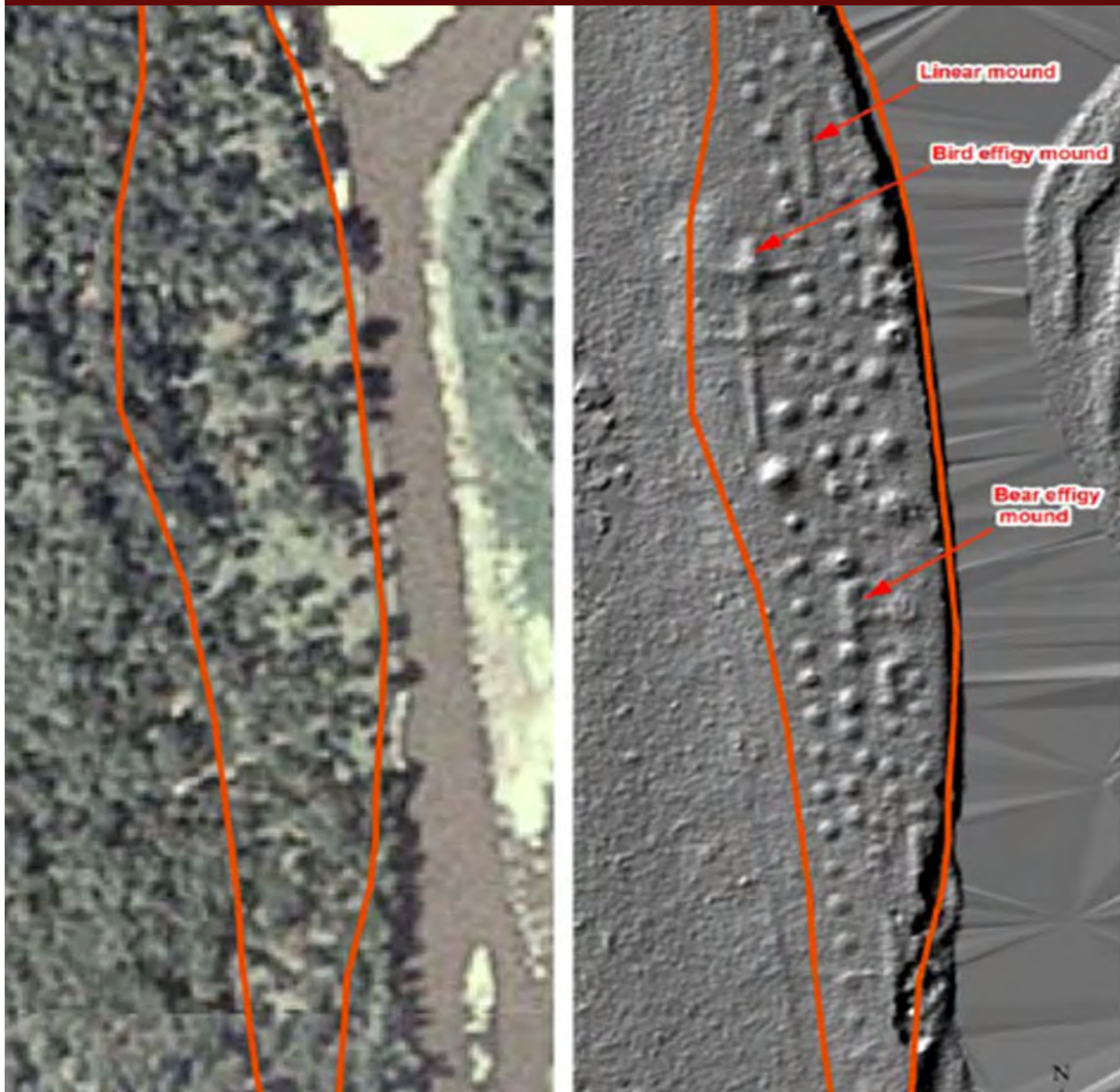




LiDar Surveyor: Automated Extraction of Archaeological Features from Light Detection and Ranging (LIDAR) Imaging Data | 2012-07

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LiDAR Surveyor: A Tool for Automated Archaeological Feature Extraction from Light Detection and Ranging (LiDAR) Elevation Data

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Executive Summary

Burial mounds, nationally significant features of prehistoric cultural landscapes, are detectable in high resolution topographic data obtained by Light Detection and Ranging (LiDAR). LiDAR measures the time the laser pulse is emitted and returned from any surface it encountered such as buildings, tree branches, cars and ground surface and calculates elevation values from that data. Like sunlight, the laser pulse can filter through tree canopy in leaf-off conditions and get accurate topology of the ground at a resolution fine enough to detect earthen archaeological features that would not be detectable from high-resolution aerial photography.

A prototype mound detection model was developed by Riley (2009) in order to aid interpretation of LiDAR shaded relief images for prehistoric burial mound sites. The model successfully detected conical mounds and other mound types from bare-earth digital elevation models (BE DEM). However, the model produced many false positives which obscured the marks on true mound features.

LiDAR Surveyor, a software tool developed for this project, also automatically scans BE DEMs created from LiDAR, seeking the symmetrical geometry of conical burial mounds. The present project sought to improve the prototype's accuracy by minimizing the detection of features that do not fit the conical mound morphology.

The tool was tested in 10 areas of interest (AOI) that are located in different landscape settings in Iowa and Minnesota. LiDAR Surveyor decreased the number of marks in the model results by up to 87%. Mounds undetected by LiDAR Surveyor were often objects that did not fit well with the conical mound morphology such as those that had been heavily cultivated, vandalized or partially cut by roads or trails. LiDAR Surveyor detected 59% of the conical mounds at the 28 test sites and detected 89% of the sites overall.

LiDAR Surveyor runs in ArcGIS, the software used by virtually all U.S. agencies and NGOs that currently employ GIS technology for historic preservation. The LiDAR Surveyor tool is packed as an ArcGIS toolbox for use in ArcGIS 10 without having to go through an installation process. An operation manual is included that explains how to load the tool into ArcGIS and explains the graphic user interface developed for each step. The tool and manual is available for dissemination to professional archaeologists and preservationists with permission from the University of Iowa Office of the State Archaeologist. The project report includes best practices in LiDAR data assessment and interpretation.

Introduction

This report presents the results of a project undertaken by the University of Iowa Office of the State Archaeologist (UI-OSA) to develop and test LiDAR Surveyor, a feature extraction model to be used with Light Detection and Ranging (LiDAR) Bare-earth Digital Elevation Models (BE DEM) to identify conical, compound and, to a lesser extent, effigy burial mounds. The primary objective was to significantly improve the processes used by Riley's (2009) prototype model in order to decrease the number of false positive, non-mound features. A second objective was to create a user-friendly graphic interface and operation manual, and make the model available to the historic preservation community in a format that can be run in ArcGIS, a widely-used Geographic Information Systems (GIS) software package.

This project was funded by a Digital Humanities Start-Up grant from the National Center for Preservation Technology and Training (NCPTT), with matching funds provided by the University of Iowa, the United States Geological Survey's (USGS) Earth Resources Observation and Science

(EROS) Center, the Iowa Geological and Water Survey (IGWS), and the Minnesota Historical Society's Office of the State Archaeologist (Mn-OSA).

BURIAL MOUNDS

Between 1000 BC and AD 1200, Native Americans in eastern and central North America interred their dead in earthen mounds (Milner 2004; Silverberg 1991). Construction of these and other earthworks were part of major changes in the demographic, economic, political, and spiritual organization of human culture throughout the North American continent (Birmingham and Eisenberg 2000; Charles 1992). The spatial organization of mounds and other earthworks on the landscape have informed scholars about territorial control (Mallam 1976) and ideology (Charles and Buikstra 2002). Archaeological excavations of mounds, although rarely conducted today, have provided important insights into prehistoric demography, diet, and pathology, through the osteological analysis of the human interments (Buikstra 2006). In addition to their significance to the humanities, burial mounds are venerated by Native Americans, whether or not they trace their ancestry to the mounds' builders (Green et al. 2001).

Mounds are also among the nation's most threatened archaeological sites. Mounds tend to concentrate along major rivers, where many of the nation's largest, most rapidly expanding cities are found. Mounds, because of their distinct size and shape, are easily found and therefore vulnerable to vandalism. Despite their importance, many mound locations are based on poor maps and anecdotal descriptions. In Iowa, for example, 37% of all mound locations are marked as having an uncertain location or boundaries (Riley 2009). Although thousands of mounds have been recorded nationwide, it is likely that thousands more have gone undetected, especially along the rugged, forested bluffs bordering large river valleys, where archaeological survey is difficult.

LIDAR IN ARCHAEOLOGY

Light Detection and Ranging (LiDAR) is an emerging technology with great promise for identifying, preserving, and studying ancient earthworks. LiDAR uses airborne lasers to measure ground surface elevations with submeter accuracy. Federal standards widely used in current data collections specify a maximum DEM vertical accuracy of 18.5 cm root mean square error (RMSE) or 37 cm at the 95% confidence level for equivalent 2 ft contour accuracy, and horizontal accuracy of 1.0 m (National Digital Elevation Program 2004). To achieve 2 ft contour accuracy, a nominal pulse spacing of 1-2 meters is required. Laser pulses penetrate vegetation to obtain "bare earth" elevations on topography, including burial mounds, that is hidden from view in aerial photographs (Figure 1). LiDAR generates huge quantities of x, y, and z point coordinates, determined from the airborne data collection.

In the 1970s, the U.S. military began developing laser profiling techniques that laid the groundwork for LiDAR. Early commercial use of LiDAR began in the early 1980s, but the airborne, large-area scanner systems like those used today did not become available until the mid-1990s. Over the past 15 years, government agencies have begun to fund large scale LiDAR collection. This increase in LiDAR collection is driven by advances in the accuracy and speed of airborne scanners, and also by increases in the processing and data storage capabilities of desktop computers and servers.

Federal, state, and local governments increasingly use LiDAR for floodplain mapping, watershed management, and land use planning. States with burial mound sites such as Pennsylvania, Louisiana, Florida, Minnesota and South Carolina are currently acquiring multi-county to statewide LiDAR coverages; Iowa, North Carolina and Ohio have completed statewide coverages (Iowa Department of Natural Resources 2012; North Carolina Flood Mapping Program 2012; Ohio Statewide Imagery

Program 2012). For national coordination of LiDAR acquisition, USGS-EROS has established the Center for LiDAR Information Coordination and Knowledge (CLICK).

Airborne LiDAR is extensively used in European archaeology, primarily for the detection and mapping of large-scale structures such as stone monuments, castles, hill forts, villages, and fields (e.g., Barnes 2003; Challis 2006; Devereux et al. 2005). Airborne LiDAR is as yet little used for archaeological purposes in the United States. Harmon et al. (2006) employed LiDAR images to study historic landscaping of two 18th century plantations in Maryland, identifying low relief features such as abandoned garden terraces. Gallagher and Josephs (2008) identified 32 potential archaeological sites in LiDAR-based shaded relief images from Isle Royale National Park, Michigan. Field survey confirmed 25 of the 32 as archaeological sites. In Ohio, Romain and Burks (2008a, b) used LiDAR to detect a 2,000 year old road, remnants of which were preserved in a wooded area as two parallel, 30-cm-high embankments rising above either side of the path. Riley (2009), Riley et al. (2010), and Whittaker and Riley (2012) successfully used LiDAR to detect low-relief burial mounds in Minnesota and Iowa. LiDAR identifications were confirmed by comparison to existing maps of known mound sites, as well as field checking and total station mapping.

To date, archaeological applications of LiDAR have relied primarily on visual interpretation of shaded relief image. Using a process called hillshading, the angle and direction of lighting creates “virtual sunlight” that can be used to enhance low-relief features. Visual scanning of shaded relief images, however, is time consuming and relies on the analyst’s experience and training, as well as the quality of the LiDAR images themselves (Gallagher and Josephs 2008; Riley 2009).

Riley (2009) successfully tested an alternative method of detecting burial mounds. She developed an automated tool to perform calculations on BE DEMs, identifying features that have the geometric parameters of conical mounds. The private and public sectors have developed many such feature extraction applications for purposes ranging from measuring and extracting building footprints, to mapping vegetation communities by measuring vegetation height and density (Mass and Vosselman 1999; Hewett 2005; Opitz et al. 2006; Maune 2007; Dilts et al. 2010). These methods, however, were not created for detecting archaeological features, and current, commercial software (e.g., LIDAR Analyst® by Overwatch Geospatial; QCoherent LP360 Extractor) cannot be adjusted to detect features like small burial mounds. ERDAS Imagine Professional, a widely used remote sensing package, has tools that identify abrupt but subtle changes in topography. These edge detection algorithms can be used to highlight the edges of large mounds, but also mark other kinds of edges such as stream banks and bluffs. The algorithms available in the ERDAS product cannot delimit small, low relief mounds.

LiDAR will eventually be available for most of the United States, and because most of the data will be government-acquired, it will be available for use by the public, as it currently is in Minnesota and Iowa. Mounds are readily visible in these data which increases the vulnerability of mounds, but it also provides an unprecedented opportunity to locate undiscovered or poorly mapped mounds. LiDAR Surveyor was developed as a method for automated processing of LiDAR data that can be implemented in ArcGIS, a widely used Geographic Information System (GIS) software package. It is intended to help federal and state agencies, especially those with large land holdings, to identify mound-like features to guide land use planning and archaeological survey prioritization.

LIDAR SURVEYOR PROTOTYPE

Riley (2009) developed the initial prototype for LiDAR Surveyor recognizing that visual scans of shaded relief images over large areas can not only be time consuming, but the shaded relief image itself may be insufficient to detect all burial mounds that may have been detected by LiDAR. The model focused on detecting conical (domed-shaped) burial mounds by applying an automated string of

geospatial analysis tools in ArcGIS to search BE DEMs for the round shape and constrained ranges of height, diameter and slope that are characteristic of that mound type. Conical mounds are the most common kind of burial mound in North America. It was also anticipated that other mound types that incorporate conical mound morphology such as the bulbous ends of linears, heads and rumps of bear effigies and the conical portions of compound mounds may also be detected. The LiDAR Surveyor prototype successfully detected all four types of burial mounds (Figure 2). Tested in three physiographically different landscapes in northeast and southern Iowa, the model detected 90% of all field-verified mounds that could be detected in shaded relief LiDAR images. However, the high detection rate was at the expense of the model results producing a high number of false positives triggered by natural and man-made features, widely distributed across the landscape (Figure 3). Riley (2009) concluded that the mound detection model, used prior to field survey, could benefit survey by reducing the area with potential mounds to less than 0.4% of the total study area, but that further work was needed to reduce the amount of false positives.

Methods

ASSESSING PROJECT DATA

Lidar data generation involves several processes between flight mission and viewing a shaded relief image (Figure 4). Initial processes of data collection and compilation at the top of Figure 4 introduce minimal horizontal and vertical error; but for detecting small archaeological features ground point density is paramount. The time of data collection is the first factor that can have an impact on the utility of the LiDAR dataset for archaeological prospection.

After the elevation and positioning data from the flight mission is downloaded and compiled, the output is a virtual 3D world of points. The point cloud represents all the objects or ground that the laser reflected off of during the flight mission (Figure 5). The processing steps after assigning the projection to the point cloud can also have great bearing on whether archaeological features would be detectable from the dataset. Sorting and filtering data points is largely an automated process relying on good algorithms and adroit technicians for accurate classification of points into ground and non-ground categories. The process of rasterization may affect the visibility of an archaeological site and diminish some of the details. There is also the chance that the LiDAR data collection was never intended to produce 1 m BE DEMs and may not be suitable for archaeological prospection.

Time of Flight Mission

The time of year the flight mission took place will have great impact on the quality of bare-earth point density in forested areas. In order to adhere with current federal guidelines for bare-earth accuracy, the flight missions should take place shortly after snow melt when the dead understory vegetation is still packed down and before new understory and canopy vegetation leafs out.

However, past studies have found that LiDAR vendors have sometimes collected data over forested areas during bud-out or leaf-out conditions (Riley 2009; Riley et al. 2010). Some of these datasets were collected before the current guidelines were in place, but the resultant data still did not adhere to the less-stringent contract specifications. For instance, Riley (2009) found that the vendor collecting data for the Iowa statewide project was collecting data in predominately cultivated areas during leaf-out or bud-out conditions in one of the study areas (Figure 6). The ground data in the greenbelt of a major river and forested areas of streams were poor quality because the canopy and understory vegetation blocked the laser light from reaching the ground. The vegetation points, errantly unfiltered in post-flight processing, created a bumpy surface not usable for interpretation either manually or with a mound detection tool (Figure 6). The faceted surface in Figure 6 indicates sizable gaps between ground points large enough to skip over any signature of a burial mound.

The vendor circumvented the intent of the 90% leaf-off contract specification through semantics of the definition of leaf-off. They maintained that they were in compliance because only 10% of the vegetation points were left after filtering; even though the number of vegetated points to start with was enormous because they collected leaf-out. Most of the collection area was “leaf-off” cultivated ground, and so it also did not matter that the vegetated area was leaf-out because it did not consist of over 10% of the total area collected in the mission. Regardless of the semantics, if the shaded relief for the area of interest (AOI) displays a lot of little bumps or facets then the data is likely not suitable for archaeological prospection and the BE DEM should not be used with LiDAR Surveyor.

Post-Flight Processing

At the sorting stage there are millions of points without any classification associated with it. The laser system records every echo (return) it receives which can be rooftops, branches, leaves, towers, vehicles as well as ground. They need to be sorted so usable data can be created specific to the project.

Software with the lidar system, proprietary software developed by the consultant, or commercial software is implemented to classify points as ground or non-ground. This is the automated method of classification, or rather semi-automated method as some human intervention is necessary for QA and control over systematic errors. Algorithms have also been developed to sort out outliers caused by birds, atmospheric effects such as dust and moisture, systematic range errors and erroneous points caused by very bright objects. Manual sorting may also be implemented, but this added feature is time consuming and expensive and for large projects it is not financially feasible. Additional filter techniques can be used for further classification of non-ground points such as vegetation and buildings.

Filtering algorithms have improved over the years so the accuracy of point classification may not be the same for an older dataset than what is expected in a current data collection. The data can also vary by vendor and among the vendor's subcontractors – so much so that contracts may specify that the same subcontractors be used throughout a large collection project in order to maintain consistency in data quality. Riley et al. (2010) found while using Crow Wing County, Minnesota LiDAR data to locate known, unmapped mounds that classification accuracy was not consistent throughout the county. The classification issues were believed to be correlated to how much leaf-out vegetation there was during collection, which varied from east (flown too late) to west (flown in optimal conditions). It seems that the point classification algorithms were over-classifying ground points as not-ground due to the high density of vegetation points in the area (Figure 7). As a result, large mounds as high as 3 m and 20 m in diameter were wiped clean from the BE DEM, and in turn, deleted from the derived shaded relief image (Figure 8). Ground points on top of mounds in the neighboring field were also misclassified as not-ground, leaving flat-topped, stumped features on the landscape (Figure 9). By using known mound sites in the area as a baseline, one could tell if these problems exist for their datasets. As discussed above, if the issue is caused by too much vegetation during the data collection, then the dataset may not be appropriate for LiDAR Surveyor.

Each ground or bare-earth laser point after the classification process is originally randomly located. They are not evenly spaced exactly to specifications (e.g. every 1 m) in a straight line (Figure 10). To create the data products, not every point may be needed. A nearest neighbor algorithm is implemented that compares elevation values of nearby points to determine if any contribute “new” information or is basically a “repeat” of a neighboring point. Thinning is used to remove the points which are not of interest. These points do not add to the definition of the required object (of course, this does not take in consideration microtopographic features of archaeological sites) but thinning laser points helps speed up post-processing.

After thinning, the points are gridded to create Digital Elevation Models (DEM) (Figure 10). Iowa and Minnesota's rasters used in this project were originally processed as 1 x 1 m grid cells; this can be done using several interpolation methods but the most common is Inverse Distance Weighted (IDW). Regardless of the interpolation method, only one elevation value can be assigned to a cell but there may have been more than one elevation point in that cell location. IDW is also a non-exact interpolation method meaning the cell value in the DEM is not equal to the value of a point that resides in that grid cell's extent. Some grid cells may not have had a corresponding point at all and was assigned the value based on nearby points' values.

The rasterization process can have a smoothing effect on the topography which is desirable for many surface modeling applications, but may make prospection of plowed down archaeological features very difficult. If all of the ground points were retained in an ASCII or LAS file, the interpreter can determine if the ground points are dense enough to create a finer resolution BE DEM for site prospection with an exact interpolator such as Spline, instead of an inexact method like IDW. However, LiDAR Surveyor is not designed to locate mounds that are plowed nearly flat. The cut-off is mounds with 3° slope because lower slope values become nearly indistinguishable from the

surrounding ground adjacent to the mound terminus. For locating sites in heavily cultivated areas, manual interpretation using vertical exaggeration of a BE DEM in a 2.5D or 3D setting with a dynamic lighting functionality (such as ArcGIS 3D Analyst extension) is very effective. Geovisualization of the ground points with vertical exaggeration may also be as beneficial.

The Intended Use of the Data

LiDAR datasets can vary greatly based on the intended use or deliverables sought after by the client. For instance, Scott County, Minnesota LiDAR data was collected in 2003 for the sole purpose of creating smooth 2 ft contours (Riley et al. 2010). The entire point cloud was not retained because Scott County's primary intention was to acquire a 2 ft contour file. It was up to the vendor for the method of how to acquire the elevation data and the Scope of Work (SOW) did not implicitly state that all of the points would be delivered, so they were not. In order to create smooth contour lines, point cloud data classified as ground was heavily thinned to retain only points that represent a set threshold change in elevation over a small distance. Unfortunately, there was no metadata about the dataset and no institutional memory of what kind of data was retained and delivered. As a result, a project for the Minnesota Historical Society where the data was to be used to locate precise mound locations turned into an example of just how sparse data can be before it is ineffectual in locating mounds (Figure 11). Unfortunately, many early county collections follow a similar scenario, but lessons have since been learned about retaining all of the point cloud data for possible later applications. Point datasets that have undergone heavy thinning for contour file creation are not suitable for creating 1 m BE DEMs for the purpose of using the LiDAR Surveyor tool, and are also difficult to use for visual interpretation and are minimally effective.

Statewide data collection projects may collect data at a density suitable for 1 m BE DEMs, but the rasters may not be available to the public at that resolution. Minnesota offers their statewide collection in county geodatabases over the internet which include a 1 m shaded relief image raster and 1 m BE DEM. Iowa serves 3 m BE DEMs via download at the Department of Natural Resources' (DNR) Natural Resources Geographic Information Systems Library (NRGIS); however, 1 m BE DEM and shaded relief datasets are available by request from the DNR-IGWS. Ohio publicly offers DEMs in 2.5 ft resolution and in North Carolina 20 ft resolution. The variance in resolution is largely due to the resources available to store and serve the data; 1 m resolution datasets can take a lot of storage space and can take quite some time to download. The resolution also varies by the state's needs and required deliverables. The statewide LiDAR projects, however, are collecting data largely following similar specifications for floodplain mapping as set by the Federal Emergency Management Agency (FEMA), so the collection density is going to be similar and likely suitable for creating 1 m BE DEMs. BE DEMs at 1 m resolution or finer may have already been created, but are not served to the public. Rasters that are served at a finer resolution than 1 m can be resampled to 1 m to use with the LiDAR Surveyor tool. If the raster resolution is coarser than 1 m, then new BE DEMs will need to be created from the classified points *if the density is suitable to do so*; consultation with the agency in charge of the collection efforts is recommended.

DESCRIPTION OF DATA

Iowa Datasets

The 1 m BE DEMs created from Iowa's statewide LiDAR project are the foundation dataset for identifying mound sites via remote sensing. The collection initiative was a partnership of the Iowa DNR with the Iowa Department of Transportation (IDOT), Iowa Department of Agriculture and Land Stewardship, Iowa office of the U.S. Department of Agriculture Natural Resources Conservation

Service (USDA-NRCS), Rock Island District of the U.S. Army Corps of Engineers and USGS. The contracted specifications for the vendor, Sanborn Map Company, were as follows:

- GPS baseline every 40 km, every 20 km for Federal Emergency Management Agency (FEMA) spec areas
- 1.4 m sample density
- Vertical accuracy:
 - o bare earth - 18.5 cm RMSE
 - o heavy vegetation - 37cm RMSE
- Absolute horizontal accuracy 1 m RMSE
- UTM Zone 15N, NAD 83 horizontal datum, NAVD 88 vertical datum
- Vertical units in meters
- 90 percent of collected data leaf-off (Young 2007).

Mass point data stored in 2-x-2 km tiles were classified by several vendors subcontracted by Sanborn. The IGWS received first and last return data in approximately 350 mi² blocks of tiles to produce the 1-meter BE DEMs, Digital Surface Models (DSM) and shaded relief rasters using QCoherent LP360 software. The agency is also in the process of creating other derivative files from the BE DEMs; all data, including the mass point data in .las and ASCII format, is available to the public for no fee.

Archaeological site locations are available in a GIS feature class file (Allsitesgeo) stored at the UI-OSA. This file is updated by the Site Records Manager as new sites or modifications to site boundaries come in. Site locations in the site file are coded by whether a boundary and location is known, location is known but boundaries are uncertain, or, boundary and location are uncertain. Mounds were a popular site type for study in the late 1800s and early 1900s, so a large percentage of mound sites were reported a long time ago and have not been field visited or verified since. Site locations from historic field notes can be tenuous because many reference locations are based on features that do not exist anymore such as large trees, fence corners and outbuildings on farms, and many were taken from archival reports with vague or sketchy location information.

Site locations are only required to be reported by drawing the boundary on a USGS 7.5' topographic map and reporting the legal location to the quarter-quarter (QQ) section; although most report to the QQQ or QQQQ section. Archaeologists usually pace out or use a tape measure from a reference point in the field to record the site location. More reports within the last 20 years generally will have a large-scale field map in addition to the topographic map of the site boundary. Location data from earlier archaeological surveys in the 1950s–80s are many times available only by the topographic map. Site boundaries reported to the UI-OSA that had been recorded by GPS coordinates is still unusual, but has increased in the last few years. It was expected that the defined boundaries of a site may not be fully accurate and may not encompass all the mounds in a mound group.

A Microsoft Access database called the Iowa Site File stores a digital record of attributes for each site in Iowa. This, too, is maintained and stored by the UI-OSA and is updated regularly. The database includes information on when the site was reported, if it has been revisited and how the location of the site was derived (i.e. pacing, tape measure, GPS) as well as descriptive information such as site type, cultural affiliation, and artifacts recovered.

A number of datasets were used in post-processing and interpretation of LiDAR Surveyor's results, including 75–100 year-old field survey maps. Other ancillary data were loaded into ArcGIS map documents via the Iowa Geographic Map Server, a Web Map Service (WMS) maintained by Iowa State University Geographic Information System Support and Research Facility. The datasets used were:

- 2004-2009 USDA National Agriculture Imagery Program (NAIP) 2-meter resolution true-color orthophotos.
- 2002 digital 1-meter color-infrared county orthophoto mosaics created by Iowa Department of Natural Resources (IDNR).
- 1990s Iowa USDA panchromatic 1-meter digital orthophotos originally photographed at 1:40,000 scale. Digital data was developed by the USDA-NRCS.
- 1970s Iowa USDA panchromatic 1-meter digital orthophotos originally photographed at 1:38,000 scale. Countywide mosaics were developed by IDNR.
- 1930s and 50s Iowa USDA panchromatic 1-meter digital orthophotos originally photographed at 1:20,000 scale. Countywide mosaics were developed by IDNR.
- Iowa 1:24,000-scale seamless digital raster graphics from 7.5' USGS topographic maps.

The Environmental System Research Institute's (ESRI) ArcGIS Online basemap imagery was also linked into the ArcGIS Desktop environment providing access to 2010–2011 1 m resolution color imagery collected by USDA-NAIP (ESRI 2012).

Minnesota Datasets

The Houston County file geodatabase was downloaded from the Minnesota ftp site which contained a mosaic 1 m BE DEM and shaded relief image (<ftp://ftp.lmic.state.mn.us>). The Minnesota statewide LiDAR data project is following recent guidelines set forth by the USGS (2010); some of the specifications are:

- 1.5 m sample density (first return)
- Vertical accuracy of ≤ 15 centimeter RMSEz
- 1 meter horizontal accuracy
- UTM Zone 15N, NAD 83 horizontal datum, NAVD 88 vertical datum
- Vertical units in meters (Minnesota Geospatial Information Office 2012).

Archaeological site locations in Minnesota are stored as point coordinates in UTM Zone 15N, NAD 27 in a Microsoft Access database. Mn-OSA selected sites in Houston County that had modern survey information where the mounds had been field-confirmed. The coordinates for the selected sites were extracted from the database and a point shapefile of the locations was generated in ArcGIS. The points were then projected into UTM Zone 15N, NAD 83 to match the datum of the other data used in the project. The ArcGIS Online basemap imagery provided by ESRI was also utilized in Minnesota.

PROJECT AREAS OF INTEREST

The AOIs were selected based on the availability of site record information of field-confirmed mound sites to ensure that the models were tested on true conical mound sites instead of errantly determining natural and man-made features that look similar to conical mounds as “successful detections” (Figure 12). Study areas were also selected in various physiographic regions to see if the model results contained more false positives in any particular landscape setting over others. AOIs such as Slinde Mound Group, Effigy Mounds National Monument and site 13LC17 in Lucas County, Iowa were used as test areas for the prototype model and were used in this project as a baseline to measure improvement in false positives with LiDAR Surveyor.

The Paleozoic Plateau physiographic region contains many well-documented mound groups including the Slinde Mound Group and sites in Effigy Mounds National Monument (Figure 12). The

Paleozoic Plateau is known for its high bluffs, bedrock outcrops, deeply entrenched streams, sinkholes and generally rough topography (Prior 1991). The areas where it is too steep for agriculture are primarily forested with deciduous trees. This region was expected to be the most difficult to detect small conical mounds on LiDAR BE DEMs because of the precarious nature of how BE DEM extraction algorithms handle heavily-vegetated and high-relief landscapes (Sithole & Vosselman 2004). The region extends north into Houston County, Minnesota and is described in the state's landscape region GIS file as "dissected bedrock terranes [sic]" adjacent to the level, fluvial plains of the Mississippi River valley (Minnesota Department of Natural Resources 2012).

Pikes Peak State Park AOI is also located in the Paleozoic Plateau, but the AOI extends into the Mississippi River Alluvial Plain region. The alluvial plain is relatively level but can contain terraces, backwater sloughs and oxbow lakes, marking where the river waters used to course through the valley. The unusually wide alluvial plains of the Mississippi River are testament to the large volumes of water the valley carried from melting ice sheets (Prior 1991).

The Southern Iowa Drift Plain is similar to the East-Central Iowa Drift Plain because of the similar glacial history (Prior 1991). The only major difference between the two regions is the Southern Plain does not have bedrock near or at the surface in the form of outcrops, and that landscape feature was tested with the Paleozoic Plateau AOIs. The Southern Iowa Drift Plain region was anticipated as being the most "cooperative" to the mound model because the topography is generally large, rolling hills. The model representing this landscape was run in Lucas County.

Calhoun 1 and 2 AOIs are located within the Iowa landform region known as the Des Moines Lobe. This region is underlain by glacial till deposited during the most recent ice advances into Iowa, approximately 12,000 to 14,000 years ago. Except along major streams, drainage systems are generally not well established. Kettle lakes, eskers, kames, and other features formed by ice wasting and meltwater discharge mark the landscape. Though many wetlands have been drained, the majority of Iowa's natural lakes are located in the region. The Des Moines River and its immediate tributaries deeply incise the till plain, exposing the underlying bedrock in many places (Prior 1991).

The Northwest Iowa Plains and Iowan Surface flank the Des Moines Lobe on either side and share major landscape characteristics. The regions' close proximity to the edge of the ice sheet 16,000 to 21,000 years ago exposed the landscape to tundra and permafrost conditions. What was once hilly landscape was worn down by weathering leaving open rolling terrain. The Blood Run AOI in northwestern Iowa represents these regions.

The Loess Hills landscape is blanketed by extremely thick deposits of windblown silt accumulated during the Illinoian (Loveland Loess) and Wisconsinan (Pisgah and Peoria loesses) glacial episodes within a long corridor adjacent to and east of the Missouri River valley. Loess deposition slowed considerably after approximately 12,500 years ago. The resulting "intricate, finely sculpted Loess Hills topography is a product of the combined effects of wind deposition, erosional processes along entrenched stream systems, and gravity-induced slumping of thick, fine-grained sediment" (Prior 1991:52–54). Severe hillslope and gully erosion, massive valley sedimentation, and stream channel entrenchment during the Holocene have episodically reworked and buried older landscapes. The steep-sided slopes and narrow ridges are similar to the eastern bounds of the Paleozoic Plateau on a macro level. However on a finer scale, the thick, eroding soil creates more prominent gullies, rills and slumping features than what is found in northeastern Iowa. Unfortunately, the potential conical mound test sites with good boundary locations are nearly destroyed by plowing – the model would not be able to differentiate the mound relics from the surrounding ground. Other potential test sites were located in areas where the bare-earth data quality was not suitable for archaeological prospection (Figure 13). The Missouri River Alluvial Plain has historically seen many large channel avulsions resulting in a valley that is overlain by meters-thick historic alluvium or near-surface channel sediments. As a result,

prehistoric sites have been destroyed by the channels, or perhaps preserved in small pockets under deep historic alluvium; no prehistoric mounds are recorded in this physiographic region.

BUILDING THE MODEL

The prototype model focused on finding what features were conical mounds and was limited to seeking features with that morphology. The LiDAR Surveyor model not only searches for conical mounds, but also emphasizes features that are not mounds and had a tendency to trigger false positives with the prototype model. These features are largely fencelines, road ditches, small streams, river banks, edges of erosion control terraces and sudden changes in vegetation. Most of these features, if completely delimited, are long thin segments – very different from the round, compact shape of a conical mound. The new model works to enhance these linear features in order to successfully differentiate them from mounds and exclude them from the model results.

Prototype Model Framework

The prototype focused on the conical mound morphology because it was supposed that other mound types that comprised components similar to conical mounds would also be detected. The prototype was built in the ArcGIS 9.2 ModelBuilder environment and comprised of three geoprocessing segments that were focused on measurable traits of a conical mound (Figure 14). An ideal conical mound will have an aspect from 0 - 360° with a consistent, moderate slope different from the surrounding ground all the way around. The slope angle will not be consistent from edge to the top-center of the mound because the slope levels out as it reaches center, creating a gradual profile instead of a pointed one. The heights of mounds are within a reasonable range, excluding outliers which are from rare, large conical mounds. This metric was used along with slope and aspect to form the foundation of the model (Figure 14). The three major variables used in building the model are reclassified using a numerical system where each variable have values with a different number of digits. Height is single digits, slope is reclassified to the tens place (i.e. 10, 20, 30), and aspect variety is reclassified to integers in the hundreds. Added together, the sum raster contains three-digit values where it is easy to determine what class of each variable has influence on detecting an actual mound and what values should be taken out of the intermediary model results raster.

The other segments of the prototype are used for preparing the BE DEM and cleaning false positives. The segment in green in (Figure 14) fills in sinks which are common with interpolated surfaces and are more numerous on finer-resolution data such as LiDAR BE DEMs (Maune et al. 2007). Flow accumulation is used in the prototype as a mask to preserve all the marks that do not exceed the amount of acceptable water flowing into its location. If the intermediary model result's raster cells were determined to collect too much water to be located on the top or side of a domed-shaped mound less than 13 m diameter, then they were deleted.

The purpose of the Majority Filter segment is to remove thin strings of cells lining stream banks, bluffs and terrace edges and single cells scattered throughout the AOI. The second purpose is to fill in large zones of mound cells that may have sporadic NoData cells within the zones. A zone is akin to a polygon in a vector file; if a zone was less than 10 cells (10 m²) it was considered noise and deleted from the model results (Riley 2009).

Rethinking the Prototype

The prototype model was brought into ArcGIS 10 and updated to make it compatible with the new software version. After a few test runs, it was apparent that something had changed from ArcGIS9x to ArcGIS 10 that made raster geoprocessing less stable in the GRID format. Unfortunately, much of the geoprocessing needs to be done with GRID files. ESRI was consulted and they informed that they

were aware that the GRID format was unstable and their (ESRI raster experts') workaround was to save the geoprocessing results in a geodatabase rather than an ordinary file folder. The old model saved everything to regular file folders, so all of the geoprocessing tools would now have to be redirected into file geodatabases.

The three metrics used in the old model were also further scrutinized, resulting in the conclusion that the height variable did not contribute much more information to the model to distinguish mounds from the rest of the landscape. After comparing results with and without the relief segment, the height variable was dropped from the model.

One of the goals with the new mound detection model was to make the resulting mound marks stronger; many of the mounds in the previous model were marked by just a few cells and were irregularly shaped. One of the contributing factors was using the flow accumulation mask which had a tendency to cut up larger zones into smaller pieces even if the entire zone was a strong mound mark. Flow accumulation would still be used in the new model, but in a different application of the tool. Identifying non-mound edges was another goal of the new model. Instead of focusing only on identifying edges of mounds, the non-mound edges were going to be enhanced as much as possible so they could be differentiated easier from the conical mounds' edges and deleted from the mound results. Finally, LiDAR Surveyor needed to have a simple graphic user interface (GUI), and be packaged and documented in a way to facilitate sharing the tool with others outside of the UI-OSA.

Step 1 Prepare BE DEM Tool

Like the prototype model, LiDAR Surveyor begins with cleaning the BE DEM. Instead of just cleaning sinks, the Step 1 Prepare BE DEM tool also puts the BE DEM through a low pass filter which smooths out noisy areas and minimizes DEM errors such as pits and spikes (Figure 15). The smoothing effect of the low pass filter was found not to be a detriment to the detectability of mounds, and aided considerably in minimizing false positives (Figure 16). Assuming the BE DEM is a floating point raster (the values are decimals) with elevation values in meters, the tool converts the BE DEM into an integer raster with elevation values in centimeters. The raster needs to be in integer format for some of the geoprocessing steps in the main model; integer format rasters are also smaller and can shorten geoprocessing time than if the data is in floating point format. There is an alternate Step 1 in case the user already has a BE DEM with values in centimeters. The output of the tool is used as input data for steps 2 and 3.

Step 2 Flow Accumulation Tool

Flow Accumulation in LiDAR Surveyor is used as a clean-up tool targeted at narrow streams, gullies and roadside ditches. By extracting all the BE DEM cells that accumulate water from over 10,000 other cells, an *ad hoc* stream network file is created for the model (Figure 15). The ArcGIS Flow Accumulation tool was not developed for elevation data as fine-resolution as 1 m, but rather 30 m datasets; therefore, the results are less than perfect. Streams delimiting roadside ditches can end at culvert boxes or at field inlets because the flow accumulation algorithm cannot compensate for flow that goes under the surface feature; it does not acknowledge that the drainage downstream on the other side of the "obstruction" is the continuation of the drainage upstream. As a result, not all roadside ditches are marked with a stream. Very subtle features such as crop furrows can also create false streams, but this can be controlled somewhat by increasing the accumulated cell threshold. The extracted stream file is used to delete anything that is within 10 m of a stream. This seemed to be the most effective distance before getting too close to actual mound sites and unintentionally deleting true mound marks. It works well in deleting any residual marks left at edges of gullies and roadsides where the linear features did not get fully defined and deleted in the earlier stages of the mound detection model. Other stream datasets available to the public, such as the National Hydrography Dataset

(NHD), are not at a scale suitable to use as a clean-up tool for this model. Even with its limitations, the *ad hoc* stream files created from 1 m BE DEMs are the best alternative.

Flow accumulation was part of the main model for the majority of the project. Unfortunately, there seemed to be an unforeseen problem with flow accumulation in ArcGIS 10 where users have been having difficulty running the tool without it taking impractically long to produce a file, or the computer crashes before completing the analysis. The project model suffered the former until consulting with USGS EROS on this issue. After comparing notes, it was determined that the flow accumulation component should be ran as a separate model and saved to a regular folder; saving the flow direction and flow accumulation process to a geodatabase slowed processing considerably. For instance, the Calhoun 1 AOI of 74 km² took 35 hours to run just the flow accumulation portion when it was incorporated into the main model. After separating it out, the flow accumulation component only takes 27 minutes. Fortunately, the GRID stability issue does not seem to plague the flow tools when results are saved outside of a geodatabase. The output of Step 2 Flow Accumulation is one of the inputs for step 3.

Step 3 Mound Detection Model Tool

While testing the performance of different models, it was observed that there is not one best model that can be used for every situation. One model that does well for low-relief mounds in areas with a lot of noise – either because of fluvial landscapes or poor vegetation filtration may not do well with preserving marks for strings of well-formed mounds that are close together on a narrow ridge. Mounds that one model may not have detected were marked heavily by the other model. The final mound detection tool of LiDAR Surveyor contains four models developed for different, yet common, situations (Figure 17). Model 1 is geared towards detecting the less-perfect shaped conical mounds, but at the same time goes through a rigorous feature enhancing and sorting processes. Models 2 and 3 are the most selective models for the ideal conical mound archetype with the domed profile; the models ensure that the ‘perfect’ conical mounds do not errantly get deleted in the cleaning process. They produce the least amount of false positives, but may reject lower mounds that do not have consistent shape all the way around or are blending in with the surrounding gentle slopes. Model 2 is specifically for conical mounds that were built close together (Figure 18). Enhancing mound marks that are close together merged the marks together into one, long shape which then would get deleted for being too large or not being round enough. Model 4 focuses on large mounds that have relatively flat or worn-down centers rather than the dome-shaped profile associated with the conical mound archetype and it does well in flat, noisier surfaces such as tall grass and reed vegetation (which can cause rough surfaces) in fluvial settings.

Before branching out into four models the process begins with extracting features by using slope and aspect. Slope for the model is calculated in degrees and reclassified according to a set of values that were queried directly from the slope raster. The slope of a mound is depicted as annuli, or ‘C’-shapes on the slope rasters created from the BE DEM; distinguishing the mound slopes from surrounding ground was not difficult (Figure 19). Slope values in the old model were reclassified as: 0-5° = 20; 5-12° = 30; 12-90° = 10. Value 30 signifies the ideal slope range for identifying a mound. Value 20 was used as a monitoring range to determine if the classification scheme needed adjustment in the course of building the model. The value 10 range was thought to have slope values too steep to be mound slopes, but the floor of this range changed in this project. The new model uses two classification schemes where the ideal slope range for models 1-3 is 5-15°, and model 4 uses an ideal range of 3-8°.

The aspect raster was reclassified from degree values to values 1-9; flat (-1) was assigned to 1, north (0-22.5° and 337.5-360°) assigned to 2, northeast values to 3 and so on clockwise (Figure 19). Then to highlight the mound’s uniqueness of having all aspects within a small area, variety was

calculated with a 5 m radius circle neighborhood. The resulting numbers 1–9 reflect the number of different reclassified aspect values that was found within the neighborhood. An ideal number for a mound would be 7, 8 or 9; but model 1 is even less selective and accepts the value 6. The previous model did not seek out variety value 9 because that would have included flat areas which are not indicative of a domed-shaped mound. However, through more study of mound characteristics on LiDAR data, many of the domed-shaped mounds even have a little “flat” spot at the top, so 9 was added to the list of acceptable aspect variety values. Model 4 also had to use a larger analysis neighborhood of 9 m radius in order to capture all the aspect directions for these larger, flatter mounds. The aspect variety files were then multiplied by 100 and the result was added to the reclassified slope rasters.

The sum raster of aspect and slope then has the conical mound values extracted from it (Figure 20). The resultant raster is similar to a result of edge detection algorithms used in remote sensing to extract features such as roads from raster images. Edge detection algorithms were tested for the prototype model and revisited again for this project. Combinations of gradient edge detection kernels in different cardinal directions, Laplacian 3x3 and 5x5 filters, and Sobel 3x3 horizontal, vertical, and combined were all tried on a slope raster. Slope is an ideal candidate because the edges of mounds are readily detectable, it is not subject to artificial shadows as in a shaded relief image, and the raster values have been scaled, in this case to degrees, in order to get meaningful output by limiting the potential range of values. None of the edge detection algorithms produced a raster any better than the slope/aspect sum raster for separating mound objects from other objects; in fact, most had “noisier” results than the sum raster. The curvature tool was also tried again with no success; the data did not add any unique information of what objects were mounds and succeeded in creating a noisier raster to sort mound objects from.

The “ideal” values are different for each model. Model 1 is the least selective by accepting values 630, 730, 830 and 930. Value 630 indicates that within a 5 m radius there are 6 different aspect values and the slopes are 5-15°, for example (Figure 20). The following steps taken are focused on eliminating features in the extracted raster that are too large or small to be a mound, eliminating others that are not round enough to be a mound and enhancing objects to help differentiate between mound and non-mound features.

The extraction rasters go through the processes of dilation and erosion. The processes are widely used in digital image processing to try to enhance or extract features from images that may or may not be linked to a spatial coordinate system (Hiejmans and Roerdink 1998). For this project, dilation is the expansion of the cells in the extracted raster to try to connect line segments that, for example, may have a 1 or 2 cell (1-2 m) gap. It was also used to try to close the crescent shapes and annuli commonly encountered with the mounds in the extracted raster (Figure 20). Erosion whittles away from the perimeter of the shapes by a designated number of cells; long, thin lines can be completely “eroded” away in this step.

Another method of filling the centers of annuli is to use the Eliminate Donuts tool where gaps of specified maximum area within polygons are filled in. Other methods were tried to fill in the donuts such as using the Union tool with the specification to not allow gaps, but this tool filled gaps between close polygons as well, producing unintended results by merging disparate polygons together. Once the polygons are filled in, the shape is compact and is mathematically more round than a round polygon with a gap in the middle. The isoperimetric quotient for compactness is calculated for each shape after some of the other cleaning methods are employed. The equation is the ratio of the area of the shape to the area of a circle having the same perimeter (Nixon and Aguado 2008). The closer the value is to 1, the closer the object is to being as compact as a circle. Long linear shapes or polygons with very irregular boundaries are closer to 0; strong, compact conical mound marks are closer to 1. A

cut-off value for acceptable ‘roundness’ was determined through trial and error and is different for each model.

One of the benefits of keeping the geoprocessing results in a geodatabase is that the vector files, the polygon feature classes converted from raster results in order to conduct other analyses, automatically have area and perimeter fields calculated. Using the area field, polygons small enough to be considered noise or too large to be a mound mark were deleted. The perimeter field is used to calculate roundness. If the vector files were in .shp format, extra steps would have to have been added to the model to calculate area and perimeter. Each model uses a combination of these cleaning processes in different order, and some processes are repeated more than others which also vary by model.

When the four models have completed their processing, the results of each of the models are merged into one file. Here the flow accumulation raster created by step 2 is employed (Figure 20). The model extracts the streams from the raster, and then model results that are within 10 m of the stream features (which also includes roadside ditches) are deleted. This eliminates smaller remnant pieces of gullies, stream banks and ditches that were not cleaned out by the previous processes. The results then go through one more pass of ‘roundness’ and ‘sort by area’ processes. The final results are provided as a polygon feature class. If the model is run from ArcMap, the final results are automatically added to the map document.

LiDAR Surveyor User Interface

All three steps are stored as tools in the LiDAR Surveyor toolbox, stored as a .tbx file. The GUI for each of the tools is deployed by simply double-clicking on the tool or right clicking on the tool and selecting Open. The GUI for each tool has a description of what the tool does and places to enter data the tool needs. The tools ask for the directory path to store data files in, what to name output files, and input files to use. Browser buttons are included with each input line, so the user can browse to their desired location rather than having to manually type in the pathname. A user guide is included with the toolbox in .pdf format.

Results and Discussion

Prototype vs. LiDAR Surveyor Results

Three test sites used for the prototype model were revisited for the development of the new model in order to directly compare and assess the how much cleaner the results of the new model are; these AOIs are Effigy Mounds, Slinde and Lucas.

Within the Effigy Mounds prototype AOI boundaries, the LiDAR Surveyor results consisted of 64 polygons, each polygon marking an object the model determined as conical mound-like (Figure 21). Total area of the polygons represents 0.1% of the total AOI. Out of the 64 polygons in the LiDAR Surveyor results, 30 (47%) polygons are marking 30 field-confirmed conical mounds including three conical components of a compound mound (Table 1). The prototype results numbered 471 polygons with 43 (9%) marks on 40 conicals. The total area of the prototype model's mound marks represented 0.35% of the AOI. The number of false positives was decreased by LiDAR Surveyor but so was the number of conical mounds detected; however the number of sites detected remained the same (Table 1). Most of the mounds not detected by LiDAR Surveyor came from one mound site where a string of small (4 m diameter) low-relief mounds were dropped due to the small size (Figure 22). The three large mounds at the end of the same site were set so close together that the strong mound marks in the preliminary results were melded together into a large, linear-shaped mark which subsequently failed the roundness or area test depending on the sub-model. However, a newly tested site for this project that consisted of a string of 10 conical mounds constructed closely to each other elicited marks from the model for 8 of the mounds (Figure 23). One bear effigy and one linear mound were also detected.

Slinde AOI includes a mound group where out of the 16 mounds mapped from a 1987 field visit of the site, 10 were marked in the prototype model results (Figure 24). Out of the six not detected, two were visible from a shaded relief image; the other four were only known for sure by using the field map. The prototype model results had 219 polygons representing 0.7% of the total project AOI. The LiDAR Surveyor model had only 15 polygons in the same AOI and detected 5 out of the 12 mounds visible on the shaded relief image. The sum area of the model results was 0.1% of the total AOI.

Lucas AOI contained a mound site consisting of two recorded mounds. Both mounds have a wide diameter of approximately 14 m but maximum height of only 55 cm on the BE DEM; they are barely detectable on the shaded relief image (Figure 25). The prototype model detected only one of them but the mark was weak (Figure 26). The prototype results in the project AOI numbered 512 polygons with sum area covering .24% of AOI. LiDAR Surveyor excluded both the mounds. One mound was initially marked but was too close to the road cut; its mark was merged into the long edge mark during a dilation process and was deleted. The other mound had a low slope and was never marked. The LiDAR Surveyor results had 97 polygons representing .11% of the AOI. Both models detected a feature that looks like a conical mound near the confluence of two streams (Figure 27).

Pikes Peak AOI

Pikes Peak AOI includes 10 recorded conical mound sites with a total of 122 mounds; 81 of those mounds are clustered together at the Sny Magill site (13CT18) (Figures 1 and 28; Table 1). The model produced 388 marks over an area of 25 km² representing 0.07% of the AOI; 84 of the marks were on recorded mounds. Out of the 41 recorded mounds not at Sny Magill, 24 were marked by LiDAR Surveyor representing all but one site.

Table 1. Summary by AOI of Number of Mounds Recorded Versus Number of Mounds Detected.

AOI	Site Number	Number of Recorded Conicals*	Number of Conicals Detected by Model
Effigy Mounds	13AM82	3	1
	13AM101	5	5
	13AM106	4	3
	13AM163	8	5
	13AM164	10	8
	13AM189	7	7
	13AM190	19	12
	13AM206	1	1
	13AM207	1	1
Slinde	13AM20	12	5
Lucas	13LC17	2	0
Pikes Peak	13CT18	81	53
	13CT59	3	2
	13CT60	3	2
	13CT61	5	3
	13CT62	1	1
	13CT63	5	3
	13CT64	12	8
	13CT65	8	4
	13CT71	2	1
	13CT261	2	0
Calhoun 1	NA	NA	NA
Calhoun 2	13CH6	5	0
Blood Run	13LO2	51	16
	13LO11	7	3
Houston 1	21HU186	2	1
	21HU51	7	11
Houston 2	21HU173	5	3
Houston 3	21HU5	4	2
Total		275	161
Mounds Detected			59%
Sites Detected			89%

*Recorded conical mounds include those in a compound mound group; excludes mounds not detected by LiDAR.

The Sny Magill group is a unique arrangement of closely packed mounds, some are very small and were difficult to field-verify as mounds according to a modern survey; these mounds were included in the count, however (Whittaker and Storey 2005). Out of the 81 conical mounds at Sny Magill, 53 were detected. Four bear effigy and three linear mounds were also marked. The mounds that were not marked were primarily too close to other mounds, or they were too small to be determined mounds by the model.

An unrecorded mound group was also detected by LiDAR Surveyor (Figure 29a-c). This was unexpected as the area had undergone thorough field survey in the 1910s by Ellison Orr, a prolific surveyor who mapped many sites across Iowa in the early 20th century (Orr 1940; Figure 29c). Further checking into Orr's (1940) notes and the Iowa Site File found that the site had been mismapped in the Iowa Site File by an archaeologist in the early 1970s. The same site record states that there may be a single, unrecorded mound on a terrace nearby. The model did detect a mound-like feature on a terrace about 400 m to the northeast of the site (Figure 29a-b). Orr's map also indicated an "old log house" on his ca. 1912 map in about the same location as a surface disturbance detected on the shaded relief image (Figure 29a-c).

Calhoun 1 and 2 AOIs

The North Raccoon River and its tributaries that run in the southwest corner of Calhoun County seem to have optimum landscapes for prehistoric archaeological sites, but no modern survey had been conducted there. LiDAR Surveyor was run on part of the North Raccoon River and its tributaries to see if there were landscapes along streams in the Des Moines Lobe that might cause unforeseen problems (Figure 30). It was also an opportunity to use the tool in the way it was intended – to run on big expanses of unsurveyed territory that might have high mound potential. The results proved that the knobby hills typical of the Des Moines Lobe region are not a problem for the model. Rough surfaces of gravel and sand quarries seemed to have triggered a lot of the false positives (Figure 31). The model results produced 1247 polygons in the 74.5 km² AOI, covering 0.06% of the area.

The model results were then manually cleaned by deleting the polygons that were obviously false positives from the shaded relief image, or could be determined as false positives using aerial photography covering several decades since the 1930s. The process took about 1.5 hours; what remained was a cleaned file of 60 polygons that marked features that need more scrutiny using other geovisualization methods or a field visit. Some of the features marked by LiDAR surveyor include what appear to be unrecorded mound groups, a ring enclosure (a rare site type in Iowa), and a mound hidden in the shadows on the shaded relief image, adjacent to a depression reminiscent (though larger) of the earthlodge LiDAR signatures in Mills County (Figures 32a-d and 33; Riley 2010).

The only recorded mound site in Calhoun County is located on the edge of a natural lake in the Calhoun 2 AOI (Figure 34). Unfortunately, the vegetated areas in this AOI were a little rough possibly due to collecting later in the season. Five out of the 11 recorded mounds at the site were visible on LiDAR data and none were detected by the model. Two mound-like features that are actually unfiltered vegetation were marked as mounds (Figure 34). The model did not leave many marks in this AOI, indicating that the topography in the region formed by the last glaciation had no negative bearing on the number of false positives produced. Out of the 2.1 km² area, there were only eight marks; five on farmsteads, one on a roadside and two on unfiltered vegetation, representing 0.01% of the AOI. All but one of the marks were on something that resembled a mound, but were other objects.

Blood Run AOI

The LiDAR Surveyor results at Blood Run had many false positives caused by a concentration of sand and gravel quarries along the Big Sioux River (Figure 35). Another concentration of false positives was in an isolated patch in the northwest corner of the AOI over a rugged surface caused by outcrops of Sioux Quartzite. The two mound sites in study area have mounds that have been cultivated. The most worn are barely visible on the shaded relief image and most did not pass the first phase of the mound detection tool due to slope being too low. If it was not for the model 4 branch of the mound detection model, only six mounds at 13LO2 and one at 13LO11 would have been detected; instead, 16 at 13LO2 and 3 at 13LO11 were detected. The total number of polygons in the mound model results was 447 covering 0.1% of the AOI.

Houston County AOIs 1-3

Houston 1 results were 28 polygons in an AOI of 3.4 km² representing 0.03% of the total AOI (Figure 36). Eight of the polygons are on mounds and there are 14 other marks on objects that are mound-like, but would need further interpretation before classifying them as possible archaeological features. Four marks are on objects that are not like a mound – roadside ditches and a saddle on a ridge. The recorded mound that was not detected at 21HU186 failed the aspect test early in the mound detection process by having only “sides” facing three different directions in the 5m and 9m neighborhoods; in other words, the symmetry of a round feature was not there (Figure 37). Four mounds at 21HU51 were not detected. Two small, 4.25–5.5 m diameter mounds were initially kept early in the processing with one of the submodels, but were cleaned out in the dilation/erosion process after trying to fill in the crescent shapes that were delimiting the mounds. The shapes did not have a strong enough signal to begin with due to low slopes on parts of the perimeters, and they could not be filled in completely. The other two mounds were too low-relief and failed the slope test early in the process.

Houston 2 results were 144 polygons in an AOI of 14.58 km² representing 0.04% of the total AOI (Figure 38). Four out of the five mounds at this site were described in a field report as being elliptical in shape, about 90-107 cm high and 5 m along the long axis (Emerson 2004). The other mound was 2.13 m in height and 9 m in diameter, but had rock slabs set upright at the top of the mound. This larger mound did not express very well on the shaded relief image and was initially detected by only one of the submodels, then dropped from the results because the area of the mark was too small to be considered a strong, conical mound mark (Figure 39). One of the elliptical-shaped mounds was also not detected because the initial mark on the mound feature melded with a linear mark along the sharp ridge and was dropped for failing the roundness test. Overall, 3 out of the 5 mounds in the group were detected.

Houston 3 results consisted of 12 polygons in the 1 km² AOI representing .04% of the total AOI (Figure 40). Two out of the four mounds at the test site were detected (Figure 41). One elliptical-shaped mound was never extracted by the model due to not having enough aspect variety for a round object. The other mound that was rejected was initially marked, but was deleted during the cleaning process.

Results Summary

The comparisons between the prototype model’s results and LiDAR Surveyor results show that the number of polygons in the final results decreased precipitously. The Effigy Mounds AOI saw a drop in model result marks by 71%. The number of conical mounds detected also decreased by 25%, but the number of sites detected stayed the same. The Slinde AOI had a decrease in mound marks by 87%, and the number of mounds detected in the AOI’s single site decreased from 10 in the prototype to 5 in LiDAR Surveyor. The Lucas AOI mound marks decreased by 54%, but the site that was detected by the prototype model (albeit weakly) was dropped in the new model.

However, the purpose of the project was to decrease the amount of false positives. This meant that if the mound’s morphology did not fit that of a conical mound, such as ones that have been heavily cultivated or vandalized, then they would be discounted as background noise as well. The results of LiDAR Surveyor in several settings demonstrated repeatedly that if the mounds had very little relief then they were not marked, largely due to the initial classification in the mound model that excludes everything with a slope less than 3°. This was necessary in order to have some differentiation between the mound feature and the surrounding ground. The conical mounds detection rate may have decreased, but the rate of sites detected was 89%, including all of the single-mound sites (Table 1).

LiDAR Surveyor has also detected at least eleven potential sites in the Calhoun 1 AOI which took the interpreter very little time to locate and study including a mound-like feature that was overshadowed in the shaded relief image and drew attention to a depression feature. The OSA plans to do field survey of these features in 2012 (Shirley Schermer, personal communication 2012).

INTERPRETING MODEL RESULTS

The new mound detection model has significantly reduced the number of false positives in the results, producing a much cleaner image for interpretation; however, false positives do remain. Fortunately, the triggers for the false positives are ubiquitous over different physiographic regions and different LiDAR datasets; in other words, the cause of false positives is predictable. Most of the false positives can easily be determined by the interpreter either by understanding the morphology of non-mound objects as presented in a shaded relief image or by using aerial photography to determine the likelihood that the mound-like object they are viewing in the shaded relief image is caused by something else.

Table 2 breaks down the results of two model runs by object category and morphology, one in Effigy Mounds National Park and the other in Minnesota. Both AOIs contain similar landscapes and vegetation, but they are different datasets collected a few years apart by different vendors. However, the results show that the distributions of the categories are similar between the two datasets. The majority (39% and 42%) of the marks in the mound results were man-made features that do not resemble conical mounds, largely ends of erosion control terraces or rural dams, edges of road ditches especially around culverts and field inlets, and rough patches in the BE DEM from filtered farmstead structures. The categories where the marks were on mound-like features were based on interpretation from shaded relief files, aerial imagery and 3D renderings of the BE DEM. Mound-like features that need more checking (12% and 16%) require interpretation from a point cloud in order to determine if the object is worth a field visit or it's just a small patch of shrubs.

Table 2. Comparison Between Classified LiDAR Surveyor Results of an Iowa and a Minnesota AOI.

	Effigy Mounds AOI (6.74 sq km)		Houston AOI 2 (14.58 sq km)	
Feature Triggering Detection	No. of Marks	Percent	No. of Marks	Percent
Man-made terrain, not like mound	36	38.7	59	41.8
Natural landscape features, not like mound	14	15.1	16	11.3
Vegetation, not like mound	6	6.5	13	9.2
DEM noise/error	2	2.1	2	1.4
Subtotal of features not like mound	58	62.4	90	63.8
Man-made terrain, like mound	8	8.6	9	6.4
Mound-like feature, need more checking	11	11.8	23	16.3
Vegetation, like mound	16	17.2	19	13.5
Subtotal of mound-like features	35	37.6	51	36.2
Total	93	100	141	100

Limitations of Shaded Relief Image Interpretation

There are some limitations to using a single shaded relief image alone for mound prospection. Part of the impetus for the prototype mound detection model is the recognition that if a feature happens to be on a lower landscape position, the adjacent, higher landscape may cast a black shadow over the lower landscape position where it is not visually interpretable (Figure 42). Simply changing the contrast and brightness of the image from desktop software does not always help. If the shadow is

solid black, lightening it up will just make an area of solid gray – the potential detail captured by the elevation data is lost. This is common in cases of high river bluffs overshadowing intermediate or low terraces; unfortunately it is a landscape arrangement that is common with mound group and earthwork locations. The alternative would be to create several shaded relief images of varying lighting angles and interpreting each of them; over a large area this is time-prohibitive. The mound detection model uses elevation data from the BE DEM so there are no shadow issues to hinder detection.

Sometimes the archaeological feature just has the unfortunate arrangement of being a little low and oriented in a way that most of the feature follows the slope of the larger landscape it is located on. The shaded relief algorithm may gloss over it as part of the larger landscape feature and not “assign” the feature a shadow. Figure 43 is an example with a mound site consisting of two linear mounds in the Effigy Mounds National Monument. The image at the top is a shaded relief image that is being served to the public. The image at bottom is a clipped BE DEM that has been vertically exaggerated in ArcGIS 3D Analyst’s ArcScene with a different lighting scheme applied. Note the terrace to the right of the bluff line that has been overshadowed in the image.

When reviewing LiDAR Surveyor results, there were a few examples of solid marks seemingly pointing out nothing on the shaded relief image only to find out when the BE DEM of the area was added to ArcScene and lighting effects applied, an object was visible. The objects did not seem to be lower in relief than many of the plowed down mounds that are barely visible in a shaded relief image. However, these visible low-relief features are in very flat surroundings and the non-visible features are occurring on gently sloped terrain. The interpreter must keep in mind that the shaded relief image is not a high-detailed photograph, but just rather an elevation data derivative created by an algorithm.

Vegetation

Highly varied vegetation such as a savannah setting of grass with isolated, small stands of trees or large shrubs can create noisy surfaces where the vegetation density (and the ground point density) suddenly drops and leaves the interpolator with less information to work with than the surrounding area when creating the BE DEM. This can create artificial localized rises if some of the surrounding point elevation data were trending that way before reaching the data dead spot where a tree or large shrub was filtered out. The other issue in these areas is that a few points that should have been classified as not ground, because they are low branches for example, get classified as ground. The sudden localized “rise” in elevation will cause objects to appear in the final BE DEM that resemble a mound (Figure 34).

The cause of these bumps can easily be identified on aerial imagery and the horizontal footprint of the rises are usually smaller (3-5 m diameter) than a typical conical mound. It is plausible that there could be a lone mound with a lone tree or shrub growing out of it, but the probability of that being the case instead of an artifact of vegetation alone is nearly zero. In forested areas, the mounds are usually clearly visible, given the data was collected leaf-off, without surrounding residual tree “bumps” because the vegetation is more homogenous and the filtering algorithms seem to perform better than in the savannah setting.

Another course of action aside from using aerial photography would be to check the actual point cloud of the area in question. This would require a 3D Analyst extension in ArcGIS to view the cloud at different angles in a 2.5D setting, or other commercial off-the-shelf software created for manipulating and visualizing LiDAR point data such as Merrick MARS or QCoherent LP360 Basic. There are also a few open source software packages but they can be limited in features, have little or no technical support and may difficult to use unless the end-user has some programming experience.

In cases of treefall, the large ball of dirt that was pulled up with the roots of a felled tree can look very similar to a conical mound on a shaded relief image. If the treefall is in a grove or forest, aerial photography is not going to be helpful. In these cases, the classified point cloud needs to be viewed in

profile transects using LiDAR geovisualization software possessing this functionality. The profile will show the root ball as having a much sharper apex than a typical conical mound and will not be very symmetrical; in some cases a trunk is also delimited by the points and can also express itself on a shaded relief image as a linear type mound.

Man-made Features

Man-made features such as fencelines, edges of roadside ditches, erosion control terrace features and rural dams will sometimes trigger false positives. In the analysis of model run results, false positives caused by man-made features that do not resemble conical mounds were much more common than man-made features that do resemble mounds.

Some of the features that appear to be obvious man-made linear objects, upon closer inspection may have gaps that cause isolated bumps. These were classified as mound-like man-made objects. There are also undoubtedly isolated, mound-like features that are man-made and could not be determined as such without a field survey (Whittaker and Riley 2012). Examples of these include old push piles, brush and junk piles.

Filtered-out buildings will also cause bumps in a BE DEM that sometimes get marked by the model; these are usually easy to interpret from topographic maps and aerial photography. The Minnesota datasets include an extracted building polygon vector file which can be used in the post-processing manual clean up. Just selecting all the mound marks that intersect a building polygon would clean up those false positives in seconds. If the interpreter has accurate and precise centerline road data, deleting marks within 15-20 m of the centerline would quickly eradicate roadside false positives. Using road data derived from TIGER line data, which is commonly available in many states' GIS repositories, is not precise enough to use for clean-up purposes.

Natural Features

The prototype model and LiDAR Surveyor are both effective at eliminating surface bedrock outcrops because most outcrops do not have a consistent slope 360°. A recent study by Whittaker and Riley (2012) in the Yellow River basin near the Effigy Mound AOI found that some surface outcrops can collect eroded soil from upslope and create conical mound morphology (Figure 44). The features appear on shaded relief imagery as mounds; checking the point cloud data also shows this as mounds. The only way to be sure these features are not mounds is by field survey.

Fortunately, most of the marks on natural features are easier to interpret such as stream banks. LiDAR surveyor would sometimes mark the heads of gullies where the surface can be rough and the slopes form a bowl shape with a narrow pour point downstream. The bowl shape can be construed as having six or seven different aspects in one small neighborhood, only the feature is concave instead of convex. Because the marked feature is at the headwaters of a stream or gully, sometimes the set flow accumulation is not high enough to form a stream to aid in sorting the marks.

Sharp, narrow upland ridges can also confound LiDAR Surveyor because there may be 6-8 aspects within a small neighborhood as the filter straddles both sides of the ridge. Sometimes this forms long lines tracing each side of the ridge which then gets deleted when sorting for roundness; but hummocky features that can be found on top of these ridges will trigger marks that can pass all the clean-up processes. Usually the hummocky features have such a shape and/or size as to be distinguishable from a conical mound, but others are difficult to determine especially in the context of being in close proximity of recorded mound features (Figure 45).

DEM Noise/Error

Some tops of sharp ridges get errantly “shaved” down by the automated mass point classification process and do not get caught by the vendor's quality checks. This will sometimes create little peaks at

the edges of the data void that can be misclassified as mound. Occasionally, there will be a small (4 m² or so) isolated patch where the surface seems to spike up. Most of these spikes are smoothed over by the Step 1 Prepare DEM tool, but some spikes may take a few filter passes before they are taken out. These seem to be a rare occurrence and only caused two false positives out of all the test areas.

Other errors mentioned earlier such as goose bump surfaces from unfiltered vegetation or facets on the BE DEMs due to lack of ground data are caused by late collection in forested areas. In those cases, the data does not have much utility in archaeological prospection and should not be used with the LiDAR Surveyor tool.

Mound-like Features and the Need for Field Checks

In the Iowa and Minnesota sample sets the percentage of mound-like features that were not recorded mounds consisted of about 37% of all marks (Table 2). Differentiating between vegetation and a true mound can be difficult but possible with high-resolution aerial photography freely available to those with an ArcGIS license (ESRI 2009). Man-made designations on the other hand, may require historic aerial photography analysis as well. Activities in the past that may have disturbed the surface may not be apparent on current color aerial photography, but georeferenced 1930s, 50s and 70s black and white aerial photography aided this project in identifying areas where there was surface disturbance (i.e., old farmsteads, soil removal and related push piles) contemporary with the photography.

Then there are the 12-16% grouped as “mound-like feature, need more checking” where shaded relief images, aerial photography and 3D rendering of the BE DEM could not rule out the possibility that the object was a mound. The next phase would be to view the objects’ classified point cloud data to check the profile and determine if the bump could be a large shrub, unfiltered tree branches, part of an unfiltered roofline of a small shed, or other unanticipated objects that are not part of the bare ground but some of the points did not get classified correctly.

Viewing the mass point file still does not provide all the answers. As Whittaker and Riley (2012) found out, there are a lot of things on the ground that can mimic a conical mound very well. LiDAR only records elevation points; there is no way to tell if a mound in a forest is made from soil or trimmed brush and branches piled by the landowner. Unfortunately, mankind continues to this day prolifically making piles in conical shapes.

Even though the interpretation process in the Yellow River study used all the resources possible, including using the point cloud and taking the context of landscape position and proximity to other mounds in consideration, a field check proved many were not prehistoric conical mounds (Whittaker and Riley 2012). Two conical shapes sharing a ridge spur with a newly field-confirmed linear mound were found to be clusters of fallen logs and brush (Figure 46). Other mound-like features were made of soil and rock but were likely natural rather than cultural features such as the outcrop previously mentioned (Figure 44). The location and morphology of the object was very convincing although the interpreter had noted that it may be an outcrop due to the geomorphological context.

A suspected two-mound site along a tributary of the Yellow River was field confirmed as likely two push piles, determined by the irregular surface of one pile and an apparent dozer scar on the other and the proximity to a trail that was graded in the past (Figure 47). The height and diameter of these push piles were well within the range for a prehistoric conical mound. The two features were noted as “weedy” from the point cloud interpretation. And then there were the ubiquitous junk and brush piles, whose owners were amused that archaeologists would take such interest in their trash. One site visit was to a lumber pile, small hay bale and brush (Figure 48). The point cloud clearly displayed three dome-shaped features, with two having a mixture of classified ground and non-ground points and a third was thought to be errantly misclassified as non-ground (Figure 49). The point cloud is similar to one misclassified at a real mound site in Minnesota (Figures 7 and 9).

Conclusions

LiDAR data is an effective tool in detecting prehistoric burial mounds, but scanning expansive areas for these small features can be time-consuming and exhaustive for the image interpreter. Using shaded relief images alone may also not be enough to detect all the features. A prototype conical mound detection model built by Riley (2009) detected 90% of the mounds in the project test areas, but the model results also had a lot of false positives which obscured the true mound marks. LiDAR Surveyor was developed for this project to decrease the amount of false positives and to make the tool easy to disseminate to archaeologists and preservationists that use ArcGIS.

Like the prototype, LiDAR Surveyor scans BE DEMs for objects that have morphology similar to prehistoric conical burial mounds, the most common mound type. During the course of the project, it was recognized that there were different arrangements and characteristics of conical mounds that required the model to be developed as four submodels. LiDAR Surveyor also employed digital image processing techniques such as dilation, erosion, and an isoperimetric quotient for compactness that were not used in the prototype.

LiDAR Surveyor proved to be a more selective tool by reducing the number of marks in the results by as much as 87%. However, the overall mound detection rate for the same sites that were used in the prototype project decreased from 90% to 67%. The reason for the decrease in detection was that in order to reduce false positives the model had to be less forgiving of objects that did not fit the conical mound morphology, including conical mounds themselves which may have been deformed due to cultivation, vandalism, or road and trail cuts. As a whole, LiDAR Surveyor detected 59% of all the conical mounds at 28 test sites and detected 89% of all test sites. The lower overall detection rate than the 67% seen at the comparison sites can be attributed to two large mound groups in the new study areas. One was in Blood Run AOI where many of the mounds have been cultivated, the other was a very unique, tightly arranged mound group at Sny Magill which contained small conical mounds that were difficult to even field-verify.

Remote sensing archaeological sites require human decision making no matter how accurate the feature detection results. Two AOIs, one each in Minnesota and Iowa, were used to tally the marks into mound-like and non-mound categories. The distribution of each classification was nearly the same between the two datasets. It was noted over the course of the project that the objects spurring false positives are consistent throughout different physiographic regions. About 37% of the detected features appeared to be shaped like a conical mound at first glance on the shaded relief image. This means that there is still more opportunity to reduce the number of false positives that are not mound-like. Other research that surveyed mound-like features detected on shaded relief images illustrated the importance of field confirmation and that LiDAR data is not a replacement for field survey, but is an excellent pre-survey planning tool.

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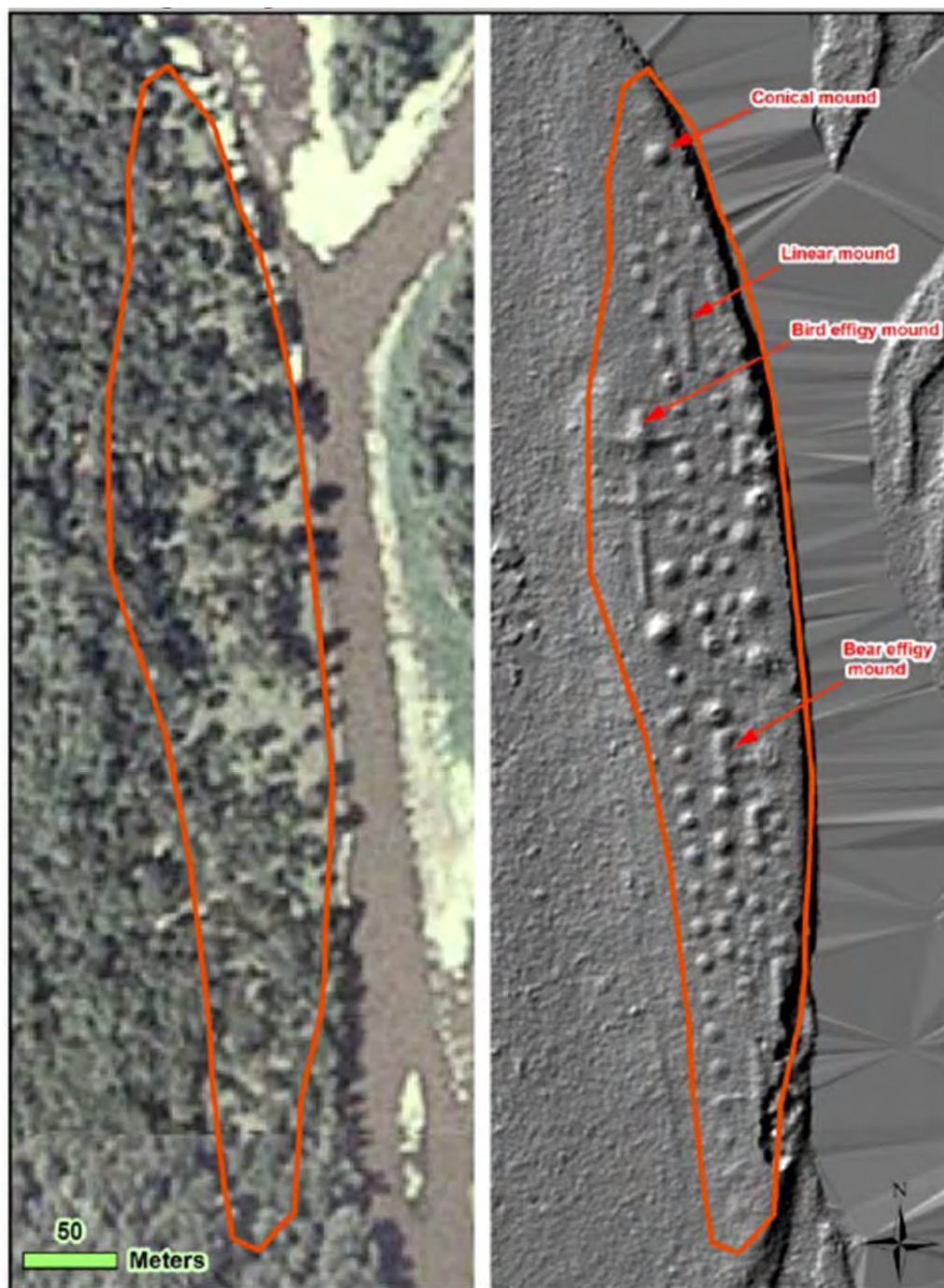


Figure 1. The Sny Magill Mound site, in Effigy Mounds National Monument as seen in aerial photograph (left) and LiDAR BE DEM hillshade image (right). Note details visible in LiDAR despite tree cover.

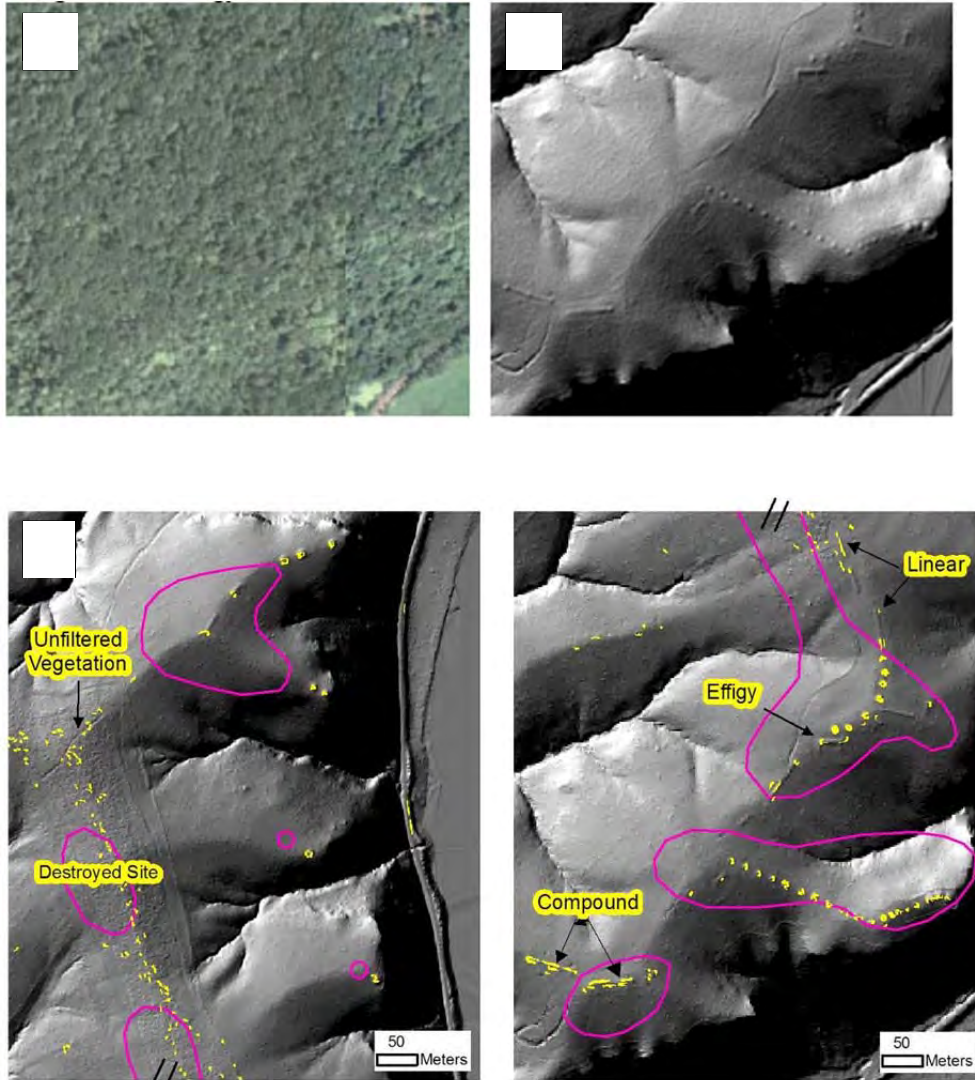


Figure 2. Successful detection of mounds at Effigy Mounds National Monument, Iowa, by the LiDAR survey prototype (from Riley 2009: Figure 41): a) Aerial photograph showing tree cover; b) BE DEM image of the same area; c) Model results, with detected mounds shown in yellow. Inaccurate site boundaries, in pink, maintained by UI-OSA were revised based on the distribution of LiDAR-detected features.

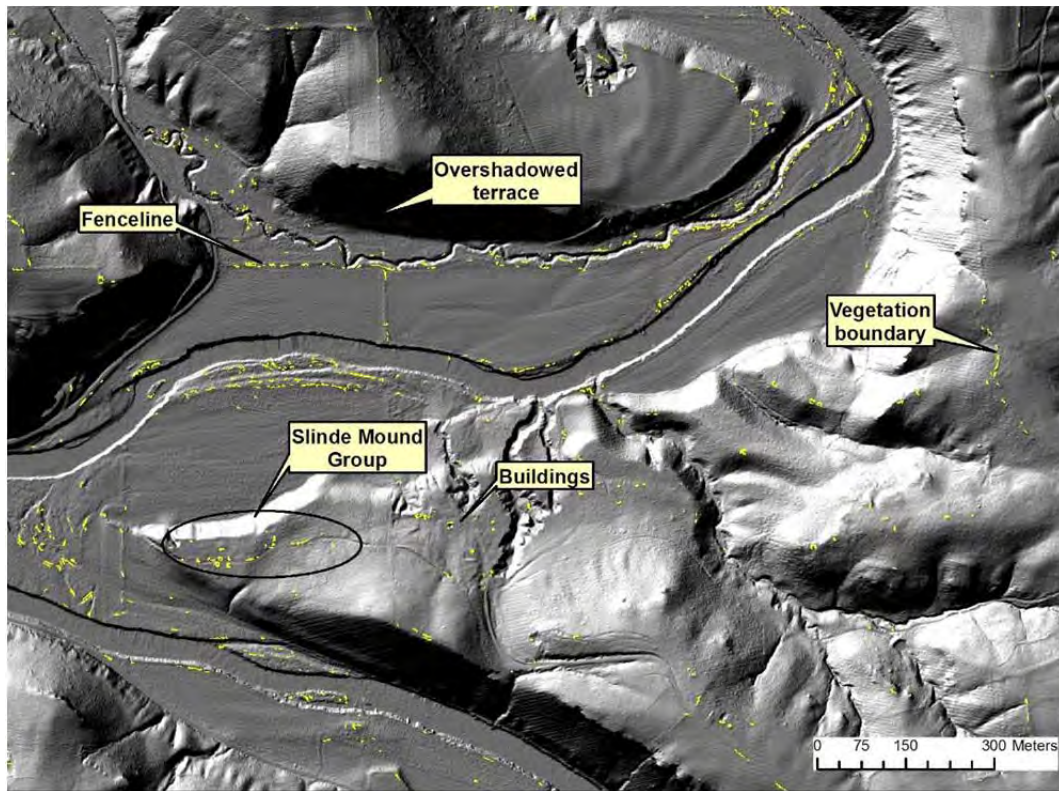


Figure 3. Prototype mound detection model results at the Slinde Mound State Preserve, Iowa (from Riley 2009: Figure 37). In addition to identifying the mounds (lower left) that comprise the Slinde Mound Group, the model also detected non-mound features such as a fenceline (upper left), buildings (center), and a tree line (right), as well as many upwardly convex features along streams.

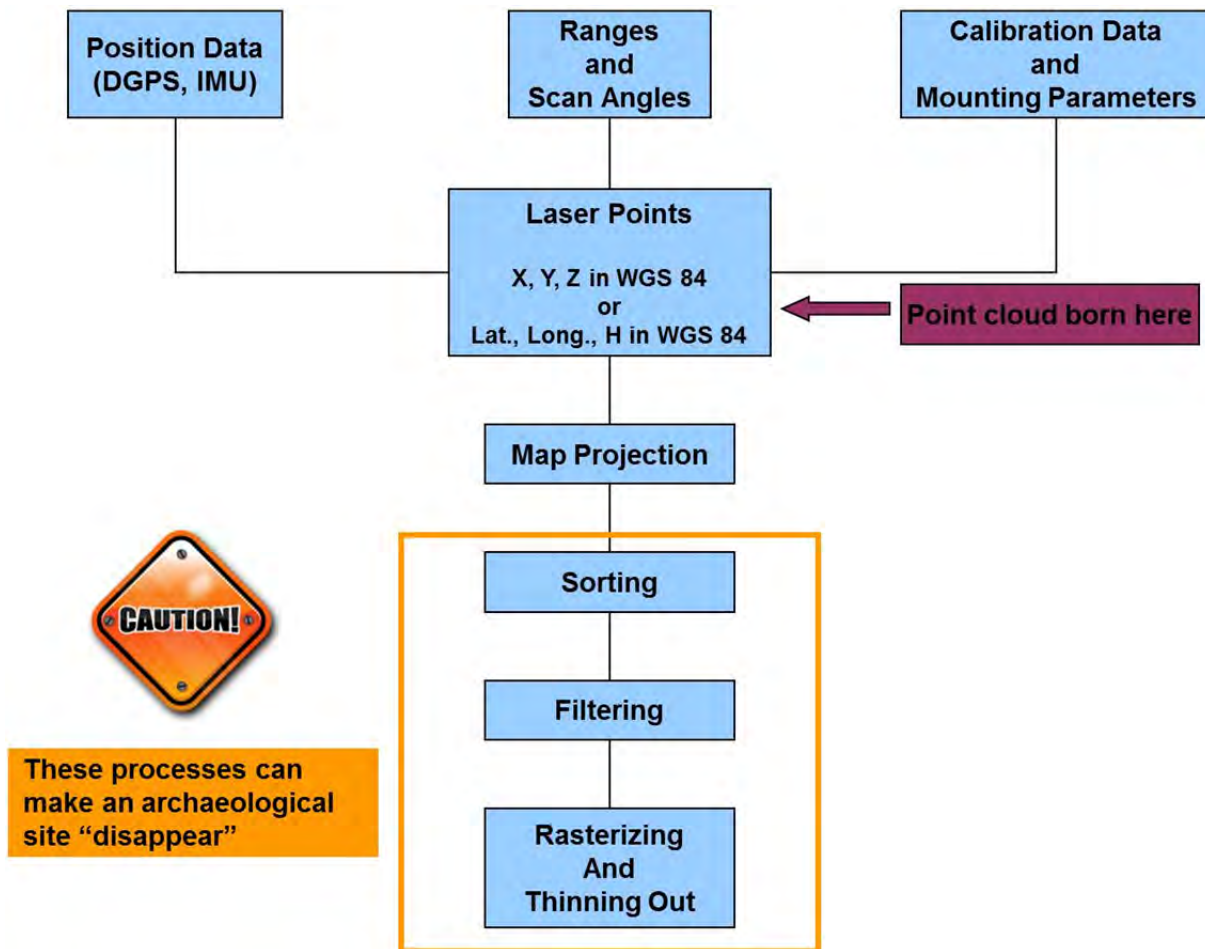


Figure 4. LiDAR collection and processing steps (Fowler et al. 2007).

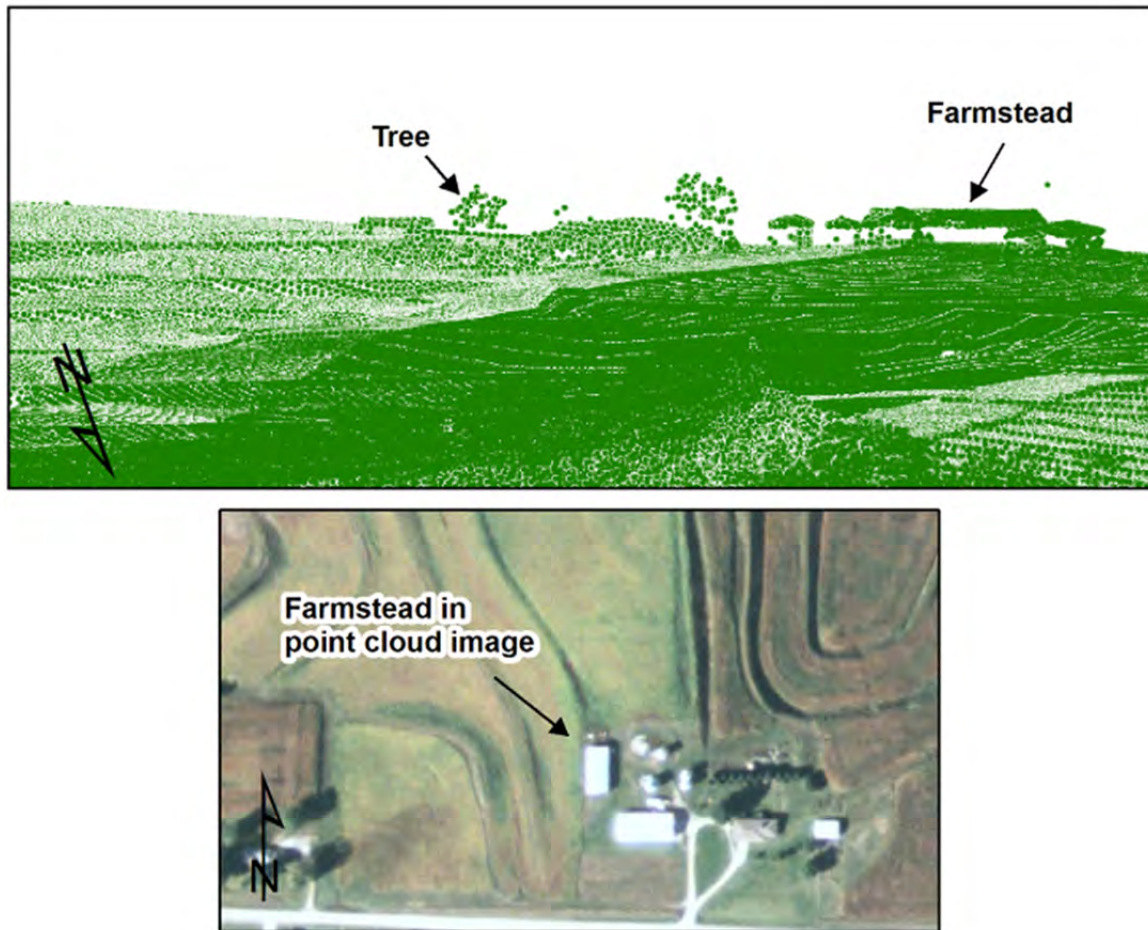


Figure 5. Top: Mass point cloud of a farm field with contour farming terraces and a farmstead. Bottom: Aerial photography of the same farmstead and field.

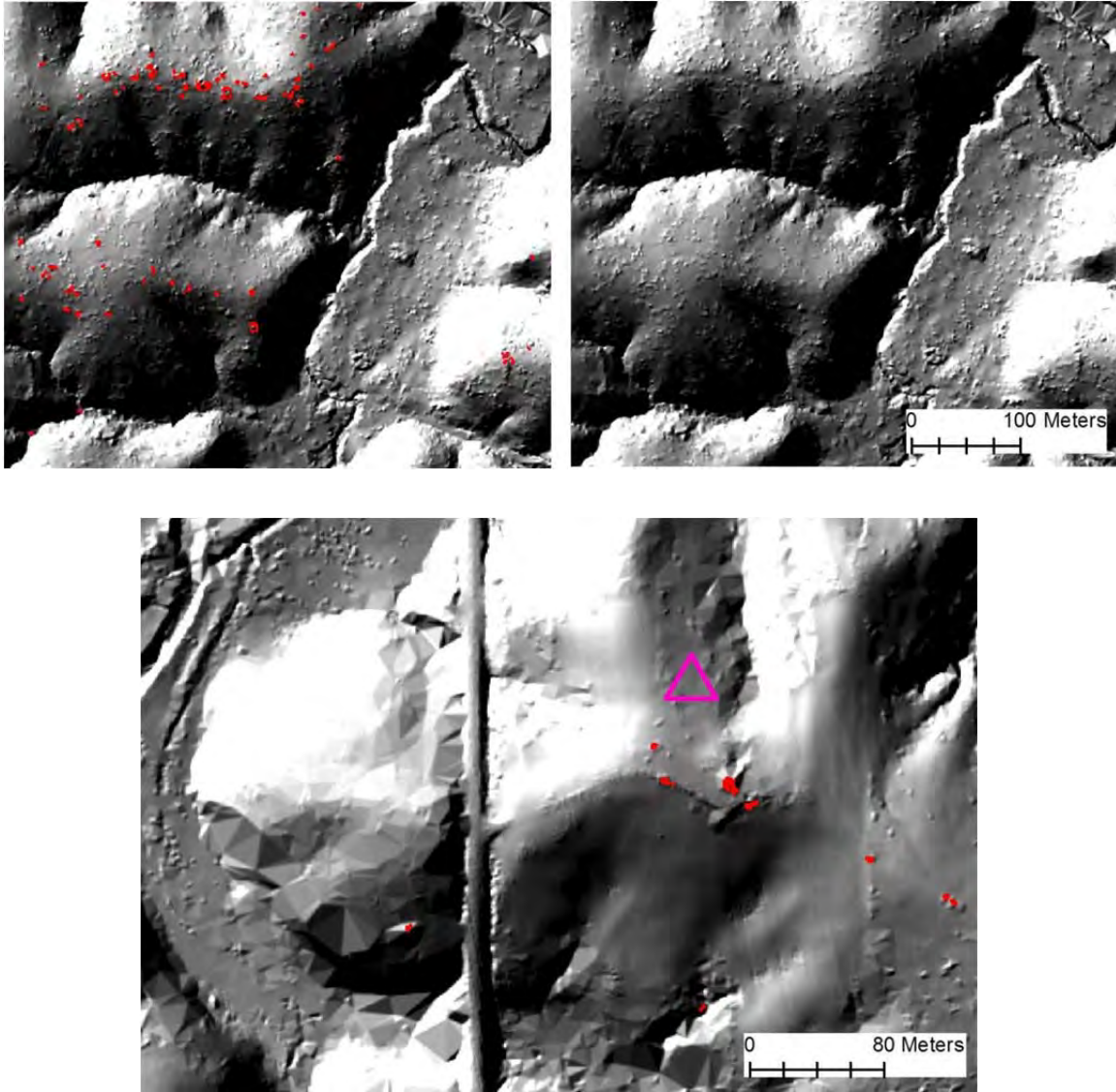


Figure 6. Top: Left, bumps on the ground surface from unfiltered vegetation trigger many false positives, in red, from the prototype mound detection model. Right, same image without the detection tool results (from Riley 2009: Figure 49). Bottom: Ground surface is faceted due to thin ground point density in forested area; pink triangle indicates a site with uncertain location is nearby (from Riley 2009: Figure 48).

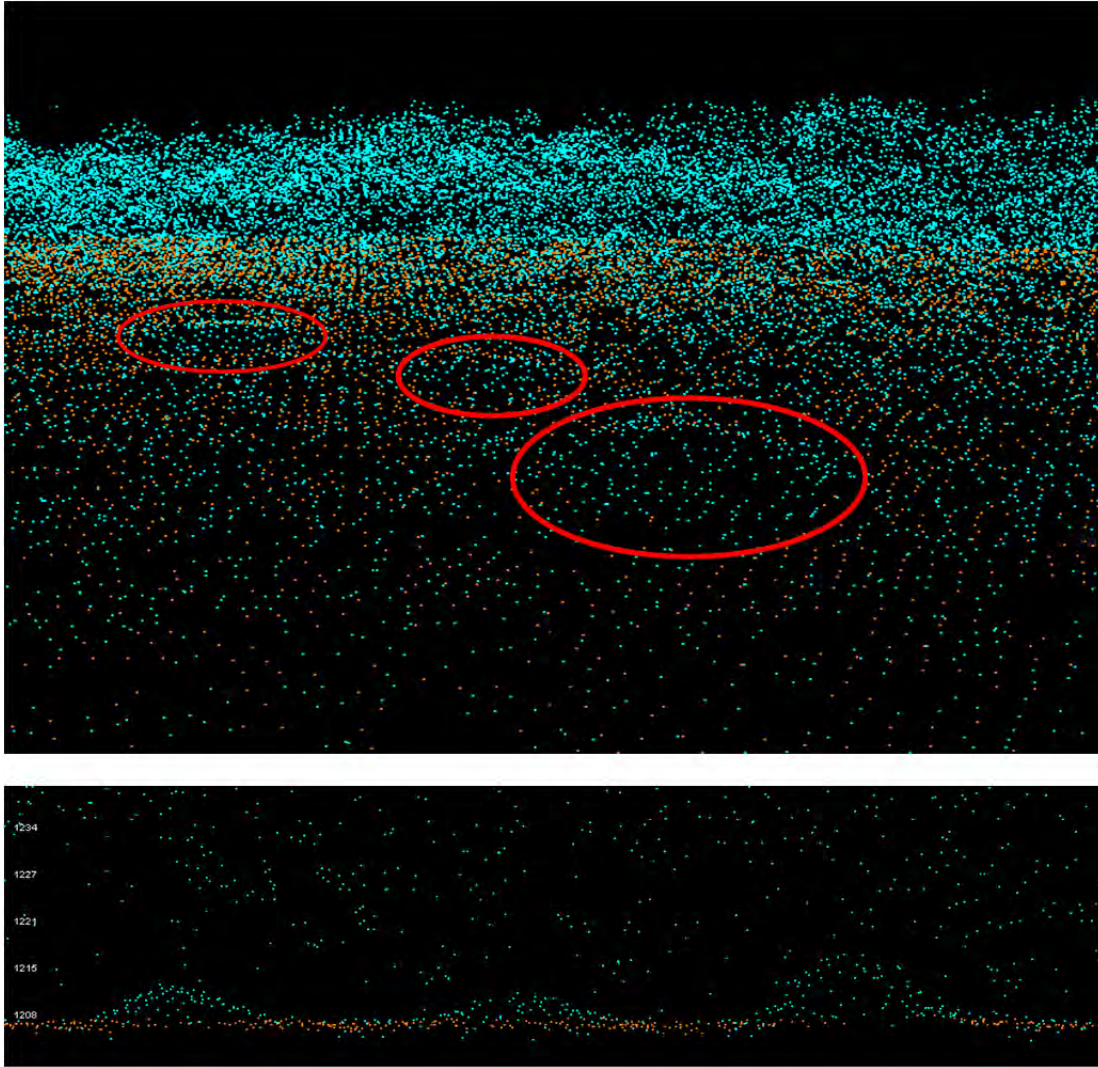


Figure 7. Top: Classified mass points of three large mounds circled in red. Blue points are classified as not ground, orange are ground points. Bottom: Profile of the misclassified mound group; the clusters of points should be orange ground points (from Riley et al. 2010: Figure 2.11).

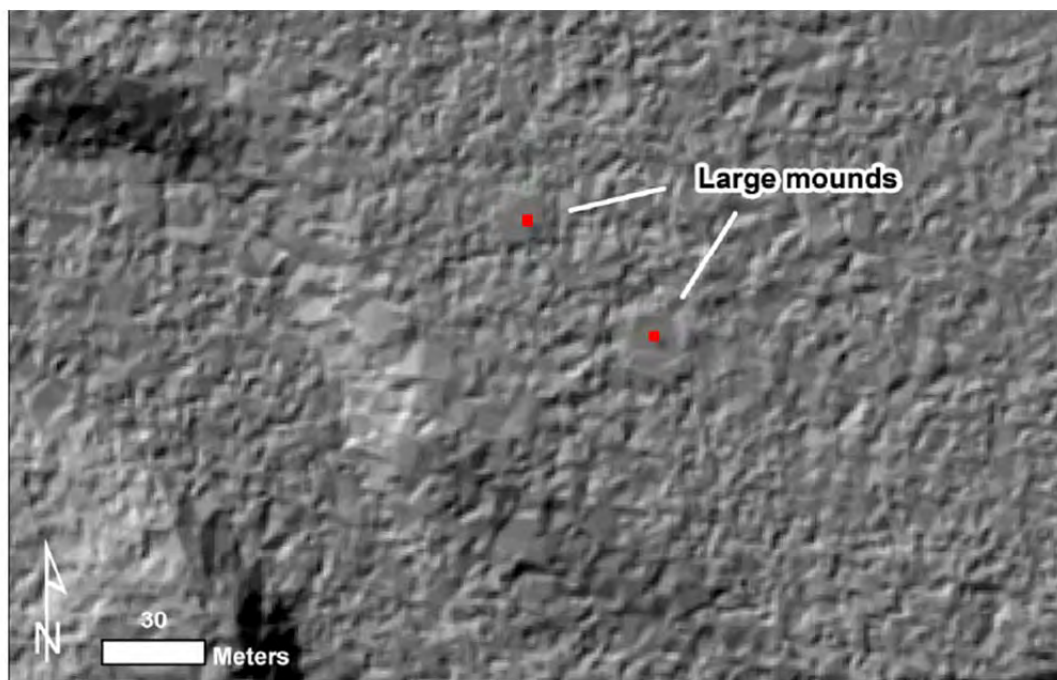


Figure 8. Red dots are centered within 10–20-m-diameter mounds that were truncated to stump-like remnants by misclassification of LiDAR returns in point cloud (from Riley et al. 2010: Figure 2.10).

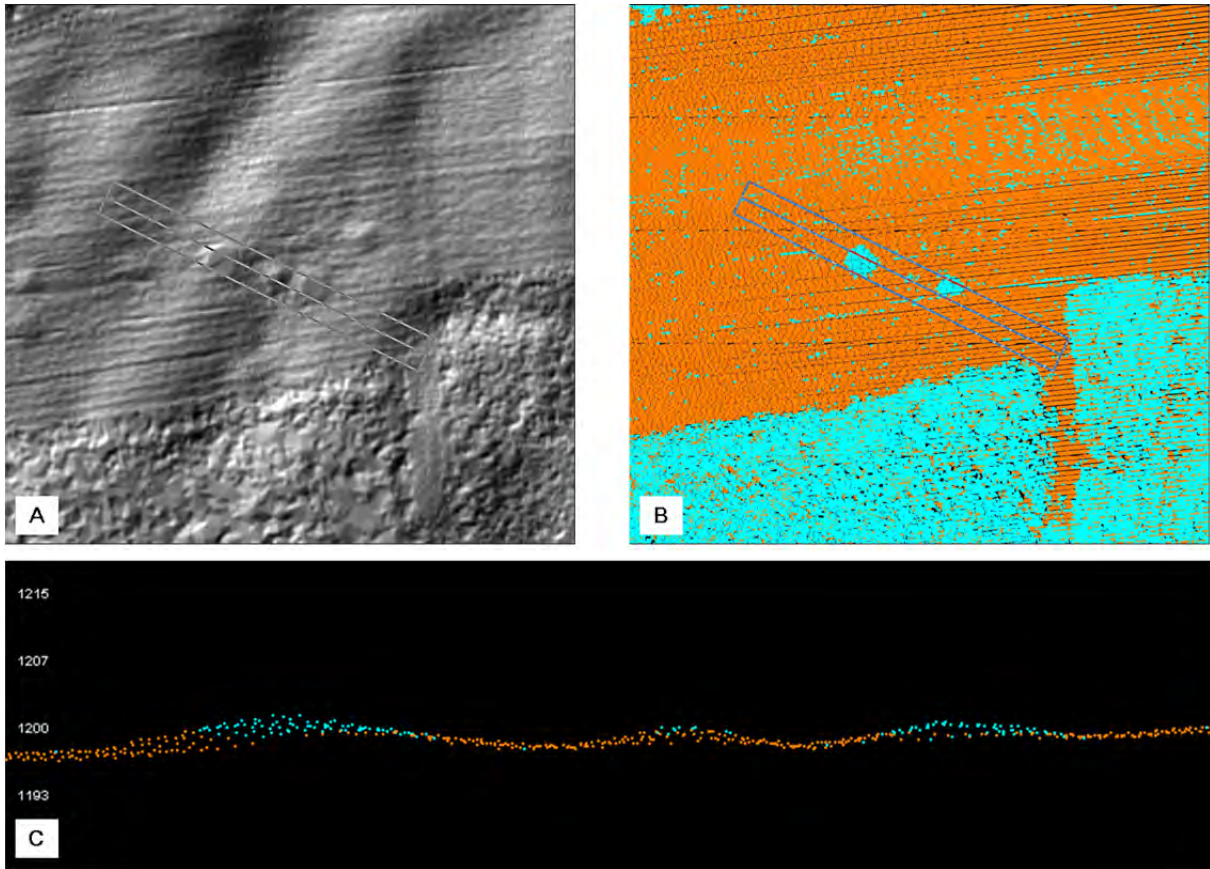


Figure 9. Misclassified mounds in an open field in Crow Wing County, Minnesota (from Riley et al. 2010: Figure 2.12): a) Mounds on the 1 m shaded relief image; b) Blue dots in field are mound points misclassified as not ground; c) Profile of the mounds along the transect depicted in a and b.

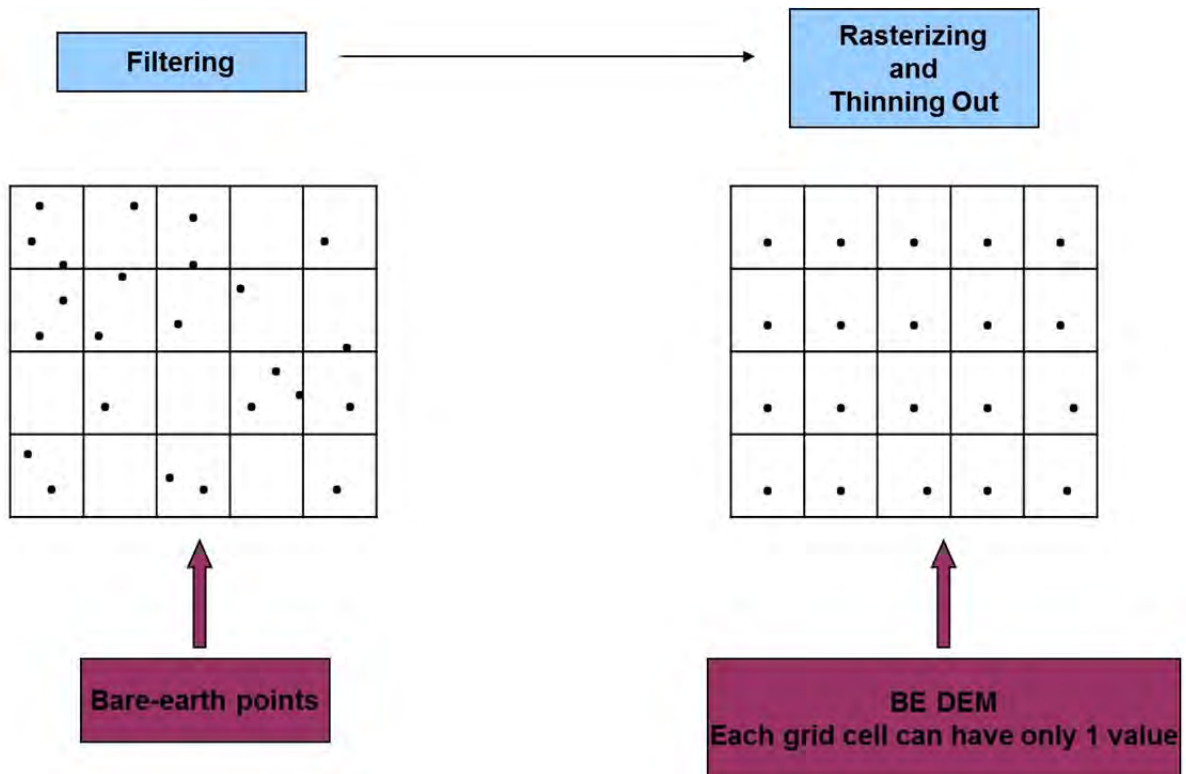


Figure 10. The processes of filtering, thinning and rasterizing can affect the visibility of an archaeological feature on the shaded relief image because not all bare-ground elevation points may be used for creating the BE DEM.

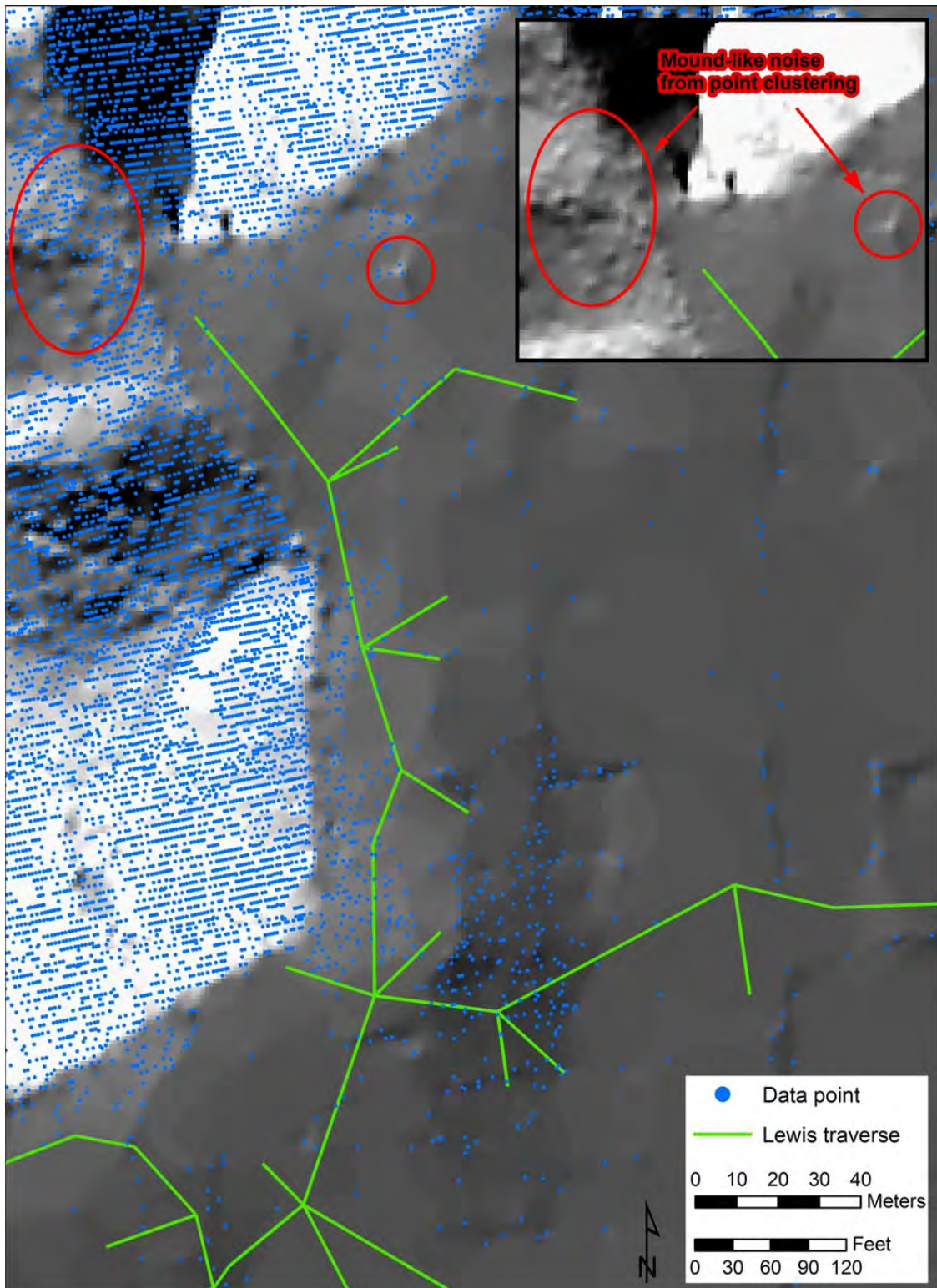


Figure 11. Bare-earth data points available from the Scott County, Minnesota dataset. Points had been heavily thinned to create smooth contour lines and mounds recently field-confirmed are not visible. Sparse points with point clusters (circled in red) create artificial bumps resembling mounds (from Riley et al. 2010: Figure 2.5).

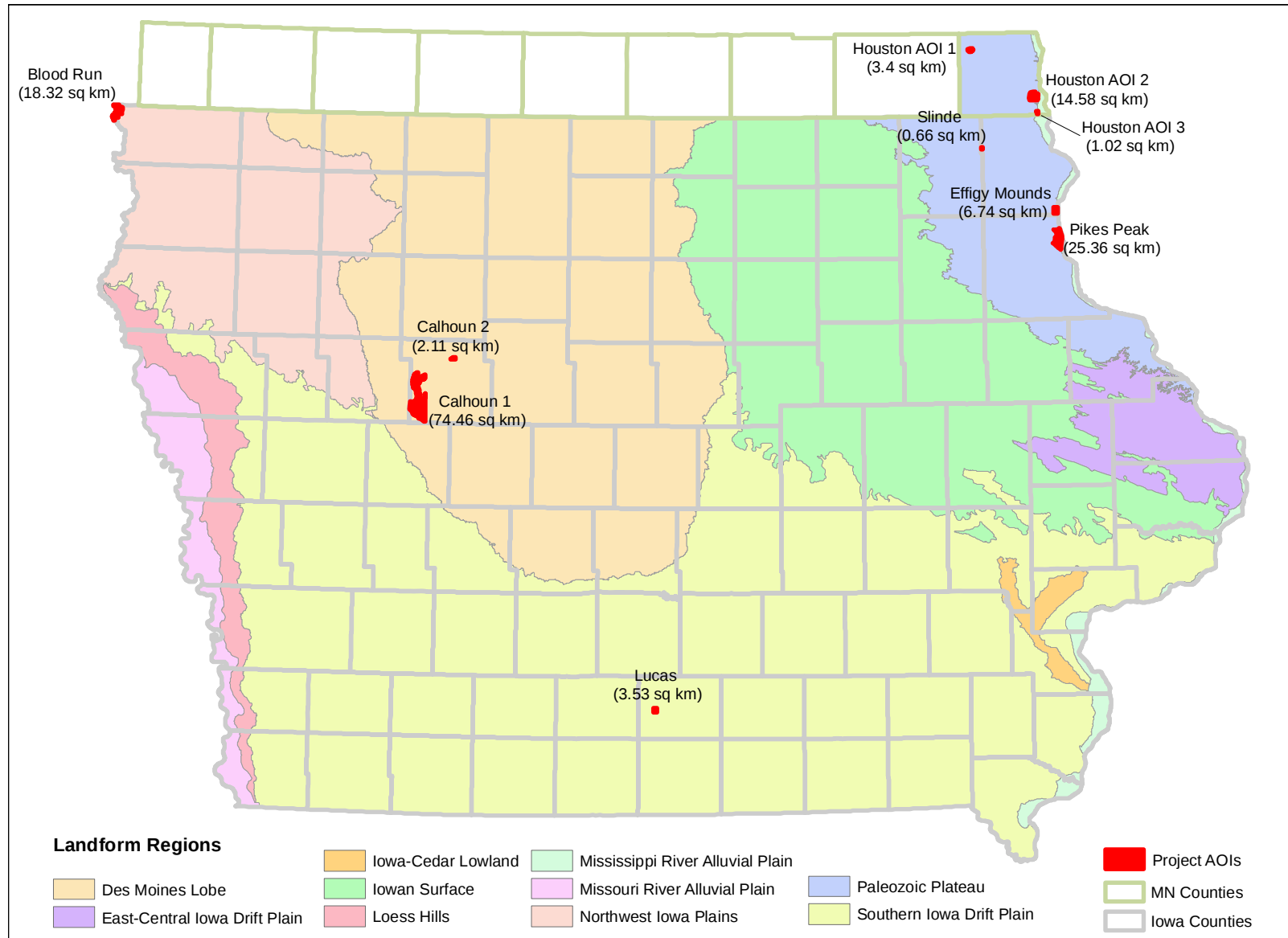


Figure 12. Areas of interest (AOI) for the project and physiographic boundaries in Iowa and Minnesota.

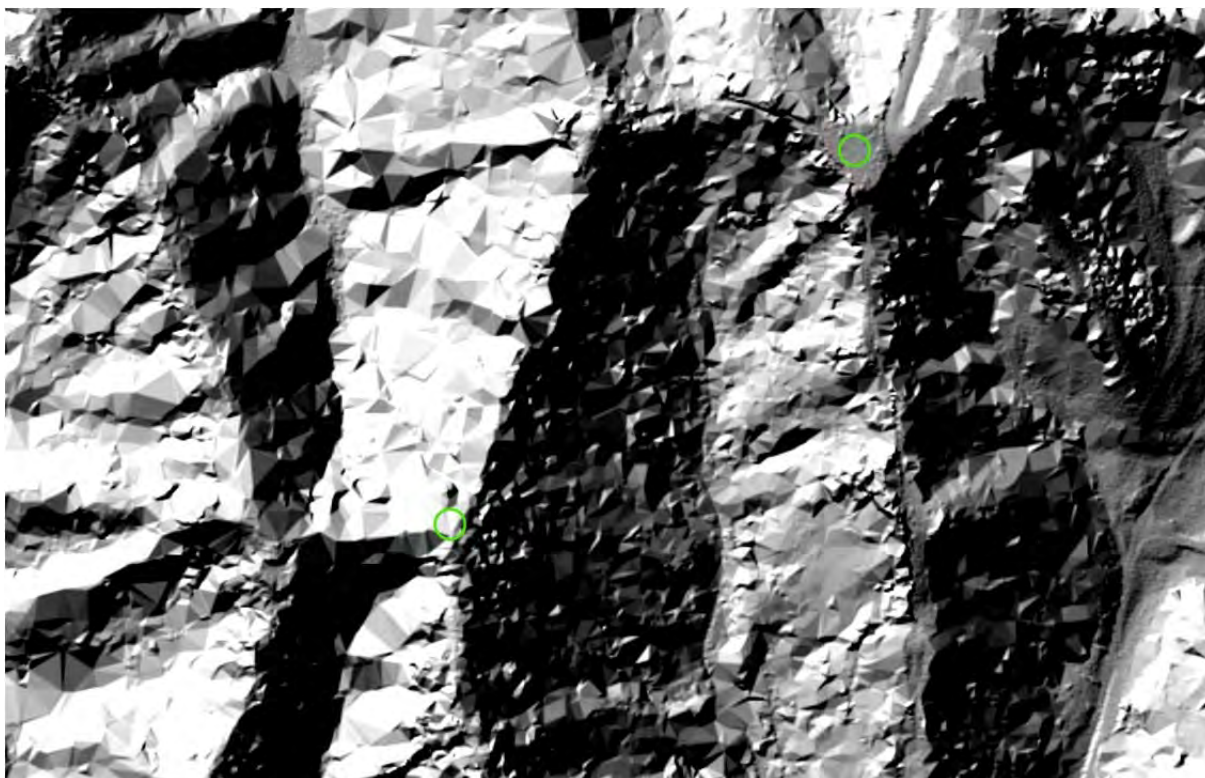


Figure 13. Mound sites as recorded in the Iowa sites GIS (in green) overlaying 1 m shaded relief image of an a forested area that was collected late in the season. This data is not appropriate for archaeological prospection and interpretation.

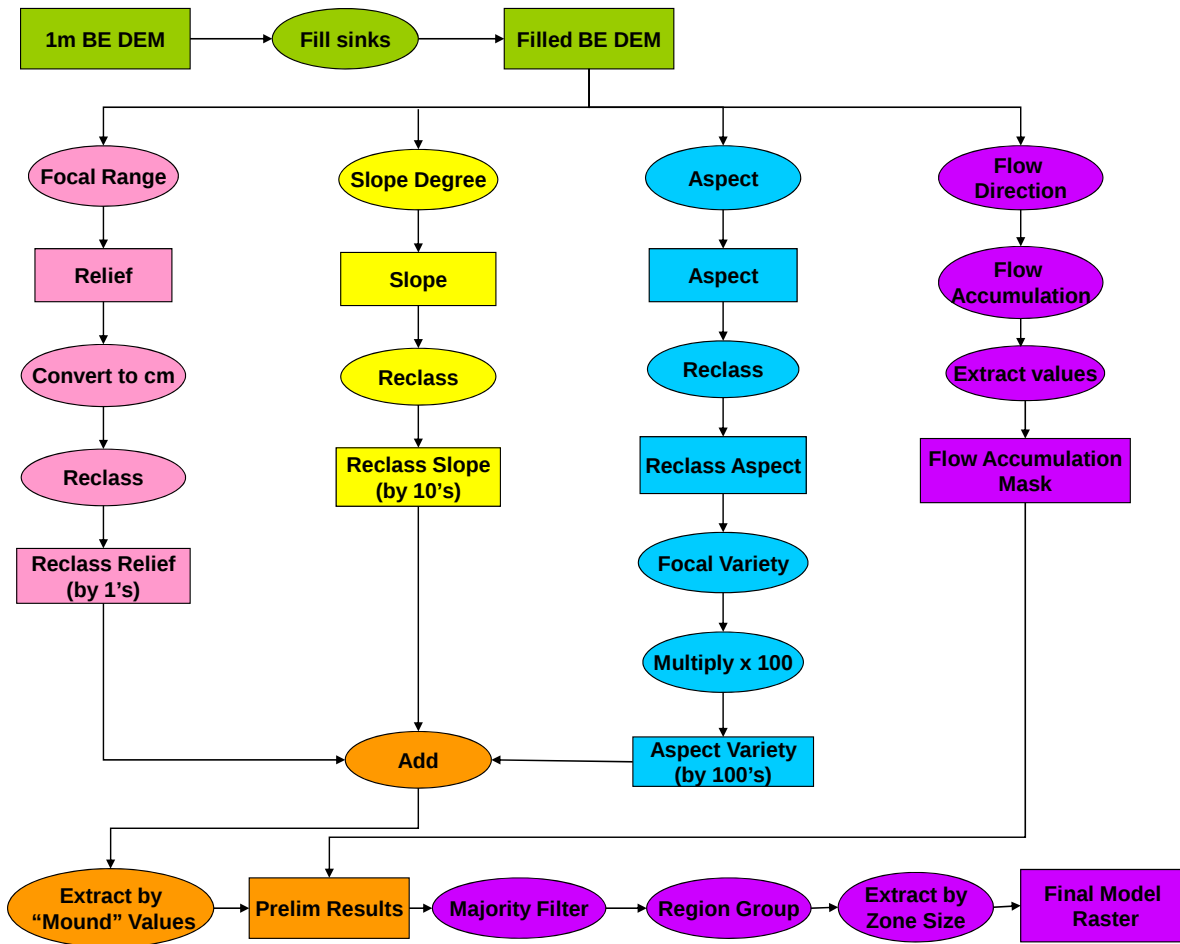


Figure 14. Conceptual framework of the prototype model.

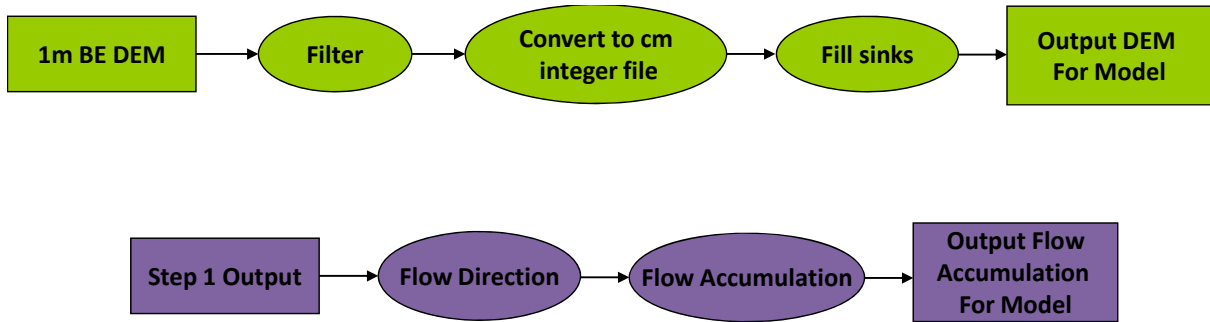


Figure 15. Conceptual framework of the Step 1 Prepare DEM model. Bottom: Conceptual framework of the Step 2 Flow Accumulation model.

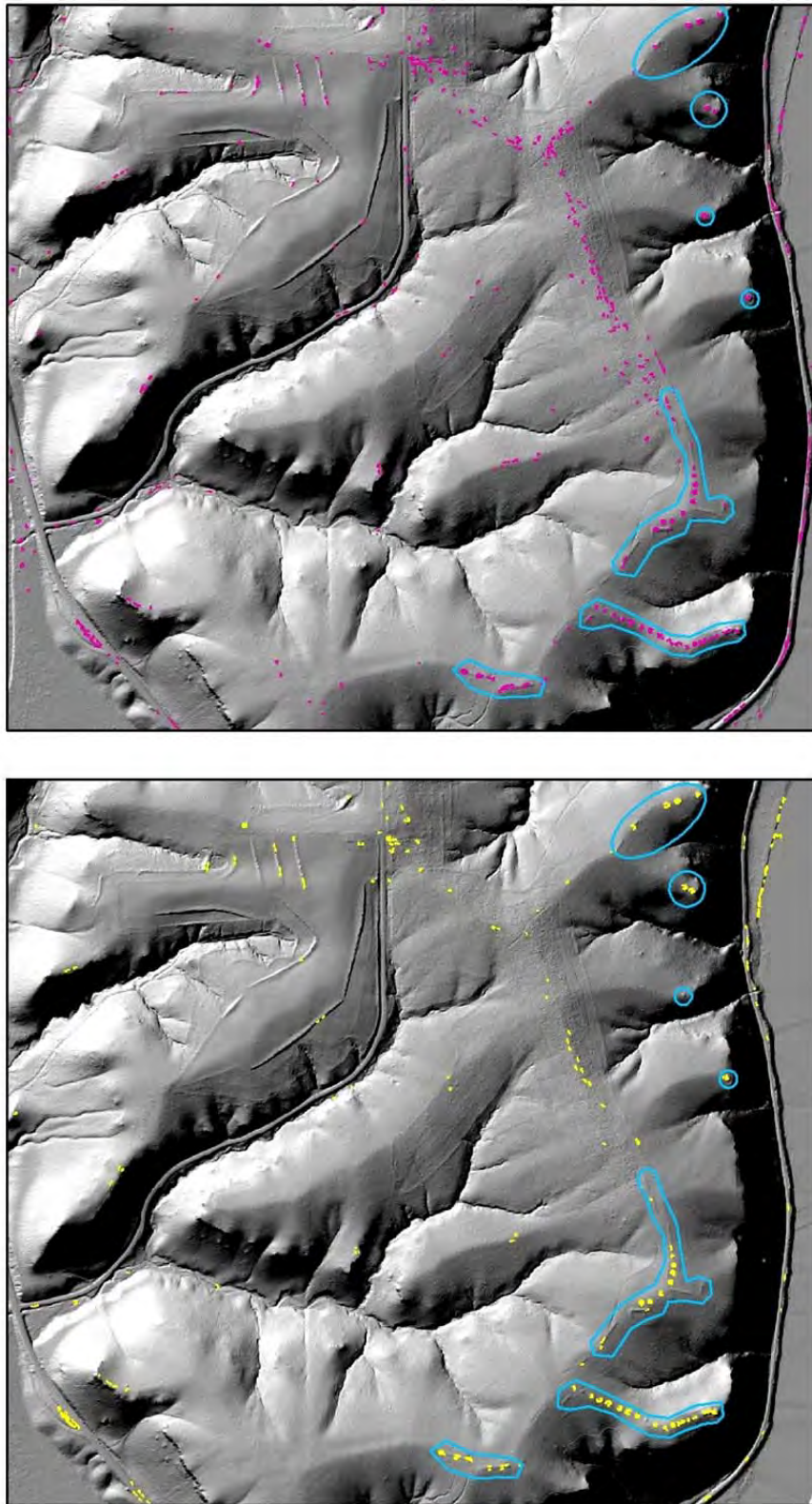


Figure 16. Top: Results of an early LiDAR Surveyor build without filtering out noise in the BE DEM. Bottom: Results from the same model build except a low pass filter was applied to BE DEM.

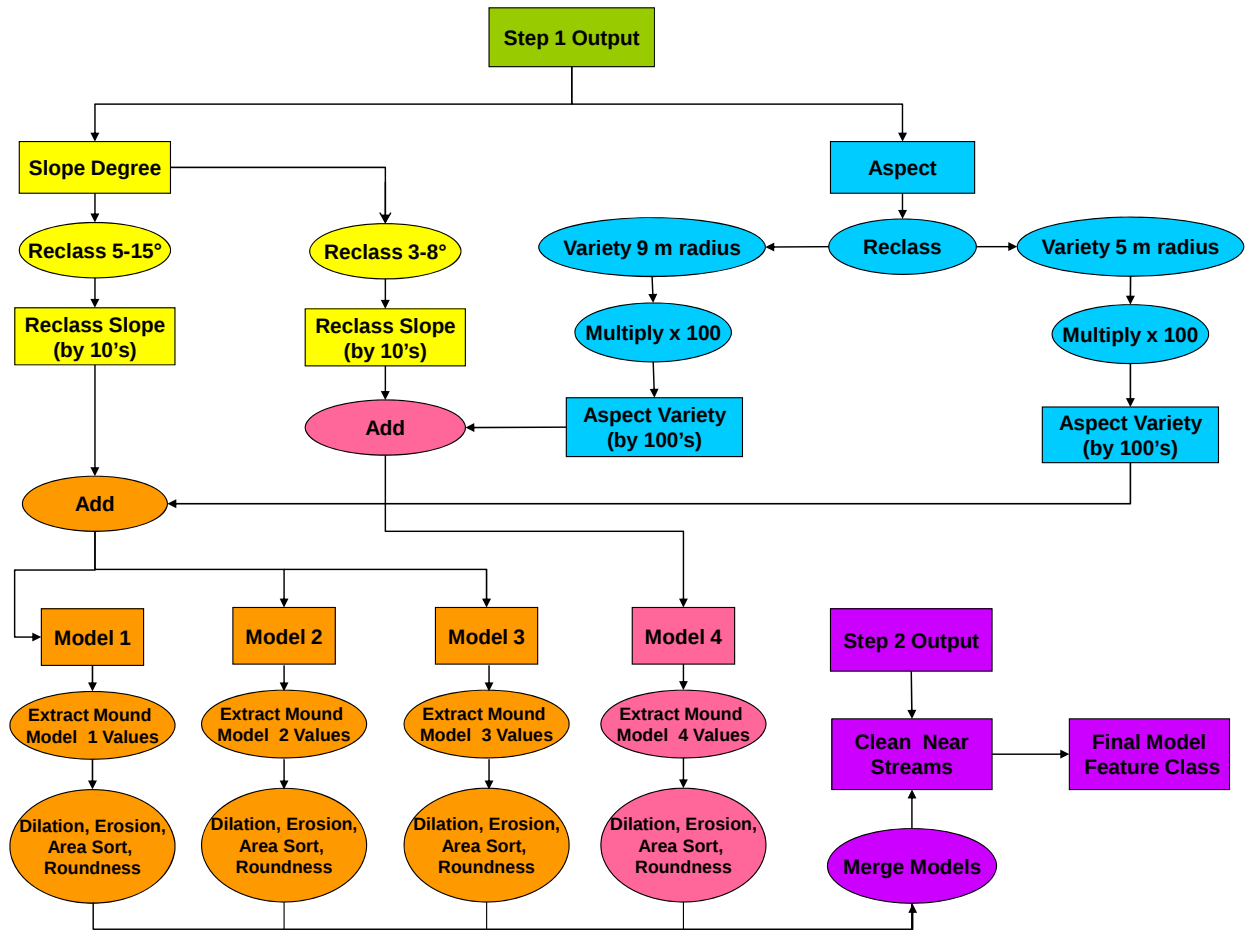


Figure 17. Conceptual framework of the Step 3 Mound Detection Model.

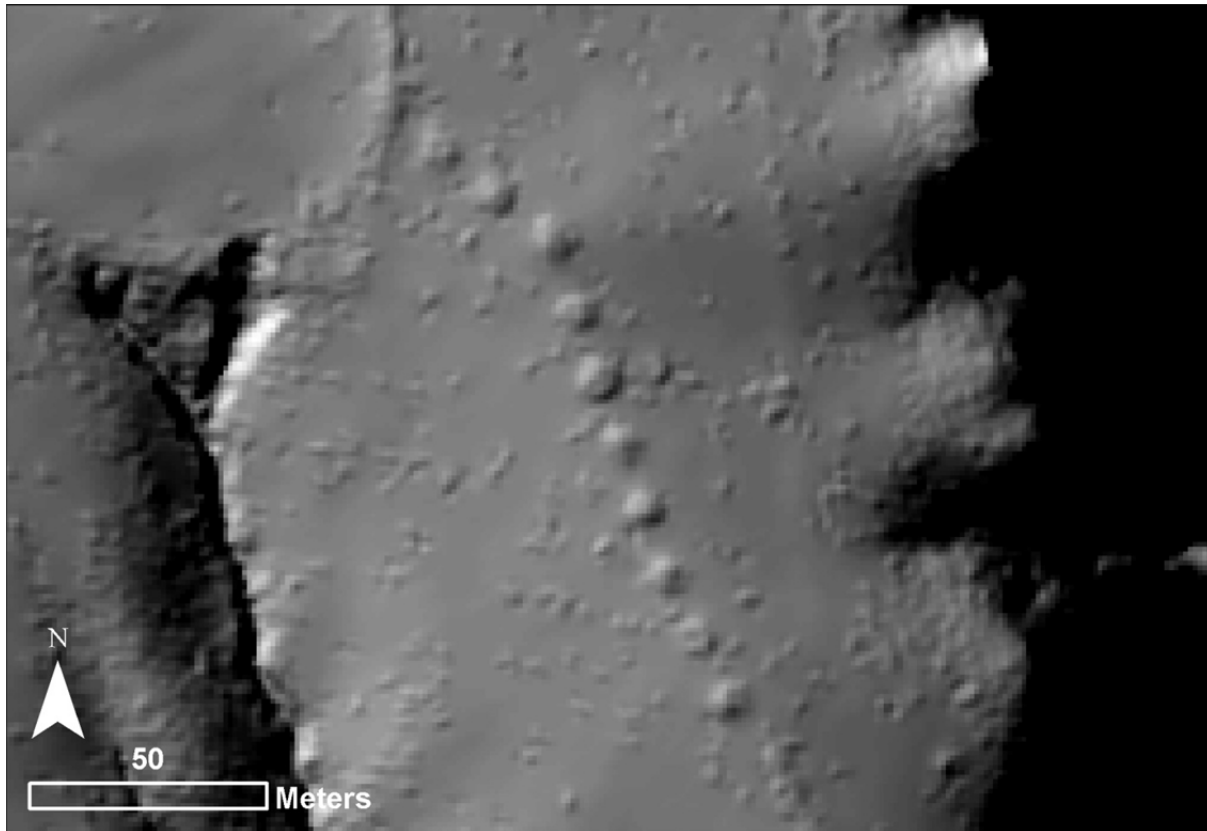


Figure 18. Example of the close mound arrangement addressed by model 2.

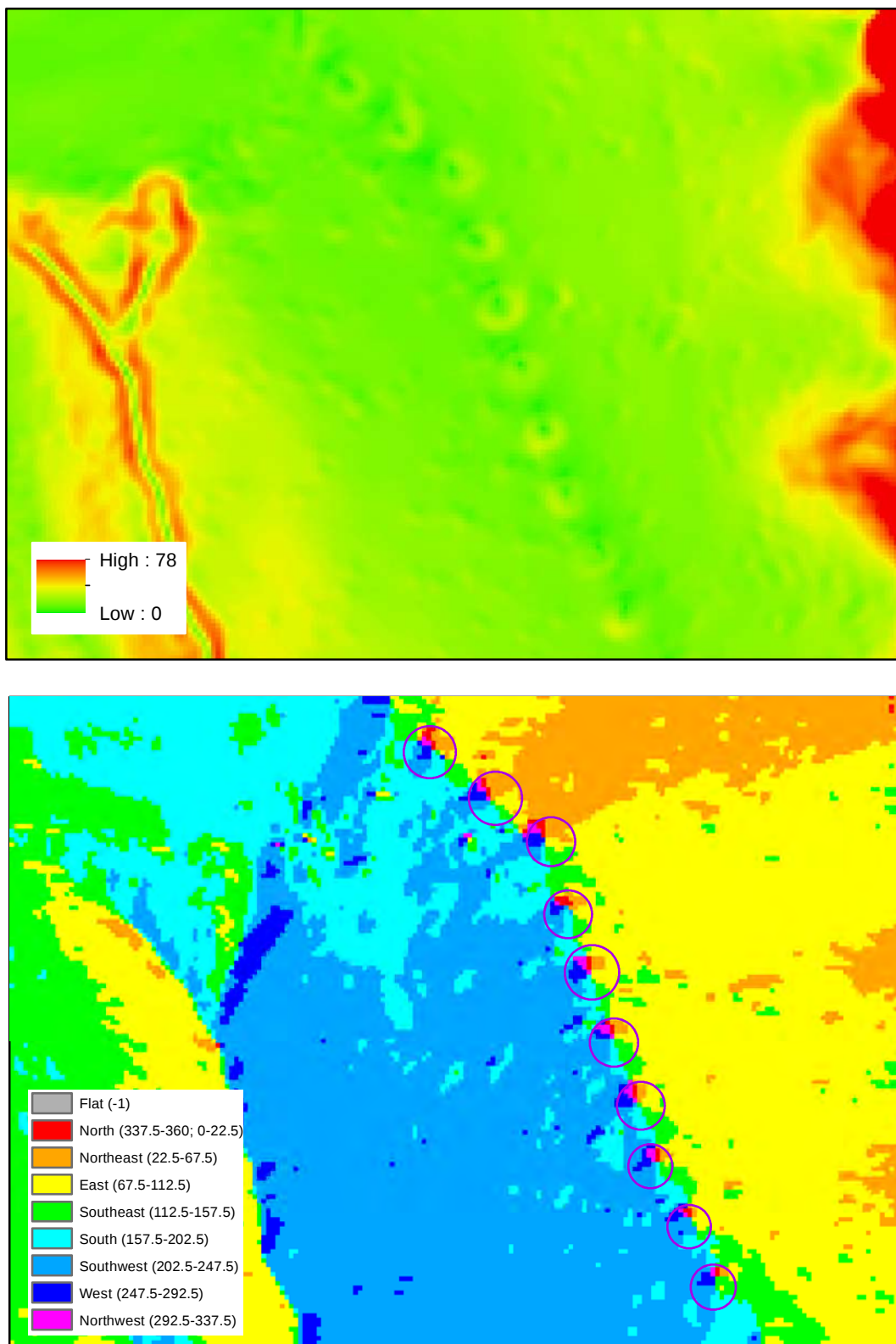


Figure 19. Same mound group depicted in Figure 18 in a slope (top) and aspect (bottom) raster. Mounds are traced in aspect image to show number of different aspect classes within their boundaries.

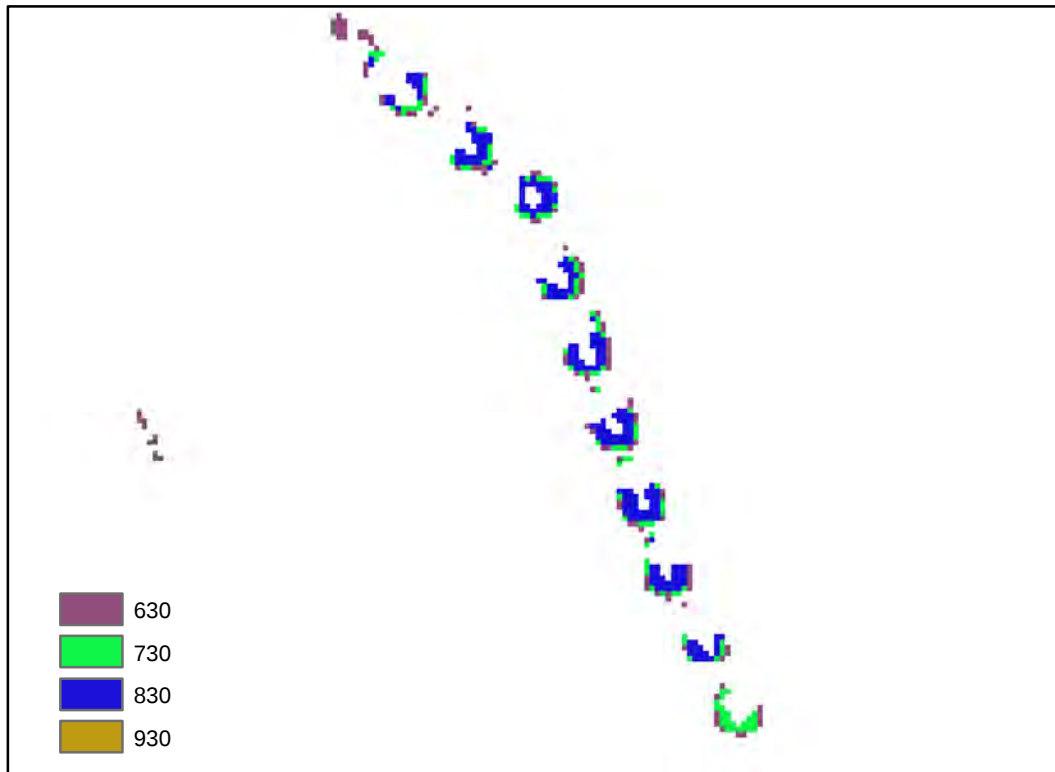


Figure 20. Same mound group depicted in Figure 18 after model 1 mound values were extracted. Note the original extracted file depicts mounds as annuli and crescents.

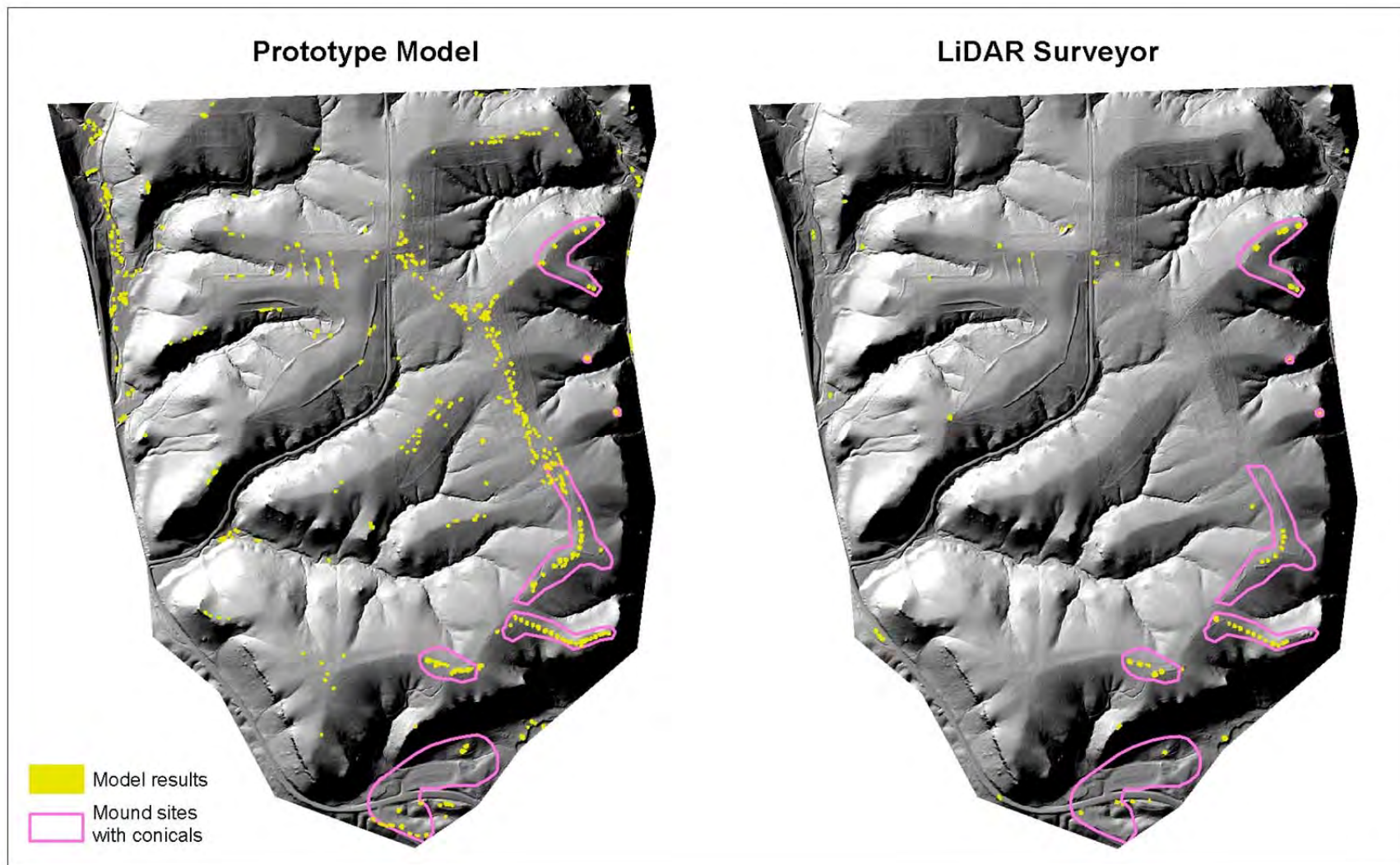


Figure 21. Comparison between prototype model results and LiDAR Surveyor results at Effigy Mounds AOI.

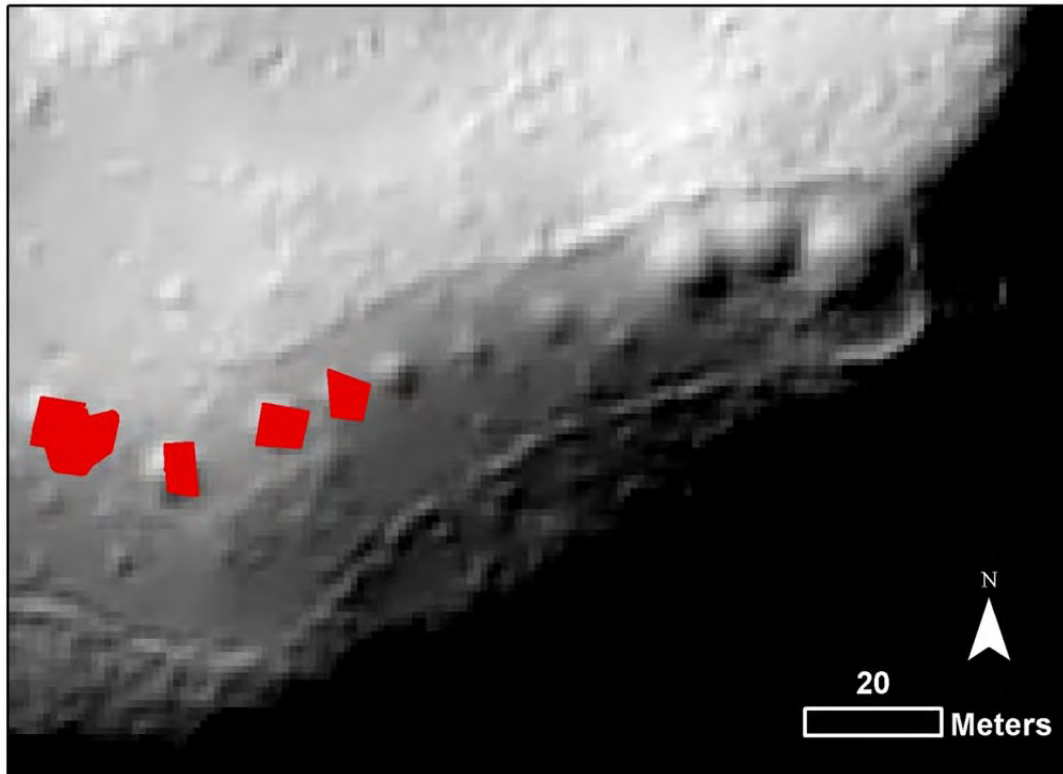


Figure 22. Small (4 m diameter) mounds and large, adjacent mounds not marked by LiDAR Surveyor.

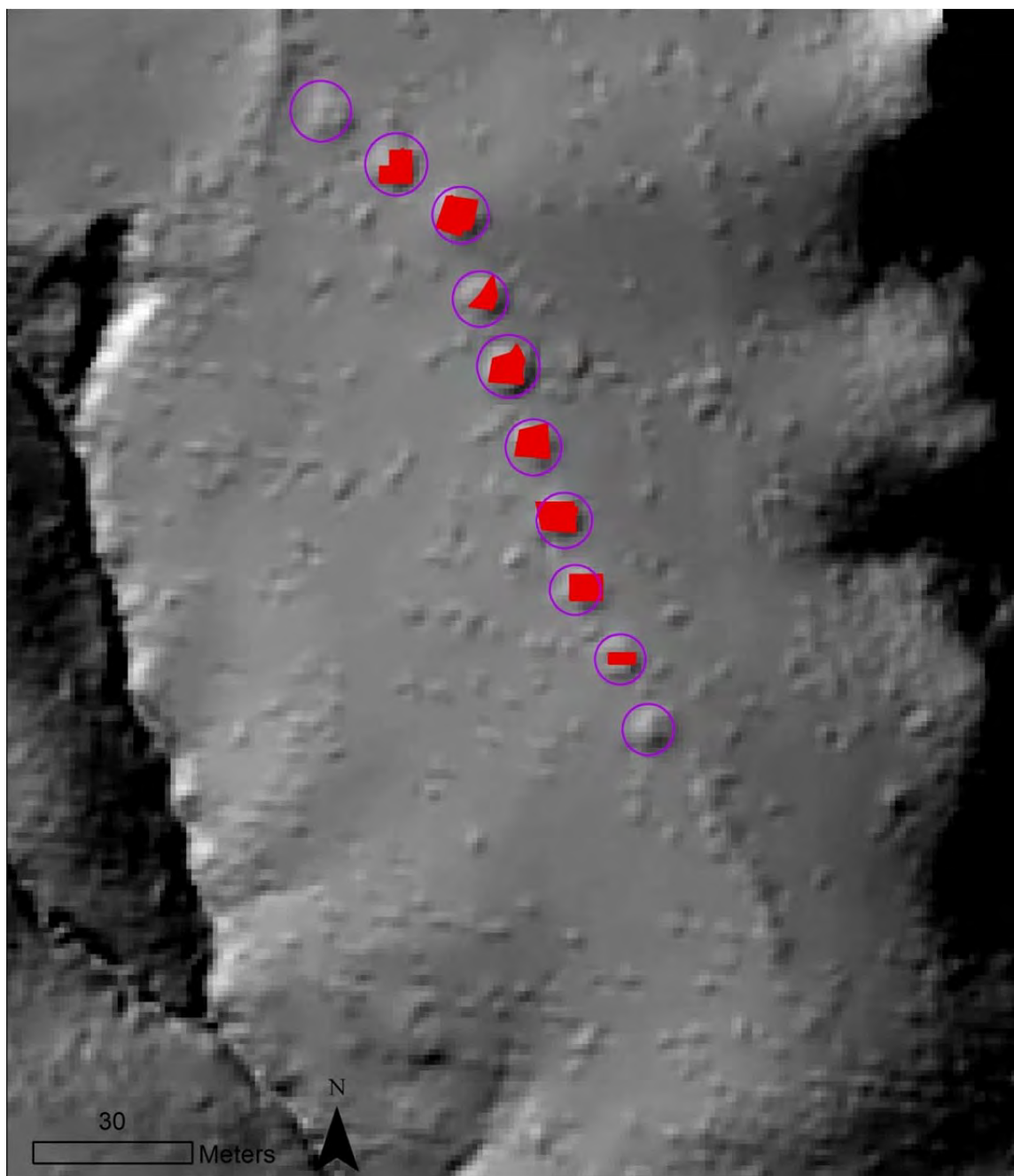


Figure 23. Mound group depicted in Figure 18 detected by LiDAR Surveyor; the model's marks are in red.

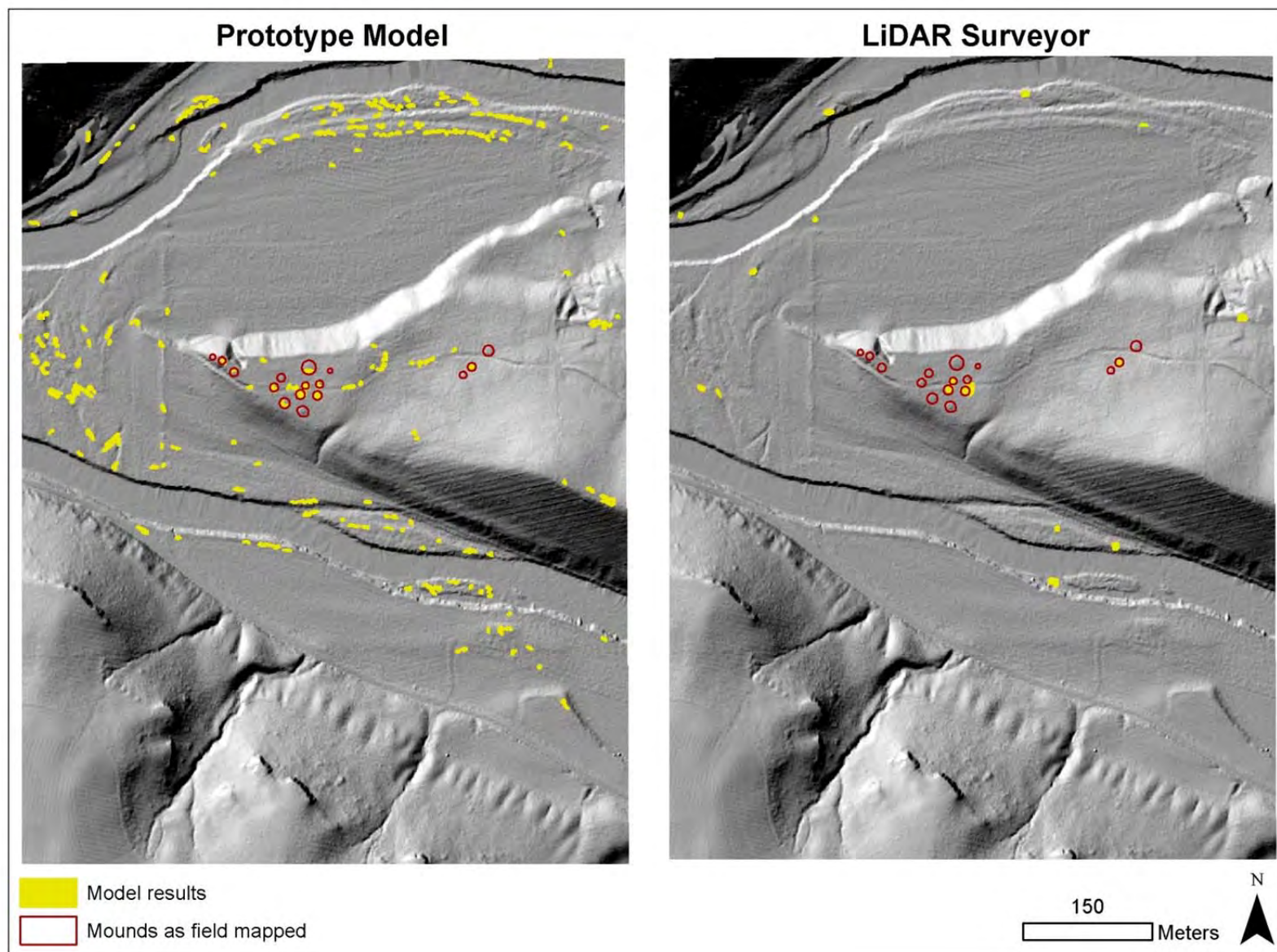


Figure 24. Comparison between prototype model results and LiDAR Surveyor results at Slinde AOI.



Figure 25. The two recorded mounds in the Lucas AOI from a 1 m shaded relief image, circled in red.

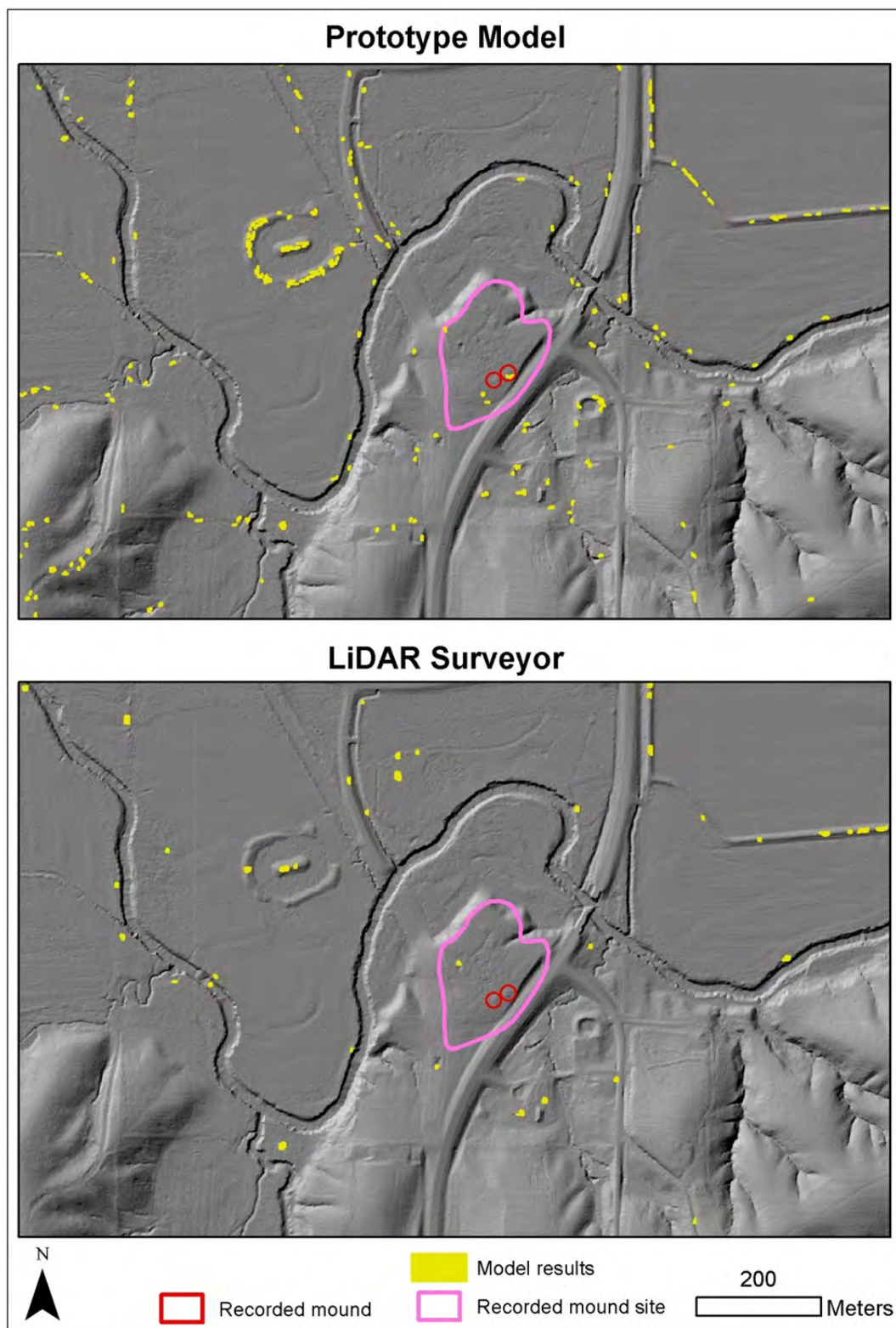


Figure 26. Comparison between prototype model results and LiDAR Surveyor results at Lucas AOI.

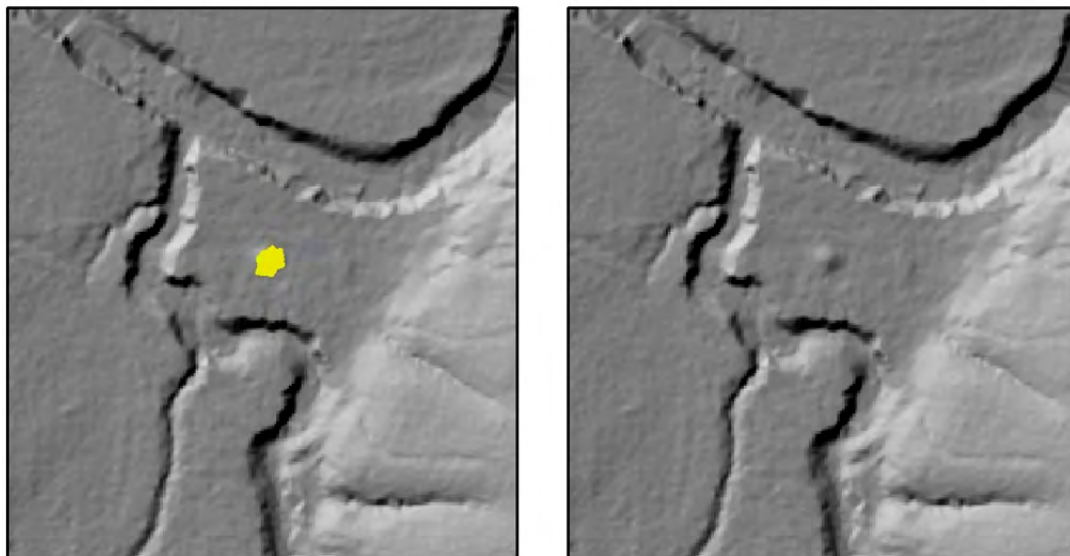


Figure 27. Possible unrecorded conical mound marked in the Lucas AOI.

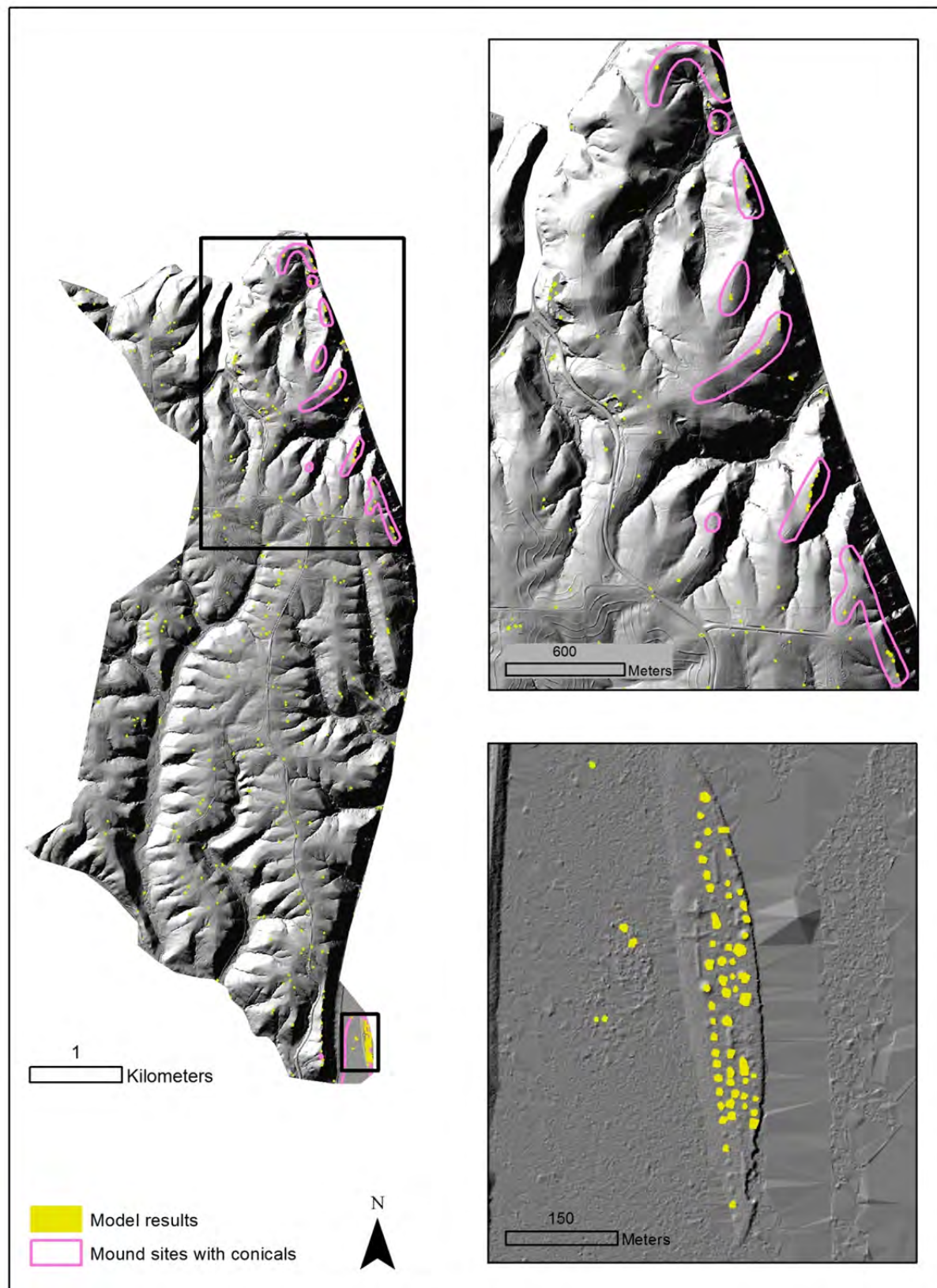


Figure 28. LiDAR Surveyor results at Pikes Peak AOI.

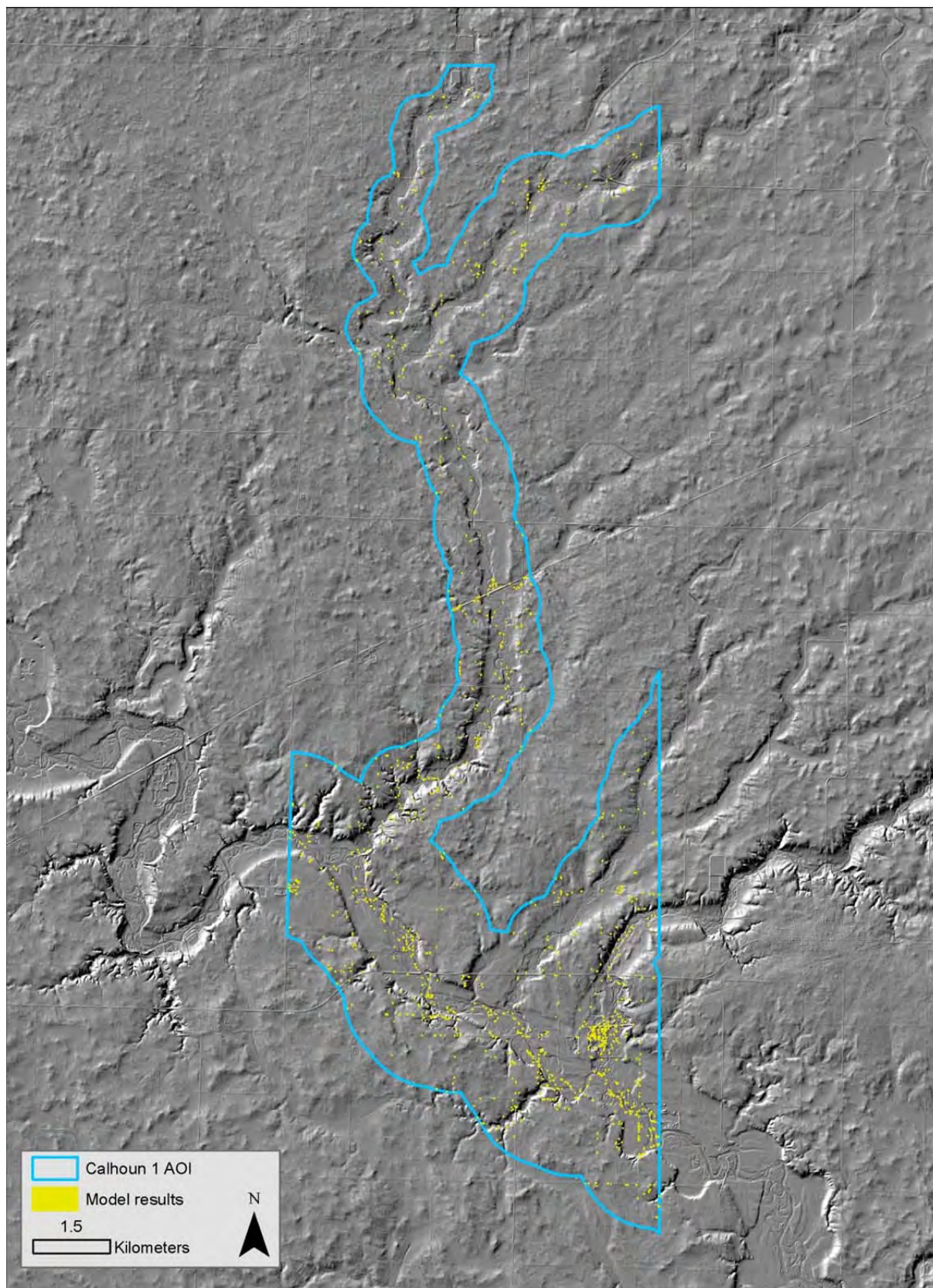


Figure 30. LiDAR Surveyor results for the Calhoun 1 AOI.

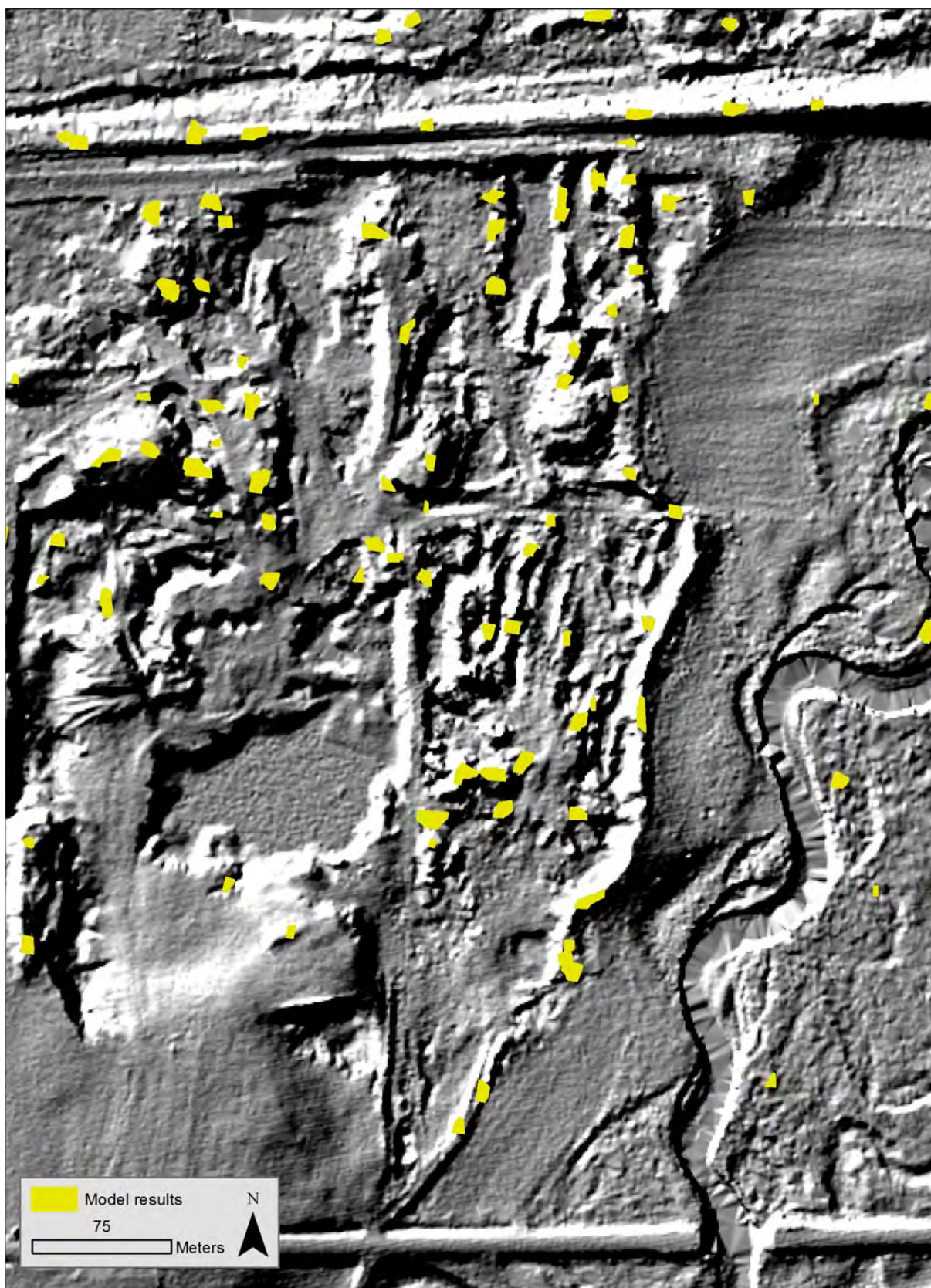


Figure 31. False positives caused by rugged surface of a quarry.

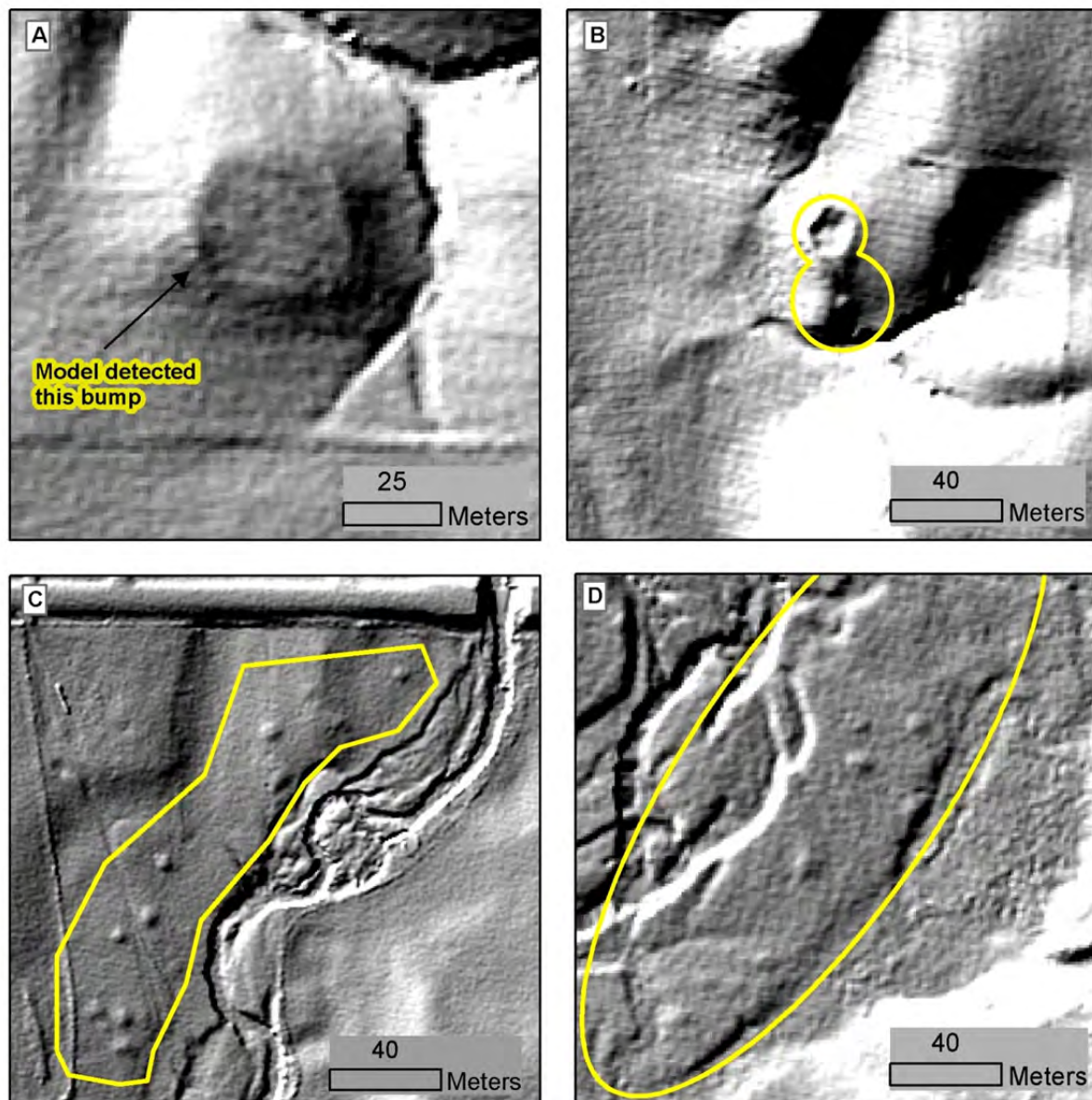


Figure 32. Detected potential archaeological features in the Calhoun 1 AOI: a) an irregular bump along an enclosure feature was detected by LiDAR Surveyor; b) conical mound feature detected in overshadowed area, depression only few meters north; c) possible unrecorded mound group; d) a second possible mound group.

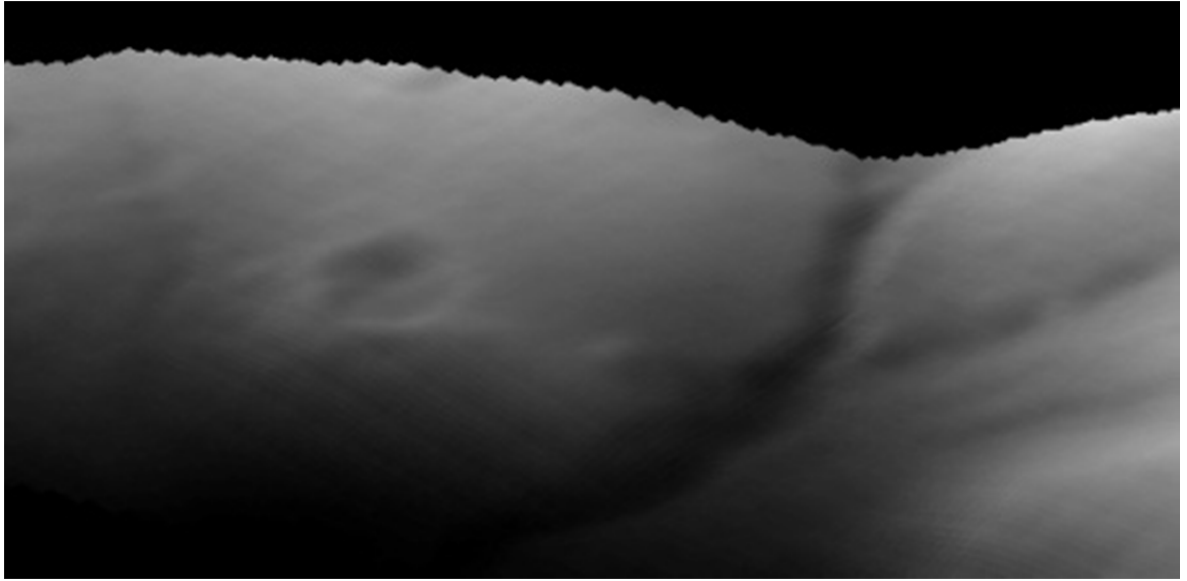


Figure 33. 3D BE DEM rendering of overshadowed mound and depression depicted in Figure 32b; view is facing east.

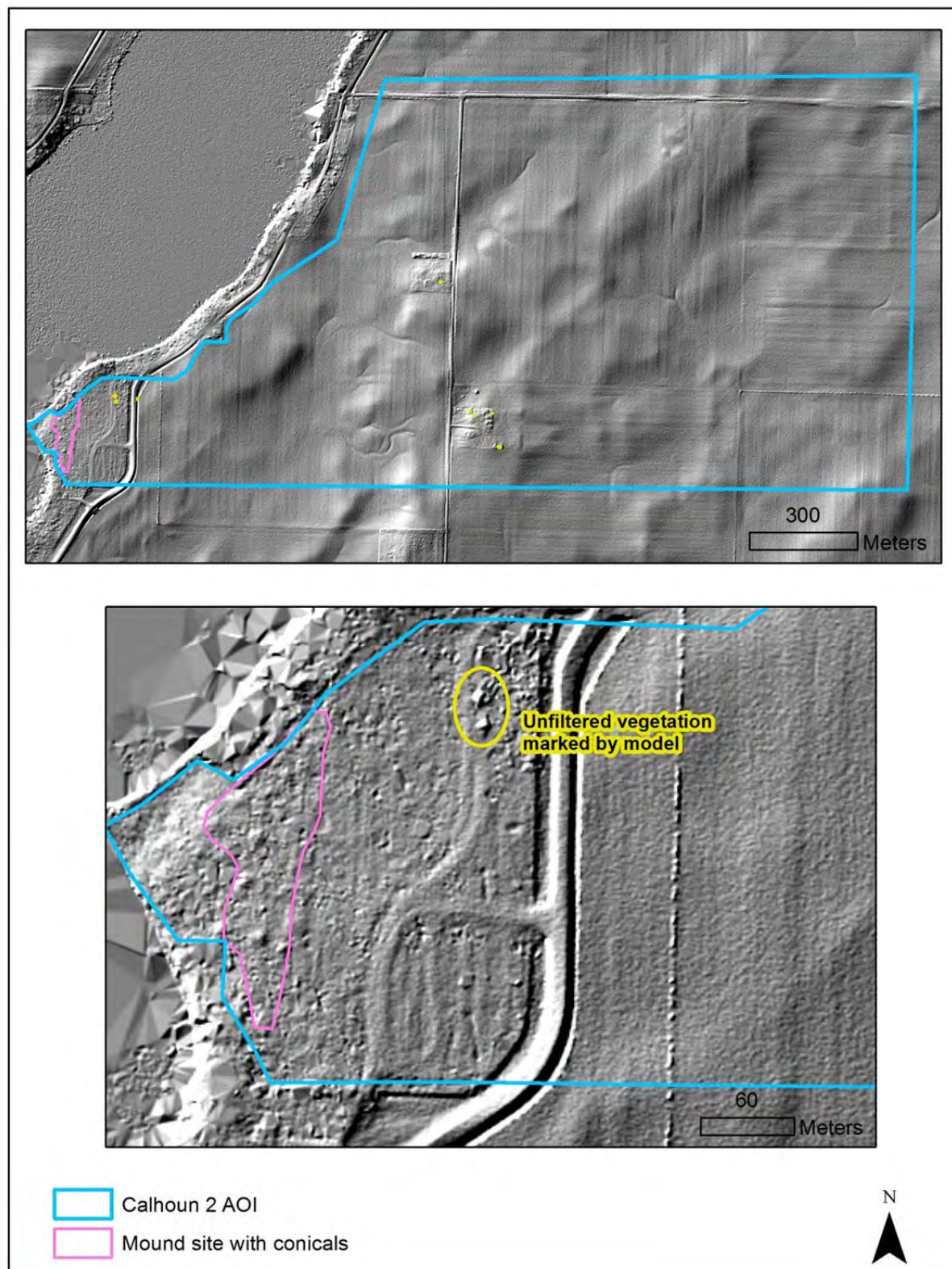


Figure 34. LiDAR Surveyor results for Calhoun 2; bottom figure shows mound shapes created by unfiltered vegetation which were marked by the model.

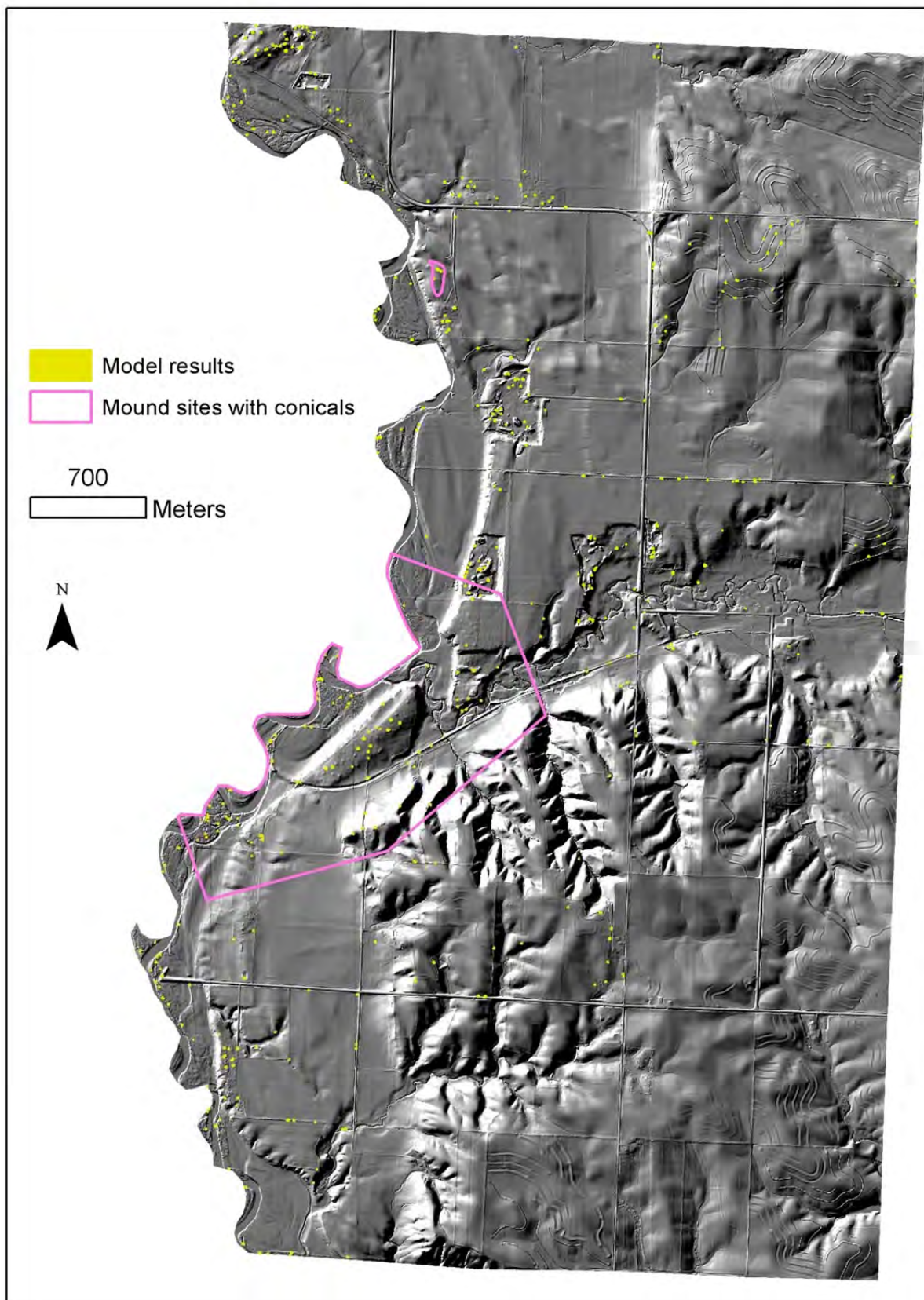


Figure 35. LiDAR Surveyor results for the Blood Run AOI.

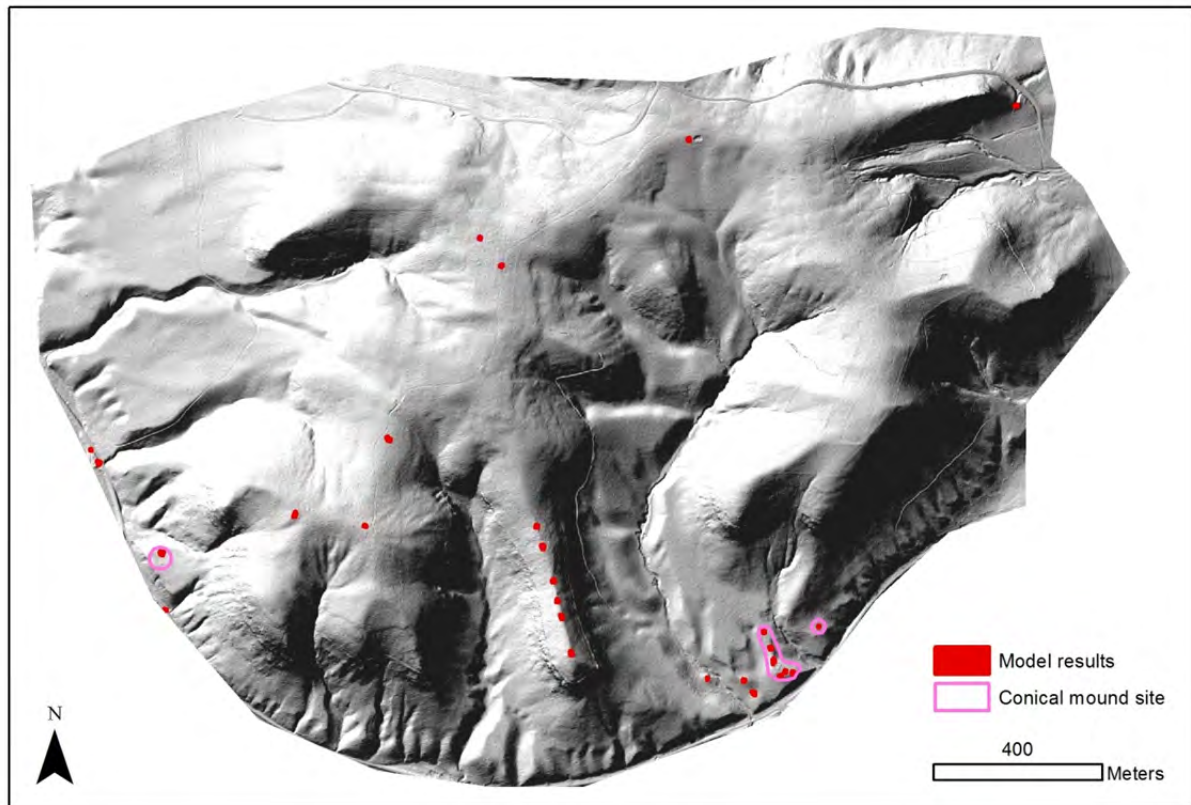


Figure 36. LiDAR Surveyor results for the Houston 1 AOI.

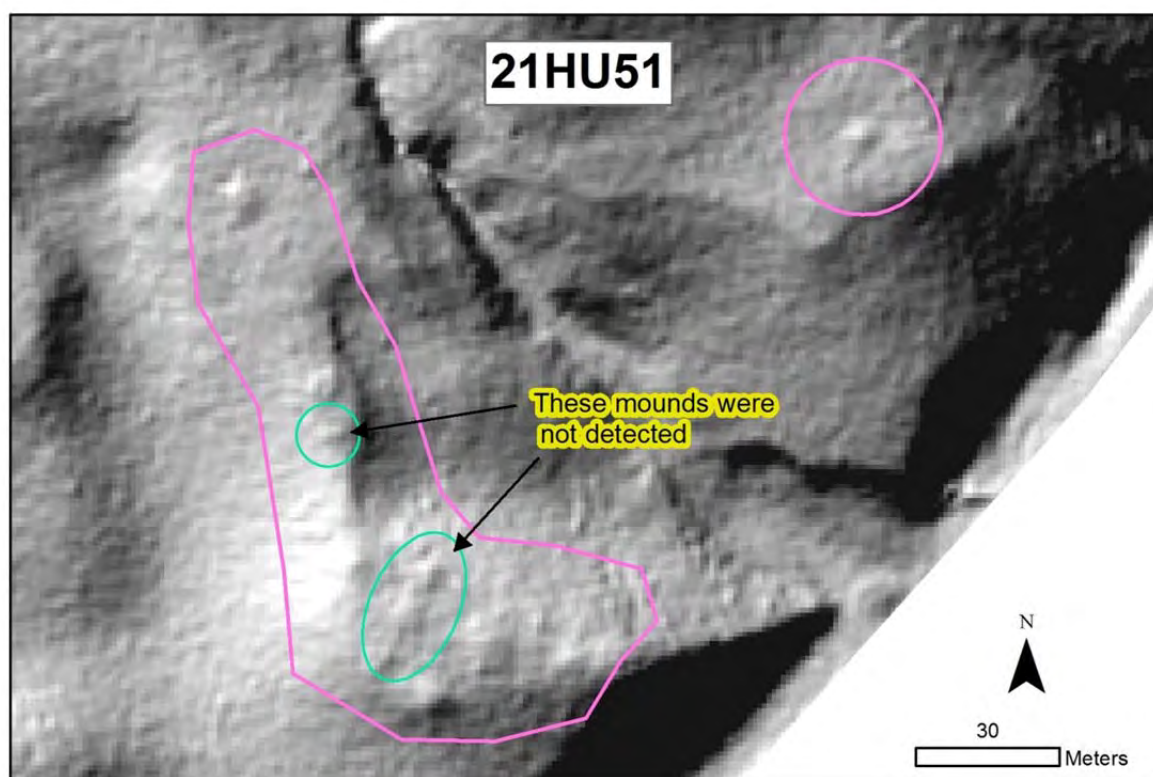
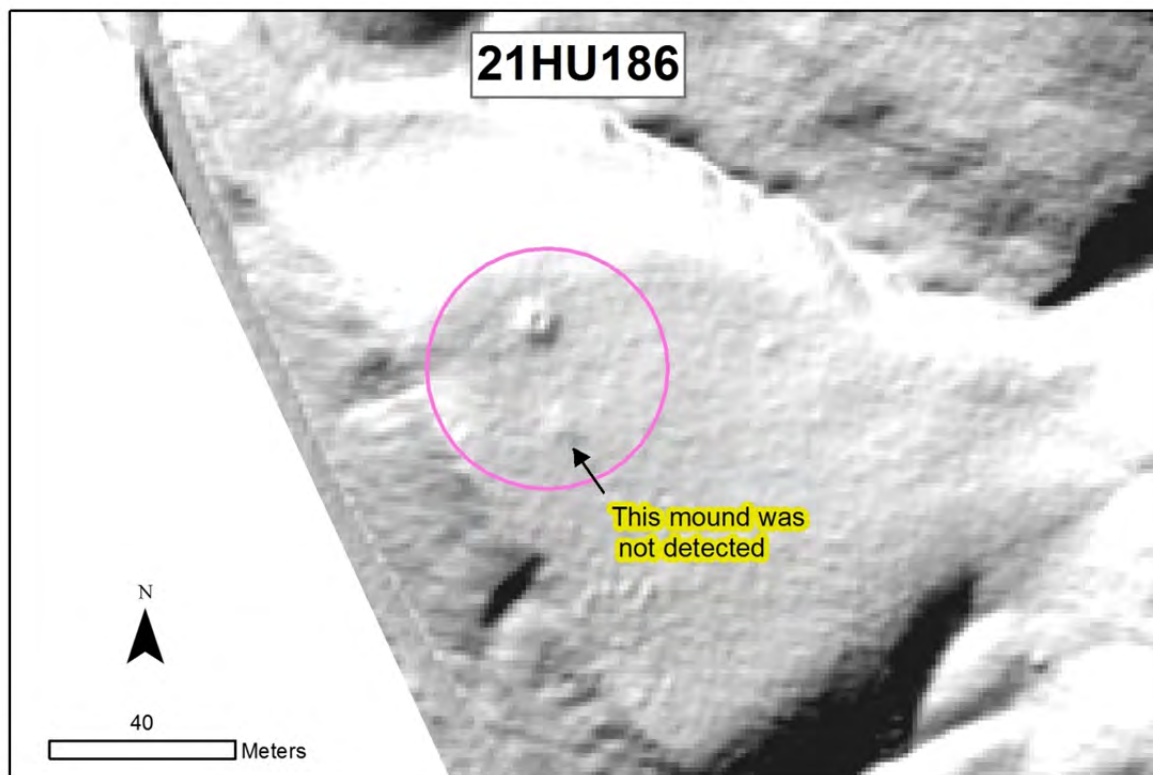


Figure 37. Recorded mounds not detected in the Houston 1 AOI.

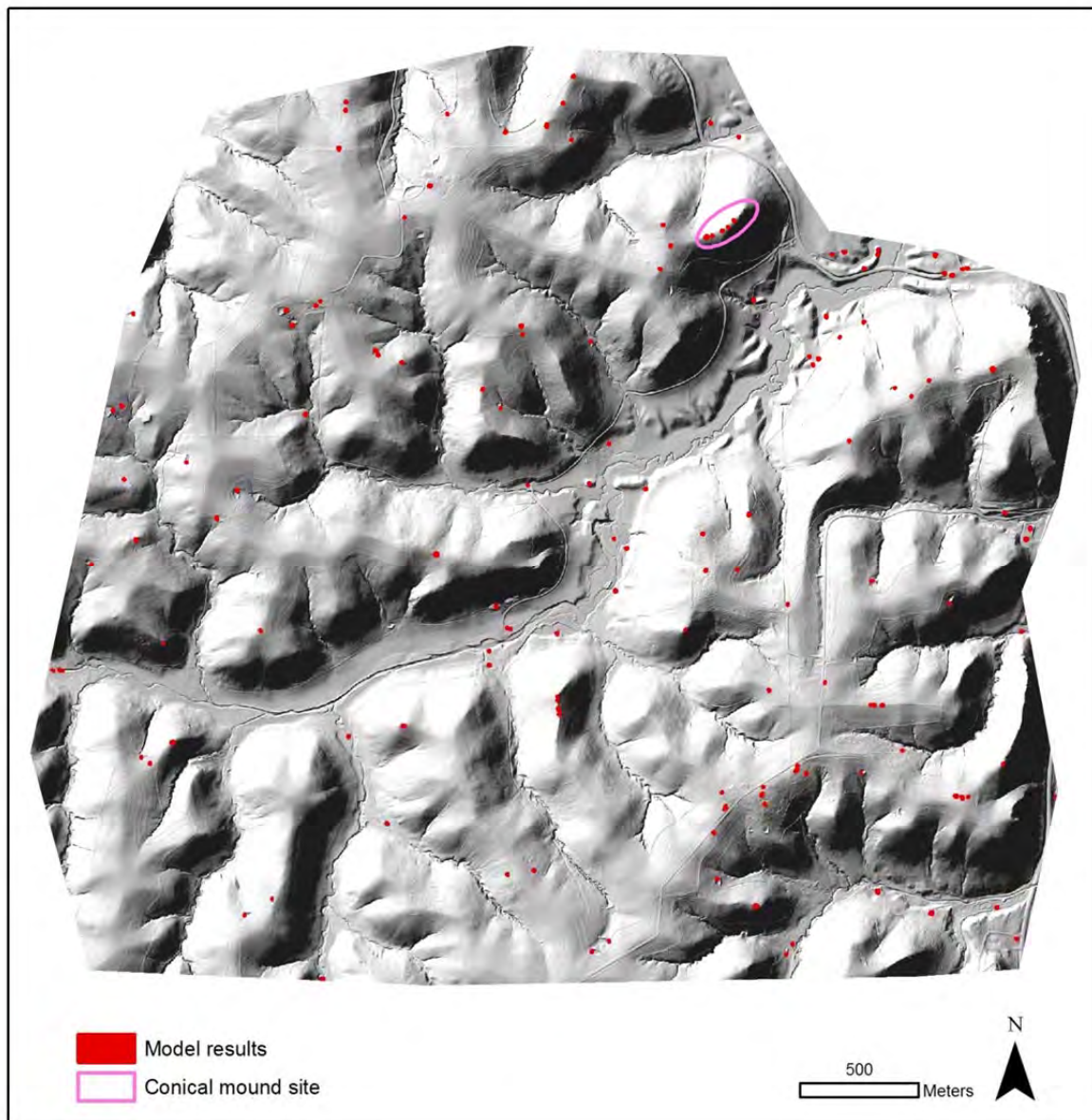


Figure 38. LiDAR Surveyor results for Houston 2 AOI.

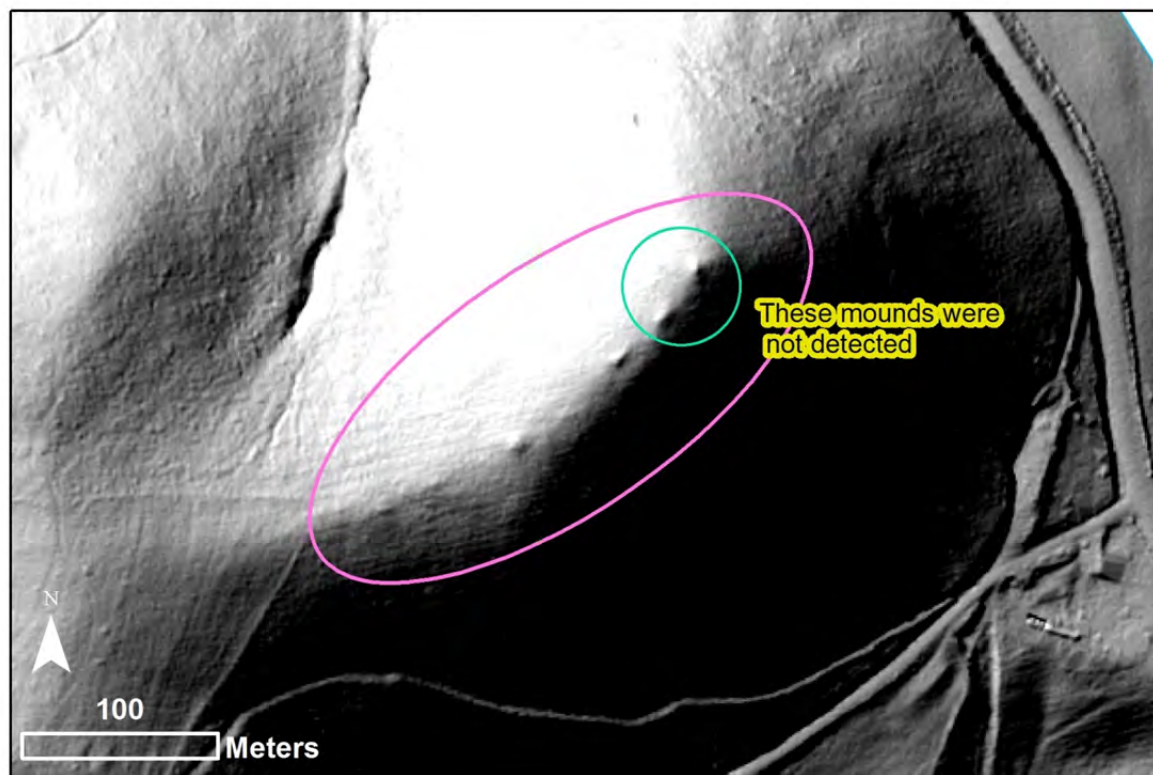


Figure 39. Recorded mounds not detected in the Houston 2 AOI.

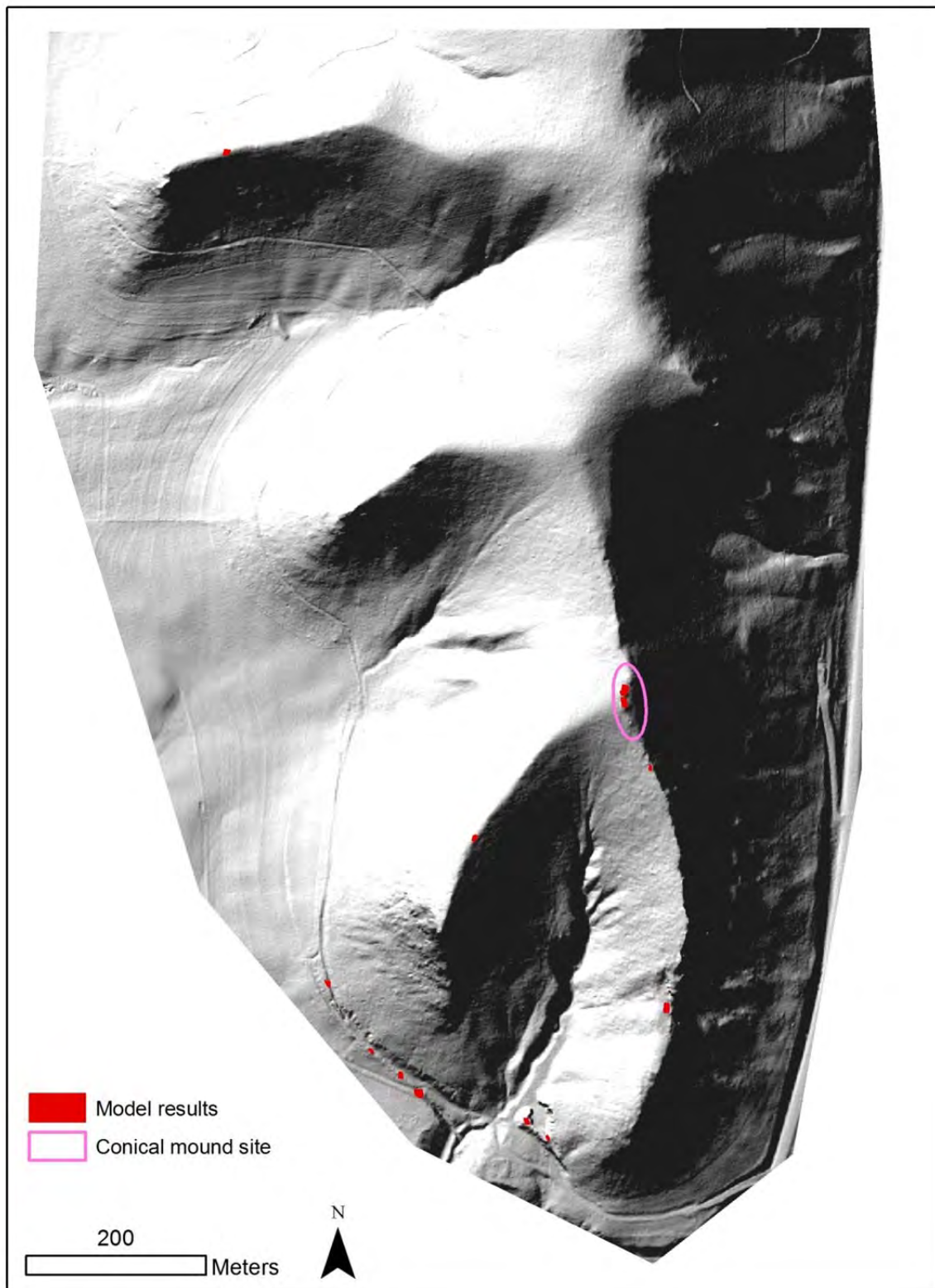


Figure 40. LiDAR Surveyor results for Houston 3 AOI.

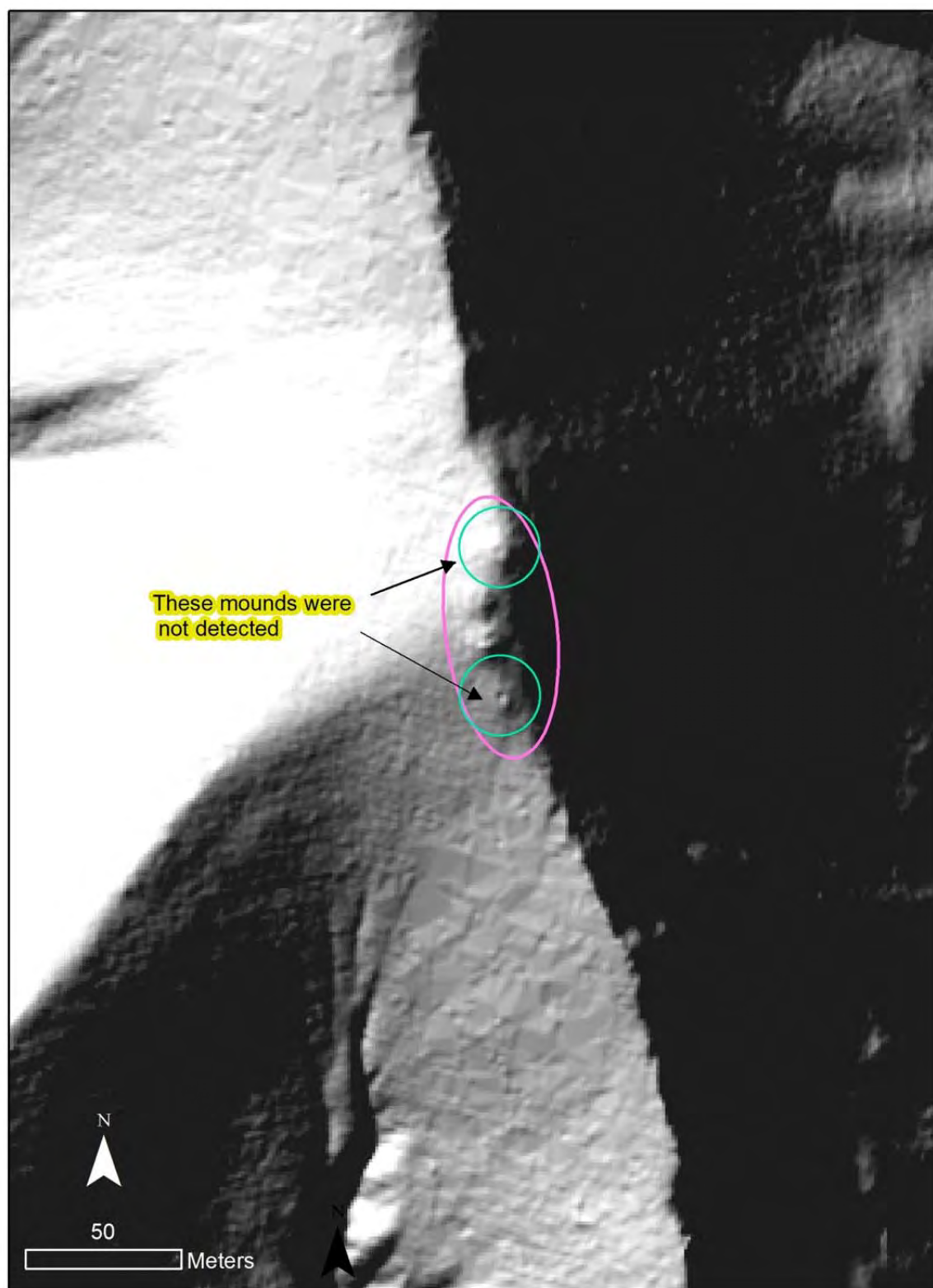


Figure 41. Recorded mounds not detected in the Houston 3 AOI.

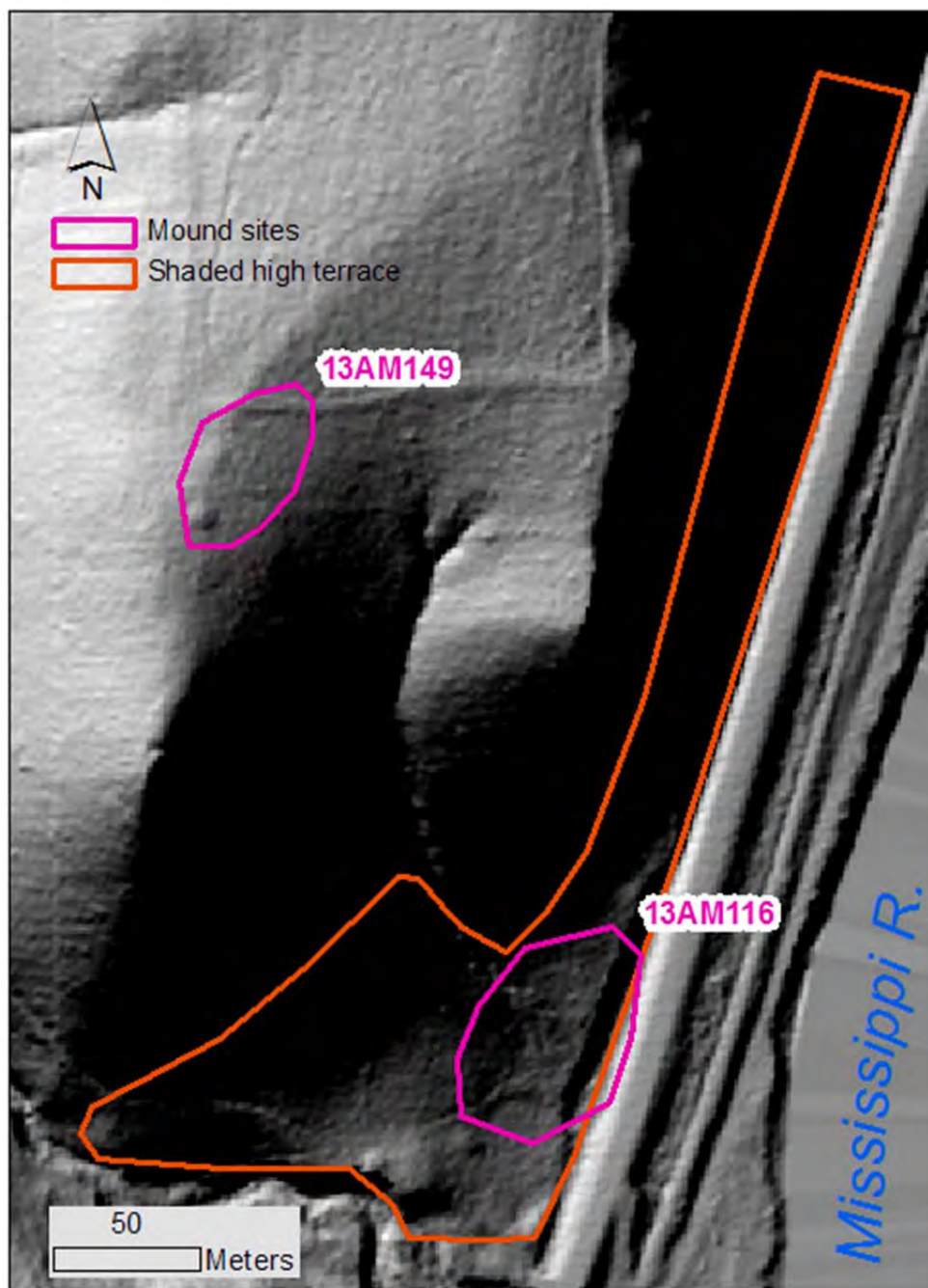


Figure 42. Area outlined in orange is a terrace overshadowed by the bluffs above. Mound sites are often found in this landscape position along the Mississippi River and other major rivers.

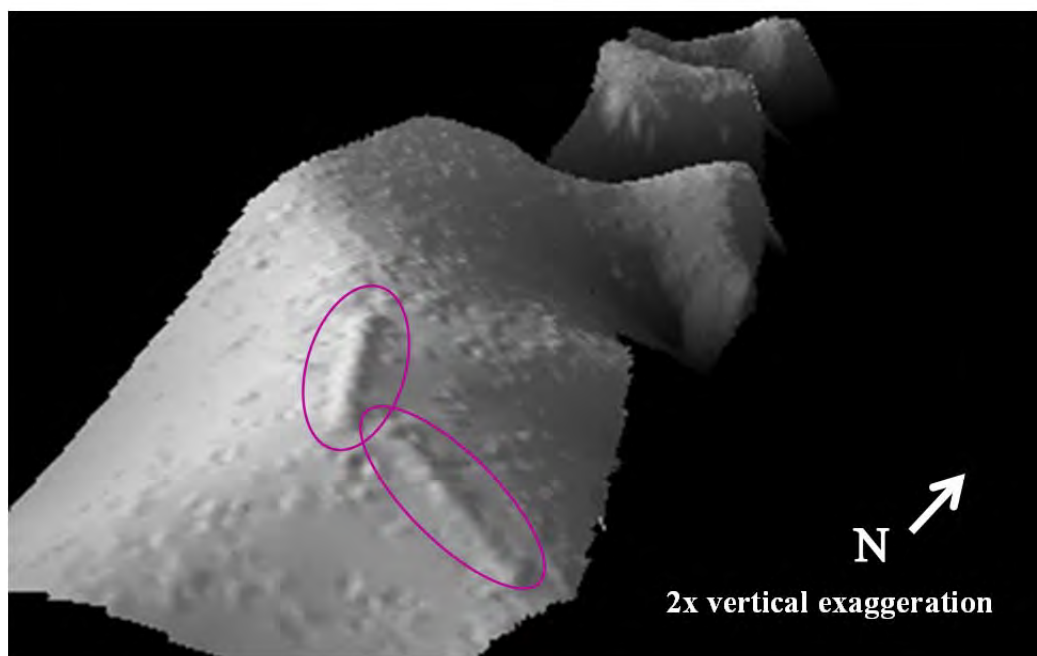
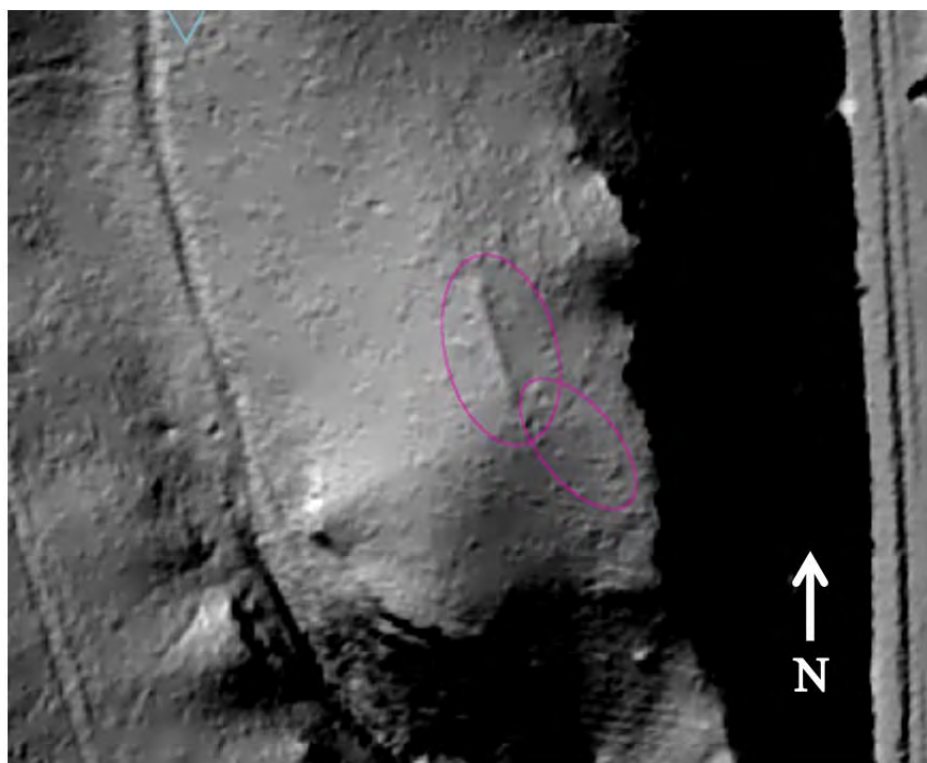


Figure 43. Recorded mound site with two linear mounds depicted in 1 m shaded relief image (top) and 3D BE DEM rendering (bottom). One of the linear mounds in the shaded relief image is not visible.

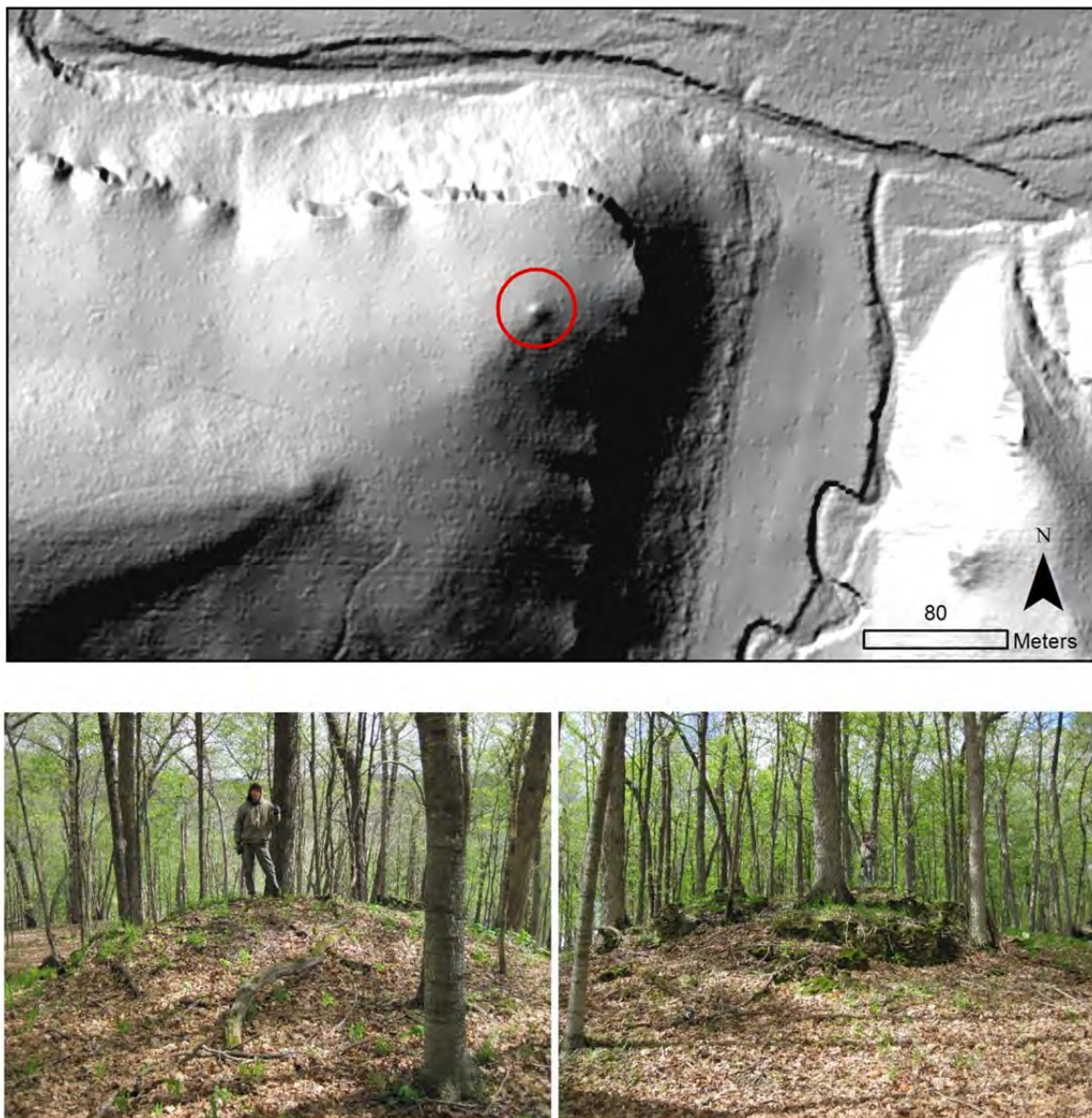


Figure 44. Top: Suspected unrecorded mound in the Yellow River basin on 1 m shaded relief image. Bottom: The object is actually a bedrock outcrop surrounded by soil (photos from Whittaker and Riley 2012).



Figure 45. Field-reported hummocky features are south of the recorded site; however, a mound-like feature is just south of the reported hummocks.

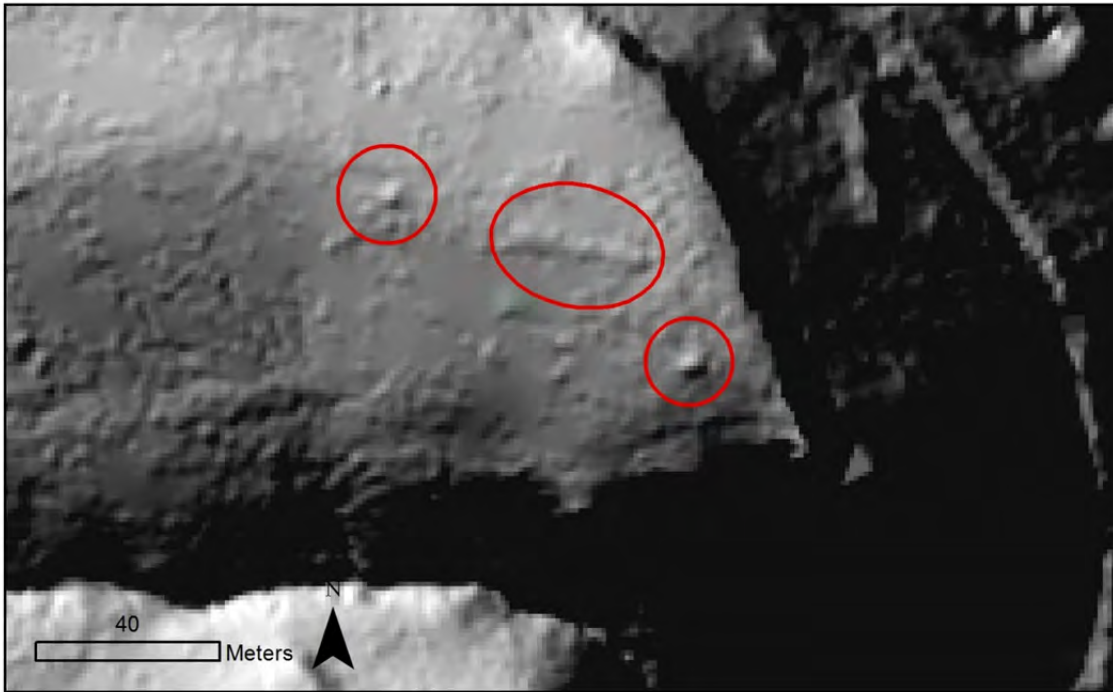


Figure 46. Linear feature was field-confirmed, but the two conical features are actually logs and brush.

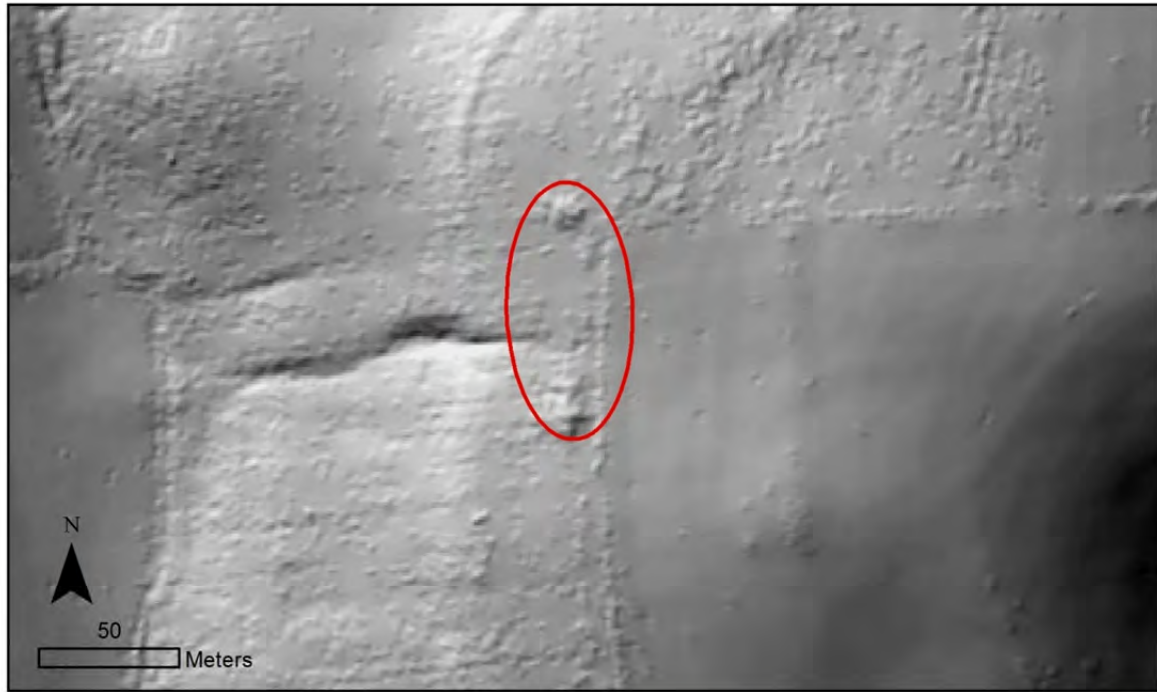


Figure 47. Top: Suspected unrecorded mounds in the Yellow River basin on 1 m shaded relief image. Bottom: The objects are actually two old push piles (photos from Whittaker and Riley 2012).

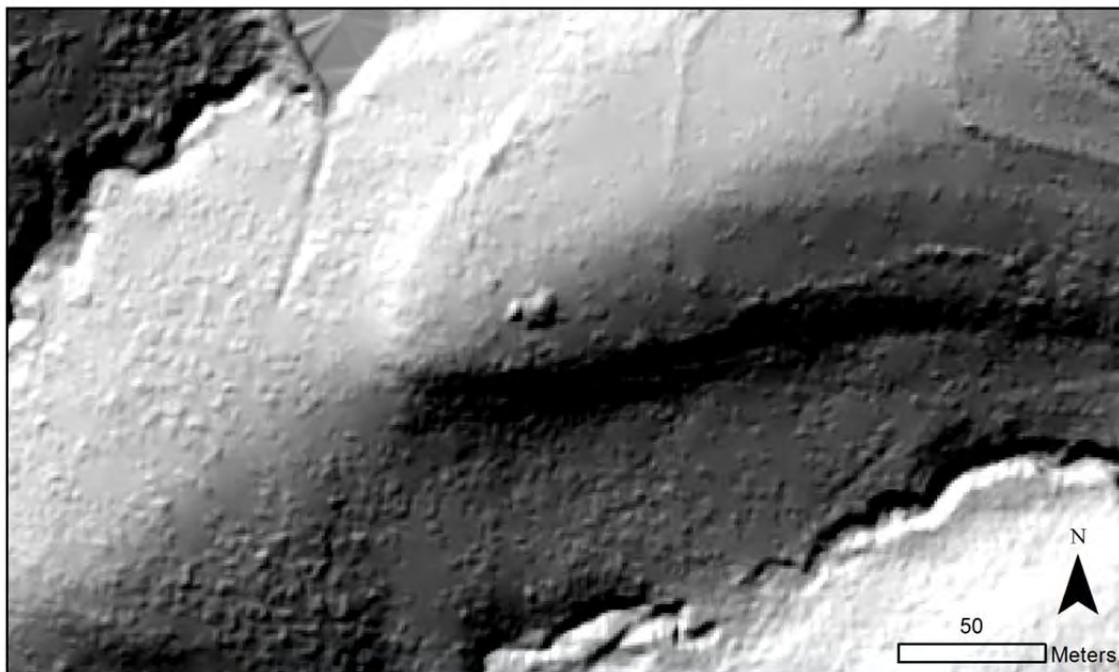


Figure 48. Top: Suspected mound site in the Yellow River basin. Bottom: The mound feature was actually a trash pile (photo from Whittaker and Riley 2012).

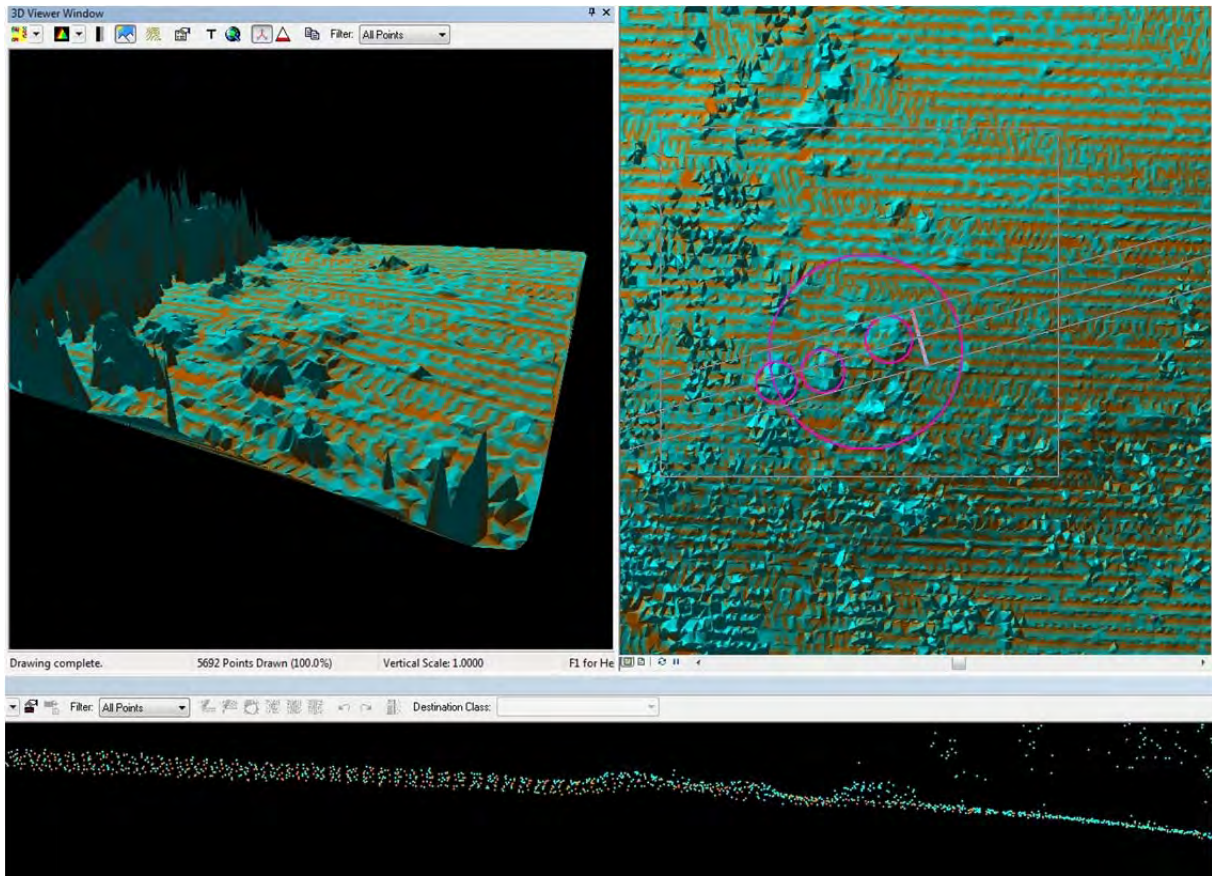


Figure 49. Three views from point cloud data of the trash pile in Figure 48. Domed-shape concentrations of non-ground points is similar to misclassified mounds in Figure 7.