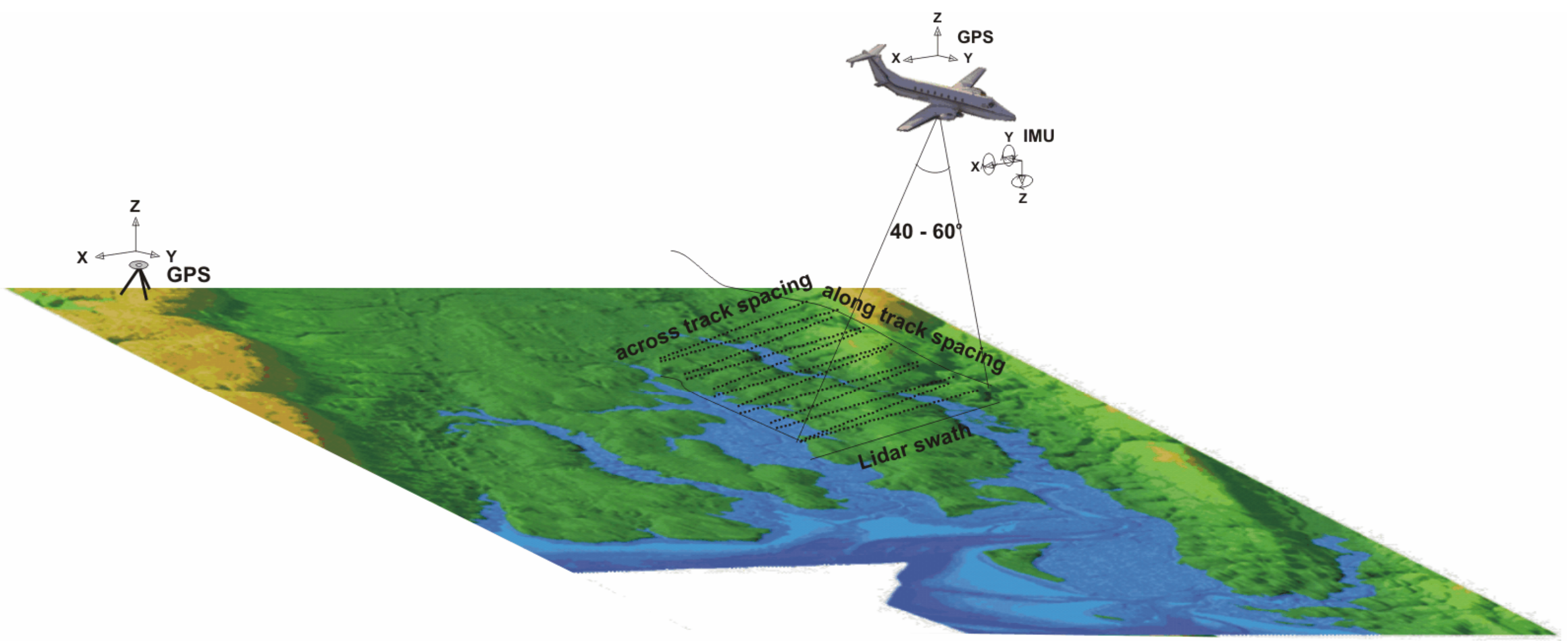
Light Detection and Ranging (lidar) Strategic Directions Report for the Province of Nova Scotia



Prepared for the GeoNOVA Steering Committee

March 31, 2012
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On behalf of the Nova Scotia LiDAR Working Group

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EXECUTIVE SUMMARY

This report is the result of the input from participants of the Nova Scotia Lidar Working Group, which reports to the GeoNova Steering Committee. The report highlights lidar technology (a remote sensing method that uses a laser ranging system in an aircraft to acquire high-resolution elevation data at 1-2 m resolution with a vertical accuracy less than 15 cm) and the many geospatial applications that can benefit from this type of information. In the past, elevations for topographic maps were derived from stereo aerial photography that had vertical accuracies on the order of 2.5 m and were degraded in forested areas. However, today lidar is the preferred method for the collection of detailed elevations of the ground and for the features above the ground like trees and buildings.

All of the provincial departments that use maps and geospatial information can benefit from a high-resolution elevation model. Lidar has been acquired for small regions of the province by different levels of government and academic institutions dating back to 1998. Most recently lidar has been used to generate flood risk maps for five communities along the coast of Nova Scotia as part of the Atlantic Climate Adaptation Solutions project led by NS Environment. Detailed lidar elevation data has also been used by NSTIR for highway projects including the planning of interchanges and twinning, resulting in substantial cost and time savings as compared to traditional methods to obtain elevations. Other applications of lidar include: more precise measurements of tree heights and timber volume, more detailed watershed boundaries and determining where water will flow (can be used to trace contaminants back to the source), making more accurate geological maps since lidar can measure the ground under the forest canopy, more accurate flood plain mapping and flood inundation from river run-off and storm surges along the coast, planning new roads and other infrastructure (power lines, pipelines, bridges, water supply and waste water treatment plants etc.) and engineering projects, development of subdivisions, line of site applications such as telecommunication tower siting, forest fire modelling, and tourism to show off our beautiful landscapes and vistas, to name a few.

The two largest municipalities in the province (CBMR and HRM) have already acquired large sections of lidar within their region. The other smaller municipalities around the province, especially those with a high proportion of their population and infrastructure along the coast or rivers could benefit in numerous ways from the acquisition of lidar. For example identifying what assets are vulnerable to flooding from run-off or sea-level rise and climate change. This will allow them to plan adaptation measures to ensure their communities are sustainable in the future. The NS Union of Municipalities has recognized the value of lidar and requested the province to assist in moving forward to acquire it, initially for high risk areas.

The report presents the current state of the technology as well as emerging technologies that could be very advantageous to a coastal province such as Nova Scotia to map our near shore resources as well as map the areas most vulnerable to erosion. Best practices for lidar procurement, defining specifications for lidar point density and vertical accuracy, data validation requirements, and GIS map product development are presented along with a summary of local experiences from all levels of government within NS for acquiring lidar. Finally, the idea of communication and collaboration in order to coordinate all potential stakeholders to pool their funding resources in order to get the best “bang for the buck” when acquiring lidar is presented. It is proposed that a group with lidar experience (provincial department or an academic research group) be tasked with the responsibility to coordinate lidar activities for the province. The report concludes with a list of recommendations the province should consider in order to coordinate and advance the acquisition and application of lidar data to solve a variety geospatial problems that face the provincial departments and municipalities within Nova Scotia.

1 PURPOSE

This report is to provide the province of Nova Scotia with feedback related to the strategic direction of lidar technology and applications utilizing lidar data. Lidar stands for Light Detection and Ranging and is similar in principal to radar (Radio Detection and Ranging) with the primary difference being that lidar uses near-infrared radiation, while radar uses energy from the microwave region of the spectrum. Initially lidar was written "LiDAR" since it represented an acronym of several words, however as it has gained popularity, it is more commonly written "lidar" similarly as we now use the term "radar". For example, one of the leading lidar manufacturers in the world is Optech from the Toronto area who uses the term "lidar" as stated on their website **"**Optech is the world's leading maker of reliable, rugged, and innovative lidar survey products, with over 35 years of experience worldwide**"**.

A lidar system is comprised of a laser ranging system mounted in an aircraft that directs a laser pulse towards the ground and measures the two way travel time it takes that pulse to leave the aircraft, reflect off the ground and travel back to the aircraft where it is received. By knowing the speed of light, the travel time is converted into a distance or "range" from the sensor-aircraft to the target-ground. By knowing the position of the aircraft from GPS, these laser ranges are positioned in space and can be used to derive very detailed maps of the topography (Flood and Gutelius, 1997; Wehr and Lohr, 1999). The details of a lidar system are further explained in section 4 of this report. Lidar systems allow the terrain to be measured at very high densities compared to traditional aerial photo methods that were previously used to obtain elevations of the ground for topographic mapping. It is not uncommon to have lidar point spacing's on the order of decimeters to meters and vertical accuracies of the points better than 15-30 centimeters.

The lidar points are classified into those representing the ground and other non-ground features (vegetation or buldings) and used to construct continuous surface models in the form of grids or rasters. Standard lidar surfaces can be derived from combinations of the ground and non-ground points. Using all of the points (ground + non-ground) a Digital Surface Model (DSM) can be constructed which incorporates the buildings and tree tops along with the ground. The most common lidar surface that is typically generated is a Digital Elevation Model (DEM) which represents the bare-earth and is built using just the lidar ground points. Another surface can then be easily derived to represent the height of objects above the ground, known as the Normalized Height Model (NHM) which is the difference between the DSM and DEM (e.g. NHM = DSM – DEM). Maune (2001) has produced an excellent reference book on the construction and applications of DEMs for a variety of application areas.

The increased detail (both horizontal and vertical) available from a lidar survey is why this technology has become so popular and is the preferred method today for the collection of elevation data for mapping. In addition, the ability to acquire the data remotely with minimal ground disturbance or ground personal has also made this method of elevation collection popular. Despite the use of lidar by the private sector and at the provincial, municipal and federal levels of government and academia, no common specifications exist to provide guidelines for the acquisition, processing and quality assurance of airborne lidar in Nova Scotia.

In 2009, the GeoNOVA Steering Committee formed a working group with the intent to provide recommendations to the Government of Nova Scotia regarding any future direction involving lidar technology. The Terms of reference of the Nova Scotia Lidar Working Group are included in Appendix 1. This report summarizes the findings of the Nova Scotia Lidar Working Group, which reports to the GeoNova Steering Committee. Other users of geospatial information will benefit from the technical and application discussions of lidar presented in this report. The goal of this report is to provide information to parties interested in procuring lidar data, using existing data, collaborating on lidar projects, and providing guidelines on lidar specifications and expected accuracy details for typical geospatial applications.

2 BACKGROUND

Lidar technology has become well known as an extremely accurate mapping tool and demand for lidar has increased in Nova Scotia. As previously mentioned, the GeoNOVA Steering Committee formed a working group with the intent to provide recommendations to the Government of Nova Scotia regarding any future direction involving lidar technology. The group was chaired by Mr. Colin MacDonald, from the GeoNOVA Program Office, and consisted of participants from provincial, federal, municipal, and educational organizations. The group met throughout 2009 and 2010, considering topics relevant to lidar technology such as data sharing, metadata, technical specifications, and collaborative approaches for lidar projects.

3 CURRENT SITUATION

Lidar mapping has been conducted in the province of Nova Scotia since 1998, starting with a demonstration survey conducted by Optech for the Geological Survey of Canada and the Canadian Hydrographic Service. The test areas that were flown included: Truro, part of Halifax, and Chezzecook Inlet. The next significant lidar campaign took place in 2000 when the Centre of Geographic Sciences (COGS) of the Nova Scotia Community College (NSCC) was funded through a Canada Foundation for Innovation (CFI) grant to explore high resolution elevation models and imagery for the coastal zone (Webster et al., 2004b). The Applied Geomatics Research Group (AGRG) was created from COGS as a result of this grant and contracted two companies to acquire lidar for the entire Annapolis Valley and coast of the Bay of Fundy from Grand Pre to Digby. The companies contracted to acquire the lidar were GeoSurv from Ottawa who surveyed the areas from Lawrencetown to west of Bridgetown and Terra Remote Sensing Inc. from Surrey British Columbia who surveyed the remainder of the areas of the valley. As a result of technical difficulties the areas surveyed by Terra Remote Sensing did not meet the contract specifications as tested and reported on by researchers at AGRG. Terra Remote Sensing re-flew the area from Lawrencetown to Grand Pre in May of 2003 and from west of Bridgetown to Digby in April of 2004. These data met the specifications of the contract and were accepted by AGRG and used to construct various surface models for the entire valley and coastal region (http://agrg.cogs.nscc.ca/LiDAR-DEM) (Fig. 1).

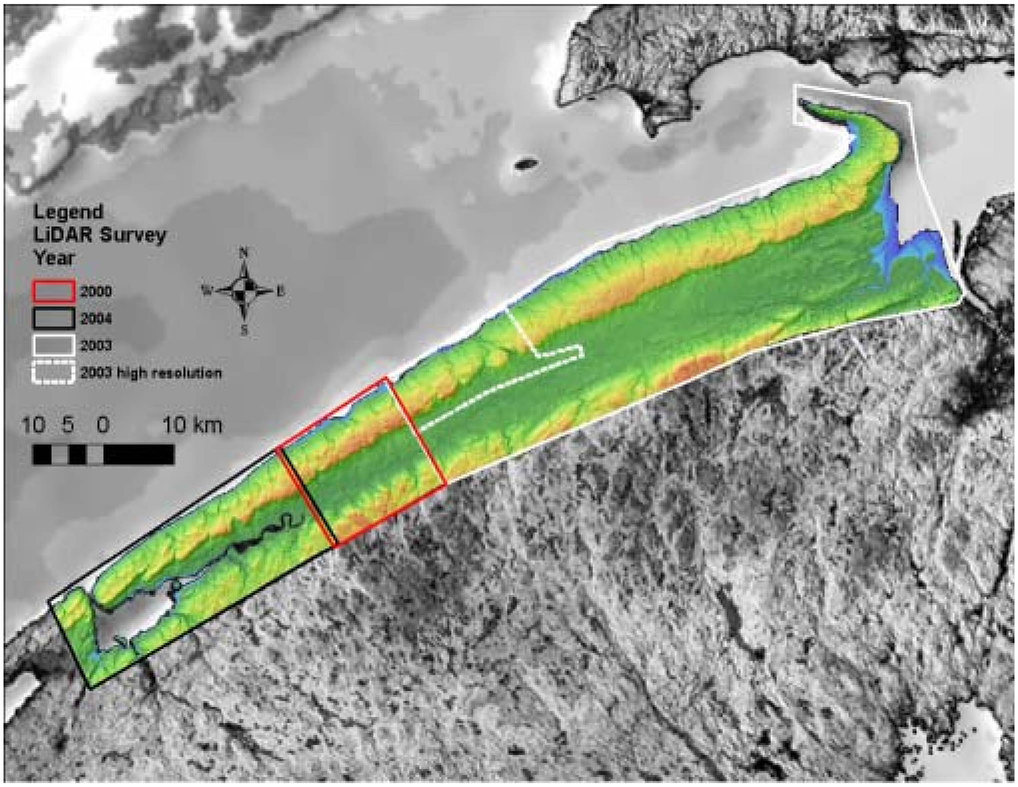

Figure 1 First wide area lidar survey covering the Annapolis Valley and coastal zone of the Bay of Fundy contracted by the Applied Geomatics Research Group, NSCC.

Lidar was used for flood risk assessment in Prince Edward Island as part of a large multi-agency climate change assessment report (Webster, Forbes, Dickie and Shreenan, 2004). This project was followed up by another multi-agency coastal assessment of the risk from climate change for the southeast coast of New Brunswick. That project also involved using lidar to generate flood risk maps for storm surge and sea-level rise (Webster, Forbes, MacKinnon, and Roberts, 2006b). Natural Resources Canada funded a much smaller project to assess the risks of climate change in communities in the Annapolis Valley and flood risk maps were generated for the Town of Annapolis Royal that utilized lidar collected in 2004 as part of AGRG's CFI grant (Webster, 2010).

In 2003 AGRG was awarded another CFI grant to acquire lidar technology which resulted in the acquisition of an Airborne Laser Terrain Mapper (ALTM) 3100 system and a ground based tripod mounted lidar known as the ILRIS 360 from Optech. Various lidar surveys were conducted from 2005 to present in order to support various research projects, including a significant portion of Nova Scotia's coastline (Fig. 2).

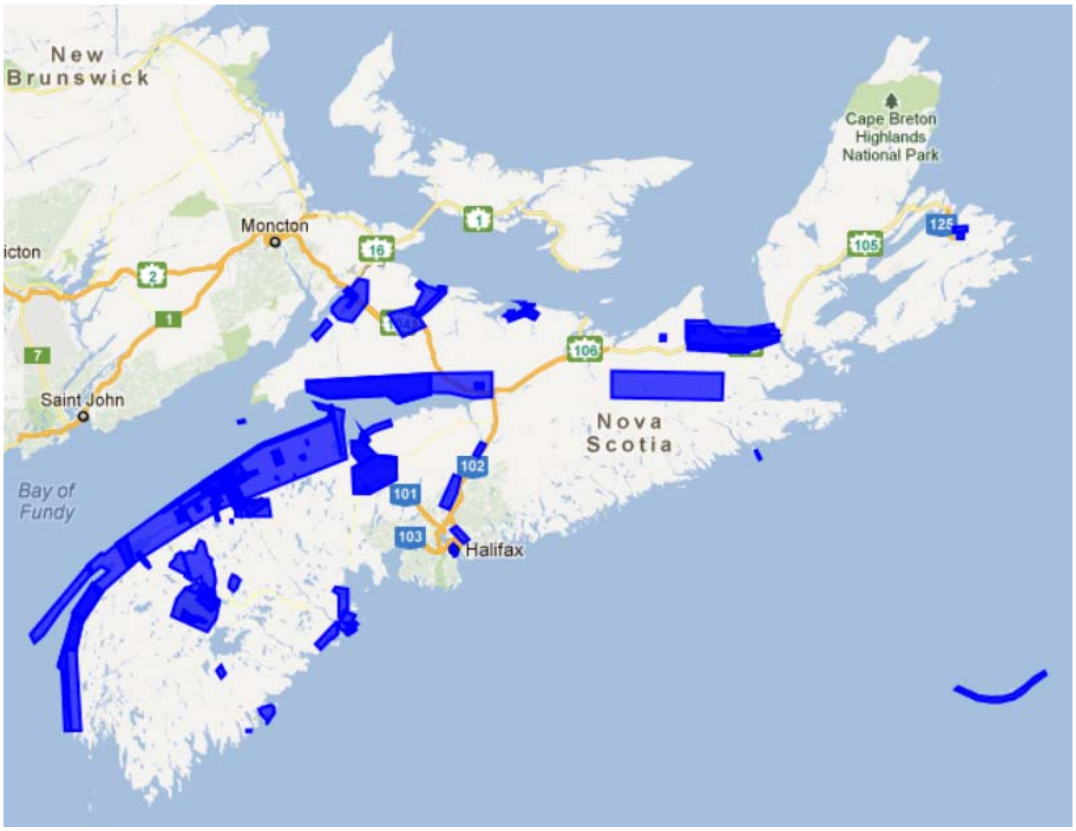

Figure 2 Lidar acquired by the Applied Geomatics Research Group, NSCC including data collected by contractors and using their own ALTM 3100 sensor as of 2010.

In 2007 the Halifax Regional Municipality (HRM) contracted PHB, out of Quebec, to acquire lidar for a large area (Fig. 3). Initially only the data around the harbor were processed and used to construct flood risk maps as a Geological Survey of Canada Open File report 6346 (http://www.halifax.ca/regionalplanning/documents/OF6346final.pdf) (Forbes et al., 2009). Recently the entire study area has been processed to construct lidar surface models (bare-earth DEM, all lidar points Digital Surface Model - DSM, and a Normalized Height Model – NHM).

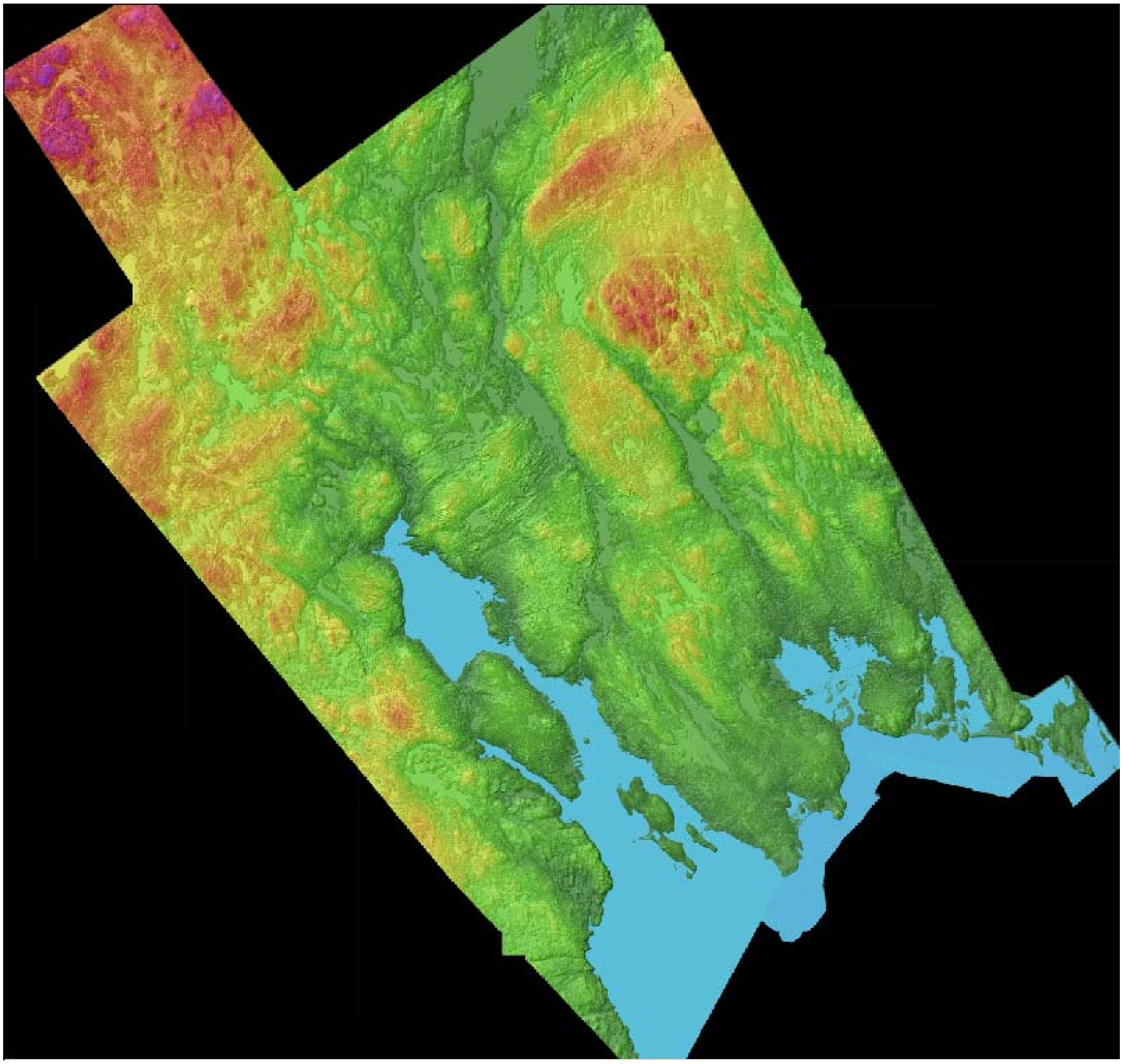

Figure 3 Halifax Regional Municipality lidar coverage acquired 2007. Halifax harbour is at the centre of the map.

In 2007 Leading Edge Geomatics (LEG) was established in Lincoln NB initially providing full digital orthophotos with their Applanix Digital Sensor System. They rented the lidar ALTM3100 from AGRG to gain experience and eventually purchased their own lidar system, a Reigal Q680. Today they own multiple lidar and camera systems along with four survey aircraft, of which one is equipped to simultaneously acquire lidar and digital aerial photos utilizing direct georeferencing.

In 2007 & 2008 the Nova Scotia Department of Transportation and Infrastructure Renewal (NSTIR) acquired lidar and digital orthophotos from Terra Point, out of Ottawa, for several projects related to the 100 series highways (Fig. 4). NSDTIR has commented that one of the major benefits of lidar is the reduction of time required to obtain detailed elevations of the land, especially if forest covered, which can translate into an overall project cost savings of one third.

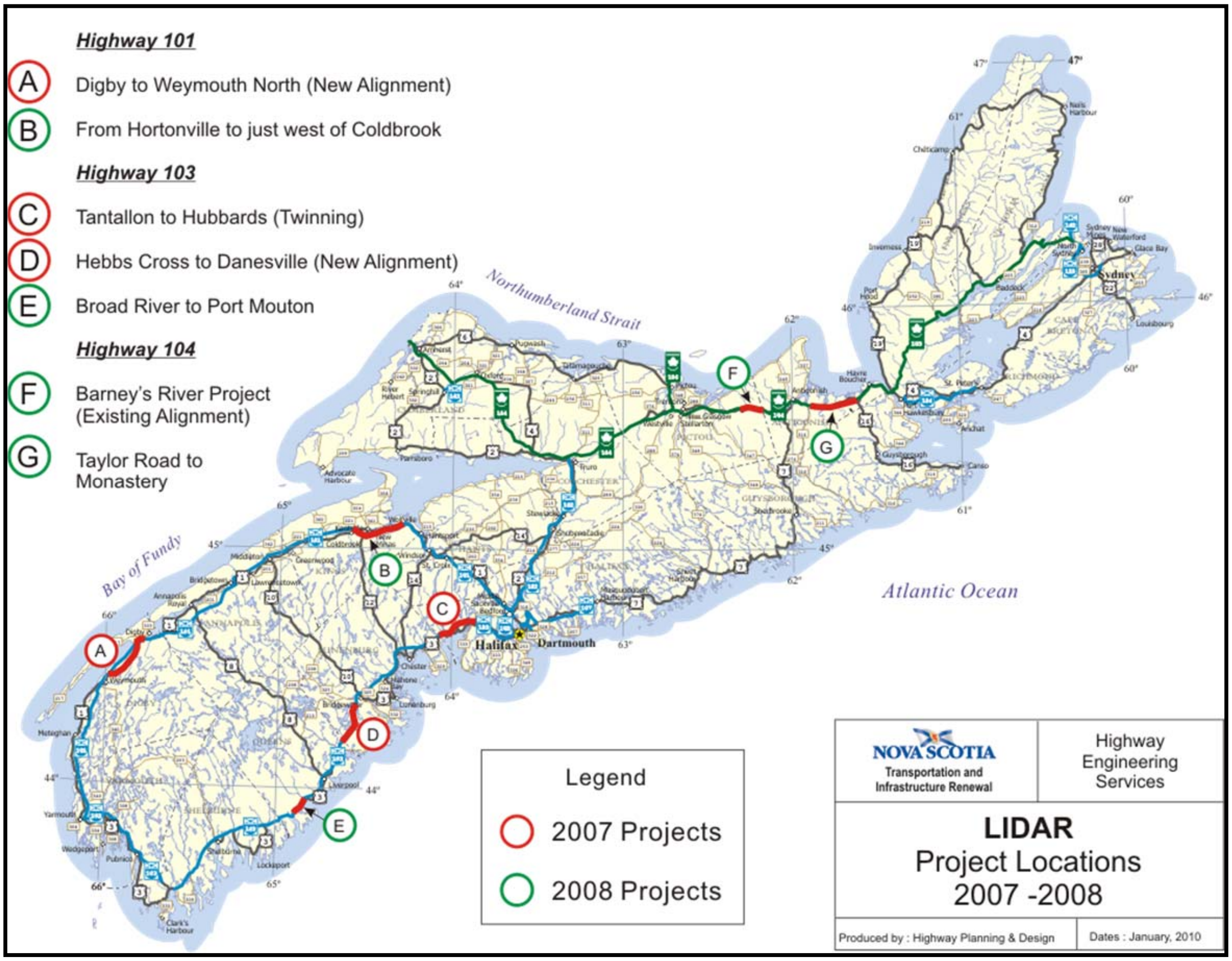

Figure 4 Lidar survey areas contracted by NSTIR for 2007 and 2008. Source Adam Osborne NSTIR.

The Cape Breton Regional Municipality (CBRM) & Partners (Parks Canada, Devco, Industry including mining and exploration companies) acquired lidar and digital orthophotos from LEG in 2008 (Fig. 5) and acquired additional data in 2010.

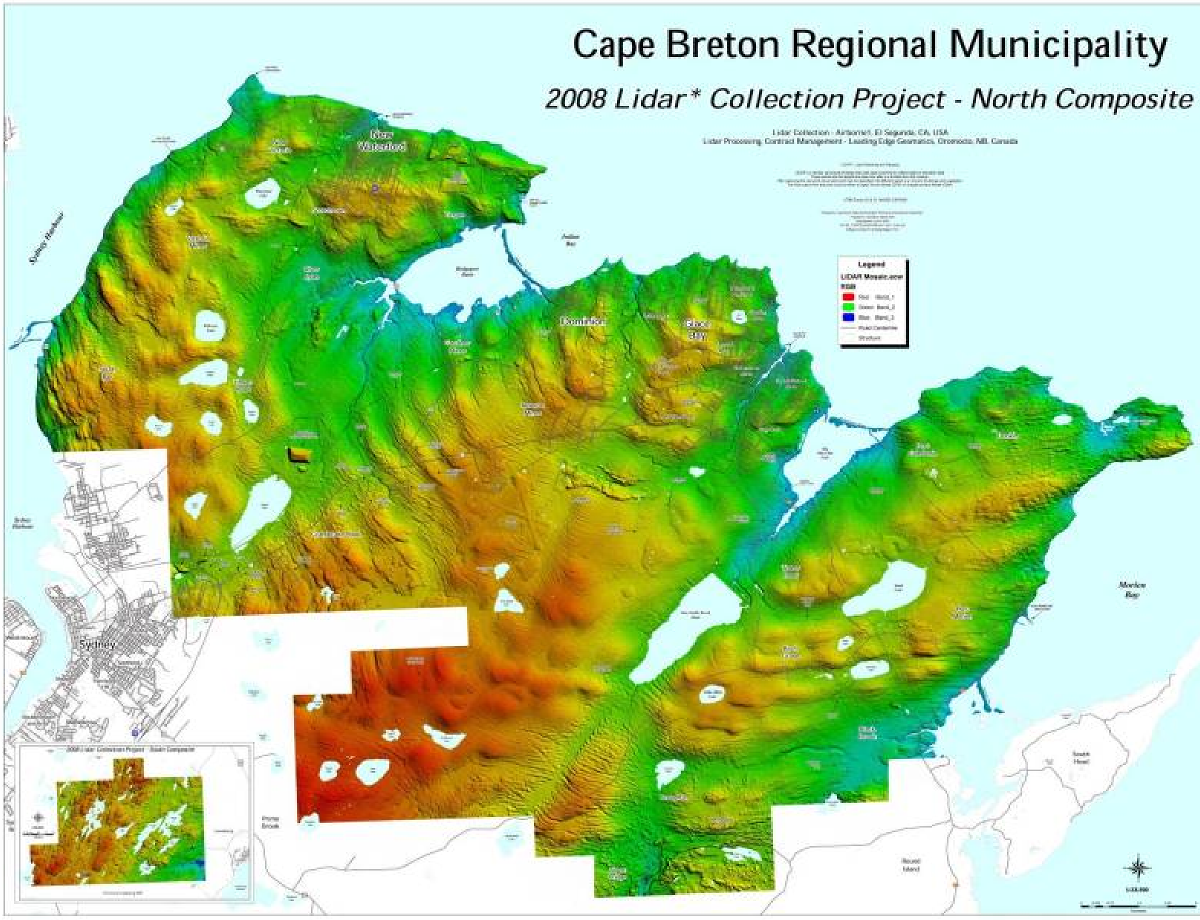

Figure 5 Example of lidar acquired by LEG for CBRM and partners 2008. Source Doug Foster, CBRM.

Public Works Government Services Canada (PWGSC) acquired lidar for the Sydney Tar Ponds Coke Ovens Remediation Project (STPCORP) from LEG utilizing an ALTM 3100 system in 2009.

In 2009 NS Environment partnered with AGRG, NSCC to acquired lidar for 5 communities (District of Lunenburg, Oxford-Port Howe, Chignecto Isthmus, Town and District of Yarmouth, and Minas Basin). Two of the communities, Yarmouth and Minas Basin were previously acquired by AGRG and made available to the project. The remaining three communities; District of Lunenburg, Oxford-Port Howe, and the Chignecto Isthmus were surveyed by AGRG in 2009 utilizing their ALTM3100 lidar system (Fig. 6) and utilized existing lidar previously acquired by AGRG for 2 additional areas (Yarmouth and Minas Basin) to support the Atlantic Climate Adaptation Solutions (ACAS) project led by the Climate Change Directorate of NS Environment.to map areas at risk of coastal flooding from storm surge and long term sea-level rise (http://atlanticadaptation.ca/node/128). The lidar was used to construct high-resolution digital elevation models (DEM) and digital surface models (DSM) of 1-2 and generate flood risk maps for each community.

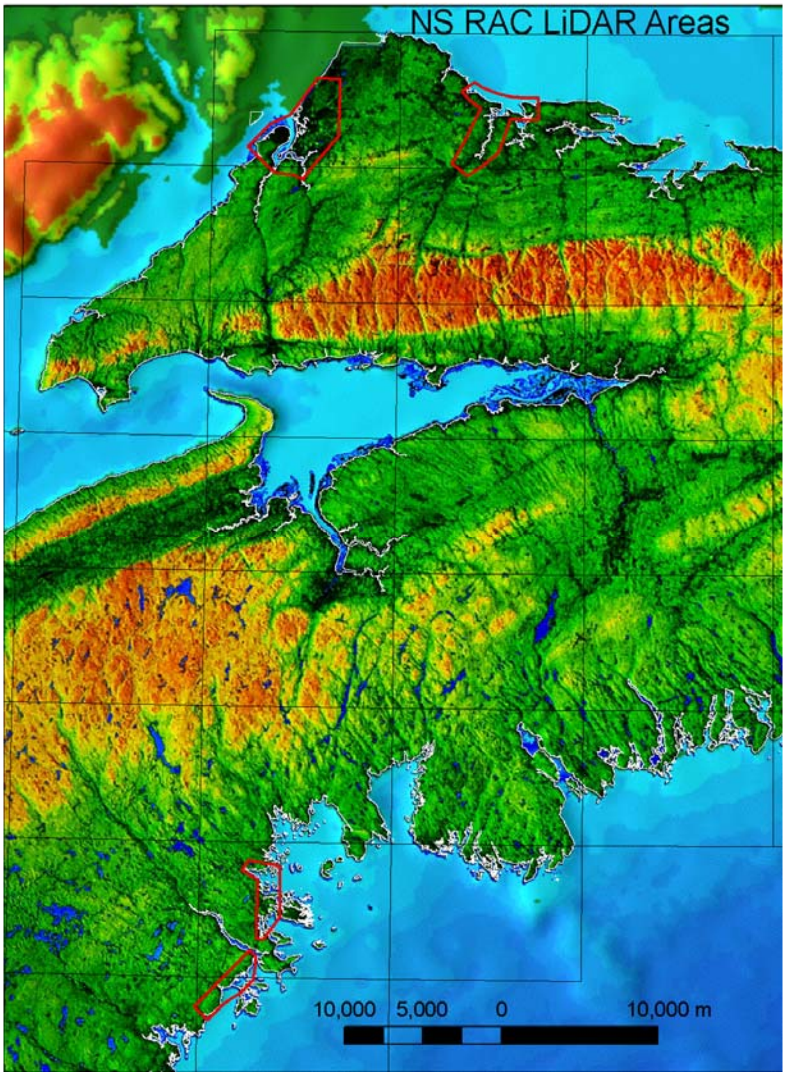

Figure 6 Lidar areas acquired by AGRG in 2009 to support the Atlantic Climate Adaptation Solutions project.

Another ACAS project between NSDTIR and AGRG evaluated the flood risk for the transportation corridor which crosses the Chignecto Isthmus. In addition to the existing lidar acquired by AGRG, LEG was contracted to acquire lidar along the highway 366 corridor in 2011. These data overlap with previous lidar data acquired by AGRG for the Amherst area in 2009 and connect the Bay of Fundy with the Northumberland Strait across the Isthmus. Lidar data acquired by LEG under contract to the NB Department of Environment as part of their ACAS project (2010-2011) was merged with the NS data in order to evaluate the potential for dyke failure and flooding of the transportation infrastructure at this critical location (Fig. 7).

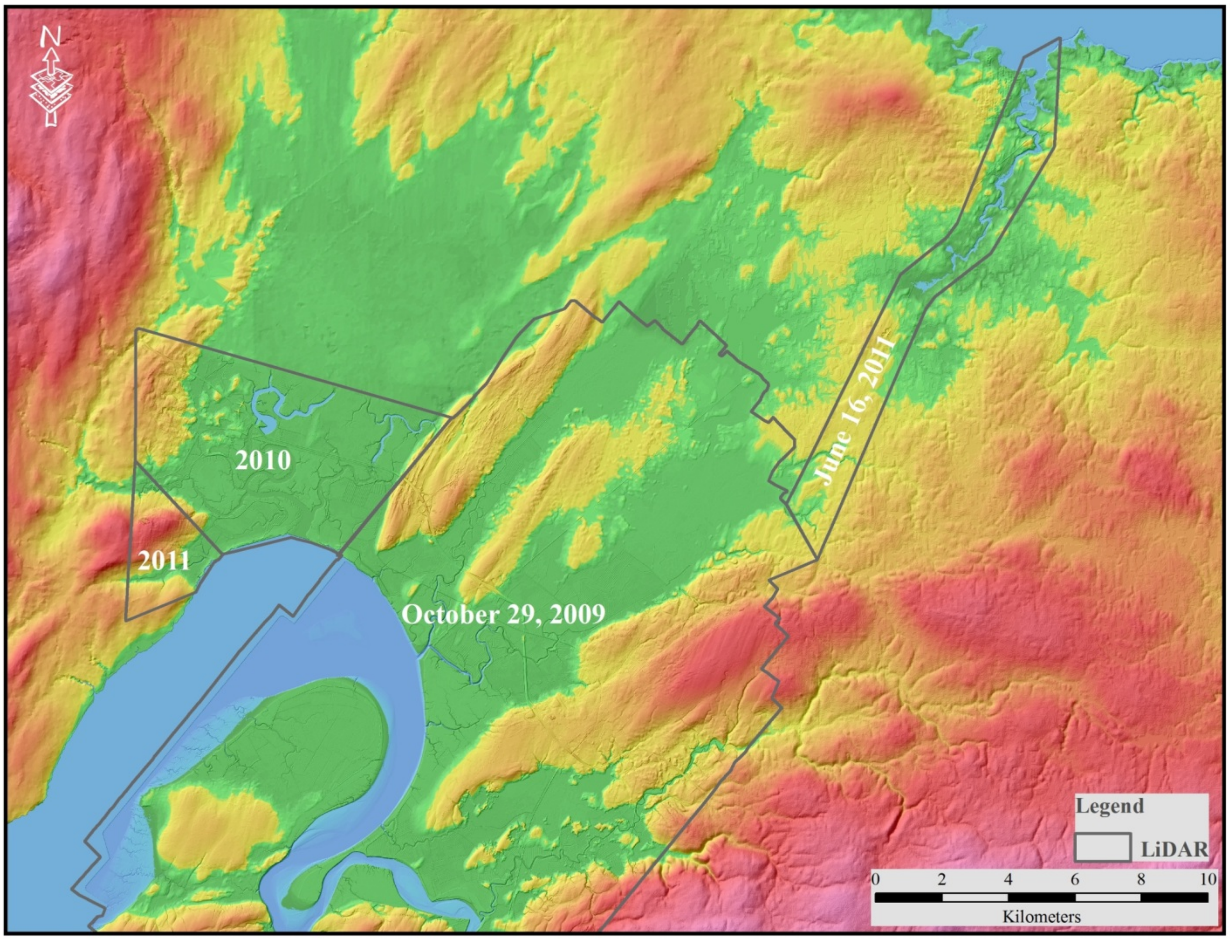

Figure 7 Lidar areas acquired by AGRG (2009) and LEG (2010 and 2011) across the Chignecto Isthmus as part of the NS and NB ACAS projects.

The Mineral Resources Branch of DNR acquired lidar for a large section of the Cobequid Highlands in December of 2010 to enhance mineral exploration and geological mapping.

As can be seen by the above list of activities dating back to 1998, there has been increased interest and initiatives to utilize lidar by a variety of provincial and federal government departments, municipalities and academic research groups. This activity, in part has led to the formation of the Lidar Working Group from GeoNova to provide a set of recommendations to the province of Nova Scotia to facilitate the utilization of lidar by the province.

Service Nova Scotia and Municipal Relations (SNSMR), Geographic Information Service via its Amherst Operations Office has had discussions with AGRG about a possible research project to further investigate the utility of airborne lidar for topographic mapping. SNSMR's Amherst Operations Office has been providing digital black and white orthophotos acquired during leaf-off conditions to the local Land Information Centre (LIC) offices as part of their updating program of the 1:10,000 Nova Scotia Topographic Database (NSTDB). Concurrent with that activity, personnel with the forestry branch at the Department of Natural Resources in Truro have been acquiring colour 1:12,500 photos during leaf-on conditions utilizing survey aircraft equipped with an Inertial Navigation System (INS) for the purpose of forest inventory. The INS information captures the aircraft's position and attitude (pitch, roll and heading) for every aerial photo frame captured. DNR has combined these data with the provincial 20 m DEM to generate digital orthophotos. These photos are then used as backdrops within the GIS environment to update the forest inventory layer. DNR officials have indicated that the 20 m DEM is not always sufficient to accurately orthorectify the aerial photos. SNSMR and DNR have partnered in this area such that the Amherst operation is now handling the storage of the colour 1:10,000 resource photography for DNR and plans to use it as a replacement for the 1:40,000 scale black and white photography previous acquired to update the NSTDB.

Recent discussions between AGRG and SNSMR have taken place to encourage aerial photography to be acquired over coastal areas at low tide. A list of several departments who could benefit from low-tide photography was supplied and discussions continue. The requirement of photos to be acquired at low tide further restricts the window of opportunity of data acquisitions, since specific sun angles are required to obtain photography with minimal sun glint or shadow problems. Thus the low tide times must correspond with appropriate sun angles and the weather must be suitable in terms of fog, cloud, and cloud shadows. These activities are mentioned in this report because many lidar providers are also equipped to acquire aerial photography, either using digital cameras or analogue cameras. The mobilization of an aircraft and the survey time for the aircraft often account for a significant portion of the overall cost of a survey and if both lidar and photos can be acquired simultaneously, it has the potential to provide significant cost savings. The benefit of a combined system is the ability to utilize the INS which facilitates direct georeferencing and the production of orthophoto map products with minimal ground control and targets. Another significant advantage of acquiring high-resolution photos concurrent with the lidar data is the richness of the dataset, having imagery with elevations. This can increase the usefulness of the dataset significantly and can enhance the interpretability of both the lidar and the photos. An example of this is the ability to use the lidar data to produce a high-resolution DEM that can be used to remove relief displacement from the photos during the production of orthophotos, thus producing a higher accuracy orthophoto in areas of higher relief. The used of a DSM which incorporates the buildings along with the terrain has the potential to compensate with the lean of buildings that is inherent with orthophotos that have been corrected using the ground model only. Since a lidar system is an active sensor, meaning it emits its own source of energy in the form of a laser pulse and measures the reflected signal retuning from the ground, it is not as restricted as to when data can be collected like aerial photography. Another consideration of a combined lidar-aerial camera system is that the field of view of each sensor (lidar or camera) should be very similar to optimize the number of flight lines in order to accomplish full coverage of the study area with appropriate overlap. The data acquired by NSDTIR and CBRM utilized a system that collected lidar synchronous with aerial photography and produced high quality orthophotos and elevation models.

4 CURRENT STATE OF LIDAR TECHNOLOGIES

4.1 Airborne terrain mapping lidar

Lidars can be used for a variety of applications including examining the contents of the atmosphere be examining the way the laser light is scattered by particles in the air. In the context of this report we are referring to lidar mapping systems. Lidar mapping systems have benefited from advancements in inertial navigation technology, laser ranging systems, and computer storage and processing improvements. A lidar terrain mapping system is comprised of a laser ranging system mounted in an aircraft that directs a laser pulse, typically with a 1064 nm wavelength, towards the ground and measures the two way travel time it takes that pulse to leave the aircraft, reflect off the ground and travel back to the aircraft where it is received (Fig. 8). By knowing the speed of light, the travel time is converted into a distance or “range” from the sensor-aircraft to the target-ground. An oscillating mirror is often used to direct the laser pulses from vertical to an angle in the direction perpendicular to the aircrafts track, referred to as the “across the track” direction. This results in a swath of laser points being collected under the aircraft as it advances forward rather than a single profile. The laser systems today can emit up to 400,000 pulses per second (400 kHz) and can receive multiple returning signals from a single emitted pulse. However, usually only the first and last pulse returned to the sensor are recoded on most lidar surveys that provide sufficient information for most applications. First returns are critical for such applications as detecting and mapping power lines, or other similarly small features that occur above the ground e.g. towers. Last returns are often reflected off the ground or near ground surface. In some situations only one pulse is returned to the sensor, this would occur in open areas where the emitted pulse only made contact with the ground, or some other hard surface such as the roof of a building. Another factor influencing how the laser pulse interacts with targets is the beam divergence. Some sensors can operate in a wide or narrow beam mode. The wide beam mode would have a larger divergence angle and would be appropriate for applications such as power line mapping, where the wider the beam the better the chance of part of it reflecting off the narrow cables of the power line. The narrow beam mode is more suitable for topographic mapping where the energy is concentrated in a smaller area and thus increases the potential of the beam going through gaps in the vegetation canopy and reflecting off the ground and returning to the receiver. The beam divergence is typically very small (0.3 rmad), resulting in a laser footprint diameter of 20-50 cm on the ground, depending on flying height. Only a portion of that beam has to make it through the gaps in the forest canopy and hit the ground in order to be reflected back to the aircraft. Thus in the forest, if one can see patches of sky above them, there is a good chance the laser beam will partially make it through a gap and make it to the ground or near ground features such as dense shrubs. This characteristic of lidar allows for more accurate and denser elevation measurements of the ground to be collected as compared to previous methods such as aerial photography that were hampered in forested areas.

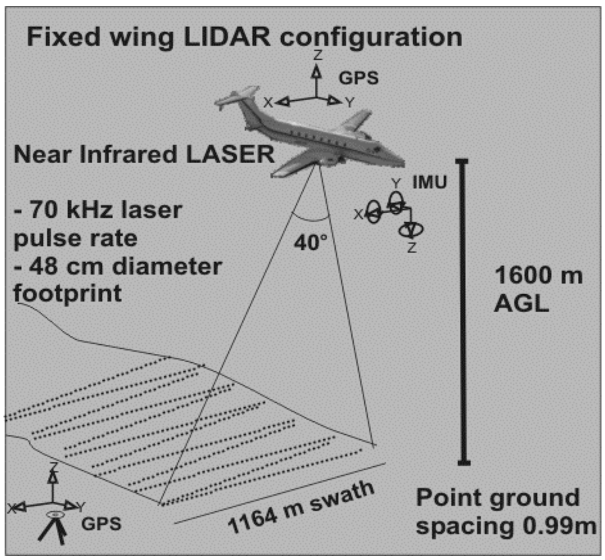

Figure 8 Typical lidar configuration used by AGRG for the coastal surveys for NS Environment as part of the ACAS project. Although the ground point spacing is approximately 1 m, the surveys were flown with 50% overlap, effectively providing a point spacing of 0.5 m.

In order to position the target that the laser pulse reflected off of (eg. ground) in space, the position of the aircraft is measured using an INS which consists of a survey grade GPS receiver and an Inertial Measurement Unit (IMU) that is used to capture the attitude of the aircraft: pitch, roll and yaw or heading (Fig. 8). In order to achieve positioning of the aircraft to a precision better than a decimeter, a base station should be setup to collect GPS signals over a known monument, such as the provincial High Precision Network. The GPS information from the plane is then post processed with that of the base station or ideally multiple base stations to obtain the most precise position of the aircraft possible. The GPS typically records the position information of the aircraft every second, or at 1 Hz. The IMU however, records the attitude of the aircraft 200 times per second, or 200 Hz to account for turbulence and vibrations. All of the information about laser ranges, scan angle, aircraft position and attitude are linked by GPS time. After the survey, the data are post processed and the GPS and IMU data are used to calculate the trajectory of the aircraft through time (Fig. 9). The laser ranges are related to the scan angle to determine the distance and direction from the aircraft. Finally the scan information is linked to the trajectory to position the targets (laser returns from the ground or trees/buildings) in three dimension space using the GPS mapping coordinate system (World Geodetic System of 1984 (WGS84) mapping system). Each flight line is represented as a swath of lidar points that are collected by the sensor (Fig. 9). The across track point spacing refers to the distance between points across the swath or roughlly perpendicular to the direction of the aircraft and the along track point spacing refers to the distance between points in the direction of the aircraft motion. The final result of a lidar survey is a georeferenced 3-D point cloud representing what the lidar reflected off of and could include the ground, vegetation, and buildings.

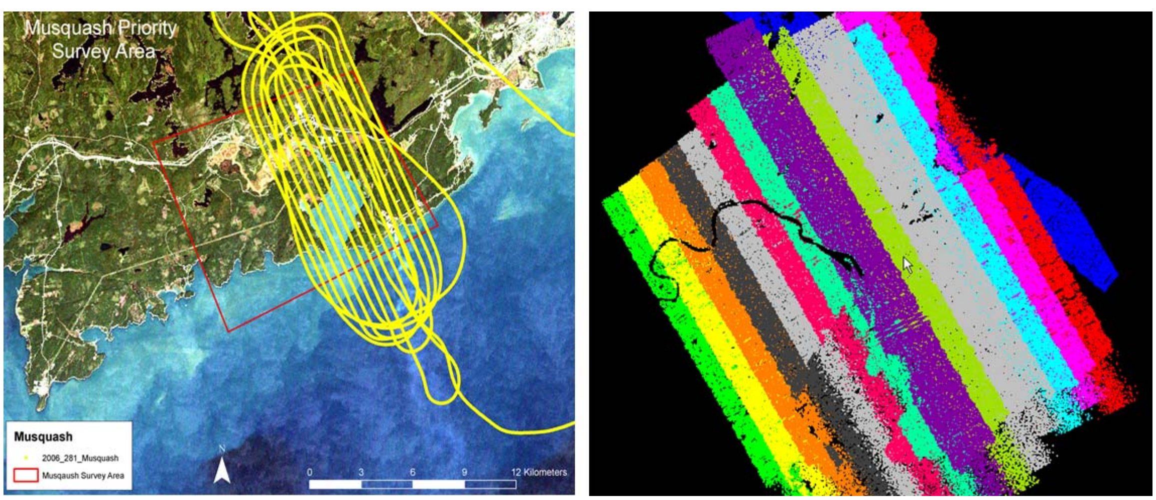

Figure 9 The left map is an example of the aircraft trajectory during a lidar survey. The right map represents the lidar swaths acquired for the survey with 50% overlap between swaths.

Since lidar is an active sensor and emits its own laser pulse, at an angle from nadir (vertical line under the aircraft), typically up to 25 degrees, in some terrain and cover types shadows may be a problem, especially for laser pulses farthest from nadir. For example in cities with tall buildings, sometimes referred to as “urban canyons”, if the laser pulse is reflected off of the side of the building, the other side of the building will be in shadow and no information will be obtained. This is also the case in forested areas where dense coniferous trees may only allow a single return to be reflected. To compensate for this potential problem of missing data, having swaths with 50% overlap between flight lines improves the chances of obtaining returns from all surfaces that may otherwise be in shadow (Fig. 9). A similar problem can occur if the surface is very smooth, often referred to as a specular reflector similar to a mirror, in this case the outer laser pulses farthest from nadir reflect off of the surface away from the sensor and no returns are measured. Standing water with no waves, or intertidal mudflats are known to cause this problem where the laser returns are restricted to angles closer to nadir. Flying with 50% overlap also helps this problem, since the edge of a swath in one flight line would correspond with the center or nadir location of the adjacent flight line, thus improving the chances of laser returns over such targets. Another benefit of flying with 50% overlap is the increased point density, as seen in figure 8 the laser pulse repetition was set for 70 KHz which under a certain aircraft speed produced an average point spacing of ~ 1 m, however considering the adjacent flight lines points it decreases the point spacing to 0. 5 m. Another advantage of 50% overlap is that is provides areas to evaluate the quality of the lidar calibration and positioning by comparing objects surveyed from two different flight lines. If the objects are offset horizontally or vertical there probably is a problem in the lidar sensors calibration which relates the offset of the navigation system and lidar sensor. Flying with 50% overlap increases the number of flight lines required to cover an area and this is not standard practice for some service providers unless specifically requested by the user, which is highly recommended.

A lidar point cloud is produced for each flight line and may consist of millions of points. The volume of the data is so large that it is typically tiled into blocks to facilitate processing. Anomalous points are flagged or removed from the dataset which are typically isolated and are below the ground or in the air. The points within each block are then processed in specialized software, such as Terrascan from TerraSolid, and classified into ‘ground’ and ‘non-ground’ targets by the data provider (Fig. 10).

Depending on the software available to the end-user, overlap between the tiles or blocks may be desirable. Often the volume of the data requires each small block to be converted from points to a grid to construct the surface models (eg. DEM and DSM). If there is no overlap between the tiles then when the blocks are put together to form a mosaic of the DEM for entire study area, seams will be visible at the boundary. Some GIS software that deals with lidar can compensate for this problem however if one simply builds surface models from the blocks and merges them seams will be a problem, regardless of the interpolation technique used.

Additional classes such as low vegetation, high vegetation, buildings, and power lines can also be classified automatically if desired. The most common procedure is to classify only the ground points however. This process evaluates a cluster of points, assuming that the lowest points represent the ground. The algorithm begins building a surface from these low points and other higher points are then evaluated against the surface based on a set of thresholds. Points with abrupt vertical changes in height compared to other points are not considered to be ground, since they would typically represent the roof of a building or top of a tree. The classification of raw lidar points is an active area of research and this method does not produce 100% accurate results thus some ground points maybe classified and 'non-ground' and vice versa.

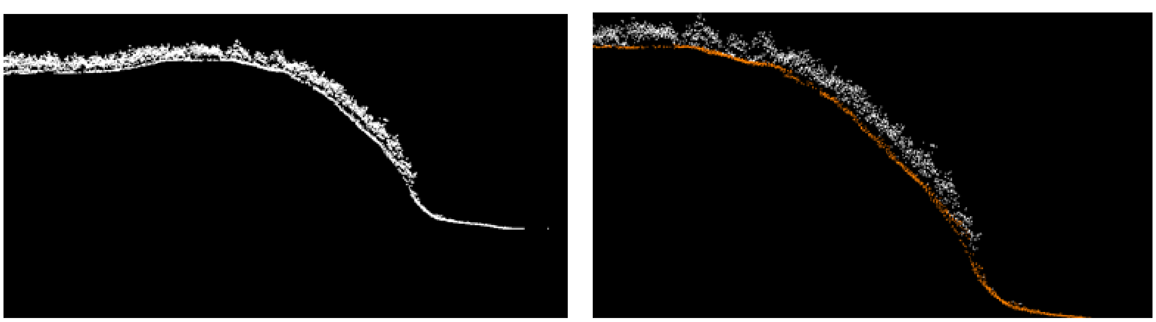

Figure 10 Cross section of the lidar point cloud of a coastal area on the left. The right image is the same cross-section with the ground points classified and coloured orange.

The lidar points are generally output to a map projection coordinate system, typically Universal Transverse Mercator (UTM) in meters east and north. The lidar elevations are referenced to the GRS80 ellipsoid used in the WGS84 mapping system and not above mean sea level or a local national vertical datum. A geoid-ellipsoid model can be used to convert the elevations from ellipsoidal to orthometric heights above the geoid. In Canada we currently use the HT_2 model supplied by the Canadian Geodetic Survey of Natural Resources Canada to relate ellipsoidal heights to Canadian Geodetic Vertical Datum of 1928 (CGVD28).

The lidar points are typically used to construct continuous surface models in the form of grids or rasters. For some application areas such as power line analysis, the lidar points are used directly. However for many other application areas such as flood risk mapping, watershed delineation, view shed analysis etc. raster surface models are derived from the lidar and used. In most GIS systems there are more tools available for spatial analysis using raster data rather than points. Triangular Irregular Networks (TINs) are another method to represent a surface constructed from the lidar points; however the number of GIS tools for analysis is more limited. Standard products that can be derived from the lidar that use all of the valid points (ground and non-ground) are known as Digital Surface Models (DSM) (Fig. 11), whereas a Digital Elevation Model (DEM) which represents the bare-earth can be derived from using just the lidar ground points (Fig. 11). In addition to a lidar sensor measuring the travel time of a laser pulse reflected from a target back to the sensor, the amplitude or intensity of the reflected pulse is also recorded. The intensity will vary based on the type of material of the target ie. land cover. For example, lush vegetation will reflect a large amount of the near-infrared (NIR) energy back to the sensor and the intensity will be high or bright. A target with a lower reflectivity of NIR energy such as asphalt will have a lower intensity. The intensity values of all the lidar points can be used to construct an image that resembles a black and white photograph, known as a Digital Surface Model Intensity (DSMI) (Fig. 11). The different lidar surface models, including intensity can be used to construct a detailed land cover map with accuracies better than 80% (Brennen and Webster, 2006).

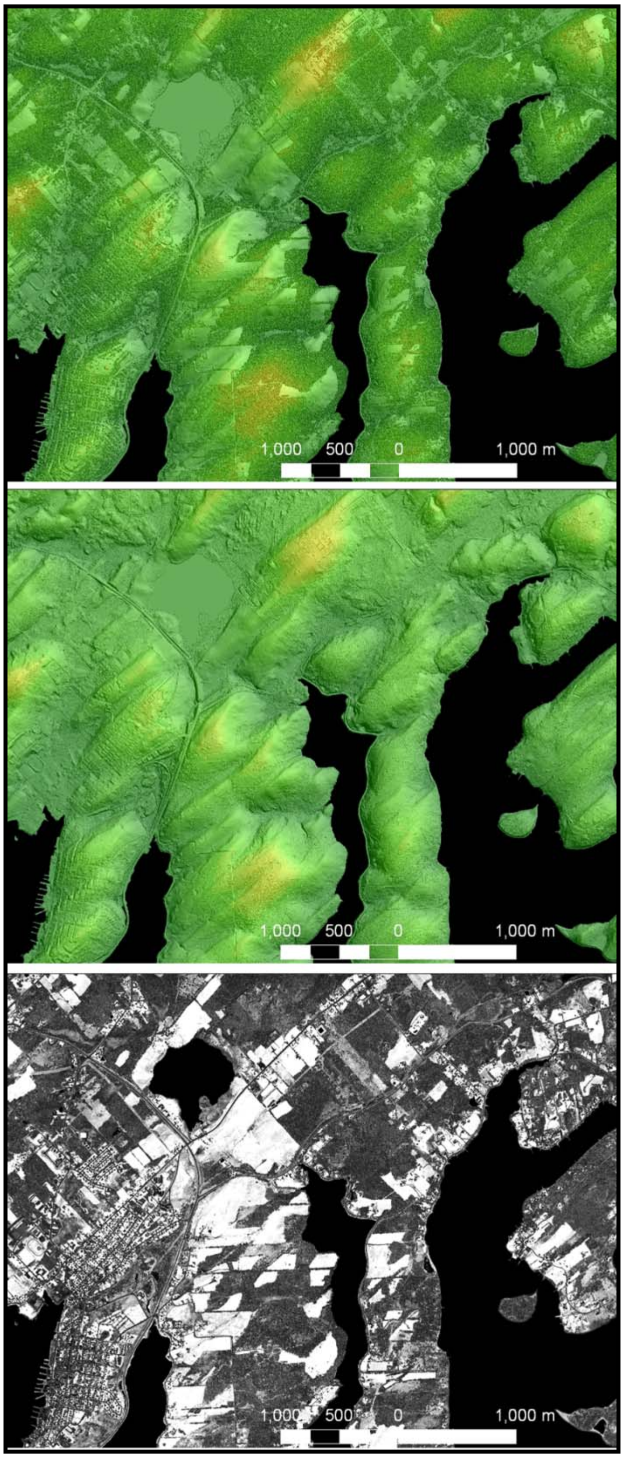

Figure 11 Examples of derived surface models from a single lidar dataset near Lunenburg. The top map is a Digital Surface Model incorporating all of the lidar points (ground and non-ground). The middle map is a bare-earth Digital Elevation Model using just the ground points. The bottom map is an image derived from the lidar intensity of all of the points (Digital Surface Model Intensity (DSMI).

4.2 Bathymetric lidar

The Canadian Hydrographic Service (CHS) and other science branches of the Department of Fisheries and Oceans (DFO) in the Maritimes have been acquiring near shore bathymetry information by contracting companies like Fugro Pelagos to utilize their bathymetric lidar system. A bathymetric lidar system works on similar principals as a terrain mapping system. The bathymetric lidar system uses two laser systems; a NIR pulse to measure or range to the top of the water, since the NIR energy does not penetrate the water column, and a green laser at 532 nm wavelength that penetrates the water column and reflects off the seabed back to the sensor receiver (Fig. 12). The power required for a bathymetric lidar system is significantly more than a terrain mapping system and thus requires a larger aircraft for surveying which increases the cost. The laser footprint diameter is much wider ~2 m than a terrain mapping system. The depths that such a system can measure are dependent on the water clarity. Optech produces a SHOALS bathymetric lidar system which is reported to measure depths 2 times the Secchi depth. Secchi depth is a measure of water clarity and is simply the depth when a disk of 20 cm diameter painted black and white in the four quadrants is no longer visible. Recent surveys by CHS-DFO in waters around the Maritimes have reported measuring depths to 10 m.

A major benefit of this type of survey is the ability to map the near-shore from depths of ca. 10 m continuously through the coastal zone up onto the land. Echo sounder technology such as multi-beam sonar can be acquired safely at depths greater than 10 m and terrestrial lidar can be acquired for the landward areas. These data can be combined to produce a seamless elevation model from land to the seabed. Many coastal processes including waves, erosion, and along shore currents are influenced by the near shore topography and these data are lacking for many studies that rely on models to predict impacts from such processes.

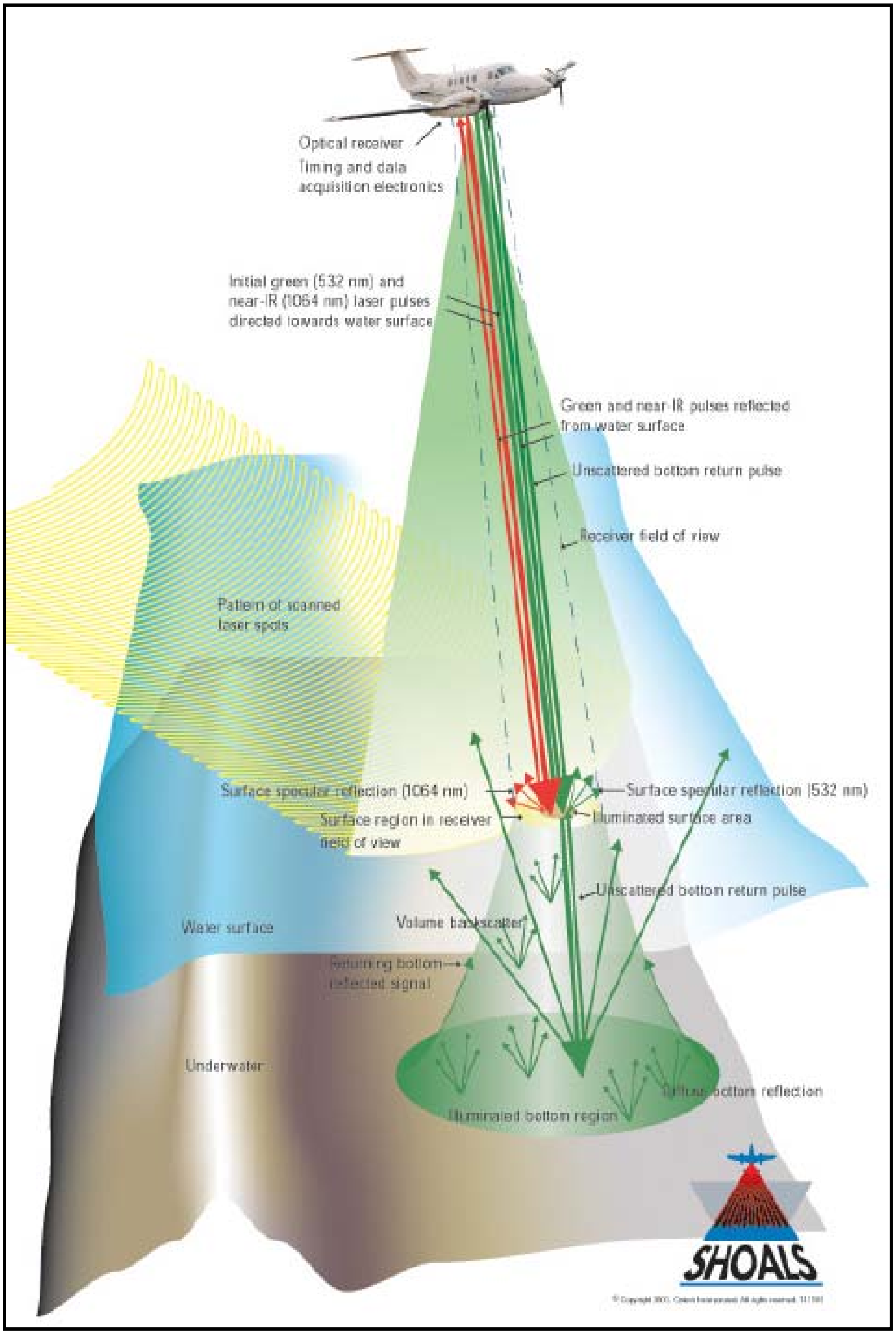

Figure 12 Typical configuration of a bathymetric lidar system for measuring the elevation of the near shore seabed. Source Optech Inc.

4.3 Static and mobile mapping lidar

Mapping lidar systems are ideal for surveying flat or rolling terrain, however as a result of the viewing geometry (Fig. 8) they are not ideal for measuring the sides of vertical features such as buildings or natural landscapes such a cliffs and coastlines. Static tripod mounted lidar systems that utilize eye safe lasers have been used to monitor open pit mining operations, glacial surfaces, and recently used to measure erosion of a section of coastline in Nova Scotia (Fig. 13) as part of the Atlantic Climate Adaptation Solutions project (see Webster et al. 2012).

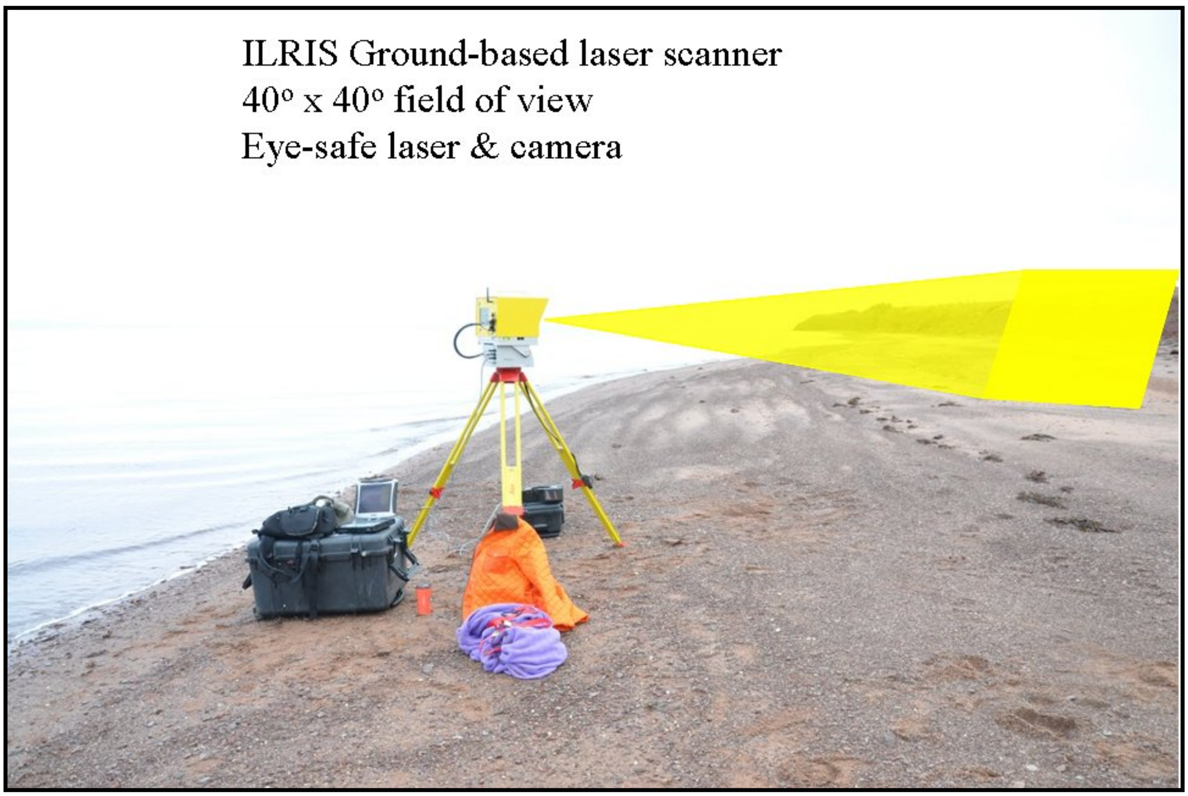

Figure 13 Example of a static lidar system mounted on a tripod to measure the steep slope surface of the coastline.

The inertial navigation systems employed in the airborne terrain mapping lidar systems have been integrated with eye safe lasers and placed on other mobile platforms such as trucks, boats, and all-terrain vehicles. These "mobile mapping" systems are becoming very popular and collect data that are not possible with the airborne lidar system. Application areas using this technology include asset mapping of street furniture, improved 3-D building visualization and modelling, transportation infrastructure (bridges, overpasses, signage, etc.), rail lines, coastlines and river banks (Fig. 14).

Figure 14 Example of mobile mapping lidar systems. Top photo of a system mounted on a truck on a rail line with associated point cloud. Bottom photo of a system mounted on a boat and associated point cloud. Examples from www.Opech.ca that show the Lynx mobile mapping system from Optech.

Dense urban areas have been surveyed using this technology that provides a rich dataset of lidar point information and photography (Fig. 15). These urban canyons cannot be surveyed to the same level of detail using airborne systems. The details of vertical features acquired from mobile mapping systems can be integrated with airborne lidar point clouds to provide a full 3-D representation of the terrain or feature of interest. This technology is relatively new but growing rapidly and there are several manufactures producing systems.

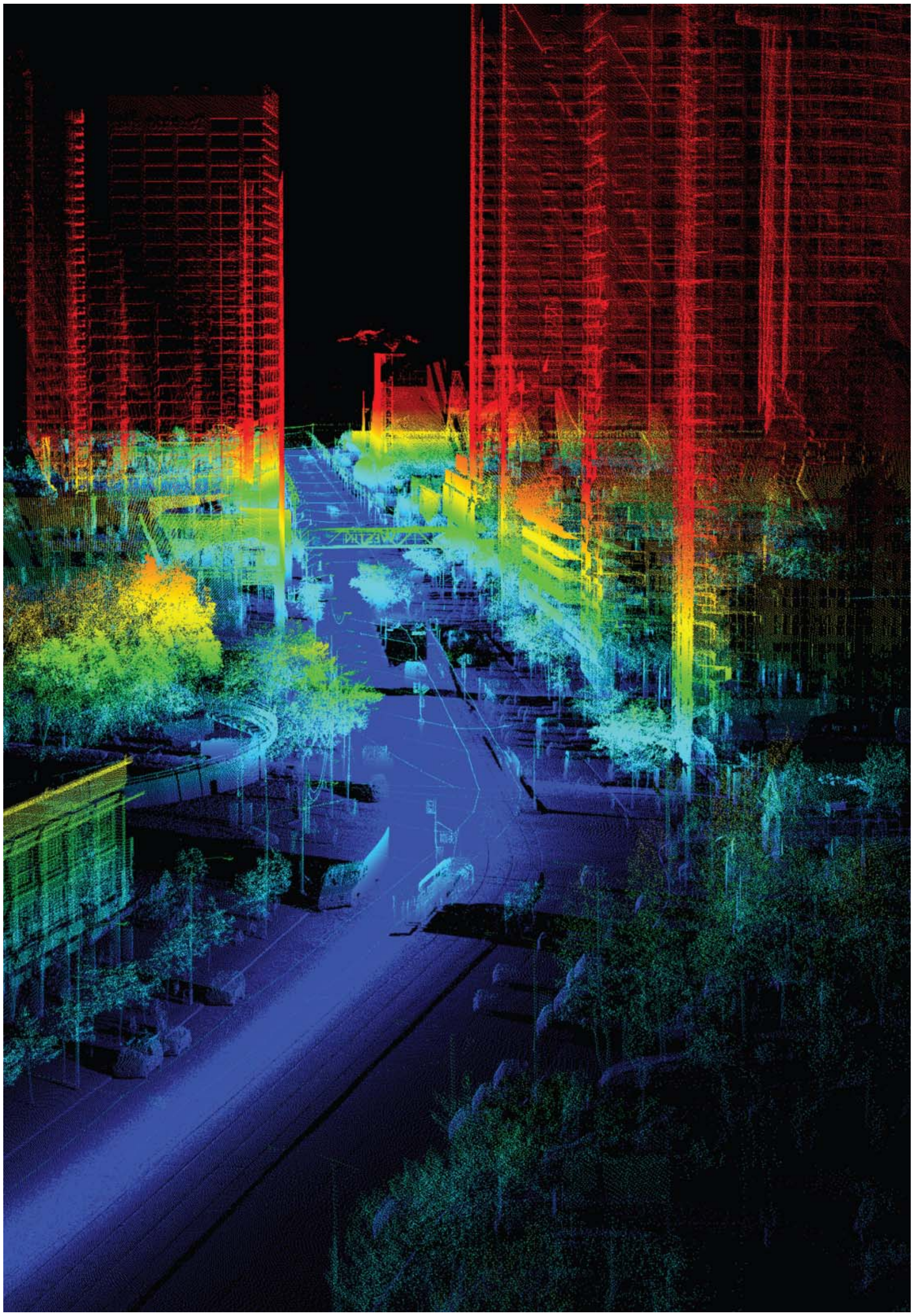

Figure 15 Example of a lidar point cloud of an urban area obtained with a mobile mapping lidar system. Image obtained from Optech.ca.

5 BENEFITS OF USING LIDAR TECHNOLOGY

The following introduction description of the benefits of lidar mapping was extracted from http://www.spatialresources.com. "The high-density accurate data, speed of data capture, the safety and convenience of remote acquisition and measurement, 3D visualization and digital imagery are the distinguishing features of laser scanning that provide the greatest benefits. Abundance of data captured in laser scanning reduces questionable data, provides over sampling to ensure accuracy and that all objects, structures, geometry are captured. High point density data ensures a complete topographic survey: all details are captured and all data captured are direct measurements. Imagery and 3D visualization provides added confidence that mapped objects correspond to actual existing conditions. Now, it is important to keep in mind that not all laser scanners are created equal, nor are laser scanning service providers. The results derived from various laser scanning equipment and laser scanning service providers can vary from scanner to scanner, service provider to service provider and laser scanning application to application. Therefore, the success of a laser scanning survey depends upon using the right scanner and the right scanning service provider for the right project."

5.1 Coastal Flood Modelling

Many coastal communities in Nova Scotia are at risk from storm-surge events. A storm-surge is an increase in the ocean water level above what is expected from the normal tidal level that can be predicted from astronomical observations. Storm surges are caused by the winds and the low atmospheric pressure of storms. The global climate is changing due to the increase of greenhouse gas emissions, the resulting warming trends will result in an increase of global sea-level (Titus et al. 1991). Future projections of sea-level change depend on estimated future greenhouse gas emissions and are predicted based on a number of scenarios (Raper et al. 2006). Global sea-level rise, as predicted by climate change models, will increase the problem of flooding and erosion making more coastal areas vulnerable (Shaw et al., 1998). Lidar has been used for a variety of coastal studies internationally (Brock et al. 2002), including flood inundation (Bates et al. 2003), and measuring changes in the breach after storms utilizing repeat lidar surveys (Stockdon et al., 2002; Sallenger et al., 2003).

The current detail of elevation information available from the province of Nova Scotia along the coastal zone is not sufficient to make accurate predictions of areas at risk to coastal flooding from storms and long term sea-level rise. For much of the Nova Scotia coast the best available terrain information is based on the Nova Scotia Topographic Database at a scale of 1:10,000 with a vertical accuracy of 2.5 m (Nova Scotia's geographic information standards). Importantly, for predicting the abovementioned impacts of storm surges, the maps define the 5 or 10 m contour as their lowest elevation inland from the shoreline. While it is noted that terrain information is available at larger scales (1:2,000 and 1:4,000) and finer elevation resolution (2 m contour intervals), these data are for small sections of densely populated areas of Nova Scotia (e.g. some towns). A 2 or 5 m contour interval remains an inadequate base for detailed coastal risk assessments. The application of lidar was recently used to construct high-resolution digital elevation models (DEM) and digital surface models (DSM) of 1-2 m resolution for all of the coastal communities within the Atlantic Climate Adaptation Solutions (ACAS) project led by the Climate Change Directorate of NS Environment.

The purpose of this project was to determine the extent of various coastal flood levels for the five ACAS case study communities around the province (http://atlanticadaptation.ca/node/128). In addition to producing the flood inundation maps from the lidar DEMs, benchmark storms were researched for each community and used to demonstrate their vulnerability to coastal flooding presently and into the future with rising sea-levels. At the recent ACAS conference held in Halifax March 5 and 6, 2012 it was abundantly clear the municipalities recognized the benefits of coastal lidar acquired during the project.

The lidar DEM was used within a GIS to construct the flood maps (Fig. 16). The process required modifying the DEM to ensure hydraulic connectivity along water ways. Roads that have streams running under them usually contain a culvert or bridge to allow for the flow of water. However, lidar point elevations only detect the surface of the road. Therefore, when determining the flow path of water to or from the ocean to low lying areas, the road in the unedited DEM would act as a dam or barrier. To ensure that low-lying areas are properly flooded if they are connected to the ocean, the DEM was modified in areas of culverts or bridges to allow for hydraulic connection following a method outlined in Webster et al. (2006b). Flood levels were generated relative to CGVD28 at 0.1 m increments up to an upper limit, typically 5 m on the Atlantic and Northumberland coasts and 10 m in the Bay of Fundy. The ACAS maps were generated using the “still water” method which assumes the ocean is a flat plane, appropriate for large scale storm surge events that cover 100-1000s of square kilomters of area, as we raise the water level to determine areas on land that will be inundated. This method does not take into account the action of wave run-up or the travel time water takes to cross a land surface. However, for the generation of static flood inundation maps that predict the extent of flooding from the total sea level (including tide, surge and wave run-up) the still water method has been found to produce results suitable for planning purposes (Webster et al. 2006b). Lidar data can be used with hydrodynamic models that require many more parameters to define, however most models cannot accept the high-resolution of lidar and the DEM is usually sampled to a coarser resolution greater than 5 m. Thus care must be taken to ensure barriers to the ocean are accurately represented in this coarser resolution DEM.

The NS Department of Agriculture is responsible to maintain 240 km of dykes that protect approximately 43,000 acres of productive marshland. As a result of continued development near the coast, these dykes now protect other critical infrastructure such as roads and sewage treatment facilities for example. They can use lidar to help delineate the marsh and provide municipalities guidance on development near these areas.

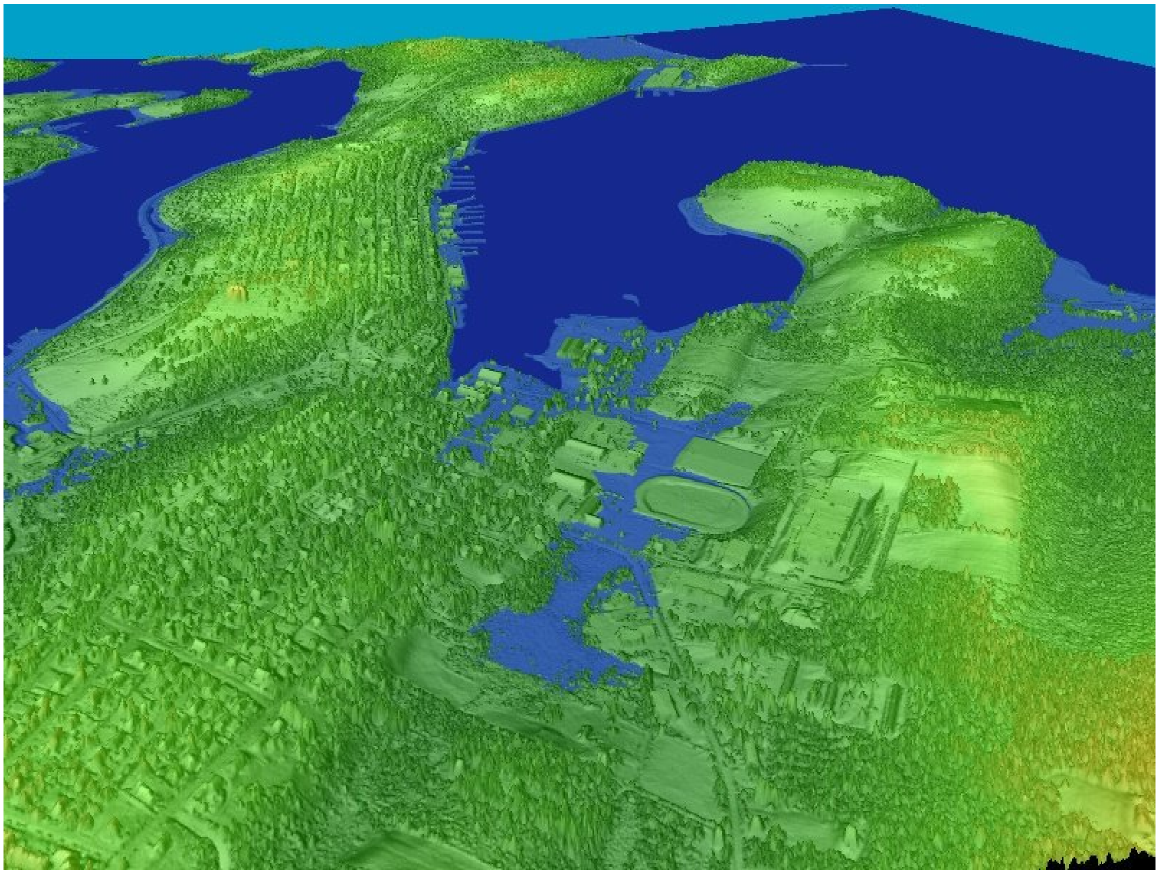

Figure 16 Example of flood inundation derived from the lidar DEM for Lunenburg. The flood level represents the Hurricane Juan water level in Halifax in 100 years with a relative sea-level rise of 146 cm. Source from Webster et al. 2011 ACAS report.

The following description of how lidar can be used for flood risk mapping was extracted from http://www.spatialresources.com. "Lidar data can accurately reflect beach topography much more efficiently than traditional methods such as photogrammetry, which can be difficult to use in areas of limited contrast. The technology also is used to map and study shore belts, coastal areas, dunes and dikes. Coastal managers use lidar data to study the effects of severe storms and hurricanes and in turn enable them to better prepare for those types of situations. Federal Emergency Management Agency (FEMA) flood maps, watershed management, hydrological modeling and flood and storm-surge inundation forecast are accomplished with the help of lidar data used by the U.S. Corps of Engineers. The information is used to create effective emergency response plans and show low elevation areas that would be hit the hardest, streets that would be cut off and what alternate routes would be available during flood events."

5.2 Watershed Delineation

Similarly to using lidar to determine where water will flow inland from the ocean for flood mapping, lidar can be used to determine how water will move towards the drainage outlet of a watershed on land. Lidar high-resolution DEMs can be used to map the extent and characteristics of watersheds to a level that is not possible using traditional methods. Although DEMs derived from photogrammetry and topographic maps has been used with GIS to generate watersheds, their accuracy was limited, compared to drainage features derived from lidar. Most GIS systems can calculate the watershed draining into a stream based on the DEM. The standard D-8 algorithm (Jenson and Dominque, 1988; Costa-Cabral and Burges, 1994) is used to determine down-stream flow direction and sinks (depressions within the DEM treated as errors by the algorithm) are filled to allow continuous down stream flow. After the flow direction has been calculated, a flow accumulation grid can be constructed and streams and basins or watersheds generated. However, when dealing with DEMs at high-resolution, other considerations must be made. Inspection of the drainage basin boundaries and stream longitudinal profiles indicates that most catchments have sinks. Many of these sinks are adjacent to the raised elevations of a roadbed captured by the high resolution of the lidar. As a culvert could not be represented on the DEM, a “notch” is cut across the roadbed and assigned an elevation of the nearest downstream cell to improve the accuracy of the flow direction algorithm and to prevent excessive erroneous sink filling operations in deriving the catchment basins and stream profiles. This modification improves the accuracy of the flow direction algorithm, prevented excessive erroneous sink-filling operations in deriving the catchment basins and stream profiles, and allowed the stream to “pass through the roadbed”. The overall result is the generation of a more accurate flow accumulation grid and basin boundary.

Watershed boundaries can be generated for the largest catchment or primary watershed as well as secondary and tertiary levels. In addition to watershed areas, the location of streams, either ephemeral or continuous. The catchment areas can be reduced to map the areas draining into any stream order. A first order stream is the smallest unit. If a first order stream drains or connects with another stream, the downstream section becomes a second order stream and so on. Thus the larger the stream, typically the higher the streams order it will be. The ability to calculate catchments or watersheds for small order streams and them aggregate them to higher order streams and catchment areas is important when trying to relate land use to water quality or flow characteristics (Fig. 17).

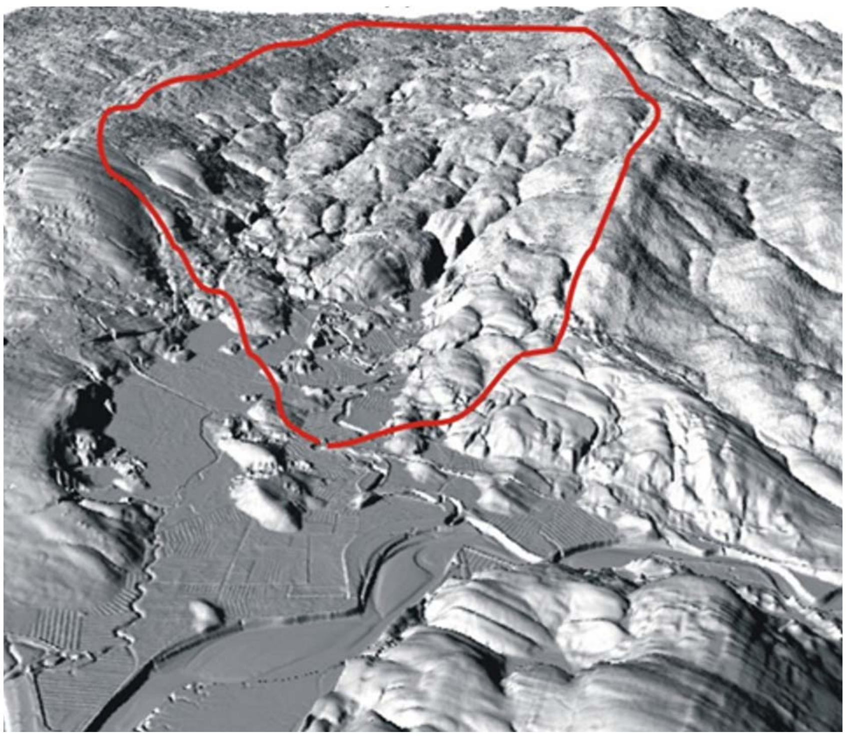

Figure 17 Example of a watershed derived from a lidar DEM for the Nappan River.

5.3 Geological mapping

The improved resolution and accuracy of ground measurements with lidar under the forest canopy often reveals details that allow traditional geology maps to be improved by revealing structures such as geological faults and fractures as well the contacts between geological rock units that were never visible on previous maps better defined. Previously, geologists had to rely on sparse outcrop locations along the coast and along stream beds in combination with interpreting aerial photographs that did not penetrate the vegetation canopy to produce geology maps. The original lidar survey was conducted to examine Piping Plover habitat, an endangered shore bird along the south shore of Nova Scotia, but the data was also adapted for other purposes including examining the geology by AGRG. The area is completely forest covered except along the coast and had been mapped by the Geological Survey of Canada, Open File 1768 (Hope et al., 1988). The lidar survey was conducted during full ‘leaf-on’ conditions, thus making penetration of the laser pulses to the ground more difficult. The lidar points were classified and surface models constructed, the DSM incorporated all of the lidar returns and the DEM utilized only the ground points. Colour shaded relief (CSR) maps of the surface models were constructed and interpreted. The ability to remove the vegetation points reveals the bedding structures of the slates and a massive dome structure in the south (Fig. 18). The variable bed resistance to erosion allows the bedding planes to be traced over large distances even under the forest canopy in the lidar DEM. The previous geology indicates that the entire area is made up of sedimentary rocks and is folded into a single syncline which passes directly through the dome structure. Based on the visual interpretation of the terrain models, shaded relief and CSR, and a visit to the site for follow up field checks, a new geology map has been derived (Fig. 18). In addition to a new fault being mapped, a granite pluton has also been added to the map. Field evidence supports the occurrence of a fault at this location. A large granite boulder or possible outcrop was found in the field which further supports the interpretation that the topographic dome evident on the lidar is a granite pluton.

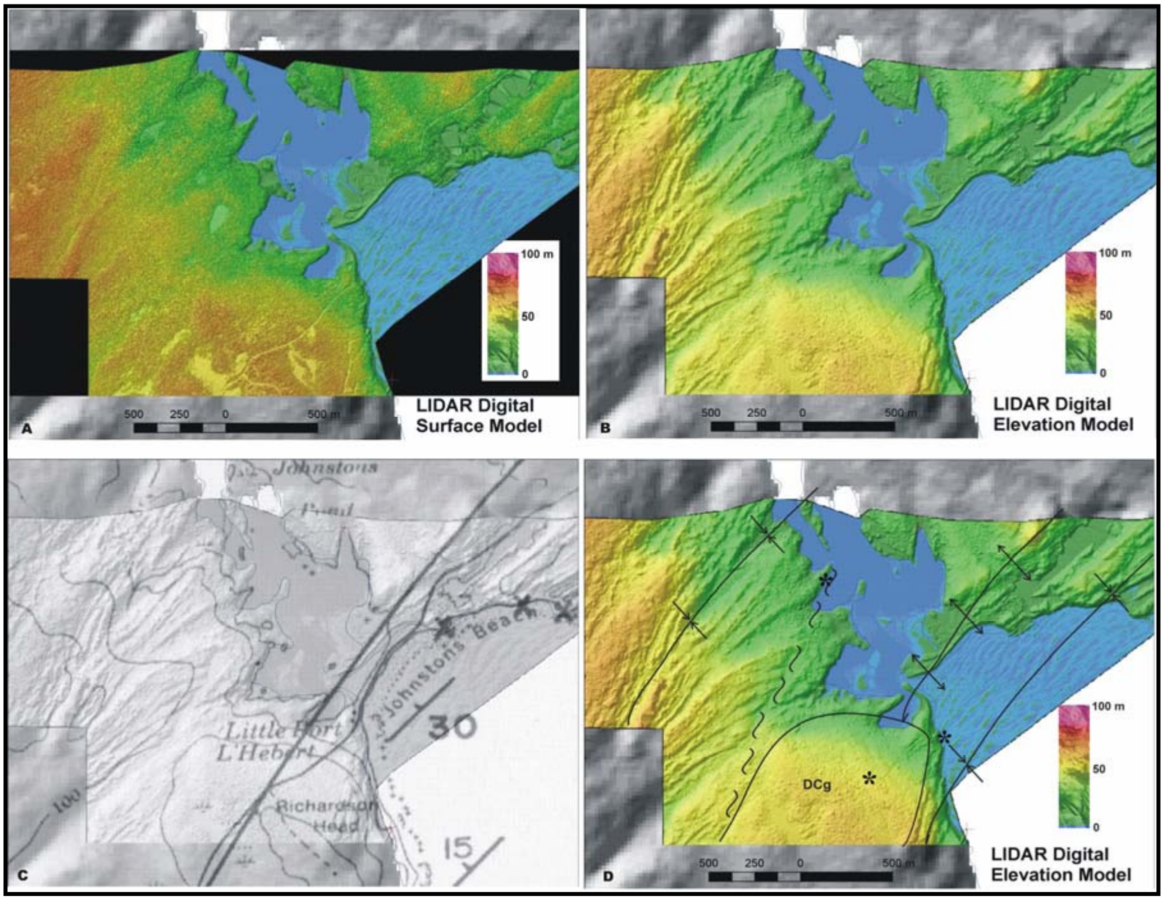

Figure 18 Example of lidar improving geological mapping. A) Lidar DSM of Johnson's Pond on the south shore of NS. B) Lidar DEM of Johnson's Pond on the south shore of NS. C) Existing mapping from GSC Open File 1768. D) Revised geology map including meta-sedimentary and granitic rocks.

The ability of the lidar to penetrate the forest canopy has assisted geologists in identifying geohazards such as sink holes and karst topography. The Windsor Group represents evaporates, gypsum and salt deposits of Carboniferous age in Nova Scotia. These deposits occur throughout Maritime Canada as sedimentary basins formed on the flanks of the highlands. The areas around Oxford and Antigonish, Nova Scotia have been studied and used to demonstrate the ability of lidar to map karst topography. This type of landscape can be a hazard as the bedrock is dissolved by the groundwater and the area can become undermined and local subsidence can occur. The lidar DEM and shaded relief maps allow the unique drainage patterns and hummocks associated with karst processes to be easily identified and mapped. Other areas around Nova Scotia where the Windsor Group is present could benefit from the interpretation of lidar surveys to identify such geohazards. Lidar has been used to map illegal pits where coal seams outcrop near the surface in Cape Breton. NS DNR Mineral Resources Branch has used lidar to map abandoned mine openings and other infrastructure from past mining operations that may be hazardous in the HRM area coverage. They have also used lidar to map tailings piles as well generate improved bedrock and surficial geology maps.

Lidar has been used for many earth science applications include the identification of fault scarps and potential landslide areas (Haugerud et al., 2003). Locally, lidar has also been used to map the different flow units of the North Mountain Basalt Formation in the Annapolis Valley (Webster et al., 2006c). Lidar has revealed new faults and geological structures along the main suture separating the Avalon and Meguma Terranes of Nova Scotia near the Antigonish Highlands (Webster, Murphy and Quinn, 2009b). Lidar derived DEMs have also been used to assist in the exploration of aggregate sand deposits in the Annapolis Valley which is a critical component to concrete (Webster, et al., 2009b).

5.4 Coastal erosion

Joggins, Nova Scotia is a world UNESCO Heritage site because of the Carboniferous fossils that occur there in the outcrop exposed along the coast. Unfortunately the cliffs are actively eroding and expected to erode faster as sea-levels rise. An airborne lidar survey was conducted over the area in 2007 and a follow up ground-based lidar survey was conducted in 2009 to obtain details on the cliff face and monitor erosion (Fig. 19). Repeat ground-based surveys are planned in order to measure the change in the cliff face position.

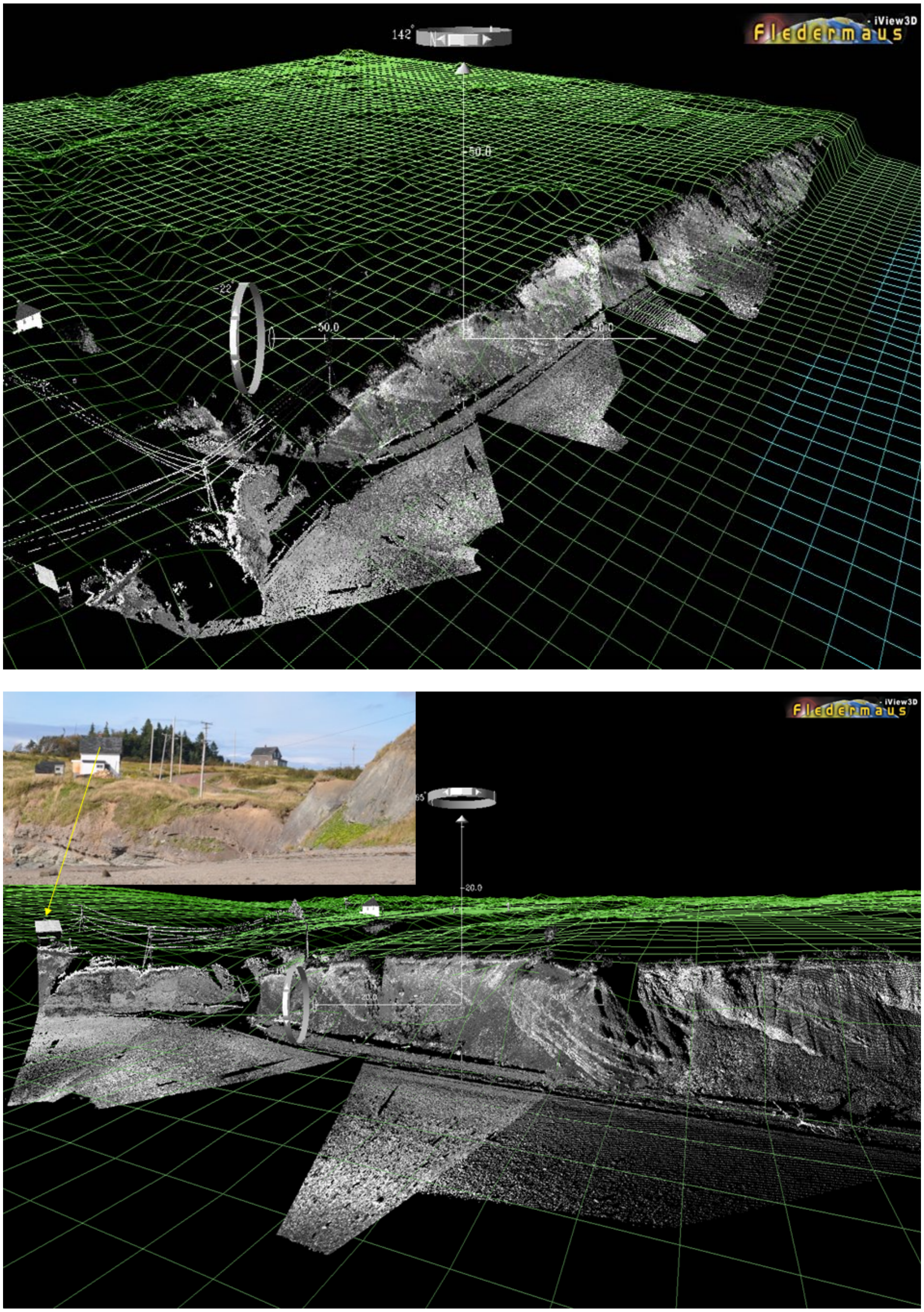

Figure 19 Example of airborne and ground-based lidar to be used to monitor coastal erosion at Joggins. The top image shows a wire frame DEM from airborne lidar merged with detailed ground-based lidar scans of the cliff. The bottom image shows the same information from the opposite viewing angle. The axis and grey rings on the figure are part of the display control system.

As part of an erosion ACAS project, AGRG established three monitoring locations on three of Nova Scotia's coasts to test the utility of combined airborne and ground-based laser scanning to monitor erosion. Ground based scans were acquired at Cape John on the Northumberland Strait, Hirtles Beach along the Atlantic coast and at Mavellette on the Bay of Fundy. At each site three typical geomorphic coastlines were scanned that consist of: dunes, glacial till bank of unconsolidated sediments, and bedrock cliffs. A significant storm surge affected the coastline of the Northumberland Strait in Dec. 21, 2010. Repeat ground based-lidar scans were used to map erosion, where 780 cubic meters of material was removed along 150 m section of the bank. Repeat airborne surveys can be used to map the volume of change as well. The magnitude of change must be large enough to surpass the precision and resolution of the airborne lidar DEMs, typically 1-2 m cell size and vertical precision of 15 cm.

5.5 Power Lines

The following description of how lidar can be used for mapping power lines was extracted from http://www.spatialresources.com. "Airborne lidar is now a well proven technology for providing accurate elevation models for transmission lines, allowing utilities to measure the shape of the ground below the transmission line, the position of the towers and poles, the sag on the wires, and the up-growth of any vegetation incursions or other possibly illegal incursions into the right of way (Fig. 20).

Lidar has shown its value in providing precise location of poles or pylons (usually within a foot or two), very accurate digital terrain models, the actual elevations of the conductors above the ground and vegetation (allowing the clearance to be measured), and the subsequent modeling of the change in sag if additional power is pushed through the conductors. Currently there is no other efficient way of accurately measuring the actual height of the lines above the ground. For transmission line surveys, the accuracy of lidar data is in the region of 6 inches absolute and closer relative. This means lidar point to lidar point data is usually within 2-3 inches in accuracy, providing a very close accuracy rating between points along the line. However, compared to local geodetic benchmarks (ground control) the absolute accuracy of any point is around six inches (ca. 15 cm).

At the same time as the lidar data are collected, color digital images are collected to provide even more information about the conditions along the right of way. These are normally provided at a minimal cost unless they need to be rectified to form a seamless mosaic. Each individual picture is registered with its center point having a GPS photo center coordinate, so it is easy to locate the image anywhere in the system (i.e. it can have a UTM coordinate or even a latitude and longitude which effectively provides a specific location compared to anywhere in North America). Utilities can effectively import the lidar data and then calculate the amount of sag that will occur to the conductors if more power is pushed through the system. They will then indicate the amount of clearance to the ground or vegetation when this is done. The lidar data provides a lot of engineering possibilities, much of which can be done without actually leaving the office. New lines can be engineered with tower or pole placement without leaving the office. Some utilities have fully engineered transmission lines without actually going out on the ground until they are ready for construction. All of the tower placement can be done using the Lidar data in the office and programming a GPS unit so the construction crews know exactly where to locate each tower.

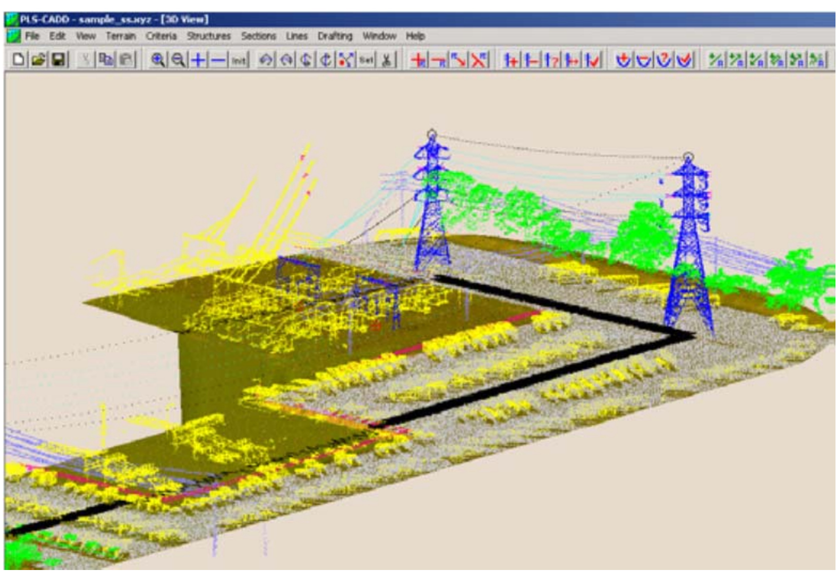

Figure 20 Example of power lines and towers detected from airborne lidar (Source GeoDigital).

Costs associated with such projects are determined by how much of the system is made up of straight major power lines to reduce the number of turns (say metal towers 132+ Kilovolts with relatively few bends, and how much is lower voltage pole lines where there are lots of twists and turns.) Very twisty lines tend to cost more because the aircraft or helicopter has to fly slowly or having to stop and change direction. Lidar providers are often able to compute the sag of wires on existing lines. However, this can add substantially to the cost of the project as each span has to be computed. Some clients want to keep costs down and perform these calculations themselves on an as needed basis. On the other hand, some utilities do not care to purchase the software to do all of these calculations themselves, and are willing to pay for a complete solution. The lidar data can be separated into 3 separate files: ground files, vegetation files and conductor files. They can be viewed independently or combined to do calculations. Typically, on larger structures more points are able to be collected, however on single pole structures the pole can be missed. In this instance, the conductors get picked up and by intersecting the catenaries of the conductors, the pole can be located, usually within about a foot. The image also helps in this respect - as you can usually see on the image what type of structure it is."

5.6 Utility, Highway & Municipal Mapping

The following description of how lidar can be used for utility mapping was extracted from http://www.spatialresources.com. "The construction of pipelines, the mapping of broad area exploration sites, route locations and geophysical exploration surveys require a precise knowledge of the topography. Airborne lidar and digital imagery are ideal technologies for the rapid and accurate acquisition of survey data for route location and broad area mapping. Lidar data sets have become an integral component in the planning and design process when conducting bare-earth assessments, risk-management studies and right-of-way surveys. Digital terrain models produced using this technology have been used for detailed planning and engineering projects, often saving tens of thousands of dollars compared to traditional techniques. Transportation engineers need to examine existing roads and highways, interchanges and access corridors, water and railroads in the development stage of highway planning and construction. Lidar data is able to provide the most economical and accurate x, y and z coordinates available for highway and transportation projects. Surveying roads and highways, particularly with active traffic or damaged bridges is best accomplished with laser scanning. Capturing complete 3 D data allows them to develop TIN meshes of the roadway surfaces, portal openings and overhead beams determining where absolute minimum clearances exist. For transportation surveys, laser scanning demonstrated about 75% savings in labor costs compared with traditional surveys, plus provided more detail and was much safer to deploy.

Airport designers and engineers need data that provides accurate and detailed terrain information in the developing and planning stages of airport construction and modification. Engineers are now employing lidar data to conduct studies involving noise abatement, Line of Site (LOS), obstruction mapping and landing patterns for optimal performance and minimal impact.

Because of the active nature of the sensor and its ability to penetrate between a lot of vegetation, lidar surveys can be conducted when other technologies are not suitable or are impractical. For example, it is not necessary to wait for leaf-off conditions. As well, the digital camera system operating on standard color wavelengths is ideal for corridor applications. With imagery, an aerial record of the ground can indicate land use and any obstacles to construction. Along existing rights of way it can be used to show vegetation growth and intrusions. The pixel size acquired by the camera varies depending on flying height from 9 inches to 2 feet (20-50 cms). Because of the low flying height and active aspects of the laser system, the unit can often be flown below clouds when other airborne sensors are not effective, or at night. (Color imagery, of course, requires daylight, but intensity imagery does not)."

As mentioned earlier NSDTIR have used lidar and digital orthophotos to assist in functional design, drainage, best route selection, cut and fill operations, the identifications of possible archeology sites, and general environmental assessment for highway projects. They have used "key points" which is a reduced set of ground points that represent the critical elevations required to accurately represent the ground surface. One of the main benefits of acquiring lidar is the major time saving for acquiring detailed elevations, as compared to traditional land surveying techniques, especially in forested areas. NSDTIR estimates this saving in time translates into a monetary saving of up to 1/3 of the overall project costs.

Municipalities can benefit from lidar surveys in many different ways to support their decision making in the areas of: asset management, wastewater and water supply infrastructure (Fig. 21), land use, risk assessment, flooding, erosion, landslides etc.), and general GIS applications.

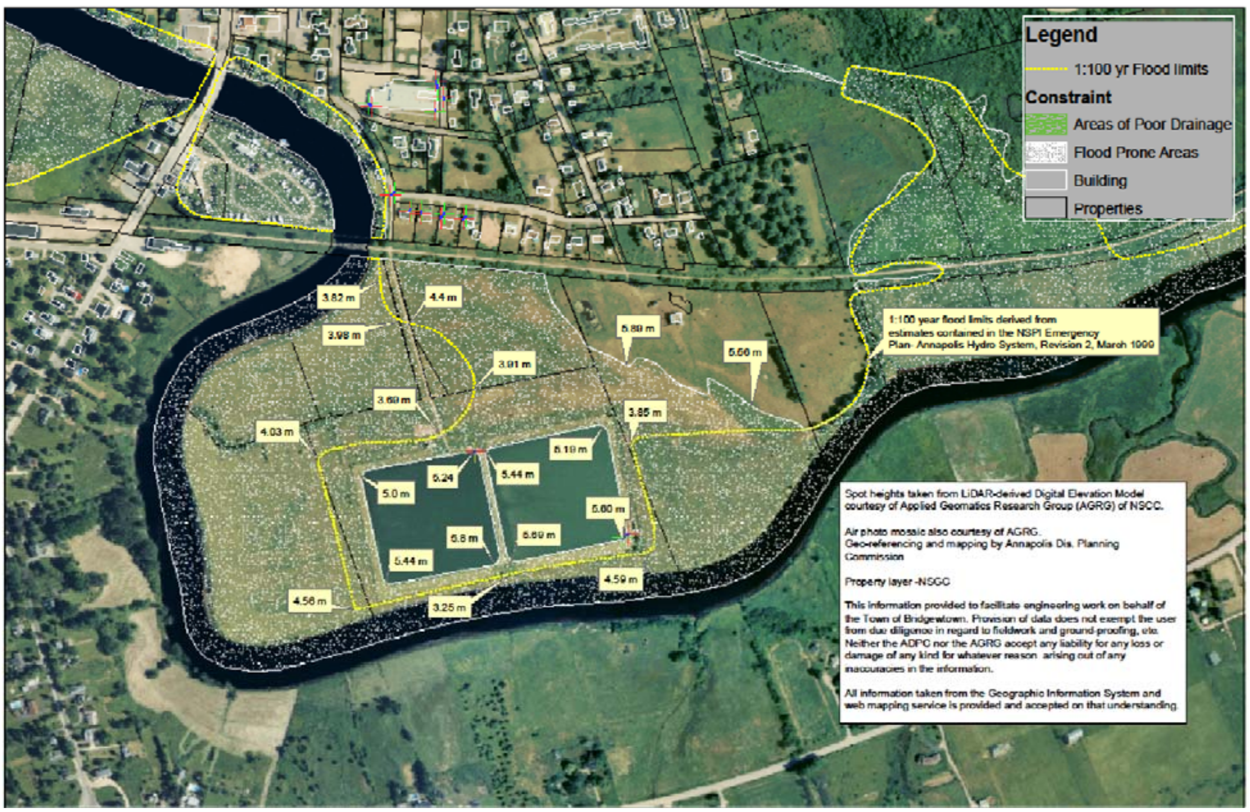

Figure 21 Example of how the Municipality of Annapolis has used lidar. This example is for the town of Bridgetown. Source Keith Saunders, Municipality of Annapolis.

5.7 Forestry

High resolution DEM data derived from lidar can be used for forest nutrient modelling, and could improve “wet areas mapping” within the province which currently is based on a 20 m DEM. Forest interpretation could benefit from the advances in digital stereo viewing and the acquisition of digital aerial photographs and lidar captured synchronously from one flight, thus reducing acquisition costs.

The following description of how lidar can be used for forestry, environment and mining surveys was extracted from http://www.spatialresources.com. “Forestry and resource managers require precise area-wide measurements that include tree stand density, tree height, canopy cover, road or corridor access, inventory management, commercial harvest estimates of standing timber volumes and ground elevations. Lidar is an accurate and economical means to gather these forest measurements which can also be applied to establish roughness coefficients for determining the resistance of water flow during flood events. Lidar measurements can reveal minute details such as tree height and distance from the canopy to the ground, shows minor undulations in relatively flat terrain and allows rapid, cost-effective, accurate mapping of linear corridors.

On the environmental front, LIDAR data is being reviewed to maintain inventory on national priority list sites, aid in watershed management and ecosystem analysis and the creation of airshed dispersion models. Surface mining use of LIDAR data is becoming vital for site planning and volumetric runoff management analysis, mine modeling, permitting, reclamation, overburden calculations, and volumetric calculations.

For construction site & engineering surveys, laser scanning demonstrated more than 60% labor savings, provided greater detail, and benefit from 3D visualization. Volume calculations, measuring quantities of rock, stockpiles of materials, quarry faces, mining or landfill applications can be surveyed economically with resulting detail that would be difficult to meet through traditional, ground-survey methods.”

At the more local level, tree heights and building heights were calculated by subtracting the lidar surface model which contained the elevations of the buildings and tree canopy as well as ground (DSM) from the ground elevations only (DEM) to form a Normalized Height Model (NHM) which represents the height of the object above the ground, as compared to the elevation of the object above mean sea level (DSM & DEM) as demonstrated with the HRM lidar dataset (Fig. 22).

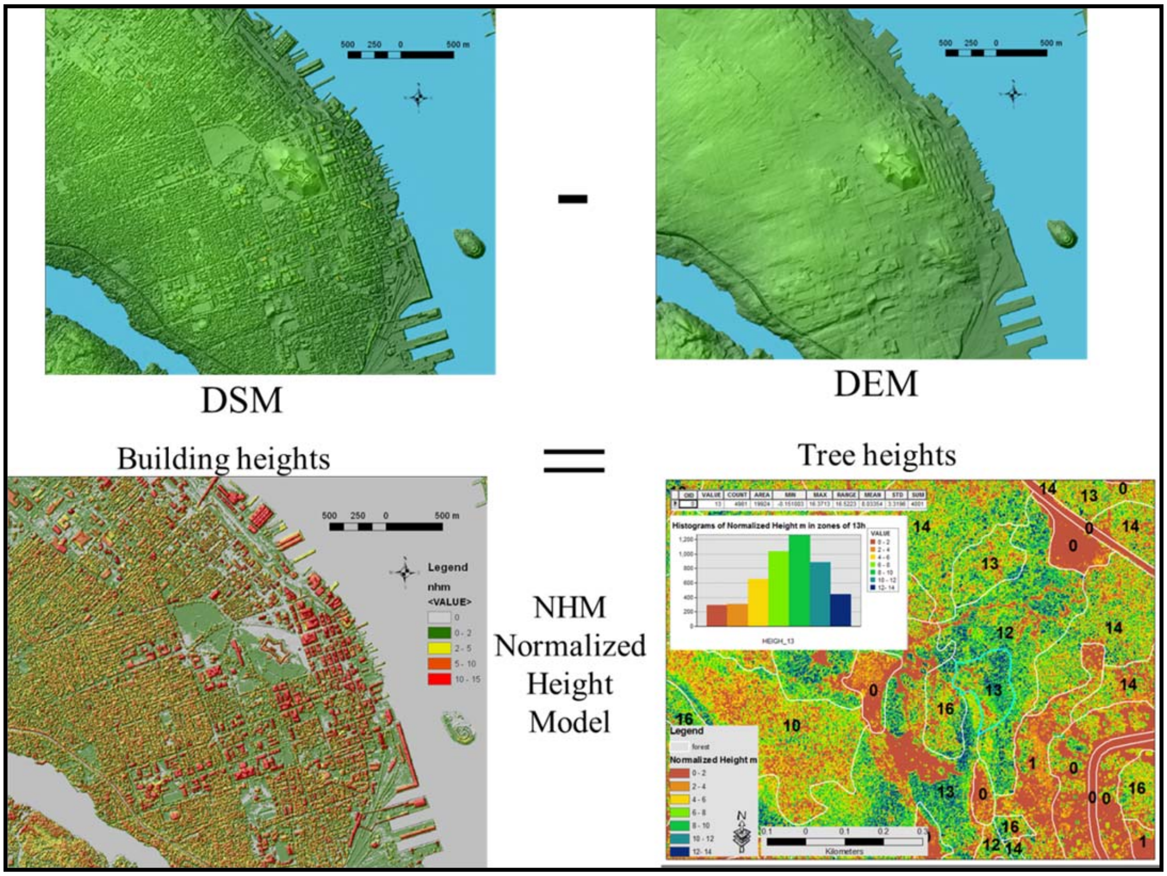

Figure 22 Example of deriving building and tree heights from lidar surface models of HRM. Top left map is the lidar DSM. Top right map is the lidar DEM. Lower left map represents the Normalized height Map (NHM=DSM-DEM) for buildings. Lower right map represents the Normalized Height Model (NHM=DSM-DEM) for trees with the DNR forest inventory and stand attributes overlaid.

5.8 Archeology

The ability to penetrate the forest canopy and survey the ground as well as the spatial and vertical resolution allows high resolution DEMs that can depict subtle topographic variations that can be the remnants of archeological sites of old structures e.g. foundations, roads or ditches. Parks Canada have used the lidar acquired at the Fortress of Louisbourg to map regimental camp infrastructure that remains from a siege during the 18th century. Features such as remnant foundations and ditches are evident on the lidar that are not visible on other topographic maps or even aerial photography (Fig. 23). The lidar helps archeologists identify potential sites of interest that they can investigate in the field and also provides the detailed landscape to better understand the strategic locations of structures and how the landscape was utilized during battles.

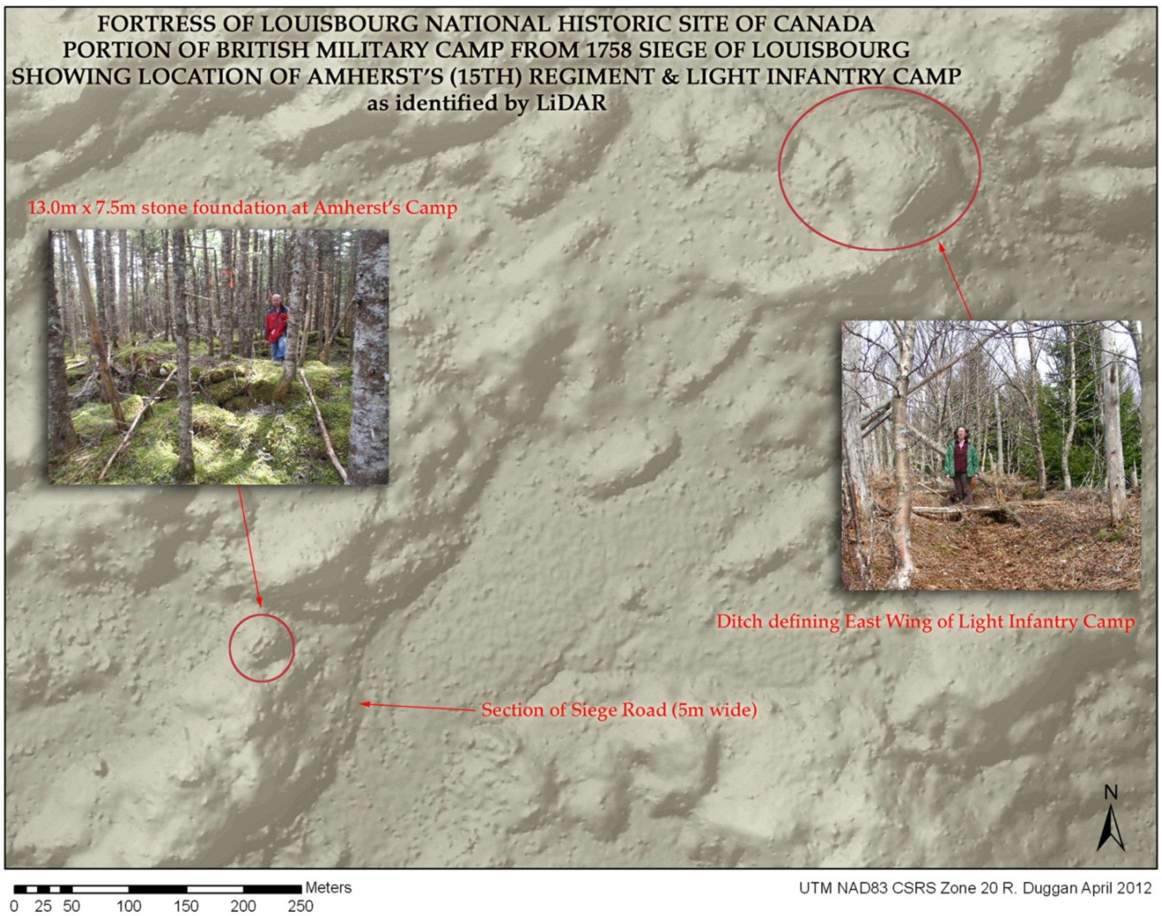

Figure 23 Example of shaded relief lidar DEM that shows archeology sites near Fortress of Louisbourg. Source, Rebecca Duggan, Senior Archeologist, Parks Canada Agency.

5.9 Mobile Mapping

The following description of how mobile mapping lidar can be used for various applications was extracted from www.3dlasermapping.com.

"Mobile Mapping Systems (MMS) use laser scanning technology combined with a navigation system to scan highways, waterways, and buildings from a moving vehicle. MMS' can be mounted on various types of vehicle, including automobiles, boats and trains. This flexibility allows for numerous applications including highway mapping, asset management, coastal, river and canal surveying, city modelling and flood mapping to name just a few. Mobile mapping systems can capture highly detailed and accurate data to support rehabilitation projects as well as the design and layout of new roads. Furthermore, since an MMS can survey at normal traffic speeds, there is no need for road closures or other safety precautions. The concept of highway asset management is becoming increasingly important for those responsible for managing highway networks. Typical highway assets comprise road pavements, footways, streetlights, cycleways, signs, drains, road markings, traffic signals, street furniture, structures and verges. Using a mobile mapping system, combined with video imagery, these network assets can be mapped accurately and efficiently. This data can then be post-processed into a number of formats including GIS and CAD. Mounted on an automobile, mobile mapping systems can capture laser data at normal driving speeds, meaning that urban environments can be mapped in a short amount of time. Combining the laser scan data with video and photographic imagery enables colour point clouds and 3D models to be created accurately with realistic texture mapping. Mobile mapping systems are ideal for coastal mapping, embankment surveying, and flood defense monitoring. An MMS can be mounted on various vehicles, which means even the remotest locations can be surveyed. Typical vehicles include boats, 4x4s and even quad bikes."

6 LIDAR BEST PRACTISES AND GUIDELINES

In order to derive an appropriate dataset from lidar to solve a specific geospatial application problem, one must ensure they request the right type of data to be collected. In general from an end users perspective the three main specifications that are supplied to a lidar service provider are: 1) the ground point spacing distance or number of points per square metre, and 2) the minimum absolute and perhaps relative vertical and horizontal accuracy of the data, and 3) the types of processing and products to be delivered. For example, most applications would require the lidar service provider to classify the point cloud into a minimum of “ground” and “non-ground” classes of points. The type of deliverables will depend on the geomatics skills and technology available to the end user. In the past, the minimum standard was the delivery of ASCII x,y,z files. Considering the other attributes that are collected during a survey, including information about the return pulse echo indicating if the return is a first return, or a last return, or one of many returns, and other attributes like the lidar intensity and other important information such as the flight-line and trajectory information, the delivery of simple x,y,z is no longer considered a best practice. Most of the popular GIS systems now have support for the binary standard format for lidar point data, known as LAS. This binary format maintains the highest level of detail and has fields that contain: standardized classification codes, elevation (referenced to a single vertical datum), intensity, flight-line number, GPS time, echo code, and scan angle. These additional attributes to elevation can be used to generate map products such as the echo code or intensity. However, the more critical use of these additional attributes of the data such as flight-line number and scan angle are for scrutinizing the lidar point cloud to ensure it is of a high quality and there are no systematic or random errors present. For example, a common problem that can occur in airborne lidar data are vertical offsets between flight-lines or anomalies at the outer edges of the lidar swath if a lidar sensor has not been calibrated correctly.

In terms of ground point spacing of the lidar data, there will always be a trade-off between the available budget of a project and the desired level of detail of the data collected and the level of value added processing and analysis. Therefore it is critical that the user of the data requests lidar to be collected with adequate specifications in order to meet or exceed the requirements of the specific application project. In addition to the specifics of the lidar survey, other best practices to consider include the time of year and ground conditions. For example if a bare-earth DEM is the main product to be derived from the lidar and the study area land-cover consists of mixed forest, then leaf-off conditions would provide the best results from a lidar survey. Leaf-off conditions occur in NS from late October to mid-May depending on the local climate. For most lidar applications it is best to survey without snow cover as this could bias the ability to accurately map the ground if the snow is very deep. However a light dusting of snow or minor remnants of snow in the forest may be acceptable for the minor influence it will have on the ground elevation measurements. Generally the spring and fall are the best times to acquire leaf-off lidar. The spring has the extra benefit of the low vegetation and shrubbery being flattened from the winter snow pack (see Webster, 2005). In the fall this low vegetation and shrubbery can persist well into winter depending on the amount of snow fall. Unfortunately at both time periods, spring and fall, we traditionally get a higher level of precipitation and saturated ground and standing water can adversely affect the results of a lidar survey. Other temporal considerations are for coastal surveys where low-tide acquisition is the best practice as these intertidal areas are problematic to survey using other methods. The fact that the lidar system is an active sensor, flights can be arranged to acquire the coastal zone at low tide irrespective of light conditions. Fog and rain can adversely affect a lidar survey and periods of the day when this is common should be avoided in order to minimize standby time when the lidar system cannot acquire data.

Some other general best practices include choosing study areas that are rectangular in nature; the most cost effective method for a lidar survey is to use a fixed-wing aircraft and to fly long straight lines. Even if the study area consists of a convoluted coastline, the survey plans will probably consist of flying a rectangular block in straight lines trying to minimize the number of aircraft turns required, since data are not collected on truns from a fixed wing aircraft the fewer terms in a survey they more economical it is. Some corridor surveys, such as for rail or power lines may be better suited to use a helicopter to acquire the lidar which can turn more effectively but is generally more expensive to operate than a fixed-wing aircraft. The length of a given flight-line is typically restricted to a maximum distance of 50 km, ideally less than 30 km from the GPS base station which is used in post processing to compute the trajectory of the aircraft and then derive the lidar point cloud. The GPS-IMU trajectory solution is typically the largest error in a lidar systems error budget, thus one should not increase the distance of the GPS baselines beyond 50 km using the current processing methods (Hodgson and Bresnahan, 2004). This limitation can be overcome using multiple GPS base stations

The preference and popularity of lidar is a result of the high density of information and the high degree of relative and absolute accuracy. Most lidar service providers can easily achieve an absolute vertical accuracy specification of better than 15 cm. In many projects where the end user does not have the knowledge or access to high precision survey data, the lidar provider is tasked with validating and reporting on the accuracy of the lidar data. Many service providers do this on their own to ensure the data meets the specifications. In addition to the service provider validation, it is a good practice to independently validate the lidar data and derived products ie. DEM. Ideally the validation should be carried out by the organization requesting the data, since they have a specific application in mind and can test the accuracy of the lidar data and data products (e.g. DEM) in that context. Webster (2005) present different methods to validate the lidar points and derived DEM product. Webster and Dias (2006) present validation methods for comparing GPS check points with proximal lidar points within a GIS environment.

In order to test if one dataset has met or exceeds the accuracy specifications outlined in the acquisition contract, one must use a dataset that is considered to have a higher accuracy than what is being tested. For example, survey grade GPS can provide precisions of 2-3 cm in the vertical and can routinely achieve accuracies better than 5 cm in the vertical using both real time kinematic (RTK) and post processed static and kinematic methods. Thus, if the lidar specification required the absolute vertical accuracy of the data to be within 15 cm, one must compare it to data of a greater accuracy, such as survey grade GPS check points with a vertical accuracy of 5 cm. Here in Nova Scotia, one should not attempt to use existing NSTDB spot elevations or DEMs from the 10:10,000 scale data to validate lidar since the accuracy of the data being used to validate the lidar is not sufficient. In the case of the 1:10,000 NSTDB the vertical accuracy of the DEM mass points is 2.5 m. The same can be said for mapping grade GPS equipment that typically only can achieve a vertical accuracy of 2-3 m.

The requirement to use a higher level of accuracy dataset as a check on the accuracy of lidar is often overlooked or not budgeted for in the lidar procurement process. This is not a good practice and leaves the end user totally dependent on the lidar provider to assure the absolute accuracy of the data, or potentially not even testing if the accuracy of the data meets the specification. It is recommended that independent check points be acquired and not shared with the lidar provider in order to validate the accuracy of the point cloud or derived products such as surface models (e.g. DEM). If a lidar system is not calibrated correctly there can be vertical and horizontal offsets of features in the point cloud between overlapping flight lines or lidar strips (Katzenbeisser, 2003; Kornus and Ruiz, 2003; Maas, 202). As well there can be errors near the edges of the scan. In order to identify these potential issues and resolve them, it is ideal to collect validation check points transverse to the flight line direction, ensuring points are collected across the entire swath and also the overlap between strips. The accuracy of the surface models is also important, such as the DEM since many of the GIS applications that benefit from lidar allow more analytical processes to be executed on grids rather than points. For example a DEM can be used to derive slope, watershed delineation, flood inundation, and line-of-sight products. Therefore to test and report on the accuracy of the DEM will provide users of derived products a sense of the absolute accuracy of the data they are using.

6.1 ACQUISITION PARAMETERS

The issue of best practices for acquisition parameters depends on the application and size of the area to be covered. Two categories of lidar mapping are generally referred to as “wide area” mapping applications such as for fluvial or coastal flood risk, and “site specific” mapping and may include applications related to forest plots, archeology sites, and highway corridor mapping as examples. In general, because of budget and data volume constraints, the lidar point spacing on wide area projects is larger than on site specific projects. Regardless of what type of mapping project, one of the largest sources of error in lidar is GPS that is used to derive the aircraft trajectory. Thus the acquisition parameters should specify that the Nova Scotia High Precision Network or the Canadian Base Network of monuments be used as control stations or temporary stations be established with an equivalent accuracy to keep the GPS base line (distance between GPS base and GPS in the aircraft) less than 50 km and ideally less than 30 km.

In general an end user will specify the minimum point spacing of the lidar points to be acquired as well as the vertical accuracy and in some cases the horizontal accuracy of the lidar points and derived products such as a DEM. The along track spacing (distance between points parallel to the aircraft motion) should be similar to the across track spacing (distance between points perpendicular to the aircraft motion) so that the lidar swath samples the terrain in a relatively even sense. The settings of the sensor configuration are sensor specific and may require flying flight lines with 50% overlap to achieve the desired sampling distribution. Past wide area projects for flood risk mapping have called for minimum point spacing between 0.5 and 1 m, or up to 4 points per square metre (equal to point spacing of 0.5 m). For example the ACAS lidar acquisitions were designed to obtain a point spacing of 0.5 m. Lidar surface models were then constructed from the ground points at 1 m and 2 m resolutions. In contrast to this, the US Federal Emergency Management Agency (FEMA) calls for lidar point spacing to be within 2-3 m and a derived DEM of 5 m grid resolution. In the case of site specific projects that required very high point densities, spacing can be reduced to less than 0.5 m or 10's of points per square metre. Other constraints may include the time of year (leaf-on or leaf-off, snow cover), state of the tide, and sun angle if aerial photos are to be acquired at the same time. In some cases where shadows or specular reflective surfaces (mirror like) may be an issue, specific overlap such as 50% may be requested. Additional details that are specific to the sensor that may play a role in the acquisition process include: beam divergence, scan angle, number of received pulses (the number of returns), and additional information such as the intensity of the returned pulse may be requested. Generally narrow beam mode is preferred for most applications with the exception perhaps of power line mapping. The beam divergence and altitude will control the diameter of the lidar footprint on the ground. In general the smaller the footptint, the more accurate the derived range. If a sensor has a beam divergence of 0.3 mrad and flies at an altitude of 1000 m above ground level, the laser footprint diameter at nadir will be 30 cm. The scan angles should be limited to less than 25 degrees either side of nadir and typically the narrower the scan angle the less error. Older lidar sensors were only capable of recording first or last laser returns. Most sensors today at a minimum can record first and last returns and many can record multiple returns, typically up to four returns. For most applications, with the exception of forest research where the structure of the tree beyond the canopy may be of interest, recording the first and last returns provides all of the detail required to derive DSM and DEM models. The intermediate returns are typically not used and increase the volume of the point cloud significantly. Similarly, older lidar sensors did not always record the intensity of the returned pulse, although most today record the intensity of all the returns. Although it has not been routinely used yet, the intensity information can provide value and insights into what type of land cover the laser pulse reflected off of.

In addition to the specific lidar acquisition parameters, it is recommended that validation check points be acquired during the airborne campaign. Ideally the check points are acquired using survey grade GPS. In the ideal case using the same GPS base station simultaneously as the airborne survey would ensure all conditions are the same between the lidar and check points (e.g. same GPS constellation geometry, PDOP etc.). However, if this is not possible, then check points should be acquired as soon as possible to ensure the ground conditions and vegetation is similar to those during the flight. If that is not possible, then check points can be acquired over open areas and hard surfaces such as roads and parking lots at any time to validate the lidar data.

6.2 TECHNICAL SPECIFICATION AND STANDARDS

Every application of lidar may require a different set of specifications and levels of accuracy and deliverables. In the example provided below, the minimum numbers of deliverables have been requested in order to keep the costs as low as possible for the client. This assumes that a member of the stakeholder team has the capability to handle LAS files and generate the standard GIS products that are expected from a lidar survey (e.g. bare-earth DEM, full-feature DSM, intensity image of all lidar returns). It does not include the collection of break lines or other additional value added processing that can significantly increase the cost of data collection.

6.2.1 Example lidar specification

A specification for a wide area survey is provided as an example with the minimal requirements:

The lidar system must be equipped with a survey grade GPS and IMU and trajectory baselines must be kept to within 50 km, ideally under 30 km. Multiple base stations may need to be employed in order to achieve this. The lidar unit must be capable of recording at a minimum, the first and last reflected pulse. The vertical accuracy of the lidar points must be within an absolute accuracy of 30 cm at the 95% confidence interval, assumed to be equal to 1.96 * RMSEz (Root Mean Square Vertical Error of the check points compared to the lidar points or derived surface using a linear TIN interpolation method). Thus the maximum allowed RMSEz is 15 cm for open areas with hard surfaces (e.g. roads). This specification should be easily met and exceeded with today’s technology. If aerial photography is to be acquired at the same time as the lidar, then the time of day must be considered to avoid shadows and sun glint. Leaf-off conditions are required and coastal areas must be acquired within 2 hours of the predicted low tide time. Survey flight lines should be orientated parallel to the coastline. Flight lines must be flown with 50% overlap, ideally in the opposite direction, to ensure no data gaps in the point spacing. Valid laser returns must have a minimum point spacing in the across track and along track direction of 0.5 m, or 4 returns per square metre. Overlap between flight lines may need to be increased over inter tidal mudflats that act as specular reflection surfaces. The lidar data will be tiled into blocks 1040 m by 1040 m in size with 40 m overlap between tiles. All valid lidar points (excluding air points and isolated points under the ground) will be classified into a minimum of ground and non-ground classes (additional classes may be required such as buildings and low and high vegetation depending on the application of these data). The horizontal coordinates to be output in UTM zone 20, NAD 83 CSRS map projection and orthometric heights referenced to CGVD28 utilizing the HT2 geoid-ellipsoid model available from NRCan, or a new accepted version of the vertical datum that is clearly documented.

Deliverables include a calibration report (procedures, results and date) of the lidar sensor, including lever arm offset measurements. Depending on the size and duration of the survey, calibration must be done at a minimum prior to the survey, and ideally at the end of the survey. A copy of the flight logs must be in the report. A report of lidar processing and adjustments to the lidar point cloud flight lines including any issues encountered (e.g offsets between lidar strips), including the details and summary of the validation of the data (point spacing and vertical accuracy), and dates and times of the coverage areas. The classified (ground and non-ground) LAS tiles with attributes in addition to elevation including flight line number, GPS time, intensity, echo code with documentation on the coding scheme, and scan angle will be delivered. The index GIS file of the tiles or blocks. The final trajectory information as Smoothed best estimate of trajectory (SBET) or ASCII including x,y,z, rotation angles (pitch, roll, heading) and precision measurements. All GPS base and rover files for the lidar mission and check point validation, including antenna height measurements.

As the data are delivered, the client has 30 days to inspect the data and accept or reject it based on the conditions outlined in the above specifications. If issues are encountered and the data does not meet the specification, the client agrees to supply the data provider with a report outlining the findings and deficiencies of the data.

6.2.2 Local examples of lidar acquisitions

There were several local examples of Request For Proposals (RFPs) and contracts related to lidar acquisition presented to the working group at the various meetings. These are summarized below and included information from the federal government, Public Works Government Services Canada; the provincial government, Nova Scotia Department of Transportation and Infrastructure Renewal; and the municipal level, Halifax Regional Municipality and the Cape Breton Regional Municipality. The Union of

Nova Scotia Municipalities passed a recommendation in 2007 which is also included, requesting the province work in partnership with the federal government and municipalities to fund the cost of providing lidar mapping services to municipalities across the province, with emphasis on the highest-risk areas.

STPCorp (STPCORP - Sydney Tar Ponds and Coke Ovens Remediation Project – Public Works Government Services Canada) and Leading Edge Geomatics (LEG), June 2009

Background taken from documents supplied by Leslie MacMillan PWGSC to the Working Group.

LEG would fly lidar, process the data to an ESRI compliant format, provide the quality assurance and processing report. Deliverables include a DEM in ASCII XYZ format, Geotiff raster. Classified bare-earth ground (stripped of > 90% of vegetation/features) ASCII files in client preferred projection and file size. First Pulse Extracted Features (vegetation/structures) ASCII files in client preferred projection and file size. Processed to ESRI compliant format. The horizontal coordinates will be provided in datum requested by the client and the Canadian Geodetic Vertical Datum (CGVD) will be used for the vertical reference. The deliverables will extend approximately 100 feet beyond the defined study area at no extra cost.

The contract agreement must be signed 15 days prior to the planned acquisition. The total project cost was $ 20,000. However the document did not include the details of the area to be covered or the point spacing of the lidar, thus making it difficult to calculate the rate per square kilometre for a given point density. Upon receipt of the final payment the data ownership is passed to the client, prior to that LEG grants a limited-time 30 day non-exclusive use to the data by the Contracting Party. In the event that the Data is being supplied to another party (end-user), Leading Edge Geomatics hereby additionally grants a limited time (30 day) pass through license to the end-user, subject to the restrictions contained herein.

The user has 15 days after delivery of the data to inspect it and indicate if it has met the specifications or not. Specifically, the following statements have been extracted from the LEG-STPCorp agreement. Contracting Party shall have the right to inspect the Data upon arrival of the data at the Contracting Party's address. Within fifteen (15) days after delivery, the Contracting Party must give notice to Leading Edge Geomatics and its subcontractor of any claim with respect to any non-conformance of the Data to the terms of this Agreement, specifying the basis of any claim in writing and in detail. Leading Edge Geomatics may, at its option, inspect the data at the Contracting Party's facilities to confirm whether the Data conform to the terms of this Agreement. Failure of the Contracting Party to comply with these conditions within the time set forth herein shall constitute irrevocable acceptance of the data by the Contracting Party. In the event that the Data do not conform to the terms of this Agreement, and to the extent that such non-conformance is communicated to Leading Edge Geomatics Ltd within the terms of this Agreement, the Contracting Party's sole remedy and Leading Edge Geomatics sole obligation, shall be, at Leading Edge Geomatics and its subcontractor option, to replace the Data at Leading Edge Geomatics Ltd's expense or credit the Contracting Party the amount of the price of the non-conforming Data. Return shipping shall be the responsibility of Leading Edge Geomatics and its subcontractor.

In no event shall either party be liable for any special, indirect, incidental or consequential damages arising out of or connected with this Agreement or the Data, regardless of whether a claim is based on contract, tort, strict liability or otherwise, nor shall damages exceed the amount of the price of the Data.

LEG planned to use an ALTM3100 operating between 25-100 khZ.
Vertical accuracy 95% at < 15 cm, and 90% < 10 cm, horizontal accuracy of 30 cm at 1 sigma (65 % of a normal distribution). They warn of poor or no laser returns from surfaces such as water, wet asphalt and tar-coated roofs.

Nova Scotia Department of Transportation and Infrastructure Renewal

Background taken from a presentation by Adam Osborne, NSTIR to the Working Group.

- Approximately 135 km of highway at a cost of $164,400
- Total Area covered = 60.4 km^2
- Hard Surfaces = +/- 5-10 cm
- Soft Surfaces = +/- 10-25 cm
- Airborne Data: 10cm Digital Orthophoto and 4 raw LiDAR points per square metre
- Use breaklines to define features, such as retaining walls, curbs, tops of ridges, and streams. Breaklines force surface triangulation along the breakline preventing triangulation across the breakline.
- Breaklines are critical to creating an accurate surface model because it is the interpolation of the data, not only the data itself, that determines the shape of the model.

Lidar enabled NSTIR to develop more accurate cross-sections. LiDAR was very accurate and enabled cost savings in terms of amount of cut & fill that was estimated and trucked in for highway widening. LiDAR greatly sped up the data acquisition process, reducing the time it took to complete the functional design stage and ultimately, the whole highway project. As an example, NSTIR flew 135 km in 2007/08 at a cost of $165,000. He said it took between 8-9 months to get the data from this LiDAR project. The alternative to gather this data would have been to use land surveyors (either NSTIR employees or to outsource). He said this process could take up to 4 years to complete and could have cost well over $1 million dollars. Surveyors would be in the brush in the example provided (Upper Tantallon to Hubbards) and in some cases, unable to pick up satellites.

$164,000/60.4 sq/km = $2720/sqkm for lidar, orthophotos and breaklines and DEM surface model.

Adam explained that a 1m gridded DEM was hard for AutoCAD 3D to handle and that the vertical accuracies they were able to achieve on hard surfaces were +/- 5 to 10cm and+/- 10 to 25cm on soft surfaces. Deliverables from the LiDAR projects included all files in both UTM Zone 20 NAD83 & MTM 4/5 ATS77 and a digital orthophoto collected at the same time as LiDAR. Data are typically delivered as mapsheet tiles no larger than 10MB for LiDAR deliverables and 125MB MB for the orthophotos that have a 10cm resolution. The Upper Tantallon to Hubbards project had 64 mapsheets. File sizes were reduced for the LiDAR data by using key points, a method for filtering point data by using only points where elevation was necessary to accurately represent the terrain.

Cape Breton Regional Municipality

Background taken from a presentation by Doug Foster, CBRM to the Working Group.

Traditional methods to acquire orthophotos and an DEM

2006 Orthoimage and 1 m DEM

- Conventional orthophoto mapping 15 cm with 1 Meter DEM grid – 390 Square Km .
- Cost to CBRM $240,000 + Provincial cost (estimated $70,000 for raw photography, Q/C, NSGC project management)
- Delivery time: 18 months, with cost overuns & delays
- Image quality decent, but contrast poor in many places
- Cost per square kilometer $800 plus
- Total NS allocation with municipal partnering at $800 per square kilometer $50,000

Latest methods to acquire digital orthophotos and lidar

2008 Digital ortho/Lidar

Comparison of conventional orthophotos/DEM and Digital orthos/Lidar

- Cost of the 2008 datasets, resolution (Fig. 24) and coverage area (Fig. 25)
- Cost of conventional Ortho/1 m DEM: $ 800
- 2008 Lidar 45 cm vertical accuracy 45 cm pixel resolution of digtial orthophoto with 411 square kilometer project $680.49
- 2010 Estimated LiDAR 15 cm vertical accuracy 15 cm pixel resolution Digital Orthophoto with 410 square kilometer area project if committed by January $410

	LiDAR 45 CM DEM	LiDAR 15 CM DEM	Digital Ortho 30 CM	Digital Ortho 15 CM
Area covered	411.3 sq. Kilometers	89.57 sq. Kilometers	50.05 sq. Kilometers	411.3 sq. Kilometers
Cost	$137,992.39	$43,008	$8,106.72	$82,396.68
Cost per sq. Kilometer	$335.50	$480.16	$161.97	$200.33

Figure 24 Example of costs for CBRM 2008 orthophoto and lidar campaign. Courtesy of Doug Foster, CBRM.

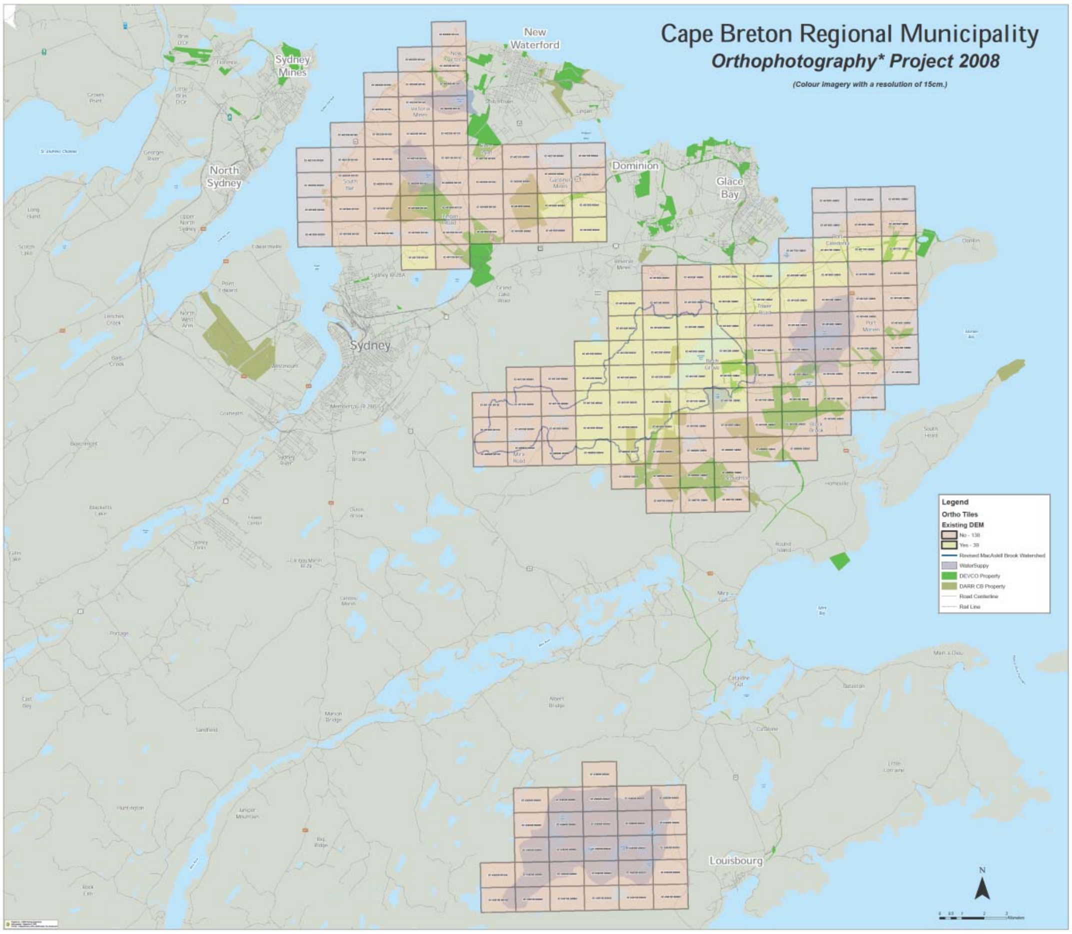

Figure 25 Coverage area of the CBRM 2008 orthophoto and lidar campaign. Courtesy of Doug Foster, CBRM.

Halifax Regional Municipality

Background taken from documents supplied by John Charles, HRM to the Working Group.

LIDAR DATA ACQUISITION FOR HALIFAX HARBOUR DRAINAGE BASIN AND EAST PETPESWICK PENINSULA AND SURROUNDS Request For Proposals

Summary: Field data acquisition must be completed during leaf-off and ice and snow-free conditions. Shore-zone data are to be acquired at times when ocean water levels are below lower low water (mean tide) plus 0.2 m. QC/QA of the lidar data, demonstrating that the technical specifications are met, is primarily the responsibility of the contractor. HRM or its designee may perform additional QC/QA testing. HRM shall review and accept/reject data within 30 days of delivery. The average cross-track and along-track spacing of laser pulses yielding valid ranges shall be no larger than 0.65 m and the cross-track and along-track spacing at the 90% frequency of occurrence of laser pulses yielding valid ranges shall be no larger than 2.5 m. The laser ranging data shall be acquired using a lidar system that collects first and last returns, or multiple returns, for each laser pulse. Geodetic GPS Base Station locations shall be control points of the Nova Scotia High Precision Network (HPN) or Canadian Base Network (CBN) or points referenced to the HPN or CBN with orthometric heights determined by differential levelling. The ground surface x,y,z data shall have vertical accuracy no larger than 30 cm root mean square error (RMSE), where RMSE is defined as the square root of the average of the set of squared differences between elevation values from an independent source of higher accuracy and linearly interpolated elevations. Geolocation (x,y,z coordinates) of all acquired laser returns with time stamp (GPS time plus date and local time of acquisition indicated for each laser shot), x and y position in metres Easting and Northing in Universal Transverse Mercator (UTM) 6-minute zone 20, NAD83, 1991 Adjustment, and z reported in metres as both ellipsoidal (WGS-84) and orthometric (CGVD28) elevations derived using the HTv2.0 geoid model from the Geodetic Survey of Canada. Geolocation (x,y,z coordinates) of laser returns identified to be returns from the ground surface, with time-stamp, to the same specifications noted previously. Geolocation (x,y,z coordinates) of laser returns identified to be returns from the uppermost surface (i.e., first-return from canopy and structure tops, or ground surface where there is no vegetation or structure), with time stamp, to the same specifications noted previously. Time-stamped GPS aircraft x,y,z trajectory with x and y referenced to UTM zone 20. Post-flight report documenting system calibration, instrument acquisition parameters, GPS ground control, data processing procedures, and validation of data quality, demonstrating that specifications in 3.1(E) have been met. Return energy amplitude for all acquired laser shots, and an image gridded at 2 metres Easting and Northing, showing the return energy amplitude derived using TIN processing and referenced to UTM zone 20 as specified above. Cross-track scan angle for all acquired laser shots, included with data in deliverables. In the case where lidar return amplitude are supplied laser head temperature and cross track scan angle are required with delivery of above.

Union of Nova Scotia Municipalities

MINUTES
Meeting of the Board of Directors
August 29th, 2007

Light Detection and Ranging (LiDAR) Mapping Resolution
Lyle Goldberg, policy analyst with the UNSM advised that Light Detection and Ranging Mapping is an advanced technology which could assist municipalities and the Province in locating all potential flood risk areas and high water marks.
He recommended that the UNSM Board of Directors introduce a resolution at the 2007 Fall Conference requesting that the Province work in partnership with the federal government and municipalities to fund the cost of providing LiDAR mapping services to municipalities across the Province, with emphasis on the highest-risk areas. The draft resolution was reviewed by the Board.
MOTION:
Moved by Warden Lloyd Hines; Seconded by Councillor Beverlee Brown:
That the UNSM Board accept the UNSM staff recommendation to present a resolution on LiDAR Mapping to the 2007 Fall Conference. Carried.

6.2.3 Other jurisdiction experiences with lidar

In addition to the local experience, several other groups in North America that have experience with lidar acquisition proposals, RFP, and specifications were discussed at the working group and are summarized below. The organizations include: FEMA, Puget Lowland of Washington State, United States Geological Survey (USGS), American society of Photogrammetry and Remote Sensing (ASPRS), and the British Columbia Agriculture and Lands Integrated management Bureau.

Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying. Federal Emergency Management Agency

Summary: A 5 m DEM grid or smaller cell size with a vertical accuracy of 37 cm for 95% confidence interval. The assumption is that the distribution of errors between the Z of check points and the Z of the lidar surface is normally distributed. Or 95% within 37 cm is the same as 1.96 x RMSEz where the maximum allowable RMSEz is 18.5 cm. (1.96 x 18.5 cm = 37 cm). An RMSEz of 18.5 cm should be met for flat terrain and a RMSEz of 37 cm for hilly terrain. A TIN should be constructed from the lidar points to check if the RMSEz is below 18 cm for flat terrain or below 37 cm for hilly terrain. They discuss the idea of removing outliers as defined anywhere from the worst 10% of the errors in accordance with the US National Map Accuracy Standard or a strict as the worst 0.25 % (3 standard deviations, 99.75%). It is recommended that at least 20 check points be tested for each land cover type. Cover types include: bare-earth and low grass, high grass and crops-weeds, brush and low trees, forested fully covered trees (hardwood and softwood), and urban areas for example. Deliverables include ASCII x,y,z files of the raw lidar data, a DEM of grid cell size 5 m or less. The original point spacing should be 3-4 m in order to derive a 5 m DEM. Breaklines are best produced by either stereo photogrammetric procedures where three-dimensional breaklines. Regardless of the technology used, the Mapping Partner shall normally produce breaklines and report the accuracy for stream centerlines, drainage ditches, tops and bottoms of streambanks, ridge lines, road crowns, levees, bulkheads, seawalls, road/highway embankments, and selected manmade features that constrict or control the flow of water.

The assigned Mapping Partner shall separately evaluate and report on the TIN accuracy for the main categories of ground cover in the study area, including the following:

1. Bare-earth and low grass (plowed fields, lawns, and golf courses);
2. High grass, weeds, and crops (hay fields, corn fields, and wheat fields);
3. Brush lands and low trees (chaparrals, mesquite);
4. Forested, fully covered by trees (hardwoods, evergreens, and mixed forests);
5. Urban areas (high, dense manmade structures);
6. Sawgrass; and
7. Mangrove.

LiDAR Data acquisition in the Puget Lowland of Washington State RFP

Summary: This proposal is an excellent demonstration of how different levels of government (federal, state and municipal) and stakeholders can collaborate to pool resources in order to acquire a large area of lidar coverage. The Puget Sound RFP calls for lidar to be acquired with an average cross-track and along-track spacing of laser pulses yielding valid ranges shall be no larger than 2 m, where a valid range is considered to be to the ground or to vegetation, buildings or structures on the ground. The cross-track and along-track spacing at the 90% frequency of occurrence of laser pulses yielding valid ranges shall be no larger than 4 m. The ground surface DEM (Deliverable II.A.b.3) shall have vertical accuracy no larger than 30 cm root mean square error (RMSE), using the NSSDA definition where RMSE for the interpolated elevations in the DEM for identical points. Quality Control/Quality Assurance (QC/QA) of the LiDAR-derived data, demonstrating that the technical specifications are met, is primarily the responsibility of the contractor. The Consortium or its designee may perform additional QC/QA testing. The contractor must field verify the vertical accuracy of the ground surface DEM to ensure that the RMSE requirement is satisfied for all major ground cover categories that predominate within the project area. The main categories of ground cover that the contractor must separately evaluate and report on the DEM accuracy for shall be:

a) Bare-earth and low grass (e.g., plowed fields, lawns, golf courses);

b) High grass and crops (e.g., hay fields, corn fields, wheat fields);

c) Fully covered by coniferous trees (e.g. softwood forests);

d) Fully covered by deciduous trees (e.g. hardwoods forests); and

e) Urban areas (high, dense manmade structures).

The Consortium shall review and accept/reject products within 30 days of delivery. Deliverables include: x,y,z geolocation including intensity and scan angle of laser returns of all laser points and those identified to be returns from the ground surface, with time-stamp and heights referenced to the ellipsoid and orthometric heights, DEM gridded at 6ft easting and northing postings of the ground surface orthometric elevations derived using triangulated irregular network (TIN) processing, Shaded relief rendition of the 6ft, ground surface DEM, x,y,z geolocation of laser returns identified to be returns from the upper-most surface (i.e., First-return from canopy and structure tops, ground where there is no vegetation or structures), DEM gridded at 6ft easting and northing postings of the upper-most surface orthometric elevations derived using TIN processing, an intensity image gridded at 6ft easting and northing postings of the return energy Amplitude of all lidar points derived using triangulated irregular network (TIN) processing Time-stamped GPS aircraft x,y,z trajectory, Final reports documenting system calibration, instrument acquisition parameters, GPS ground control, data processing procedures, and validation of data quality demonstrating that specifications have been met.

Lidar for the Northeast USGS ARRA Funding opportunity

Summary: This proposal is an excellent demonstration of how different levels of government (federal, state and municipal) and stakeholders can collaborate to pool resources in order to acquire a large area of lidar coverage. The proposal calls for lidar data to be acquired for 13,561 square miles of coastal area in New England and New York, including all coastal towns and cities from New York City to Eastport, Maine. These cover all or portions of all coastal watersheds in this region. Deliverables will include lidar point cloud data in .LAS format, breaklines used for hydro-flattening, a 2-meter resolution digital elevation model (DEM), and lidar intensity data. The vendor will be required to meet all of the specifications outlined in the USGS Base Lidar Specification, which is the same as those adopted by ASPRS. Areas where enhanced lidar data will provide support and stability to our economy and promote the retention and development of new jobs in our region include:

• Transportation Infrastructure – Providing engineers, surveyors, planners with a geospatial database that will enable them to develop plans to improve our aging roads, highways, and bridges throughout the region.

• Alternative energy development – Enhanced elevation data will help in attracting the industrial base for the assembly and maintenance of alternative energy systems for the northeast. Accurate elevation data are critical in finding suitable sites for wind power facilities.

• Communications and utilities- Enhanced elevation data will improve network and planning operations for electric, gas, broadband, phone, and cable providing for more effective and efficient equipment deployment while reaching a larger number customers.

• Climate change – Our coastal and flood plain managers are requiring comprehensive and highly accurate elevation models to determine resources at risk from long-term inundation threats and the increase in the frequency and intensity of storms.

• Emergency preparedness – Our emergency personnel have a need for highly accurate elevation models for use in disaster preparedness for, response to, and recovery from potential hurricanes and nor'easter events.

• Watershed protection and wastewater management – Better data will result in better management and conservation of drinking water resources while enhancing water quality for fisheries, recreation, and tourism.

• Forestry and wildlife - Forest and wildlife managers rely on enhanced elevation models to characterize forest resources and develop baselines for forest fire fuel modeling and monitoring. The result will be more and better resources for the economy and reduced risks.

American Society of Photogrammetric engineering and Remote Sensing (ASPRS) Lidar Specifications

Summary: As a general rule, horizontal error is more difficult than vertical error to assess in lidar datasets. This is because the land surface often lacks distinct (well defined) topographic features necessary for such tests or because the resolution of the elevation data is too coarse for precisely locating distinct surface features. For these reasons, ASPRS does not require horizontal accuracy testing of lidar-derived elevation products. Instead, ASPRS requires data producers to report the expected horizontal accuracy of elevation products as determined from system studies or other methods. Compute Accuracy (z) = 1.9600 * RMSE(z) = Vertical Accuracy at 95 percent confidence level. When 40 or more checkpoints are consolidated for two or more of the major land cover categories, representing both the open terrain and other land cover categories (for example, forested), a *consolidated vertical accuracy* assessment may be reported as follows:

1. Compute 95th percentile error (described above) for open terrain and other categories combined.
2. Report. Tested ______(meters, feet) consolidated vertical accuracy at 95th percentile in: open terrain, (specify all other categories tested).
3. In the metadata, document the errors larger than the 95th percentile. For a small number of errors above the 95th percentile, report x/y coordinates and z-error for each QC checkpoint error larger than the 95th percentile. For a large number of errors above the 95th percentile, report only the quantity and range of values.

British Columbia Ministry of Agriculture and Lands Integrated Land Management Bureau (ILMB) Base Mapping and Geomatic Services Branch LiDAR SPECIFICATIONS

Summary: They promote the methods used by the US National Standard for Spatial Data Accuracy – NSSDA uses the 95% tile of the vertical error between check points and the linearly interpolated ground lidar points, or 1.96 x RMSEz. In the case of the horizontal accuracy of the lidar points which is much more challenging to test, they quote NSSDA specifications for a circular radius error from check point to lidar points as NSSDAr = 1.73 RMSEr.

6.3 PROCUREMENT

The procurement of lidar with or without simultaneous aerial photography for a wide area will have benefits to a wide audience of stakeholders and ideally involve funding from multiple agencies including the different levels of government (federal, provincial and municipal) as well as local stakeholders that can collaborate to pool resources in order to increase the area of lidar coverage. The procurement process should also consider the collection of independent validation check points and the analysis to ensure the lidar accuracy and coverage specifications are met. Additional funding may be required to ensure the data are processed and products derived that can be easily used and understood by the various stakeholders. If the province begins to acquire more lidar, they should consider establishing a standing offer with lidar acquisition firms to facilitate the acquisition of the data once a budget has been approved since many lidar acquisitions are time sensitive and may require leaf-off and no snow cover conditions.

In many lidar acquisition contracts that have been presented in this report the client is allowed only 30 days to inspect the lidar data and accept or reject it based on the specifications outlined in the contract. This requires a dedicated group of practitioners who are familiar with this type of processing and analysis. This timeframe also requires that validation checkpoint data exists or will be collected very quickly. It would appear reasonable to make the time to inspect the delivered lidar data and products based on the size of the project areas. For small surveys, say less than 500 sqkm, then 30 days should be sufficient to review and accept or reject the data. However for large projects where 1000-10,000 sqkm or more could be delivered that will require time to adequately test the accuracy.

The general process for procurement should involve a collaboration of stakeholders to pool their funding, and decide on the lidar specification in discussions with a designated group who has lidar experience. This group would then seek multiple quotes from lidar service providers requesting as much detail as possible as related to the specifications.

These quotes will then be reviewed to ensure they meet the specifications and the budget constraints. Adjustments may need to be made at this stage to modify the area requested, lidar specifications, and or deliverables (e.g. point spacing or level of value added processing from the lidar provider) to reconcile the budget and desired outcomes of the project. In general the more processing that is expected of the lidar service provider the higher the costs will be. Therefore a discussion of lidar processing capacity of the stakeholders and a plan for lidar validation, processing and product development and distribution should be discussed between the stakeholders early in the process.

If the project proceeds and a lidar service provider is selected, a planning meeting should be held to ensure all parties are aware of the acquisition plan and constraints (time of year, tide state, etc.). Ideally independent validation check points are collected simultaneously with the lidar and aerial photography for multiple cover types, with the highest density of points collected transverse across the dominant flight line direction. This allows for potential offsets between flight lines to be examined. General ground conditions including the state of vegetation and moisture levels that may influence the lidar returns should be documented.

Upon delivery of the lidar/orthophoto data and any derived products the first priority is to ensure the data meets the specifications in terms of area coverage, density, and accuracy. This type of due diligence is highly recommended and simply depending on the lidar contractor to provide the only quality assurance and quality control of the data is not recommended. This will require dedicated resources to effectively test and report on the validation of the data in order to accept or reject the data. The timeframe allowed for the procurement agency to inspect the data is typically 30 days; however depending on the size of the study area this should be considered to be expanded to allow adequate time for detailed validation. Once accepted, the additional processing and product development of GIS layers (DSM, DEM, intensity maps, further derived products such as slope, hill shades, flood inundation etc.) should commence and be distributed to the stakeholders. One agency or group, at a minimum, should be tasked with ensuring the data are properly archive, backed up and are available for distribution. SNSMR’s GIS Section appears to be the logical choice for this task.

6.4 DATA SHARING AND LICENSING

In order to effectively acquire large areas of lidar, different levels of government (federal, provincial and municipal) and stakeholders could collaborate to pool resources in order to increase and maximize the coverage area. Most lidar providers pass full ownership of the data on to the client once the full payment has been received for the service. Therefore it is up to the stakeholders and those that have provided the funding to determine how they want to share and distribute the data to others. In the case of research projects, where lidar data have been collected, processed and applications research conducted by the Applied Geomatics Research Group for government and other stakeholders, AGRG retains the ownership of the data but gives a perpetual license to the research client(s). The agreement states that the research client can distribute the data to whomever they wish, however they cannot sell or use the data for commercial purposes. AGRG maintains ownership of the data and agrees not to use it for other purposes for an agreed period of time, typically two years. This effectively gives the research client the rights to share the data freely but not for financial gain.

Given the above conditions from lidar providers and research groups, the GeoNova Alliance, drafted back in 2010 and still awaiting legal review and approval, may be well suited to enable the sharing of the data. As an alternative, lidar products could be distributed through the SNSMR’s GIS Section geospatial data portal or SNSMR’s Data Locator application to allow Nova Scotia users access to the data. The original lidar data can exist in several forms and at different levels of processing that can be extremely large. The derived products such as surface models (DEM, DSM) are typically more manageable in file size and can be readily used in most GIS systems. It is expected that these types of high-resolution derivative products will be in the highest demand and should be given priority in terms of distribution and availability.

6.5 METADATA CATALOGUING

Proper metadata cataloguing is a generally accepted practise for discovering available geospatial data. Examples of metadata repositories include: the Nova Scotia Geographic Catalogue, the GeoConnections Discovery Portal, and the NSCC-AGRG LiDAR MetaData Repository in Canada (LiMeRiC). For lidar data, the critical factors include: the date(s) of acquisition, possible ground conditions (snow cover/moisture, leaf-on or off), point spacing, map projection of horizontal coordinates, vertical datum of lidar elevations, some form of accuracy assessment on both the lidar points and derived products (eg. DEM), and the methods employed to derive the products (e.g. TIN of lidar ground points to derive the DEM). Some lidar providers, such as Leading Edge Geomatics, follow the United States Federal Geographic Data Committee (FGDC) standard for Digital Geospatial Metadata.

6.6 ACCESS AND AVAILABILITY

One of the concerns / issues that always seems to arise when discussing lidar projects is, “Where will the data reside, and how does everyone access it at a single source”. Data acquired by the province of NS should be freely available to end users. SNSMR’s GIS Section should house and distribute the data. For example, the lidar data products delivered to NS Environment by AGRG as part of the ACAS project to develop flood risk maps resides within SNSMR’s GIS Section of growing corporate geospatial infrastructure. The lidar data acquired by AGRG is licensed to NS Environment who has the right to distribute those data to anyone they wish. The data was passed to GeoNova for storage and further distribution. As mentioned earlier lidar data occupy large volumes of computer disk space and new investments may be required in order to effectively store and serve these data to end-users. In addition to the lidar surface models and other GIS layers, a set of flood risk maps are being published and hosted by NS Department of Natural Resources Minerals Branch GIS group.

6.7 TYPICAL COSTING SCENARIOS

Lidar costs for an airborne terrain mapping campaign typically cost between $ 200 - $ 500 sqkm for lidar acquisition, vendor QA-QC, ground classification, with ASCII and LAS format delivery of point clouds. The cost is influenced by mobilization fees, the size of the area, the point density, and any additional constraints (e.g. simultaneous aerial photography acquisition, coastal low tide acquisition). In general the more that is requested of the lidar provider in terms of value added processing beyond the data collection and minimum processing, the higher the costs will be. Generally large rectangular polygons provide the most efficient and cost effective method to acquire lidar. Although the cost is often quoted by square kilometre, a thin convoluted polygon will still have to be flown with straight flight lines if a fixed wing aircraft is being used and no cost savings are achieved. Generally a fixed wing aircraft is cheaper to operate than a rotary wing aircraft. One of the most significant costs in a lidar acquisition campaign is the mobilization and demobilization of the aircraft (e.g. moving the aircraft, equipment and crew to the survey site), thus to ensure good communication to all potential stakeholders ahead of time so that funding resources can be pooled is critical to ensure the most cost effective acquisition of lidar. The cost per square kilometre will reduce as the size of the survey area increases. This is a result of the mobilization charges being spread out for the entire survey area and thus as the area increases the proportion of the mobilization charges to the entire project decreases. In other words if a lidar aircraft is going to be in the region, that is the time to acquire lidar data in the most cost effective manner. That is not to say, wait until a survey is being conducted and then request large additional blocks. This may be able to be accommodated, however most survey companies are very busy during the leaf-off season and may not be able to accommodate large ad hoc additions, although most companies try to be flexible. Weather can play an important role in lidar acquisition since it must be fair weather to acquire good quality data. If a large lidar campaign were planned, it is ideal to provide alternative target study areas to the lidar provider. For example, a coastal section of one study area may have fog during low tide, therefore cannot be acquired. If the lidar provider can survey another area during this time, the project does not suffer with the aircraft and crewed being grounded in standby mode. Thus having multiple areas of interest that may have different timing constraints provides the survey crew alternatives to optimize the data collection process.

6.8 LIST OF PROVIDERS

1. **Leading Edge Geomatics**

Address	2384 - Hwy 102 Lincoln NB 506 446 4403
Tel	+1-506-446-4403
Fax	
E-Mail	inquiries@legeo.ca
Homepage	http://www.lego.ca

2. **4DM Inc.**

Address	4850 Keele Street Toronto ON M3K 3K1 Canada
Tel	+1-416-410-7569
Fax	+1-416-410-7569
E-Mail	info@4dm-inc.com
Homepage	http://www.4dm-inc.com

3. **Lasermap Image Plus/GPR**

Address	16 Sixth Line Bristol RR 4 Quyon, Quebec, J0X 2V0 Canada
Tel	+1-819-647-3085
Fax	+1-819-647-3085
E-Mail	info@lasermap.com
Homepage	http://www.lasermap.com

4. **LiDAR Services International, Inc.**

Address	310, 3115 - 12 St. N.E. Calgary, Alberta CANADA T2E 7J2
Tel	+1-403-517-3130
Fax	+1-403-291-5390
E-Mail	art.silver@lidarservices.ca
Homepage	http://www.lidarservices.ca

5. **Terra Remote Sensing Inc.**

Address	1962 Mills Road Sidney, BC V8L 5Y3 Canada
Tel	+1-250-656-0931
Fax	+1-250-656-4604
E-Mail	terra@terraremote.com
Homepage	http://www.terraremote.com

7. **GeoDigital International Inc.**

Address	McMaster Innovation Park 175 Longwood Road South, Suite 400A Hamilton, ON L8P 0A1
Tel	+1-905-667-7204
Fax	+1-905-667-7203
E-Mail	
Homepage	http://www.geodigital.com

6. **North West Group**

Address	Suite 212, 5438 11st NE Calgary, Alberta, T2E 7E9 Canada Suite 700 303 East 17th Avenue Denver, Colorado, 80203-1260 USA
Tel	+1-403-295-0694 +1-303-832-4232
Fax	+1-403-295-2444
E-Mail	info@nwgeo.com
Homepage	http://www.nwgeo.com

Other lidar service providers from http://www.geolas.com/Pages/links.html.

North America:

- 3001 Inc, USA (service provider, AeroScan system)
- 3Di LLC, USA (see Spectrum Mapping LLC)
- 4DM, Inc., Canada (service provider, ALTM system)
- Advanced Lidar Technology Inc. , USA (service provider, ATLAS-SL/(LMS-Q140-based) system)
- Aerial Cartographics of America, Inc., USA (service provider)
- AeroFocus Geomatics, Canada (service provider, TopEye system)
- AeroMap U.S., USA (service provider, ALTM 3070 system)
- Aeroscan International Inc., Canada+US (service provider, ALIS systems)
- AerotecUSA LLC, USA (service provider, TopEye system)
- Airborne 1 Corp., USA (service provider, ALTM 2025, 2033, 2050 + 3100 systems)
- The Aleutian Group, USA (service provider, ALTM 1020 + 1225)
- Analytical Surveys Inc., USA (see The Sanborn Map Company)
- Atlantic Technologies, USA (service provider, ALTM 1210 system)
- Canaan Valley Institute, USA (service provider, ALTM 3100 system)
- John Chance Land Surveys, Inc., USA (service provider, FLI-MAP system)

- Cheseapeake Bay Helicopters, Inc., USA (service provider, LiteMapper 2800 system)
- Dewberry & Davis LLC, USA (service provider)
- EagleScan Inc., (see Spectrum Mapping, LLC)
- Earthdata Inc., USA (service provider, AeroScan system)
- EnerQuest Systems LLC, USA (see Spectrum Mapping LLC)
- GEOsurv Inc., (see Mosaic Mapping)
- GRW Aerial Surveys, Inc., USA (service provider, ALTM 2033 system)
- HJW GeoSpatial, Inc., USA (service provider)
- Hauts-Monts, Canada (service provider, ALTM 1020 system)
- Horizons, Inc., USA (service provider, ALS-40 system)
- Kucera International Inc., USA (service provider, ALS50 system)
- LandAir Mapping, Inc., USA (service provider, ALS-40 system)
- Laser Mapping Specialists Inc., USA (service provider, ALTM 2033 system)
- Lasermap Image Plus Inc, Canada (service provider, ALTM 2050 system)
- LiDAR Services International, Inc., Canada (service provider, HELIX helicopter system)
- Merrick & Company, USA (service provider, ALS-40 system)
- Mosaic Mapping Systems, Inc., Canada (service provider, ALMIS-350 + ALTMS systems)
- North West Group, Canada+USA (service provider, ALS40 (AeroScan) system)
- Photo Science, Inc., USA (service provider, ALS50 system)
- The Sanborn Map Company, Inc., USA (service provider, ALTM 1210 system)
- Spectrum Mapping LLC, USA (service provider, AeroScan/ALS-50 systems)
- Spencer B. Gross, Inc., USA (service provider, AeroScan system)
- Terramatics Systems, Inc., Canada (provider of mapping and system development services)
- TerraPoint LLC, USA (see Mosaic Mapping Systems, Inc.)
- Terra Remote Sensing Inc., Canada (service provider, custom system)
- TopoBird, LLC, USA (service provider, ALS-40 system)
- Topographic Imaging Inc., USA (service provider)
- Tuck Engineering, Inc., USA (service provider, AIMS 350 system)
- Verimap Plus, Inc., Canada (service provider, ALTM 2033 system)
- Visual Intelligence Systems, Inc., USA (service provider, ALS40 system)
- Waggoner Engineering Inc., USA (service provider, ALTM 1020 system)
- Walker and Associates, USA (service provider)
- Woolpert LLP, USA (service provider, ALTM 1210 + ALS50 systems)

7 TRAINING AND TECHNOLOGY TRANSFER

Currently the only comprehensive lidar operations and applications course that is offered in Nova Scotia is at the Centre of Geographic Sciences, NSCC in the Advanced Diploma program. The course is administered and jointly offered by research scientists at the Applied Geomatics Research Group and COGS faculty. They have the distinct advantage of owing their own lidar system, ALTM 3100 from Optech. Other GIS courses introduce the idea of lidar and there are numerous resources on-line for lidar. There are opportunities to expand the training and education in lidar in all aspects including: data acquisition, validation and accuracy assessment, and numerous applications for example.

8 INTER-JURISDICTIONAL COLLABORATION OPPORTUNITIES

Communication is the key to inform all potentially interested parties in the possibility of a lidar acquisition campaign. Then issues such as the extent of the survey, specifications and cost sharing can be discussed between the interested parties. Doug Foster at the Cape Breton Regional Municipality and the federal government agencies (PWGSC and Parks Canada) as well as private sector stakeholders in the mining community such as Xstata have partnered to acquire lidar. The province could contract a group with experience in lidar acquisition and contracting as well as validation, product development and applications to oversee the coordination of lidar activities within the province if a single department did not want to take this task on. An educational research group such as AGRG could play this role as an example. Issues such as “equitable collaboration” were discussed by the working group where issues of final ownership, the use of a “broker” or agency lead, in-kind versus real fiscal support, and distribution rights were discussed. The idea of actively promoting a collaboration-based model for lidar projects was also discussed. This could be achieved with presentation materials, advertising the costs of the data and processing, and showing examples of the value of lidar. The possibility of collaboration software and on-line blogs was also mentioned.

9 CONCLUSIONS AND RECOMMENDATIONS

The Working Group was successful in raising the awareness and knowledge around the acquisition and application of lidar data. The result of their combined activity has led to the production of this report. A set of numbered recommendations is included at the end of this section. The terms of reference of the working group and a list of working group members are presented at the end of this report. The minutes of the working group meetings are stored and are available from the GeoNova Program Office. The report has highlighted how lidar works, the current state of the technology and a variety of applications that benefit from the high-resolution and accuracy of the data. New emerging laser scanning technology was also been highlighted including bathymetric lidar and mobile mapping systems. The report outlines the experience of several organizations, both within the province and within North America, in terms of lidar requests for proposals and specifications and accuracy testing procedures. As a result, an example lidar specification has been put forward in this report. The example specification is meant as a guide and is not meant to be all inclusive of every application. The report has attempted to emphasize that there will always be a trade-off between the size of the survey area and the level of detail of the lidar and the budget constraints of the project. As the GIS community matures with respect to lidar processing and validation, requirements of lidar providers to do value added processing above the minimal processing and classification procedures to produce lidar derived products will decrease and the costs should decrease.

The idea of collaboration between different level of governments and stakeholders to acquire lidar for an area where the data can be used for multiple purposes and serve multiple GIS applications is one of the key outcomes from this report. Although collaboration between stakeholders has been done in some lidar projects, the province of Nova Scotia could benefit from a dedicated group, such as AGRG, NSCC as an example or a government department, to act as a coordinator of lidar activity. They would have the responsibility to lay out a plan with budget contributions from different departments as a base to start discussions from. They would then be tasked to communicate the potential activity to as many stakeholders within and outside of all levels of government as possible for funding contributions. Once a critical funding mass was achieved, they would then be tasked to work with the stakeholders to define the specific survey area and the lidar specifications and deliverables, including validation of the data. They would then prepare a lidar acquisition Request for Proposal and ensure that lidar providers become aware and submit proposals. They along with representatives from the stakeholder groups would then evaluate the lidar acquisition proposals and decide on a lidar provider. A contract and schedule would be implemented between the lidar provider and the coordinating agency. The coordinating agency would then take the initial delivery of the lidar data and do the validation analysis to recommend acceptance or rejection of the data. Then depending on the stakeholders and level of processing and products-applications required for the project, produce the various products and pass the data to SNSMR GIS Section for storage as a corporate asset and dissemination to the stakeholders.

This group could also establish a set of guidelines and standard for typical applications through further discussions with the various funding agencies and stakeholders. It is anticipated that once lidar data are acquired and available, new applications of the data will be realized that were not envisioned during the initial scoping phases of the project.

In addition to terrain mapping lidar, the province should look to lead in the area of applying emerging laser scanning technologies including bathymetric lidar and mobile mapping. For example, the province should coordinate with the Canadian Hydrographic Service of the Department of Fisheries and Oceans who has been contracting the acquisition of near shore bathymetric lidar in the region. NS Department of Fisheries and Aquaculture, DNR and NS Environment could all benefit from the acquisition of a continuous elevation model from greater than 10 m depths to above the coastal zone.

Another group that should be consulted to assisting in funding some of the activity is the NS Union of Municipalities who requested the province to work with all levels of government to acquire lidar for higher risk areas. The continuation and completion of lidar along the coastal zone is an obvious choice to assist municipalities, considering so much of our population and infrastructure is located in this areas. The coastal areas are also the most at risk to the effects of climate change in the form of sea-level rise and possible increased storm surge intensity. A significant portion of the coast has already been acquired by AGRG, AGRG-NS Environment, HRM and CBRM and thus represents a good starting point to build on and acquire lidar for the remaining coast for addressing concerns of Nova Scotian’s. Ideally an annual budget should be allocated for lidar acquisition and a plan devised to acquire data over the most at risk areas.

Specific Recommendations

1. A program should be established to acquire lidar every year. This would ensure a stable budget for lidar acquisition that could stimulate collaboration and pool financial resources to expnd the lidar coverage area beyond the initial program budget.
2. Nova Scotia should partner with an organization with experience in all aspects of lidar, such as the Applied Geomatics Research Group, NSCC to act as a coordinator of lidar activity. They would have the responsibility to lay out a plan with budget contributions from different departments as a base to start discussions from. They would then be tasked to communicate the potential activity to as many stakeholders within and outside of all levels of government as possible for funding contributions.
3. The general process for procurement should involve a collaboration of (federal, provincial and municipal) and stakeholders to pool their funding, and decide on the lidar specification in discussions with a designated group who has lidar experience.
4. As the province begins to acquire more lidar, they should establish a standing offer with lidar acquisition firms to facilitate the acquisition of the data once a budget has been approved since many lidar acquisitions are time sensitive and may require leaf-off and no snow cover conditions.
5. The procurement process should also consider the collection of independent validation check points and the analysis to ensure the lidar accuracy and coverage specifications are met.
6. Additional funding may be required to ensure the data are processed and products derived that can be easily used and understood by the various

stakeholders. This requires a dedicated group of practitioners who are familiar with this type of processing and analysis. This timeframe also requires that validation checkpoint data exists or will be collected very quickly.

7. Establish a set of guidelines and standard for typical applications through further discussions with the various funding agencies and stakeholders.
8. The original lidar data can exist in several forms and at different levels of processing that can be extremely large. The derived products such as surface models (DEM, DSM) are typically more manageable in file size and can be readily used in most GIS systems.
9. The coordinating agency would then take the initial delivery of the lidar data and do the validation analysis to recommend acceptance or rejection of the data. Produce the various products and pass the data to SNSMR GIS Section for storage as a corporate asset and dissemination to the stakeholders.
10. Proper metadata cataloguing is a generally accepted practise for discovering available geospatial data. Examples of metadata repositories include: the Nova Scotia Geographic Catalogue
11. For small surveys, say less than 500 sqkm, then 30 days should be sufficient to review and accept or reject the data. However for large projects where 1000-10,000 sqkm or more could be delivered that will require time to adequately test the accuracy.
12. The continuation and completion of lidar along the coastal zone is an obvious choice to assist municipalities, considering so much of our population and infrastructure is located in this areas. The coastal areas are also the most at risk to the effects of climate change in the form of sea-level rise and possible increased storm surge intensity.
13. There are opportunities to expand the training and education in lidar in all aspects including: data acquisition, validation and accuracy assessment, and numerous applications for example. The government could contract educational-research organizations such as AGRG to develop training material and support employees to attend courses from appropriate departments.

14. The province should look to lead in the area of applying emerging laser scanning technologies including bathymetric lidar and mobile mapping. For example, the province should coordinate with the Canadian Hydrographic Service of the Department of Fisheries and Oceans who has been contracting the acquisition of near shore bathymetric lidar in the region. Mobile mapping applications could be very effective at mapping Nova Scotia long and complicated shoreline and used to measure erosion and map areas at risk of coastal flooding and erosion.

10 WORKING GROUP PARTICIPANTS

Colin MacDonald, Chair of the Government of Nova Scotia's LiDAR Strategic Directions Working Group. GeoNOVA, Service Nova Scotia and Municipal Relations.

Trista Bloom (SNS, Admin) and Heather Chisholm (SNSMR) assisted with taking minutes of the meetings.

Adam Osborne, Highway Services, Transportation and Infrastructure Renewal

Doug Foster, Director of Planning, Cape Breton Regional Municipality (CBRM)

Darrell Hingley, Agricultural Technician, NS Department of Agriculture

David Mitchell, Coastal Strategist, NS Department of Fisheries and Aquaculture. Sean Weseloh McKeane also attended some LiDAR Working Group meetings filling in for David Mitchell.

Jeff Merrill, Acting Director of Planning, Municipality of the District of Luneburg (MODL)

Will Green, Program Administration Officer, Climate Change, Nova Scotia Environment

Kyle McKenzie, Adaptation Specialist, Nova Scotia Environment

Tim Webster, Research Scientist, Applied Geomatics Research Group, NSCC

Don Forbes, Research Scientist, Atlantic Division - Geological Survey of Canada, Natural Resources Canada (NRCan)

Dawn Allen, Geomatics Specialist, Parks Canada

Marianne Murphy, GIS Manager, Halifax Regional Municipality. Darren Talbot and John Charles also attended some LiDAR Working Group meetings filling in for Marianne Murphy.

Leslie MacMillan, Public Works Government Services Canada

James Bruce, GIS Analyst, Forestry Division, NS Department of Natural Resources. Rob O'Keefe also attended some LiDAR Working Group meetings filling in for James Bruce.

Ian Holmes, Supervisor of Topographic Mapping, Nova Scotia Geomatics Centre (NSGC), Service Nova Scotia and Municipal Relations (SNSMR)

Brian Fisher, Minerals Branch, NS Department of Natural Resources.

Keith Saunders, Annapolis District Planning Commission

11 REFERENCES

Bates, P.D., Marks, K.J., Horritt, M.S. 2003. Optimal use of high-resolution topographic data in flood inundation models. Hydrological Processes, **17**, pp. 537-557.

Brennen, R. and Webster, T.L. 2006. Object Oriented Land Cover Classification of LiDAR Derived Surfaces. Canadian Journal of Remote Sensing, Vol. 32, No. 2, pp. 167-172.

Brock, J.C., Wright, C.W., Sallenger, A.H., Krabill, W.B., Swift, R.N. 2002. Basis and methods of NASA airborne topographic mapper LIDAR surveys for coastal studies. Journal of Coastal Research, **18,** pp. 1-13.

Costa-Cabral, M.C. and Burges, S.J. 1994. Digital Elevation Model Networks (DEMON): A model of flow over hill slopes for computation of contributing and dispersal areas. Water Resource Research, **30**, No. 6, pp. 1681-1692.

Flood, M. and Gutelius, B. 1997. Commercial implications of Topographic Terrain Mapping Using Scanning Airborne Laser Radar. Photogrammetric Engineering and Remote Sensing, **4**, pp. 327-366.

Forbes, D.L., Manson, G.K., Charles, J., Thompson, K.R., and Taylor, R.B. 2009. Halifax Harbour Extreme Water levels in the Context of Climate Change: Scenarios for a 100-Year Planning Horizon. Geological Survey of Canada, Open File 6346, 21 p.

Haugerud, R.A., Harding, D.J., Johnson, S.Y., Harless, J.L., Weaver, C.S., and Sherrod, B.L. 2003. High-resolution lidar topography of the Puget Lowland-A bonanza for earth science. Geological Society of America Today, **13**, No. 6, pp. 4-10.

Hodgson, M.E., Bresnahan, P. 2004. Accuracy of airborne lidar-derived elevation: empirical assessment and error budget. Photogrammetric Engineering and Remote Sensing, **70**, no. 3, pp. 331-339.

Jenson, S.K., and Dominque, J.O. 1988. Extracting Topographic Structure from Digital Elevation Data for Geographic Information Systems Analysis. Photogrammetric Engineering and Remote Sensing, **54**, no. 11, pp. 1593-1600.

Katzenbeisser, R. 2003. On the calibration of LIDAR sensors *In* 3-D reconstruction from airborne laserscanner and InSAR data. *Edited by* H.-G. Maas, G. Vosselman, G. and A. Streilein. Institute of Photogrammetry and Remote Sensing, GITC, The Netherlands, pp. 59-64.

Kornus, W., Ruiz, A., 2003. Strip Adjustment of LIDAR data. *In* 3-D reconstruction from airborne laserscanner and InSAR data. *Edited by* H.-G. Maas, G. Vosselman, G. and A. Streilein. Institute of Photogrammetry and Remote Sensing, GITC, The Netherlands, pp. 47-50.

Maas, H.G. 2002. Methods for Measuring Height and Planimetry Discrepancies in Airborne Laserscanner Data. Photogrammetric Engineering and Remote Sensing, **68**, No. 9, pp. 933-940.

Maune, D. F. 2001. Digital Elevation Model Technologies and Applications: The DEM Users Manual. *Edited by* D.F. Maune, American Society of Photogrammetry and Remote Sensing. pp. 1-250.
Nova Scotia's Geographic Information Standards. Available from http://www.gov.ns.ca/snsmr/land/programs/post/manual/default.asp [cited September, 2003].

Raper, S. C., & Braithwaite, R. J. 2006. Low Sea Level Rise Projections from Mountain Glaciers and Icecaps Under Global Warming. Nature, 439, pp. 311-313.

Sallenger Jr, A.H., Krabill, W.B., Swift, R.N. and Brock, J. 2003. Evaluation of Airborne Topographic LiDAR for Quantifying Beach Changes. Journal of Coastal Research, **19**, pp. 125-133.

Stockdon, H.F., Sallenger, A.H., List, J.H., Holman, R.A., 2002. Estimation of shoreline position and change using airborne topographic LIDAR data. Journal of Coastal Research, **18**, No. 3, pp. 502-513.

Shaw, J., Taylor, R., Forbes, D., Ruz, M., & Solomon, S. 1998. Sensitivity of the Coasts of Canada to Sea-level Rise. Geological Survey of Canada (Bulletin 505), Natural Resources Canada , pp. 1-79.

Titus, J. G., Park, R. A., Leatherman, S. P., Weggel, J. R., Greene, M. S., Mausel, P. W., et al. 1991. Greenhouse Effect and Sea Level Rise: The Cost of Holding Back the Sea. Coastal Management , **19**, pp. 171-204.

Webster, Tim. L. 2010. Flood Risk Mapping Using lidar for Annapolis Royal, Nova Scotia, Canada. Open Access Remote Sensing ISSN 2072-4292. Vol. 2; doi:10.3390/rs2092060, pp. 2060-2082.

Webster, T., Templin, A., Ferguson, M., Dickie, G. 2009. Remote Predictive Mapping of Aggregate Deposits using lidar. Canadian Journal of Remote Sensing. Vol. 35, Suppl. 1 (Special Issue on Remote Predictive Mapping), pp. S154-S166.

Webster, T., Murphy, J.B., Quinn, D. 2009. Remote Predictive Mapping of a Potential Volcanic Vent Complex in the Southern Antigonish Highlands using lidar, Magnetics, & Field Mapping. Canadian Journal of Remote Sensing. Vol. 35, No. 5, pp. 486-495.

Webster, T., & Dias, G. 2006. An Automated GIS Procedure for Comparing GPS and Proximal LiDAR Elevations. Computers & Geosciences , **32**, pp. 713-726.

Webster, T.L., Forbes, D.L., MacKinnon, E. and Roberts, D. 2006. Floodrisk mapping for storm-surge events and sea-level rise in Southeast New Brunswick. Canadian Journal of Remote Sensing, Vol. 32, No. 2, pp. 194-211.

Webster, T.L., Murphy, J.B., and Gosse, J.C. 2006. Mapping Subtle Structures with LIDAR: Flow Units and Phreatomagmatic Rootless Cones in the North Mountain Basalt, Nova Scotia. Canadian Journal of Earth Sciences. Vol. 43, pp. 157-176.

Webster, T.L. 2005. LIDAR validation using GIS: A case study comparison between two LIDAR collection methods. GeoCarto International. Vol. 20, No. 4, pp. 11-19.

Webster, T., Forbes, D., Dickie, S., & Shreenan, R. 2004. Using Topographic LiDAR to Map Risk from Storm-surge Events for Charlottetown, Prince Edward Island, Canada. Canadian Journal of Remote Sensing , 30, No. 1, pp. 64-76.

Webster, T.L., Christian, M., Sangster, C. and Kingston, D. 2004*b*. High-Resolution Elevation and Image Data Within the Bay of Fundy Coastal Zone, Nova Scotia, Canada. *In* GIS for Coastal Zone Management. *Edited by* Bartlett, D. and Smith, J., CRC Press. Boca Raton, Florida, pp.195-218.

Wehr, A., and Lohr, U. 1999. Airborne laser scanning—an introduction and overview, ISPRS Journal of Photogrammetry and Remote Sensing, **54**, No. 2-3, pp. 68-82.

APPENDIX 1 LIDAR Strategic Directions Working Group Terms of Reference

Introduction:

LiDAR (Laser Imaging Detection and Ranging) is an optical remote sensing technology which measures properties of scattered light to find range and / or other information of a distant target. Simply put, LiDAR technology combines lasers, GPS, and inertial navigation systems into a single system that acquires data to produce high-resolution topographic maps that are accurate to within a few centimetres.

LiDAR mapping technology is increasingly being recognized in Nova Scotia as an effective tool for mapping highly dynamic environments such as the coastal zone and to support long-term planning. Subsequently, many jurisdictions in Nova Scotia are considering this technology for their own business purposes. For the most part, these considerations and reviews have been conducted independently.

Role of LIDAR Strategic Direction Working Group:

Although LiDAR is recognized as a useful tool, many questions about its application and costs remain. The LiDAR Strategic Directions Working Group will be tasked with providing an overview of LiDAR. This assessment will focus on:

Identify the detailed objectives and outcomes of a LiDAR Strategic Directions Report for the GeoNOVA Steering Committee. This could include, but not limited to:

Identifying a working definition for LiDAR and its key deliverables, such as topographic mapping;

Identifying which dynamic environments would benefit from LiDAR;

What long term planning goals can LiDAR best facilitate, such as the protection of people and property; and

How LiDAR mapping can facilitate achieving these long-term planning goals.

Review the LiDAR inventory in the Nova Scotia Geographic Catalogue

Examine inter-jurisdictional collaboration opportunities for working with LiDAR.

Deliver a detailed outline of the Working Group's objectives to the GeoNOVA Steering Committee.

Deliver a draft report to the GeoNOVA Steering Committee outlining the strategic direction of LiDAR in the Province of Nova Scotia by January, 2010.

Deliver a final report to the GeoNOVA Steering Committee outlining the strategic direction of LiDAR in the Province of Nova Scotia by March, 2010.

Members and Chair person(s):

The LiDAR Strategic Direction Working Group will consist of up to fourteen members.

Four municipal representatives

Two academic representatives

Two federal government representatives

Six provincial government representatives

The GeoNOVA Secretariat will provide administrative support for the group's work, including a non-voting Chair.

Governance:

The LIDAR Strategic Directions Working Group will report directly to the GeoNOVA Steering Committee.

Meetings:

The LiDAR Strategic Direction Working Group will meet monthly at an agreeable place and time as set out by the Chair.

Remuneration:

The LiDAR Strategic Direction Working Group members serve without remuneration.

Amending Procedures:

The GeoNOVA Steering Committee must approve amendments to these terms of reference.