**Archaeological case studies of drone photography and photogrammetry 2017**

Scott Hamilton Lakehead University
Jason Stephenson Lakehead University

## Introduction

We are evaluating radio-controlled drones (Unmanned Aerial Vehicles or UAVs) as a tool for archaeological and other heritage site documentation. This began by: 1) determining basic equipment requirements for archaeological site documentation; 2) developing data collection protocols under different conditions; and 3) exploring the strengths and weaknesses of the technology (see Hamilton and Stephenson 2016). Current research focuses on the application of computer-aided photogrammetry, including production of image mosaics, digital elevation models and 3d renderings of archaeological sites and landscapes. This research note outlines three case studies to highlight the potential of low-elevation air photography using drones, and also the cost-effectiveness of data collection balanced with accuracy/utility of output.

Aerial photography has a long history in archaeology, but the rapid development of consumer-grade drones offers unprecedented new opportunities. Drone technical capabilities have rapidly improved, with better flight endurance and reduced crash risk. They are now marketed as 'user-friendly' and 'ready-for-use' consumer products. As is often the case with emergent technology, implementation as a research tool is more complicated than first thought.

Our initial 2014 equipment purchase proved inadequate for archaeological research, and our field evaluations were interrupted by a crash in the spring of 2015. By the fall of 2015, technological development permitted purchase of a new model (DJI Phantom 3 Advanced™) that overcame most of the identified limitations. This drone has been superseded by new models, a trend that will continue into the future. Software has also sharply improved with more sophisticated telemetry readout, improved radio range, and also tablet-based apps that enable planning and execution of semi-autonomous mapping flights. The latter is particularly important for archaeological application because it permits replicable flights, standardized data collection and uniform image coverage.

Implementation of drone photography to support research must also address technical and regulatory hurdles. While billed as 'easy to fly', these machines are quite sophisticated. The integrated components (gimbal, digital camera, GPS, altimeter, compass, accelerometer, radio transmitters and receivers, synchronized electric motors, etc.) are managed through radio communication to the controller attached to a tablet or smart phone. This equipment requires regular maintenance, software updates and routine calibration. Very little of this equipment can be repaired by the average owner-operator, requiring long delays and unanticipated expenses if it has to be shipped back to the manufacturer.

Actual flight requires attentive and skilled operation, and fast action in the event of an in-flight mishap. If and when difficulties are encountered crash risk is high, usually resulting in drone damage, and perhaps also property damage or personal injury on the ground. Since drones are now widely available, these risks are real in an increasingly crowded and comparatively unregulated airspace. Transport Canada has established a regulatory process, with UAV operation for research or commercial purposes requiring a Special Flight Operations Certificate (or SFOC). Responsible drone use requires careful flight planning, risk assessment, and skill development. While we initially thought that drones might be widely and routinely used for archaeological documentation, our experience suggests that it will become the domain of specialists (with the necessary certificates and insurance coverage) who operate increasingly sophisticated machines carrying diverse sensors.

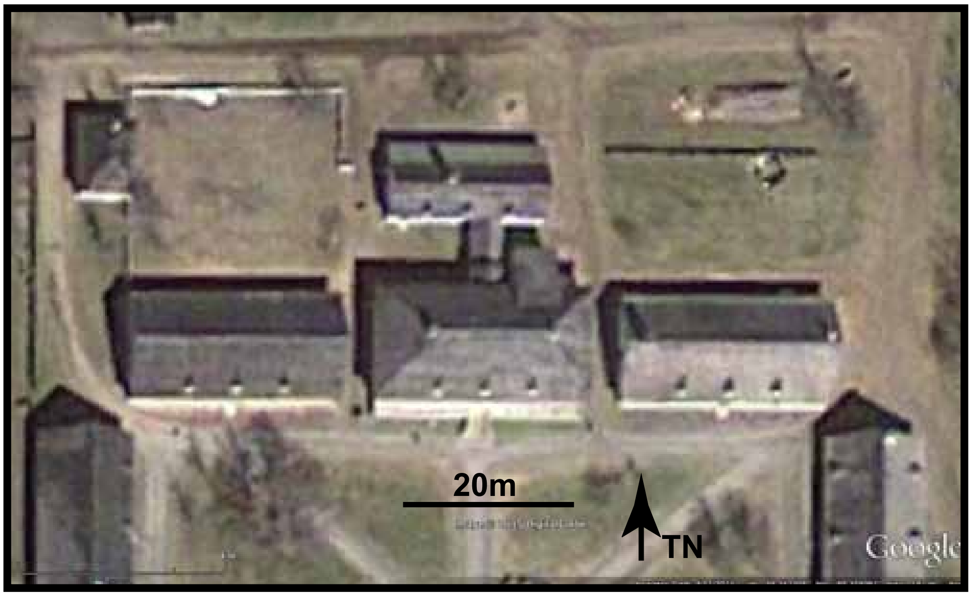
**Fort William Historical Park**

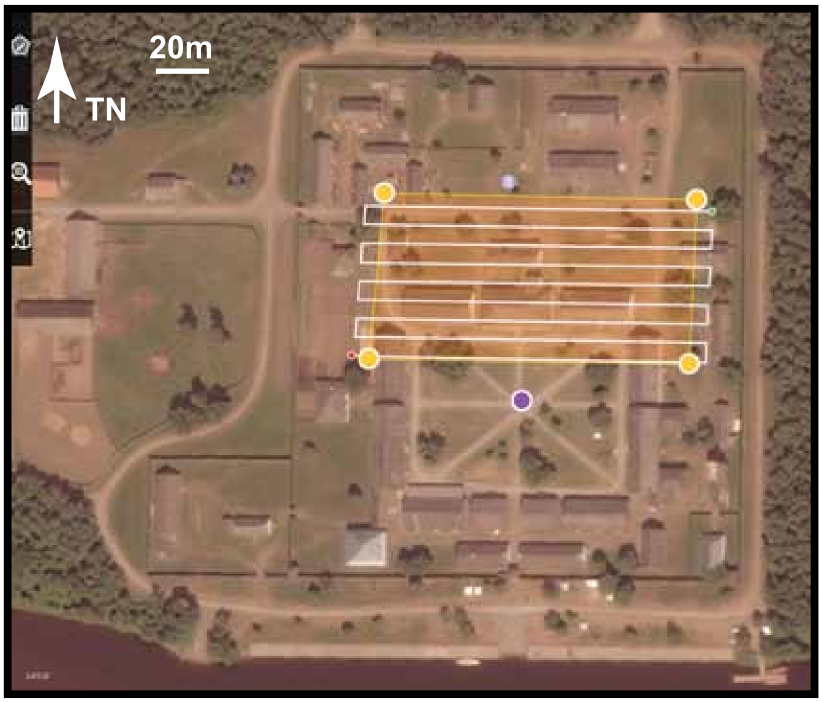
One of our first tests of drone mapping involved flights over parts of the Fort William Historical Park, a reconstruction of the early 19th Century North West Company depot near Thunder Bay, Ontario (Figure 1). We were focused on testing flight planning software (MapPilot™), image resolution, and the output deriving from a photogrammetry service (MapsMadeEasy™). It involved two flights over the Officers' Quarters complex (388 images collected over two 12 minute flights) using the same flight plan (Figure 2). The first flight collected imagery with the camera pointing straight down, and the second with it oriented forward at about a 45° angle. The latter sought to maximize the detail of building walls and rooflines to aid the 3d modelling.

Figure 3 illustrates the image mosaic conducted at 40 metres elevation, at a speed of 2 metres/second, and with 90% overlap between adjacent images. These specifications were calculated to assess the best possible output from this machine. Figure 3 is less than 10% of the size of the original output, resulting in considerable detail loss. As each image is tagged with its geographic coordinates (decimal degrees), the resultant mosaic imagery is also geo-referenced as a 'GeoTiff'. This allows it to be immediately uploaded into GIS software. While the actual geo-referencing precision is not readily available, it meets or exceeds that of available satellite imagery, and far exceeds that of conventional cartographic maps. The inset included in Figure 3 reveals that quite small features are captured at an interpretable resolution.

The Digital Elevation Model (Figure 4) derives from the photogrammatic processing of overlapping images, and uses colour to represent relief variation. It does not directly measure the relief, but rather, uses differences in perspective between adjacent overlapping images to estimate it. It also does not necessarily represent 'bare earth' elevation, but rather, that of the top surface detected by visible light photography. This might represent bare ground, agricultural crops, tall grass and shrubs, or the tree canopy. This obviously constrains archaeological application in some situations unless considerable pre-flight site preparation is undertaken. The precision of relief representation within the DEM is not currently known. As part of Stephenson's Masters thesis research, he will be directly measuring 'hard surface' elevation changes at various locations around the buildings to determine how precisely the DEM represents reality. The inset images included in Figure 4 reveal an astonishing level of detail that suggest that quite fine relief change is captured. This includes the


**Figure 1 The three Case Studies in s. Manitoba and n.w. Ontario**




Up: Google Earth image of the Officer's House complex that was the focus of drone flight.

Left: Google Earth overview image of Old Fort William, with the white lines marking the Drone Flight path, and the orange zone marking the area subjected to analysis.

**Figure 2 Fort William Historical Park. Upper image is a detail captured from Google Earth, with the lower image being the entire complex overlaid with the flight plan area.**

edges of planks used to create a raised garden, the declining height of firewood stacked in rows near the summer kitchen, and also overturned pitch cauldrons adjacent to the canoe shed (Figure 4).

Figure 5 is a 3d model of the structures in question. Such models can be rotated and re-scaled on screen in order to view the subject area from different perspectives, and can even be reproduced using a 3d printer. While close examination of Figure 5 reveals some distortion of vertical surfaces, this could be addressed by adding more images to aid the modelling process. While the analytic value of such 3D models is not immediately obvious, its site interpretative and education value is readily evident.

**Lowton Site**

During the 1990s and early 2000s research led by Dr. B.A. Nicholson of Brandon University focused on the investigation of several southern Manitoba sites thought to represent the northerly limits of Plains

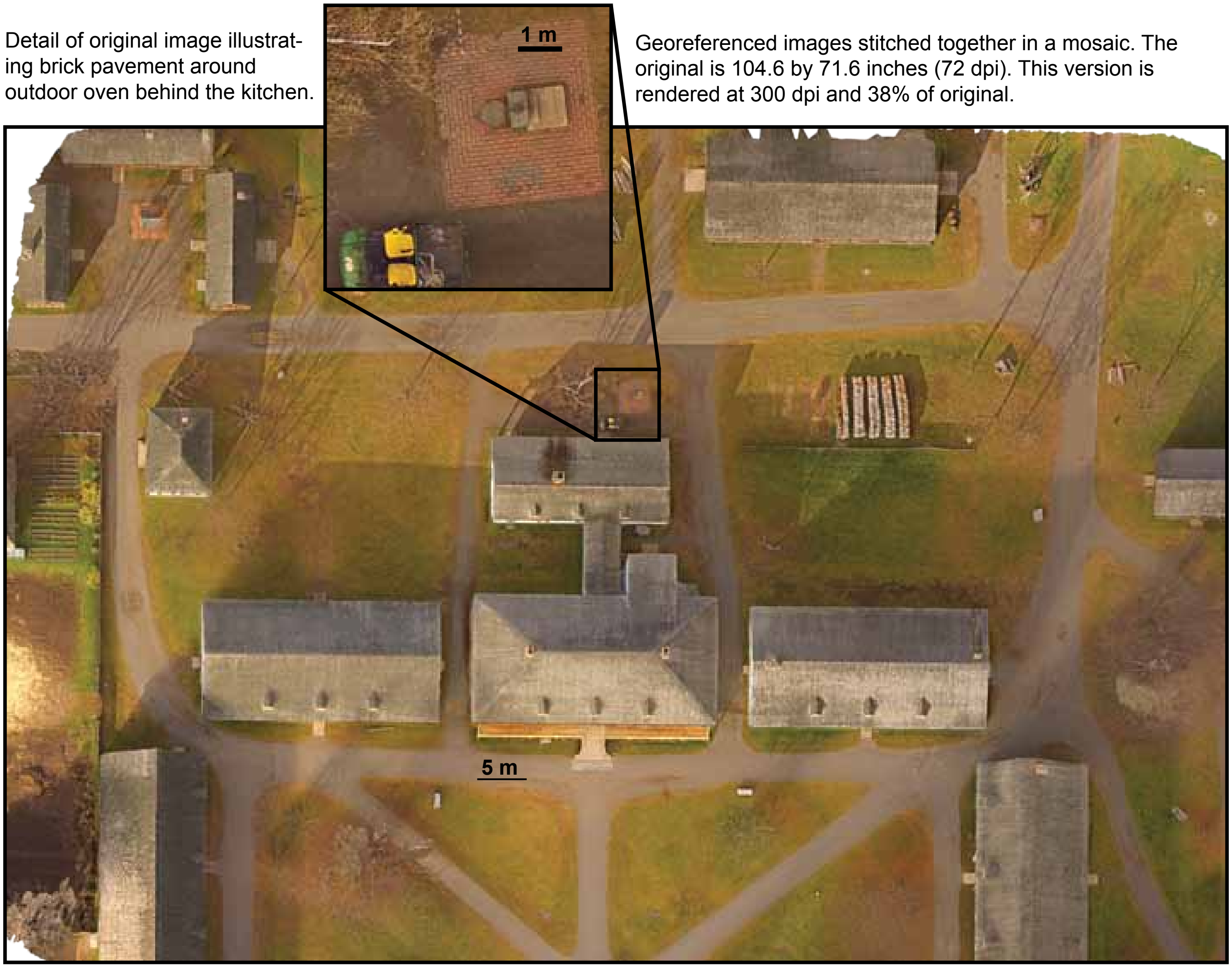



**Figure 3 Photo mosaic of the Officer's Quarters area at Old Fort William. Note the inset detail showing the outdoor oven surrounded by a red brick pavement.**

Woodland occupation. They yielded artifacts suggesting cultural affiliation to groups best known in western Minnesota, Iowa and the eastern Dakotas. These sites are associated with Late Pre-contact populations who practised a mixed foraging and agricultural economy. Nicholson and his colleagues sought to address whether the most northerly of these people persisted in this forager-farmer economy as they migrated into southern Manitoba.

One such site is the Lowton Site, located in an agricultural field along the southern flanks of the Tiger Hills End Moraine (Figure 1, 6) between Ninette and Belmont, Manitoba. Site inspection (coupled with paleo-environmental contextualization based upon historic documents) suggests that the locality was at the ecological boundary between forested uplands and rolling prairie-wetland savannah. It was proposed that the south-facing exposures provided suitable growing conditions for Indigenous cultigens, while the surrounding wetlands provided surface water and protection from prairie fires. Remnants of these wetlands are evident in the field (Figure 6). However, the available maps did not represent the site and its environs in sufficient detail, leading Hamilton to undertake topographic mapping (Figure 7). This was done over the course of a week using conventional field survey methods (theodolite, laser level, etc), with several more weeks invested to generate the contour map and then render it as a Digital

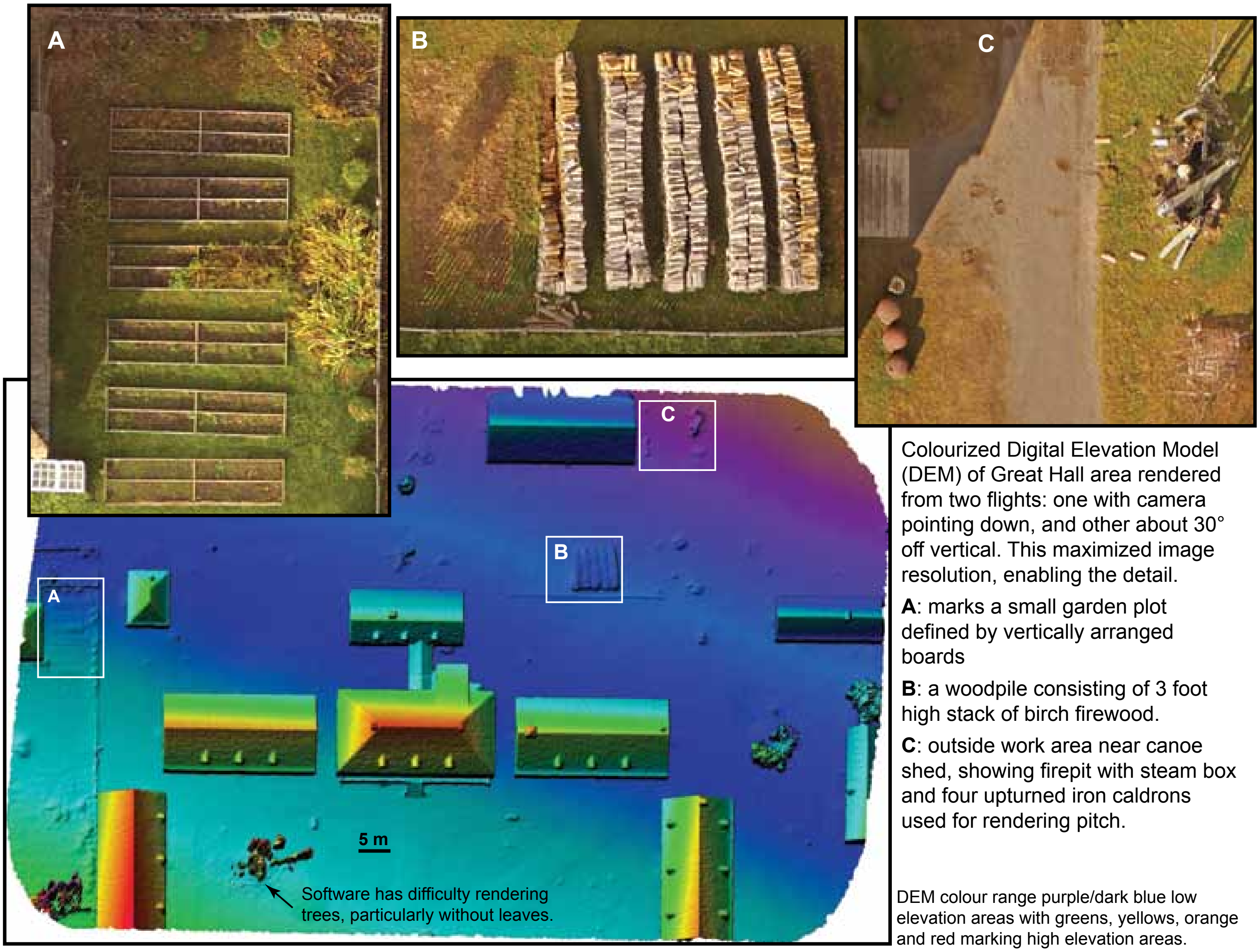



**Figure 4 Digital Elevation Model of the Officer's Quarters area, with detail zones A, B and C showing the actual photo coverage.**

Elevation Model (DEM). The output effectively represented the site area upon a ridge extending south from the main Tiger Hills upland (Figure 7). This ridge is surrounded by internally draining lowlands that historic records indicate once contained water and supported wetland vegetation. This map supported our interpretations, but at a significant cost in field and lab time for data collection and processing. The drone flights sought to determine whether aerial mapping could produce results consistent with the ground mapping, and if so, whether it offered a more cost-effective alternative for site documentation.

Two flights of about 14 and 16 minutes each were conducted at 40 metres elevation, with 80% overlap between adjacent images (Figure 6). This generated 380 images that were uploaded to the photogrammetry service for processing. The latter was completed in about 4 hours, and the output was then downloaded for viewing and analysis. The documentation occurred in early June and the canola crop (broad leaf) was already sufficiently advanced to obscure the ground surface. Figure 8 represents the image mosaic with relevant topographic and excavation grid information overlaid on top. It is severely downscaled in order to permit conventional printing.

Figure 9 presents the Digital Elevation Model deriving from the photogrammetry, again overlaid with the original contour lines and other site information.

Two flights with different camera orientations provided enough data to render this 3D model. It can be spun, re-scaled and viewed from different perspectives to provide a sence of perspective. Continued research is required to determine whether the Z axis is accurately represented.

**Figure 5 3D model of Officer's Quarters at Fort William.**

When comparing Figures 7 and 9, the general relief trends are consistently represented. However, subtle differences are observed when considering localized knolls and depressions upon the ridge. Some are not effectively represented in the drone-generated DEM, while the south-western corner of the DEM in Figure 9 (shaded yellow-orange) is not the highest point on the site. The contour lines demonstrate that other ridge surfaces are actually higher, but are not appropriately colour-coded (green instead of yellow-orange) (Figure 9). Close examination of the south margin of the field also demonstrates that the DEM is incorrectly interpreting tall grass and shrubs growing along the fence line as a topographic high (Figure 9). The nearby high relief area in the field (incorrectly shaded yellow-orange) is likely exaggerated due to differentially lush crop growth in that area. These are important considerations when undertaking site characterization using remotely sensed data. Ground truthing of the output is important for appropriate interpretation. That said, the 2-3 weeks required for the original efforts at field data collection, processing and map production was reduced to less than one hour of drone flying time, with about 4 hours for data processing.

### Brockinton Site

The Brockinton Site is located along the east bank of the Souris River, about 10 km south of Melita, Manitoba (Figure 10). Dr. E. Leigh Syms investigated this site in 1971, and documented stratified Late Pre-contact deposits representing a succession of communal bison kills. It is currently being re-investigated by Kevin Brownlee of the Manitoba Museum, and he notes substantial bank erosion, resulting in significant loss in Syms' excavation area, coupled with exposure of new deposits along an extensive downstream cutbank.

Syms interpreted the site as a communal bison kill, with animals being driven from the open rolling

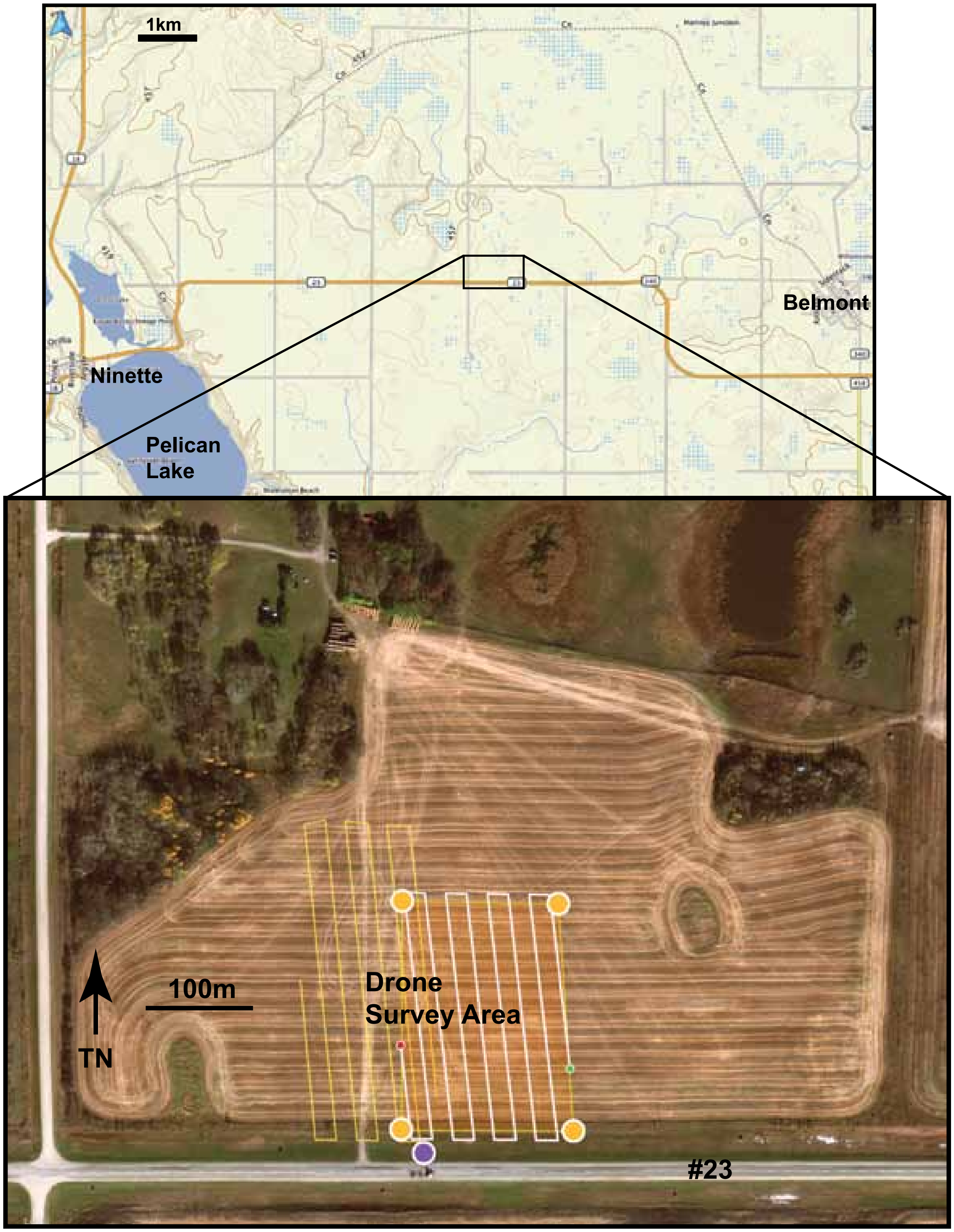



**Figure 6 The location of the Lowton Site. The satellite image shows the agricultural field containing the site, with the two flight missions used to document it.**

plains towards the Souris River bank. As the animals approached the valley wall, they were likely stampeded down dry gullies and into the forested river bottom, where the pound and hunters waited in ambush. Successive layers of cultural material divided by sterile flood silt demonstrate the utility and effectiveness of this trap location. A drone flight was undertaken in the fall of 2016 to assess its utility for routine monitoring of threatened sites, and to augment and update 45 year-old site plans and sketch maps. Figure 10 contains a Google Earth satellite image overlaid with the flight plan. The satellite image dates to a spring flood episode, with much of the lower terrace containing the archaeological deposits submerged.

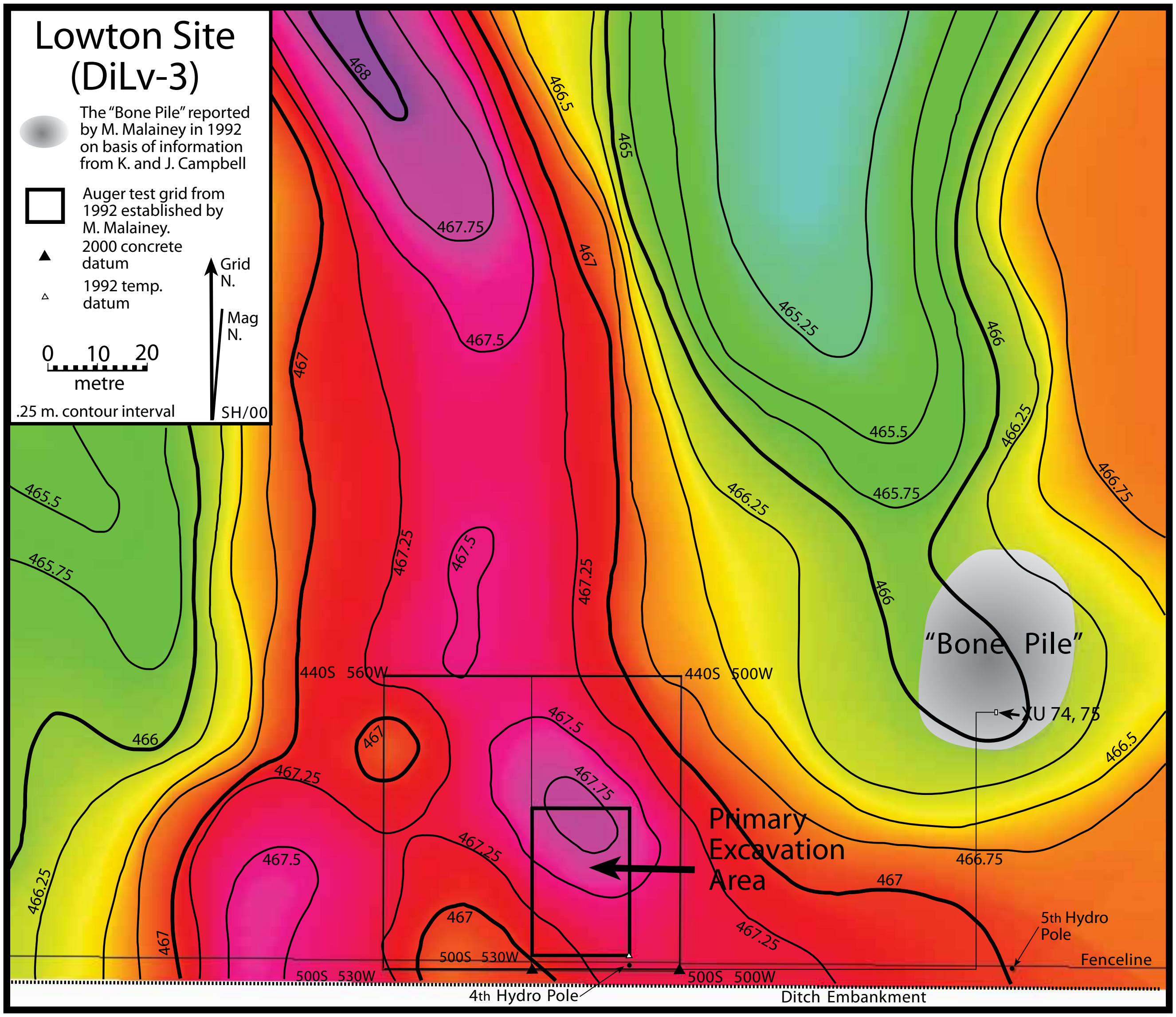



**Figure 7 Topographic map of the Lowton Site constructed using conventional survey methods. The topographic information was then digitized and integrated into a GIS where the data was used to produce a Digital Elevation Model.**

A brief flight (7.5 minutes) was conducted at 40 metres elevation and with 80% image overlap. The flight generated about 140 images that were processed through the photogrammetry service within 3 hours. The image mosaic is represented in Figure 11, with the digital elevation model presented in Figure 12. Syms' original 1971 sketch map was re-scaled and re-oriented and then laid on top. When one zooms in to examine details of the original mosaic output, the eroded plastic sheeting lining Syms' excavation pits is evident. Syms' sketch map represented the valley using hatched lines to denote the slopes and dry gullies. This was likely conducted with a compass and 30 metre tapes, and such approaches remain common for early stage site documentation. While often sufficiently accurate to schematically represent sites and their context, they are vulnerable to scale distortion and error, particularly in forest situations. When the original sketch was overlaid on the drone output, it fit surprisingly well. Of particular interest here is that the drone enabled collection of mapping data over a more expansive area in less than 10 minutes of field time. It also permitted effective map annotation that relocated the original excavations, the position of Brownlee's subsequent salvage efforts, and

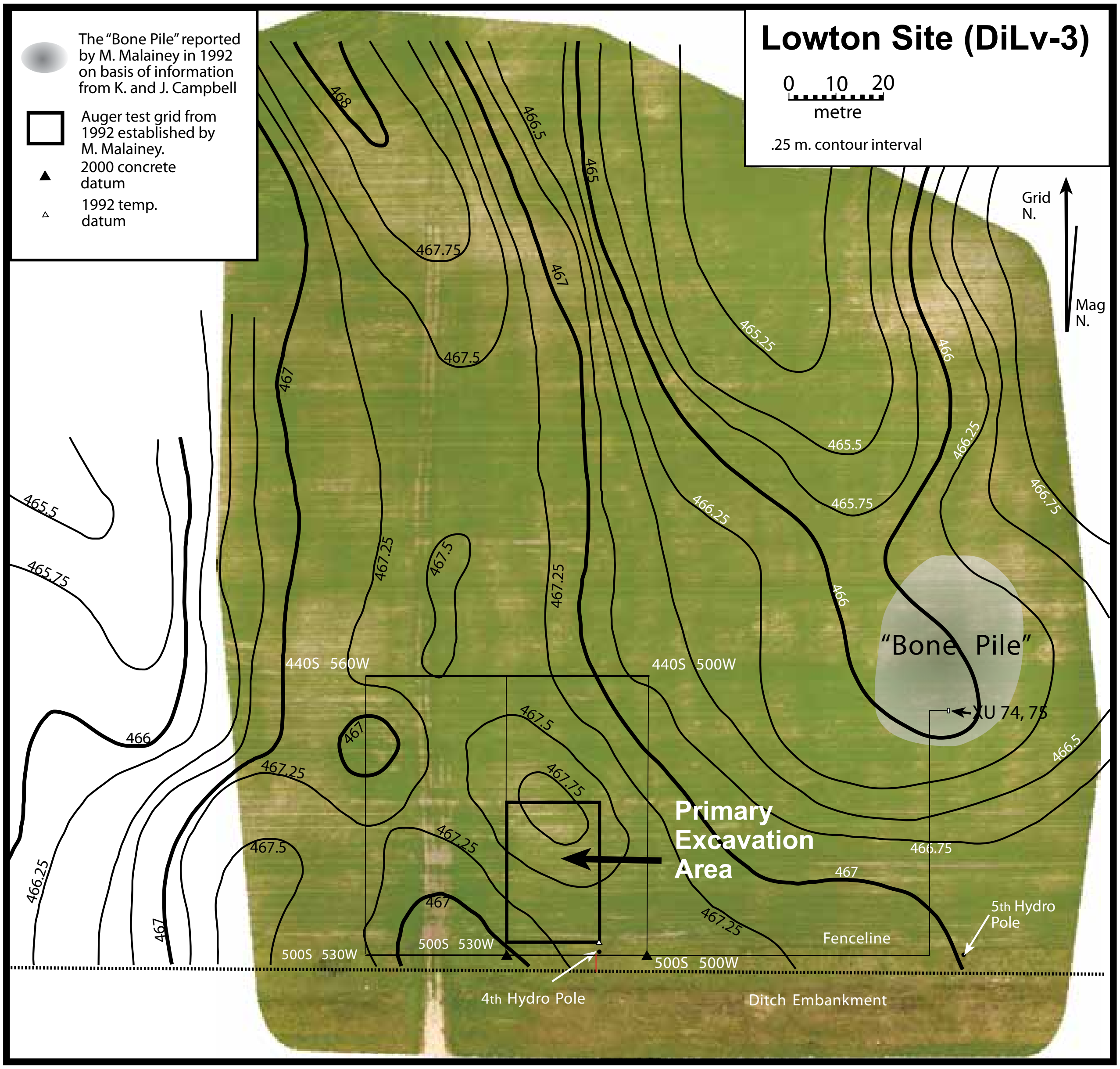



**Figure 8 Photo mosaic of the Lowton Site showing the surface conditions of the field, with the topographic data overlaid on top.**

documented the degree and severity of shoreline erosion since 1971. The planview maps also offer a more intuitive understanding of the site and its locality to support interpretations. Clearly, drone photography offers an effective means of monitoring archaeological sites to aid in Cultural Resource Management decision-making. While we address destruction and transformation from natural processes, the same strategies could be employed to monitor archaeological sites that are vulnerable to ongoing looting and vandalism.

## Conclusion

These case studies represent diverse situations to illustrate the research potential of drones. While recreational use is described as straightforward, operational flying to support aerial mapping and photogrammetry research is a different matter. Drone photography and computer-aided photogrammetry are affected by lighting conditions, camera exposures, aircraft speed, wind and temperature, and other conditions. Managing these variable conditions to achieve useful results is a matter of experience built up through trial and error.

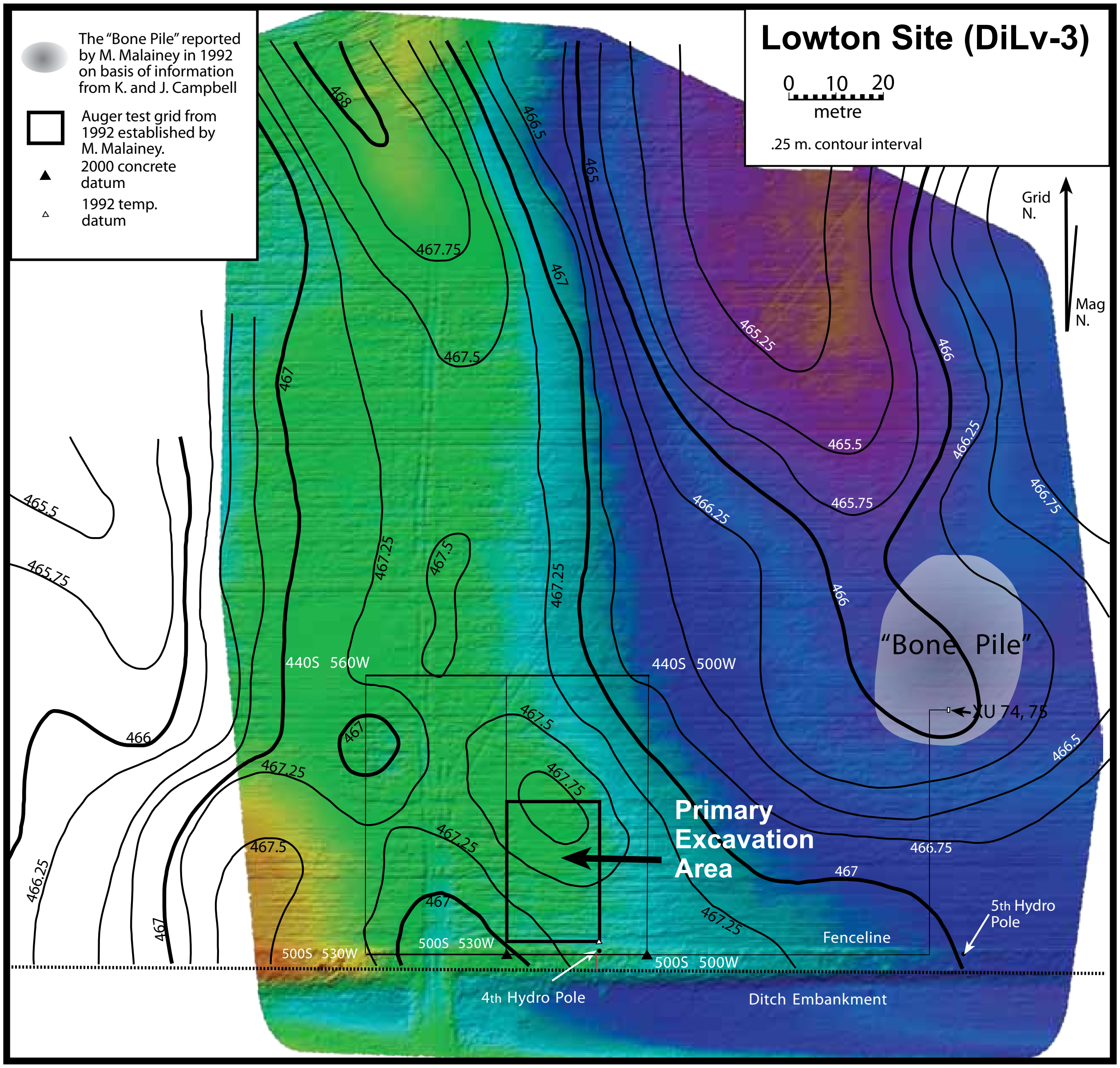



**Figure 9 Digital Elevation model of the Lowton Site derived from drone imagery.**

One consideration is the short flight duration of these battery-powered craft (ca. 15 to 25 minutes). Manual flights are challenging, particularly while simultaneously maintaining the optimal position, monitoring the telemetry information, and framing and photographing the areas of interest. Semi-autonomous flight plans significantly improve efficiency and data quality. The flight paths, elevation, speed and the percent of image overlap are all specified prior to the flight. This flight information is stored on the tablet for upload to the drone at flight initiation, whereupon it is automatically executed. Such flight plans can also be repeatedly used under different light and weather conditions, or at intervals throughout the season. Repeated flights can also be undertaken to document phases of archaeological excavation. As the images collected from such missions are standardized, photogrammetry quality is optimized.

Image resolution is a matter of camera quality and the elevation of the flight. The drone images featured here were taken with a 12 megapixel camera. At 40 metres elevation, this provides an estimated image resolution of 1.7 cm per pixel. As we generally fly missions at a slow speed (2 metres/second), sharp and well-exposed images can be generated even in comparatively low light. This allows detection and representation of quite small ground features, but the image mosaics are quite

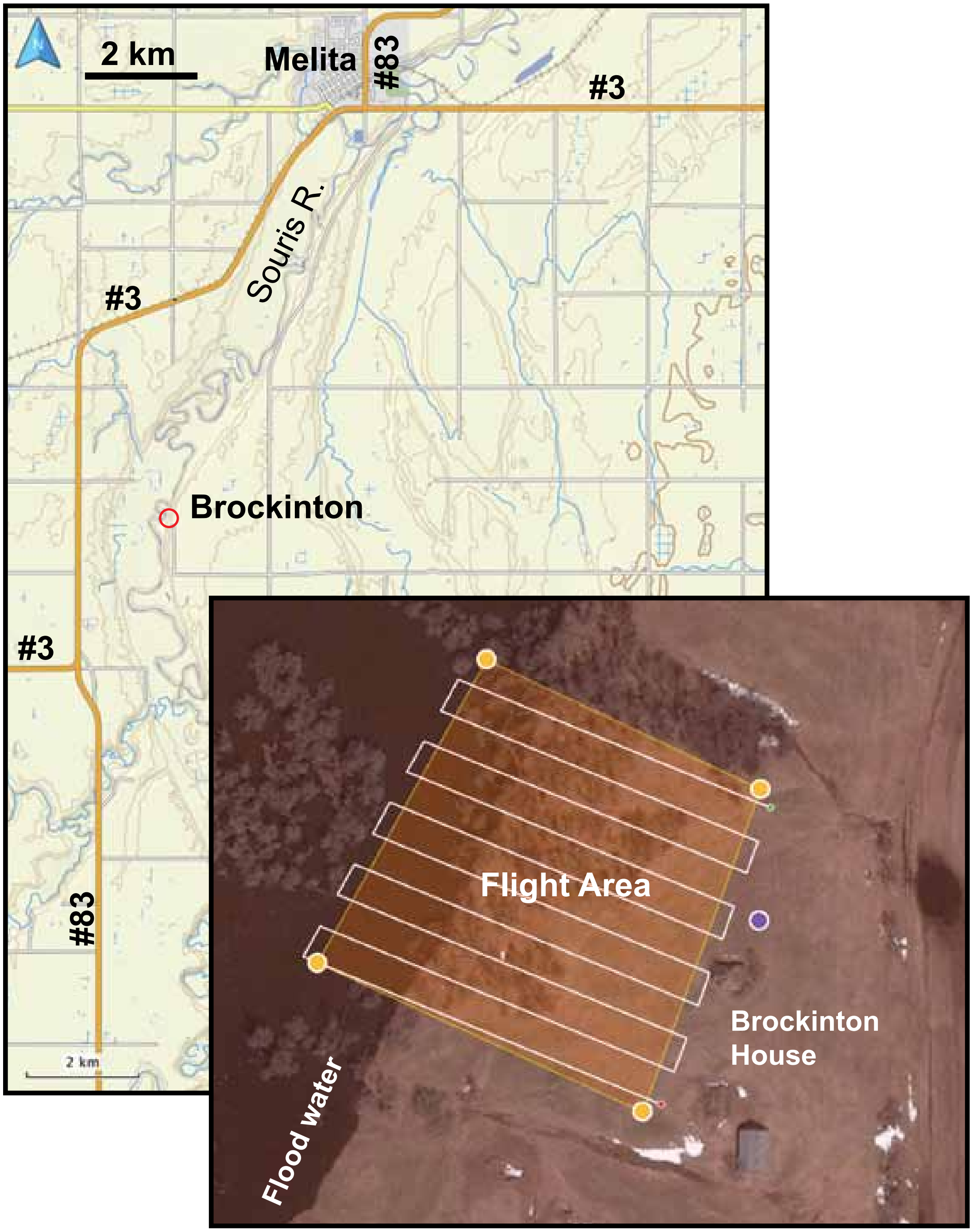



**Figure 10. The location of the Brockinton Site, with the inset satellite image recording site area during a spring flood, and with the flight area.**

large. The original mosaic of Fort William is 118 by 75 cm in size (92 MB), the Lowton Site mosaic is 164 by 194 cm (387 MB), and the Brockinton Site mosaic is 135 by 140 cm (151 MB). Such large files are difficult to view except on a large computer screen, with details only becoming visible after zooming in. Their use in printed reports requires significant downscaled, with attendant loss of detail. It remains a cartographic challenge to find balance between expansive coverage versus representation of details. One approach has been the use of inset photos of details as presented in Figures 3 and 4.

The rendered images are precisely registered in Cartesian space (decimal degrees) and can be immediately uploaded into GIS projects. In effect, such low elevation mosaics can be treated as accurate site plans

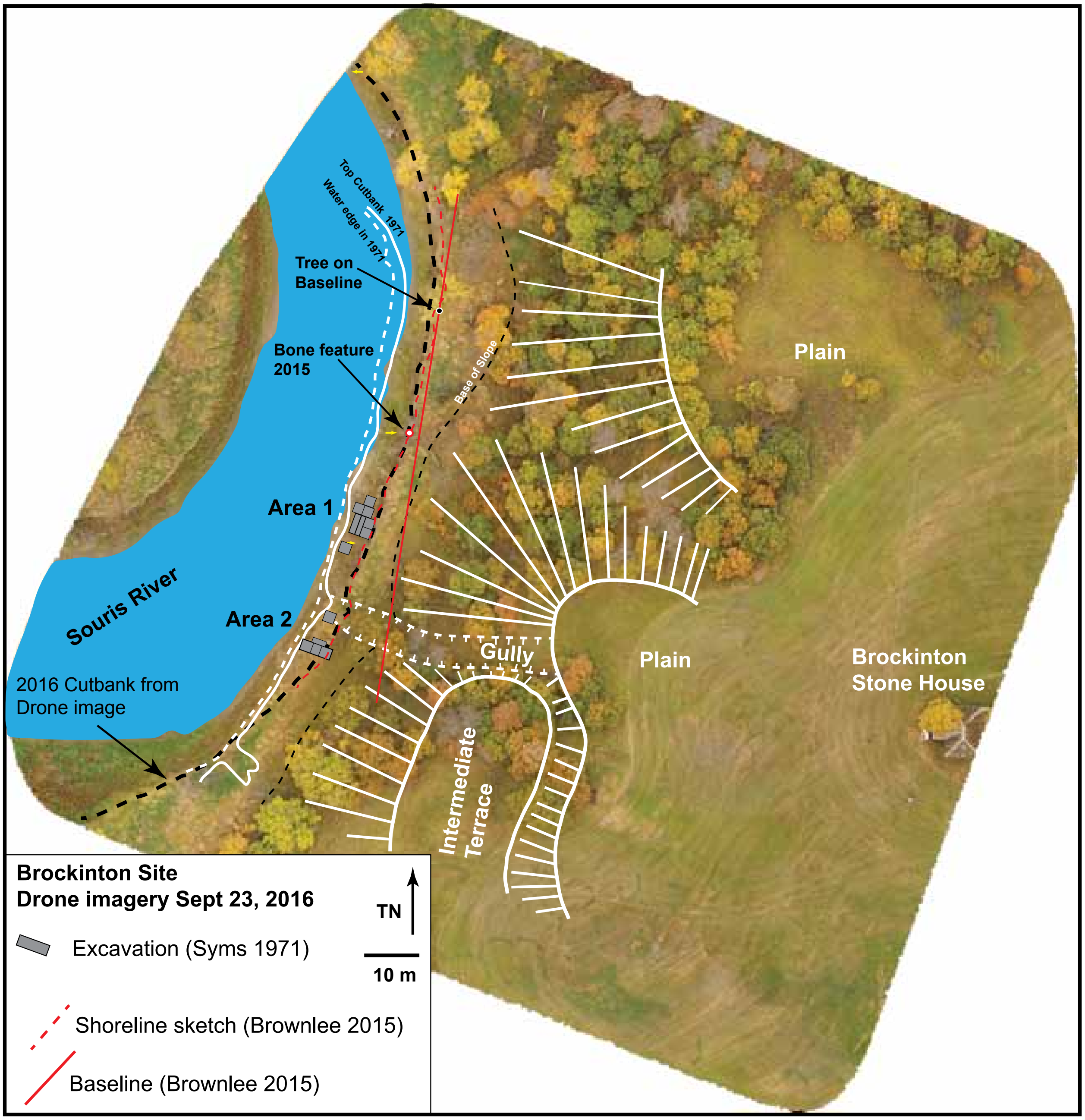



**Figure 11 Photo mosaic of the Brockinton Site overlaid with Syms' 1971 site sketch map and annotated with recent field observations.**

upon which other thematic information can be overlaid to aid in site documentation (see Figure12). While evaluation of precision and accuracy of the digital elevation models is ongoing, within the limits discussed with the Lowton Site, surprising consistency has been observed at several sites where 25 cm contour interval site maps have been compared to the drone output. Improved flight times coupled with semi-autonomous flight plans involving multi-battery missions enable high resolution mapping of comparatively large areas around the site of interest. This offers considerable promise for high quality large-scale mapping to aid in site contextualization and landscape archaeology. These possibilities are currently being explored with other 'case study' sites.

Better quality consumer grade drones equipped with digital cameras range between $1000 and $1800. Auxiliary equipment includes spare parts, extra batteries and sd cards, lens filters, transfer cases and tablets, while other costs include liability insurance, repairs and post-crash replacement equipment. Rapid techno-

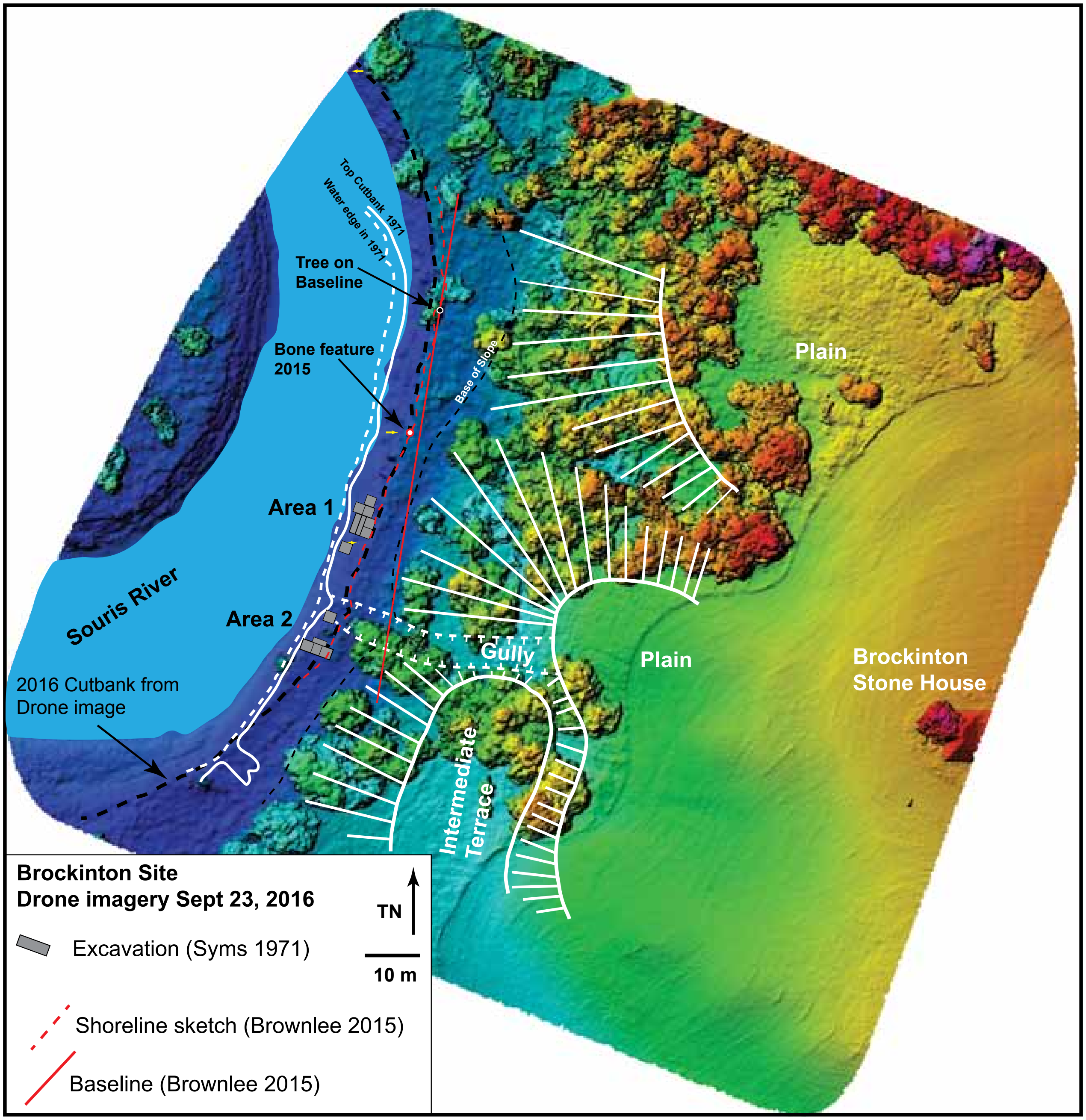



**Figure 12 Digital Elevation Model of the Brockinton Site overlaid with Syms' 1971 sketch map.**

logical development and successful consumer marketing has fostered improved equipment capacity coupled with declining purchase price. Not unlike other electronic equipment, drones rapidly become obsolete. This raises important questions whether such technology offers a research return that justifies the financial investment. Perhaps the best way to answer this question is to consider the real costs in equipment and personnel time associated with collection of comparable cartographic data using conventional approaches. This demonstrates the 'value' of drone photography in sharply reducing time and personnel costs for site documentation.

## References


Hamilton, S and J. Stephenson
2016 *Testing the utility of UAV (quadcopter) aerial photography and photogrammetry for archaeological documentation*. Electronic discussion paper available at https://www.researchgate.net/publication/299503960_Testing_UAV_drone_aerial_photography_and_photogrammetry_for_archaeology.