Mapping Precontact Burial Mounds in Sixteen Minnesota Counties using Light Detection and Ranging (LiDAR)

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Abstract

The University of Iowa Office of the State Archaeologist (UI-OSA) employed Light Detection and Ranging (LiDAR) data to verify and improve the accuracy of mapping of burial mounds for 16 Minnesota counties. UI-OSA analyzed LiDAR data for all known mound sites within the 16 counties, producing LiDAR images of mounds, and synthesizing data on land use, site condition, historic/modern survey information, and other data for the mound sites. The project area includes 650 previously recorded mound sites with documentation of 7646 individual mounds. Analysis of historical maps and archaeological survey data resulted in the georeferencing of the possible locations of 6,223 of these mounds. LiDAR data from these sites were analyzed using a number of methods, including default hillshades, custom hillshades, and point clouds of data. A total of 2181 mounded features were clearly seen in LiDAR data within site areas (28.4 percent), and an additional 597 were possibly observed but were too indistinct to be certain, for a total of 2778 mounds possibly observed (36.2 percent of all mounds). As a side benefit, although this project was not intended to prospect for mounds, 118 possibly new mounds were observed at 12 sites in six counties. Mound density per county ranges from .05 to .81 mounds/km^2 and averages 11.7 mounds per site. Half the sites contained three or fewer mounds. Fifty-four percent of mounds were found in predominantly wooded areas, and only 7.5 percent of mounds occurred in developed areas and road rights-of-way. Mound survivorship is negatively correlated with the year the mound was first recorded. Only about 5 percent of mounds first recorded in the nineteenth century were identified in LiDAR versus ca. 80 percent of those recorded since 1990. Sites recorded before 1880 average 17 mounds per site, primarily in large groups, declining to an average of 2.5 mounds per site after 1990. This project demonstrates that LiDAR is a useful tool for the evaluation of known-location mounds, provided they are large enough to be detected. While field verification is always important, especially for first-time detections, the important result of this study is that the USGS specifications adhered to by Minnesota's LiDAR acquisition appears to have produced BE-DEMs that are quite reliable for the detection of prehistoric earthworks.

Chapter I. Introduction

Burial mounds are among the most significant and endangered of all archaeological resources in Minnesota. They are a manifestation of collective labor and spiritual belief systems that spanned much of eastern North America between 1000 B.C. and A.D. 1800. Almost 12,000 mounds are recorded in Minnesota, but thousands were undoubtedly destroyed without being recorded, and an unknown number remain to be discovered. Of the 11,868 recorded mounds, there is no reliable estimate of how many are still extant or what condition they are in (Arzigian and Stevenson 2003:63–64).

Light Detection and Ranging (LiDAR) is a technology capable of addressing the status of burial mounds in Minnesota. LiDAR data, providing high resolution elevation data, are available for the entire state, and can be used to search for and map burial mounds.

This project examined LiDAR data for 650 known mound sites in 16 counties (Figure 1; Table 1). Using historic maps and LiDAR, the project compiled a systematic overview of mound survival. The project demonstrates the feasibility of using publicly-funded LiDAR as a tool for identifying precontact earthworks.

The Oversight Board of the Statewide Survey of Historical and Archaeological Sites (Board) originally identified 27 counties to be studied by this project (Minnesota State Historical Society 2012). Based on experience in a previous pilot project (Riley et al. 2010), however, UI-OSA considered this beyond the scope of the available funding. The Board accepted UI-OSA's alternative, to work with only 16 Minnesota counties, but to focus on those unusually rich in mounds. The selected counties (Figure 2) represent only 12.6 percent of the state by area, but include 64 percent (7646 of 11,868) of the recorded mounds in Minnesota, and in addition included some of the most developed and fastest developing parts of the state.

The Office of the State Archaeologist of the University of Iowa (UI-OSA) prepared this report under the terms of an agreement between UI-OSA and the Minnesota Historical Society (MHS). Joe Alan Artz served as principal investigator and lead report author; Emilia L. D. Bristow served as LiDAR analyst. William E. Whittaker led historical research into Minnesota mound sites with assistance from Jennifer Mack. Scott Anfinson and Bruce Koenen at Mn-OSA, Patricia Emerson at MHS, and Tim Loesch, at the Minnesota DNR, provided much appreciated advice and support, as did Marc Linderman and Sugumaran Ramathan in the Department of Geography, University of Iowa. The authors are indebted to Melanie Riley, who was a true pioneer in the application of LiDAR in mound detection through her work on sites in Minnesota and Iowa.

HISTORICAL BACKGROUND

The present project employs twenty-first century technology to map mound sites, many of which were initially recorded by the late nineteenth century archaeologists T. H. Lewis and J. V. Brower. The field surveys of these two individuals laid the foundation for the study of prehistoric earthworks in Minnesota. The two surveyors recorded hundreds of mound sites, with Lewis in particular demonstrating a technical competence that is commendable even by modern standards (Dobbs 1991; Haury 1993). In much the same way that present-day civil surveyors still refer to the original General Land Office surveys to establish benchmarks for modern surveys, modern archaeologists routinely turn to Lewis' notes and maps in conducting present field surveys and analyses of mounds and mound sites.

Because of the importance of these early archaeologists in this study, the following paragraphs summarize the life and work of these individuals who figure most prominently in the early records used in this study. This section is adapted from a longer overview written by Robin Lillie, UI-OSA, and included in a previous report (Riley et al. 2010).

Lewis (1856–1930) was trained as a surveyor, and put these skills to work mapping mounds and earthworks in Ohio and the Mississippi River valley, prior to relocating to St. Paul in 1880. There, he made the acquaintance of A. J. Hill (1833-1895), a draftsman and map maker by trade, who was concerned by the wanton destruction of mounds by looting, farming, and development, and intent on recording as many of them as possible. In 1881, Hill and Lewis formed the Northwest Archaeological Survey (NAS). Hill provided financial support, and Lewis conducted the fieldwork.

The area traversed by Lewis would eventually extend throughout Minnesota and into surrounding regions, including the present-day states of North and South Dakota, Wisconsin, Iowa, Illinois, Indiana, Nebraska, Missouri, Kansas, and Michigan, and the Canadian province of Manitoba (Dobbs 1991; Finney 2006; Haury 1990, 1993).

Hill and Lewis's partnership lasted for 15 years, during which time Lewis traveled over 54,000 miles, walking more than 10,000 miles. "In its regional extent and duration, the NAS constituted the largest privately funded archaeological project ever undertaken in this country" (Finney 2006:2). The NAS documented over 17,000 mounds and earthworks at over 2,000 mound and village sites (Dobbs 1991). In Minnesota, the NAS mapped more than 7,700 mounds at 761 sites in 65 counties (Arzigian and Stevenson 2003; Dobbs 1991).

Results of the Hill-Lewis collaboration were never published in their lifetimes. Hill died suddenly in 1895 and, despite Lewis' efforts to obtain them, the NAS notebooks, papers, and maps were divided between Hill's two nephews in England and Canada. Lewis continued to publish articles on archaeology until 1898. He left Minnesota in 1911 and died in poverty in St. Louis in 1930 (Finney 2006).

Although Lewis was never recognized for his achievements during his lifetime, his work continues to be of value. His detailed maps and drawings depict sites that have been damaged or completely destroyed (Benchley et al. 1997:52). Lewis recorded sites on a Minnesota landscape that in many places does not exist today.

Another early recorder of Minnesota archaeological sites was Jacob Vradenburg Brower (1844–1905). An avid collector of archaeological materials, maps, and books, he became involved with the Minnesota Historical Society in 1899 and collaborated with A J. Hill between 1889 and 1895 (Benchley et al. 1997:52). He conducted surveys of archaeological sites and performed excavations, but worked independently of Lewis, without detailed knowledge of where Lewis worked. Initially collaborators, the two men developed a deep antagonism toward one another. Hill and Brower, however, remained close.

Brower published his Minnesota work in several volumes (e.g., Brower 1900, 1901, 1902). Although Brower's maps are more schematic than Lewis', his contributions are nevertheless significant (Benchley et al. 1997:53; Birk 1986:27). Some of the sites he surveyed and excavated have since been disturbed or destroyed, and his maps are the only record of their existence.

One of Brower's most significant contributions to Minnesota archaeology occurred around 1903 when he pushed the Minnesota legislature to purchase the NAS records from Hill's heirs. The Minnesota Historical Society obtained the NAS records after the legislative purchase. The records include 41 field notebooks, site maps drafted by Hill, and correspondence. Brower died in 1905 before he could write and publish a compendium of his own archaeological studies with those of the NAS. He planned to refer to the combined works as the "Hill-Brower Explorations," without no mentioning Lewis (Haury 1993:84).

Newton Winchell (1839–1914) became the Minnesota Historical Society's archaeologist in 1906 after serving as the first director of the Minnesota Geological Survey from 1872 to 1900. Winchell's annual reports expanded knowledge of relatively unknown site types such as chert quarries (Benchley et al. 1997:53). His greatest scholarly contribution was *The Aborigines of Minnesota* (Winchell 1911), a detailed compilation of Minnesota archaeology and ethnography. The volume incorporated the NAS Minnesota records, including Lewis' surveys, along with brief notes on antiquarian investigations. Like the works of Lewis and Brower, Winchell (1911) is valuable to modern researches as a record of mounds long-since destroyed.

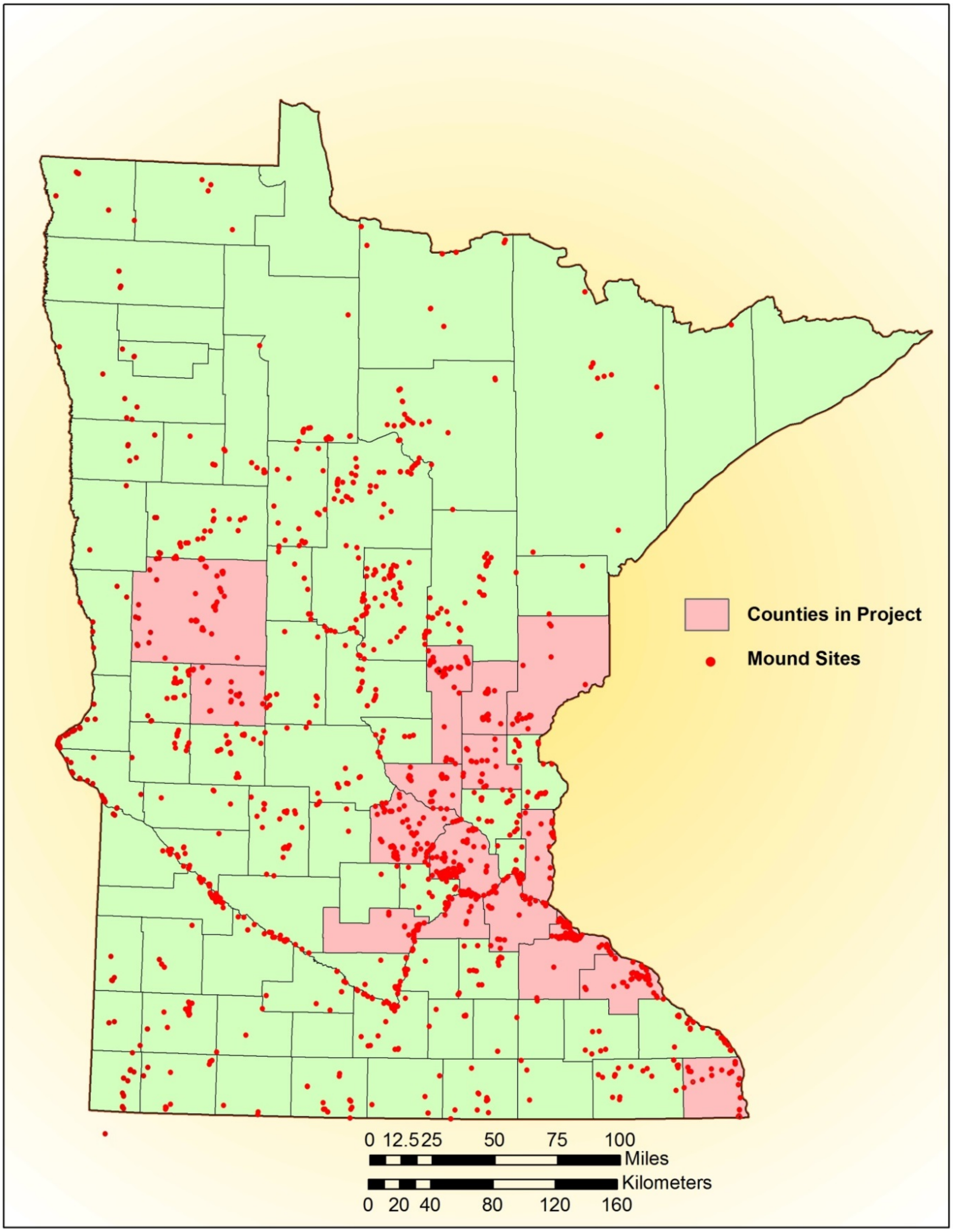

Figure 1. Overview of Minnesota mound sites and counties in study.

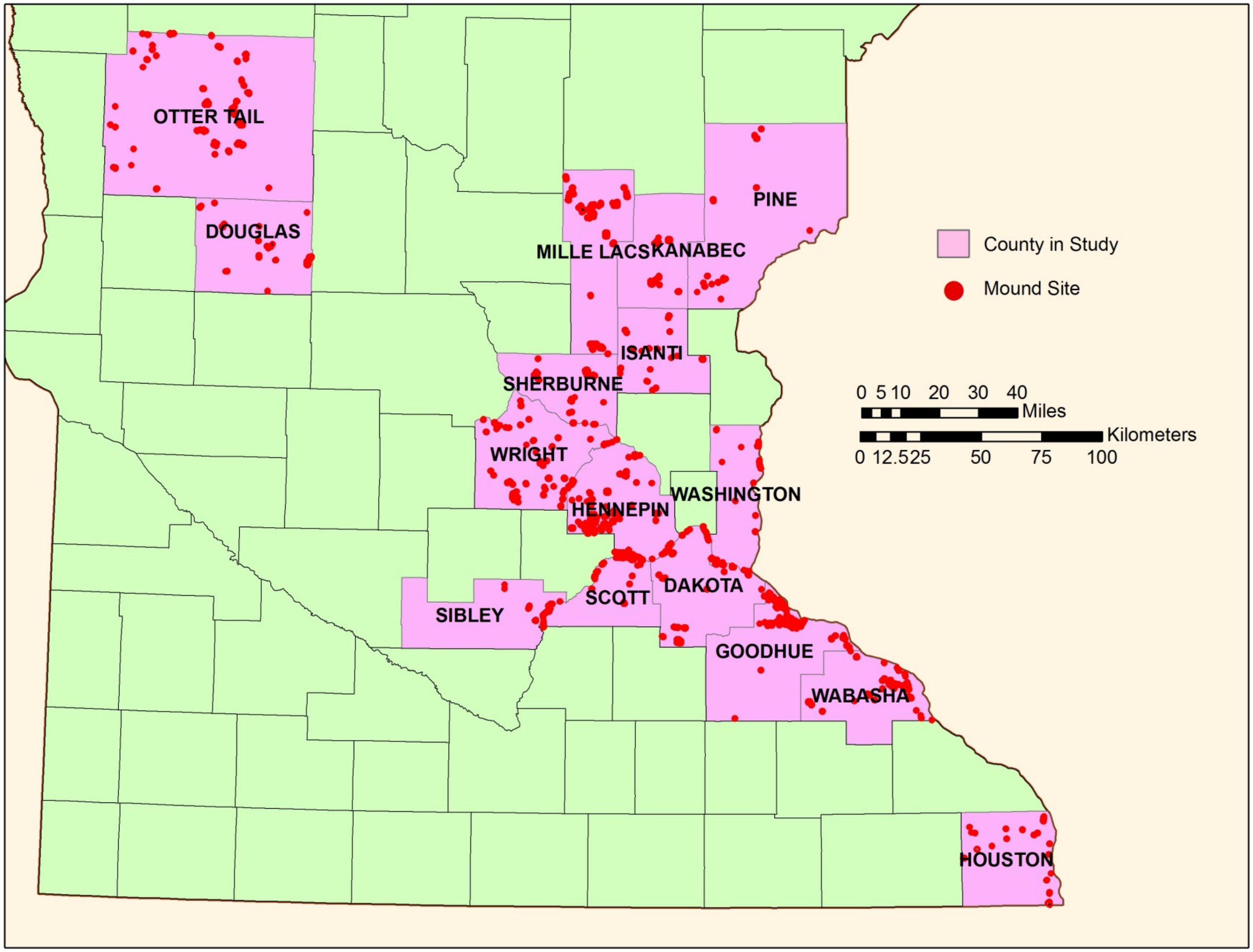

Figure 2. Map of counties included in this study.

Table 1. Summary of Counties and Mound Sites in the Project.

County	Mound Sites	Recorded Mounds: This Study	Recorded Mounds: Arzigian and Stevenson (2003:63-64)
Dakota (DK)	28	337	330
Douglas (DL)	20	180	178
Goodhue (GD)	112	1363	1535
Hennepin (HE)	111	1151	1160
Houston (HU)	23	267	269
Isanti (IA)	20	174	169
Kanabec (KA)	25	346	346
Mille Lacs (ML)	42	676	499
Otter Tail (OT)	52	530	516
Pine (PN)	16	184	172
Scott (SC)	37	641	636
Sherburne (SH)	26	334	331
Sibley (SB)	12	204	199
Wabasha (WB)	48	567	591
Washington (WA)	22	309	304
Wright (WR)	57	383	394
TOTAL	651	7646	7629

Chapter II. LiDAR in Minnesota

This section provides a brief summary of LiDAR technology, adapted from Bristow (2013). A more extensive treatment of LiDAR is provided by Riley (2009) and Riley et al. (2010). The Minnesota Geospatial Information Office's (MnGeo's) LiDAR Elevation Data for Minnesota web page (MnGeo 2012) also has information about LiDAR, both in general, and concerning Minnesota's statewide LiDAR program.

LiDAR is a remote sensing technology that employs lasers to measure distances to and from a target. Two types of systems, terrestrial and airborne, are in current, wide-spread use. Terrestrial LiDAR systems acquire data from a ground-based sensor, often mounted on a tripod, much like a total station. The devices are used for detailed mapping of surface features such as buildings. In airborne systems, the laser scanners are flown aboard an aircraft, directing continuous streams of laser pulses toward the ground. The LiDAR data used in this study were acquired by airborne systems.

As the plane flies, lasers pulse beams of light, often at a 1064 nanometer wavelength, towards the ground. The pulses are reflected back towards the plane as they encounter "targets," i.e., surface and near-surface objects such as vegetation, structures, water, and transmission lines. Sensors aboard the aircraft record the return time of the reflected pulses. The distance to the target is calculated as the return time divided by two times the speed of light. As these incredibly precise measurements are recorded by the LiDAR sensors, the location of the plane is recorded with similar precision with GPS. Other onboard sensors recorded the pitch, yaw, and roll of the aircraft, measurements that allow the target distances to be adjusted for the angle at which they traveled to and from the target.

Like a flashlight beam aimed at a distant wall, light beams from the aircraft grow wider as they travel. Thus, a single pulse can be reflected multiple times. For example, as the pulse passes through a tree, it may encounter, and reflect from, several branches. Each branch reflects a portion of the pulse's energy, allowing the remainder to pass. Each of these multiple returns is recorded aboard the plane, and through post-flight processing, is transformed into the x, y, and z coordinates of a single point in space where all or part of a pulse reflected off a material it encountered. The coordinates are precisely located with respect to the earth's surface, in units of latitude, longitude, and elevation.

The total returns from an airborne LiDAR flight, when viewed in three dimensions on a computer, comprise a three dimensional cloud consisting of hundreds of thousands of points. The complexity of the raw data is overwhelming, and to be usable, must go through several stages of post-flight processing.

This "point cloud" data of post-processed total returns are usually provided as LAS files. These are simple ASCII text with the x, y, and z coordinates as well as metadata attributes for each point. The x, y, and z points can be plotted in 3-D space using software such as ESRI's 3D Analyst and LiDAR analyst (http://www.esri.com/products), and Q-Coherent's LP360 (http://www.qcoherent.com/).

One of the more important products derived from Log ASCII Standard (LAS) point cloud files is the bare-earth digital elevation model (BE-DEM). Filtering algorithms are used to identify "last returns," consisting of those parts of multiple return pulses that traveled the farthest distances, indicating that they reflected off the ground surface. The filtering process, in essence, is intended to mathematically identify and remove all intermediate between the airplane and the ground surface.

A BE-DEM consists of a regular grid of cells, each cell of which is assigned an elevation value. The LiDAR returns, however, are not regularly spaced, clustering in some areas, and leaving gaps in others. The point cloud is therefore thinned using a statistical procedure, nearest neighbor analysis, to remove extraneous points that provide redundant data. The BE-DEM is created by assigning elevation values to a regular-spaced grid of points based on interpolation among the thinned last returns. Each of these acquisition and processing steps can introduce error into LiDAR-derived products; ground features can be improperly filtered from the LiDAR point data and thus missing from a BE-DEM, and interpolation between sparse points can produce an incorrect ground surface. This potential for error must be kept in mind during LiDAR analysis.

The BE-DEM can be further processed in a variety of ways for visualization and analysis. Topographic contours can be created by interpolating lines of equal elevation among the grid points. Slope grids can be created by calculating the difference in elevation between adjacent grid cells and dividing by the distance between grid center points, yielding a percent change in elevation per unit distance. The slope grids along with the facing direction of slopes can be used to create a hillshaded map. The shading is calculated by specifying an azimuth and zenith for a light source that “illuminates” the landscape. Common parameters for hillshade maps include a light source coming from the northwest at a zenith of 45 degrees above the horizon. Another derivative product is a shade relief map, wherein ranges of elevation are assigned color values for illustrating topography.

The Minnesota Elevation Mapping Project began collecting statewide LiDAR data in 2010 under a grant from Minnesota’s Clean Water, Land, and Legacy Amendment. Overseen by the Minnesota Department of Natural Resources, LiDAR flights were completed in 2012, and completed state-wide data were made available in June, 2013. The project was funded by nearly $9,000,000 in appropriations from the state legislature, Local governments provided in-kind assistance, primarily as work by county surveyors who collected high-accuracy cadastral-quality survey points – over 100 points per county -- against LiDAR accuracy was validated. Data were collected in five phases encompassing a total of 45,349 mi^2. These and many other details of the project are available at http://www.mngeo.state.mn.us/committee/elevation/mn_elev_mapping.html.

The horizontal and vertical accuracy of the Minnesota LiDAR datasets are based on United States Geological Survey (USGS) specifications (Heidemann 2012). For geospatial datasets, accuracy is expressed as a root mean square error (RMSE). The Minnesota Geospatial Information Office (2013) requires a horizontal accuracy of 1 m RMSE, meaning that 95 percent of the points must be within 1 m of the x, y coordinate assigned to the points. Vertical accuracy must have an RMSE of <= 15 cm, and 27 cm in vegetated areas. Riley (2009) found these accuracy standards to be sufficient to detect mounds as small as 5 m diameter and 30 cm high.

Chapter III. Methods

Project methods involve analysis of previously recorded mound site data and analysis of mound sites using LiDAR imaging. Previously recorded mound sites were georeferenced when possible, and this data was used as a basis for LiDAR analysis.

ELECTRONIC DATA SOURCES

Table 2 presents the data sources used in this project, all were provided by Mn-OSA, except for LiDAR and basic geographic data, which were downloaded directly from Mn-Geo's Data Deli.

Table 2. Electronic data sources used by project.

Dataset Name	Format	Owner	Description
MnBurial.accdb	Microsoft Access	Mn-OSA	Master electronic file of burial sites in Minnesota
Sites.mdb	Microsoft Access	Mn SHPO	Master database of all archaeological sites in Minnesota
MnBurials.shp	shapefile	Mn-OSA	Point locations of burial sites in Minnesota
Cemetery1.mdb	Microsoft Access	Mn-OSA	Statewide burials database compiled by Arzigian and Stevens (2003)
1:24K USGS Quads	TIF	Mn SHPO	Scanned and georeferenced quad maps from plotting all sites in the 16 project counties
Lewis Notes	pdf	Mn-OSA	Scans of T. H. Lewis field notes from the 16 project area counties
Basic geographic data	shapefile	MnGeo	Base layers such as counties, corporate boundaries, roads.
LiDAR data	various	MnGeo	See LiDAR Analysis, below

A variety of base layer GIS datasets were downloaded from the Minnesota Department of Natural Resources' GIS Data Deli. These include ESRI datasets for roads, streams, lakes, land use, geomorphology, and boundaries for counties, cities, and Public Land Survey System townships. Additional image (raster) data layers including quadrangles, land cover, and color orthophotos were not downloaded because they are available on the Internet through connection to the Data Deli's web map service.

SAMPLING

A list of 682 mound sites to be considered in this study was compiled from the Mn-OSA's master database of human burials (MnBurials.accdb). The database copy provided to UI-OSA is current through July 1, 2012. The database contains one table, ARCHBUR, with 2933 records, which lists all archaeological sites with burials. Mounds are one of several mortuary feature types included in this database, and it was therefore necessary to extract mound sites from the database.

The following bracket-enclosed fields in ARCHBUR contain information pertinent to identifying records for sites with mounds:

- [Mounds] has integer values that record the number of mounds per site. Mound presence is indicated by non-zero values, and 893 sites meet the criterion [Mounds] > 0.
- [Function] is a text field that assigns a burial type, one of which is BMound. Only 123 records, however, meet the criterion [Function] = 'BMound." Six of these have 0 as the value listed for [Mounds].
- [Sitename] has 349 records that contain the character string "Mound."

Sites in the 16 project counties comprise 1,010 of the 2,933 records in the database. Filtering to remove non-mound internments pared the list to 899 records pertaining to sites with mounds. This list contained 682 unique site numbers, with each site having between 1 and 10 records in the database. This initial list was further reduced as the project progressed, eventually to a total of 650, as duplicate and misidentified sites were eliminated from the sample.

Recorded site locations were plotted as points in a shapefile provided by Mn-OSA. MnBurials.accdb also contained Universal Transverse Mercator (UTM) eastings and northings for the sites, and these could be plotted in ArcGIS as x and y coordinates. Most of the site locations were plotted with reference to the North American datum of 1927 (NAD 27). A datum is a set of mathematical equations that define the ellipsoidal shape of the earth’s surface. Minnesota’s GIS datasets, including LiDAR, use the more accurate datum of 1983 (NAD 83). At the latitude of Minnesota, pairs of coordinates plotted in NAD 27 are offset. ca. 200 m north of the same coordinates plotted in NAD 1983. The burial site locations were therefore re-projected from NAD 27 to NAD 83. Obviously incorrect locations (e.g., plotting outside the correct county boundaries) were corrected if possible.

SITE RECORDS AND GEOREFERENCING HISTORICAL MAPS

Before LiDAR analysis could begin, it was necessary to determine as accurately as possible the expected location of individual mounds within the 16 county project area. This was done through the georeferencing of survey reports and maps. Georeferencing is the process of registering a source map to the coordinate system and scale of a base map. This involves translating the map into the new coordinate system, and adjusting the map to match the compass orientation and scale of the base map. In this case, historic maps of mound sites were georeferenced to aerial images and topographic maps displayed in Universal Transmercator (UTM) coordinates in a GIS. The old maps and surveys were found by searching Minnesota site files and older texts.

Mn-OSA and SHPO Files

In October 2012 and February 2013, UI-OSA researchers traveled to the Twin Cities to examine and copy records pertinent to the 650 mound sites in the 16 county study area. Records are housed at Mn-OSA at Fort Snelling and the State Historic Preservation Office (SHPO) in St. Paul. The Mn-OSA collection largely consists of site summary folders. The folders contain information on individual sites, including site forms, copies of report excerpts dealing with individual sites, and occasionally original maps, handwritten comments, and typed summaries of site visits and interviews with collectors and landowners. Files could be quite large, and given the limited time available and the size of the project, it was not feasible to review every document. Instead, researchers focused on finding maps that showed the location of individual mounds. The SHPO files were generally less exhaustive than the Mn-OSA files, mostly containing site forms. One exception is the alphabetical designation site files. Alphabetical site designations, e.g., “21DKac”, are used for archaeological sites that have not been confirmed or have poor location information. The SHPO maintains a full collection of the alphabetical site files, and pertinent records were copied.

Because it was not feasible to review every page of every document at Mn-OSA and SHPO, some relevant information could be missed, such as a passing reference to a mound having been visited or destroyed, or a reference to a separate report that might have more information. Likewise, it was beyond the scope of this project to search the extensive library of thousands archaeological reports maintained by Mn-OSA and SHPO. Unquestionably, there are other sources of data for pinning down the location of mounds, but the Mn-OSA and SHPO site files are the largest, most comprehensive, and best organized archival sources, including electronic databases and GIS datasets.

Lewis, Winchell, and Other References

In addition to the Minnesota archaeological site files, several published reports contain information about the location and condition of mounds and mound sites. Foremost of these were the Lewis survey notes and the Lewis maps redrawn by Winchell (1911). The Lewis surveys and subsequent difficulties in publishing them are discussed in by a number of researchers, including Arzigian and Stevenson (2003), Benchley et al. (1997), Dobbs (1991), Finney (2006), Haury (1990, 1993), Riley et al. (2010) and Winchell (1911).

Lewis mapped or noted 70 percent of the mound sites in the 16 county project area (458 of 650 total) and 94 percent of all known mounds are from sites recorded by Lewis (7192 of 7646 total). More than half of mounds Lewis mapped were in five counties: Goodhue, Hennepin, Scott, Wabasha, and Otter Tail.

Lewis mapped mounds with a surveyor's compass, canvas tape, engineer's level, and stadia rod. His compass bearings were recorded as cardinal directions, e.g. 11 degrees west of north, equivalent to an azimuth of 349 degrees. Lewis appears to have used magnetic north, which in the 1880s was about 7 degrees east of true north, but occasionally used true north. Sometimes, the orientation of his maps deviates significantly from either magnetic or true north. True north could have been determined in the field by adjusting for magnetic declination using readily available correction tables, or if he set up his compass at local noon, when the sun is due south. Erroneous orientations are likely due to the compasses of the late nineteenth century, whose needles tended to stick if they were not perfectly level or were used under poor conditions.

Lewis shot from center of mound to center of mound and noted the angles and distances. He made sketch maps of the general arrangement of mounds in his notebooks, but these were not scaled or oriented. Lewis did not close his survey lines by back-sighting to existing points, which means that errors tended to increase as his survey progressed. Lewis noted very few landmarks in his sketches, typically bluff edges, and these were often roughed in, rather than measured. Occasionally he depicted houses, roads, and field edges are depicted, but these are rare, and often not helpful for georeferencing, since most of these landmarks are gone. Lewis typically gave the legal locations of mound groups, but plat maps were notoriously unreliable in the nineteenth century, and legal location was hard to determine in wilderness areas. In populated parts of the state, Lewis often recorded lot numbers. Unfortunately, few maps with lot numbers from that era are accessible.

Most of the Lewis maps were re-drawn by Winchell (1911). He corrected the maps for scale and orientation, but still used whichever north, magnetic or true, that Lewis used. Winchell omits many landmarks noted by Lewis, and occasionally committed transcription errors, or made incorrect assumptions about location. These sources of error aside, the maps are generally useful for georeferencing because they are drawn to scale and can be rotated in the GIS software environment to approximate their cardinal orientation.

In this project, Winchell's maps were georeferenced, but Lewis' original notes were consulted if the site was not mapped by Winchell, or if there were not enough landmarks to georeference the Winchell maps. In a handful of occasions, Lewis mound maps were redrawn based on his original notes.

Near the turn of the century, Brower surveyed several mound groups in Minnesota. Three of his published volumes (Brower 1900, 1901, 1902) contain information on 5 percent of the mound sites (35 of 650), and 11 percent of the total mounds (867 of 7646) in the 16 county project area. Many of these were also mapped in whole or part by Lewis. Brower's maps are often schematic, showing the general orientation of mounds on the landscape. Sometimes his maps of mound groups appear to have been measured with transit and tape, but these are the exception. The original notes of his surveys typically do not include bearings and distance measurements.

Another useful book was Arzigian and Stevenson's (2003) *Minnesota's Indian Mounds and Burial Sites*. The volume contains few maps useful for georeferencing, but often provides information about the condition of mounds, whether or not mounds actually were observed in a site, and who visited the sites.

Other documents consulted for this study were excerpted from site file updates, archaeological surveys that were site-specific, or short accounts in county histories and geological surveys. In Dakota County, a thin, but useful, volume was *Burial Places of the Aborigines of Kaposia* (Werner 1974), which updated many of the mound sites in South Saint Paul. Other surveyors who contributed surveys of numerous mound sites in the 16-county area include Scott Anfinson, Douglas A. Birk, Clark Dobbs, Guy Gibbon, G. Joseph Hudak, Albert E. Jenks, Elden Johnson, Leslie Peterson, and Lloyd A. Wilford (Arzigian and Stevenson 2003).

Georeferencing

For this project, historical maps and survey notes were used to georeference the expected locations of mounds and mound sites so that the LiDAR analysis had baseline data for searching for mounds. A total of 556 historical survey maps were georeferenced for this project, most of them Winchell's (1911) redrawing of the Lewis surveys (figures 3–5). All georeferencing was done in ArcMap 10; the projection used was NAD 83, UTM Zone 15. A few mounds in the western part of Otter Tail County are in UTM Zone 14, but these were reprojected to Zone 15.

In addition to the georeferenced images, two shapefiles were produced during georeferencing, one consisting of polygons containing the georeferenced mounds, and one consisting of points representing the location of individual mounds. Both were digitized directly from the georeferenced maps, and were intended to aid the LiDAR analyst in locating sites and mounds. The shapefiles were named BoundaryGeoref.shp and MoundGeoref.shp; the features they depicted are only approximations because of the vagaries of positioning historical maps on high-accuracy geospatial datasets.

BoundaryGeoref comprises polygons that outline the entire area where the mounds within one site could plausibly exist, based on information gleaned from the site file and the references utilized. The boundaries were intended only to assist the LiDAR analyst, and are not intended to represent the actual archaeological site boundaries. In the project area 657 mound sites had boundaries that could be determined. Boundaries could be quite large, for example if all that is known about a mound group is that it is in the southwest quarter of a section, the whole southwest quarter of the section is included in the boundary.

Mound points were georeferenced in the shapefile, MoundGeoref. Of the 657 mound sites, 414 had mounds that could be georeferenced (63 percent). Of the 7677 recorded mounds, 6233 were georeferenced (81 percent).

The Minnesota SHPO and Mn-OSA both maintain site files. The SHPO maintains USGS 7.5' quad maps with site boundaries marked in red. The Mn-OSA maintains a database with burial site UTM center points, as well as individual maps in their site files. In general, they agree with each other, with the Mn-OSA center point of a mound group plotting near the center of the SHPO boundary, but occasionally there is a disagreement in location.

Both site boundaries and mound points were determined in the same ways. The current mapped location of the site was found using the georeferenced SHPO USGS maps and the Mn-OSA center point data. Notes copied from the Mn-OSA and SHPO site files were reviewed. Available maps of the site were examined to determine if sufficient landmarks were present to allow points on the map to be georeferenced to points in modern digital maps and aerial photos. If there is no mound map, the likely boundary of the mound group was estimated using legal locations and descriptions of the site's landform and landmarks, and this boundary was mapped in BoundaryGeoref. If there were multiple mound maps of one site, the quality of the maps was evaluated to decide which was the best for georeferencing. Mound maps that are measured rather than sketched were preferred, and mound maps that include multiple landmarks were preferred over maps with few landmarks or old landmarks (e.g., roads and riverbanks subject to change through time). Multiple maps were georeferenced for the same site if it was useful for determining mound location.

To georeference mound maps, map images were imported into Photoshop, and the map was trimmed to the area containing mounds with nearby landmarks. Contrast and brightness were adjusted to accentuate map lines. The image was saved in jpeg format, named with the site number followed by the last name of the creator of the map, e.g., 21GD0012Winchell.jpg. The map image was imported into ArcMap in the approximate area of mound site. The map was scaled, for Winchell's maps of Lewis' surveys, the maps were scaled using known mound diameters or distances between mounds or landmarks. Other maps often had scale bars, or notes on distances, or showed extant landmarks. The mound map was rotated so that the expected true north is at top. Winchell's maps of Lewis' surveys were typically rotated approximately 7 degrees clockwise to compensate for magnetic north. The re-orientation was checked against extant bluffs, roads, or other landmarks. The map was positioned over the landform, looking for the location that provided best concordance with topography and known landmarks. USGS 1:24,000 quadrangles and recent aerial photos were useful. In some of the later georeferencing attempts, LiDAR-derived 2-ft contour shapefiles were used to aid positioning. These 2-ft contour maps showed topography much better than USGS maps and often showed extant larger mounds. The position, scale, and orientation of the map was adjusted until the best fit was found. The image was updated to save its georeferenced coordinates. The procedure used in the project created a "world file," a simple text file with the same name as the source image that stores the information needed to move, rotate and scale the image to its "real world" location.

Points were digitized at the expected centers of mounds in the MoundGeoref.shp shapefile. Each mound point was coded by site number and mound number, if a mound number could be determined from historical accounts. If no mound number could be determined, it was labeled "x". If a mound was long, such as a linear mound or large effigy, multiple points were created, and labeled based on their compass orientation. For example, 22W, 22C, and 22E are the western, center, and eastern points of Mound 22, respectively. For final mound tallies, this mound was counted only once. The data fields in MnBurials.shp were updated to provide information about the surveyors, current ground conditions, and number of mounds visible based on most recent survey. For larger sites, ground conditions listed the land use in order of area, for example, a site that is mostly wooded with an area of plowed land is listed as "Wooded, agricultural". For each site, notes were recorded in an Excel spreadsheet (mounds.xls) stating which maps were georeferenced, and justification for georeferencing, and any problems encountered. These notes are presented in Appendix 1.

Limitations of Georeferencing

There are many factors which can prevent a true georeferencing. Original surveyors such as Lewis did not always know exactly where they were. Their listed legal location can be different from what is expected, given their description of the site relative to lakes and other landmarks. Their survey can have errors; Lewis' errors are noted by almost every subsequent researcher (Arzigian and Stevenson 2003; Benchley et al. 1997; Dobbs 1991; Finney 2006; Haury 1990, 1993; Riley et al. 2010).

It is usually not clear if magnetic north, true north, or a local grid north was used in surveys. Surveyors did not always see every mound, and sometimes did not have time to map all the mounds they did see.

Early surveyors such as Lewis and Brower did not include many landmarks that still exist. Winchell did not always redraw Lewis' maps correctly, and he often left out many of his landmarks. There can be false landmarks, such as a newer house 100 m from the since-demolished house shown on the original map.

Topography is often subjective. For example, Lewis often drew bluff lines, but the exact location of these topographic breaks can be hard to identify, particularly if slopes are long and gentle. Topography changes. Cutbanks eat away bluffs. Road construction and other activity move large amounts of soil. False mounds can be created by human activity such as septic tanks, spoil piles, and even brush piles. Contours on USGS maps are imprecise and relatively low accuracy, and tend to smooth out contours and eliminate subtle changes in bluff edges. Later archaeologists, especially before the advent of GIS, sometimes georeferenced old maps incorrectly. Finally, LiDAR is not perfect. It can hide mounds, and create false mounds.

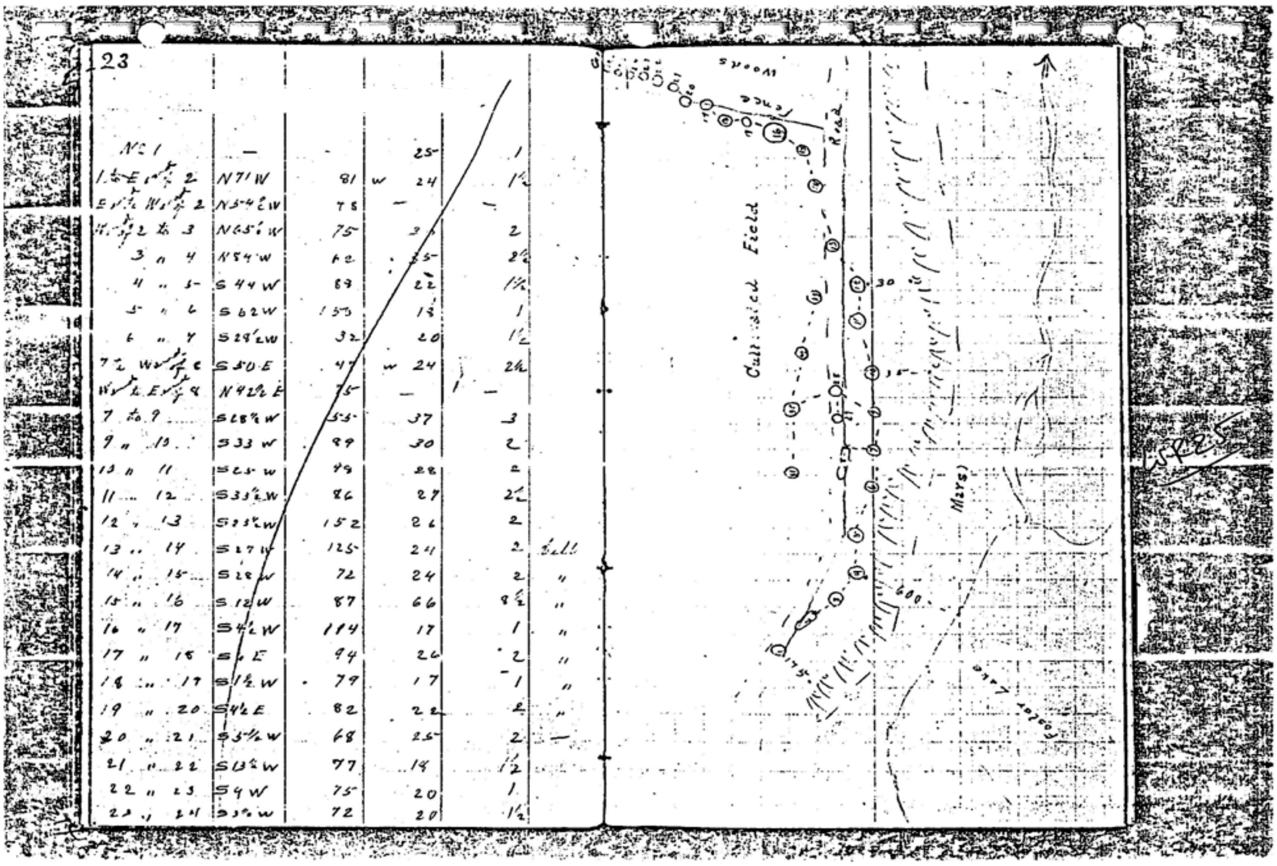

Figure 3. Example of Lewis' original survey notes, Foster Lake Mound Group (21WR0025). Scan of photocopy provided by Mn-OSA.

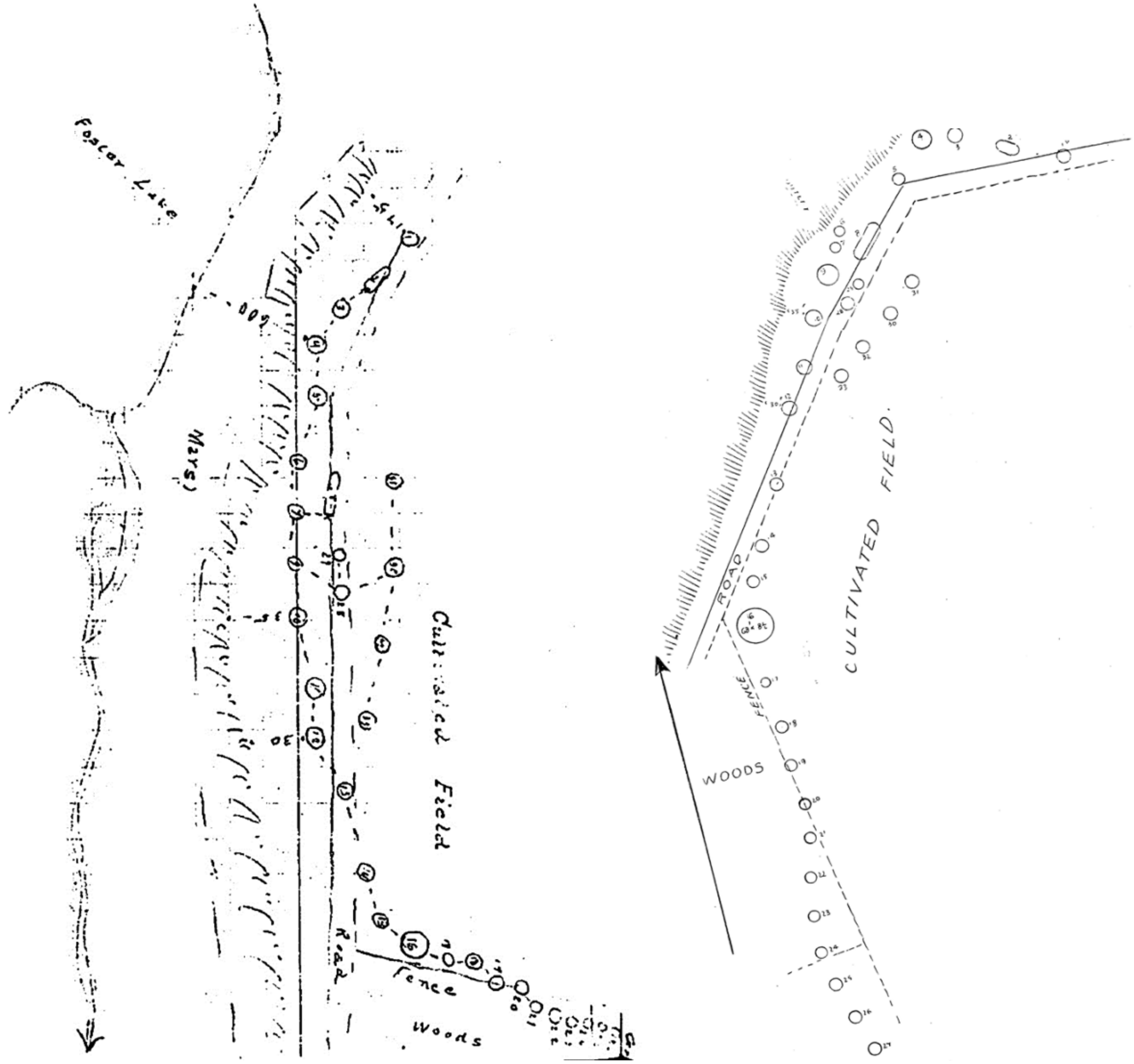

Figure 4. Comparison of Lewis' original 21WR0025 map (reoriented with north at top) with Winchell's (1911:210, 212) redrawing. Winchell shows the scale and distances correctly, but eliminates most of the landmarks useful for georeferencing; he does not correct for magnetic north.

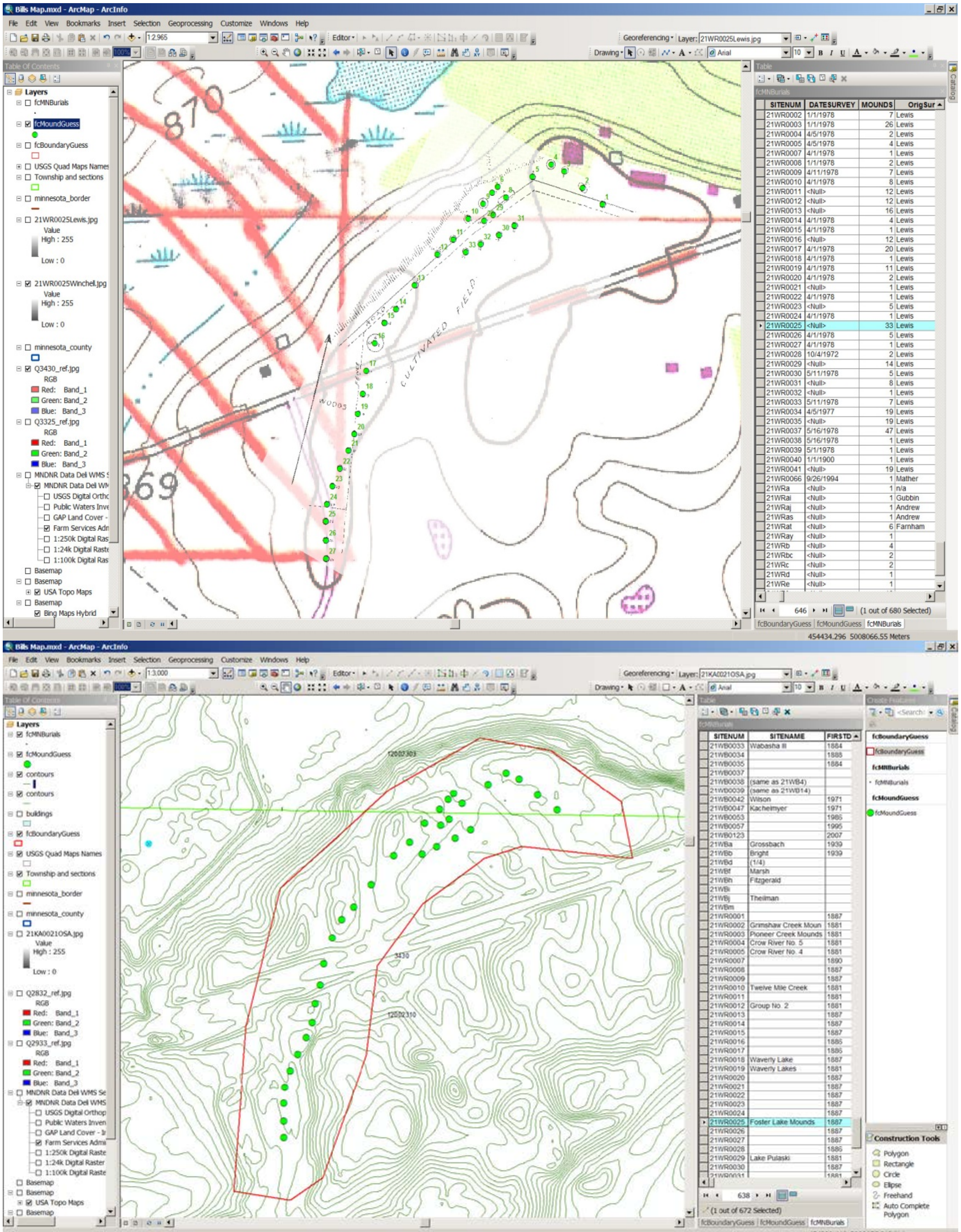

Figure 5. Georeferencing the Foster Lake Mound Group (21WR0025). Upper: Winchell map projected onto SHPO USGS site file map, old site boundaries are red hashed area. Lower: georeferenced mound locations on 2-ft contour map. Red line is new site boundary.

LIDAR ANALYSIS METHODS

After georeferencing historic mound map and survey data, LiDAR analysis was performed at all mound sites. LiDAR analysis includes several steps to define the datasets, to project them into usable maps and other figures, and to analyze the data to determine if there is evidence of extant mounds at the expected location.

Data Sources

Most Minnesota LiDAR data and products are sectioned into tiles, each of which covers 1/16th of a USGS 1:24,000 quadrangle and is roughly 3.5 km north-south by 2.4 km east-west. All LiDAR tiles that fell within 500 m of a georeferenced mound site boundary were included in this study, providing ample allowance for the misplotting of sites due to errors in the coordinates derived from the original Mn-OSA burials database or in UI-OSA georeferencing. LAS point cloud data and 1-m DEMs for a total of 527 tiles were downloaded from MnGeo (2012). County-wide 1-m DEMs were obtained for Pine and Wright counties, which do not have tiled DEMs. County-wide 2 ft elevation contours for all 16 counties were downloaded. Other ancillary GIS data were obtained by UI-OSA from the Minnesota DNR Data Deli (MnDNR 2012) or through Environmental Systems Research Institute, Inc. (ESRI) basemaps featuring Microsoft Bing aerial imagery. Site records and SHPO USGS quads showing site locations were also used to support LiDAR analysis of sites.

One-meter hillshade (shaded relief) images were produced from the 1-m DEMs using default settings of the hillshade tool in ArcGIS, and 10-cm elevation contours were created for each LiDAR tile using the ArcGIS contour creation tool. In cases where initial analysis was inconclusive, ArcGIS and LP360 software were used to generate additional hillshade and contour products and to display LiDAR data in other formats.

Interpreting LiDAR Data

The initial analysis step for each site was to examine the positioning of the georeferenced historic maps in the context of the LiDAR data (Figure 6). In some cases, LiDAR offered topographic clues to suggest an adjustment of the site boundary or mound locations digitized from georeferenced historic maps.

Each site was then examined in the default 1-m hillshade image overlain with 10-cm contours and a semi-transparent colored image of the 1-m DEM (Figure 7). Many existing mounds were detectable with this combination of data. Subtle mounds were sometimes not detectable in the default hillshade alone, as their minimal relief does not cast a shadow at the default 45 degree lighting angles, and mounds can be overshadowed by tall bluffs in hillshade images with default light angles. However, the addition of 10-cm contours and a shaded DEM largely compensate for these problems by highlighting very subtle relief changes, regardless of their calculated shadow characteristics. Hillshade images with varying vertical exaggeration and lighting angles were generated for a number of sites early in the study, but this was not found to be more useful for finding mounds than adding 10-cm contours to default hillshade images.

Features were classified as present mounds when they matched the shape and relative location of a documented mound and were at least 30 cm high as determined by 10-cm contours (figures 8 and 9). Features were classified as uncertain if they were less than 30 cm high or if they deviated from the expected shape or location of mounds at the site, or if context suggested that, despite mound-like shape, they are not prehistoric features. Mounds were classified as not present when no evidence of their presence was detected in the LiDAR data. Lack of evidence of mounds may be due to the physical destruction of the mounds prior to acquisition of LiDAR data from the site, inaccurate documentation of the site when first recorded, inaccurate georeferencing of site boundaries, or poor LiDAR data quality.

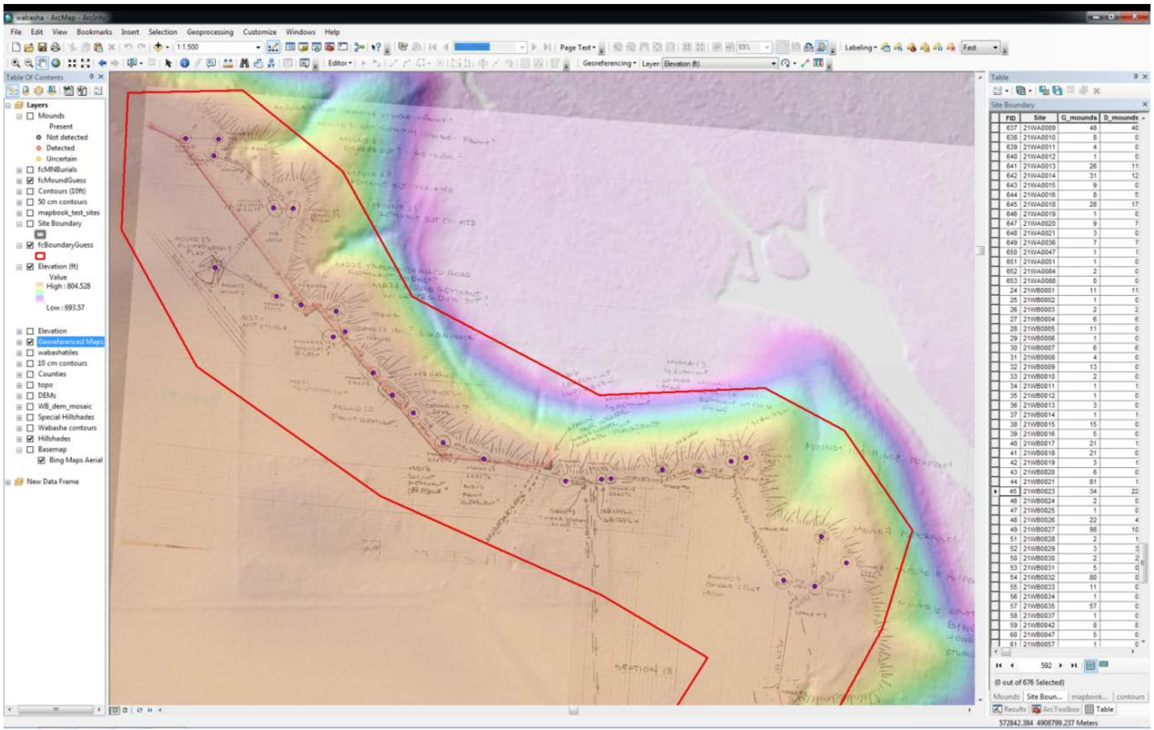

Figure 6: View of site 21WB0023 with 1-m hillshade, 1-m DEM, georeferenced site boundary and mound locations, and 1993 Peterson site map.

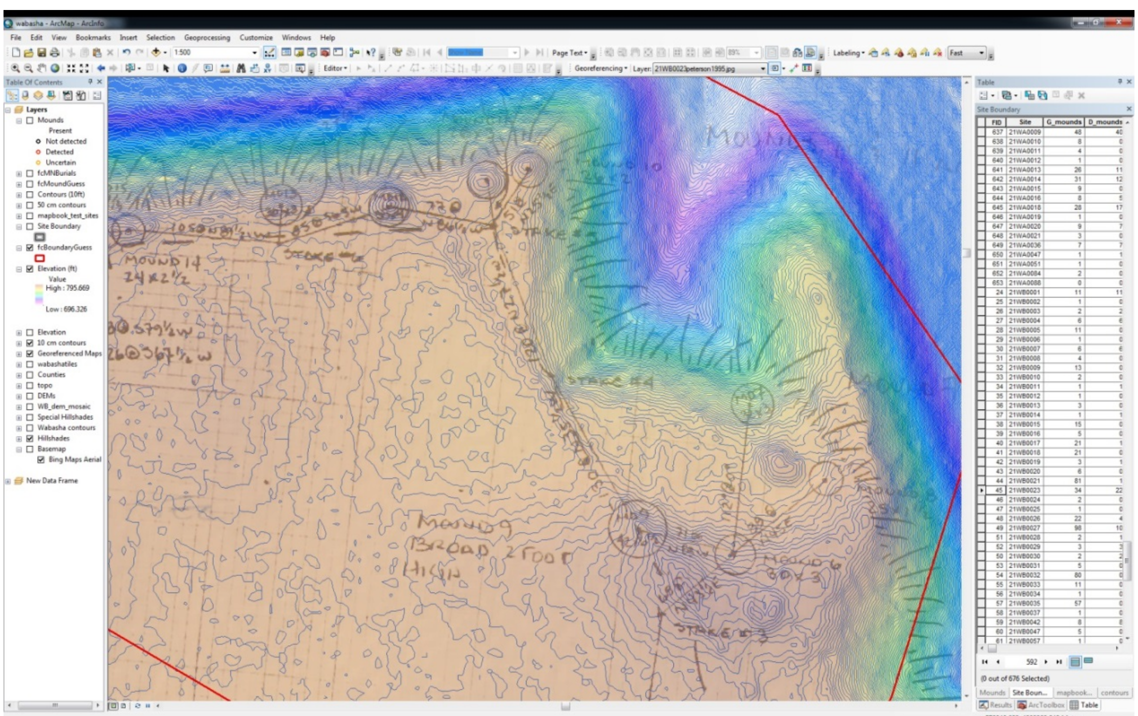

Figure 7: Detail of site 21WB0023 with 1-m hillshade, 1-m DEM, 10-cm contours, and Peterson reference map moved to correspond with detected mounds along the north edge of the frame. Note that mounds are also visible in the southeast quarter of the frame but their location on the map relative to the northern group is slightly inaccurate.

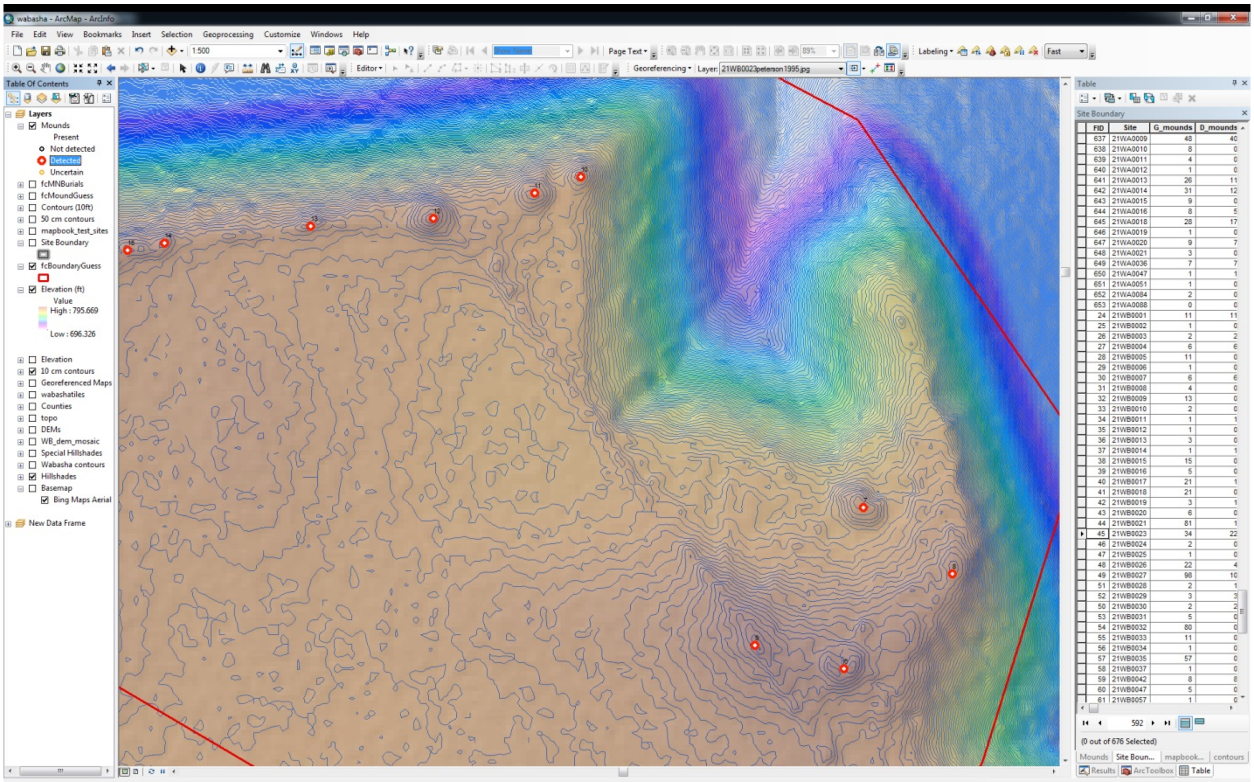

Figure 8: Detail of site 21WB0023 with mound locations marked.

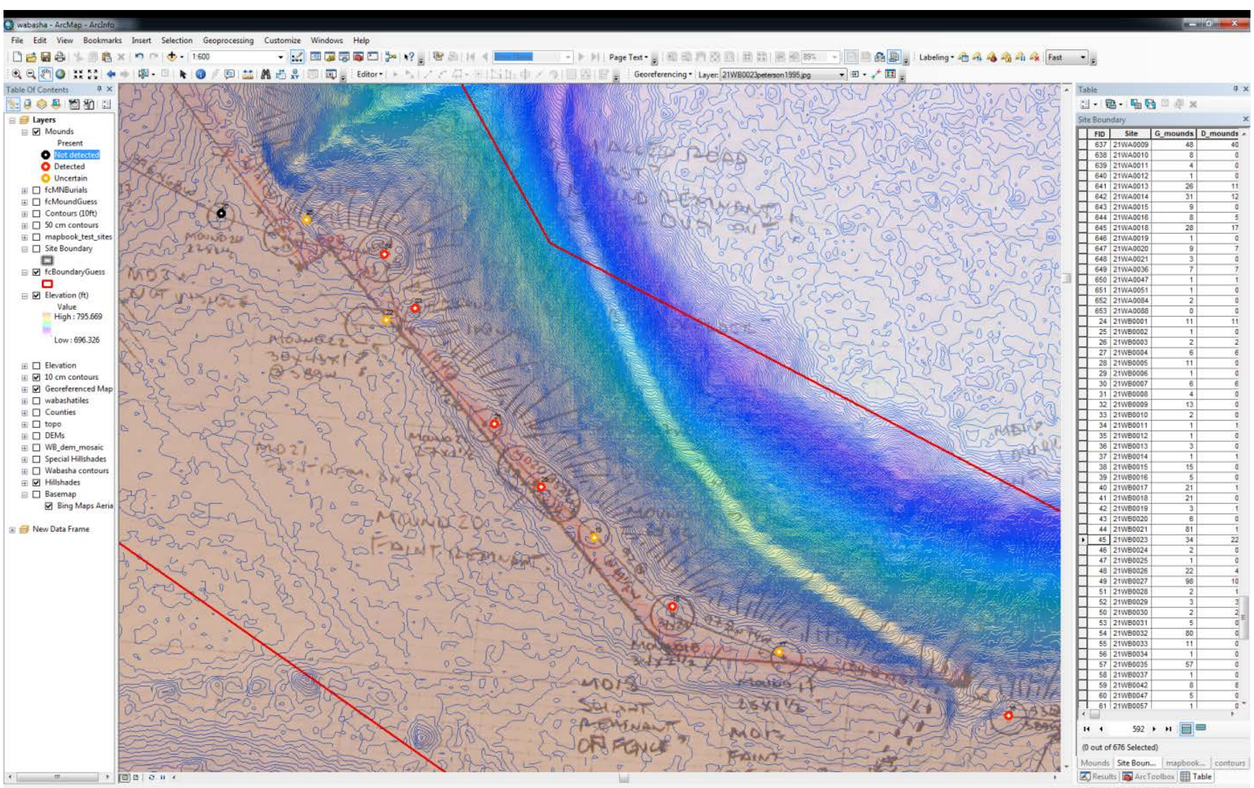

Figure 9: Detail of 21WB0023 showing mounds marked present (red circles), uncertain (orange circles), and not present (black circles).

Use of 1-m hillshade, 1-m DEM, and 10-cm contours was sufficient for analysis of about 95 percent of sites. In cases where this data was difficult to interpret due to surface roughness or suspected LiDAR processing errors, more advanced analysis steps were undertaken. While hillshade vertical exaggeration and varied lighting angles were tested for analysis of difficult sites, these methods were not superior to 10-cm contours for detection of mounds. Point cloud analysis was undertaken only in cases where poor LiDAR bare-earth processing was suspected due to odd features in the LiDAR products such as unnaturally flat spots, suggesting truncated surface features. Site 21HE0065 (Figure 10) contains a clear example of a bare earth filtering error. The processing algorithms used by nonarchaeologists to create BE-DEMs from LiDAR point cloud data are developed to recognize and remove trees, buildings, and other above ground features. The algorithms are not "trained" to look for low conical features. Fortunately, however, as this figure shows, they do not completely eradicate the mound, but instead leave a low, completely flat area that readily stands out in a good-quality hillshade.

ArcScene 3D display of hillshade images and point clouds was initially explored as a method for advanced analysis of LiDAR for sites, as it allows viewing of unfiltered LiDAR point clouds and vertical exaggeration of this point cloud data and the hillshade image draped over a 3D elevation surface, a technique that can make subtle topographic features more detectable. However, the use of 10-cm contours largely obviated the need to view exaggerated hillshade images and LP360 software proved more convenient for displaying and analyzing 3D point cloud and point cloud vertical profile data. For the bulk of the project LP360 alone was used for advanced analysis of sites. This analysis of point cloud data did not result in more mound detection at most of the sites for which it was undertaken; only two sites, 21HE0065 and 21WR0029, actually contained mounds that were improperly filtered from the bare-earth LiDAR data (Figure 11).

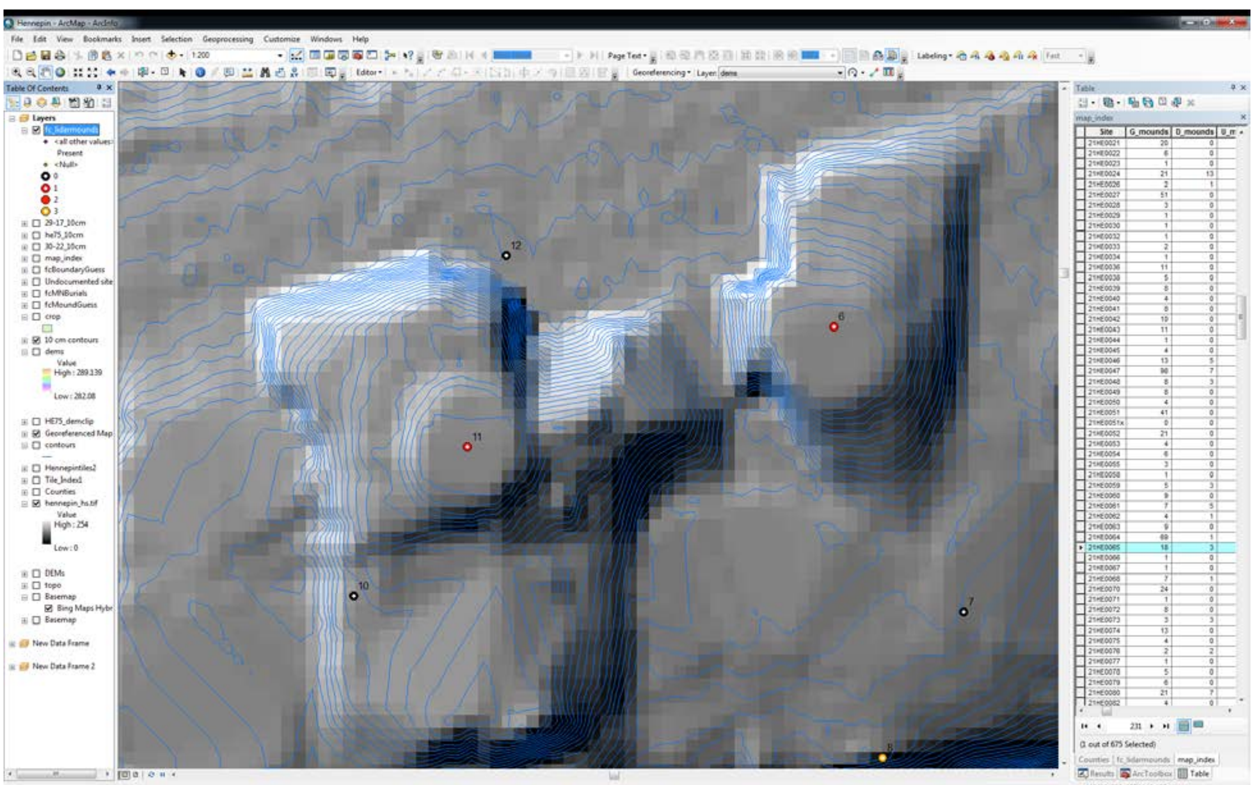

Figure 10: Detail of 21HE0065 showing improperly truncated features, mounds 11 and 6, marked with red dots.

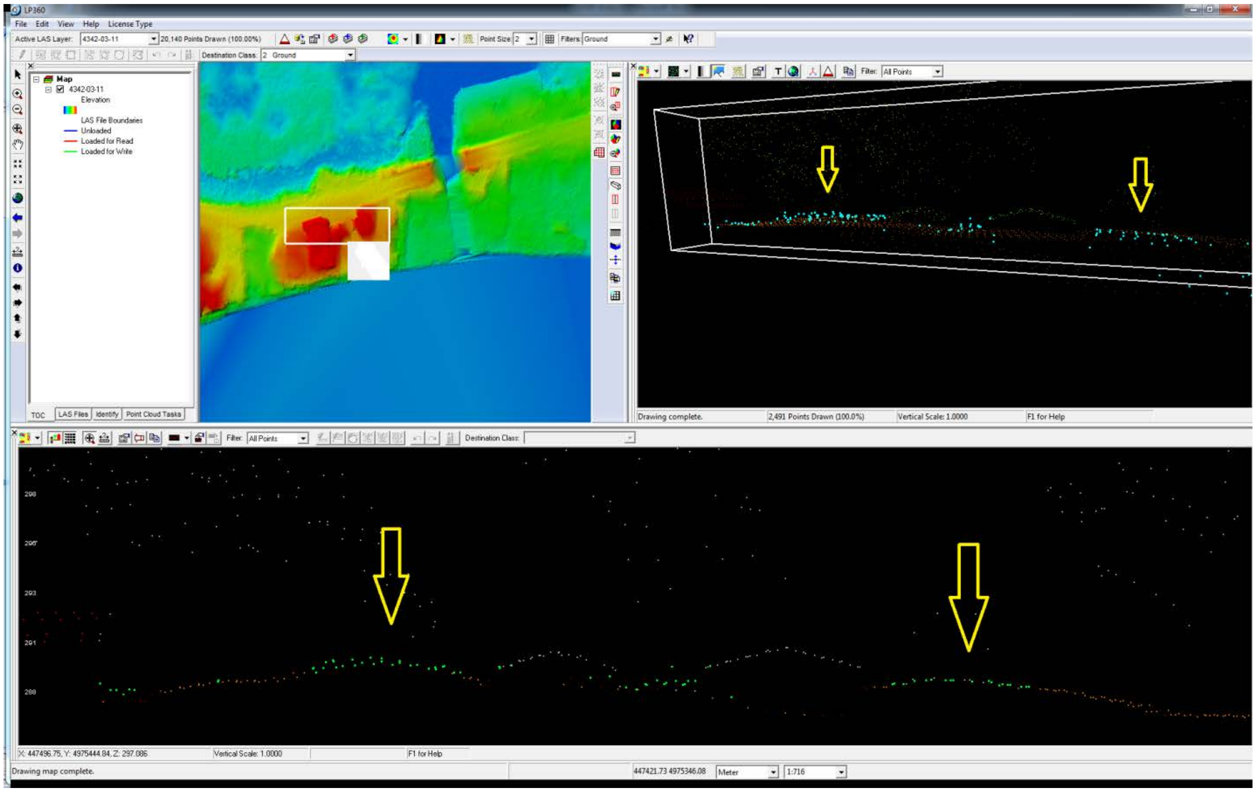

Figure 11: LP360 profile and 3D view of 21HE0065 point cloud detail, showing mounds improperly classified as low vegetation and removed from bare-earth DEM.

Some sites appeared unnaturally bumpy in LiDAR data, in most cases due to forest landcover or development interfering with LiDAR acquisition and bare-earth point filtering (Figure 12). While 3D analysis was undertaken at sites that were difficult to interpret due to this LiDAR quality problem, it did not improve mound detection for these sites. Without site visits, it is impossible to tell which ground textures are actually present and which are caused by LiDAR errors, but bumpy or difficult-to-interpret DEM texture was noted for around 16 sites.

Several possible undocumented mounds were detected in LiDAR data over the course of this study. When they were situated among a group of documented mounds at a site, they were included as new mounds within the existing site, and are identified with an "N" designation in the mound numbering system. Mounds detected outside of existing sites were recorded as new sites with provisional site numbers. The new sites were given their Smithsonian Institution Trinomial System (SITS) state and county designators. The numeric part was assigned in order by county, with an "n" prefix indicates it is newly recorded site. Work for this project focused on detecting mounds at known mound sites, so it did not involve a systematic search for new mound sites and new mounds were detected serendipitously in the course of investigating known sites.

Recordkeeping

LiDAR analysis records were kept in shapefiles of boundaries and mound center points, and in an Excel spreadsheet of narratives and site statistics. The containing boundary shapefile (map_index.shp) was based on BoundaryGeoref, the shapefile of georeferenced boundaries of areas containing mounds. The boundary polygons were altered as appropriate to include all detected mounds at a site or to reduce the extent of an overly large boundary. The site boundaries in this shapefile do not necessarily correspond to, and are not intended to represent of modify, the official site boundaries as recorded with SHPO, and

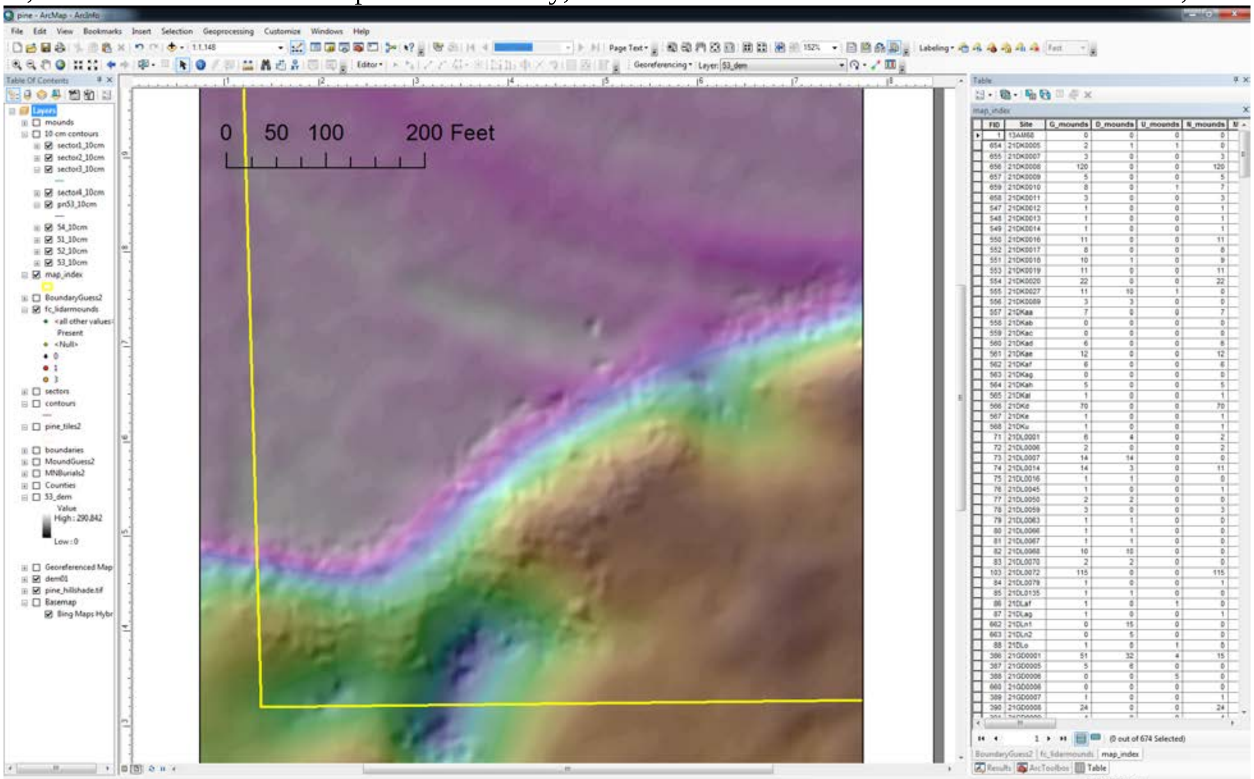

Figure 12: Detail of 21PN0006, showing bumpy DEM texture

they may not include non-mound features such as habitation areas that are included in the site record. Previously undocumented sites were recorded with provisional site numbers prefixed with “n”, as in 21HUn1 and 21WBn1.

The mound point shapefile (lidarmounds.shp) was also based on a similar shapefile of georeferenced mound center points (MoundGeoref), and was updated based on LiDAR analysis results. Mound center points were shifted to the center of detected mound features, and in some cases center points of mounds that were not detected in LiDAR were also moved based on their position in a mound group with detected mounds. Undocumented mounds detected at existing sites were given provisional mound numbers prefixed by “N” . Some mounds at documented sites are mapped but do not appear to have mound numbers in the records provided to UI-OSA for this study. Such mounds were assigned provisional mound numbers prefixed with “X”. Finally, there are some sites where mounds are reported but not mapped. These mounds, when detected, were assigned provisional numbers prefixed with “M”. A narrative of findings, methods, and other observations for each site was maintained in an Excel spreadsheet. This was adapted for site narratives in this report (Appendix I).

Chapter IV: Results and Analysis

RECORDS ANALYSIS AND GEOREFERENCING

Filtering of the Mn-OSA master burials database identified 682 mound sites and 7722 individual mounds within the 16 county project area (Tables 1, 3). After analysis, these numbers were reduced to 650 mound sites with 7646 individual mounds. This total is reasonably close to the tally of 7629 mounds in these counties made by Arzigian and Stevenson (2003:63-64). These 16 counties contain 64 percent of the 11,868 known mounds in Minnesota.

Sites and mounds were eliminated from the project for a number of reasons. Often, there were duplicates of the same site number in the master databases. Closer inspection of available site records indicate that no mounds were ever observed or indicated in the site. Errors in the total number of mounds listed in historical documents; for example, Lewis or Winchell would occasionally skip or duplicate a mound number, or the Mn-OSA list included a total number of mounds that differed from the original documents. Sometimes sites were combined into one site, for example Mound 21HE0034 was an isolated mound mapped by Lewis in 1887, but is probably part of the site 21HE0033, a mound group Lewis previously mapped in 1883.

The total of 7646 individual mounds within the 650 sites is an approximation, and probably underestimates the number of mounds observed in the field by past surveyors. Often sites would be noted as having mounds (plural), but the number of mounds was not specified. In such cases, the Mn-OSA burials database records the number of mounds as two, since there had to be at least two mounds, but there could have been many more. On a few sites, Lewis noted an area that had mounds but was unable to ascertain the number. For example at 21GD0017, Lewis noted 50 to 75 mounds in a cornfield in the center of the site that he was unable to survey.

The majority of mound sites in the project (444 of 650, 68 percent) were originally mapped or noted by T. H. Lewis (Table 4). Lewis also recorded the majority the 7646 individual mounds (6357, 83 percent). Jacob Brower provided information on 35 sites (5 percent of the total), five of them duplicated by Lewis. Within the 35 sites, 876 mounds were noted (11 percent of the total).

Of the 650 mound sites in the 16 counties, 414 (63 percent) had mapped mounds that could be georeferenced (Table 5). Of the 7646 individual mounds known from historical accounts, 6223 (81 percent) could be georeferenced using historical maps to a specific point with some degree of confidence. Mounds were not georeferenced for a number of often overlapping reasons. There was no site map showing mound location, or the map location was too vague or contradictory (all or part of 217 sites); the landscape has changed to the extent that no georeferencing could be made because of a lack of landmarks (13 sites); or the site appears to be a part of another site (29 sites; Table 6).

Alphabetical site designations are used by Mn-OSA for sites where the location was determined to be uncertain. For example, site 21HEai was noted as an isolated mound, but the only locational information is its quarter-quarter section. Of the 650 mound sites, 111 (17 percent) have alphabetical designations. Of the 111, only 13 had enough information to georeference individual mounds (12 percent; comprising 2 percent of the 414 total georeferenced sites). A total of 75 individual mounds were georeferenced at alphabetical sites.

The average number of mounds per site is 11.7. A plot of the number of mounds per site reveals they are distributed in an exponential power curve (Figure 13). Of the 650 sites, half (n = 327) contain three or fewer mounds. Isolated mounds (n = 170) make up a quarter of the sites (26 percent), but only 2 percent of the total mounds. Lewis recorded 91 isolated mounds.

Table 3. Summary of Previously Recorded Mounds and Mound Sites by County.

County	Mound Sites	Recorded Mounds	Sites w/ Georefer-enced Mounds	Georefer-enced Mounds	% Sites with Georefer enced Mounds	% Recorded Mounds Georeferenced	Mounds from Arzigian and Stevenson (2003:63-64)
Dakota (DK)	28	337	15	212	53.6%	62.9%	330
Douglas (DL)	20	180	12	56	63.2%	31.6%	178
Goodhue (GD)	112	1363	78	1239	68.4%	92.1%	1535
Hennepin (HE)	111	1151	74	1093	65.5%	93.0%	1160
Houston (HU)	23	267	16	246	66.7%	93.2%	269
Isanti (IA)	20	174	18	169	90.0%	97.1%	169
Kanabec (KA)	25	346	18	302	72.0%	87.3%	346
Mille Lacs (ML)	42	676	15	192	34.9%	27.2%	499
Otter Tail (OT)	52	530	32	475	59.3%	92.2%	516
Pine (PN)	16	184	5	147	29.4%	80.8%	172
Scott (SC)	37	641	29	577	80.6%	90.6%	636
Sherburne (SH)	26	334	18	280	72.0%	83.6%	331
Sibley (SB)	12	204	7	87	58.3%	43.9%	199
Wabasha (WB)	48	567	35	539	74.5%	94.9%	591
Washington (WA)	22	309	17	280	77.3%	90.6%	304
Wright (WR)	57	383	26	329	44.8%	80.6%	394
TOTAL	651	7646	414	6223	63.0%	81.1%	7629

Note: Excludes duplicated sites and mounds.

Table 4. Summary of Recorded Mounds and Mound Sites.

	Mound Sites	% of 650	Mounds	% of 7646
Total Mounds				
Numeric	546	83.9%	7137	93.3%
Alphabetical	106	16.3%	509	6.7%
Total recorded	651	100.0%	7646	100.0%
Mean mounds/site			11.7	
Other Statistics				
Isolated mounds	170	26.1%	170	2.2%
Lewis	444	68.2%	6357	83.1%
Brower	35	5.4%	876	11.5%

Note: there is much overlap in these percentages, so percentages will not add up to 100%.

Table 5. Summary of Georeferenced Mound Sites.

	Mound Sites	% of total	Mounds	% of total
Total with georeferenced mounds	414	63.6%	6223	81.4%
Numeric	401	61.6%	6158	80.5%
Alphabetical	13	2.0%	75	1.0%
Mean mounds/site			15.0	

Table 6. Probable Duplicated Sites.

Site Number in OSA Database	Georef-erenced	Probably Part of Site	Notes (see Appendix 1 for Details)
21DK0015	No	21RA0003	Same site as 21RA0003 in OSA records
21GD0061	No	21GD0058	Same site as 21GD0058 in OSA records
21GD0062	Yes	21GD0058	Recorded by Lewis as isolated mound, but is near and may be part of the nearby 21GD0058.
21GD0114	No	21GD0071	Same site as 21GD0071 in OSA records
21GD0120	No	21GD0052	Same site as 210052 in OSA records
21HE0034	No	21HE0033	An isolated mound at essentially the same location as 21HE0033. UI-OSA did not map this site.
21HE0081	No	21HE0084	Location of 21HE0081 is not certain. It may be the same site as 21HE0084
21HE0092	Yes	21HE0002	OSA records indicate this may be the same site as 21HE0002
21HE0103	Yes	21HEe	21HE103 is like to be one or more of the mounds recorded as part of the Fish Lake Mound Group, 21HEe
21KAak	No	21KA0080	Same site as 21KA0080 in OSA records
21ML0016	No	21ML0009	Considered part of 21ML0009 in OSA records
21ML0018	No	21ML0012	Considered part of 21ML0012 in OSA records
21ML0022	Yes	21MLc	The location depicted for this site in OSA records is probably a misinterpretation of a map by Brower, which shows the mounds farther south, at location of 21MLc
21ML0030	No	21ML0001	Considered part of 21ML0001 in OSA records
21OT0004	No	21OT0023	May be same site as 21OT0023 in OSA records
21OT0045	No	21OT0023	Probably associated with 21OT0023 in OSA records
21OT0048	No	21OT0027	Same site as 21OT0027 according to OSA records
21OTa	Yes	21OT0012	May be part of 21OT0012 in OSA records
21OTan	Yes	21OTp	Location of 21OTp and 21OTan are poorly documented, but in the same general location.
21OTbs	No	21OT0022	Probably the same site as 21OT0022 in OSA records
21OTx	No	21OTc	Site is considered part of 21OTc in OSA records
21OT}	No	21OTan	May be part of 21OTan.
21PN0002	No	21PN0001	Considered part of 21PN0001 in OSA records
21PNq	Yes	21PN0001	Is probably a mound located within and part of 21PN0001
21SC0001	No	21SC0023	Considered part of 21SC0023 in OSA records
21WA0003	No	21WA0013	Considered part of 21WA0013 in OSA records
21WA0004	No	21WA0013	Considered part of 21WA0013 in OSA records
21WB0038	No	21WB0004	Same site as 21WB0004 in OSA records
21WB0053	No	21WB0026	Considered part of 21WB0026 in OSA records
21WR0030	Yes	21WR0031	Probably the same site as 21WR0031, although a possible alternative location for a separate site is suggested based on georeferencing of Winchell's map.

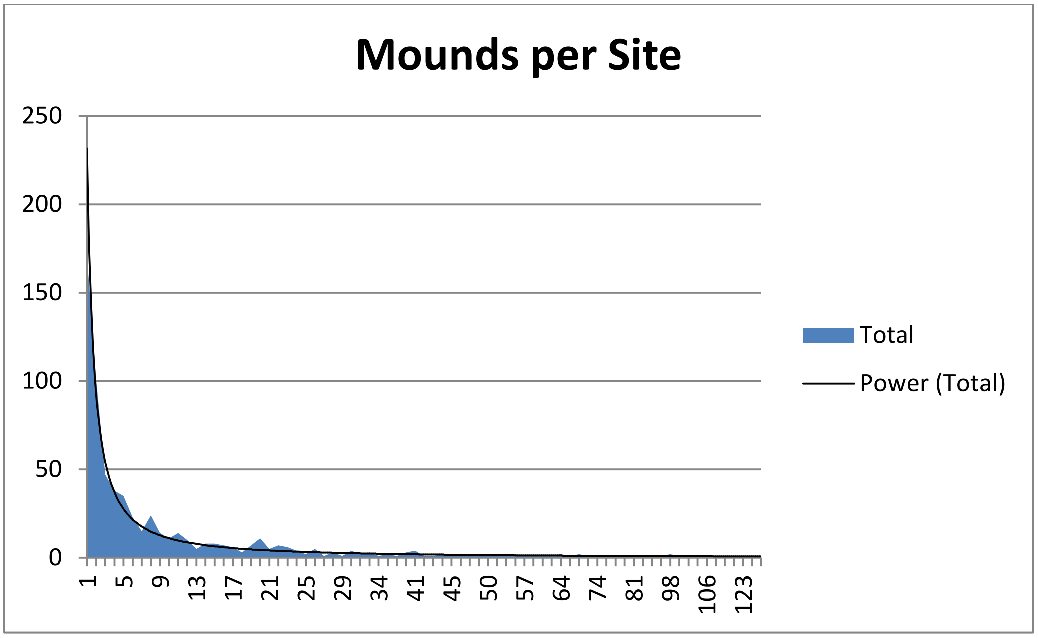

Figure 13. Histogram showing number of recorded mounds per site.

LIDAR ANALYSIS

Methodological Assessment

The methods employed by this project in LiDAR analysis, listed in order of increasing complexity, included hillshading, topographic contouring, stretch rendering of shaded relief maps, vertical exaggeration of shaded relief maps, and visualization, profiling, and reclassification of LAS (point cloud) data. The simplest methods, hillshading and 10 cm contouring, were the only methods employed at 96 percent of the sites where mounds were detected (Table 7). At these sites, the BE-DEMs were of sufficient quality, in terms of the density and distribution of last return points, that further processing was deemed unnecessary. The more advanced techniques were necessary for 30 sites, 60 percent of which were in wooded areas where the BE-DEM was less accurate. Another 23 percent of the sites requiring advanced analyses were in residential areas and farmsteads, where a combination of shade trees and buildings created additional "noise" that interfered with the representation of possible mounds in hillshades and contours.

Table 7. Methods Used for Mound Detection in Relation to Land Use.

	Hillshade, Contours		Other (Advanced)		Total	
Primary Land Use	**Sites**	**%**	**Sites**	**%**	**Sites**	**%**
Agricultural	122	19%	1	3%	123	18%
Developed	31	5%	1	3%	32	5%
Grassy/Park	38	6%	2	7%	40	6%
n/a	3	0%	0	0%	3	0%
Residential/Farmstead	200	31%	7	23%	207	31%
Road/ROW	16	3%	1	3%	17	3%
Wetland	6	1%	0	0%	6	1%
Wooded/scrub	223	35%	18	60%	241	36%
Total Sites	**639**	**100%**	**30**	**100%**	**669**	**100%**
Percent	**96%**		**4%**		**100%**	

Detections were coded as certain or uncertain (Table 8). The detection was rated as certain when the mounds were symmetrical in plan and cross section, and were appropriate diameters and heights for mounds. Certainty was also increased when the distributional pattern of the detected features, and their diameters and heights, corresponded with those recorded on good quality site maps. The quality of LiDAR data, and its coincidence with good mapping, ca. 80 percent of the detected mounds were identified with certainty, and only 20 percent were deemed uncertain due to such factors as ambiguities in geometric shape, height, and landscape position. Uncertainty increased in developed areas and along road-rights of way. Of the 85 mounds detected in these two highly-modified landscapes, 50 percent of the mound detections were coded as uncertain. The proportion of certainty to uncertainty was also higher (64 percent certain versus 36 percent uncertain) in residential areas, probably also due to the extent of historic land modification in these settings.

Mounds as low as 20 cm were successfully detected by this analysis. This is attributed to the quality of the statewide LiDAR. By comparison, Riley et al. (2010) reported that only mounds 60 cm or higher could be confidently detected in the data available for their study.

Georeferencing was crucial to success of the project. Not only did previous maps lend confidence to LiDAR detections, the maps were an excellent guide to the search for mounds in the LiDAR data. The maps allowed the analyst to quickly determine where to concentrate her search for mounds. In some

Table 8. Certainty of Detection in Relation to Land Use.

	Certain		Uncertain		
Primary Land Use	**Mounds**	**%**	**Mounds**	**%**	**Total**
Agricultural	257	72%	102	28%	359
Developed	35	51%	34	49%	69
Grassy/Park	173	78%	49	22%	222
Residential/Farmstead	342	64%	193	36%	535
Road/ROW	7	44%	9	56%	16
Wetland	6	86%	1	14%	7
Wooded/scrub	1371	87%	211	13%	1582
Grand Total	**2191**	**79%**	**599**	**21%**	**2790**

Data includes only mounds detected by LiDAR.

ways, this was a detriment to critically assessing the validity of LiDAR for mound detection. In other words, our detection efforts were not a "blind test," where the LiDAR analyst would work without prior knowledge of mound distributions, with her results compared to the existing maps afterward. To some extent, this approach differs little from the use that archaeologists have made for years of the T. H. Lewis maps. Haury (1990), for example, notes that when re-surveying Lewis sites with low or plowed-down mounds, once one mound was found, Lewis' bearings and distances were often sufficient to navigate to the other features.

Detection Rates

Mn-OSA site records document a total of 7646 mounds at 650 sites in the 16 counties. LiDAR analysis detected a total of 2778 mounds at 376 of the 650 sites (Table 9). Failure of detection at 65 percent of the examined sites is undoubtedly due to site destruction through time, as well as the uncertain location of many sites.

Determining how many previously recorded mounds were detected in LiDAR is not as simple as dividing the total detected by the total reported. The result, 36 percent, is too low for several reasons. First, 157 of the mounds detected in LiDAR by this project are believed to be previously unrecorded. This includes 39 mounds that although within known sites, do not correspond to the documented location of known mounds. In addition, 118 mounds were detected at 12 new sites located outside known site boundaries. Thus, 2633 of the 2778 detected mounds are likely to have been previously recorded (Table 10).

Second, hundreds of recorded mounds have been disturbed or destroyed since they were initially recorded. Indeed, even T.H. Lewis mentions mounds that were known to have been destroyed at sites prior to his reaching them. This project's review of site records (Appendix 1) documents surveyors' observations for the destruction of 884 of the 7646 recorded mounds were no longer extant at the time of the last site visit, bring the number of mounds available for LiDAR detection to 6762 (Table 10). This is undoubtedly a low estimate, since so many sites were recorded by Lewis and Brower, and so few of these have been revisited since.

Table 10 gathers data on the number of previously recorded mounds documented by LiDAR analysis. Part 1 shows the distribution of recorded mounds and LiDAR-detected mounds among sites, with sites grouped according to those with SITS numbers (e.g., 13DL0001), letter designations (e.g., 13DLa), and new sites recorded by this analysis (e.g., 13DLn1). Part 2 subtracts mounds reported as destroyed from the total mounds recorded. This number, 6781, is a minimum estimate of the numbers of mounds that were potentially available for detection by LiDAR. Part 3 subtracts the mounds recorded for the first time

Table 9. Comparison of Recorded and Detected Mounds by County.

	Sites		Recorded Mounds		Detected				Total Detected	
					Certain		Uncertain			
County	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**	**n**	**%**
Dakota (DK)	28	4.3%	337	4.4%	6	1.8%	3	0.9%	9	2.7%
Douglas (DL)	19	2.9%	180	2.4%	40	22.2%	2	1.1%	42	23.3%
Goodhue (GD)	112	17.2%	1363	17.8%	387	28.4%	104	7.6%	491	36.0%
Hennepin (HE)	111	17.1%	1151	15.1%	244	21.2%	145	12.6%	389	33.8%
Houston (HU)	23	3.5%	267	3.5%	31	11.6%	13	4.9%	44	16.5%
Isanti (IA)	20	3.1%	174	2.3%	122	70.1%	10	5.7%	132	75.9%
Kanabec (KA)	25	3.8%	346	4.5%	146	42.2%	27	7.8%	173	50.0%
Mille Lacs (ML)	42	6.5%	676	8.8%	142	21.0%	54	8.0%	196	29.0%
Otter Tail (OT)	52	8.0%	530	6.9%	201	37.9%	70	13.2%	271	51.1%
Pine (PN)	16	2.5%	184	2.4%	23	12.5%	7	3.8%	30	16.3%
Scott (SC)	37	5.7%	641	8.4%	172	26.8%	71	11.1%	243	37.9%
Sherburne (SH)	26	4.0%	334	4.4%	196	58.7%	22	6.6%	218	65.3%
Sibley (SB)	12	1.8%	204	2.7%	38	18.6%	8	3.9%	46	22.5%
Wabasha (WB)	48	7.4%	567	7.4%	80	14.1%	25	4.4%	105	18.5%
Washington (WA)	22	3.4%	309	4.0%	164	53.1%	18	5.8%	182	58.9%
Wright (WR)	57	8.8%	383	5.0%	71	18.5%	18	4.7%	89	23.2%
TOTAL	**651**	**100.0%**	**7646**	**100.0%**	**2181**	**28.5%**	**597**	**7.8%**	**2778**	**36.3%**

* Excludes 118 possible new mounds discovered during LiDAR analysis.

Table 10. Minimum Detection Rate of Previously Recorded Mounds by LiDAR.

		SITS-Numbered	Letter Sites	New Sites	Total
	1. Base Data				
1	Sites	567	115	12	694
2		82%	17%	2%	100%
3	Reported Mounds	7170	528	0	7698
4		93%	7%	0%	100%
5	Detected in LiDAR	2612	60	118	2790
6		94%	2%	4%	100%
	2. Adjustments to Number of Reported Mounds				
7	Reported Mounds (line 3)	7170	528	n/a	7698
8	Reported Destroyed	884	33	n/a	917
9	Extant Mounds (Minimum)	6286	495	n/a	6781
	3. Adjustments to Number of Detected Mounds				
10	Total Mounds Detected (line 5)	2612	60	118	2790
11	New Mounds Detected	39	0	118	157
12	Recorded Mounds Detected	2573	60	0	2633
	4. Minimum Detection Rate of Previously Recorded Mounds				

13	Available for Detection (line 9)	6286	495	n/a	6781
14	Detected (line 12)	2573	60	n/a	2633
15	Detection Rate	41%	12%	n/a	39%

in this analysis from the total of detected mounds, which represents the number of detected mounds that correspond to previously recorded mounds. Finally Part 4 calculates the minimum percentage of previously known mounds that were detected by this analysis.

By these calculations, at least 39 percent of the previously recorded mounds that were available for detection were detected by the LiDAR analysis. The detection rate was considerably lower (12 percent) for letter sites, where the location of the site itself, not to mention of individual mounds within it, is uncertain. The actual detection rate is probably considerably higher. The actual number of mounds destroyed prior to LiDAR acquisition is undoubtedly more than 884. As previously discussed, most of the sites in the 16 county sample were first recorded by Lewis or Brower and have not been revisited since. When revisits have taken place, fewer mounds have been observed to survive. Mound attrition and survivorship is discussed further in a subsequent section.

DISTRIBUTION OF MOUNDS BY COUNTY

The number of mounds per km^2 varies widely among counties, from .05 to .81 (Table 11, Figure 14). This variation is due to three factors: the number of mounds originally constructed; and the number of mounds recorded before they were demolished; and the amount of survey conducted. The number of mounds originally constructed likely varies with landform. Mounds seem to be more common on stream terraces and bluff tops of major waterways, and on shores of large lakes, than in upland areas or along minor waterways. This may be skewed because upland areas were more likely to be plowed than blufftops or terraces. The number of mounds recorded before they were demolished depends on the timing and amount of effort spent looking for mounds. Earlier surveys are more likely to find mounds because they were conducted prior to significant plowing and development. On the other hand, early surveyors such as Lewis and Brower were less likely to spend time looking for mounds in extremely remote areas because of the difficulty in travel and a lack of local informants, and therefore mounds in remote areas are likely underrepresented.

Hennepin County likely has a high density of recorded mounds (.81/km^2) because its large waterways, the Minnesota, Mississippi, and Crow rivers, were likely preferred by mound builders, and also because survey was comparatively easy in the 1880s. This part of the state had an extensive road system, numerous inns, and was well populated with potential site informants. In contrast, the density of recorded mounds in Pine County, .08/km^2, is only a tenth that of Hennepin, probably because its largest waterway, the St. Croix River, is fairly small, and survey would have been very difficult in the nineteenth century, with few roads, inns, or informants to help.

LAND USE AND MOUND SURVIVORSHIP

The survivorship of mounds is likely predicated on land use. A mound that has been plowed for 150 years is unlikely to survive, nor is a mound in an area subject to quarrying or intensive earthmoving during construction. Mounds in remote or inaccessible wooded areas are more likely to survive.

Land use was recorded for each site based on examination of 2012 Bing Map aerial photographs, and coded into seven classes (Table 12, Figure 15). Sites were coded by their dominant use. For example, a large site that is mostly in a plowed field with a smaller area of woods is coded as "agricultural." Urban areas, quarries, hospitals, and other areas dominated by large structures or signs of intensive land leveling or filling, are coded as "developed" and houses and farmsteads with yards were coded as "residential/farmstead."

Table 12 and Figure 15 show mound survivorship in the different land use categories. The 7646 reported mounds are used as a proxy for the original number of mounds present at the sites considered in this report. Letter sites are excluded, since their uncertain location precludes confident land use assessment. The number of reported mounds is considered an underestimate of the mounds originally

Table 11. Mound Density per County.

County	Mound Sites	Recorded Mounds	County Area (km^2)	Recorded Mds/ km^2
Dakota (DK)	28	337	1475	0.23
Douglas (DL)	20	180	1643	0.11
Goodhue (GD)	112	1363	1964	0.69
Hennepin (HE)	111	1151	1442	0.80
Houston (HU)	23	267	1446	0.18
Isanti (IA)	20	174	1137	0.15
Kanabec (KA)	25	346	1360	0.25
Mille Lacs (ML)	42	676	1488	0.45
Otter Tail (OT)	52	530	5127	0.10
Pine (PN)	16	184	3655	0.05
Scott (SC)	37	641	924	0.69
Sherburne (SH)	26	334	1130	0.30
Sibley (SB)	12	204	1525	0.13
Wabasha (WB)	48	567	1360	0.42
Washington (WA)	22	309	1014	0.30
Wright (WR)	57	383	1711	0.22
TOTAL	651	7646	28,401	0.27

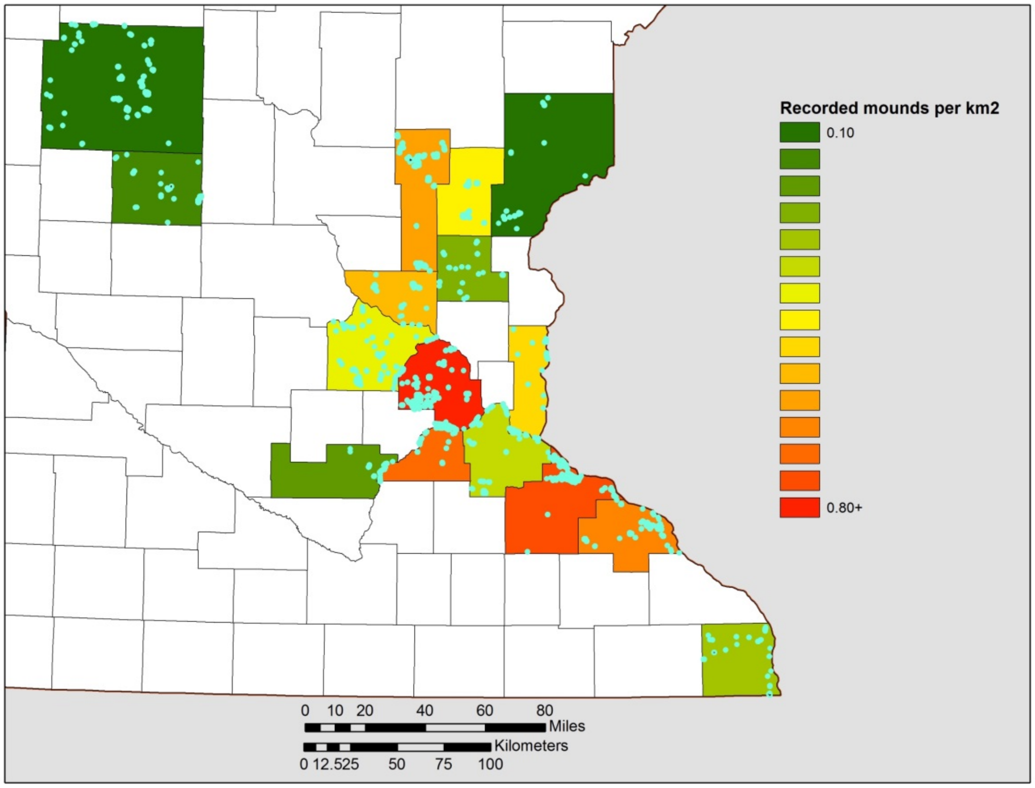

Figure 14. Recorded mounds/km² per county.

Table 12. Mound Survivorship and Land Use.

Current Primary Land Use	Reported Mounds* (n)	Reported Mounds (%)	LiDAR Detected** (n)	LiDAR Detected (%)	Net Loss (n)	Net Loss (%)
Agricultural	1450	18.8%	359	13.4%	1091	75.2%
Developed	782	10.2%	69	2.6%	713	91.2%
Grassy/Park	358	4.7%	201	7.5%	157	43.9%
Residential/Farmstead	2477	32.2%	535	20.0%	1942	78.4%
Road/ROW	237	3.1%	16	0.6%	221	93.2%
Wetland	24	0.3%	7	0.3%	17	70.8%
Wooded/scrub	2342	30.4%	1485	55.6%	857	36.6%
n/a	28	0.4%	0	0.0%	28	100.0%
Total	**7698**	**100.0%**	**2672**	**100.0%**	**5026**	**65.3%**

** Including both certain and uncertain confidence assessments, and excluding newly recorded sites and mounds.

Note: Totals vary slightly from previous tables because of differencers in the way the duplicated sites (Table 6) were handled in compiling data.

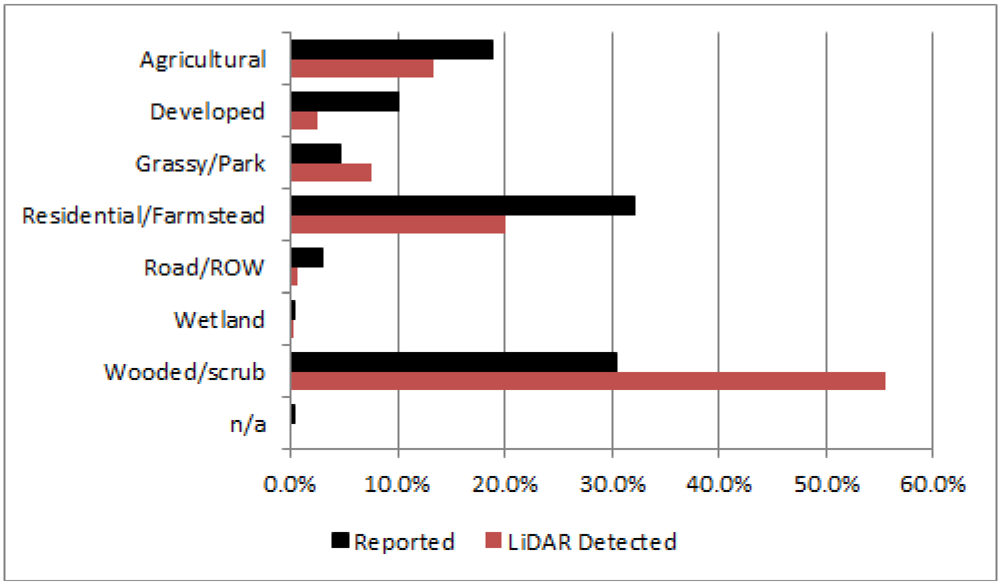

Figure 15. Differences in present-day land use between all reported SITS-numbered mound sites (black bars) versus those where mounds were detected in LiDAR (red bars).

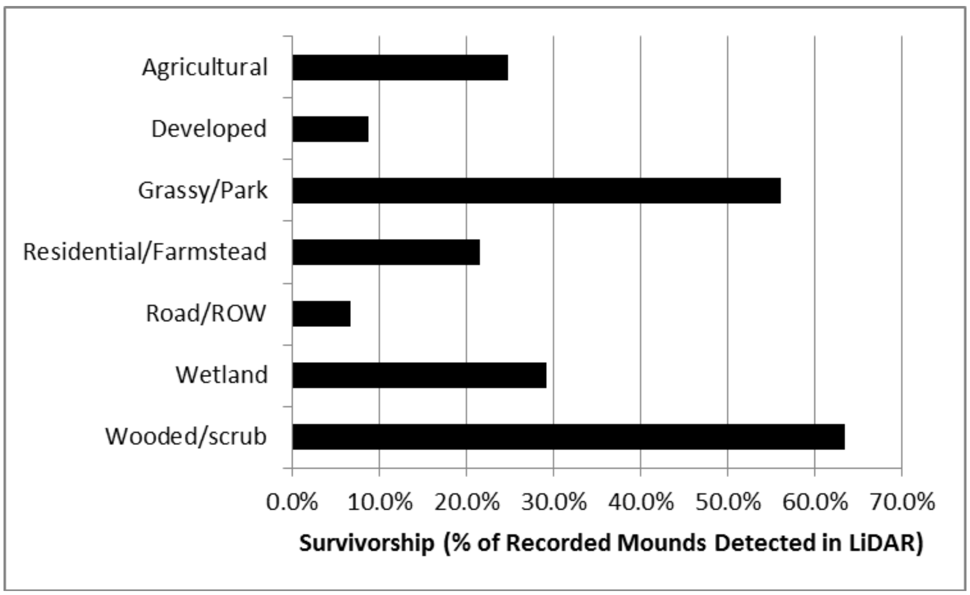

Figure 16. Survivorship of mounds within land use classes.

present, because, as discussed in the following section, many sites were not recorded until after development had occurred, removing uncounted mounds from the totals. The LiDAR-detected mounds serve as a proxy for the mounds that have survived, and includes only those mounds that are associated with previously known mounds. This excludes 157 mounds detected for the first time in this report.

The reported mounds were located predominantly in areas that are now either woods/scrubland or residential/farmstead, categories that together incorporate ca. 60 percent of the reported mounds, with ca. 30 percent in areas that are now cropland or developed (Figure 15). The mound survivorship profile (red bars in Figure 15) is quite different. About 55 percent of the remaining (LiDAR-detected) mounds are in woods/scrubland, a significant shift in the distribution of the surviving mounds toward undeveloped, wooded areas.

Figure 16 shows patterns in mound survivorship within land use classes. The overall survivorship of mounds, calculated as the percent of reported mounds that were detected in LiDAR, is 35 percent, but there is considerable variability of survivorship with land use. Survivorship in the wooded/scrub and grassy/park categories is ca. 60 percent, but only ca. 5 percent in developed areas and roadsides. Survivorship under cropland and residential/farmstead use is ca. 20 percent.

Table 13 further examines the role of woodlands in mound preservation by collapsing land use categories into "wooded" and "unwooded." Having most of the site in woods appears to improve mound survivorship from 20 percent to 62 percent.

These data indicate the extent to which survivorship is a factor of land use and management practices. Not surprisingly, the less intensive the use of the land, in terms of ground disturbance, the greater the likelihood that mounds are preserved. From this perspective, mound survivorship in residential areas is probably also a factor of the presence of yards and other green spaces. Modern preferences in suburban development tend toward expansive lots and planned set-asides of woodland. LiDAR analysis suggests that a number of large mound groups are preserved in the green spaces among the widely spaced houses. (Figure 17).

Table 13. Mound Survivorship and Woods (see note at end of Table 12).

Primary Land Use	Recorded	Detected	%
Wooded/scrub and grassy/park	2700	1686	62.4%
Not wooded	4998	986	19.7%
Total	7699	2672	34.7%

ATTRITION OF MOUNDS OVER TIME

This study can provide some insight into the rate of attrition of mounds over time. Not surprisingly, mounds recorded more than a century ago are less likely to be seen in LiDAR than mounds recorded in the past 20 years. Table 14 presents the LiDAR detection rates for mounds recorded in different time periods. The time span intervals are not equal because the rate of mound discovery is not constant over time. Lewis and Brower found the majority of known mounds in Minnesota in the 1880s and 1890s. There were few mound discoveries in the decades before and after. In order to create meaningful samples for different time periods, data were grouped into arbitrary time ranges. This table includes only those mounds with known years of discovery, excluding those for which this data is not available.

Table 14. Detection Rate of Mounds from Historic Periods

Period Reported	Reported mounds	LiDAR, Certain		LiDAR, Uncertain	
1840-1879	136	7	5.1%	37	27.2%
1880-1889	3399	753	22.2%	1001	29.4%
1890-1899	797	321	40.3%	380	47.7%
1900-1949	479	108	22.5%	140	29.2%
1950-1989	580	250	43.1%	285	49.1%
1990-2012	126	101	80.2%	118	93.7%

Of mounds discovered between 1840 and 1879, only 5 percent are clearly visible in LiDAR, compared to 80 percent of those discovered after 1990. If "uncertain" mounds found by LiDAR are included, the percentages increase. Figure 18 presents this graphically, showing the general trend of mound loss over time.

In Figure 19, the median year for each time period is plotted against the percentage of mounds not detected found by LiDAR and therefore presumably destroyed. Linear regression indicates a relatively good correlation with a correlation coefficient (R^2) of 0.6771, meaning about two-thirds of the variation can be explained by the regression. This provides a proxy for the attenuation rate of mounds, approximating the rate at which mounds disappear over time.

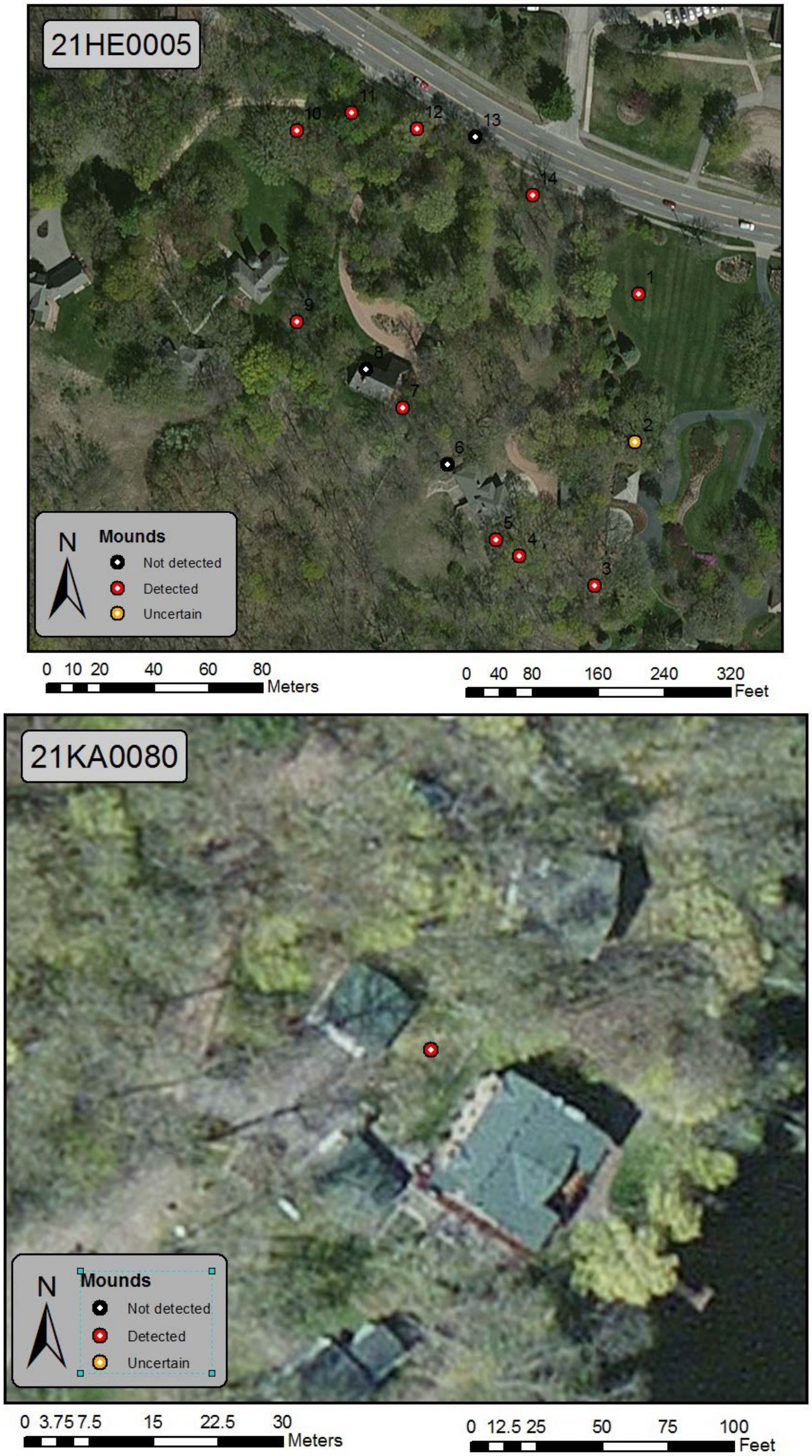

Figure 17. Bing aerial photographs of 21HE0005 and 21KA0080 showing mound-like features detected in LiDAR that may indicate preservation of mounds in residential areas.

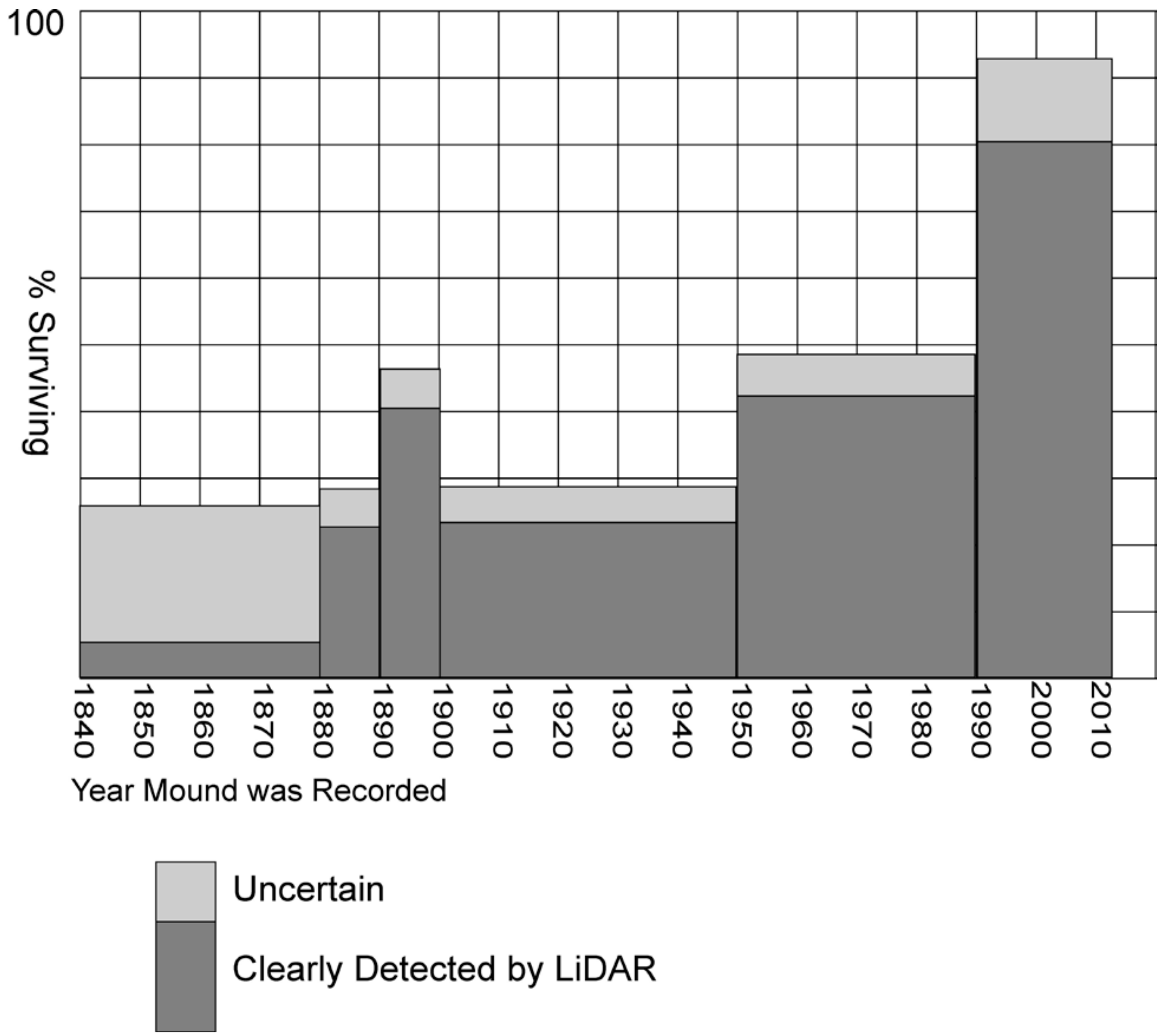

Figure 18. Percent of mounds observed by LiDAR by period in which they were first recorded. This chart is used as a proxy for mound survivorship, indicating that mounds recorded long ago are less likely to survive. Time periods are not equal because the rate of mound discovery is not constant over time, and several decades typically had to be combined to make large enough groups for analysis. Only mounds with known year of discovery were included.

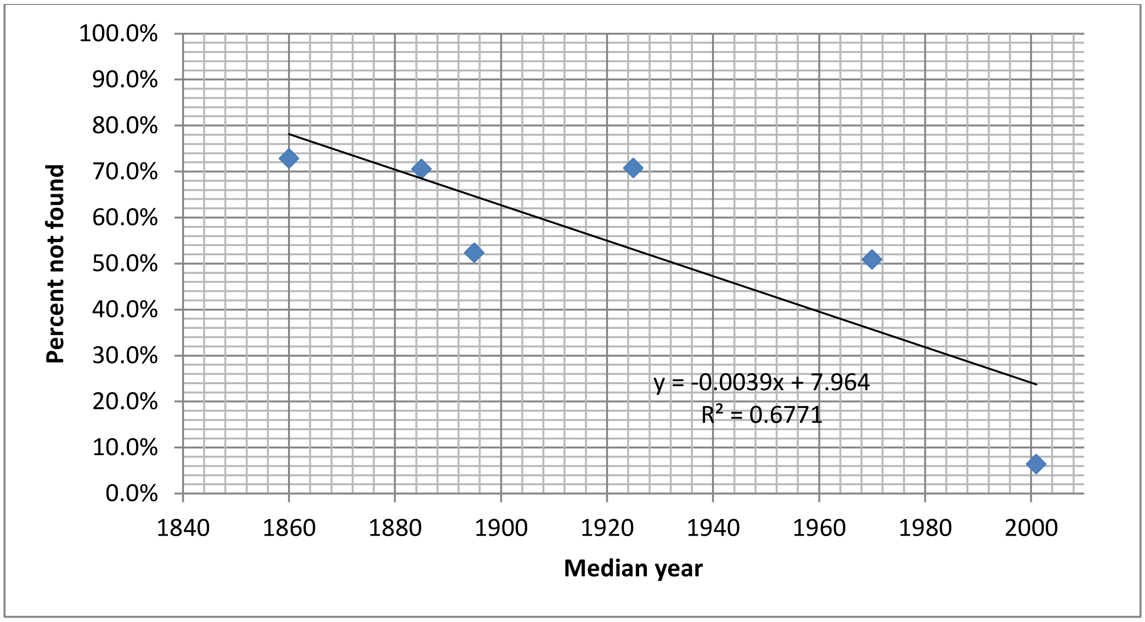

Figure 19. Percentage of mounds not identified by LiDAR by time period. Median period for each group was plotted against the percentage of mounds identified in that time period that were not detected by LiDAR. The linear correlation can be used as a proxy for mound attrition over time.

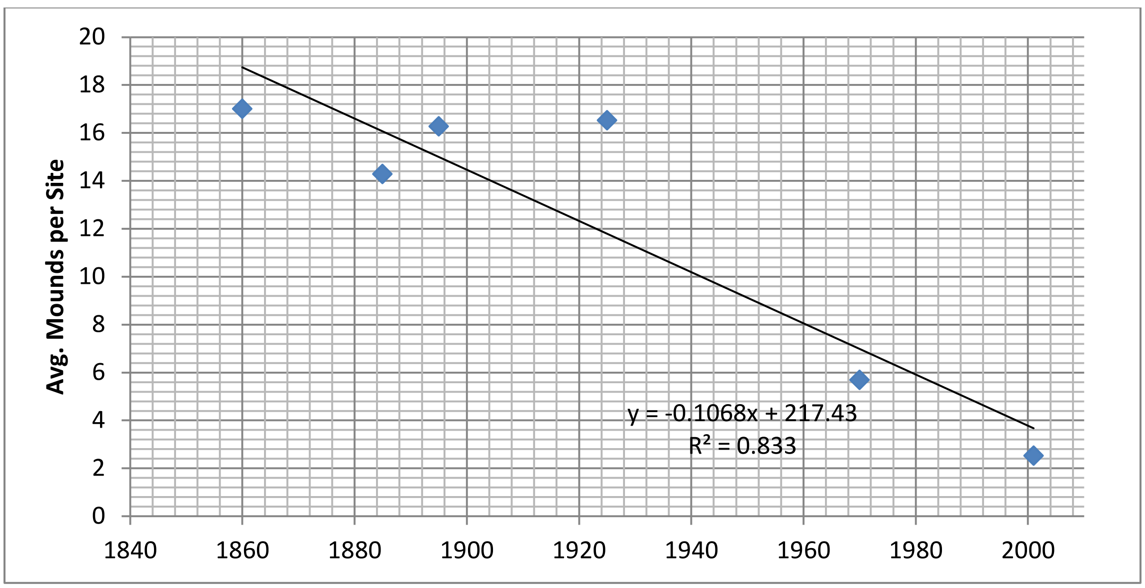

Figure 20. Mounds per site identified per time period. This chart reflects large mound groups being identified early, with small groups and isolated mounds being found later.

The average size of mound groups decreases over time, as well, declining from 17 mounds per site before 1880 to 2.5 mounds per site after 1990 (Table 15). This reflects the fact that all surviving, very large mound groups have been recorded, and the unrecorded mounds left are often isolated mounds in less accessible, overlooked locations.

Table 15. Mounds Recorded per Site from Historic Periods

Period Reported	Average Number of Mounds per Site
1840-1879	17.0
1880-1889	14.3
1890-1899	16.3
1900-1949	16.5
1950-1989	5.7
1990-2012	2.5

Chapter V. Summary and Recommendations

All recorded mound sites in 16 Minnesota counties were examined to verify their location and assess their preservation status using a combination of map, site records, and LiDAR analysis. The present study examined 650 previously recorded mound sites with 7646 individual mounds. Analysis of historical maps and archaeological survey data resulted in the georeferencing of the possible locations of 6,223 of these mounds. LiDAR data from these sites were analyzed using a number of methods, including default hillshades, custom hillshades, and point clouds of data. A total of 2181 mounded features were clearly seen in LiDAR data within site areas (28.4 percent), and an additional 597 were possibly observed but were too indistinct to be certain, for a total of 2778 mounds possibly observed (36.2 percent of all mounds). As a side benefit, although this project was not intended to prospect for mounds, 118 possibly new mounds were observed at 12 sites in six counties.

Analysis of the original mound data reveals variation in mound density per county, from .05 to .81 mounds/km^2. The count of mounds per site is distributed in an exponential power curve, averaging 11.7 mounds per site. Half the sites contained three or fewer mounds. Mound survivorship varies greatly by land use. Fifty-four percent of mounds were found in predominantly wooded sites, but only 7.5 percent of mounds occurred in developed areas and road rights-of-way. Mound survivorship is negatively correlated with the year the mound was first recorded. Only about 5 percent of mounds first recorded in the nineteenth century were identified in LiDAR versus ca. 80 percent of those recorded since 1990. The number of mounds per site at the time of its discovery declines over time. Sites recorded before 1880 average 17 mounds per site, primarily in large groups, declining to an average of 2.5 mounds per site after 1990.

GEOREFERENCING AND RECORDS REVIEW

Review of site records is essential prior to LiDAR analysis. As with any statewide site records system, conflicts and inconsistencies invariably, and arguably only, come to light when records are examined on a site-by-site basis. A thorough site records analysis *must* precede LiDAR analysis to verify mound counts and to check for discrepancies such as overlapping boundaries among sites and duplicated site numbers. Georeferencing is also a useful task if applied to historic maps that are drawn relatively accurately and to scale. This enhances the usefulness of the maps for planning and research, and also benefits LiDAR analysis by making it easier to locate and verify known mounds, and to assess the certainty of detection.

The use of 2 foot (or closer), LiDAR-derived contours is important. Often, bluff lines are the only landmarks given on Lewis' and Brower's maps that can be used for matching the map to the modern landscape. The contours on 1:24,000 USGS topographic quadrangles, which have an elevation accuracy of one-half the contour interval, are often not sufficient to identify these breaks in slope.

LIDAR ANALYSIS

This project demonstrates that statewide LiDAR datasets are of sufficient quality to detect most surviving mounds at previously recorded sites, as well as identify previously unrecorded mounds. While field verification is always important, especially for first-time detections, the important result of this study is that the USGS specifications adhered to by Minnesota's LiDAR acquisition appears to have produced BE-DEMs that are quite reliable for the detection of prehistoric earthworks. This contrasts with the mound detection pilot project undertaken by Riley et al. (2010), prior to the statewide acquisition project, in which successful LiDAR detection was severely hampered by substandard LiDAR datasets.

Although MnGeo LiDAR has been flown and post-processed to rigorous specifications, its users must always be aware of its limitations. The data available for downloading has been extensively processed prior to release. Even the LAS data, with XYZ coordinates for thousands of points, have been extensively thinned to remove redundant data. Although sometimes called "the raw data," they are not. The 1-m BE-DEM is the derivative product of greatest use to archaeologists, since it models the land surface. This product, however, is also the result of extensive processing of the total-return data. The points have been sorted by elevation, classified to identify and extract non-ground points, and thinned and interpolated from a random scatter of points into a regular grid of elevation values. In particular, archaeologists must be aware that the processing algorithms that result in the selection of points interpreted as the ground surface are created by nonarchaeologists for nonarchaeological purposes. The emphasis is on the removal of vegetation and of modern structures such as buildings that are primarily rectilinear and straight sided. Conical mounds of earth are not the kinds of features the algorithms are "trained" to look for. Nevertheless, as this study shows, the last return point density is usually sufficiently dense and the algorithms sufficiently robust, that mound-like features are readily detectable, especially in areas where the vegetation canopy is sparse. In wooded and developed areas, however, a common occurrence is the planar "scalping" of the mound, in which the upper parts of the mound are classified as non-ground points and removed, leaving only a flat-topped "stump" of a mound in the DEM (e.g., Figure 10).

The LiDAR derivative perhaps most often used by archaeologists are the hillshaded relief surfaces created from the BE-DEMs. In this study, most of the LiDAR-detected mounds were visible in the 1 m hillshades generated from MnGeo BE-DEMs. However, it must always be kept in mind that the default hillshade used by programs such as ArcGIS, and most commonly seen in LiDAR data available on-line is set to mimic a light source from due northwest, 45 degrees above the horizon. This angle may be too high to bring low relief features such as burial mounds into view. At sites on east and south facing slopes, the default northwest light source may cast shadows that obscure, rather than heighten the relief of Precontact earthworks.

Two-foot contours produced from LiDAR are also available for downloading from MnGeo. While useful for many applications, including the georeferencing of historic maps, their use for mound detection should be avoided. The contours are not generated directly from the 1 m BE-DEMs. Instead, the BE-DEM is simplified to a 3 m resolution by interpolating a value based on interpolation from 3 x 3 m blocks of 1 m cells. Instead of being interpolated from a grid of one point for every 1 m^2, the contours are interpolated from a grid of one point for every 9 m^2. Features the height and diameter of burial mounds are easily lost in creation of the 2-ft contours.

For archaeological purposes, generation of contours directly from the 1 m BE-DEM is strongly recommended. In using default hillshades and the 2-ft contours obtained from MnGeo, archaeologists must be aware that these products, out of the box, are not designed for the detection of low relief earthen features, and must be used with caution.

FIELD VERIFICATION

LiDAR successfully detects mound-like rises. In the present project, the geometry and morphology of most of the detected features was consistent with their interpretation as mounds, and this was further supported by their spatial correspondence to mounds observed and mapped previously. Even if the georeferencing is not exact, the maps could still show the spatial relationships among the mounds in a group, which served to verify that the LiDAR is correctly detecting mounds.

Mounds identified solely based on LiDAR analysis, however, should be field verified. Whittaker and Riley (2012) found that many features that appear mound-like in LiDAR were actually features such as brush piles, bedrock outcrops, straw bales, late historic piles of earth, and false images created in LiDAR.

FUTURE STUDIES

The 16 counties included in this study are unusually rich in mounds. Although they represent only 12.6 percent of the state by area, they include 64 percent of all known mounds in Minnesota. This leaves more than 80 percent of the state and 36 percent of known mounds uninvestigated. Studies such as this one, carried out for the rest of Minnesota, will provide the state with an essential baseline for management and threat assessment to protect the burial places of the Precontact populations of the state.

Although mound prospection was not a goal of this project, 12 possible new sites with 118 possible mounds were identified in LiDAR. Several new mound sites have been found in Iowa though chance observations in LiDAR (e.g. Whittaker et al. 2013). Riley (2012) developed a model for detecting mound-like features in LiDAR over large areas that also has promise for initial identification of possible mounds to help develop effective field survey strategies.

CONCLUSION

The project was made possible by four factors. First, desktop GIS software is ideally suited for the integrated study of geospatial information from multiple sources. In the present study, these ranged from 19th century maps and field notes to 21st century remote sensing data. Second, GIS technology has led to the development of an immense array of publically available, interoperable geospatial data sets. Data used in this project ranged from relatively simple county boundary shapefiles to high resolution aerial photos. Third, recent completion of statewide LiDAR coverage for Minnesota offers an unprecedented opportunity to visualize and analyze surface features of the landscape. Prehistoric earthworks are but one of the kinds of relatively subtle landscape features that are detectable using LiDAR. Minnesota’s LiDAR data is provided at no charge by the Mn-Geo, both in its “raw” LAS form, and as derivative products including BE-DEMs, hillshades, and 2 ft contours, all of which were put to use by this project.

Last in this list but arguably first in importance, to this project and Minnesota archaeology in general, is the revenue stream provided by Minnesota’s Legacy Amendment. The Amendment partially funded not only statewide LiDAR acquisition, but also the present project. It can be hoped that more LiDAR detection projects like this one will be similarly funded, until a LiDAR-based examination of all Minnesota has been completed.

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Appendix I. Site-by-Site Summary of Georeferencing and LiDAR Results

The brief site descriptions that follow are transcriptions of notes written by Whittaker, for map and records analysis, and Bristow, for the LiDAR analysis. The notes were initially compiled in Excel, and then imported into the Microsoft Access database submitted as a deliverable for this project.

References to published sources are identified by the use of parentheses, following Society for American Archaeology citation format. When not enclosed in parentheses, names and dates are those that appear on site forms on file at Mn-OSA. For example, "Arzigian and Stevenson (2003)" refers to a published reference. "Peter Jensen 1959" refers to a site form.

Individual Site information edited out of public version.