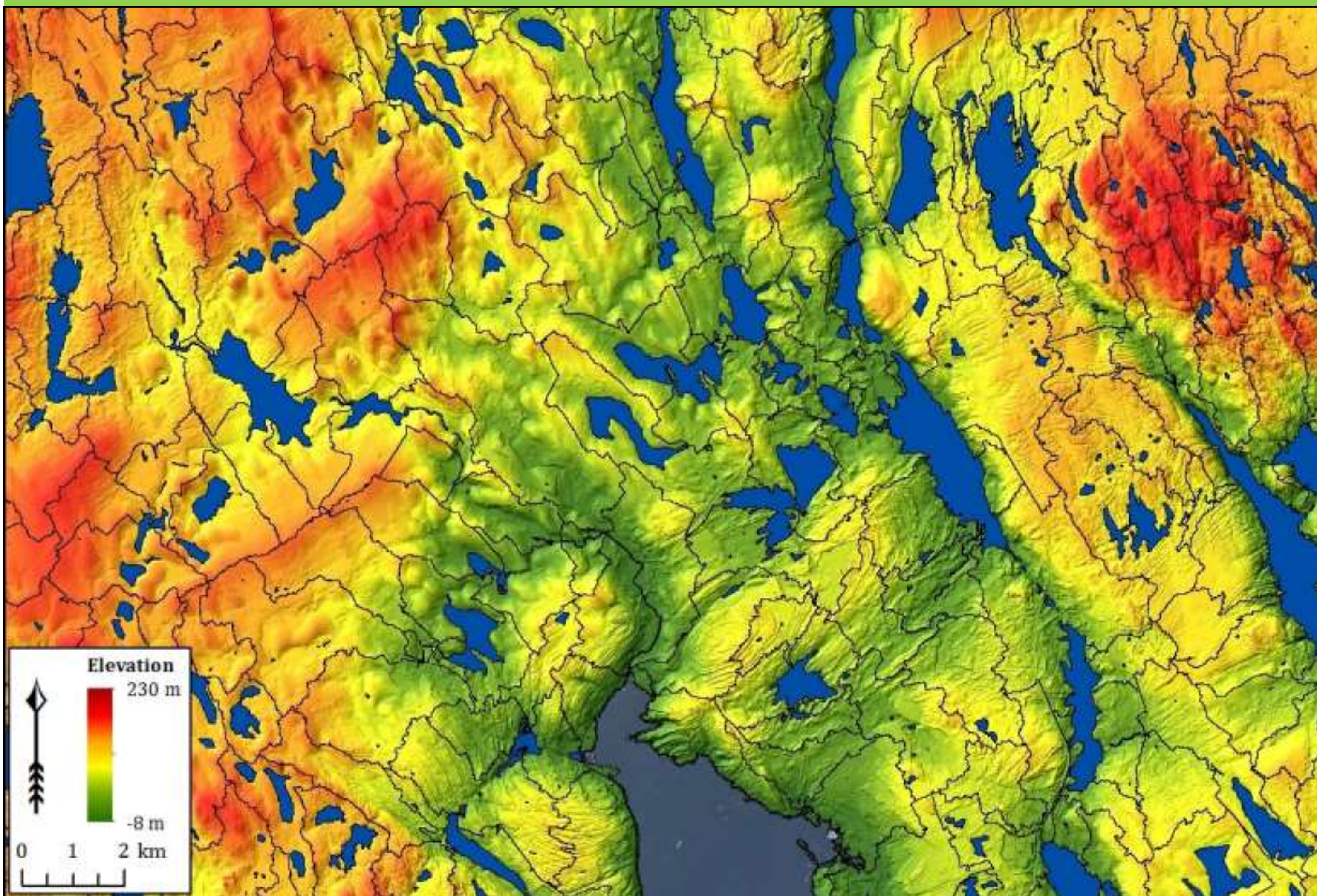
Lidar DEM Derived Watershed Development for Stormwater Tracking in Halifax Regional Municipality



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1 Introduction

1.1 Background and Study Area

Halifax Water is the municipal water, wastewater and stormwater utility serving the residents of the Halifax Regional Municipality (HRM). Halifax Water is interested in tracking stormwater to determine which of the utilities' features are active in evacuating stormwater precipitation.

Lidar elevation data is particularly well suited for surface hydrology related purposes such as watershed generation. The ability to remove all surface features such as trees and buildings to generate a bare-earth Digital Elevation Model (DEM) from lidar data, as well as its superior vertical accuracy of within 15 cm on hard, flat surfaces, permits the most realistic modeling of the flow of surface water.

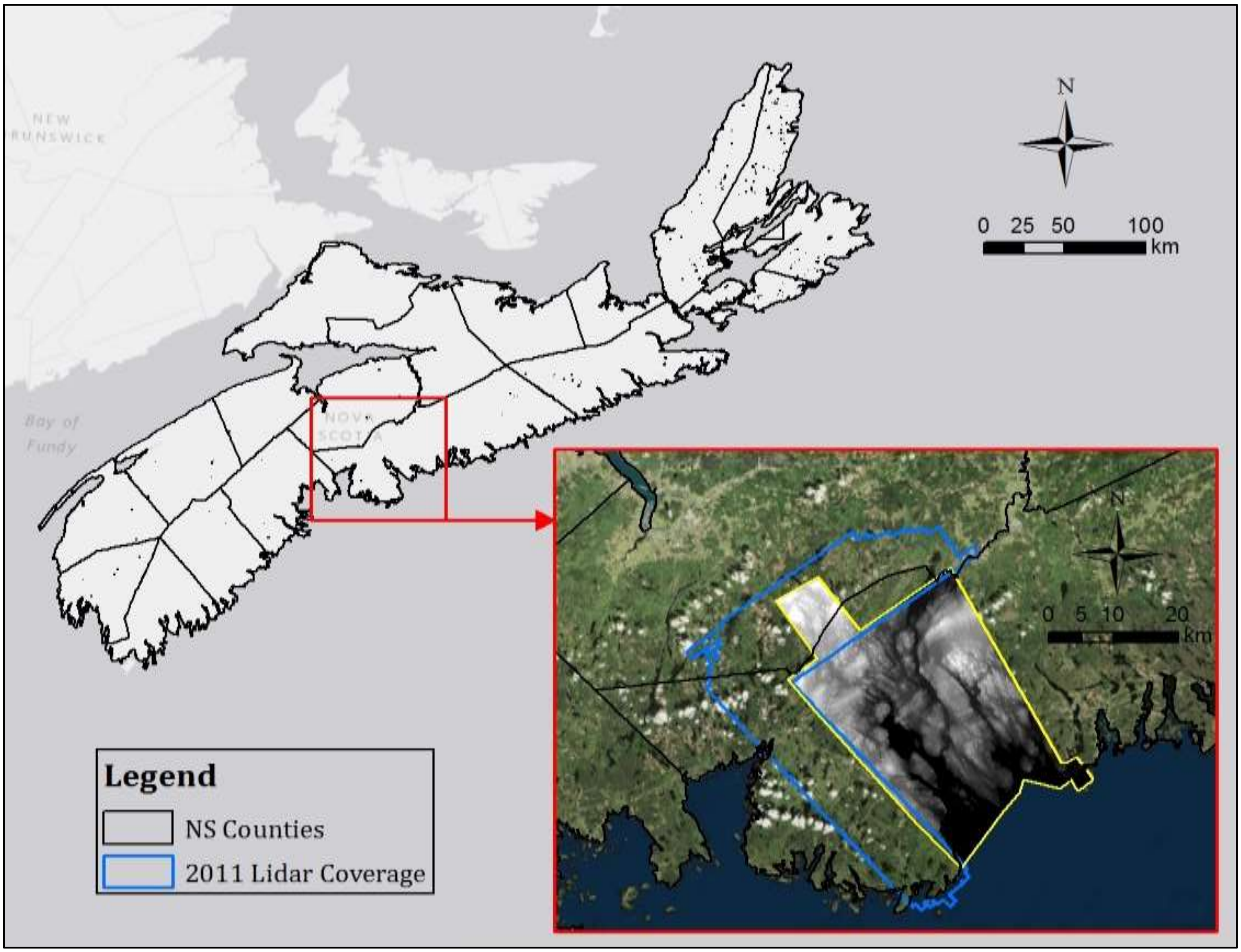


Figure 1. Two lidar datasets have been collected within the Halifax Regional Municipality - the inset map (red outline) shows the lidar DEM which was acquired in 2007 (yellow outline) and the adjacent additional lidar extent acquired by AGRG in 2011 (blue outline).

Halifax Water had previously acquired a lidar dataset of the Halifax Regional Municipality (HRM) that was captured in 2007 and processed by the Nova Scotia Community College's Applied Geomatics Research Group (AGRG) in 2011. In addition to that piece of lidar, shown in the Figure 1 inset map, AGRG captured additional and adjacent lidar coverage in 2011, shown in the same inset map. These data were processed in a basic fashion to ensure gapless coverage, though they were never processed to the full extent.

AGRG has been commissioned to process the 2011 lidar data to a bare-earth Digital Elevation Model (DEM), to merge it with the 2007 DEM, and to use internal AGRG and external ArcGIS tools to construct watersheds at a user defined accumulation threshold which yields results suitable for Halifax Water's desired applications.

The tools used in the subsequent analysis generate watersheds, which are areas which drain surface water to a single outlet (U. S. Geological Survey, 2015), as well as larger basins, which are composed of many watersheds and drain surface water in a larger outlet.

1.2 Copyright and Data Ownership

The Applied Geomatics Research Group of the Nova Scotia Community College maintains full ownership of all data collected by equipment owned by NSCC and agrees to provide the end user who commissions the data collection a license to use the data for the purpose they were collected for upon written consent by AGRG-NSCC. The end user may make unlimited copies of the data for internal use; derive products from the data, release graphics and hardcopy with the copyright acknowledgement of "Data acquired and processed by the Applied Geomatics Research Group, NSCC". Data acquired using this technology and the intellectual property (IP) associated with processing these data are owned by AGRG/NSCC and data will not be shared without permission of AGRG/NSCC.

2 Methods

2.1 2011 Lidar Processing and Merged 2007 – 2011 DEM Construction

Raw lidar points from data collected in 2011 were classified within Terrascan into ground and non-ground classes. The ground classified points were analysed and refined to reduce noise, and eventually converted into a raster surface at a 2 m spatial sampling interval using ArcGIS. The original elevations were referenced to the NAD83 ellipsoid, thus the DEM was converted so that the elevations are orthometric heights, thus referenced to the Canadian Geodetic Vertical Datum of 1928 (CGVD28) and consistent with the vertical reference of the 2007 lidar DEM.

The 2007 lidar DEM, which was originally produced as a 1 m DEM, was resampled using a cubic convolution technique to a 2 m DEM to accord with the newly gridded 2011 DEM resolution. The two rasters were mosaicked together, with the 2007 data used to fill in areas where no 2011 data existed. The edge where the 2011 DEM touches the 2007 DEM was blended to smoothen the topography in this area between 2007 and 2011 (Figure 2).

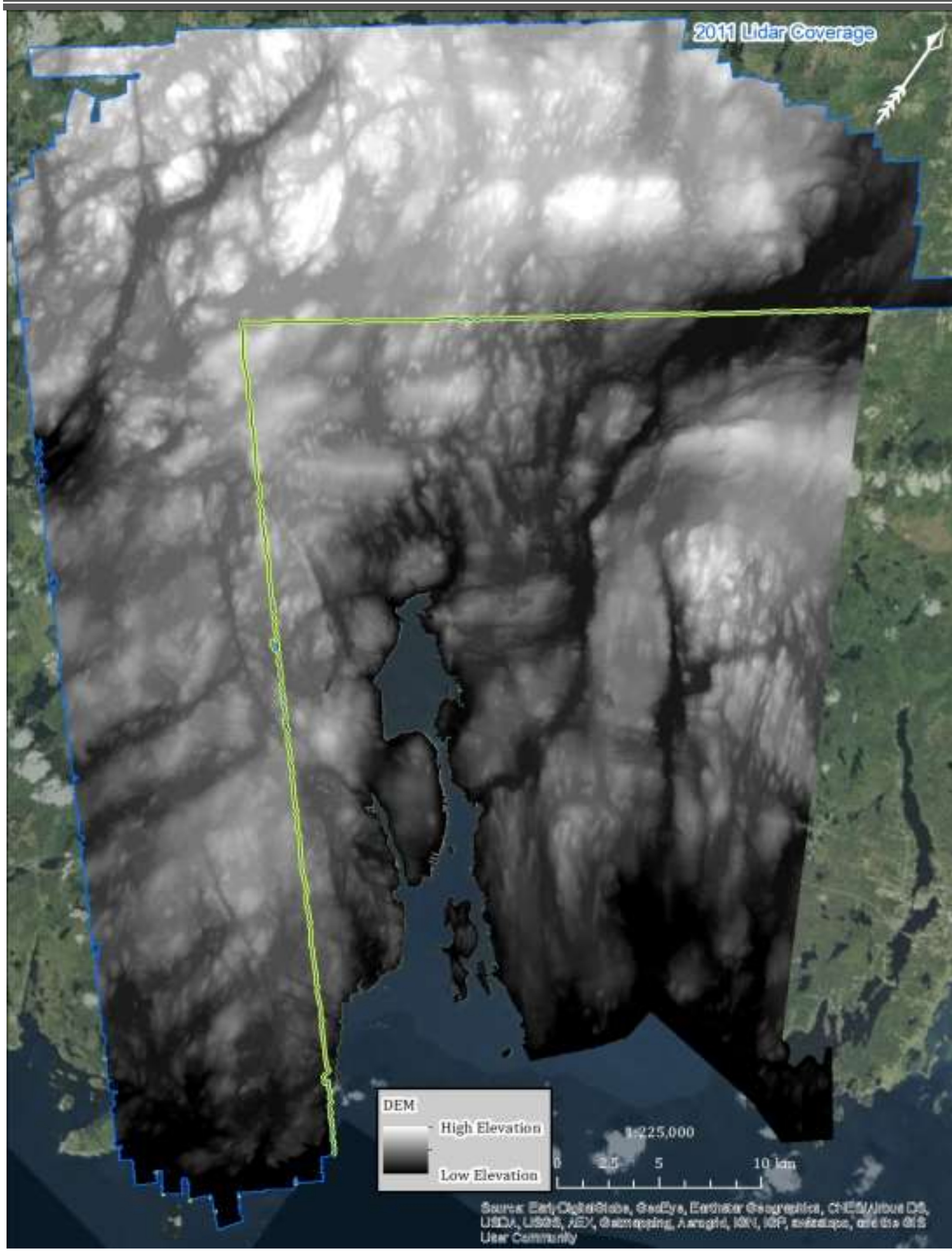


Figure 2. The merged seamless lidar data collected in 2011 (inside blue polygon) and 2007 (inside yellow polygon).

2.2 Hydraulic Connectivity

Prior to watershed development, the merged DEM must be modified to ensure hydraulic connectivity along water ways. Roads that have streams running under them typically contain a culvert or bridge to allow for the flow of water under the road. However, lidar points survey the surface of the road, not what is underneath it. Because of this, roads, bridges, or overpasses in the raw DEM act instead as barriers to water flow, much like a dam, and must be modified to reflect the real world water flow. For this purpose, hydroconnectivity data comprised of culverts, bridges, or overpasses within the study area were constructed as a line shapefile using various sources (Figure 3).

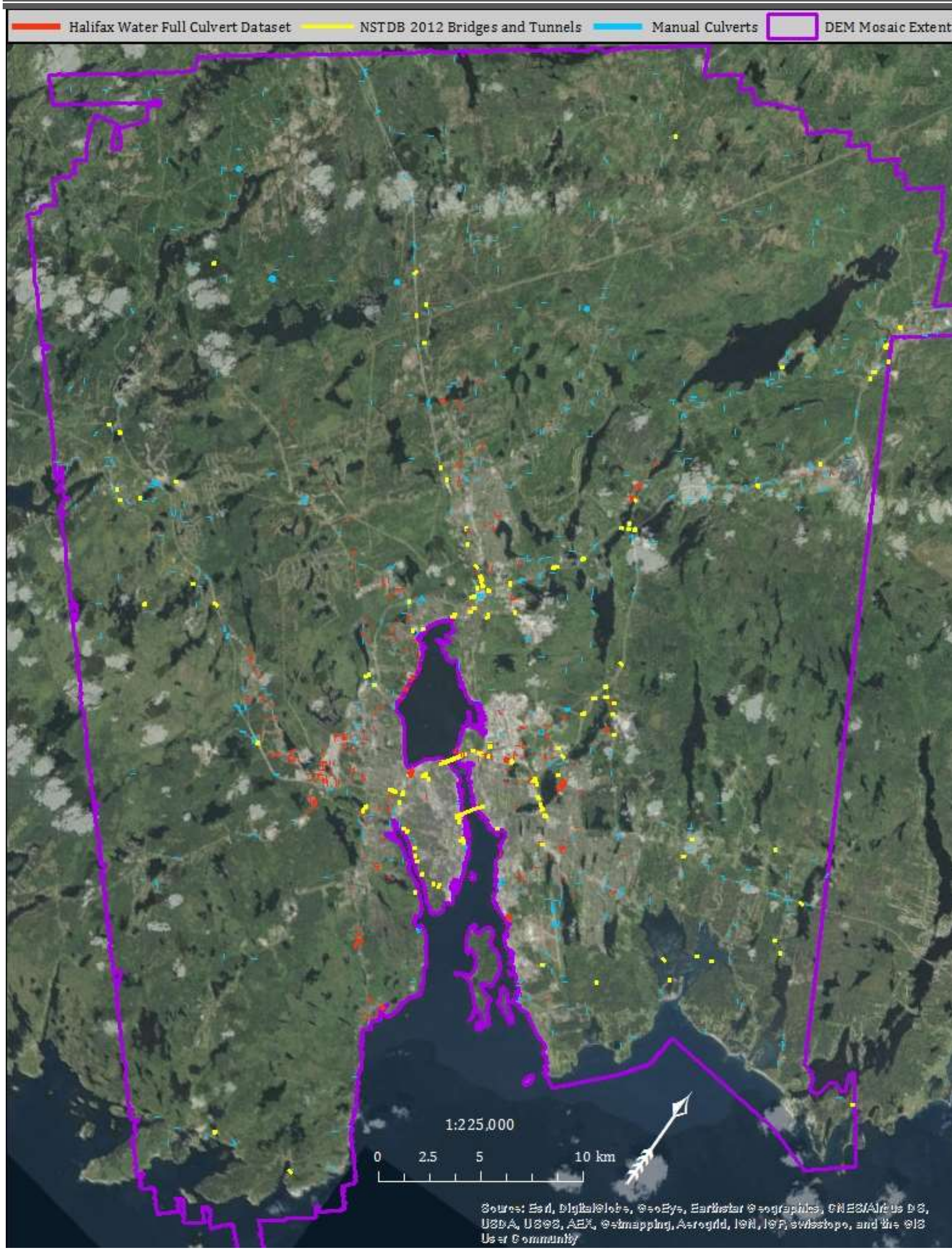


Figure 3. A line shapefile representing culverts, bridges, and overpasses was constructed from 3 sources: a Halifax Water features survey, the Nova Scotia Geographic Database roads layer, and a manual visual investigation.

A ready made culvert dataset was provided to AGRG by Halifax Water as a line shapefile comprised of 1128 features which were physically surveyed for Halifax Water. While helpful, these data covered only a portion of the study area (Figure 3), and lacked features such as overpasses and bridges.

To complete the hydroconnectivity data (furthermore simply called ‘culvert data’) for the remaining study area, various other datasets were used. First, the 2002 Nova Scotia Topographic Database ((Province of Nova Scotia, 2015) roads layer, which is information on roads, bridges, overpasses, and other road-related features except for culverts, was used to locate bridges and overpasses acting as barriers to water passage. At these locations, line features were manually constructed as hydraulic connections to modify these locations within the DEM (Figure 4).

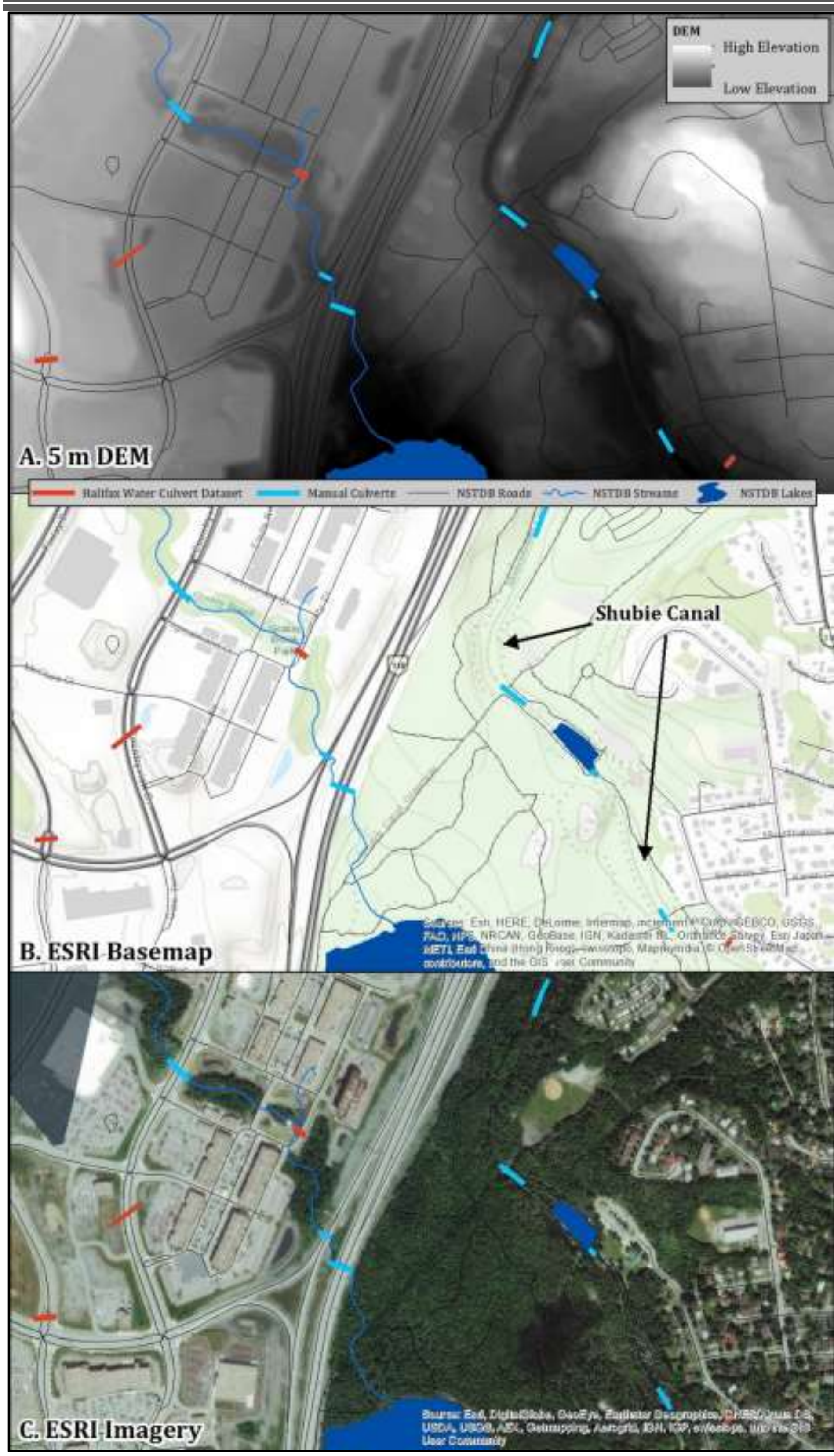


Figure 4. Visual inspection of locations where the Nova Scotia Topographic Database streams and roads layers intersect revealed various roads acting as barriers to water flow for the streams which flow underneath. Thus, culverts were manually constructed for these areas to connect the lower elevations (streams) on either side of the higher elevation barrier (the road) as shown on the DEM (A), on an ESRI basemap showing the Shubie Canal (B), and on ESRI imagery (C).

Next, the 2002 Nova Scotia Topographic Database (NSTDB) streams layer, which is information on rivers and streams in the province, was intersected with the NSTDB roads layer to determine where streams pass underneath roads, as culverts are likely at these junctions. To determine if a culvert does exist there, the 2 m DEM was investigated to determine if the elevations of the stream area on both sides of the road were similar, and if the road appeared to be acting like a barrier (Figure 4). If there was further uncertainty surrounding the existence of a culvert, the area was reviewed on Google StreetView for a definitive answer. In this manner, culverts located at the junctions of streams and roads were constructed manually to ensure hydroconnectivity.

The manual culvert dataset was merged with the Halifax Water culvert dataset to produce a final culvert dataset for the study area. Collaboration between Halifax Water and AGRG determined that the most appropriate DEM resolution for constructing watersheds is 5 m, so the 2 m DEM was resampled using a cubic convolution resampling method, and the culvert line shapefile was converted to a 5 m raster to match the resolution of the DEM to be modified. Then through a series of raster calculations involving the resampled 5 m DEM and the 5 m culvert raster, the pixels representing culverts in the new hydrodynamically (HD) correct 5 m DEM were set to a value of zero (0), representing zero metres elevation, thus providing a low elevation pathway to ensue water passes ‘under’ the road/bridge/overpass (Figure 5).

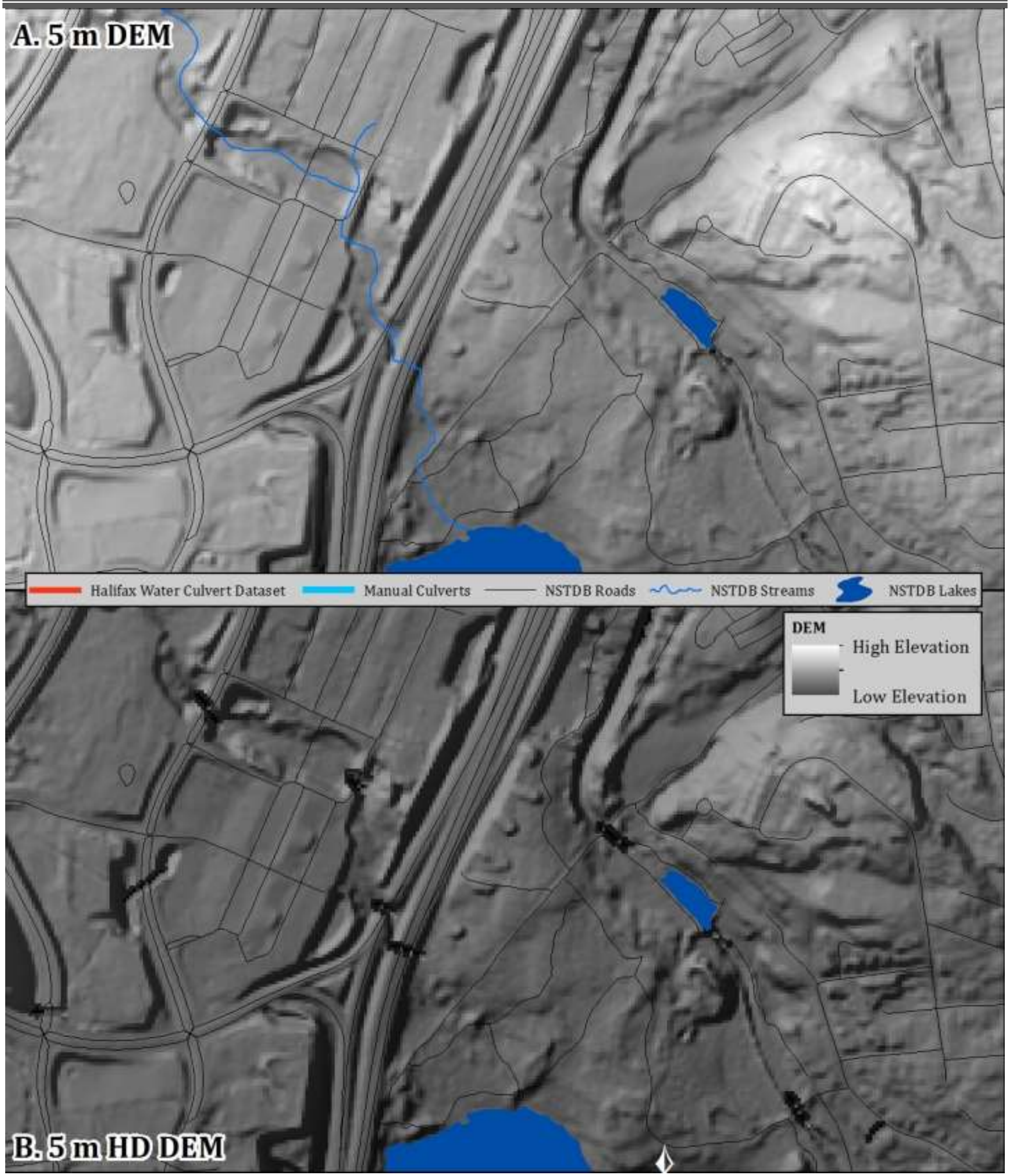


Figure 5. The HRM 5 m DEM before (A) and after (B) the process to make it hydrodynamically correct.

2.3 Watershed Development

2.3.1 Lidar processing

2.3.1.1 Deriving Basins and Watersheds

Further consultation between Halifax Water and AGRG determined that the most suitable accumulation threshold for the watersheds is 50,000, which results in a mean watershed size of roughly 220 hectares, or 2.2 million square metres. The GIS tool used in this process is an internal AGRG tool written for the purpose of delineating watersheds and their larger drainage basins at various thresholds. The user-defined threshold represents the minimum allowable accumulation area used to delineate a watershed which contributes to stream formation. Larger drainage basins possess the same extents regardless of the user-defined threshold, though basins along the landward edge of the DEM may not be accurate, as is explained further in Section 2.3.1.3.

2.3.1.2 Watershed Cleaning

Deriving watersheds from a lidar DEM results in boundaries that are located in areas covered by lakes. These lines are caused by multiple watersheds draining into one lake, as well as the similar elevation of the surface of the lake from one end to the other in the lidar DEM, and the watershed boundaries get divided into straight lines typically down the middle of the lake (Figure 6). To resolve these boundaries, polygons representing lakes and the Nova Scotia coastline were used. The lakes and NS coastline data are from the NSTDB. A full extent of the data used for cleaning can be found in Appendix C: Data Used for Refining Watersheds.

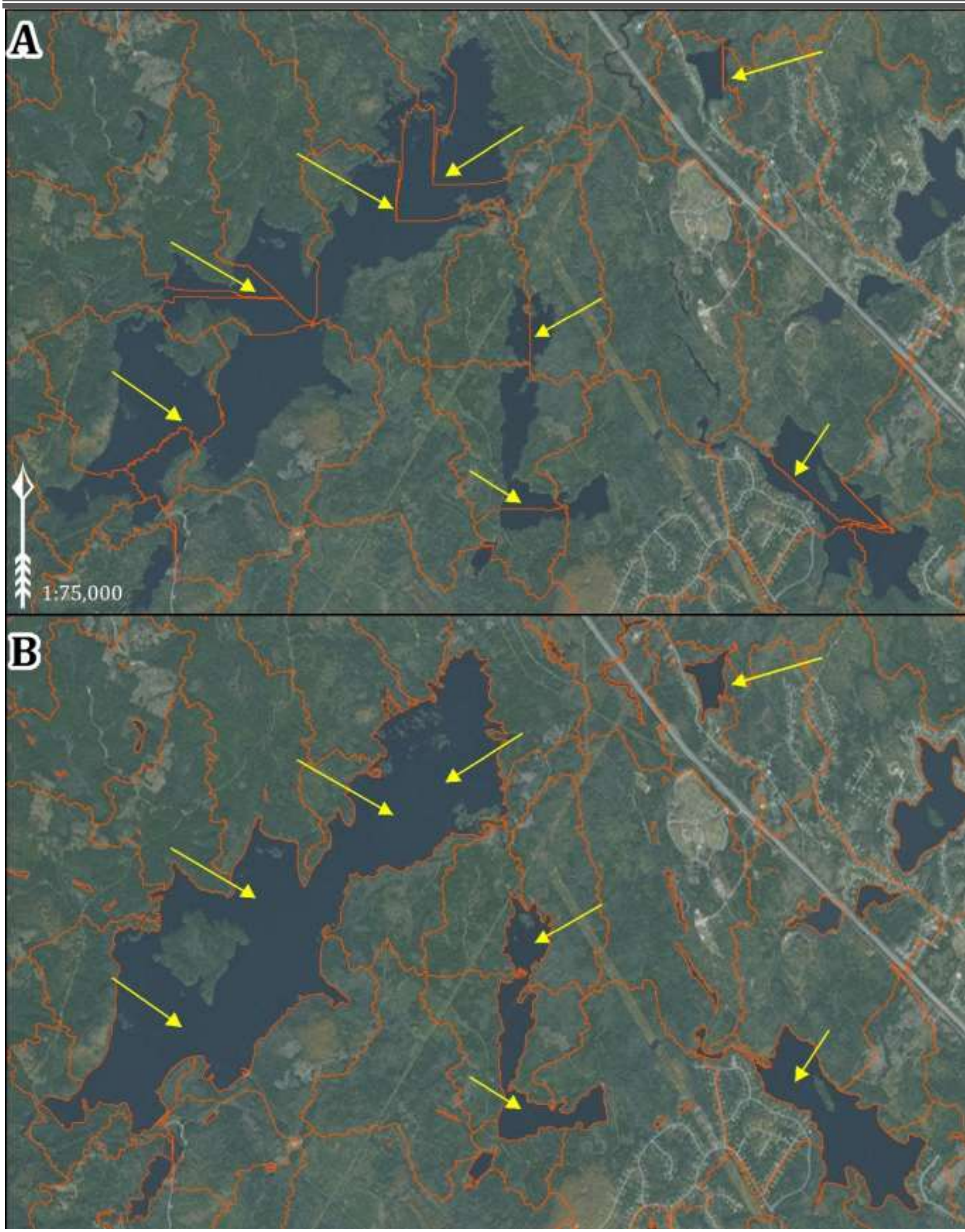


Figure 6. The raw watershed output (A, orange polygons) included unaesthetic lines in lake areas (shown by the yellow arrows) which were removed (B) using lake and coastline data layers.

This refining process results in more realistic watershed polygons. However, any islands that may exist within these lakes will not be included in any watersheds (Figure 7), though water on the islands clearly drain into their respective lakes.

Figure 7. Islands located in lakes (yellow arrows) within the HRM were removed from any watershed during the watershed cleaning process.

2.3.1.3 Watersheds Draining Outside DEM Limits

Areas along the edges of the DEM whose accumulation does not exceed the accumulation threshold of 50,000 result in gaps in the watershed results such as in Figure 8. However, the Arc tool still constructs drainage basins for these areas. Most of the basins are quite small, and along the landward edges of the DEM these basins would likely extend beyond the edge. However, along the Halifax Harbour edge of the DEM, the basins drain into the harbour. Consequently, basins along the harbour edge of the DEM were extracted for further refinement while watershed gaps along the landward edges of the DEM were regarded as incomplete and thus ignored.

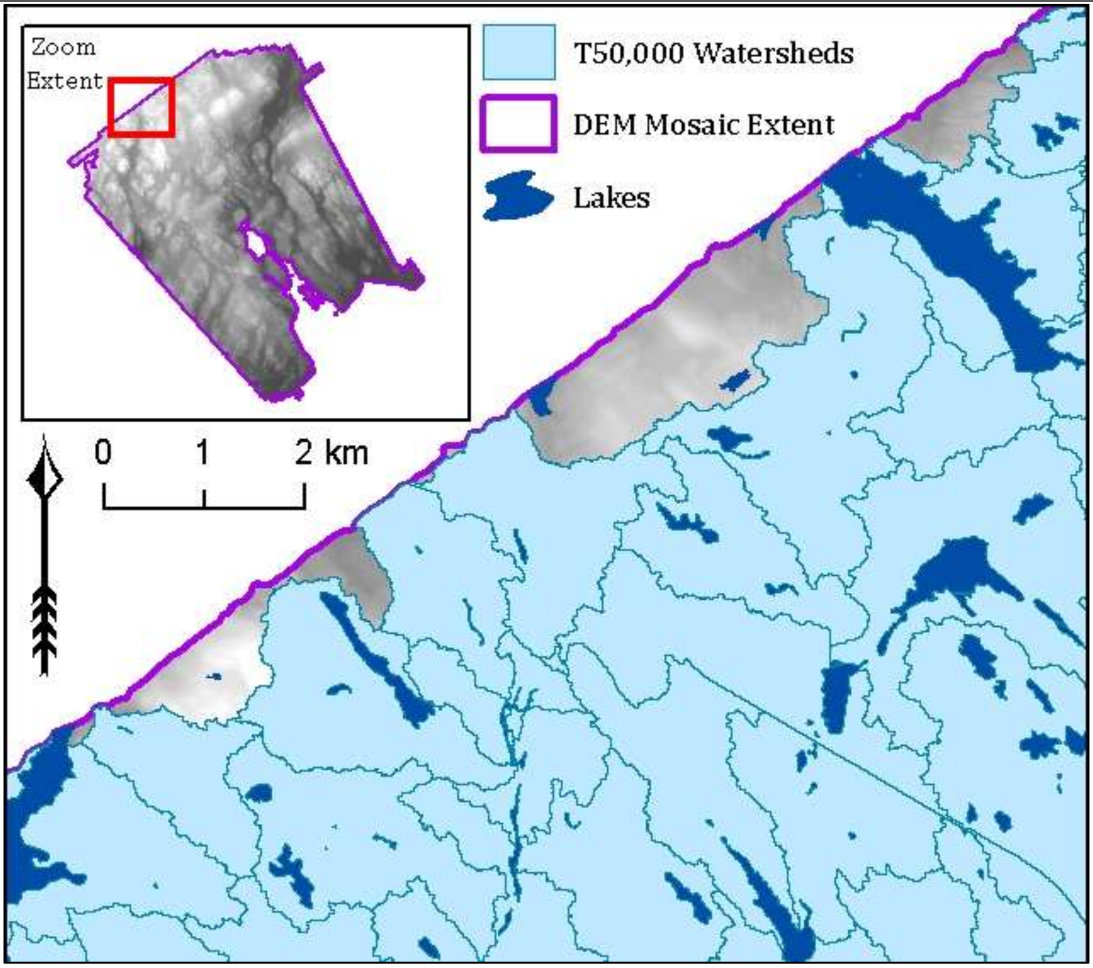


Figure 8. Portions of watersheds whose accumulation does not exceed the threshold at the edge of the DEM extent result in gaps around the edges of the study area.

2.3.1.4 Watersheds Draining Into Halifax Harbour

Basins which were output with a direct drainage path into the Halifax Harbour (either directly or via the Bedford Basin or Northwest Arm) were output as 7,573 separate and mostly very small basins (henceforth considered watersheds for this purpose), the mean size being 6,619 m^2, though 5,484 m^2 (or 72%) of the watersheds are under 1,000 m^2 in size. These 7,573 watersheds were merged into one larger watershed within the final watersheds polygon layer, as well as provided as a separate independent layer of unmerged watersheds (Appendix D: Individual versus Merged Watersheds Draining into Halifax Harbour).

3 Results and Conclusion

Both watersheds and larger basins were constructed from the merged 5 m DEM at a threshold of 50,000. Although basins are generally larger and composed of multiple watersheds, many small basins were generated around the edges of the DEM for areas whose drainage outlet lies outside the DEM (on land-locked edges) or in the Halifax Harbour (Figure 9).

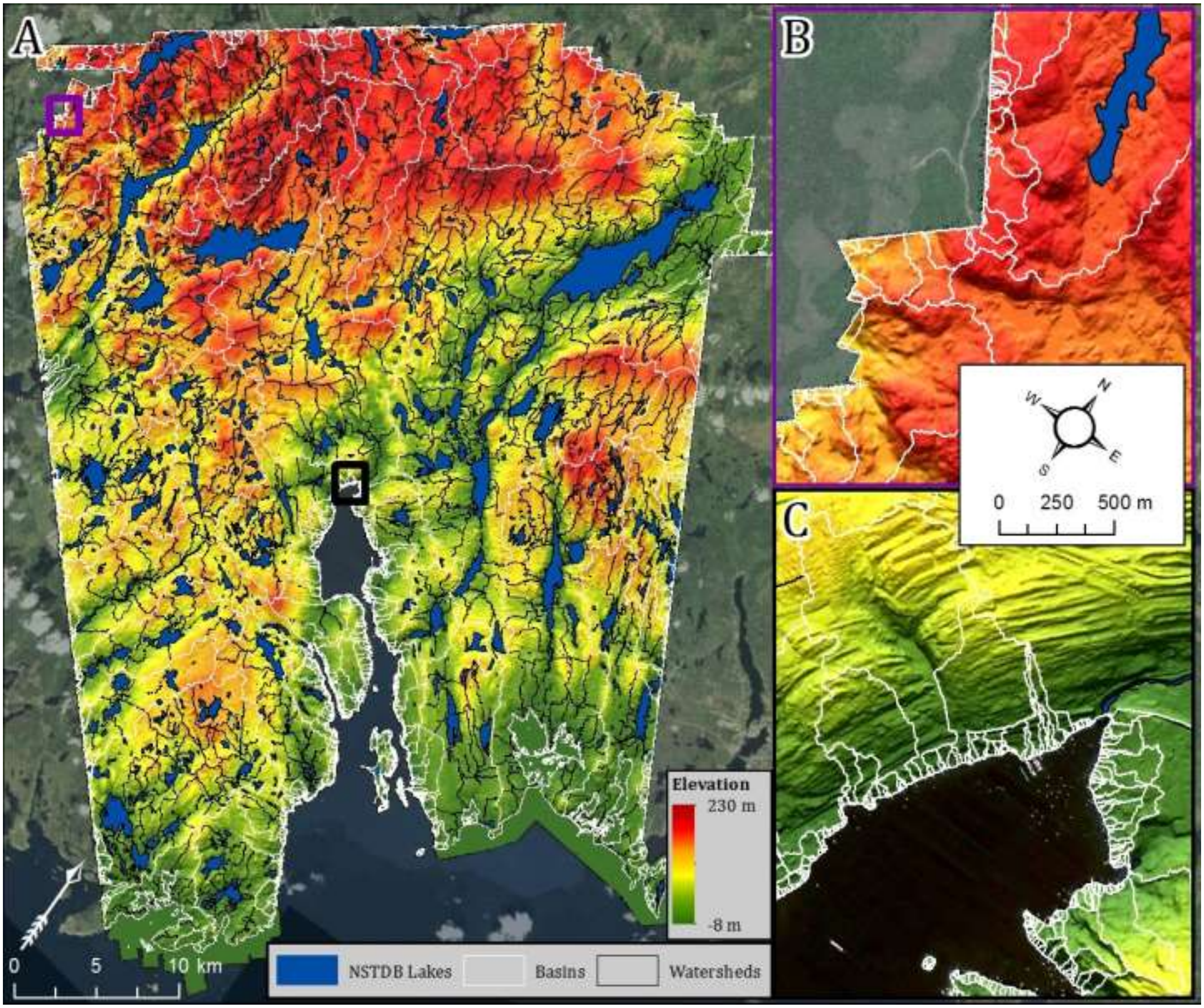


Figure 9. All basins and watersheds derived from a 5 m HD DEM analysis (A), with insets showing various small basins along a land-locked edge (B, purple extent) and the Halifax Harbour (Bedford Basin) edge (C, black extent) of the DEM. Maps are shown on a colour shaded relief with ESRI imagery as a backdrop.

The 7,573 watersheds (derived from the resulting basins shapefile as detailed in Section 2.3.1.4) which drain into Halifax Harbour were extracted and provided as an independent shapefile. The mean (average) size of these small watersheds is 6,619 m^2, with a median size of 345 m^2 (Table 1). The median value is much smaller than the mean, indicating that the majority of these features are much smaller than the average, which the statistics support, as 7,162 out of 7,573 (or 94.6%) of these harbour draining watersheds are under 1 hectare in size.

In addition, these 7,573 features were merged together as one watershed and added to the watershed shapefile, resulting in a final total of 770 watersheds. The average watershed size is 2,134,706 m^2, while the median watershed size is 1,710,035 m^2, indicating that the majority of the watersheds in the area are smaller than the average.

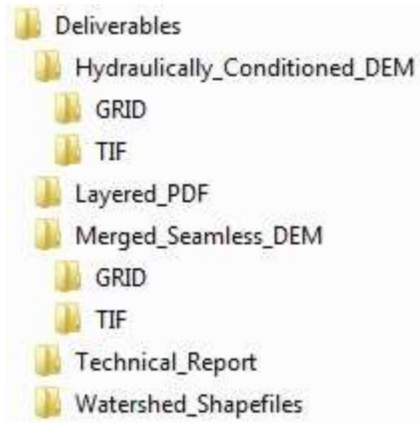
Finally, 11,994 basins were generated for the area, with the mean size of 154,769 m^2 and a median size of 384 m^2 (Table 1). While true basins are composed of multiple watersheds together, as is evidenced by the comparatively larger maximum basin size, the mean basin size is significantly less than the mean watershed size. This results from 92.2% of the basins (or 11,060 our of 11,994) being less than 1 hectare in size, most of which are found along the edges of the DEM.

Table 1. Statistics including minimum, maximum, mean, and median size in square metres for the three shapefile deliverables - all watersheds, watersheds draining into Halifax Harbour, and all basins.

Shapefile Dataset	Number of Features	Minimum (m^2)	Maximum (m^2)	Mean (m^2)	Median (m^2)
Watersheds (all; merged watershed draining into Halifax Harbour)	770	6,864.55	50,127,254.88	2,134,705.87	1,710,035.31
Watersheds (only individual ones draining into Halifax Harbour)	7,573	0.58	1,226,800.00	6,619.19	345.71
Basins	11,994	0.002	383,221,800.00	154,768.93	384.02

4 Deliverables

A total of ~ 9 GB of spatial data, plus this technical report comprise the deliverables. Data deliverables are in accordance with the contract deliverables. The data delivered in the top level directory (Deliverables) falls into one of five categories: Hydraulically_Conditioned_DEM (includes GRID and TIF folders), Layered_PDF (includes results in a layered PDF format), Merged_Seamless_DEM (includes GRID and TIF folders), Technical_Report, and Watershed_Shapefiles, as shown below. All spatial deliverables are projected in NAD83 UTM Zone 20 North.



The hydraulically conditioned DEM is a 5 m DEM that has been modified to include culverts and bridges, while the merged seamless DEM is the original, non-hydraulically connected DEM in both 2 m and 5 m resolutions.

The watershed shapefiles contain various attributes which are explained in Table 2, as well as the names and details of each raster that has been delivered.

Table 2. Full list of all delivered shapefiles (with their associated attributes) and rasters.

Shapefile	Information
T50000_watersheds	Watersheds constructed with an accumulation threshold of 50,000 (T=50,000)
T50000_watersheds_HarbourDrain	Individual watersheds (T=50,000) draining into Halifax Harbour either directly or via the Bedford Basin or Northwest Arm
T50000_basins	Drainage basins constructed with an accumulation threshold of 50,000 (T=50,000)
Attribute	***Meaning***
FID	*Internal ARC attribute*
Shape	*Internal ARC attribute; polygon shapefile*
Area_m2	*Computed surface area of the watershed in square metres*
Area_ha	*Computed surface area of the watershed in hectares*
Area_ac	*Computed surface area of the watershed in US acres*
Raster	**Information**
Hydraulically_Conditioned_DEM	Merged seamless DEM which has been hydraulically conditioned to include culverts, bridges, and overpasses; 5 m resolution only
Merged_Seamless_DEM	Merged lidar datasets collected in 2007 and 2011 for the Halifax Regional Municipality; 2 m and 5 m resolution

5 Appendix A: Resulting Basins and Watersheds on a Colour Shaded Relief

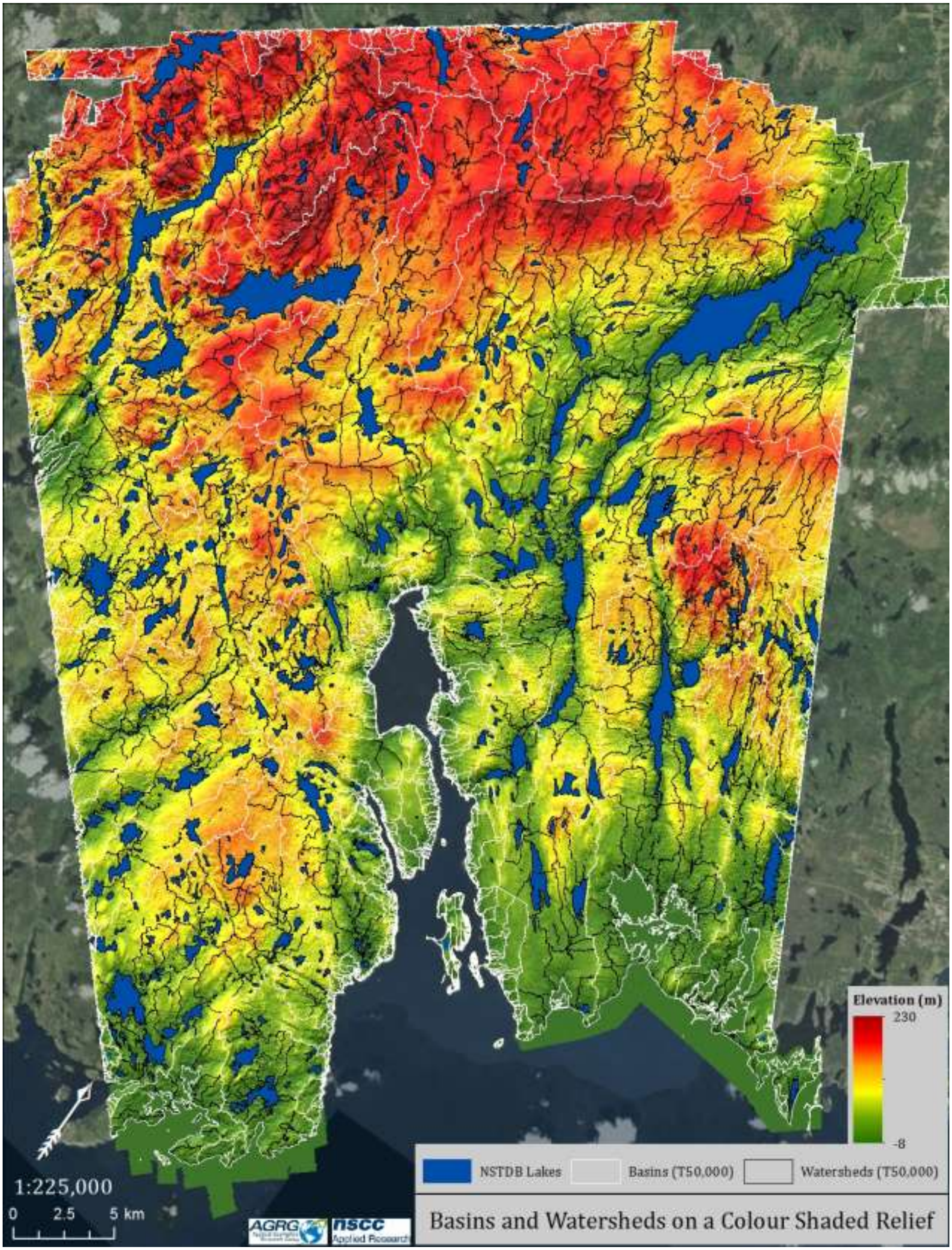


Figure 10. Basins (white outlines) and watersheds (black outlines) resulting from a threshold of 50,000, shown on an elevation-coloured hill-shaded relief atop ESRI base imagery.

6 Appendix B: Culvert Data

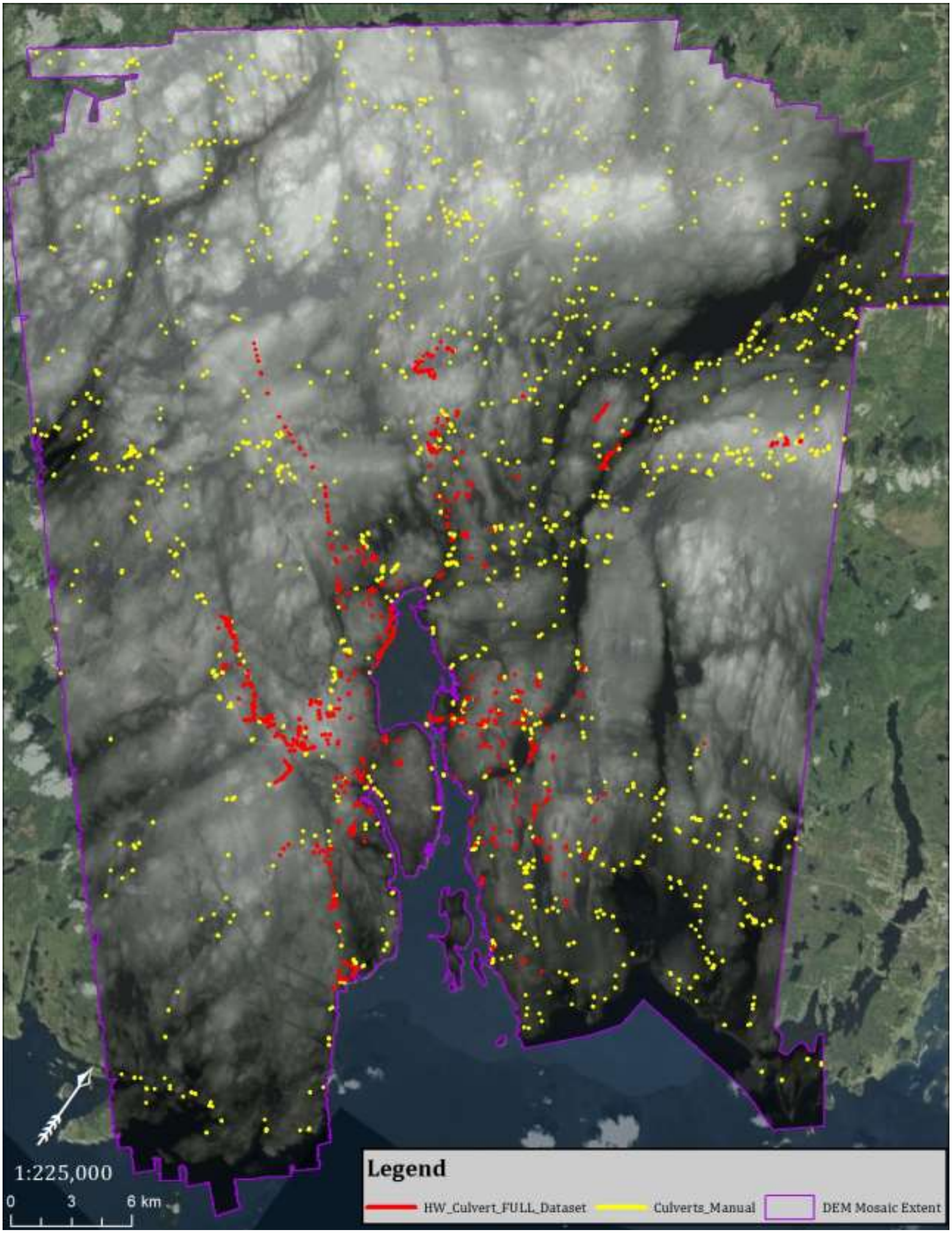


Figure 11. The culverts used to modify the DEM includes a culvert dataset from Halifax Water (in red) and manually constructed culverts (in yellow).

7 Appendix C: Data Used for Refining Watersheds

Figure 12. The Nova Scotia Topographic Database lakes layer, along with the NSTDB coastline layer, were used to clean artifacts from the resulting watershed results.

8 Appendix D: Individual versus Merged Watersheds Draining into Halifax Harbour

Figure 13. A portion of the 7,573 individual watersheds (A) which drain into the Halifax Harbour (pictured is the Northwest Arm), and the merged dataset (B).