Applications of LiDAR in Archaeology: Case Studies in Landscape Archaeology

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LiDAR (Light Detection and Ranging) is an emerging technique in Archaeology. The applications of LiDAR to archaeological prospection, recording, and analysis are continually being improved upon and refined as data becomes more widely available for free. The development of regional frameworks for identifying and recording archaeological sites with LiDAR technologies would greatly increase the ability of archaeologists to make use of LiDAR data and GIS systems. LiDAR analyses by archaeologists are best undertaken if the data produced are comparable between researchers. Comparable LiDAR derived datasets can aid in the production of predictive models and increase archaeologist's ability to interpret historical landscapes. In combination with previous archaeological data, LiDAR can be utilised to model the excavated strata in a GIS and delineate topographical features on archaeological landscapes. The constant improvement of LiDAR and computing technologies in combination with the increasing availability of free LiDAR datasets both encourage archaeologists to record metric field data digitally, while supplementing those records with handwritten nuanced data not readily presented by metrics.

What is LiDAR

LiDAR is an active remote sensing technique which uses the difference in time and amplitude between emitted and return values of pulses of light to measure distances precisely and accurately (**Figure 1**).[1] Though electronic range finders used for collecting distance measurements and object avoidance could be considered LiDAR units, the technology is typically only referred to as LiDAR when the data is subsequently used to construct a digital representation of a portion of the real-world. LiDAR is a product of late-nineteenth and 20th century technological achievements in digital computing, physics, and engineering.[2] Appropriate combination of digital computers, light sensors, lasers, and airplanes all contributed to the development of LiDAR technology, the following paper will briefly explore the technology itself before moving to an examination of methods employed by archaeologists to make use of LiDAR.

Light Detection and Ranging

A simple explanation of LiDAR methodology is that light is pulsed from a datum point, and the return values from that pulse are measured (**Figure 1**). These data are used alongside the speed of light and the location of the datum to calculate latitudinal, longitudinal, and elevation values for the point of reflectance where the light 'hit' the object. The following section will clarify how data is collected and how light is used to detect and present measurements of an object.

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1 Thomas M Lillesand, Jonathan W Chipman, and Ralph W Kiefer, "*Remote Sensing and Image Interpretation*," 6th ed (Hoboken, NJ John Wiley & Sons, 2008): 714.

2 A google translated version of Hertz' initial German report (cited below) demonstrating the photoelectric effect is available here. Heinrich Hertz *(1887). "Ueber einen Einfluss des ultravioletten Lichtes auf die electrische Entladung".* in Annalen der Physik. 267 (8): 983–1000. Bibcode:1887AnP...267..983H. doi:10.1002/andp.18872670827.
"The First Laser," http://www.press.uchicago.edu/Misc/Chicago/284158_townes.html;
B. Jack Copeland, "The Modern History of Computing," in *The Stanford Encyclopedia of Philosophy*, ed. Edward N. Zalta, Winter 2017 (Metaphysics Research Lab, Stanford University, 2017), https://plato.stanford.edu/archives/win2017/entries/computing-history/.

Acquisition of Data

LiDAR data is collected from a datum point, which can either be moving or in a fixed location during data collection. Each method of acquiring LiDAR data makes use of different techniques to add control to their datum location(s). In the case of aerial LiDAR the datum will be moving, which necessitates a high precision GPS to accurately record position, and an IMU (inertial measurement unit) to record the location of the sensor during flight.[3] This contrasts with stationary terrestrial LiDAR, which only requires two fixed points: one for the LiDAR unit to be placed upon, as well as one for control as a backsight.[4] Both methods of data acquisition have their own niche they can fill within archaeology. Aerial LiDAR is great for landscape surveys, covering a relatively large area of the earth's surface in a short period of time, while terrestrial LiDAR more efficiently produces better data at the site or feature level due to the high resolution and mobility of these units. Though most archaeologists need not worry themselves about how to collect LiDAR data, an overview of how the technology is applied may aid in interpretation of the results.

LiDAR units need some basic technology to properly collect and aggregate their data. First, a LiDAR unit needs a laser that emits pulses of light, typically from 10k to 100k times per second.[5] Second, a sensor must be used to receive the return value(s) from the emitted laser pulses. To calculate distances from the light pulses, the LiDAR unit requires a highly accurate clock to record the emission and return times.[6] With these components, datum control, and a computer to store the recorded data, a user has a rudimentary LiDAR unit.

Figure 1 illustrates the path followed by one pulse from an aerial LiDAR unit. The emitted pulse then travels until it hits solid matter. When the pulse hits most matter a portion of the light is reflected to the sensor on the plane while the pulse continues through until it hits matter which completely reflects the beam. When the pulse returns to the sensor, the emission and reflectance values are used in combination with the speed of light to calculate where the object was in relation to the sensor. The position of the object is then translated into real-world coordinates with the aid of the IMU and GPS.

An appropriate combination of digital computers, light sensors, lasers, and airplanes all contribute to the production of LiDAR derived datasets; however, the application of LiDAR data to archaeology is in a constant state of infancy due to the high rate of technological advancement and the large degree of variation between visible attributes of archaeological features. Archaeologists are increasingly applying LiDAR to their discipline in many novel ways, and would be savvy to remain accustom to emerging technologies to foresee the novel or opportunistic applications of these to archaeology. In the next section, some of the many archaeological methods facilitated by the application of LiDAR will be presented in three short case studies.

[3] Thomas M Lillesand, Jonathan W Chipman, and Ralph W Kiefer, "*Remote Sensing and Image Interpretation*," (2008): 715.
[4] "In 30 Minutes, Everything You Need to Know About the Leica BLK360," *U.S. CAD* (blog), May 18, 2017, https://uscad.com/blog/30-minutes-everything-leica-blk360/.
[5] Lillesand, Chipman, and Kiefer, "*Remote Sensing and Image Interpretation*(2008): 715.
[6] Ibid.

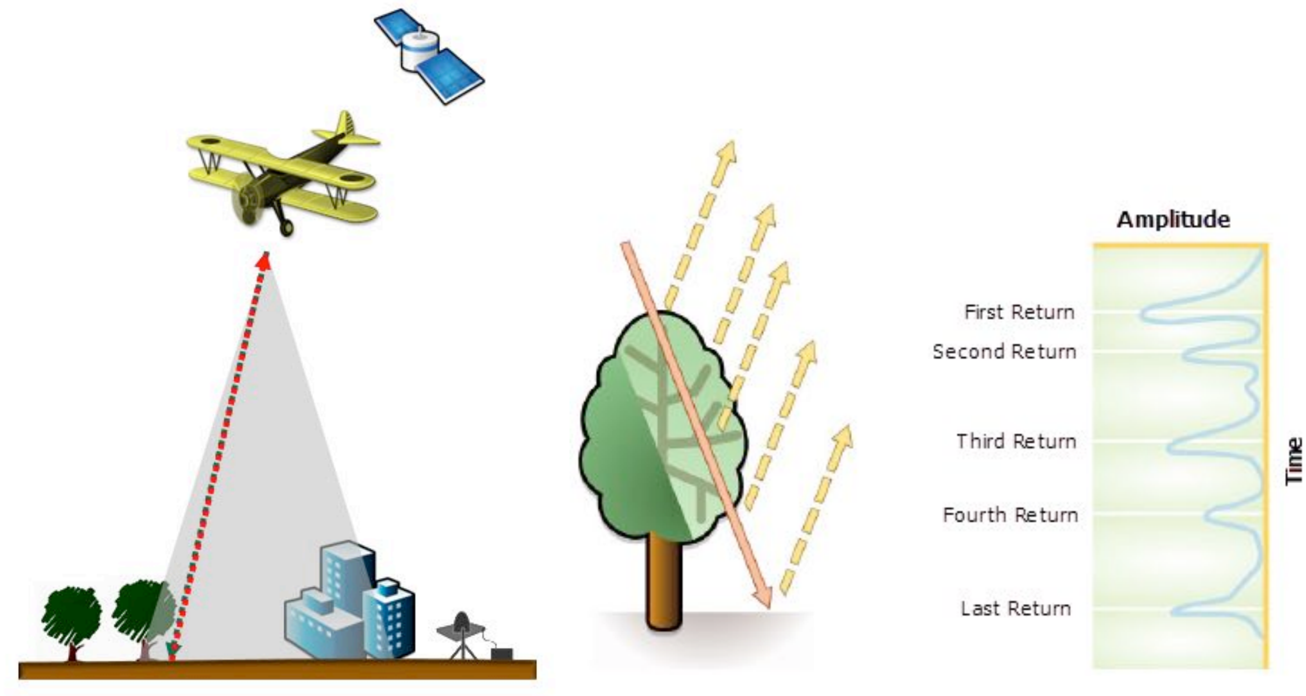

Figure 1[7]: *Illustrations of LiDAR technology collecting data: 1a(Left) - A photogrammetric airplane following flight lines. The dotted red line shows the trajectory of pulsing beam of light used to calculate elevations; 1b(Right) – A diagram showing a relative relationship between return values of the light, presented as Amplitude (frequency: Hz). The amplitude of the return value depends on the reflectance value of the object (e.g: rock will reflect close to all of the light; whereas, organic matter allows some amount of light to pass). Images obtained from ESRI ArcGIS help page "What is LiDAR Data?"*

Applications of LiDAR in Archaeology

Since the inception of hominins to the landscape we have been leaving our mark on the landscape through what archaeologists describe as features and artifacts. In the case of Atlantic Canada, contemporary theory asserts that the earliest occupation of the area happened by 13kya BP on the interface of Debert and Belmont NS.[8] Consequently, archaeological research is confined to the Holocene Epoch in Atlantic Canada, which is the period of focus for the following case studies.[9]

Identification of High Potential Areas

The first step of any archaeological investigation after identifying an area of interest (AOI) is the development of high potential areas within that area. This can be achieved by visualizing the data in various forms to delineate areas with attributes that match those of a high potential area. For example, if high, flat-

[7] Images in **Figure 1** are originally from the following source: "*What Is Lidar Data?—Help | ArcGIS for Desktop,*" http://desktop.arcgis.com/en/arcmap/10.3/manage-data/las-dataset/what-is-lidar-data-.htm.

[8] Leah Morine Rosenmeier, "*What About Those Dates?*" (Mi'kmawey Debert Cultural Centre, 2016), 2, http://www.mikmaweydebert.ca/home/wp-content/uploads/2016/07/Debert_UPS_Dating_corrected_July2016.pdf.

[9] "The Holocene Epoch," http://www.ucmp.berkeley.edu/quaternary/holocene.php.

topped ridges are the characteristic being searched for then an analysis can be performed in ArcGIS to isolate and highlight large areas that fit these criteria. After an AOI and high potential areas are identified within, LiDAR data can further be used to highlight features of interest.

Identification of Features

As with delineating an AOI, isolating features requires knowledge from the archaeologist about what physical attributes the features display on the surface. The attributes of features vary regionally from culture to culture over time; therefore, different methods are utilized to identify features in different circumstances. The methods explored in the subsequent case studies will be DEM and hillshade manipulation with contrast, brightness, vertical exaggeration, and dynamic lighting; DEM classification by elevation; elevation profiles of LAS point data; georeferncing of historical maps using a DEM; as well as a novel technique to make use of test excavation data to model stratigraphic topography.

Locating a Hopewell Mound Enclosure: Middle Woodland, Iowa

The Hopewell cultural complex existed South of the great lakes within the woodland period from the Appalachians to the Midwest.[10] Hopewell was part of a long tradition of mound building in the Americas, which began in North America by 4000BC near the transition from the Middle Archaic to Late Archaic periods of human history in North America. [11] Evidence of expansive Hopewellian trade and social networks are evidenced by shared symbolism, ritual, architecture, and dress with pre-Classic Mesoamerica, while Hopewell dress, art, and symbolism is partially shared with Algonkian culture.[12] These pieces of evidence lend to the idea that Hopewell was a hub of trade in North and Central America, facilitating cultural exchange and trading of resources across vast distances.

The Havana tradition (200B.C – 300AD) in Hopewell culture appears in the Middle Woodland period, lasting into the early Late Woodland period. [13] Toolesboro National Historic Landmark Mound Group is one of the remaining Havana features visible on the landscape. However, the Toolesboro mounds themselves are not the only reported feature of the site. In 1841, John B. Newhall mapped the area noting a large earthwork enclosure that he labels a 'fort' (**Figure 2**). [14] The earthworks themselves have been ploughed flat since Newhall recorded them; however, a 2014 investigation of the site by Riley and Tiffany using freely available LiDAR data has demonstrated that LiDAR can be used to identify microtopographical features easily passed over during pedestrian survey.[15]

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[10] George R. Milner, and W.H. Wills, "Complex Societies of North America," *The Human Past: World Prehistory & the Development of Human Societies,* Christopher Scarre, ed., (New York: Thames & Hudson, 2013) 680-681.

[11] Although mound sites predating North American mounds are found throughout South and Central America, the research was restricted to North American mound sites for this project. David L. Bowman, Gayle J Frtiz, and Patty Jo Watson, "Origins of Food-Producing Economies in the Americas," *The Human Past: World Prehistory & the Development of Human Societies,* Christopher Scarre, ed., (New York: Thames & Hudson, 2013) 308, 328-329.

[12] Olaf H. Prufer, "The Hopewell Complex of Ohio," in *Hopewellian Studies*, vol. 12, Illinois State Museum Scientific Papers 1 (Illinois State Museum, 1964), 7-83.

[13] Melanie A. Riley and Joseph A. Tiffany, "Using LiDAR Data to Locate a Middle Woodland Enclosure and Associated Mounds, Louisa County, Iowa," *Journal of Archaeological Science* 52, no. Supplement C (December 1, 2014): 143–51, https://doi.org/10.1016/j.jas.2014.07.018, 143.

[14] Ibid.

[15] Ibid.

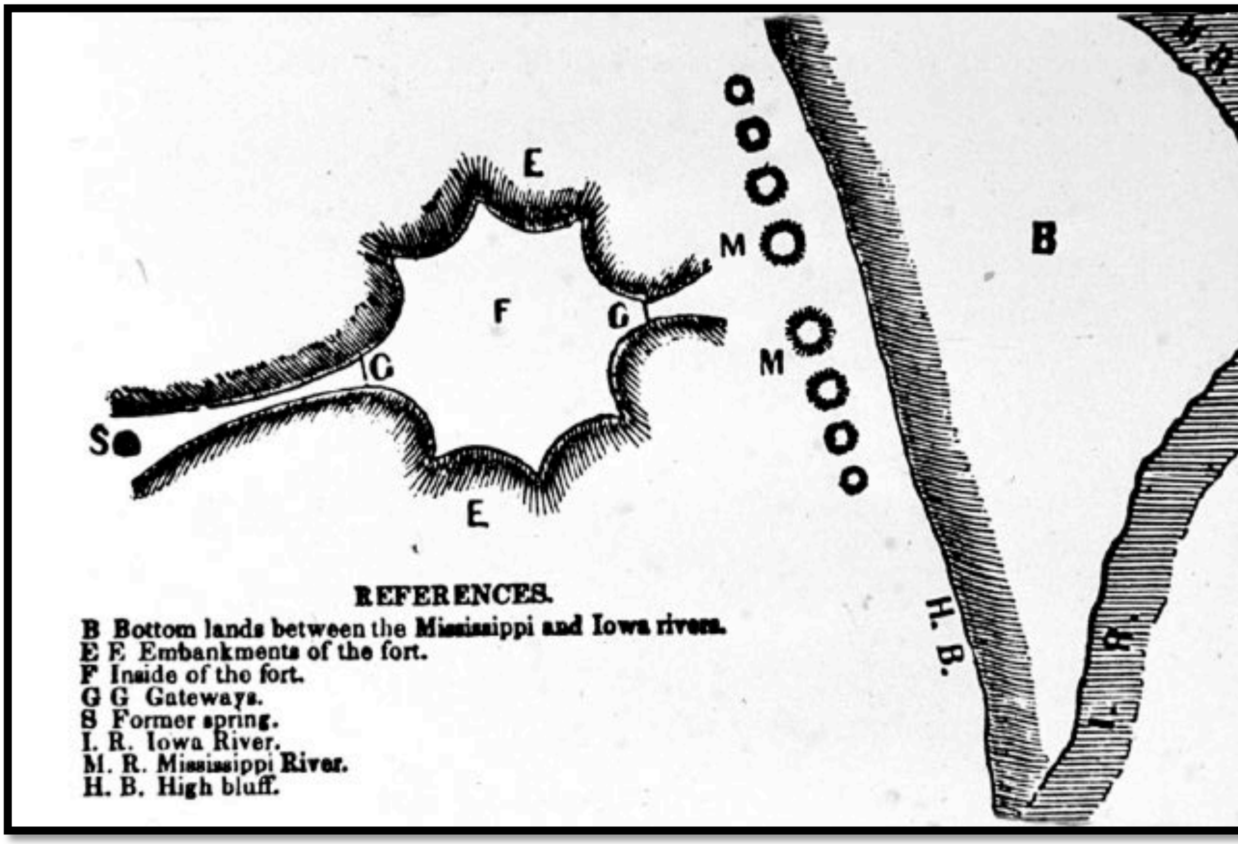


Figure 2[16]: *Original sketched map by John B. Newhall used by Riley and Tiffany in their archaeological application of LiDAR data. The enclosure is labelled as a 'fort' in the sketch, possibly due to the reuse of the area by later chiefdom societies of the Mississippi River valley known to be war waging people.[17]*

Methodology

The LiDAR analysis located the enclosure, eight mounds, a possible unrecorded ninth mound or spoils pile and an anomaly to the Northwest of the enclosure.[18] To locate the enclosure, two methods were tested. First, a Digital Elevation Model (DEM) containing the study area was obtained from the Iowa Geologic and Water Survey, a hillshade was produced from the DEM and analyzed using only contrast and brightness manipulation. The first method produced only very faint indications of the features reported on the site.[19] Five of the eight reported mounds were identified using this method, while for any trace of the enclosure to be viewed Adobe Photoshop CS6 was used to manipulate brightness and contrast.[20] The second method deployed by Riley and Tiffany was the use of ArcScene

[16] Riley and Tiffany, "Using LiDAR Data to Locate a Middle Woodland Enclosure and Associated Mounds, Louisa County, Iowa," *Journal of Archaeological Science* 52, (2014), 145.

[17] Riley and Tiffany mention the Oneota village on the site within the enclosure. Oneota surface artifact finds are void of Hopewell or Middle Woodland materials. Ibid. 143.
George R. Milner, and W.H. Wills, "Complex Societies of North America," *The Human Past: World Prehistory & the Development of Human Societies,* Christopher Scarre, ed., (New York: Thames & Hudson, 2013) page 687-690.

[18] Ibid. 145

[19] Ibid. 146.

[20] The use of Adobe Photoshop software to manipulate brightness and contrast on a hillshade is not necessary as this is a feature of ArcMap.

to make use of the dynamic lighting and vertical exaggeration features of the software. This method displayed the enclosure more readily, and showed circular surface relief approximately in the middle of the enclosure. The enclosure feature had maximum measurements of 160 x 200m, while the circular relief in the centre of the enclosure had a diameter of 34m. Surface relief of these features did not exceed 5-10cm.

After the enclosure was located, Riley and Tiffany underwent a different analysis of the data to locate the mounds themselves. LAS files were brought into ArcMap to view the classified ground points. An elevation profile was created using the LAS dataset toolbar. This method allowed for the identification of all eight reported mounds, and a possible ninth mound or spoils pile. This method proves very helpful to delineate features under forest canopies or which have few ground point returns.

Remote Site Prospection at Fort Belcher, Onslow, Nova Scotia

Fort Belcher has recently become but a place name to most Nova Scotians, if the name is even known. However, situated on a knoll at the East edge of the Chiganois River in Cobequid Bay once stood Fort Belcher (**Figure 3**). Fort Belcher begins to appear on maps around 1761, and it is possible that **Figure 3** is from that year. The map has no author or date attached to it; however, the map resembles Charles Morris' cartography, and during the year of 1761 Morris "was on an extended tour through northern Nova Scotia, surveying and mapping the townships of Cobequid, Chignecto, and the Saint John River.[21]

Whenever Fort Belcher was built, it was in disrepair by 1767 when Captain William Owens visited Richard Upham's land on the 22nd of September.[22]

Though the designation of fort was given to Fort Belcher, perhaps the complex held the function of fortified barn or storage area to the local inhabitants. Evidence of this appears in 1761 when Lieutenant-Governor Belcher gave the Upham family "liberty to occupy such part of the Barracks at Onslow, as shall be necessary for the use of you [Richard Upham] and your family."[23] Further evidence for the non-military function the fort played in early Cobequid comes from Upham's position as the customs officer for Cobequid, making the Fort Belcher wharf Cobequid's principal landing site for ships.[24] As Upham was also a trader with his own vessel, it is not out of the realm of possibility that Fort Belcher served as a sort of trading post during it's time standing as well.[25] A request to Lieutenant-Governor Richard Hughes during the purchase of Richard Upham's property in 1780 by Thomas Brown infers that fort must have been demolished or have completely fallen by this time.[26] Due to this, site formation processes indicate the short life of the fort would preserve material culture of early planter Cobequid from 1761-1780 rather than an 18th century British military material culture.

[21] Carol Campbell, *Necessaries and Sufficiencies: Planter Society in Londonderry, Onslow and Truro Townships 1761-1780* (Sydney, N.S.: Cape Breton University Press, 2011), 25-27.

[22] William Owen, "Journal of Captain William Owen", PANS F100 OW2.

[23] Carol Campbell, *Necessaries and Sufficiencies* (2011), 28.

[24] Ibid. 73.

[25] Ibid. 50.

[26] Thomas Brown and Charles Morris, "license to occupy Fort Belcher land in the township of Onslow. Also a petition for the said license", *Nova Scotia Archives - Nova Scotia Land Papers 1765-1800*, https://novascotia.ca/archives/landpapers/archives.asp?ID=62&Doc=memorial&Page=201100181/.

Figure 3[27]**:** *A map of King's Village in Onslow, Nova Scotia. The map is thought to be authored by Charles Morris, and produced during his surveying tour in 1761.*

Methodology

Remote site prospection is a well-known method in archaeological research that probably first developed by comparing historic maps to aerial photography; however, digital forms of remote site prospection allow for a variety of analyses to be taken on by an archaeologist from a remote location. At Onslow's Fort Belcher, the methods utilized were an overlay of an historic map on elevation data (**Figure 4**), and temporary classification by symbology in ArcMap (**Figure 5**).

First, the DEM and historic map were loaded into ArcMap. The historic map was then roughly positioned to the East of the mouth of the Chiganois river. Very basic manipulation of the map, such as scaling, shifting, and rotating was performed to preserve the geometry of the survey being taken while aligning the map to the elevation displayed by DEM. To estimate the AOI of the cartographer, no control points were used to georeference the map. This showed that the area of highest accuracy was within King's Village itself, as would be expected when surveying lots within a village.

[27] Charles Morris (?), *Plans of Colchester County Portfolio 16 - A Plan of King's Village in the Township of Onslow* (Onslow Township, Colchester County, Nova Scotia, n.d.), NSDNR.

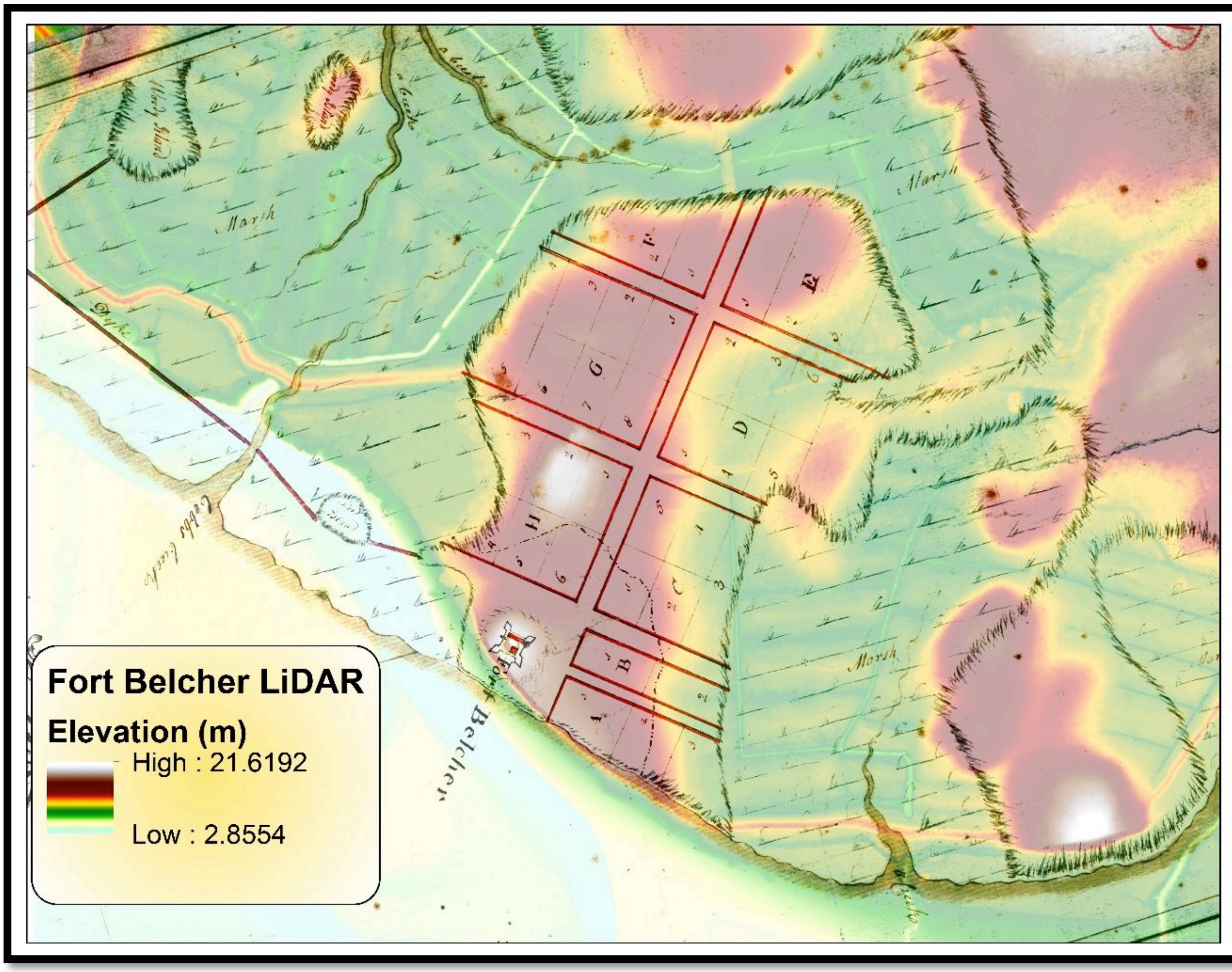


Figure 4: *An overlay of* ***Figure 3*** *on a LiDAR derived DEM and produced within ArcMap. The figure clearly shows the landform where King's Village and Fort Belcher once stood has not eroded into the bay. The accuracy of the map in the Kings Village area is impeccable, seemingly because this was the subject of the map and the surrounding landscape is for reference. LiDAR data courtesy of Tim Webster, Applied Geomatics Research Group, Nova Scotia Community College, Middleton, NS.*

The overlay allowed for a high potential area for the fort to be determined. **Figure 3** clearly shows a small knoll on the highest point of land directly East of the Chiganois river. This information was used to clip and resample a portion of the DEM to the small knoll where Fort Belcher is thought to have stood (**Figure 5**). This data provided a visualization of sub-rectangular microtopographical relief within the high potential area. The surface relief of the anomaly ranges from approximately 5-15cm, and the maximum dimensions are approximately 25 x 25m. Future geophysical survey of the high potential area and ground truthing of the anomalies is necessary to confirm the presence of Fort Belcher at this location.

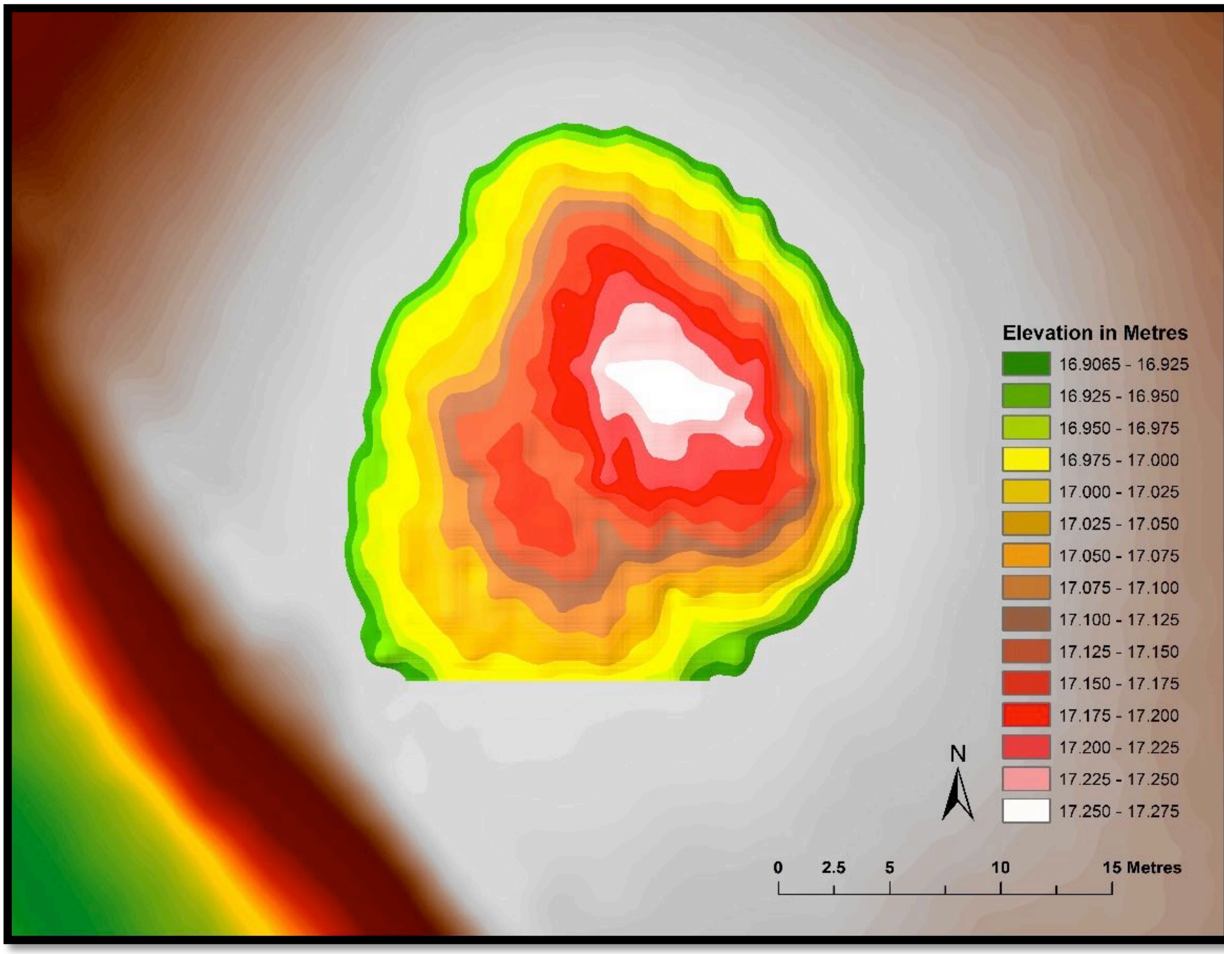


Figure 5: *A clipped and resampled DEM of the high potential area of Fort Belcher. DEM was resampled at 25cm resolution to allow smooth edges of the elevation classes. The elevation was temporarily classified by symbology, using a 2.5cm defined interval for the classes. To allow for a better display of the surface relief, elevation values below 16.9065m were excluded. LiDAR data courtesy of Tim Webster, Applied Geomatics Research Group, Nova Scotia Community College, Middleton, NS.*

Stratigraphic Topography Modelling at Debert, Nova Scotia

On August 29th of 1948, E.S. Eaton, a professor at the Truro Agricultural College, and his wife were attracted to an area in Debert for its flourishing patch of blueberries. Upon exploration of the area, Eaton noticed a small quantity of artifacts eroding from the exposed sands in the area.[28] In 1955, the area was brought to the attention of the National Museum of Canada's chief archaeologist at the time, R.S. MacNeish. MacNeish then took on an archaeological survey and testing of the area in September of 1962 with the Director of the R.S. Peabody Foundation for Archaeology, D.S. Byers.[29] Excavations of the Debert Main Site (**Figure 6**) proceeded in the following two years. The excavations uncovered 4471 lithic tools and 23000 flakes from the production of lithic tools that date back to around 13kya, a

[28] George F. MacDonald, *Debert: A Paleo-Indian Site in Central Nova Scotia* (Ottawa, Ontario, Canada: The Queen's Printer, 1969), 1-2.
[29] Ibid.

previously unheard-of date for a site in Nova Scotia.[30]

Methodology

Archaeological mitigation was performed in the area by Kelman Heritage in November 2015.[31] Depth measurements recorded on test pit forms while in the field were used to create a raster surface from the depth measurements. The application of LiDAR in this case study explores methods for organization, display, and analysis of archaeological depth below surface (DBS) measurements. The goal of this project is to present a method which aids the understanding of landscapes in which archaeological features existed; however, it cannot be overlooked that the grid pattern of testing in the Debert/Belmont area provides a unique opportunity to apply this methodology.[32] As this technique involves multiple steps, the steps have been listed as they are presented in a preliminary project report delivered to the Nova Scotia Museum[33]:

1. Data extracted from permit #A2015NS060 report into excel and saved in TXT format (tab delimited).
2. TXT file brought into ArcMap by using *Make X, Y Event Layer* tool. The result is a layer that can be viewed in ArcMap.
3. Layer is then exported to the project geodatabase as a point feature class.
4. A polygon feature class is created in the project geodatabase. A rectangle feature is created at the location of the excavation area using coordinates from the PID layer on the GeoNOVA Elevation Explorer application.
5. The point feature class is then used as the input for the *IDW* tool within *Interpolation* in the Spatial Analyst toolbox. This tool must be run once for each stratigraphic layer using the field that corresponds to it. The resulting files contain a DEM of each lot.
6. DEMs are georeferenced to the polygon feature by using the test pits which lay on the edges of the excavation grid.
7. The lot DEM values are then subtracted from the elevation values of a LiDAR derived bare-earth DEM using *Minus* in *Raster Math* in the 3D Analyst toolbox.[34]
8. The resulting DEM is used to create a hillshade using the *Hillshade* tool within *Surface* in the Spatial Analyst toolbox.

The result of the above workflow provides a topographical view of the underlying stratigraphy which can be readily viewed in ArcMap or ArcScene. **Figure 6** shows the first complete product derived from this workflow, a surface of bedrock measured by archeologists during testing in the area. The DEM in **Figure 6** shows a channel running Northwest-Southeast seemingly emptying into a larger depression. When

30 For reference to the number of artifacts and flakes, see: Ibid, 58, 109.
Reference to 13kya see: Leah Morine Rosenmeier, "*What About Those Dates?*" (016), 2.

31 Darryl Kelman and Emily Pudden, "PID #20153698 Lancaster Crescent Archaeological Assessment Debert, Colchester County, Nova Scotia," Archaeological Assessment (Kelman Heritage Consulting, November 2015), Nova Scotia Museum.

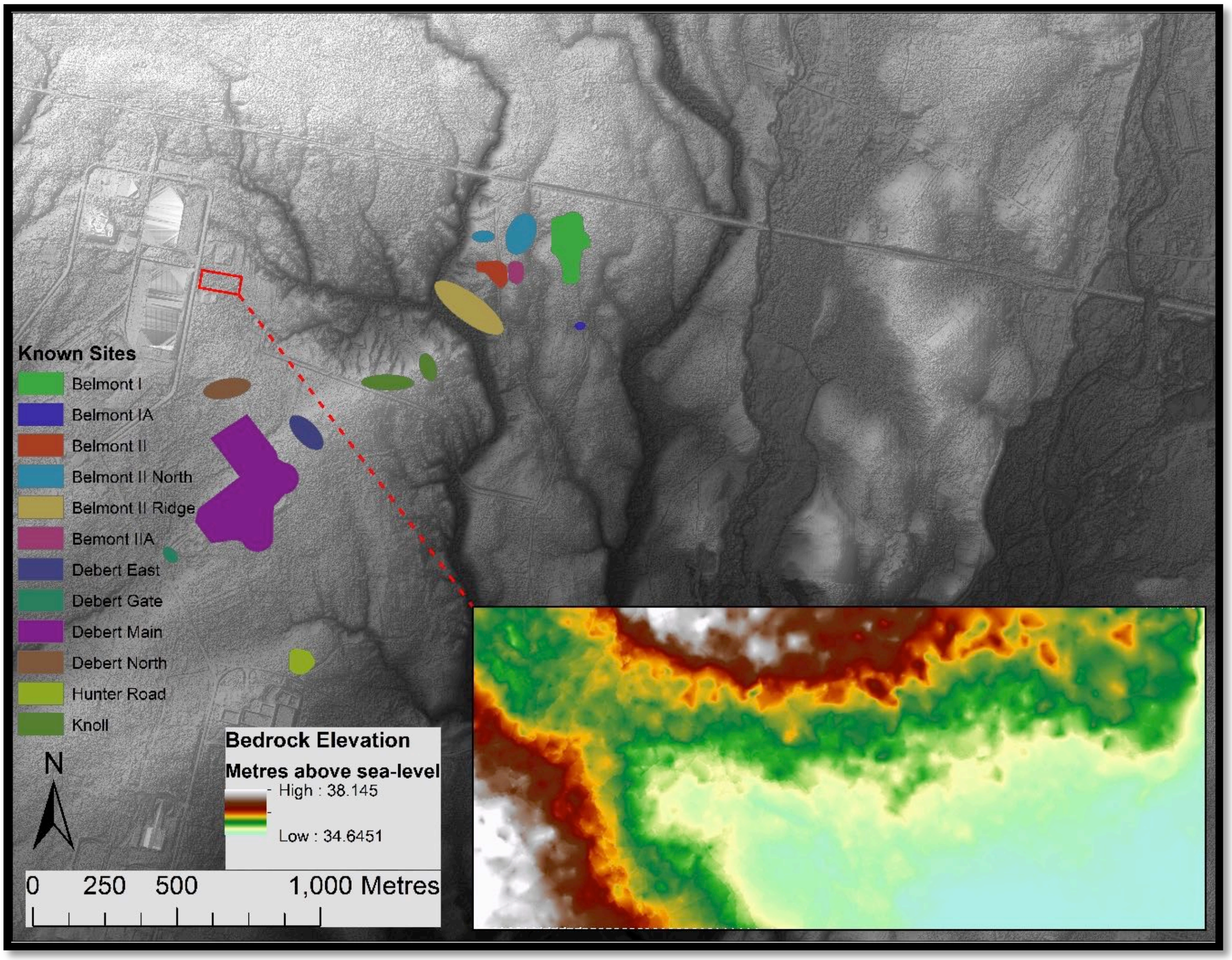
32 "Archaeology Permits and Guidelines | Communities, Culture and Heritage," https://cch.novascotia.ca/exploring-our-past/special-places/archaeology-permits-and-guidelines.

33 The following preliminary report is attached as an appendix to this paper for reference purposes:
Wesley Weatherbee, "Debert, Nova Scotia - DBS to Raster," Preliminary Archaeological Research, November 2017.

34 Bare-earth DEM derived from LAS files obtained from the Nova Scotia government's GeoNOVA elevation exporter portal.

compared to the glaciolacustrine sand deposits shown in **Figure 7**, noted by MacDonald as 'laminated sand', the bedrock elevation DEM (**Figure 6**) occupies the area just North of the deposits left by a glacial lake.[35] The product of the above workflow outlines the Northwest edge a linear fluvial deposit in a drainage channel which likely terminated into the glacial lake. Though, results so far only show the elevation of one lot recorded by Kelman Heritage Consultants in 2015, bedrock, when more the stratigraphy is interpolated using this method further analysis into the formation and interpretation of the landscape experienced by the first people to settle Mi'kma'ki (Nova Scotia) can be performed.

Figure 6: *A map showing known sites in Debert in relation to the study area, and a DEM of the bedrock in metres above sea-level. The archaeological data were digitized from a map available at the Mi'kmawey Debert website.*



[35] For glaciofluvial and glaciolacustrine deposits in Debert, see: Rudolph Stea, "Geology and Paleoenvironmental Reconstruction of the Debert/Belmont Site" (Stea Surficial Geology Services, 2014), 7-8, http://www.steasurficial.ca/pdf/dbsite.pdf.
For MacDonald, see: George F. MacDonald, *Debert: A Paleo-Indian Site in Central Nova Scotia* (Ottawa, Ontario, Canada: The Queen's Printer, 1969), 7.

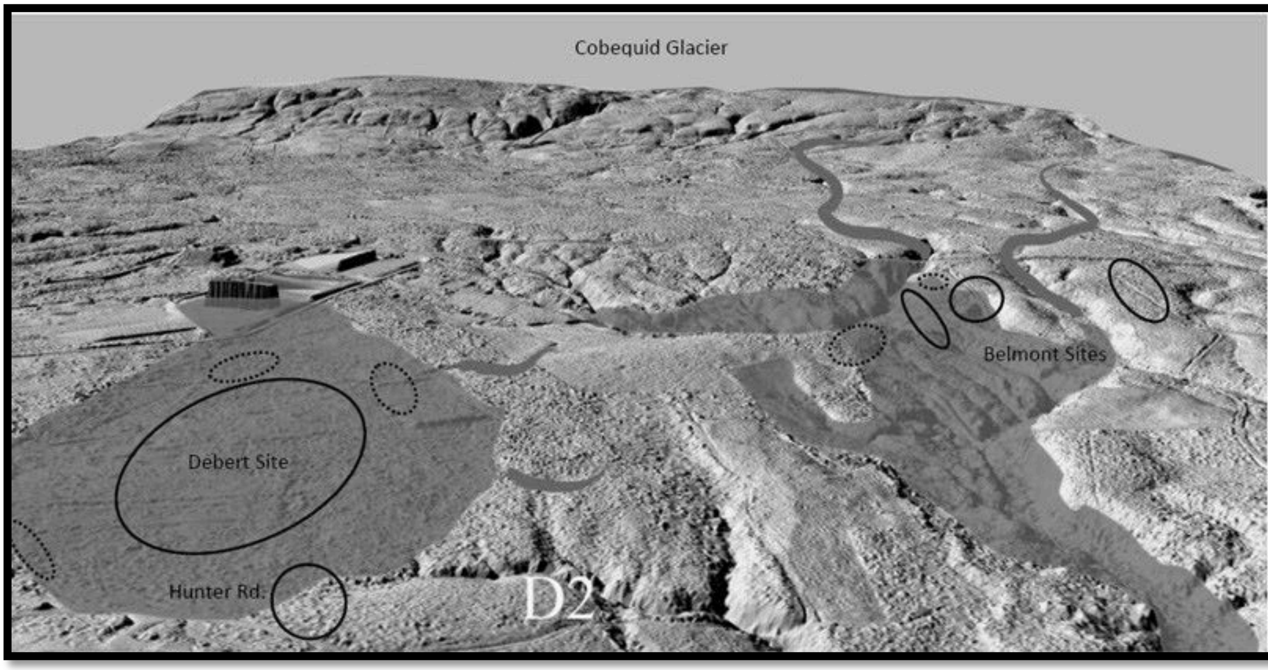


Figure 7: "*Digital Elevation Model (DEM) showing sites in relationship to glacial deposits. LIDAR base image courtesy of Tim Webster, Centre of Geographic Sciences, Lawrencetown, Nova Scotia. Base map data courtesy of Tim Webster, Applied Geomatics Research Group, Nova Scotia Community College, Middleton, NS."*[36] *Image located at the [Mi'kmawey Debert Cultural Centre website](http://www.mikmaweydebert.ca/home/ancestors-live-here/debert/understanding-and-protecting-the-sites/).*

Accessing LiDAR Data - GeoNOVA

The government of Nova Scotia has recently released a large amount of LiDAR data to the public through the online GEOnova portal.[37] The data is available for most of the Northwestern half of Nova Scotia surrounding the Bay of Fundy, extending down the Shubenacadie river valley almost extending to Halifax. Through the Elevation Explorer application of the Data Locator, data may be viewed and downloaded free of cost.[38] The two formats available should allow users of varying skillsets to make use of the data. The two formats will be explained in the following.

RAW DEM

RAW DEM files are available as georeferenced raster datasets in TIF format. These datasets give the user a basic understanding of ground elevation, and in areas with a lack of or low vegetation allow the archaeologist to visualize how microtopographical features are expressed on the surface as a result of past human activity. Digital elevation models can be used to aid an archaeologist in site prospection, cartography, analysis of high potential areas, and many uses yet to be discovered.

[36] "Understanding and Protecting the Sites," *Mi'kmawey Debert Cultural Centre* (blog), http://www.mikmaweydebert.ca/home/ancestors-live-here/debert/understanding-and-protecting-the-sites/.
[37] Government of Nova Scotia, "GeoNova," https://geonova.novascotia.ca/.
[38] Government of Nova Scotia, "GeoNova: DataLocator - Elevation Explorer," https://nsgi.novascotia.ca/datalocator/elevation/.

LAZ Format

LAZ is the file format of compressed LiDAR data for exchange between vendors and customers.[39] The format will not open directly in software such as ArcGIS and will have to be unarchived using a free application called LASzip.[40] LASzip is a product built specifically to facilitate the easy transfer of LAS files between users. The product is free to use and has toolboxes specifically built for both ArcGIS and QGIS which allows users of any budget to make use of open sourced LiDAR data.

The clear advantage of having data in the LAZ format over a pre-constructed DEM is that the user can use knowledge of the landscape to be classified to produce a higher resolution product. This, of course, rests on the archaeologist's ability to make use of geospatial data; therefore, creating the two options for using the GeoNOVA data portal for archaeology: "Quick 'n' Dirty" (RAW DEM); and, High Accuracy Classification. The ability for archaeologists with little experience in GIS to make use of the data is integral to the integration of LiDAR to archaeological prospection and analysis, benefitting the advancement of our science now and for future generations.

Accessing LiDAR Data - Advance Geomatics Research Group (ACRG)

As the name suggests, the AGRG are interested in geomatics research. I first contacted the AGRG at the beginning of this project, promptly I received a reply from Tim Webster, research scientist at the AGRG, who arranged for the requested data to be sent to me. The data was not only received without a hitch, but the AGRG extended their services as geomatics specialists as well. Had I not been so keen to expand my GIS toolbox to archaeology, I surely would have taken that offer.

Conclusions and Future Applications

While technologies for acquiring and analyzing LiDAR data are continually becoming more advanced, it is reasonable to consider the application of LiDAR to archaeology is still in its infancy. Presentation of the previous three case studies has barely skimmed the surface of the archaeological applications of aerial LiDAR without delving into the myriad of archaeological applications for LiDAR facilitated by terrestrial LiDAR. The methodologies explored in the above three case studies demonstrate a few of the simple analyses in which aerial LiDAR can aid archaeological research. Archaeologists continue to discover innovative new ways to apply LiDAR data to archaeology, and as the process of aggregating large digital datasets in all areas of fieldwork driven science becomes commonplace ⍰ the ability of an archaeologist to access, utilize, and interpret digital datasets across disciplines is becoming more important to their research, analysis and fieldwork data collection.

Currently, the most provident methods of archaeological analysis employing LiDAR seem to be for remote site prospection; however, awareness of and adequate training with archaeological and geographical data in GIS environments may lead to expediated workflows for more complicated analysis of archaeological data using LiDAR and other forms of remote sensing data. Development of these workflows is foreshadowed by the methods employed at

[39] DataTypes.net, "Open LAZ Files | File Extension LAZ," https://datatypes.net/open-laz-files.
[40] LASzip, "LASzip - Free and Lossless LiDAR Compression — LASzip 3.1.1 Documentation," https://www.laszip.org/.

the Mi'kmawey Debert site complex. The method demonstrates how archaeological field data could be used alongside LiDAR data to produce large georeferenced datasets. Though only a bedrock surface was interpolated from DBS data in Debert as of present, future work with this data will provide a surface model from each of the stratigraphic lots recorded. However, products are not limited to topography. Artifact and feature locations can also be plotted within a GIS for visualization and comparison of their spatial distribution.

The possibility for comparative analyses between sites is seemingly endless if digital catalogues of artifacts and excavation units are available to a researcher. For the moment, caveats to performing these sorts of analyses are that complete sets of digital archaeological data are infrequent, and the datasets are typically not structured for use in a GIS environment or large dataset synthesis. With these current caveats standing in the way of archaeological analyses, we are limited in what can be achieved by the amount of time available for the drone-like work of data entry. A digital revolution in the methods of archaeological data acquisition would free up time for archaeologists to both expand skills within and make use of GIS environments for analysis.

Digital data collection and analysis has already been deemed essential to the Debert site by Stephen Davis, and the importance of using laser mapping, such as a total station for artifacts and terrestrial LiDAR units for excavation areas, has been noted by George MacDonald at the 2005 Debert Research Workshop.[41] Participation in the development of data integrity standards for archaeological fieldwork is necessary in these early formative years of digital data collection within Nova Scotian archaeology. The product of data integrity standards would be province-wide comparable datasets, which are vital to the high resolution large scale data synthesis projects that can aid archaeologists in their interpretations of heritage resources ranging in size from artifacts to whole regions. It is the intent of the author that this paper will serve as an informative piece of writing for archaeologists and can serve as a reference point for future uses of LiDAR data, and GIS to archaeological research.

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[41] For Davis' comments see: Stephen A. Davis, "Mi'kmamkik Teloltipnik L'nuk ☐ Saqiwe'k L'nuk: How Ancient People Lived in Mi'kma'ki," in *Ta'n Wetapeksi'k: Understanding From Where We Come*, ed. Tim Bernard, Leah Morine Rosenmeier, and Sharon L. Farrell, Proceedings of the 2005 Debert Research Workshop (Debert, Nova Scotia, Canada: Eastern Woodland Print Comminications, Truro, Nova Scotia, 2011), 17.
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