CANADIAN FORCE BASE GAGETOWN

Choosing the Best Digital Elevation Model

The process of achieving environmental stewardship is bound to available Digital Elevation Model (DEM) accuracy. A good DEM helps directly locate and monitor streams, sensible slopes and watersheds. Indirectly, it enables the production of orthophoto maps, intervisibility analyses and three-dimensional visualisation. In this project, three different DEMs covering Canadian Forces Base Gagetown in Atlantic Canada were tested: one DEM created from Lidar, and two DEMs generated photogrammetrically using high-resolution imagery. Comparison of data management, flexibility and software requirement confirmed the superiority of Lidar DEMs.

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Three different DEM datasets were used for this project. A Lidar DEM was acquired through collaboration between the New Brunswick Emergency Measures Organisation (EMO), the Nova Scotia College of Geographic Sciences (COGS) and the University of New Brunswick (UNB). The DEMs generated photogrammetrically from high-resolution imagery collected with an Applanix Digital Sensor System were also processed using two software packages: Inpho (Version 5.3) and Leica Photogrammetry Suite (LPS Version 9.3). Few details were available concerning the third available DEM, although it was the only one used by CFB Gagetown up until initiation of this project.

To assess the vertical and planimetric accuracy of the DEMs, their elevations were compared to 1,500 ground control points distributed over three study areas and collected from GPS survey.

The hydrologic modelling control measure consisted of an accurate (5m) stream layer digitised from high-resolution imagery, coupled with Canadian government terrain expertise.

Vertical Accuracy

Approximately 65% (715km^2) of the whole training area is covered by forest. In its constant effort to improve the environment, CFB Gagetown cannot afford to monitor projects with only a poor approximation of ground topography. Over flat areas the hydrographic network dynamic relies on small changes in elevation; high-resolution DEM and centimetre-level accuracy are required to map these sharp details. Research from Suárez has proved that a bare-ground DEM can be extracted from Lidar data in very dense forest conditions. In terms of accuracy, Reutebuch has published promising results with a mean Root Mean Square Error (RMSEz) of 0.15m.

With these objectives underlined, Figure 2 illustrates the large discrepancies in quality among DEMs tested for this project. Although two software packages were tested to generate DEMs with imagery, only the result from Inpho will be presented in this section. The LPS licence, despite being more expensive than its Inpho equivalent, did not contribute to increasing the accuracy of the DEM. Lidar DEMs clearly yield better accuracy for all feature classes. Independent of DEM origins, the results show a direct relationship between spatial resolution and vertical accuracy. DEMs generated with imagery in this case provided accurate bare-ground elevation under forest canopy, but this should not be considered a general rule. Indeed, the study area selected for forest feature was very small (1.5ha), and not at all representative of average forest area within the training area.

Hydrologic Modelling

Pits, spikes and flat areas occur in most raster DEMs, and involve fewer but larger surfaces in lower-resolution DEMs of small relief landscapes. As Wang and Liu stated in 2006, whether they represent real or artificial depressions, pits always artificially truncate flow, which prevents proper analysis of downstream flow paths. However Hyyashi and later Pond found that true depressions play an important role in the storage of water, in sedimentation of nutrients, in groundwater recharge, and in the creation of wetland habitat. Both objectives are important for CFB Gagetown, and the selected DEM should enable their identification.

Sample stream networks were generated using the hydrology tool provided in ArcGIS (Version 9.2). The objective part of the comparison was conducted by computation of mean distance between generated and digitised stream. As illustrated in Figure 2, the Lidar DEM generated a stream representation very similar to the version digitised from the imagery, with a mean distance of 9m. This result is impressive, since the dynamic of a stream over flat terrain relies heavily on characteristics such as soil texture, while the software only considered slope. Results obtained with Inpho and LPS software were similar for DEMs with spatial resolutions under 4m. However, the mean distance was significantly higher for the DEMs with a spatial resolution of 10m.

To complete this evaluation, the expertise was required of Canadian government specialists on the base to conduct a subjective analysis of all products. The first aspect considered by the Department of Fisheries and Oceans (DFO) was the usefulness of generated streams in terms of watershed management. For example, as shown in Figure 3, the generated stream is a strong indicator of the optimal placement of culverts. Misplaced culverts generally lead to water accumulation along roads, which in turn can have a direct impact on maintenance costs.

Planimetric Accuracy

As Wolf describes in 2000 the role of the DEM in the orthorectification process is to eliminate terrain-induced displacement and scale difference due to sensor tilt and terrain relief. It has been demonstrated in 1997 by Simard that DEMs produced from a smaller-scale image may be employed to orthorectify aerial images from other photography the photo scale of which is up to seven times larger, without significant impact on overall orthophoto accuracy. Indeed, as Ackermann remarked in 1994, DEM point-elevation accuracy and DEM density are to some extent interdependent, and both should be considered when assessing DEM quality. According to these observations, the resolution of the existing DEM (10m) rather than its vertical accuracy would appear a limiting factor for the generation of orthophotos. As may be seen from Figure 4, the existing DEM introduces sufficient error in the orthorectification process, and the generated orthophotos failed to meet the American Society of Remote Sensing (ASPRS) standard for accuracy. However, all DEMs succeeded when the outliers where removed with a Student Test of observations (95%). Although the planimetric accuracy provided by the Lidar DEM is not considerably superior to that of other DEMs, it was sufficient to smooth and simplify the orthorectification process. To validate the accuracy of these results the same analysis was made in a second study area. Here planimetric errors were higher, but still within the ASPRS standard, since the resolution of the imagery was lower (40cm).

Concluding Remarks

Ultimately, Lidar DEMs provided better results throughout the analysis. However, this particular approach is also by far the most expensive option. CFB Gagetown already possesses its own digital aerial camera and high-resolution imagery covering the entire training area. After allowing for capital costs, the cost of DEM generation with high-resolution imagery involves only software licence fees and labour time. Because Lidar acquisition and processing would be sub-contracted out to an industry supplier, the associated cost should be conservatively multiplied by a factor of approximately two. Added to this, sub-contracted Lidar DEM production involves estimated aircraft expenses, equipment location and contractor profit amounting to roughly Can$200,000 for the 1,100km^2 covered by CFB Gagetown.

However, the major concern with DEMs produced using aerial imagery is their inability to accurately model bare-ground elevation under large areas of forest canopy. This hole could significantly hinder the outcome of environmental projects, and consequently the achievement of the primary objective of CFB Gagetown: the safety of its soldiers through realistic training. If we consider that an accurate DEM can facilitate the implementation of successful environmental stewardship, then higher costs are easier to accept.

Further Reading

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Canadian Forces Base (CFB) Gagetown

Officially opened in 1958, Canadian Forces Base (CFB) Gagetown covers 1,100 km2 and lies 20km from the City of Fredericton (Figure 1, see top). The impact of more than fifty years intensive military training over a geographical area consisting largely of poorly drained soil and wetland ecosystems has been tremendous. Work was therefore needed to better balance military requirements against effective environmental stewardship. Two projects are currently being presented in *GIM International*. Last month we published ‘Riparian Buffer Evaluation, Remote Sensing for Environmental Protection at CFB Gagetown. This month's feature presents the study to produce specific recommendations from hydrologic modelling and objective assessment of accuracy, both vertical and planimetric.