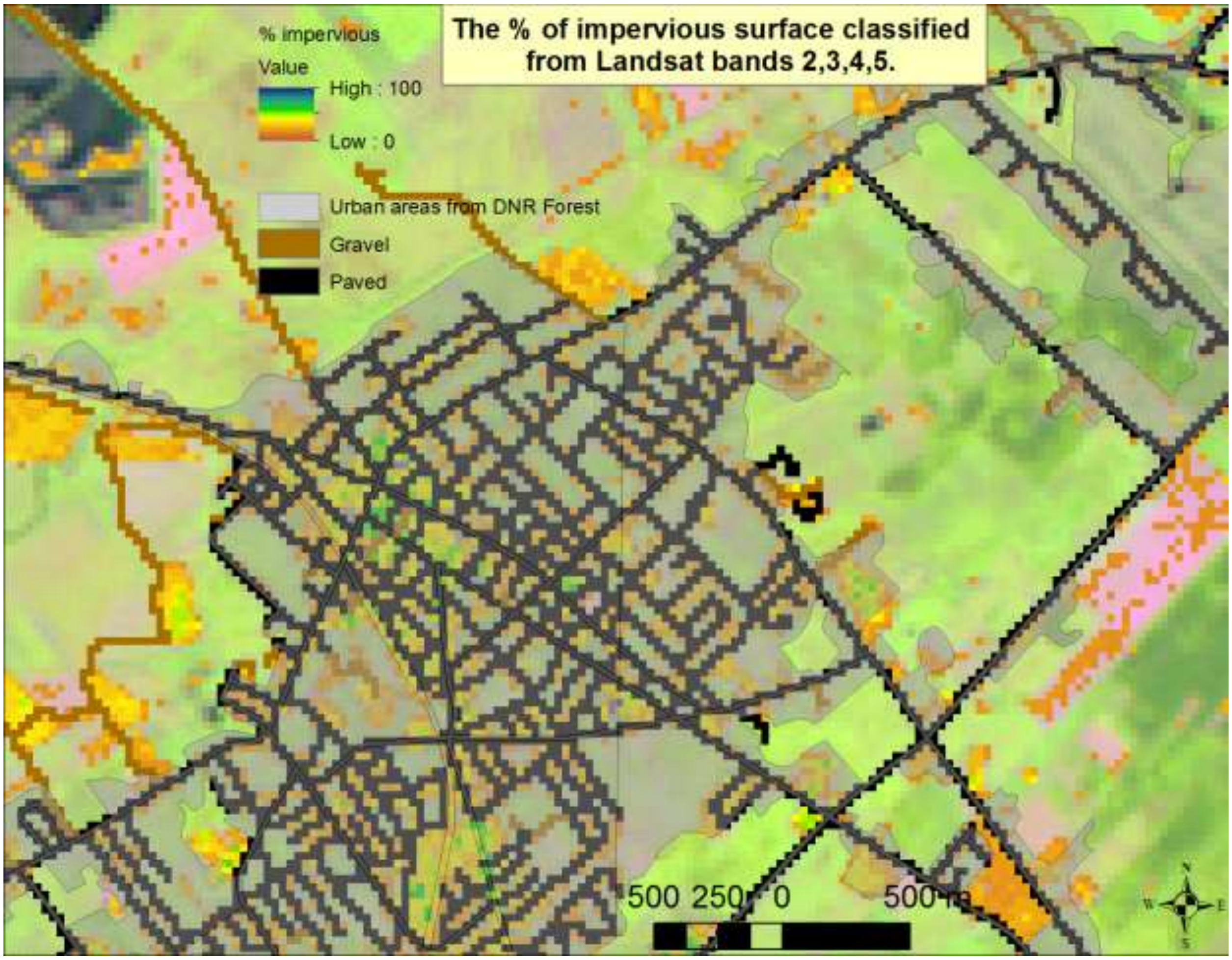

Figure 2-11 Urban polygon from the DNR forest inventory (grey transparent layer) and the NSTDB roads layer (brown for gravel and black for paved) overlaid on the %ISA Landsat image.

The urban polygon was converted to a 30 m raster and used as a mask to clip the %ISA image. The roads were converted to a 30 m raster and coded by the material type which is stored in their attribute table. The raster gravel and paved roads were overlaid on the 30 m %ISA training image to determine what the average percentage of impervious surface area was for each type of road since gravel roads are typically narrower than paved roads. The average %ISA of the gravel roads was 12 while the paved roads were 22. After the classified %ISA was clipped by the urban mask, any roads that were not classified were assigned to the image based on the NSTDB data and were given the appropriate %ISA value (12 or 22) based on their attribute code. The resultant image of %ISA was now reduced of omission and commission errors based on this logical modelling (Figure 2-12).

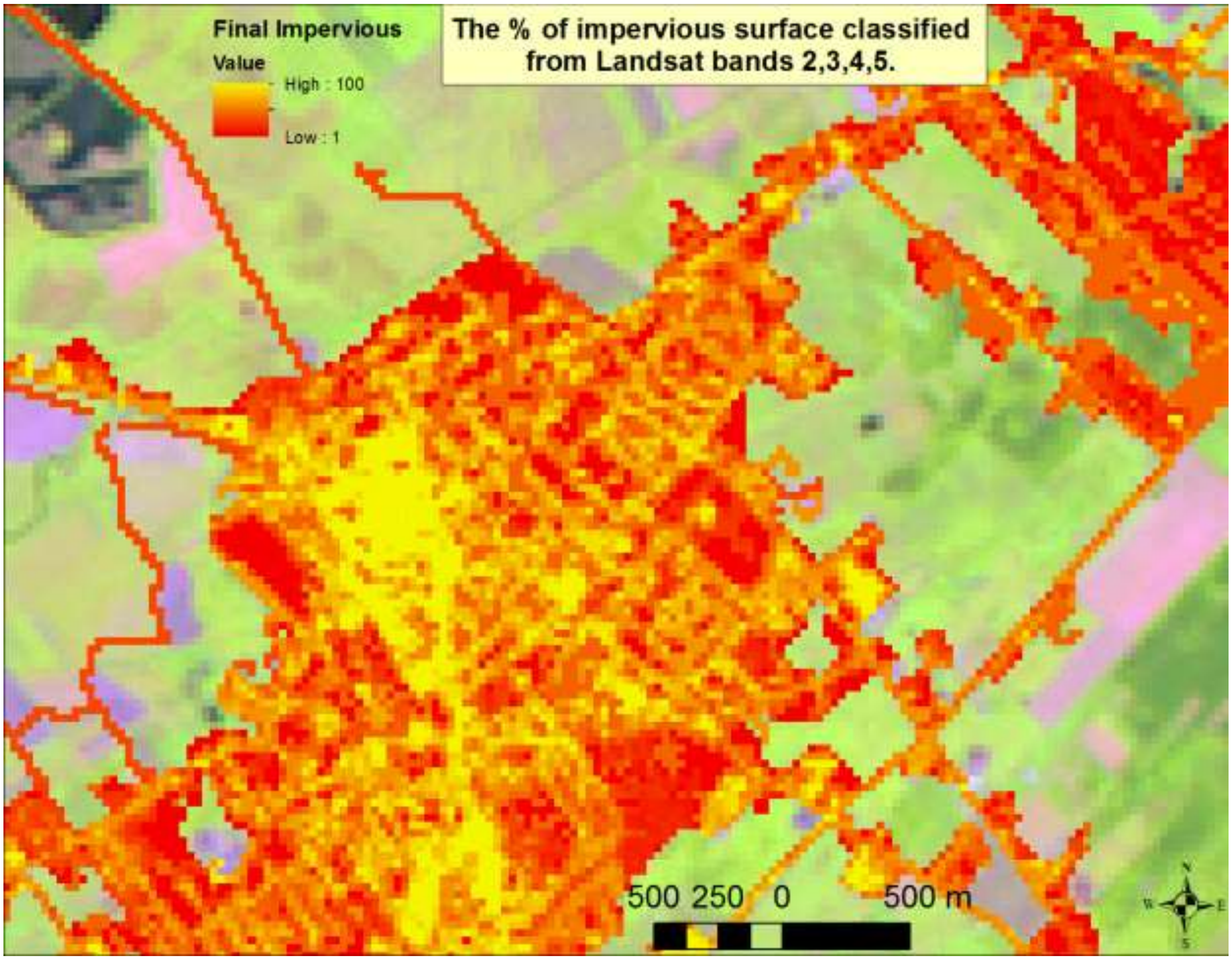

Figure 2-12 Final %ISA (red to yellow) image from the Landsat imagery of Amherst after it has been refined using other GIS databases.

The vintage of roads must be considered as well as the date of the NS DNR forest inventory. The NSDNR forest inventory is on a 10 year update cycle.

2.4. Example of HRM manual refinement and 2005-2013 development

A similar process as described for Amherst was followed for the other scenes that cover Nova Scotia. Considering the Halifax Regional Municipality (HRM) is the fastest growing area in the province for development, we paid special attention to ensuring that the area was classified as accurately as possible. As well, we took the opportunity to compare the developed areas from 2005 with a recent Landsat image of 2013 to demonstrate how these types of data can be used to track and update development and the amount of %ISA in a watershed. Similar to Amherst, a Quickbird HR image was used to classify the impervious cover types and construct a developed training dataset (Figure 2-13). In this case the near-infrared false colour composite image is on the left and the classified image is on the right, where impervious materials are coloured white (Figure 2-13).

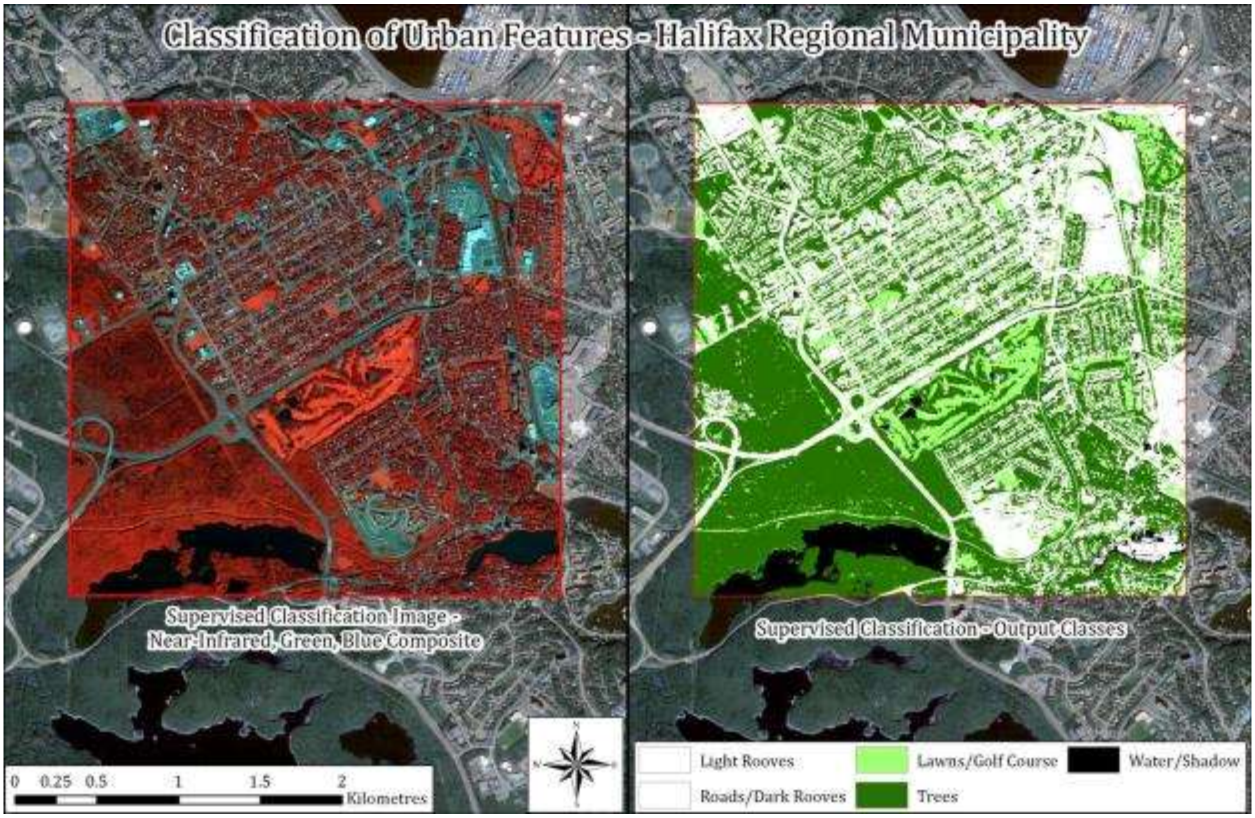

Figure 2-13 Quickbird false colour composite (left) and classified image (right) of an area near Fairview within HRM. The impervious cover types are colour coded white on the classified image (right).

This image was then reclassified into a binary image of developed area and used to calculate the focal sum and develop a training image for the classification of the 2005 Landsat image (Figure 2-14).

Figure 2-14 Halifax false colour composite Landsat image (2005) with developed areas derived from the Quickbird image (black developed areas south of Bedford Basin).

The training image was then used to classify the %ISA from the Landsat image for the entire scene. The resultant %ISA image was then refined using the NS DNR urban mask and NSTDB road layer as described earlier for Amherst. The final %ISA classification for this section of HRM was compared to the original 2005 Landsat image (Figure 2-15).

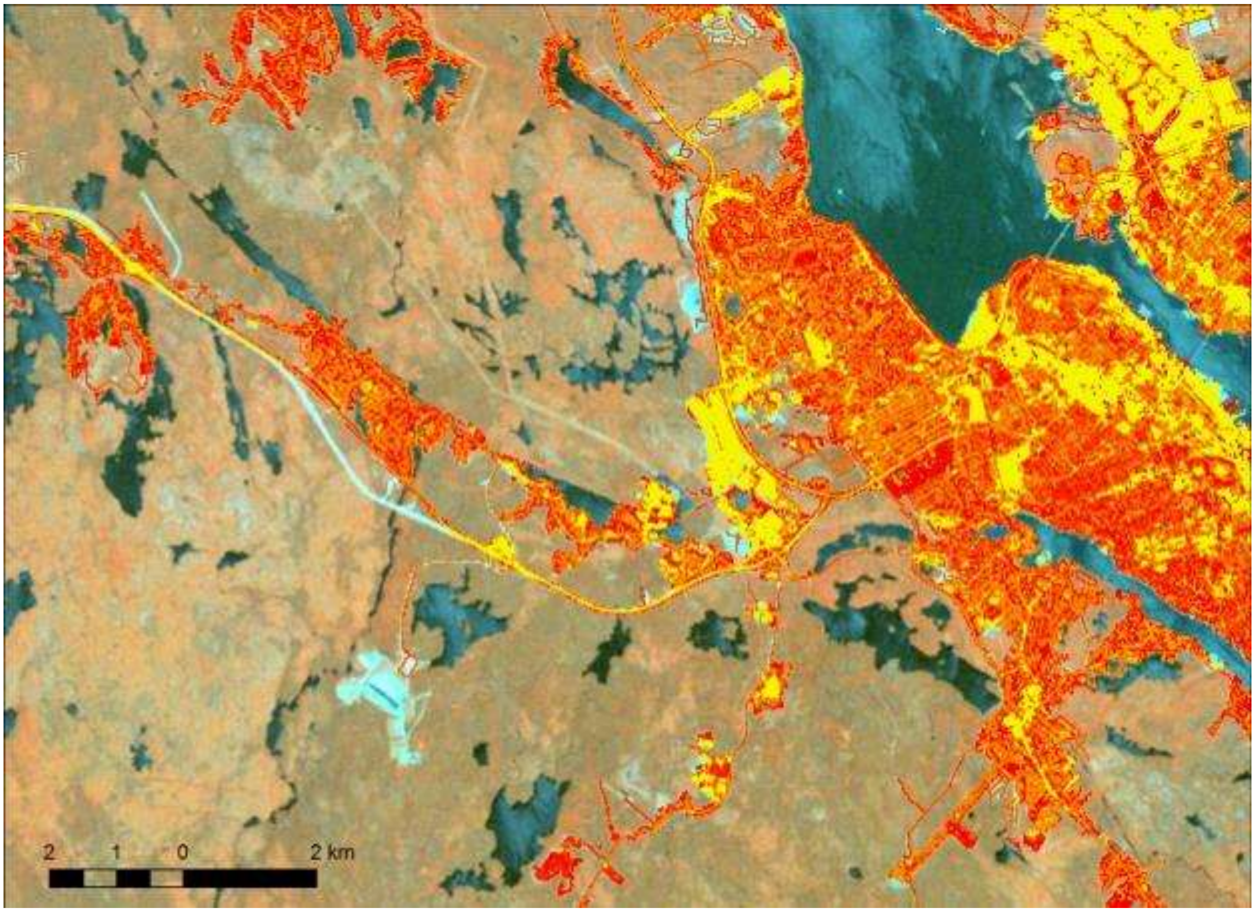

Figure 2-15 Classified %ISA (red to yellow) from the 2005 Landsat image overlaid on the false colour composite of the Landsat image where the cyan colour indicates impervious material or bare soil

As can be observed there are several areas of cyan colour that appear to be either impervious material or bare soil (quarry or gravel pit). Many of these areas were classified correctly as %ISA but have been removed during the refinement process when the mask and roads were applied to the %ISA image. The areas of cyan colour (Figure 2-15) were examined in Google Maps where high resolution imagery is available and many areas were determined to represent impervious material that should have be included in the classification. The mask and road information was manually updated for these areas and re-applied to the original classified %ISA image. The revised final %ISA map shows the updated areas as a result of refining the mask manually (Figure 2-16).

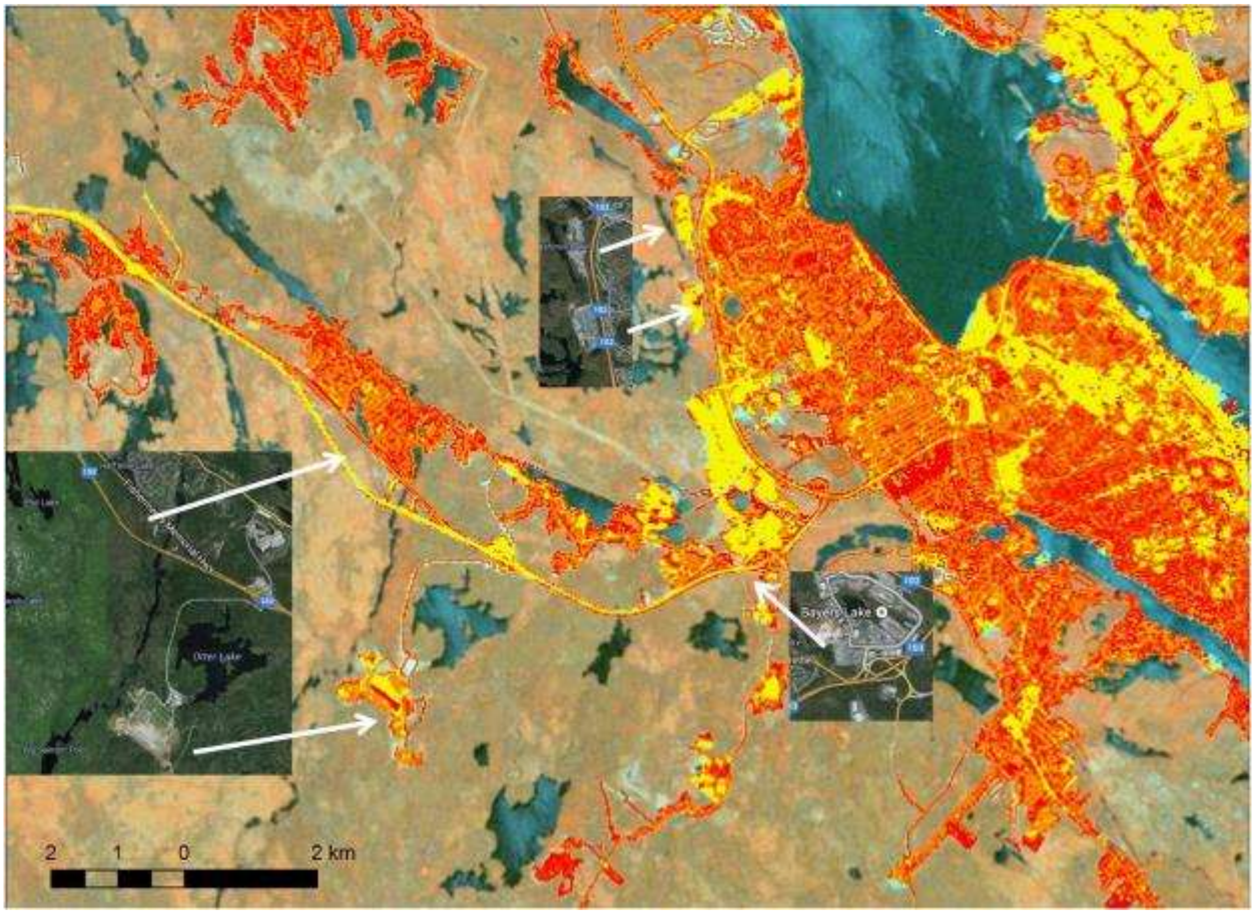

Figure 2-16 Revised %ISA to update the mask for new developed areas. Inset of Google Map images with white arrows indicating where the mask was refined to include these developed areas.

Recall that the Landsat image is from 2005 and development around HRM has continued since then. To examine how much development has taken place since 2005, a Landsat image acquired in the spring of 2013 was downloaded and compared to the final %ISA mask derived from the 2005 Landsat imagery (Figure 2-17). As can be observed on the 2013 Landsat image when compared to the %ISA from 2005 there has been a significant amount of development which includes the expansion of subdivisions adjacent to already developed areas as well as new roads being developed farther from the suburbs. The new development areas from 2005 to 2013 are highlighted in the figure with white ovals and are clearly visible on the 2013 Landsat imagery (Figure 2-17).

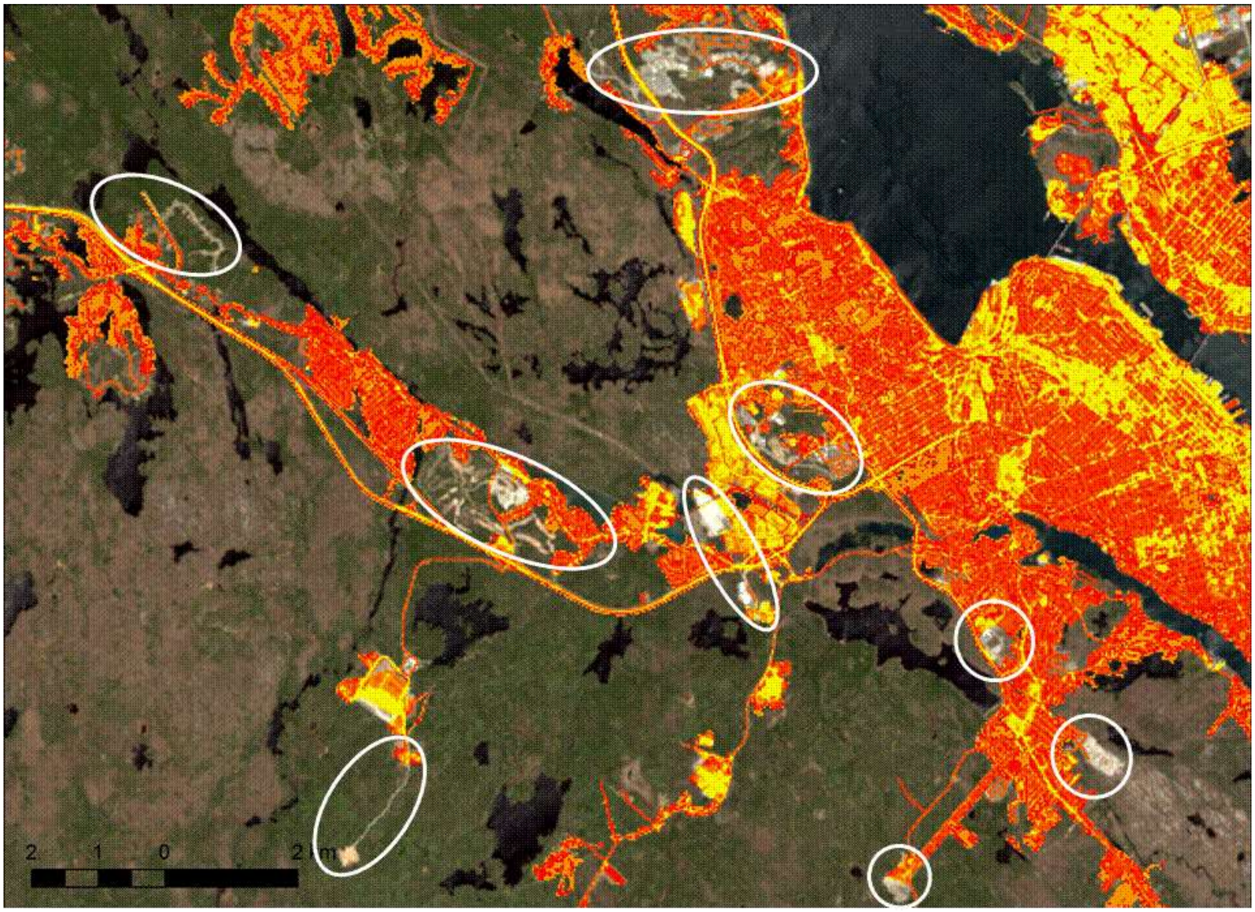

Figure 2-17 Landsat image from spring 2013 overlaid with the %ISA map from 2005. The development between 2005 and 2013 is clearly visible as white areas on the 2013 Landsat image and highlighted by the white ovals on the image.

A similar analysis was done for north of the Bedford Basin where the urban mask was updated based on areas classified as %ISA from the 2005 imagery and confirmed through Google Maps or Quickbird and the urban mask updated for those developed areas based on the %ISA from the 2005 (**Error! Reference source not found.** A). Some of the white areas on the 2005 image that are not in the mask (black) or mapped as %ISA where deemed to be quarries or recent cleared forest areas that are not currently developed, thus were not included in the revised mask. The revised %ISA from 2005 was then compared to the spring 2013 Landsat image (**Error! Reference source not found.** B). In figure 2:18 the mask is coloured black in the top figure (A) and the new %ISA areas are highlighted in red to yellow with increasing percentage of impervious surface area (**Error! Reference source not found.** A). The areas that have been developed between 2005 and 2013 are visible as white on the 2013 Landsat image and are highlighted by white ovals (**Error! Reference source not found.** B). The 2005 %ISA image is overlaid in colours ranging from red to yellow with increasing percentage of impervious surface area (**Error! Reference source not found.** B).

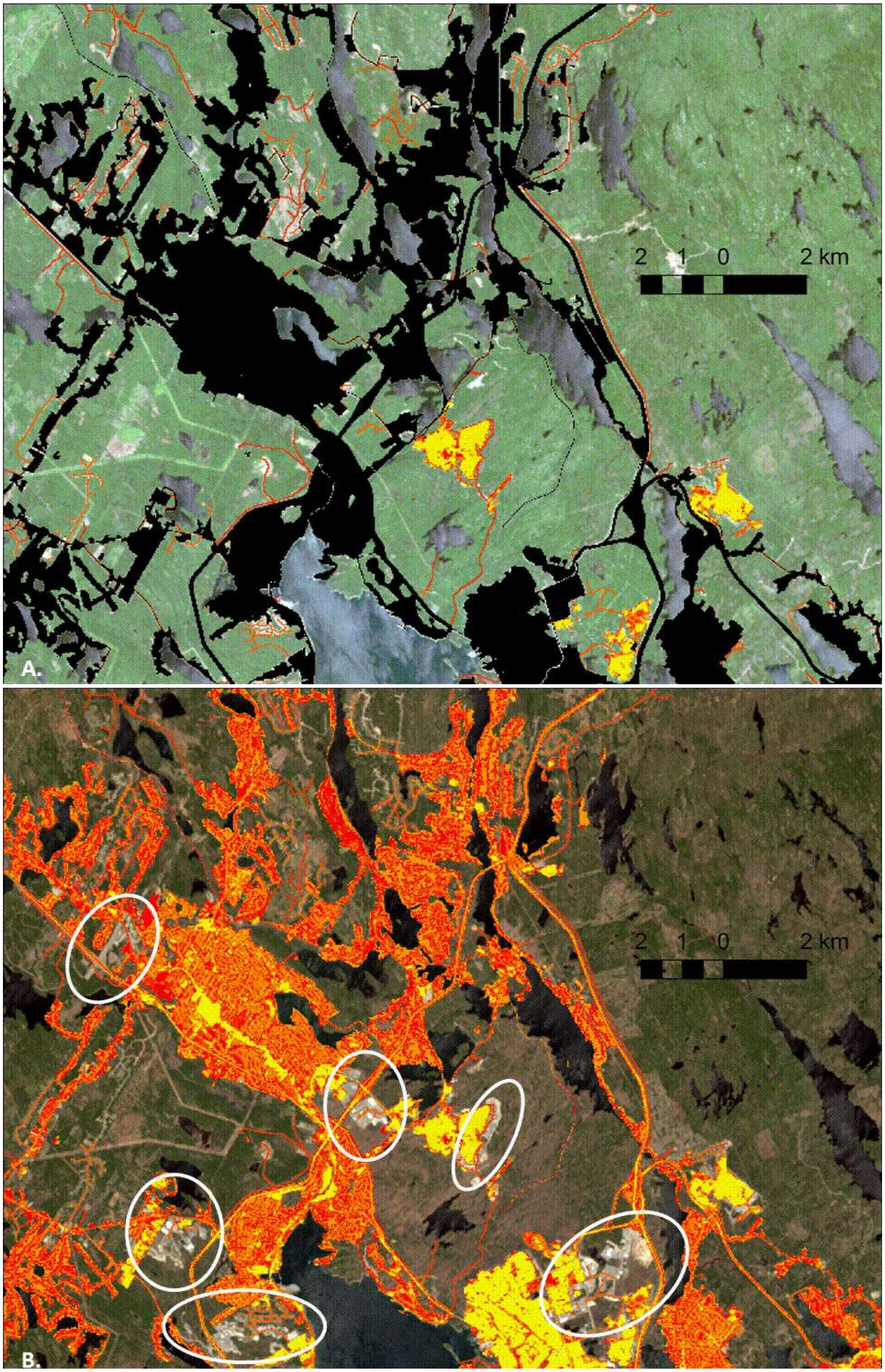

Figure 2-18 (A) Top image show 2005 Landsat image with urban mask (black) and %ISA areas in red-yellow. (B) The lower image shows a 2013 Landsat image with the revised %ISA map (red to yellow) and new development from 2015-2013 (white ovals).

3. Results

3.1. New Brunswick %ISA GIS layer

There was no report on the methods and procedures used to construct the %ISA GIS layer for NB. Although the same USGS procedures that were presented to our researchers were presented to the NBCC researchers involved in the original mapping. The NB %ISA layer was examined in the GIS and it became apparent that no refinement or clipping of erroneous data had been conducted on the dataset we received. The NB %ISA included water in the Bay of Fundy and many classified features appeared to be agricultural land and clear-cuts (Figure 3-1). The top image shows the entire extent of the NB %ISA which includes sections of NS and Maine. It is apparent that no refinement has been done on this layer and the seams between the Landsat scenes are clearly visible in the top image (Figure 3-1 A). A comparison of the NB %ISA and the %ISA from this study for the Annapolis Valley shows that there are a significant number of areas in the NB %ISA that appear to be agricultural fields (shades of red) as compared to the developed areas (shades of purple) (Figure 3-1 B). The lower image (B) shows the developed area associated with the town of Kentville in the east and the Greenwood airfield and runway in the west in shades of purple (Figure 3-1 B).

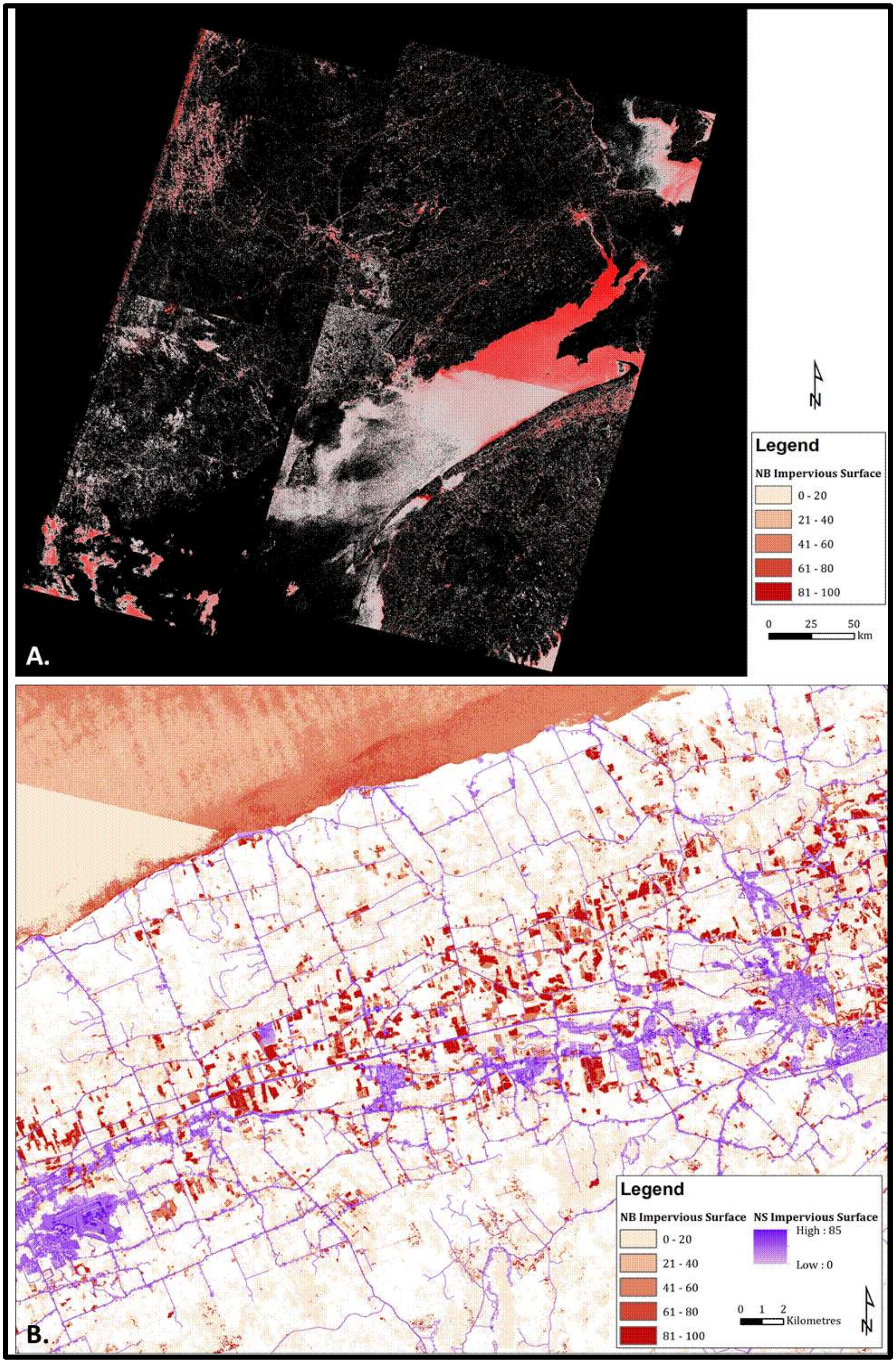

Figure 3-1 (A) Top image is the %ISA received from NB which includes water and many other erroneous features. (B) Lower image is a comparison of the NB %ISA (red) with the %ISA from this study (purple) for the Annapolis Valley.

We downloaded various GIS layers from Service New Brunswick's GeoNB site (http://canadiangis.com/geonb-map-viewer-free-new-brunswick-digital-data-sets.php) and attempted to refine the NB %ISA layer. The NB %ISA layer was clipped to the land extent and water bodies removed (Figure 3-2 A). There was still a significant amount of commission error where the NB %ISA far exceed the developed areas and it did not appear as a PDF map that we had been given at the beginning of the project. We further investigated setting a threshold to remove erroneous %ISA areas and eventually settled on setting all %ISA values between 2 and 20 to not show on the map (Figure 3-2 B). This resulted in a map that looked similar to the PDF document we were supplied with early in the project. There is still a significant amount of erroneous %ISA along the Saint John River Valley that appears to be associated with the agricultural fields in the potato belt in western NB (Figure 3-2 B). Further refinement of this layer was beyond the scope of this current study however.

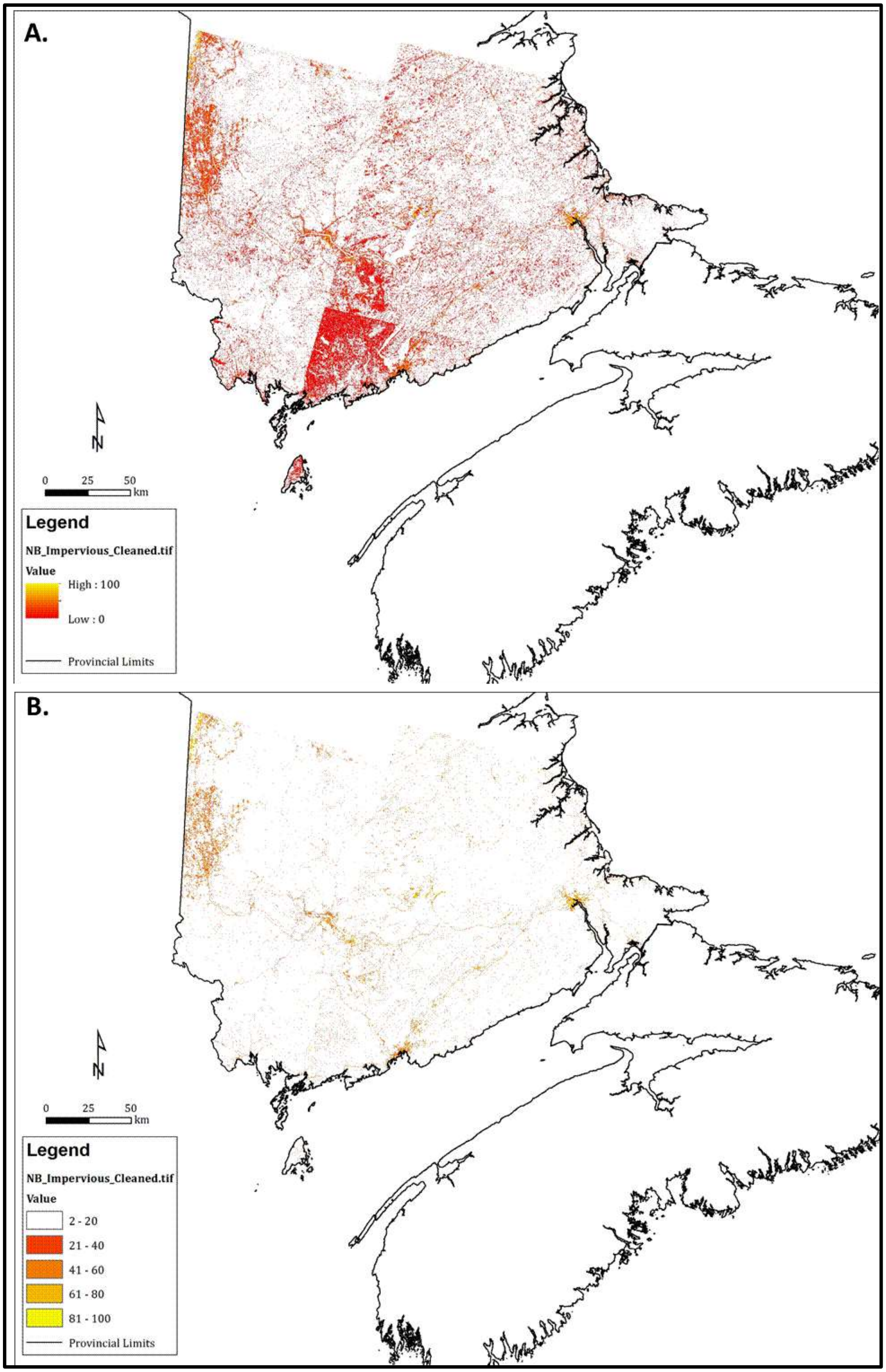

Figure 3-2 (A) Top image is the NB %ISA after it has been clipped based on the land extent and water bodies removed. (B) Lower image is the clipped NB %ISA with values 2-20% impervious not shown.

3.2. NS %ISA GIS Layers and Layered PDF Map output

Each Landsat scene for Nova Scotia was classified for %ISA and refined based on the urban mask and road network as described earlier. Some limited manual inspection also took place to update the mask; however this was not extensive given the limited time available to conduct the project. As a result of the variations in the dates, seasons and atmospheric conditions between the scenes, the resultant %ISA images were examined and scaled between 1-100% impervious (Table 3-1). Table 3-1 shows the original %ISA maximum for each of the Landsat scenes, each scenes was linearly scaled from 1-maximum value to 1-100%.

Table 3-1 Landsat scene upper maximum values of %ISA that were scaled 1-100%.

Landsat Path/Row	Landsat Imagery Date	Pre-Scaled (Raw) High Value
6/27	7/21/2005	68
6/28	8/12/2007	79
7/28	9/17/2006	76
7/29	8/21/2008	83
8/28	7/3/2005	85
8/29	7/3/2005	80
9/29	8/27/2005	74
9/30	8/27/2005	48

The project timeline did not permit for extensive validation of the results and thus the information on %ISA should be used with caution and a full understanding of the process of how it was derived should be clear if it is to be used quantitatively. When the %ISA images from each scene are viewed as a GIS layer in ArcGIS, the default setting is to stretch the image values (0-100% %ISA) from 0-255 based on 2 standard deviations either side of the mean of the image. We have used a standard colour ramp ranging from low %ISA in red to high %ISA in yellow for visualization and the map output. This provides an appropriate level of contrast between densely developed areas and areas that have a mix of vegetation and development. The %ISA images for all the scenes were merged into a single file that covered all of Nova Scotia. Once merged, the overall image histogram of %ISA values changed and the contrast between dense and sparse developed areas became less apparent because the differences are not as significant in many areas of the province when compared to the urban centres around Sydney and Halifax (Figure 3-3 A). As a result, we have constructed a rural %ISA for visualization purposes where we have scaled the values from 1-50 to 0-255 so they can be displayed without any automatic stretching applied (ie. ArcGIS 2 standard deviations) (Figure 3-3 B). Users of these data should please read the metadata documentation to ensure the correct file is being used to compare one area of the province with another. For example, it would not be advisable to use the file that was constructed to enhance visualization of the rural areas to quantitatively compare %ISA values.

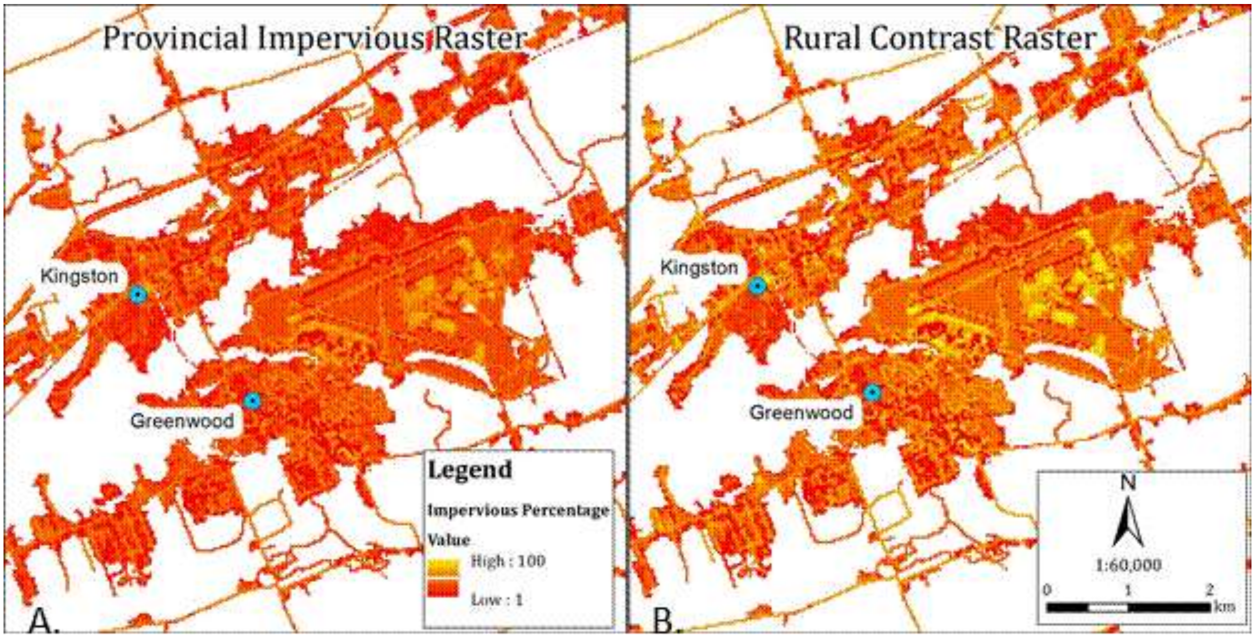

Figure 3-3 Example of the provincial %ISA and the rural enhanced version which has been scaled and no automatic stretching applied in ArcGIS. (A) Provincial %ISA for Greenwood area and (B) rural enhanced version of %ISA for Greenwood.

In addition to delivering the data as GIS layers for the entire province, we have also constructed various PDF files to examine the %ISA. The PDF format and standard viewers supports the ability to layer information and toggle these layers on and off. Layered PDF files allow one to combine multiple GIS layers such as the %ISA image with the primary watershed boundaries and place names for example. When viewing the PDF file these layers can be toggled on and off in a similar fashion to functionality within a GIS. We have constructed a province wide layered PDF that includes the %ISA, primary watershed layers, place names and the National Topographic Series (NTS) 1:50,000 scale map sheet boundaries and labels (Figure 3-4).

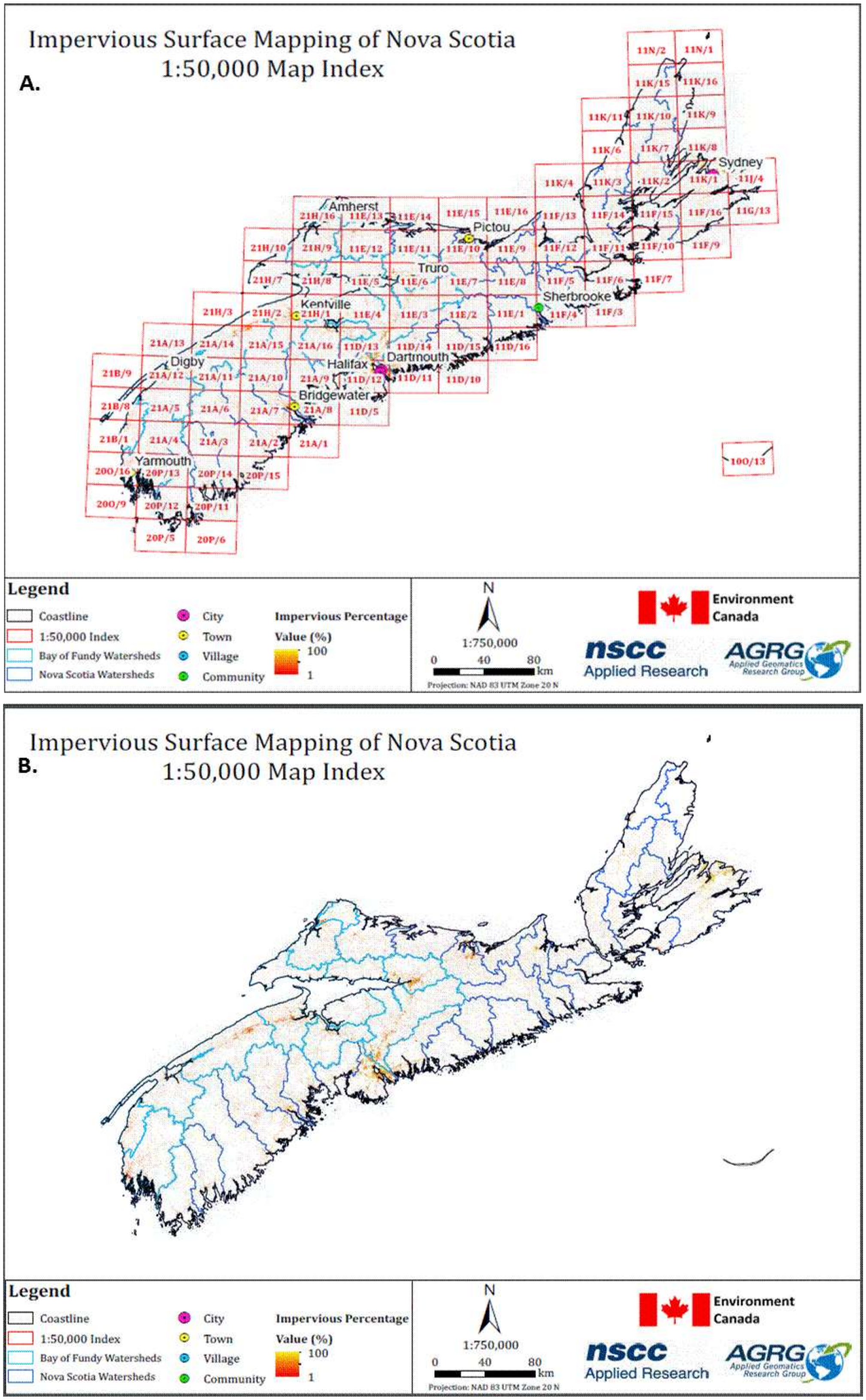

Figure 3-4 Layered PDF of the %ISA for the province with NTS index and labels (A) and grid and labels toggled off with watershed boundaries (B).

Various layers can be toggled on and off as mentioned and the map can be plotted accordingly. In order to examine areas in more detail and organize the information, we have also constructed layered PDF files that include the %ISA, primary watershed layers, and place names for each of the 1:50,000 NTS map sheets (Figure 3-5). The PDF files are named based on each map sheet (e.g. 21H1.pdf) and the province wide PDF can be used to act as an index map in order to find specific areas and NTS map sheets (Figure 3-4). This will allow the data to be easily shared with non-GIS users and they can access other ancillary data such as the watershed boundaries to compare the amount of %ISA between watersheds (Figure 3-5). An example of the layer controls for a layered PDF in Adobe Reader are shown in Figure 3-5 A and the layers can simply be made visible or not by toggling the eye icon as shown in Figure 3-5 B.

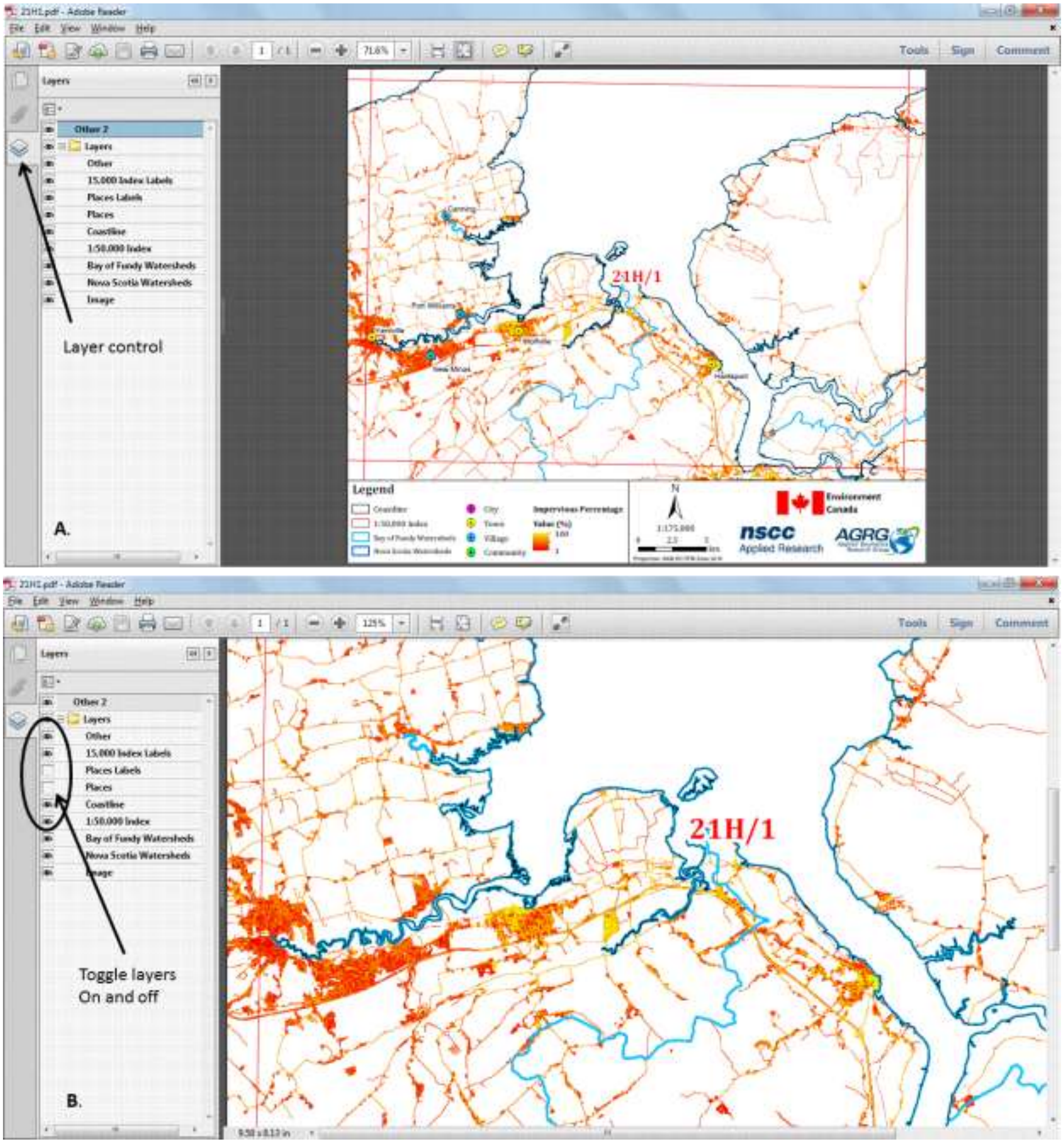

Figure 3-5 Example of 1:50,000 NTS map sheet 21H/1 layered PDF file with %ISA, primary watershed boundary and place names. Top image shows the layer controls on Adobe Reader for a layered PDF (A). Lower image is a zoom with Wolfville in the centre of the map with the place names and place dots toggled off (B).

4. Conclusion

This project was both challenging and very rewarding for our research team. At the onset of the project it took some time and a significant amount of correspondence to eventually track down the NB %ISA layer and the appropriate contact at the USGS. However, as this went on we researched alternative methods to derive the %ISA and compiled the various Landsat and high resolution imagery that was required. Once contact and information was exchanged with the USGS and their method understood and the software tools acquired, we began implementation and researching refinement strategies for the imagery covering all of Nova Scotia. After the initial classification of %ISA for each Landsat scene, our experience and familiarity of the various federal and provincial GIS databases was essential to determine the best method to refine the %ISA classification and reduce the inherent omission and commission errors. After the refinement process, all of the Landsat %ISA scenes were visually inspected for errors and general quality control. The refinement masks were manually edited in the Kings County region of the Annapolis Valley and the area around HRM and re-applied to the %ISA data. The final %ISA image for each scene was merged to have complete coverage across the province. In addition to this we have examined and demonstrated how more recent Landsat imagery from 2013 can be used to update and thus track the amount of development since 2005 around HRM.

The construction of a province wide impervious surface layer will have many benefits to both GIS practitioners and policy analysts who are concerned about runoff of contaminants and degradation of our aquatic ecosystems. This %ISA layer will act as a baseline of information that represents the spatial distribution of impervious material for 2005 (with some exceptions for areas where 2007 data had to be used) and can be used in the future to track the changes in development and the amount of impervious material. These data can be used in spatial analysis with watershed boundaries to assess which watersheds have the most %ISA and thus pose the most risk of runoff and possible contaminant exposure to our waterways, coastal areas and marine ecosystems. In addition to delivering GIS data layers that can be used for such quantitative analysis, we have also delivered the data in a convenient and informative layered PDF file format. This gives non-GIS users the ability to share, and through toggling layers on and off, visualize and understand the relationship of %ISA and the watershed boundaries and urban centre locations. This project has demonstrated an innovative approach to mapping %ISA using multi-source remote sensing data and refinement using GIS databases to produce a high quality information product that can assist in the protection of our ecosystems and allow for better landuse planning in the future.

5. Acknowledgements

We thank Colleen McNeil and Kelly Osmond from Environment Canada for administrating the project. We especially thank Sophia Foley from Nova Scotia Environment for contacting us to do the project and assisting with contacts at NB and USGS. We are grateful to Jon Dewitz for taking time out of his schedule to present the USGS methods on %ISA mapping and explaining the relationship between IMAGINE and Cubist. We thank Reid MacLean of NB Local Government for sharing the NB %ISA as well as other people we corresponded with in an attempt to track that data down and understand the previous project including: Rob Capozi of NB Environment and Lee Sochasky of St. Andrews NB.

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