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Description of the Cerro Grande Fire Laser-Altimetry (LIDAR) Data Set

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DESCRIPTION OF THE CERRO GRANDE FIRE LASER-ALTIMETRY (LIDAR) DATA SET

by

J. William Carey
and Greg Cole

ABSTRACT

Digital elevation models (DEMs) were created by Airborne Laser Swath Mapping (ALSM; also known as LIDAR) of the Pajarito Plateau region following the Cerro Grande Fire. Two sets of ALSM data were collected: a lower-resolution data set on June 22–25, 2000 and a higher-resolution data set on July 1–9, 2000. The ALSM data included the following digital products:

- 1 foot bare-earth DEM
- 4 foot bare-earth DEM
- 1 foot canopy DEM
- 4 foot canopy DEM
- 1 foot intensity grid
- 4 foot intensity grid
- The raw elevation and intensity data used to create the DEMs
- The raw data collected by the ALSM instruments

A quality assurance analysis of the DEMs was conducted by comparison to elevation data obtained from ground measurements (by GPS and total station). For the 1' DEM, 74% of 654 measured elevations differed by < 1' with only 1 measurement differing by >5'. For the 4' DEM, 96% of 688 measured elevations differed by <5' and only 24 measurements differed by >5'. An upper bound on the horizontal accuracy was obtained by analysis of the ALSM data density. These indicate that objects in the 1' DEM can be resolved, on average, to 2.63' and objects in the 4' DEMs can be resolved, on average, to 4.67'. The ALSM DEMs are in general more accurate than the existing 1992 DEMs and represent a major improvement in the topographic depiction of canyons and heavily vegetated areas. The DEMs are now available to authorized personnel through GISLab. This document provides supporting documentation for metadata of the DEM data set.

INTRODUCTION

Background. Following the Cerro Grande Fire, Los Alamos National Laboratory (LANL) (the Environmental Restoration Project and ESH Division) contracted with Merrick & Co. to provide digital elevation models (DEMs) of the Pajarito Plateau region at 4' and 1' resolutions. The lower-resolution (4') region consists of 320 square miles and extends from the Santa Clara canyon on the north to the Cochiti reservoir on the south; and from the Valles Caldera rim on the west to the Rio Grande on the east (Figure 1, see page

27). The higher-resolution (1') region consists of 150 square miles located in the central part of the lower-resolution study area and includes all of LANL property (Figure 1, page 27). The project was designed to encompass the entire watershed of lands burned in the Cerro Grande fire of May 2000 as they affect LANL, the county of Los Alamos, Bandelier National Monument, and the Santa Clara, San Ildefonso, Santo Domingo, and Cochiti Pueblos. The DEM data were obtained to assist with analyses of flooding hazards, hillslope erosion, stream-channel sediment delivery, assessment of potential contaminant transport, and to aid efforts to mitigate rainwater damage through erosion control. The data were used to orthorectify the 2000 aerial photography [Carey and Cole 2001] and the 2000 AVIRIS data [Tsai et al, in prep.]. In addition, the data were collected to enhance integration of all forms of remote sensing data (satellite imagery, AVIRIS data, orthophotography, etc.) and to provide an improved topographic base for environmental studies.

Laser Altimetry. The DEM data were obtained by laser altimetry, which is known by several acronyms including LIDAR (light detection and ranging), LADAR (laser detection and ranging), ALSM (airborne laser swath mapping), and ALTM (airborne laser terrain mapping). In laser altimetry, an airborne laser and detection system measures the travel time of light to the ground and back. Ground elevations are calculated from the laser travel time and the position of the airplane (determined from Global Positioning System, GPS). The raw laser altimetry data are post-processed to provide three products: bare-earth DEM (reflections due to vegetation and buildings are removed), canopy DEM (elevation of first returns, indicating vegetation and building tops), and an intensity grid of the reflected laser signal. Laser altimetry is a relatively new technology and consequently, this report will include a discussion of the details of data acquisition and processing.

Acquisition of elevation data for 4' DEM (cf., Appendix I).

- Flight Dates: June 22–25, 2000
  (The Cochiti Reservoir area was covered in a reflight in Fall 2000)
- Flight Region: approximately 320 square miles
- Flight Altitude: approximately 6,550' above mean terrain
- Data collected in region bounded by Cochiti Reservoir (south), by Santa Clara Canyon (north), by Valles Caldera Divide (west), and by the Rio Grande (east)

Acquisition of elevation data for 1' DEM (cf., Appendix I).

- Flight Dates: July 1–9, 2000
- Flight Region: approximately 150 square miles
- Flight Altitude: approximately 3,300' above mean terrain
- Data collected in region bounded by Frijoles Canyon (south), by Guaje Canyon (north), by Valles Caldera Divide (west), and by the Rio Grande (east)

Contract Specifications. The ALSM project was contracted to Merrick & Co. of Denver, Colorado (see Appendix II). The contract specified the following survey parameters:

- Survey areas (cf., Figure 1, page 27)
- Survey point density
  - >1 point per 16 ft^2 (lower-resolution study)

    - >1 point per 2.43 ft^2 (higher-resolution study)
- Vertical accuracy
    - 2.5' (lower-resolution study)
    - 0.5' (higher-resolution study)
- Horizontal accuracy
    - 8' (lower-resolution study)
    - 1' (higher-resolution study)
- Meet national map standards
    - 1" = 400' (lower-resolution study)
        - ≥90% of data better than 8' horizontal position
    - 1" = 100' (higher-resolution study)
        - ≥90% of data better than 2' horizontal position
    - 10' contours (lower-resolution study)
        - ≥90% of data better than 5' vertical position
    - 2' contours (higher-resolution study)
        - ≥90% of data better than 1' vertical position

Merrick & Co. subcontracted the acquisition of laser altimetry data to Applied Geomatics International of Houston, Texas (AGI). AGI subcontracted the acquisition of the raw laser-altimetry data to Airborne1 of Los Angeles, California. Airborne1 operated the aircraft and laser scanner and provided GPS and inertial measurement unit (IMU) corrected data to AGI. AGI post-processed the data from Airborne1 to generate the bare-earth and canopy DEMs and the intensity grids.

Project Funding. The ALSM contract and subsequent data stewardship activities were supported by

- The Environmental Restoration Project—coordinated by Diana Hollis
- The Environment, Health, and Safety Division—coordinated by Steve Rae

LANL Data Steward Activities. The data stewards at LANL for the ALSM project are Bill Carey, Greg Cole, Bob Beers, and Steve Lloyd. The primary roles of the data stewards are as follows (see the following pages for a report on these activities):

- Develop the contract for ALSM services
- Ensure that the contract was completed satisfactorily
- Inventory and archive data
- Conduct QA analyses of data quality
- Conduct QA analyses of data positional accuracy
- Provide for electronic distribution
- Ensure ALSM products metadata are in compliance with established Federal Geodetic Control Committee (FGDC) standards
- Create LAMS report documenting the data set

TECHNICAL DETAILS OF LASER ALTIMETRY DATA ACQUISITION

There are three primary instruments used in the acquisition of laser altimetry data:

- GPS system
- IMU

- Laser scanner

The GPS system provides the position of the aircraft (X, Y, Z) along its flight trajectory. The IMU provides the orientation of the laser relative to the aircraft position (i.e., pitch, roll, and yaw of the aircraft affect the laser firing angle). And the laser scanner provides the orientation of pulses of light directed towards the ground as a mirror is scanned through a fixed angle. All three components are synchronized in time and each can affect the accuracy of the ALSM data.

The following details the system specifications and data collection conditions used in this project:

Aircraft

- Twin engine: Cessna 401
- 6,550' above ground level (4' survey)
- 3,300' above ground level (1' survey)
- Flight speed: approximately 125 knots

GPS

- Airborne differential GPS: Dual frequency Novatel Millenium
- Ground station GPS: Trimble 4,000 Ssi
- 1 Hz data collection
- Maximum position dilution of precision (PDOP) of 3 (i.e., flight times were adjusted to optimize the geometry of satellites used in the GPS data collection)
- Number of ground base stations: 2–4 depending on flight line (cf., Appendix I)

IMU

- Litton inertial measurement unit
- Operated at 50 Hz

Laser Scanner

- Optech ALTM 1225
- 25 kHz data collection rate
- Mirror type: single-axis oscillating
- Scanning angle (Hz): 15 (4' survey), 16 or 17 (1' survey)
- Scanning rate (Hz): 18 (4' survey), 25 (1' survey)
- Laser type: NdYag producing 1064 nm light

Data Processing

- GPS and IMU data corrections were applied by Airborne1 using proprietary software provided by the laser manufacturer [Optech]
- Filtering of the laser altimetry data to produce bare-earth and canopy DEMs and the intensity grids was performed by AGI using TerraScan and TerraModeler software (available through Airborne1)

- DEMs were generated by AGI by triangulation of the elevation data and resampling to a regular grid using TerraModeler software
- 1' DEMs were generated by AGI using DrDTM software by performing an iterative minimum curvature algorithm to the elevation data

Discussion of expected accuracy and quality of laser altimetry derived topography. ALSM data differ in important qualitative and quantitative ways from topography derived by traditional photogrammetric methods. These differences may be appreciated by comparing the DEMs generated by this ALSM survey with the 1992 DEMs generated by photogrammetry [Cole 1993; Figures 2 and 3, pages 28–29]. The advantages of ALSM include

- Much greater point density on the ground leading to more realistic and detailed picture of topography
- Ability to sample ground elevation in areas with heavy vegetation (laser returns include reflections from the vegetation canopy as well as some data that penetrates the canopy and is reflected from the ground)
- Potential for higher accuracy due to greater point density, especially in regions of extreme topography (canyon walls) and in heavily forested areas (where photogrammetry can not determine the ground)

The disadvantages of ALSM include

- Contours are noisier and do not have the aesthetic value of photogrammetric contours (i.e., photogrammetrically derived contours tend to be subparallel and create a more easily visualized topographic surface)
- Breaks in topography (stream channel bottoms, ridge crests, mesa edges, buildings) are not explicitly defined
- The data processing that removes vegetation and buildings in the creation of a bare-earth DEM can be inappropriately applied and lead to artifacts in the elevation model (see QA analysis)

Two independent processes determine the accuracy of DEMs derived from ALSM data: the inherent instrumental accuracy of the laser system itself (i.e., the raw location of objects on the ground), and the accuracy of the software processing (filtering) that produces a DEM surface from the raw data.

A variety of studies indicate that in optimal conditions (no vegetation on a topographically smooth surface) ALSM data are accurate to 5-15 cm, vertically. There is much less information on horizontal accuracy (due to the difficulty in precisely identifying reference objects in ALSM data), but Hofton et al. [2000] determined that horizontal accuracy under optimal conditions is better than the size of the laser footprint. In addition, the laser-spot density limits the possible horizontal accuracy (i.e., objects cannot be located more precisely than the average spacing between laser data points).

The post-processing of the ALSM data to produce useful products, such as a bare-earth DEM, introduces additional errors. The post-processing includes removal of clear artifacts (e.g., reflections from birds) and the separation of ground reflections from vegetation and building reflections. This processing is imperfect and as a consequence there are errors introduced through misclassification of points. In areas of dense vegetation, there may be no signals returned from ground leading to a potentially false bare-earth elevation. In addition, the filtering process removes data points so that the surface is defined by a sparser set of points (leading to errors in regions of rapidly changing topography).

AGI used the following classification algorithm (cf. Appendix III):

- A starting search region is defined
- The points in the search region are scanned to find a maximum likelihood ground point (typically the lowest elevation point in the region)
- The software then "builds" a ground surface from this starting point by querying whether adjacent points satisfy criteria for "belonging to the ground surface" that is based on the maximum expected angle of elevation change.

The search region must be larger than any building or likely region of dense vegetation not producing a ground signal. A search region that is too large will tend to miss accurate definition of mesa tops. In practice, AGI produced an initial coarse ground surface through heavy filtering and then reprocessed the data using a fine filter with the initial ground surface as a starting point.

DATA STEWARD ACTIVITIES: DATA AND DATA QUALITY

The primary responsibilities and current status of quality assurance (QA) activities conducted by the data stewards for the ALSM project are as follows:

<u>Development of Contract Specifications</u>

- Completed in June 2000. See Appendix II for a copy of the contract and the introduction for a brief summary of contract specifications

<u>Contract Completion.</u> The contractual obligations were satisfied except for the following:

- Data density
- Data accuracy
- Deliverable deadlines

<u>Inventory and Archive of Data.</u> The ALSM project generated the following data products:

- Raw output from output from ALTM 1225 laser scanner
- Airborne and ground GPS receiver files in RINEX format
- Calibration records (pre- and post-flight) for laser system
- Unfiltered GPS- and IMU-corrected laser data in 9 column ASCII-format
- Bare-Earth DEM at 1' and 4' resolution
- Canopy DEM at 1' and 4' resolution
- Intensity grid at 1' and 4' resolution

The gridded data (DEMs and intensity) were prepared with the following characteristics:

Higher-resolution data

- Resolution: 1' pixel
- Tiling scheme: 3,000' easting by 2,000' northing tiles comprised of 3,001 by 2,001 grid points (centered on 0 to 3,000 east and 0 to 2,000 north). The tiles overlap by 1 pixel. This schema was adopted to allow in-tile interpolation over the entire region of the tile without requiring adjacent tiles.
- 1' DEM naming scheme:
  Example name: lg770663-001b
    - lg: LIDAR grid
    - 770663: lower-left corner of grid is 1,770,000' northing and 1,663,000' easting
    - 001: 1' pixel
    - b: year 2000 data set
- 1' DEM coverage (see Figure 1, page 27)
- DEM cell centering:
  Example tile: lg770663-001b.tif
    The outside corner of the lower-left cell is located at 1,769,999.5' (northing), 1,662,999.5' (easting) (i.e., the center of the lower-left cell is located at 1,770,000', 1,663,000')
- DEM Format: floating point (binary) file
- DEM Projection: Central New Mexico State Plane survey feet using the NAD-83 horizontal datum and the NGVD-29 vertical datum
- File Size: 24Mb

Lower-resolution data

- Resolution: 4' pixel
- Tiling scheme: 12,000 easting by 8,000' northing tiles comprised of 3,001 by 2,001 grid points (centered on 0 to 12,000 east and 0 to 8,000 north). The tiles overlap by 1 pixel. This schema was adopted to allow in-tile interpolation over the entire region of the tile without requiring adjacent tiles.
- 4' DEM naming scheme:
  Example name: lg772654-004b.tif
    - lg: LIDAR grid
    - 772654: lower-left corner of grid is 1,772,000' northing and 1,654,000' easting
    - 004: 4' pixel
    - b: year 2000 data set
- 4' DEM coverage (see Figure 1, page 27)
- DEM cell centering:
  Example tile: lg772654-004b
    The outside corner of the lower-left cell is located at 1,771,998' (northing), 1,653,998' (easting) (i.e., the center of the lower-left cell is located at 1,772,000', 1,654,000')
- DEM Format: floating point (binary) file
- DEM Projection: Central New Mexico State Plane survey feet using the NAD-83 horizontal datum and the NGVD-29 vertical datum
- File Size: 24Mb

Data set designation:

- lg: bare-earth digital elevation model (e.g., lg772654-004b)
- lc: canopy digital elevation model (e.g., lc772654-004b)
- li: intensity grid (e.g., li772654-004b)

An overview of the total number of tiles and their geographic location is provided in Table 1.

Table 1. Tile inventory

Data Set	Number of Tiles	Area of Coverage
1' Bare-Earth DEM	763	Figure 4 (page 30)
4' Bare-Earth DEM	134	Figure 5 (page 31)
1' Canopy DEM	764	Figure 6 (page 32)
4' Canopy DEM	83	Figure 7 (page 33)
1' Intensity Grid	764	Figure 8 (page 34)
4' Intensity Grid	85	Figure 9 (page 35)
Total	2593 (62Gb)	

Summary of Data Quality. Data quality was assessed by examination of shaded-relief images of the DEM, by comparison of DEM elevations to survey data, and by characterization of the data density. The shaded-relief images revealed several types of artifacts in the DEMs caused by either poor data density or by mistakes in the filtering process. In areas of poor data density, the elevation data are extrapolated over long distances. Mistakes in filtering are manifested in bumps or depressions in the DEM. See the section Detailed Discussion of QA Analyses for further details.

The vertical accuracies of the 1' and 4' bare-earth DEMs were characterized by comparison to surveyed elevations. The difference between the 1' DEM and 654 surveyed elevations was –0.41± 1.11 feet. The minimum and maximum differences were –5.69' and 5.39'. An analysis of the absolute value of the differences showed that 74% of the DEM elevations were within 1' of the surveyed elevations.

The difference between the 4' DEM and 688 surveyed elevations was –0.21±2.11 feet. The minimum and maximum differences were –8.87 and 8.02'. An analysis of the absolute value of the differences showed that 96% of the DEM elevations were within 5' of the surveyed elevations.

Data density was used to characterize the horizontal accuracy of the DEMs because this density reflects the practical limit at which objects can be resolved. The 1' DEM had an average data point spacing of 2.43' with a 1 standard deviation range between 2.15' and 2.86'. The 4' DEM had an average data point spacing of 4.67' with a 1 standard deviation range between 3.79 ' and 6.69'.

DATA STEWARD ACTIVITIES: DETAILED DISCUSSION OF QA ANALYSES

QA Analyses of DEM Quality. The QA analysis focused on the bare-earth DEM because it is considered the most important ALSM product and requires the greatest amount of post-processing of the ALSM data. DEM quality was assessed by examining shaded-relief images of each of the tiles to identify obvious artifacts in the data. These artifacts occur primarily because of mistakes in the post-processing of the data:

- Regions of missing data (Figure 10, page 36)—gaps in laser data result in estimated topography
- Pits in the DEM (Figure 11, page 37)—multi-path reflections create depressions in the DEM
- Inaccurate building footprints (Figure 11, page 37)—incomplete or improper filtering of reflections from buildings
- Elevation steps across flight lines (Figure 11, page 37)—inadequate flight line elevation data
- Residual vegetation mounds (Figure 12, page 38)—incomplete or improper filtering of vegetation
- Hashing texture (Figure 13, see page 39)—misalignment of overlapping flight lines
- Striping textures (Figure 13, page 39)—misalignment of overlapping flight lines
- Dimple-Pimple texture (Figure 14, page 40)—data processing problems
- Integer elevation values (Figure 15, page 41)—truncation of elevations to integer values
- Linear artifacts of unknown origin (Figure 16, page 42)

These artifacts appear to result in localized degradation of the accuracy of the DEM and degradation of the fidelity of the DEM to the actual land surface. The artifacts appear to have only a localized affect on accuracy (see positional accuracy report below) as adjacent areas satisfy accuracy requirements. Some of the textural artifacts (e.g., hashing) have smaller amplitudes than the specified accuracy requirements (0.5' or 2.5'). However, these do reduce the capacity to resolve fine-grained features of the landscape (e.g., small rills or gullies or flood-plain terraces).

For high-accuracy applications of the bare-earth DEM data, we recommend that the necessary tiles be screened for artifacts and reprocessed to remove problem areas. Potential problems observed in high-resolution bare-earth tiles are described in Appendix IV.

Artifacts in the canopy DEM and the intensity data are assumed to be minimal (because these do not require data filtering). However, these data sets do suffer from the same regions of missing data as identified in the bare-earth DEM. Note that there were no provisions made to ensure that the canopy DEMs are always at greater or equal elevation when compared to the bare-earth DEMs.

<u>QA Analyses of Vertical Accuracy</u>. An assessment of the ALSM data positional accuracy was limited to the vertical dimension and to the bare-earth DEM. (However, accurate vertical data implies accurate horizontal data in areas of moderate to significant topographic variability.)

The ALSM data vertical accuracy was assessed by the following methods:

- Comparison to GPS-based total station survey points (Appendix V)
- Comparison to total station survey points [Gardner et al. 1999]

- Comparison to 1992 photogrammetric survey [Cole 1993]
- Comparison to USGS DEMs derived from digital line graphs

The contract specification for the 1' DEM data reads, "The positional accuracy of this data shall be 15 cm (0.5') vertical and 1' horizontal." Similarly, the contract specification for the 4' DEM data reads, "The positional accuracy of this data shall be 2.5' vertical and 8' horizontal." The contract does not specify statistical criteria for this positional accuracy and does not qualify or otherwise limit the features of the data that must comply with this accuracy.

Although the contract also states that the data shall meet National Map Accuracy Standards, this criterion is a less restrictive requirement. The current (1947 revision) Standard states that not more than 10% of "well-defined points" shall be in excess of 1/50" at map scale or ½ of the contour interval. This standard results in the following requirements shown in Table 2:

Table 2. National Map Standard accuracy limits for the high- and low-resolution DEMs.

Data Set	Map Scale	Horizontal 10% limit	Contour Interval	Vertical 10% limit
Higher-resolution	1" = 100'	2'	2'	1'
Lower-resolution	1" = 400'	8'	10'	5'

The National Map Accuracy Standards were developed with respect to photogrammetric data, for which "well-defined points" are defined as "easily visible or recoverable on the ground, such as the following: monuments or markers, corners of large buildings or structures (or center points of small buildings); etc." Note that much of the survey area is characterized by steep, irregular topography and/or dense vegetation and would not have to meet the accuracy requirements of Table 2.

Laser altimetry is a relatively new technology in surveying and, consequently, there are as yet no established standards or criteria for accuracy that are specific to ALSM. The contract accuracy specifications are probably realistic in areas lacking vegetation or buildings (cf., the discussion of expected accuracy of ALSM data), but are probably unrealistic in areas of dense vegetation or rapid topographic change.

Comparison of ALSM Elevations to Survey Data. There are several sets of elevation data that can be used as point checks of the accuracy of the ALSM data: a total station[§] survey with GPS-based monuments conducted by Merrick, Inc. (Appendix V); total station survey data collected during geological studies by LANL personnel [Gardner et al. 1999]; total station survey data collected by LANL personnel to provide additional control data for this study [Alexis Lavine 2001, personal communication]; survey data used in the 1992 quality assurance report of orthophotography [Cole 1993]; and survey data used in the 2000 orthophoto study [Carey and Cole 2001].

The reference data were compared to ALSM-derived elevations by interpolating values from the 1' or 4' grid to the position of the survey point (Table 3, shown on page 12). The

§ Total station is a high-precision laser-based surveying system.

expected accuracy of the Merrick GPS-monumented survey is 0.1' horizontal and 0.1–0.2' vertical. The expected accuracy of the total station data used in the geological studies is better than 3 feet horizontal and 0.25 vertical over the course of 10,000 linear feet [Gardner et al., 1999] in addition to any error associated with the monumented base-stations (with locations obtained from the FIMAD database). The expected accuracy of the additional control data is difficult to characterize because the reference monuments have uncharacterized accuracies [Alexis Lavine 2001, personal communication], although the total station methods were the same as described in Gardner et al. [1999]. The expected accuracy of the 2000 orthophoto surveys "meets or exceeds" Geodetic accuracy standards and specifications for using GPS relative positioning techniques as set forth by the FGDC in there [sic] most current publication for second order (1:50000) horizontal control" and "[v]ertical precision exceeds the accuracies necessary to meet the National Map Accuracy Standards" [Merrick & Co., 2000]. In practice, closures among reference base stations were generally better than about 0.2' in horizontal and vertical with a maximum near 0.5'. The expected accuracy of the 1992 orthophoto survey data is "at sufficient accuracy to meet National Geodetic Standards (NGS), 2nd order, class 1 specifications (accuracy of 1 part in 50,000). Analysis of the results of the GPS survey indicates that horizontal accuracy of the control points is about 0.1 feet, and vertical accuracy is about 0.2 feet" [Cole 1993].

A summary of the differences between the survey points and the ALSM data is given in Table 3. There are several possible sources of error or approximation leading to the differences in Table 3: 1) elevation error in the ALSM data; 2) elevation error in the survey; 3) interpolation inaccuracies; 4) horizontal error in the ALSM data; and 5) horizontal error in the survey data. As a consequence, it is not straightforward to apply the results in Table 3 to a general accuracy criterion (e.g., Table 2). However, the results do allow a general assessment of the contribution of the combined vertical and positional error to the error in elevation values.

Table 3. Summary of differences in elevation between surveys and digital elevation models. 1' ALSM: 1 foot DEM from 2000 ALSM mission; 1' 1992: 1 foot DEM from 1992 aerial photography mission; 4' ALSM: 4 foot DEM from 2000 ALSM mission; and 4' 1992: 4 foot DEM from 1992 aerial photography mission.

	Merrick GPS Survey: QC1 (Appendix V)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	0.09	0.15	0.98	-1.61
Std. Dev.	0.60	0.60	1.64	1.99
Minimum	-1.34	-0.59	-1.36	-3.64
Maximum	0.56	0.80	3.39	0.32
Number	9	5	9	4
	Merrick GPS Survey: QC2 (Appendix V)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.67	0.84	-1.15	
Std. Dev.	0.96	2.77	2.42	
Minimum	-4.42	-5.08	-7.12	
Maximum	2.23	10.13	4.63	
Number	143	143	143	0
	Merrick GPS Survey: QC3 (Appendix V)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.41		1.91	-0.49
Std. Dev.	0.51		0.82	3.57
Minimum	-1.79		0.23	-5.08
Maximum	0.46		3.80	10.15
Number	61	0	61	61
	Merrick GPS Survey: QC4 (Appendix V)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.63		0.47	-0.84
Std. Dev.	0.87		1.18	3.91
Minimum	-3.72		-2.77	-12.15
Maximum	1.71		4.01	9.61
Number	83	0	83	83
	Merrick GPS Survey: SP1 (Appendix V)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.59	0.11	-1.21	
Std. Dev.	1.53	3.86	2.18	
Minimum	-5.69	-9.73	-8.87	
Maximum	5.39	31.08	6.42	
Number	159	159	159	0

	Merrick GPS Survey: SP2 (Appendix V)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.07		-0.27	-4.56
Std. Dev.	0.67		1.99	5.69
Minimum	-1.91		-6.51	-21.77
Maximum	2.20		4.49	4.71
Number	63	0	63	63
	Merrick Orthophoto Survey (Carey and Cole 2001)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.05	0.10	0.30	-0.00
Std. Dev.	0.56	1.04	1.22	3.84
Minimum	-1.48	-3.03	-1.69	-5.02
Maximum	1.76	3.22	6.33	6.06
Number	62	51	95	11
	1992 Orthophoto Monument Locations (Cole 1993)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	0.27	0.58	0.46	0.67
Std. Dev.	1.12	1.66	1.86	3.58
Minimum	-1.46	-2.67	-5.03	-4.83
Maximum	4.15	8.30	8.02	8.17
Number	74	63	75	13
	LANL Total Station Survey: Los Alamos Canyon (Lavine 2001)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.17	-0.87	-0.28	
Std. Dev.	1.13	1.83	1.55	
Minimum	-2.77	-4.02	-3.70	
Maximum	13.06	12.29	13.28	
Number	280	280	280	0
	Geologic Contacts: LA Canyon Steep Trees(Gardner et al. 1999)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	0.99	5.30	-0.87	
Std. Dev.	1.23	6.32	2.26	
Minimum	-1.55	-10.32	-8.67	
Maximum	3.13	19.45	2.33	
Number	36	36	36	0
	Geologic Contacts (Gardner et al. 1999)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	1.07	0.43	-0.42	
Std. Dev.	6.46	7.03	6.25	
Minimum	-27.28	-22.08	-38.55	
Maximum	85.69	53.94	89.78	
Number	2007	2007	2007	

	LANL Total Station Survey: Hamilton Bend (Lavine 2001)			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	0.24	0.61	-0.40	
Std. Dev.	0.74	1.34	1.90	
Minimum	-1.14	-4.87	-7.07	
Maximum	5.62	5.76	8.04	
Number	187	187	187	0
	SUMMARY			
	All Data			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	0.62	-0.90	-0.66	-1.64
Std. Dev.	5.94	7.37	5.45	4.67
Minimum	-27.28	-30.44	-38.55	-21.77
Maximum	85.69	53.94	89.78	10.15
# > 5' diff.	340	295	185	11
# < -5' diff.	211	501	375	33
Number	3663	3430	3697	235
	GPS Data Only			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	-0.41	0.43	-0.21	-1.64
Std. Dev.	1.11	2.98	2.11	4.67
Minimum	-5.69	-9.73	-8.87	-21.77
Maximum	5.39	31.08	8.02	10.15
# > 5' diff.	1	19	4	11
# < -5' diff.	3	9	20	33
Number	654	421	688	235
	Total Station Data Only			
	1' ALSM	1' 1992	4' ALSM	4' 1992
Average	0.85	-1.09	-0.76	
Std. Dev.	6.51	7.77	5.95	
Minimum	85.69	53.94	89.78	
Maximum	-27.28	-30.44	-38.55	
# > 5' diff.	339	276	181	0
# < -5' diff.	208	492	355	0
Number	3009	3009	3010	0

Note: The reported differences are between surveyed elevations at a point and a value interpolated from a grid derived from ALSM or aerial photography data. As such they are not direct measurements of point differences, and the nearest actual ALSM data point may be, in some cases, several feet from the survey control points.

Discussion of GPS-Based Surveys. Merrick's GPS-based survey combined with the orthophoto survey data represent the most complete and accurate survey data set. These reference data test accuracy at easily defined locations in addition to canyon walls, under trees, stream channel bottoms, etc. A summary of these results is given in Table 3, and shows that for the 1' ALSM data, only four of 654 survey points had discrepancies greater than 5' and for the 4' ALSM data, only 24 of 688 were greater than 5'. Histograms of the frequency of the absolute values of the errors are given in Figures 17 and 18 (see pages 43–44). These show that the 1' data do not meet the criteria given in Table 2 as 74% of the values are within 1' elevation. The 4' data do meet the criteria given in Table 2 as 96% of the values are within 5'. If the criterion for the 1' data were relaxed to 1.5' as a rough approximation of errors not due to the ALSM data, then about 85% of the values would satisfy the accuracy standards.

A note of caution: the errors depicted in Figures 17 and 18 are not normally distributed (cf., the normal distribution curve in Figure 17, page 43). Therefore, one should not use the standard deviation values from Table 3 to construct confidence intervals for the ALSM data (e.g., normally distributed errors for the 1' data predict that only about 57% of the data would be within 1'). The confidence intervals should be constructed directly from the figures.

The ALSM data are consistently more accurate than the 1992 elevation model, for each of the individual surveys (Table 3) and have a significantly lower error magnitude for the entire GPS-based and orthophoto-survey data set (Figures 17 and 18, pages 43–44).

Discussion of Total-Station Data. Table 3 also contains comparisons of the ASLM data to total station survey data from geological studies [Gardner et al., 1999] and from data provided by A. Lavine [2001, personal communication]. These results are more difficult to evaluate for several reasons. Many of the geological contact data occur along cliff edges where small errors in horizontal position can make large differences in elevations derived from the DEMS. In the case of the Los Alamos Canyon and Hamilton Bend surveys of Lavine [2001], the base stations were monuments that do not have a stated accuracy. This is the most likely cause of some of the larger errors reported in Table 3 for these types of surveys.

Discussion of Comparisons to Other DEMS. The ALSM data were also investigated by comparing elevations of ALSM DEMs vs. elevation data provided by the 1992 aerial photography survey [Cole 1993] and vs. elevation data obtained by creating DEMs from USGS Digital Line Graphs (DLGs; i.e., contour data). These two DEMs do not provide sufficiently accurate elevations to assess the accuracy of the ALSM data, but they are very helpful in identifying blunders or offsets of the data. Cole [1993] provides accuracy information for contours derived from the 1992 aerial photography data. For the 1" = 100' (1' DEM) at the 90% confidence level, vertical errors are < 1.3' and horizontal errors are < 2.1'; for the 1" = 400' (4' DEM) at the 90% confidence level, vertical errors are < 6.8' and horizontal errors are < 9.9'. As with all aerial photography products, these estimated accuracies apply to "well-defined" points (i.e., areas with heavy forest or shadowed-cliffs have uncharacterized potential errors). The nominal accuracy of the DEMs derived from the United States Geological Survey (USGS) DLG contours is, at the 90% confidence level, vertical errors <10'.

Difference maps were created for the ALSM data compared to the other DEMs for the range of all available data. An example of a difference map is shown in Figure 19 (see page 45). This illustrates the occurrence of several suspect features in the data (cf., section on artifacts in the data). These difference maps were used to check for major errors and to develop descriptive characterizations of artifacts in the tiles. These plots led to the contractor resubmitting several tiles.

Summary statistics for the observed differences in elevation between the ALSM DEM and the 1992 photogrammetric DEM and USGS contour data are shown in Table 4.

Table 4. Summary statistics for comparison of ALSM DEMs and DEMs derived from aerial photography (1992) and USGS contour (DLG) data (each comparison tile has 1 million cells).

Grids	Average Min Difference (ft)	Average Max Difference (ft)	Average Mean Difference (ft)	Aggregate Standard Deviation (ft)	# of tiles
1' ALSM – 1' 1992	-30.93	44.82	-0.27	1.73	356
1'ALSM – 4' 1992	-263.75	112.13	1.66	3.55	38
1'ALSM – 8' DLG	-127.64	355.55	-2.07	3.92	21
4'ALSM – 1' 1992	-76.57	76.20	-0.21	1.90	30
4'ALSM – 4' 1992	-122.66	183.33	-1.40	3.47	52
4'ALSM – 8' DLG	-161.40	264.33	-1.00	2.86	37

An example of the distribution of the absolute values of DEM differences between 1' DEMs from ALSM and aerial photography is shown in Figure 20 (see page 46). This figure was calculated by determining the percent of cells in each tile that differs by more than 4' in elevation from the photogrammetric DEM. Most tiles had relatively few cells that differed by more than 4' (i.e., less than 5% of the cells differed by this amount). However, a significant fraction of the tiles (about 10%) had more than 20% of the cells that differed by more than 4'.

DEM Comparisons in Cross-Section. The GPS-based surveys (summarized in Table 3) provide a basis for constructing cross-sections and comparing elevations between the ALSM and the photogrammetric DEMs. The cross-sections can also illustrate the fidelity of the DEM to actual ground features (e.g., slope breaks, stream channels, etc.).

Figure 21 (see page 47) shows a cross-section derived from GPS-based survey SP1 (cf., Table 3) taken in Los Alamos Canyon just west of the Diamond Ave. Bridge. The three surveys (1' and 4' ALSM and 1' photogrammetry) show high accuracy and agreement in the canyon center (i.e., along the road) and on most of the northern canyon wall. However, none of the surveys capture the southern wall of the canyon with accuracy and both of the ALSM surveys miss the stream channel along the southern wall. The photogrammetric survey gives some indication of the channel, but the profile is rather indistinct. The 4' ALSM and the photogrammetry miss the gully on the north side of the canyon, while the 1' ALSM shows a distinct feature but does not have the full depth measured by GPS.

Figure 22 (see page 48) shows a cross-section derived from GPS-based survey SP1 (cf., Table 3) taken in Los Alamos Canyon in the vicinity of TA-2 (Omega Reactor). The three surveys (1' and 4' ALSM and 1' photogrammetry) show high accuracy and agreement in the canyon, along the north canyon wall, and in the depiction of the stream channel. The 4' ALSM (which should be inherently less accurate) is systematically displaced by about 1' from the GPS ground surface. On the south canyon wall, the 1' photogrammetric data depart significantly from the true ground surface.

Figure 23 (see page 49) shows a cross-section derived from GPS-based survey SP2 (cf., Table 3) taken in Guaje Canyon near the confluence with Rendija Canyon. The three surveys (1' and 4' ALSM and 4' photogrammetry) show good agreement and accuracy. The 4' surveys differ from the true ground values by amounts within accuracy expectations. The 1' ALSM data shows no substantial deviations from ground truth.

Figure 24 (see page 50) shows a cross-section derived from GPS survey SP2 (cf., Table 3) taken in Guaje Canyon about 2000' west of the confluence with Rendija Canyon. The 4' photogrammetry DEM contains significant departures from the true topography. The 1' and 4' ALSM DEMS are in good agreement with the GPS data and depict the stream channel and stream bank locations with good accuracy.

Cross-sections from the total station data [Alexis Lavine, 2001, personal communication] provide a similar method of evaluating the ALSM data. However, because the total station data do not have precise location data, the resulting cross-sections should be viewed as qualitative measures of accuracy. Thus all data sets should depict a stream channel accurately, although the precise position of the stream bank or channel center may differ.

Figure 25 (see page 51) shows a cross-section at Hamilton Bend in Pueblo Canyon (cf., Table 3). Of the three data sets, 1' ALSM, 4' ALSM, and 1' photogrammetry, only the 1' ALSM accurately depicts the central stream channel. The 4' ALSM accurately captures the elevation of the canyon floor, but it does not see the incised channel and appears not to capture the steepness of southern canyon wall. The 1' photogrammetry is accurate at the furthest end of the section, but it does not show a stream channel. It also significantly underestimates the elevation of the canyon floor (although the potential for real changes in stream channel morphology since the 1991 survey should be considered).

Figure 26 (see page 52) shows another cross-section at Hamilton Bend in Pueblo Canyon (cf., Table 3). The 1' photogrammetry DEM shows significant differences with the total station data indicating a more pronounced channel and lower elevations on the near end of the section. Again, some of these differences could be accounted for by real geomorphologic changes. The 1' ALSM is in good agreement and accurately depicts the steep bank at the far end of the section. The 4' ALSM shows some noise and does not accurately capture the location of the steep bank.

<u>Summary of Cross-Section Observations.</u> The 1' ALSM survey is more accurate and depicts geomorphology with greater fidelity than the other surveys. Some of the apparent errors in photogrammetry may be due to actual changes in ground surfaces [cf., Hamilton Bend]. Some of the errors in the ALSM DEMs may be a result of sparse

measurements (i.e., a given cross-section point might be taken several feet from the nearest ALSM data point).

Horizontal Accuracy of ALSM Data. The horizontal accuracy of ALSM data is difficult to quantify, because, in general, it is difficult to assign a reference location to a given ALSM data point. For ground control, the ALSM survey used reflective panels. The center of these panels can be located using the reflectivity images. Unfortunately, the contractor did not supply the statistical fit of the ALSM data to their ground control. In any case, it is very difficult to identify independent ground controls using reflectivity.

The best measure of horizontal precision available is the density of the ALSM points on the ground. The contract specification was 1' horizontal for the 1' ALSM DEM and 8' horizontal for the 4' ALSM DEM. These accuracies are consistent with claims made by a variety of ALSM vendors. However, objects on the ground cannot be resolved or located any more precisely than the ALSM point density on the ground. Therefore it is not practically meaningful to claim a horizontal accuracy finer than the point density.

The maximum point density on the ground was obtained by data processing of the raw ALSM data delivered by the contractor (see section on 9-column data). (A maximum point density because some values are removed during filtering of the data to produce the several DEM products.) The observed point densities versus the delivered point densities are given in Table 5 and summarized in Figures 27-30 (pages 53–56).

Table 5. Summary of observed raw point densities in square feet per raw data point as measured in 1000 x 1000' blocks.

DEM	Contract sq ft. per pt.	Mean Tile sq ft. per pt.	Range of Std Dev sq ft. per pt.	Min sq ft. per pt.	Max sq ft. per pt.	Count
1'	2.43	5.92	4.64-8.17'	2.43'	22 empty	4296
4'	16	21.8	14.4-44.7	4.41	1738 empty	7551

The raw high-resolution data averaged less than half of the original contract specification (Table 5 and Figure 28, see page 54). However, there is substantial variation in the point densities and several blocks (22) had no points. An inspection of the DEMs showed nothing abnormal in the area of blocks with no data or with little data. Using only the delivered raw data, an average horizontal resolution of 5.92' is obtained for the 1' DEM.

The low-resolution data set had an average horizontal resolution of 21.8' based on the available data. Approximately 20% of the blocks with data exceeded the contract specifications for point density.

Accuracy of Canopy and Intensity Data Sets: The horizontal and vertical accuracy of the canopy and intensity data sets were not specifically evaluated. The accuracy of these data sets is *assumed* to be the same as that found with the bare ground data. With further effort, the vertical accuracy of the canopy data could be investigated using elevations from building roofs. The accuracy of treetop elevations would be difficult to evaluate because there is not a method of determining whether the data records the top-most branches or some lower part of the tree. The intensity data set includes information on the relative reflectivity of objects on the ground. It is most useful as a means of visualizing the ground surface with ALSM data. The intensity values are relative measurements and do not relate to a particular physical property of the ground surface. Accordingly, no attempt was made to evaluate the quality of the intensity data.

9-Column Raw ALSM Data: As part of the contract, unfiltered raw ALSM data were delivered in 9 column ASCII format (Table 6). The file name identifies the date of acquisition (e.g., NM177 refers to data collected on day 177 or June 25, 2000). The first column of the files contains the GPS time measured in seconds from midnight of Sunday of each week. The GPS time servers as a unique ID during each week but may be repeated in subsequent weeks. Since the laser operated at 25 kHz, in general there is a data point every 0.00004 seconds.

Columns 2-4 of the raw data files contain the X, Y, and Z locations of the first return from the ground. Columns 5-7 contain the X, Y, and Z locations of the last return from the ground. The locations are given in meters in UTM (zone 13) coordinates using the NAD83 horizontal datum and a vertical position based on the WGS84 ellipsoid. In practice the first and last returns are defined by setting criteria for intensity thresholds marking the leading and ending edge of the reflected waveform. A difference in the location of the first and last return is caused by reflections from objects at different elevations within the laser footprint (e.g., tree tops and bare-ground). In the processing of the ALSM data, the first returns are used to define the canopy DEM and the last returns are used in the creation of a bare-earth DEM. However, since the last returns may not derive from the ground surface (e.g., because of dense vegetation or the presence of a roof) additional processing of the last return signal is required in the development of the bare-earth DEM (e.g., Appendix III).

Columns 8 and 9 contain the intensity of the reflected laser signal for the first and last return respectively. The intensities are recorded as integer values between 0 and 255.

The raw data were provided as either a single large file for each flight day or as a number of smaller files derived by subdividing the flight day (Table 6). Unfortunately, in the delivered data some flight days were present in more than one set of files. It was not possible to obtain clarification as to whether all raw data files were used in preparation of the DEMs or whether a subset was used.

In Table 6, the file dates can be used as one method of evaluating whether one data set on a given flight date has priority over another. However, examination of the data sets indicated that while some of the data records in multiple files from a given flight date were duplicates, other records were unique. In addition, files with names such as "final" are more likely to be primary data, and files such as "calib" are less likely to have been used in creation of the DEMs.

Table 6. List of raw data files. Where multiple files occur for a single date, the original time stamp of the file is provided for reference.

Data Set	Flight Date (2000)	File Name	File Dates (if multiple files)
1 foot	183: July 1	NM183.asc	
1 foot	184: July 2	NM18400.asc	
1 foot	185: July 3	Nm18500Final.asc	
1 foot	186: July 4	Nm18600.asc	
1 foot	187: July 5	NM187Final.asc	
1 foot	188: July 6	Nm188BC.ASC	
1 foot	189: July 7	STRIP2.ASC STRIP3.ASC STRIP4.ASC STRIP5.ASC STRIP6.ASC STRIP7.ASC STRIP8.ASC	12/5/2000
		18900b.asc	8/5/2000
1 foot	190: July 8	NM19000.asc	
1 foot	191: July 9	191.ASC	10/9/2000
		191_8_18.asc	8/18/2000
4 foot	174: June 22	17400_new.asc	8/18/2000
		17400_10_1.asc	8/5/2000
		17400_11_1.asc	
		17400_12_1.asc	
		17400_13_1.asc	
		17400_14_1.asc	
		17400_15_1.asc	
		17400_16_1.asc	
		17400_17_1.asc	
		17400_18_1.asc	
		17400_19_1.asc	
		17400_20_1.asc	
		17400_21_1.asc	
		17400_22_1.asc	
		17400_23_1.asc	
		17400_24_1.asc	
		17400_25_1.asc	
4 foot	174: June 22	17400_26_1.asc	8/5/2000
		17400_27_1.asc	
		17400_28_1.asc	
		17400_29_1.asc	
		17400_30_1.asc	
		17400_31_1.asc	
		17400_32_1.asc	
		17400_33_1.asc	
		17400_34_1.asc	
4 foot	175: June 23	17500_new.asc	8/18/2000
		17500.asc*	8/5/2000
		175_2.ASC	8/18/2000
		175_1.asc	7/28/2000

Data Set	Flight Date (2000)	File Name	File Dates (if multiple files)
		175_2.asc	
		175_3.asc	
		175_4.asc	
		175_5.asc	
		175_6.asc	
		176A_1B.ASC	
		176A_2B.ASC	
		176B_1C.ASC	
		176B_2C.ASC	
4 foot	176: June 24	176B_3C.ASC	
		176a_2.asc	
		176b_1.ASC	
		176b_2.ASC	
		176b_3.ASC	
		177Calib.asc*	8/4/2000
		177Final.asc	8/18/2000
		177001_1.asc	
		177002_1.asc	
		177003_1.asc	
		177004_1.asc	
		177005_1.asc	
4 foot	177: June 25	177006_1.asc	8/3/2000
		177007_1.asc	
		177008_1.asc	
		177009_1.asc	
		177010_1.asc	
		177011_1.asc	
		177012_1.asc	
		177013_1.asc	
		177014_1.asc	
		177015_1.asc	
		177016_1.asc	
		177017_1.asc	
		177018_1.asc	
		177019_1.asc	
		177020_1.asc	
		177021_1.asc	
		177022_1.asc	
4 foot	177: June 25	177025_1.asc	8/3/2000
		177026_1.asc	
		177027_1.asc	
		177028_1.asc	
		177029_1.asc	
		177030_1.asc	
		177031_1.asc	
		177032_1.asc	
		177033_1.asc	
		177034_1.asc	
4 foot	Refly of Cochiti Reservoir area in Fall 2000	Line1.ASC	
		Line2.ASC	
		Line3.ASC	

Data Set	Flight Date (2000)	File Name	File Dates (if multiple files)
		Line4.ASC	
		Line5.ASC	
		Line6.ASC	
		Line7.ASC	
		Line8.ASC	
		Line10.ASC	
		Line11.ASC	
		Line12.ASC	
		Line13.ASC	
		Line14.ASC	
		Line15.ASC	
		Line16.ASC	
		Line9.ASC	
		Line17.ASC	
		Line18.ASC	
		Line19.ASC	
		Line20.ASC	
		Line21.ASC	
		Line22.ASC	
		Line23.ASC	
		Line24.ASC	

*Files were not processed. The file 17500.asc was not processed because the last part of the file was corrupt. The file 177Calib.asc was not processed because it contains irregular length records. (Note: the data in 17500.asc and 177Calib.asc do not explain the missing data in Figure 29, see page 55.)

All of the 9-column raw data were projected into New Mexico State Plane coordinates and assigned to a 1000 x 1000' block to facilitate QA analyses and to place the data in the locally used coordinate system. The blocks are labeled by the location of the lower-left corner. Thus the block 742630 refers to all of the raw data located in a 1000 x1000' tile with lower-left corner at 1,742,000 northing and 1,630,000 easting. Each data record was tagged with the originating file.

The aerial distribution of the data for the 1' and 4' sets is shown in Figures 27 and 29 (pages 53–55). There are blocks without data in both the high- and low-resolution data sets. Because the DEMs in these areas exist, it is apparent that LANL did not receive all of the raw data. It is also apparent that data were collected within a much larger area than specified in the contract for both the high and low-resolution data. However, we received finished products (i.e., DEMs) only within the contract-specified portions of the study.

Raw Data from Airborne1. Airborne1 made the following deliveries of raw data:

- Raw data output from the Optech laser scanner
- GPS data from the base-stations, receivers
- Position data from the internal measurement unit
- Calibration records for the ALSM system

These data were processed by Airborne1 to create the 9-column raw data discussed above. The data from the laser scanner are in a proprietary format that requires Optech software to process. The data from the GPS units are in RINEX format. LANL acquired these data to permit complete reprocessing of the data if ever required.

Electronic Distribution of Data

The bare-earth, canopy, and intensity DEMs are available through the EES Division GIS Laboratory, Facility for Information Management, Analysis, and Display (FIMAD), or by contacting the authors.

Create Documentation of the Data Set

This report may be cited in documents using the orthophoto or aerial photography results.

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Hofton, M. A., Blair, J. B., Minster, J.-B., Ridgway, J. R., Williams, N. P., Bufton, J. L., and Rabine, D. L. (2000) "An airborne scanning laser altimetry survey of Long Valley, California," *International Journal of Remote Sensing*, 21: 2413-2437.

Lavine, A. (2001) "Total station surveys in Los Alamos Canyon near the Diamond Ave Bridge and near TA-2 and in Pueblo Canyon near Hamilton Bend." (Personal Communication, June 2001).

Merrick & Co. (2000) Los Alamos, New Mexico. Los Alamos National Laboratory. Cerro Grande Fire. GIS Mapping Project. GPS Survey Report. 50013790, June 2000.

ALSM and subcontractor Web Sites

Laser manufacturer—Optech:	www.optech.on.ca
Applied Geomatics International:	www.agi-houston.com
Airborne1:	www.airborne1.com
Merrick and Co.:	www.merrick.com
TerraScan and TerraModeler software:	www.airborne1.com/Pages/terrascan.htm
DrDTM software:	www.ecqc.com

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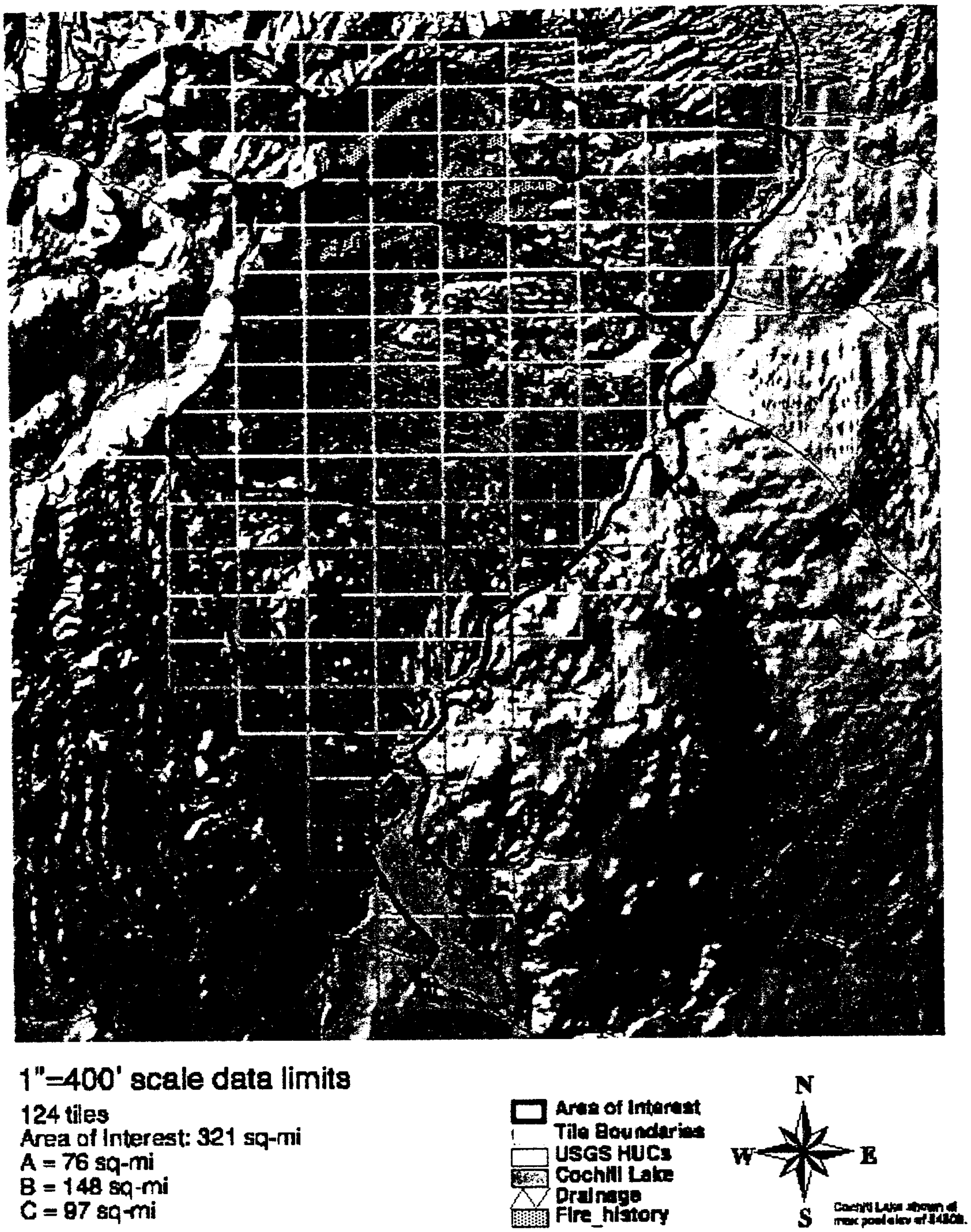


Figure 1. Shaded-relief image of the ALSM study area—defined by the red polygon. Areas A, B, and C represent three sub regions of the study. The yellow boxes represent the tiles used in the delivery of the 4' digital elevation models (DEMs).

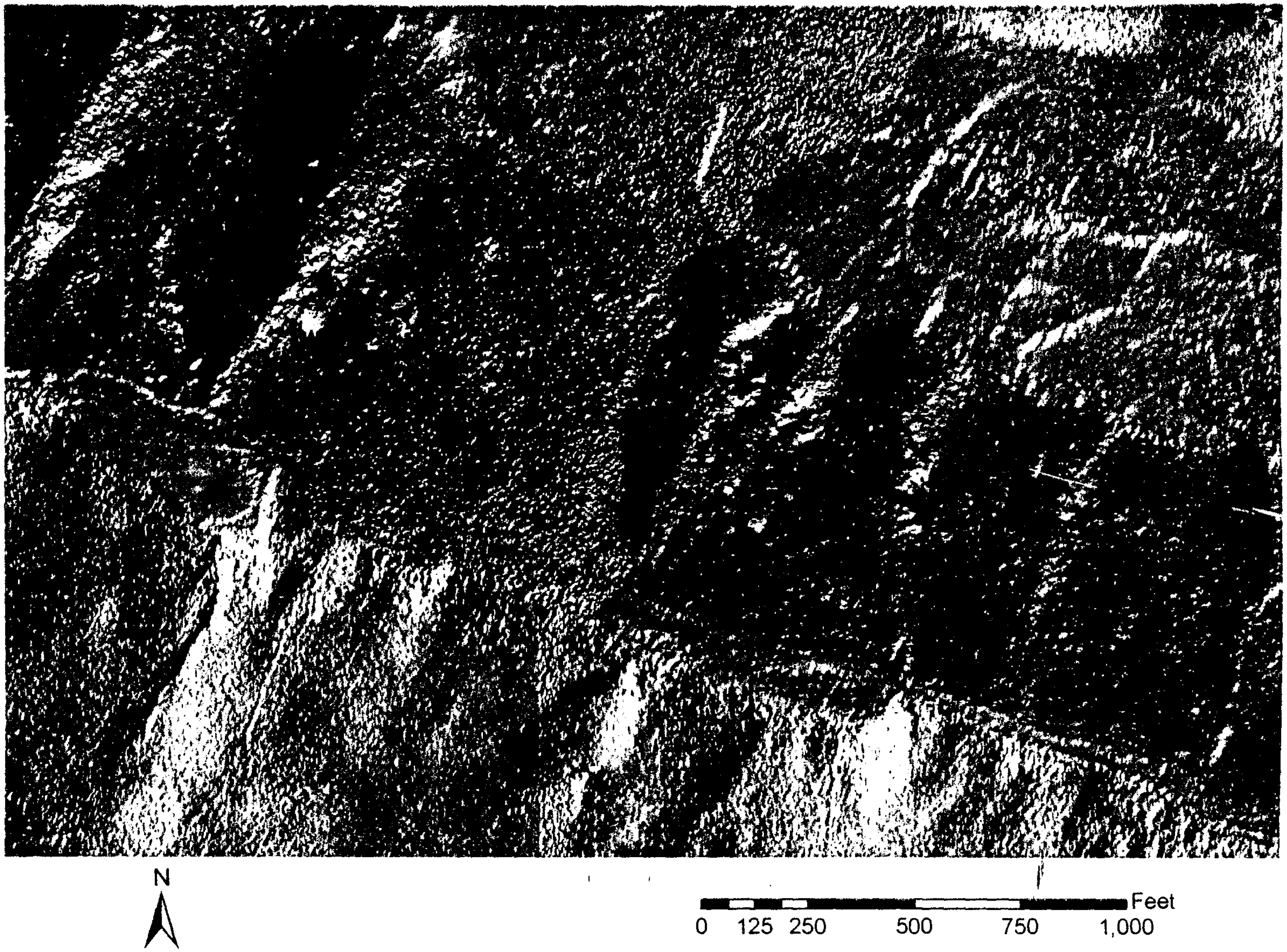


Figure 2. Shaded-relief image of one tile (776609) from the high-resolution 1' bare-earth ALSM data set. The Los Alamos Canyon Reservoir is located at the western end of the image.

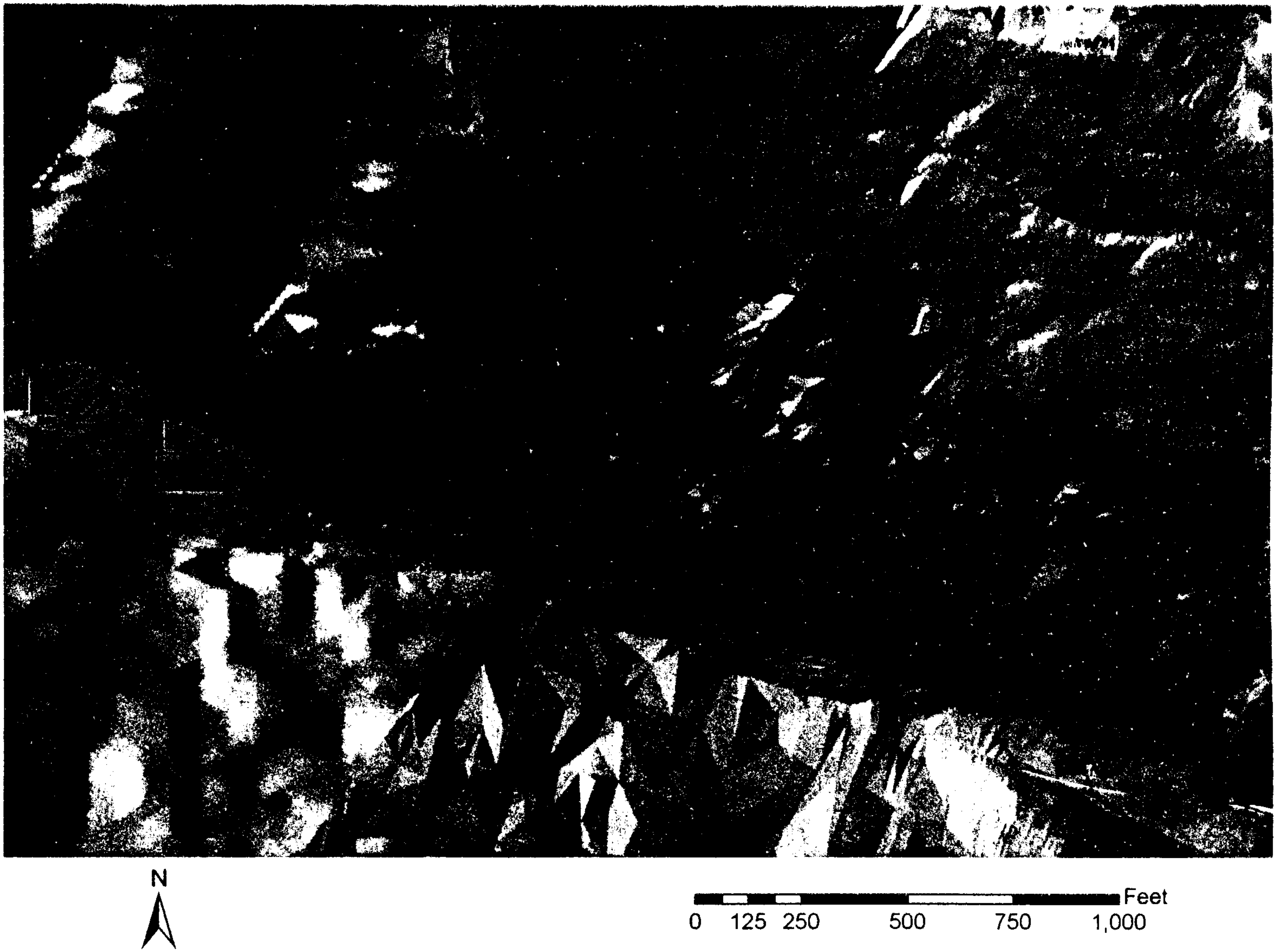


Figure 3. Shaded-relief image of one tile (776609) from the high-resolution 1992 1' DEM. The Los Alamos Canyon Reservoir is located at the western end of the image.

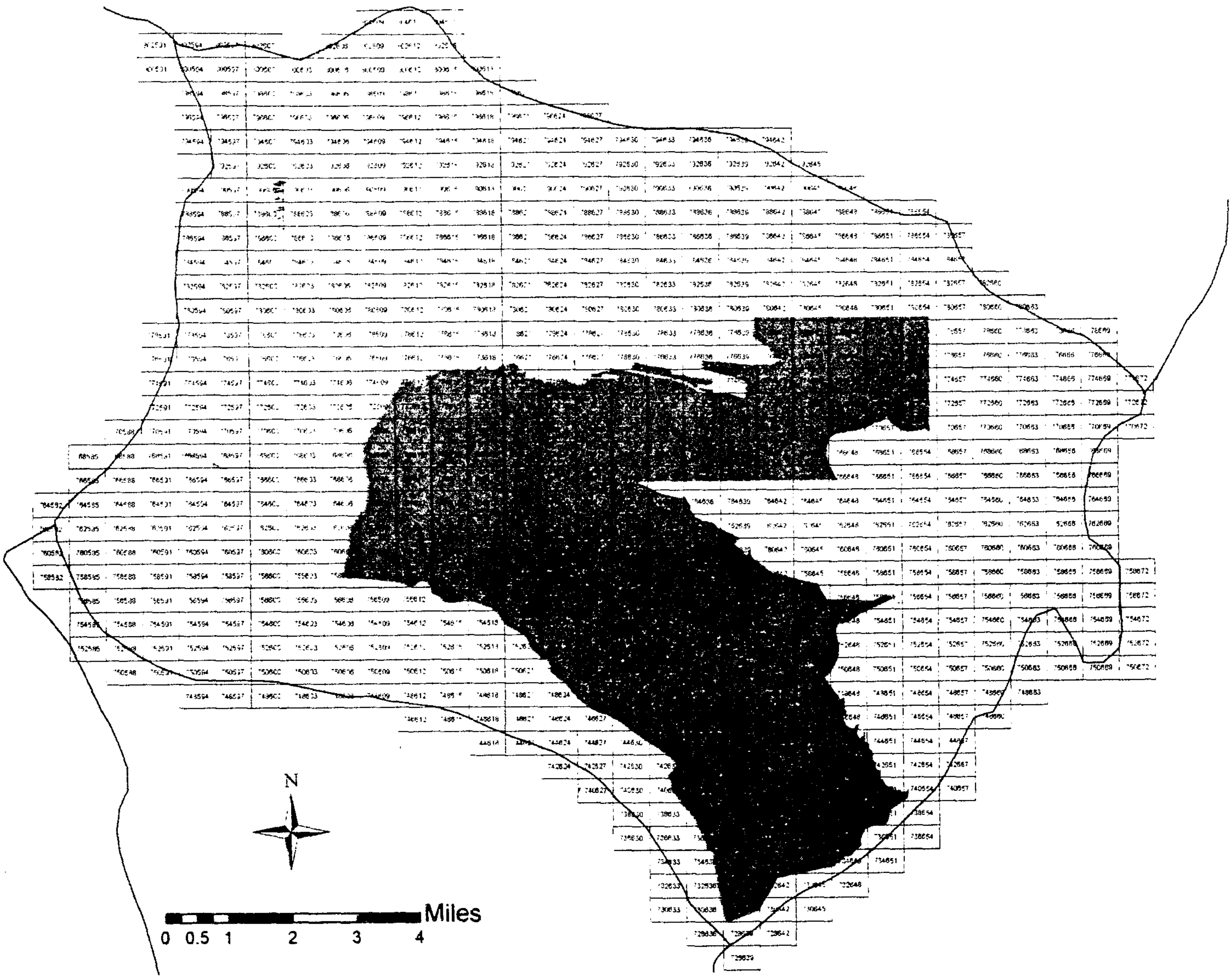


Figure 4. The distribution of 1' bare-earth DEM tiles. The Los Alamos National Laboratory area is shown by the shaded polygon. The tile-naming scheme is discussed in the text.

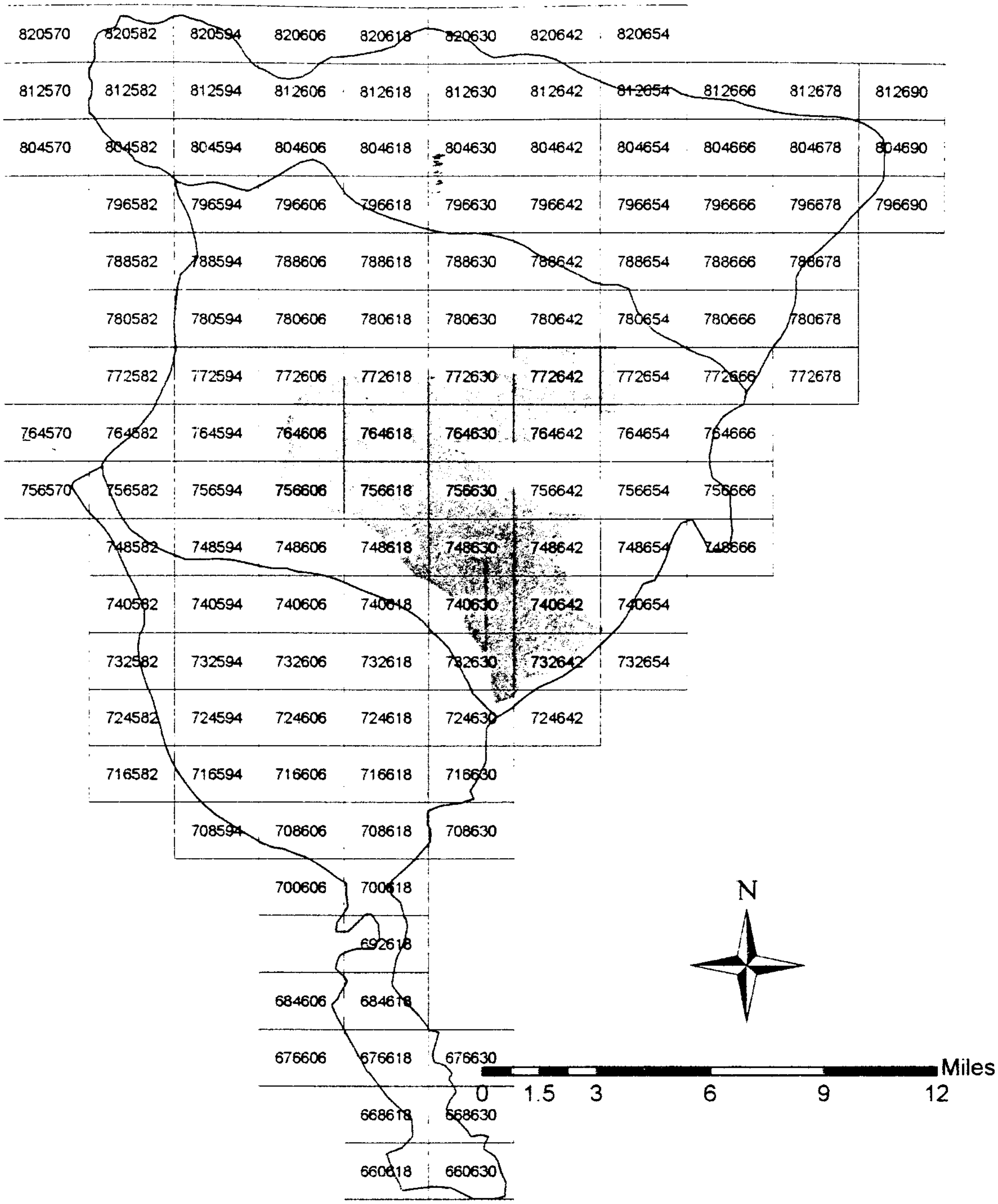


Figure 5. The distribution of 4' bare-earth DEM tiles. The Los Alamos National Laboratory area is shown by the shaded polygon. The tile-naming scheme is discussed in the text.

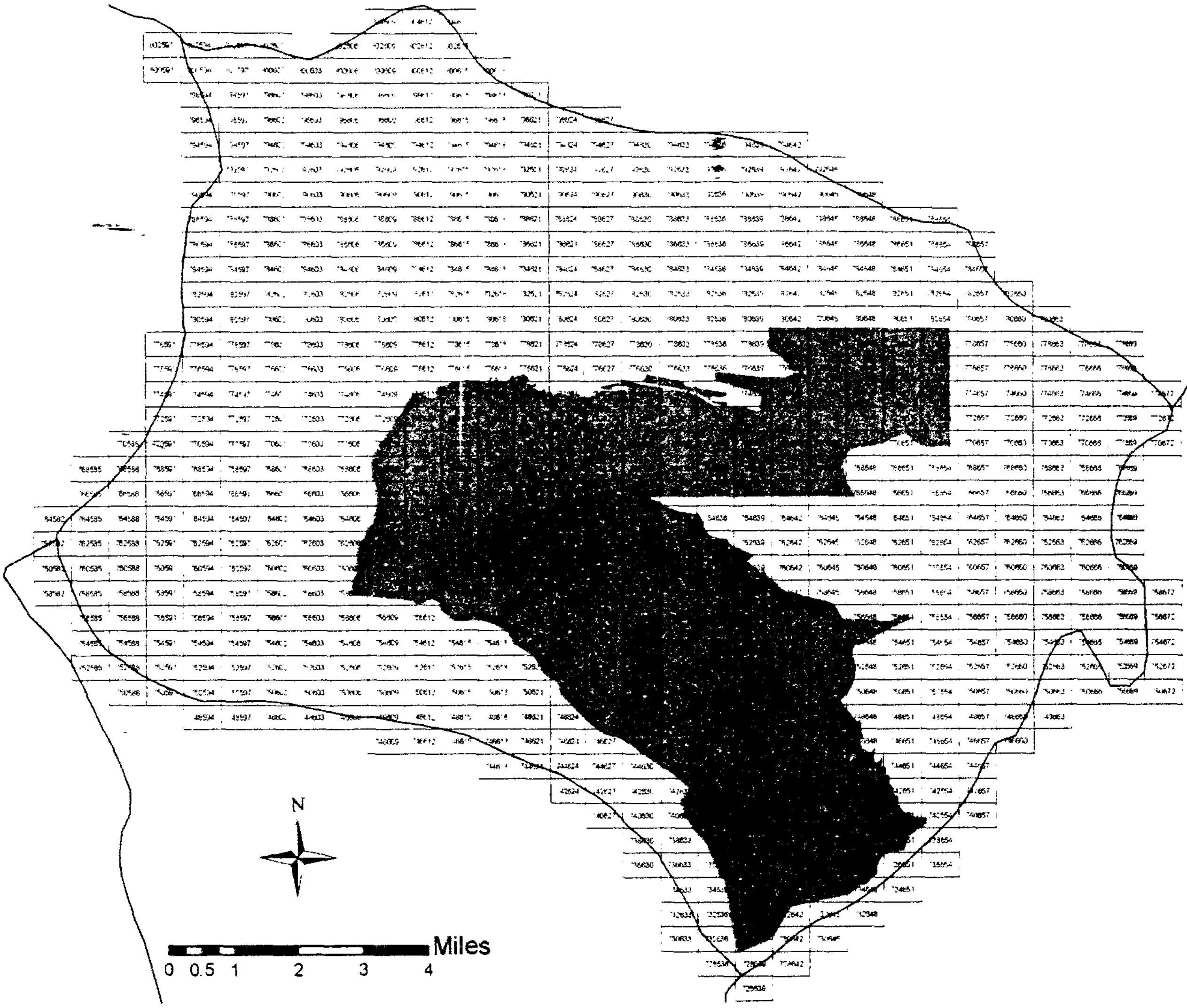


Figure 6. The distribution of 1' canopy DEM tiles. The Los Alamos National Laboratory area is shown by the shaded polygon. The tile-naming scheme is discussed in the text.

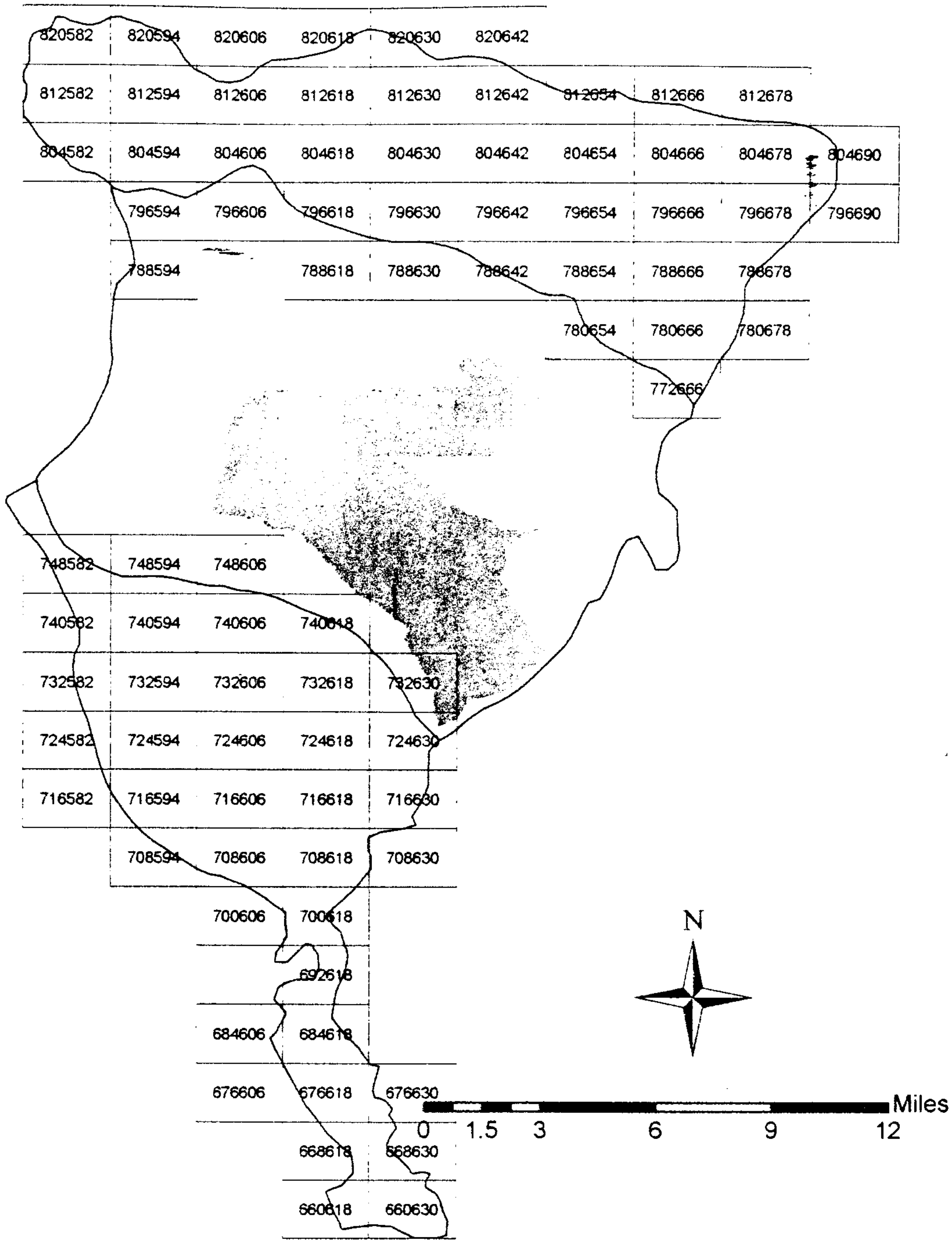


Figure 7. The distribution of 4' canopy DEM tiles. The Los Alamos National Laboratory area is shown by the shaded polygon. The tile-naming scheme is discussed in the text.

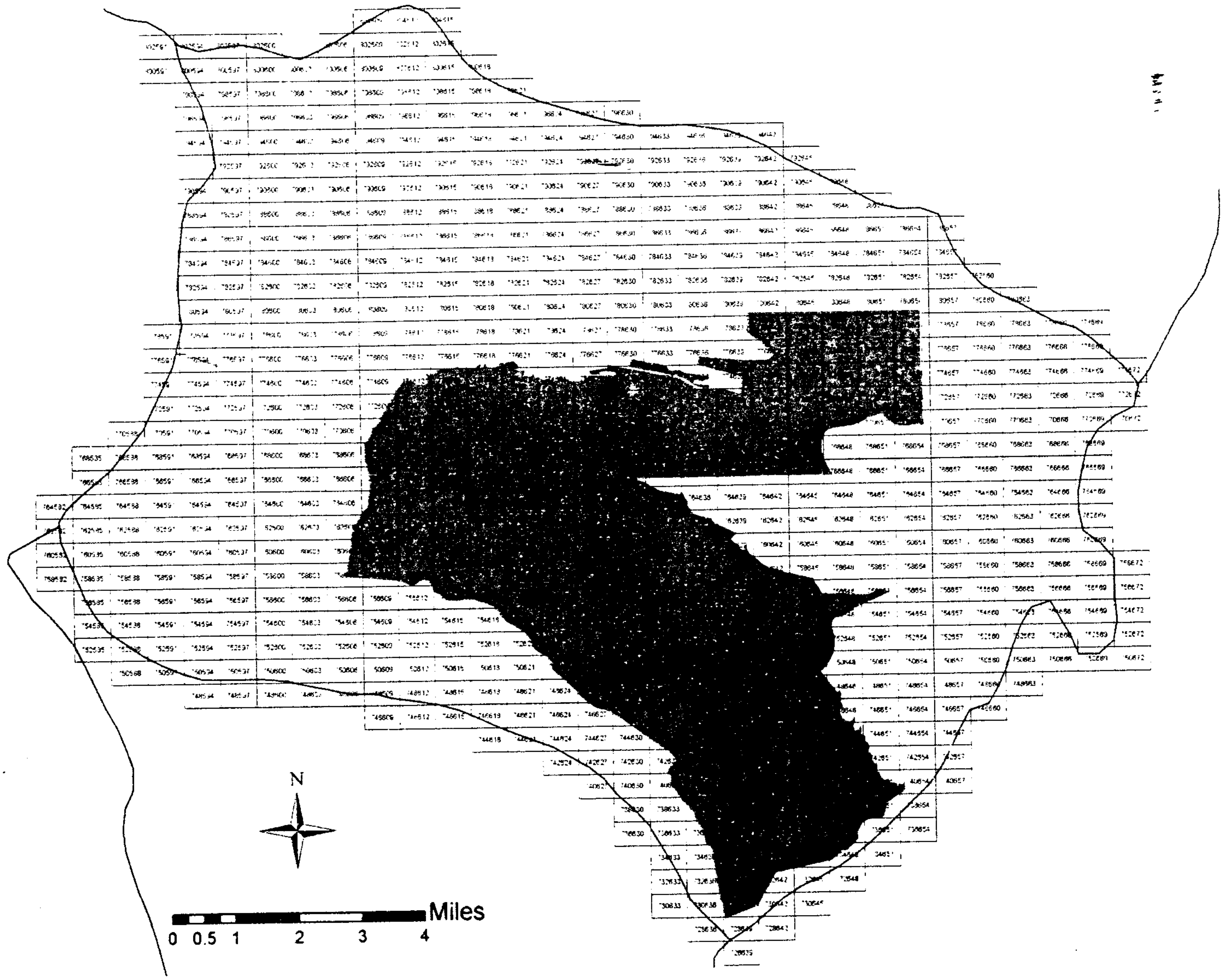


Figure 8. The distribution of 1' intensity tiles. The Los Alamos National Laboratory area is shown by the shaded polygon. The tile-naming scheme is discussed in the text.

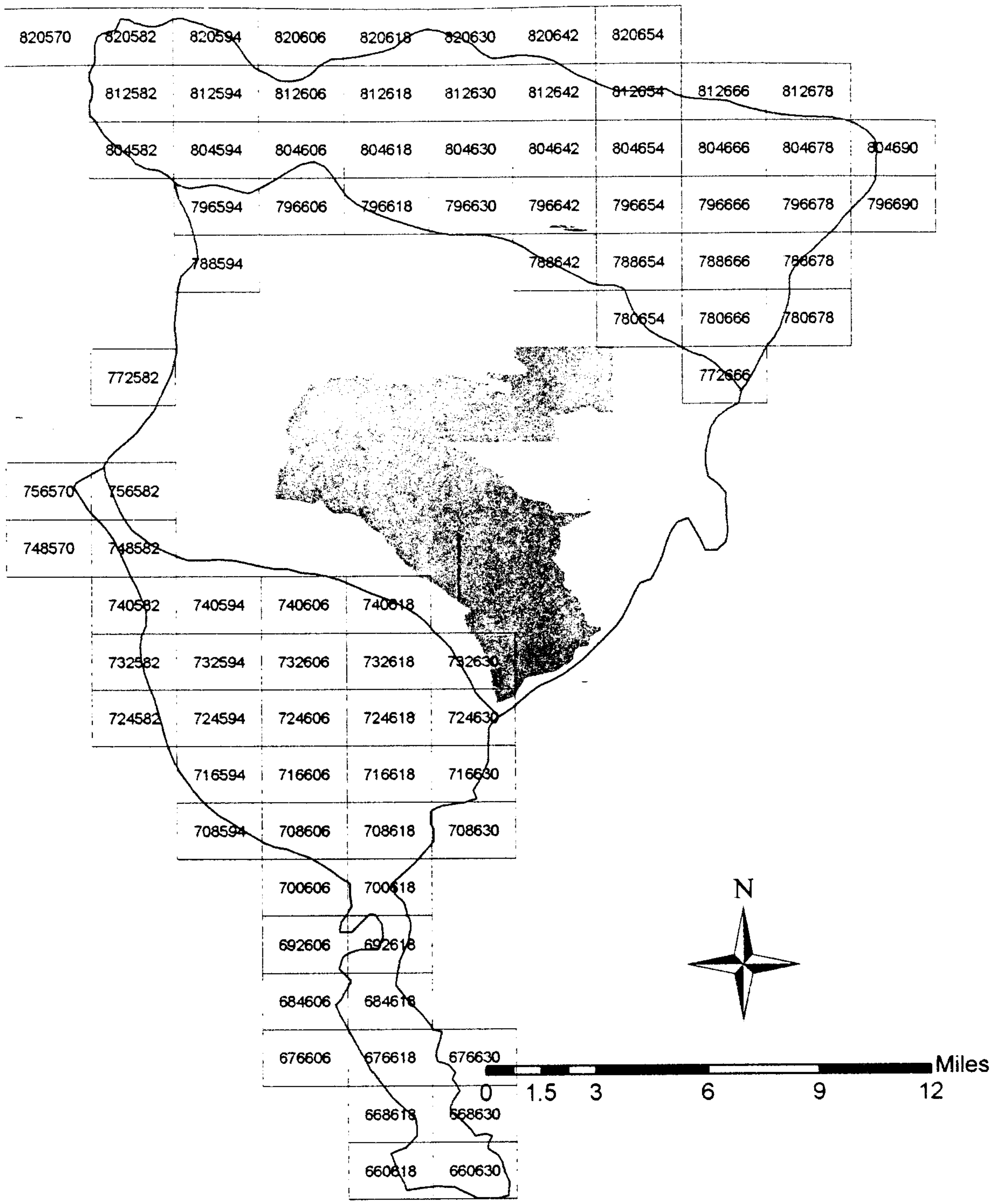


Figure 9. The distribution of 4' intensity DEM tiles. The Los Alamos National Laboratory area is shown by the shaded polygon. The tile-naming scheme is discussed in the text.

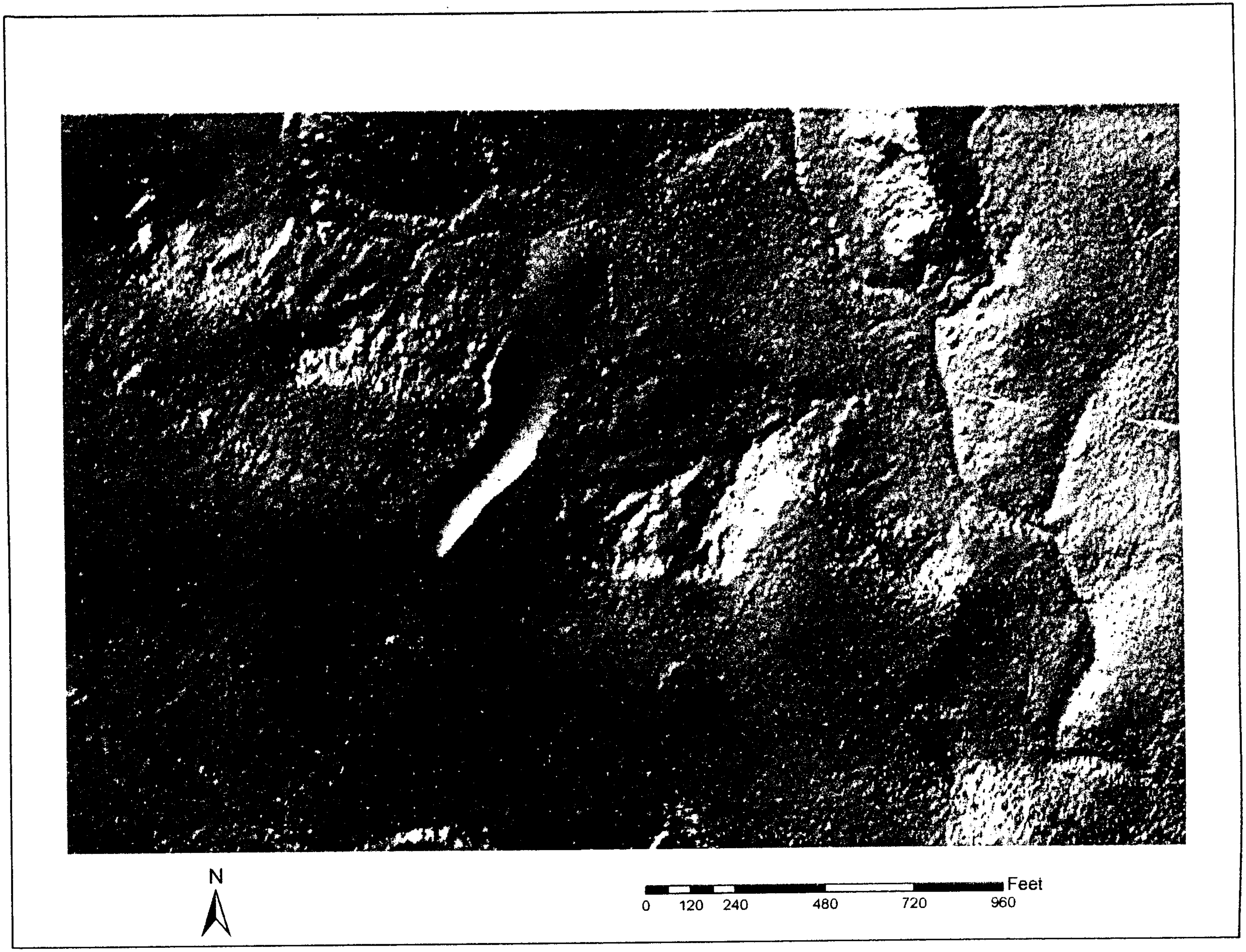


Figure 10. Shaded-relief image of one tile (748645) from the 1' ALSM DEM bare-earth data set. In the center of the image, the DEM has been filled in where data were missing.

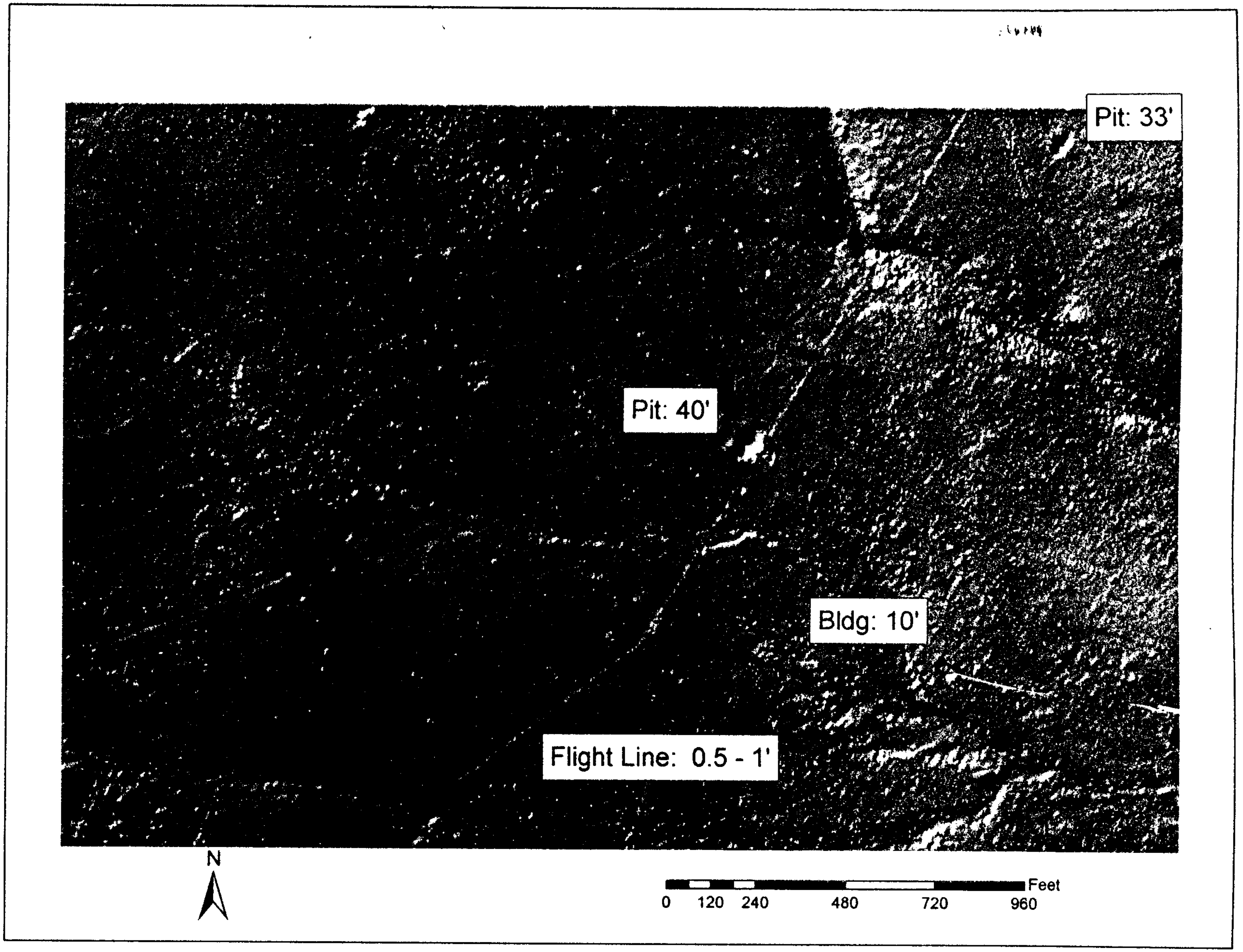


Figure 11. Shaded-relief image of one tile (750651) from the 1' ALSM DEM bare-earth data set. The image illustrates several data processing artifacts labeled by type and size including pits, flight lines, and incomplete removal of buildings.

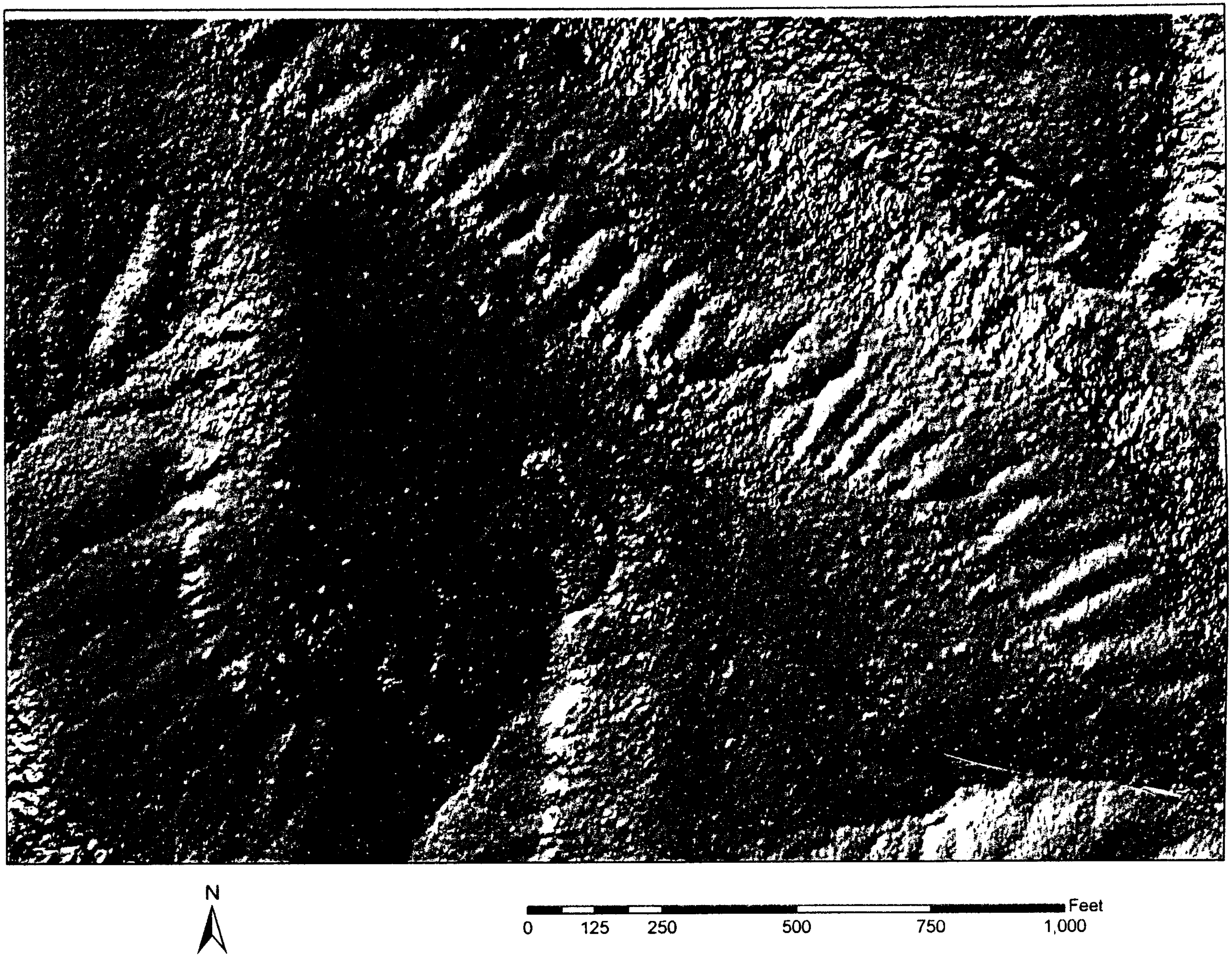


Figure 12. Shaded-relief image of one tile (752618) from the 1' ALSM DEM bare-earth data set. The image illustrates incomplete removal of vegetation during processing (especially evident along arroyo in center of image).

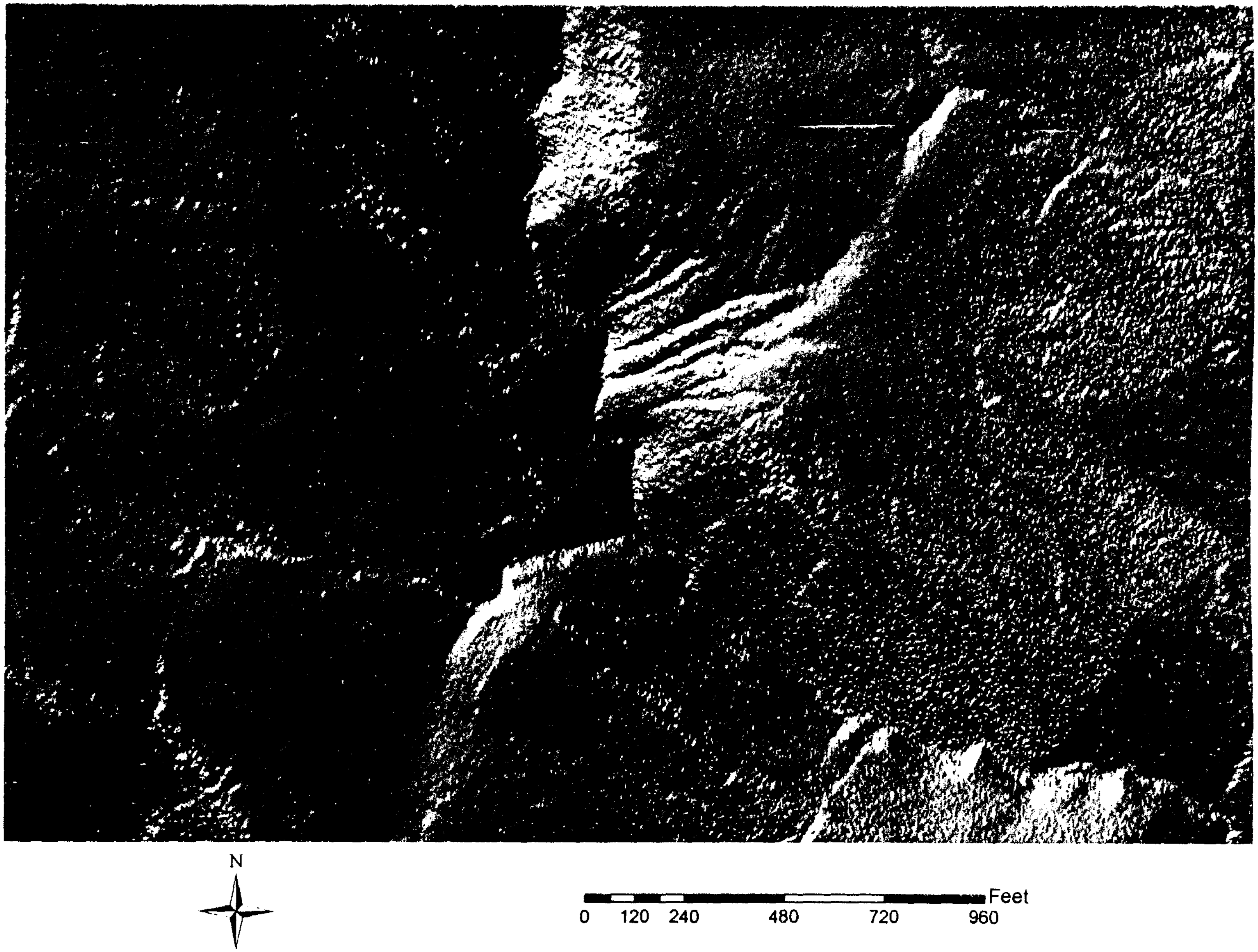


Figure 13. Shaded-relief image of one tile (778609) from the 1' ALSM DEM bare-earth data set. The image illustrates several artifacts including hashing (east side of image) and striping (top-central part of image).

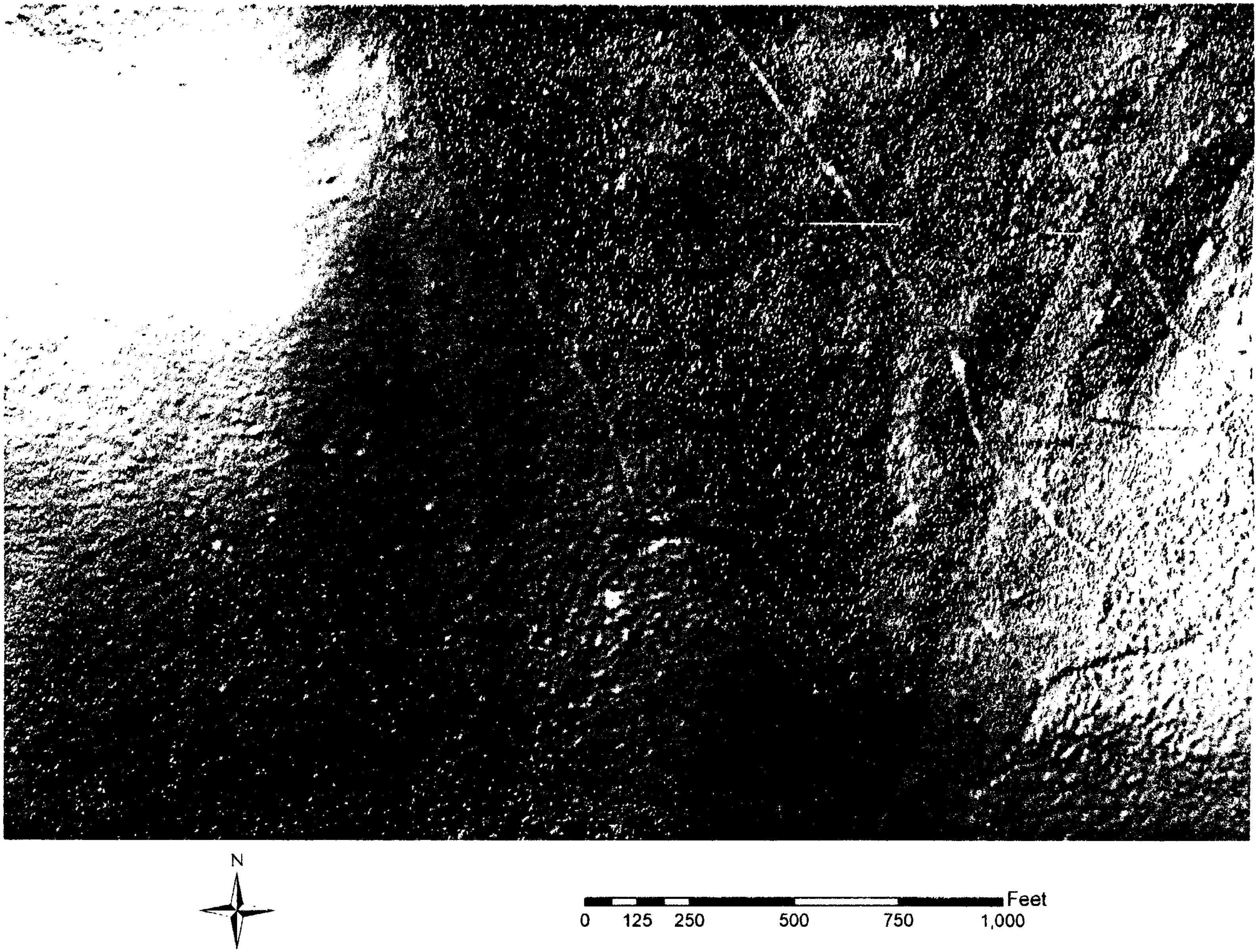


Figure 14. Shaded-relief image of one tile (778594) from the 1' ALSM DEM bare-earth data set. The image illustrates a dimple and pimple texture.

Figure 15. Shaded-relief image of one tile (744654) from the 1' ALSM DEM bare-earth data set. The image illustrates a "jigsaw" texture in which elevation is represented by integer values creating 1-foot steps.

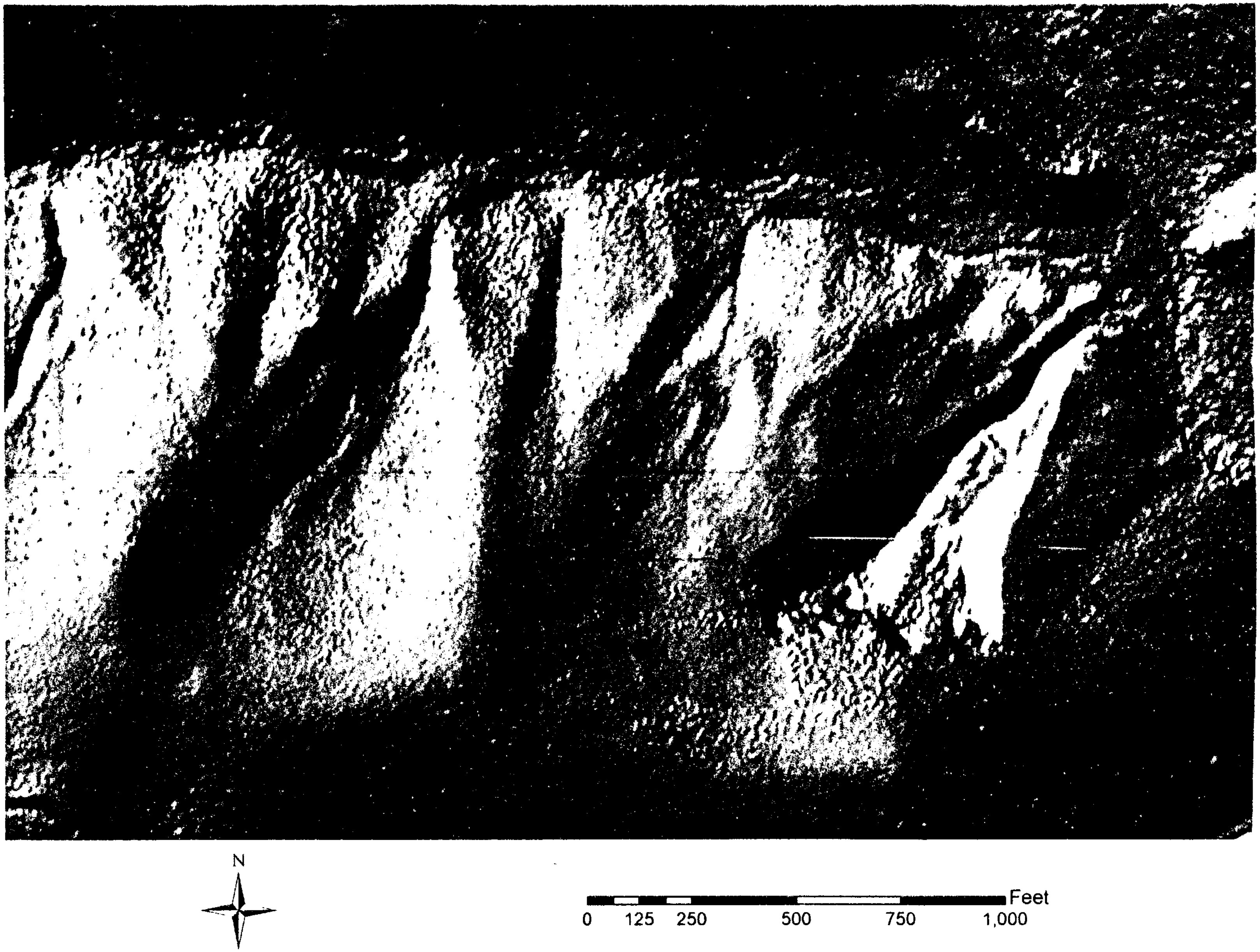


Figure 16. Shaded-relief image of one tile (780603) from the 1' ALSM DEM bare-earth data set. The image illustrates a linear artifact that runs E-W across the DEM.

High-Resolution 1' ALSM Survey and 1992 1' DEM vs. GPS Data
654 Measurements vs. 421 Measurements

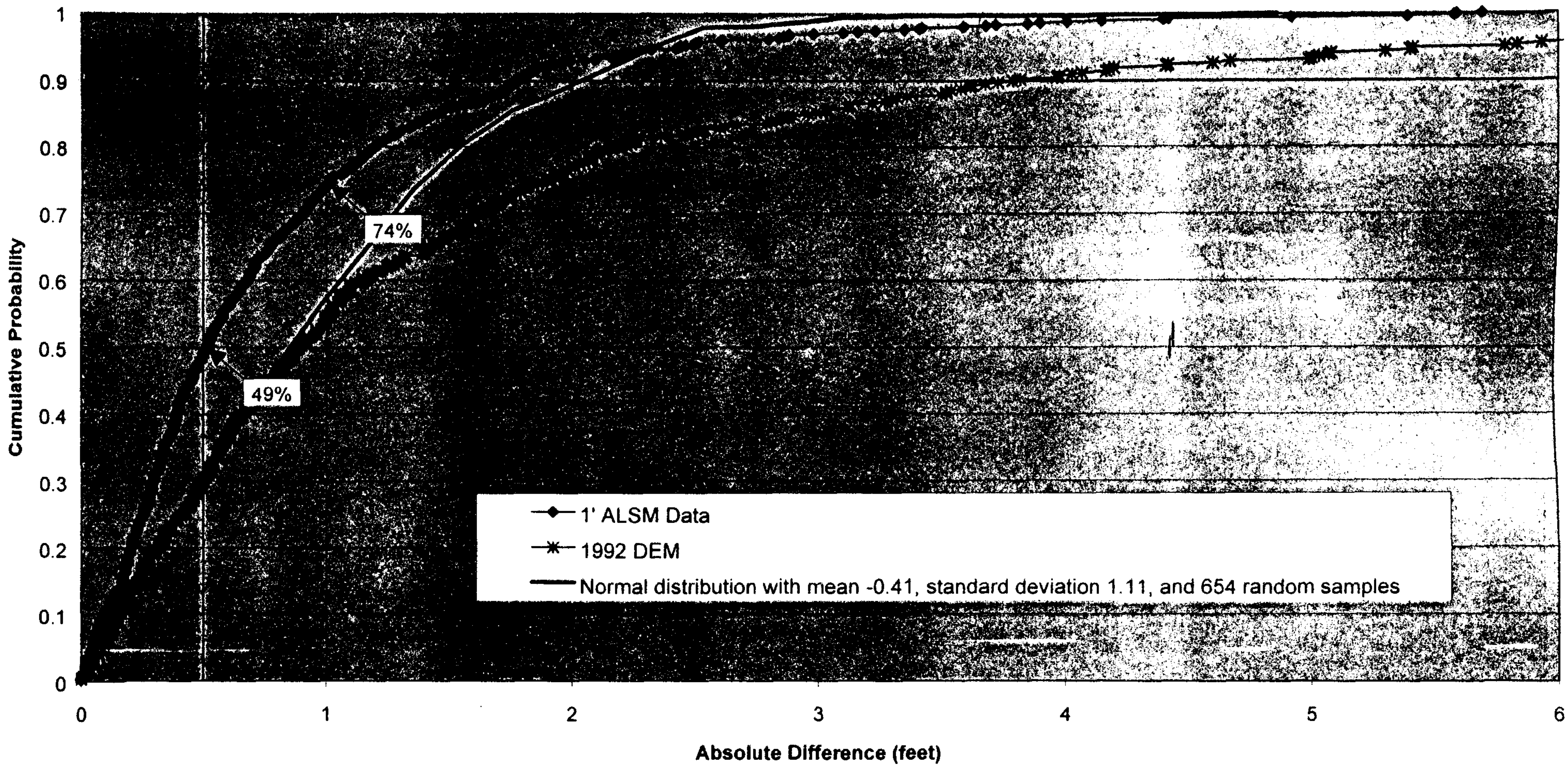


Figure 17. A summary comparison of the absolute value of the differences between GPS-based survey data and ALSM data (blue) and the 1992 DEM (maroon). For example, 90% of the 1' ALSM data differs by less than about 1.9' from the survey data. For comparison, a simulation of a normal distribution curve with the statistical properties of the ALSM data is given in brown.

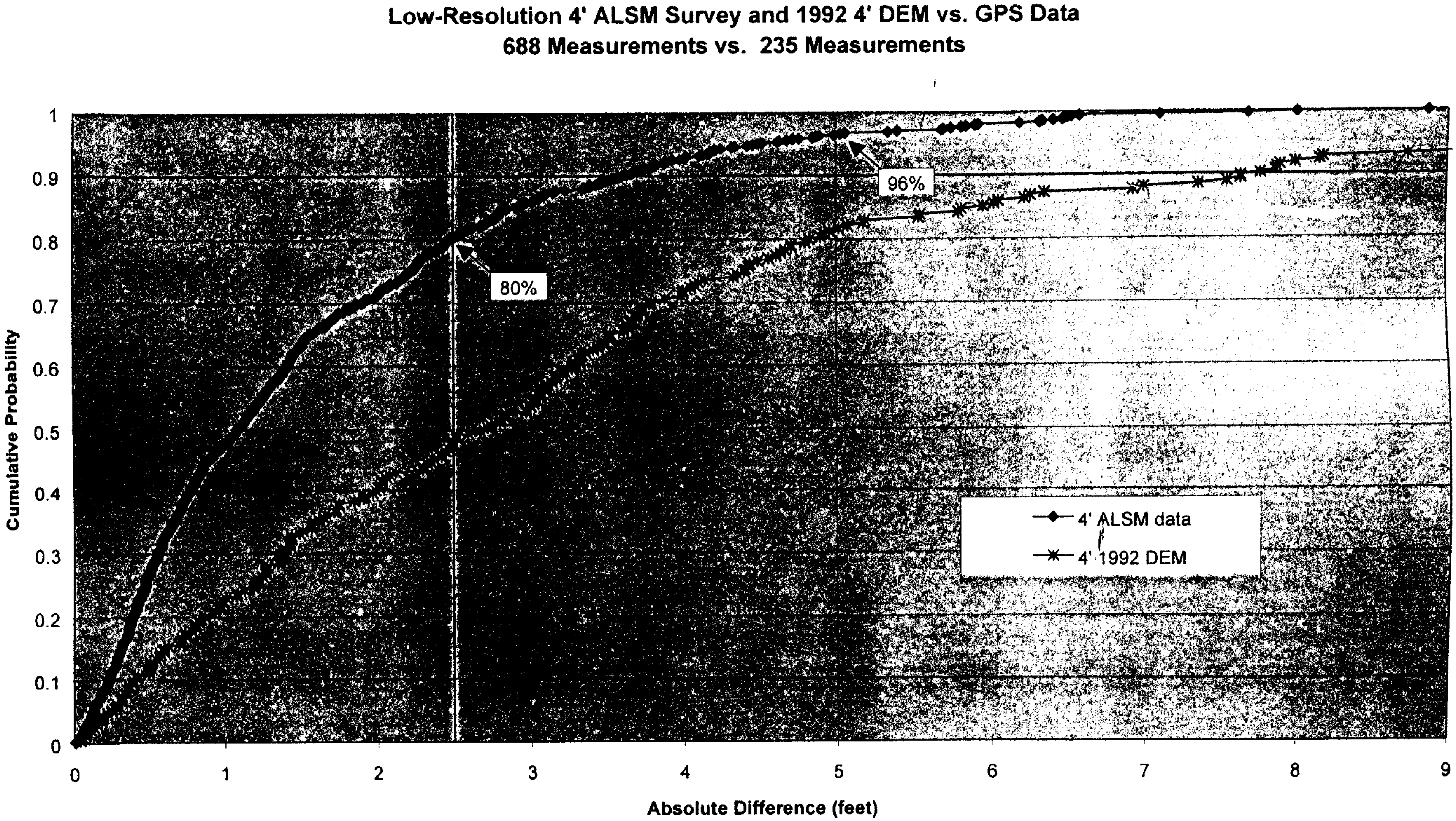


Figure 18. A summary comparison of the absolute value of the differences between GPS-based survey data and 4' ALSM data (blue) and the 4' 1992 DEM (maroon). For example, 90% of the 4' ALSM data differs by less than about 3.7' from the survey data.

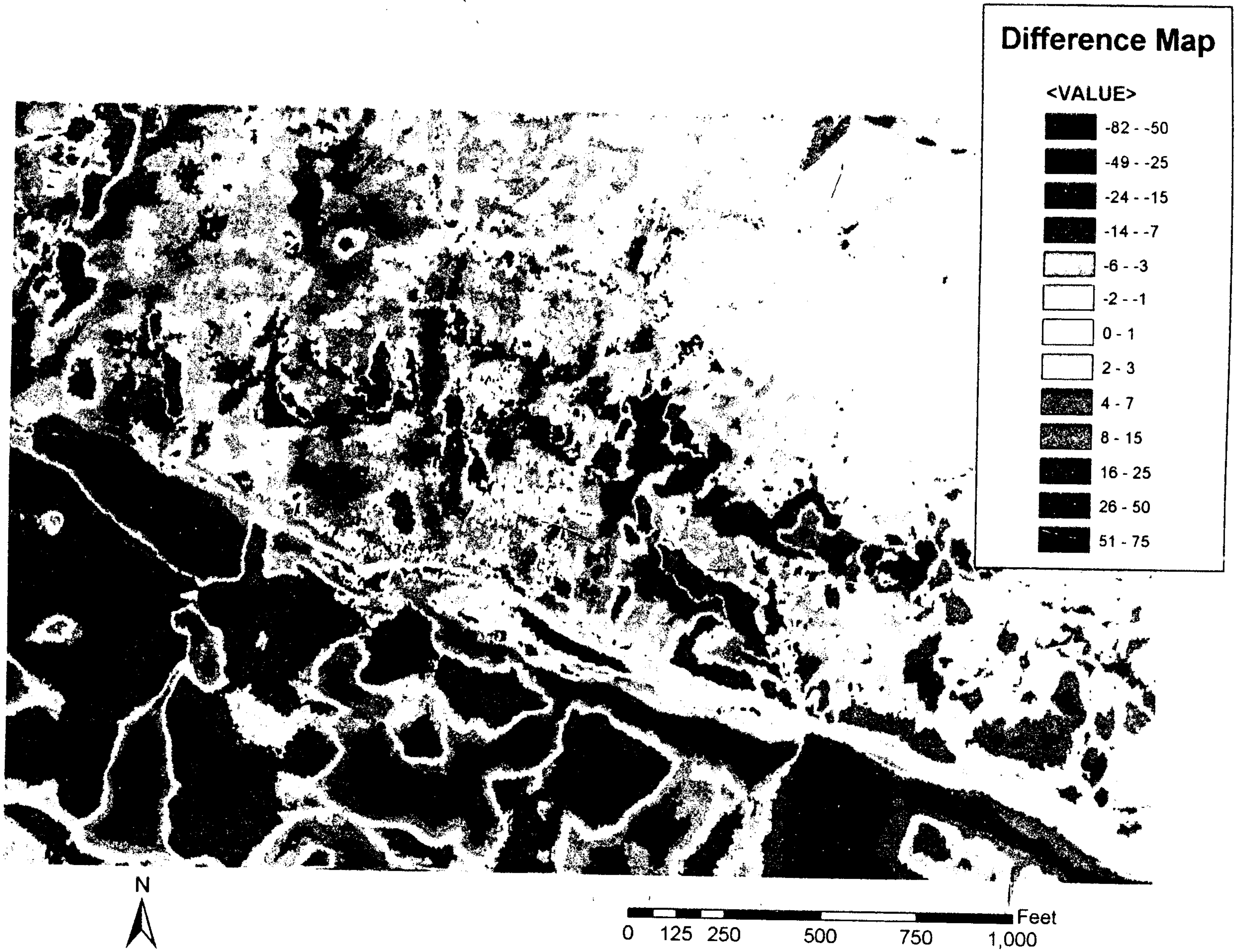


Figure 19. A difference map created by subtracting the ALSM-derived 1' DEM from the 1992 1' DEM for tile (776609). The source tiles are illustrated in Figures 2 and 3. The differences are given in feet.

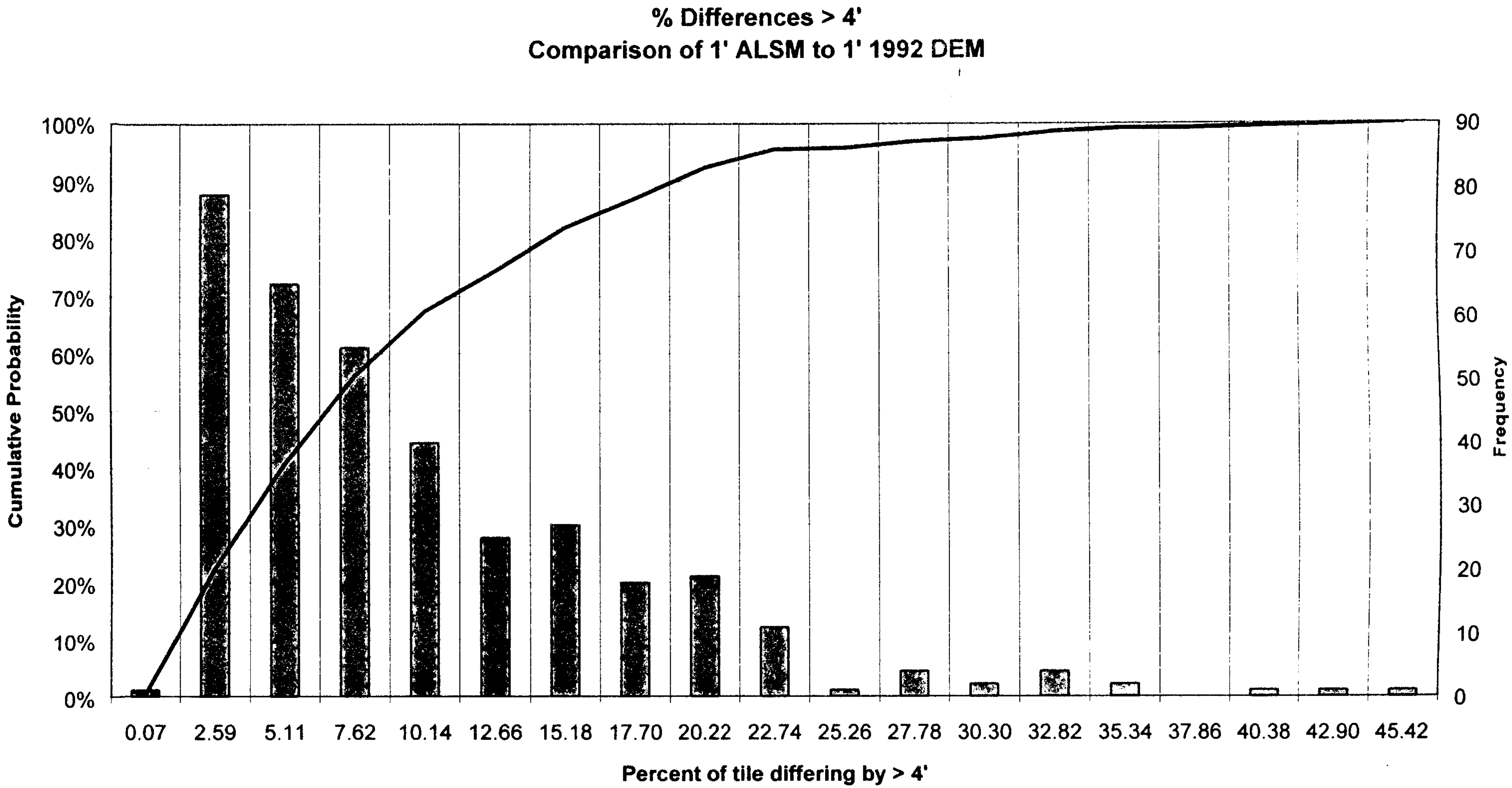


Figure 20. Histogram summarizing the differences observed between elevations of the 1' ALSM data and the 1992 1' DEM. In the figure 356 tiles are compared and the number of tiles with more than X% of the cells having absolute differences in excess of 4' is shown. For example, in about 55 tiles approximately 7.6% of the cells differing by more than 4' in a comparison of ALSM and 1992 data.

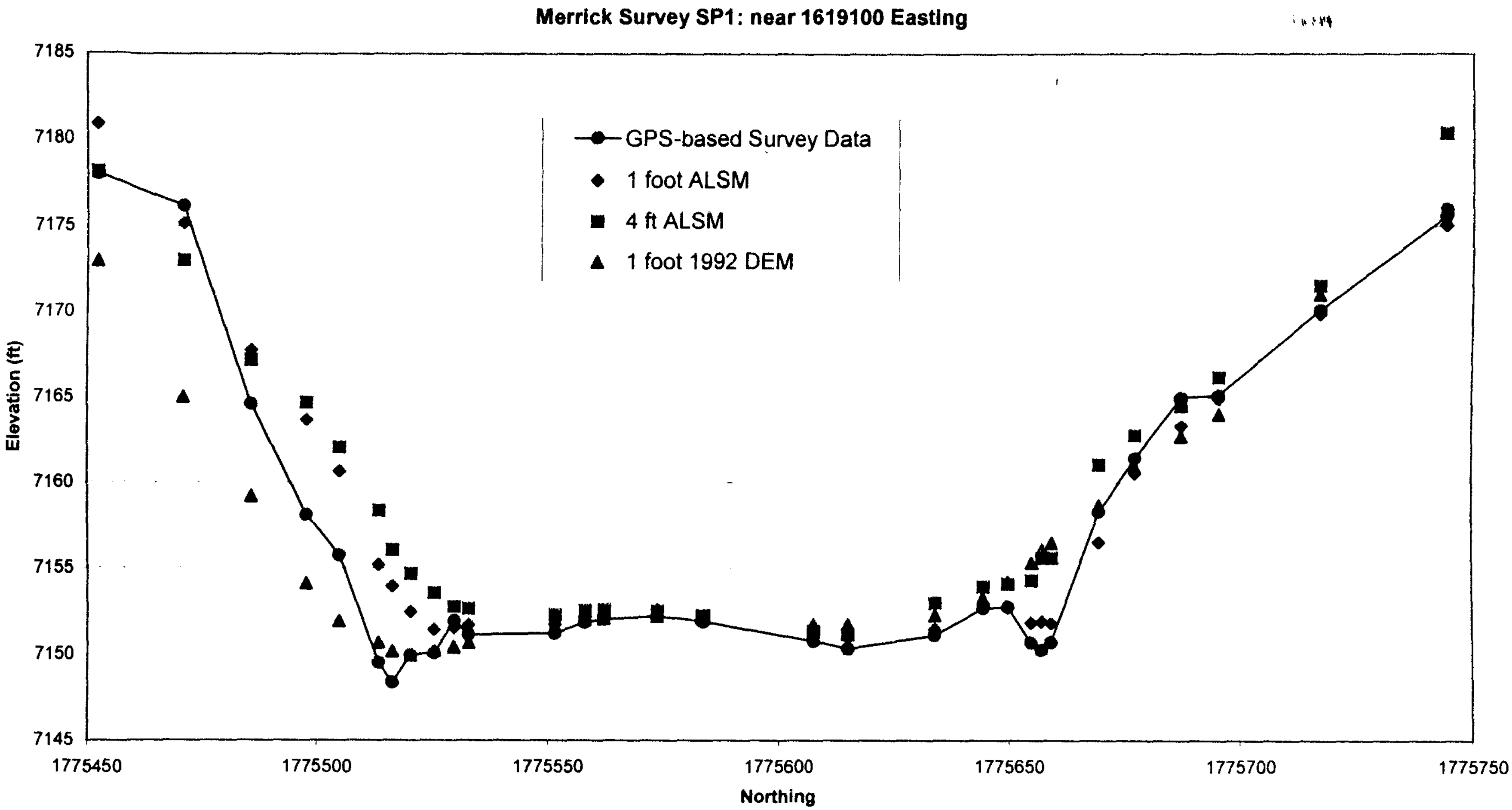


Figure 21. Comparison of GPS-based survey data with the 1' and 4' ALSM and the 1' 1992 DEM in a section of Los Alamos Canyon.

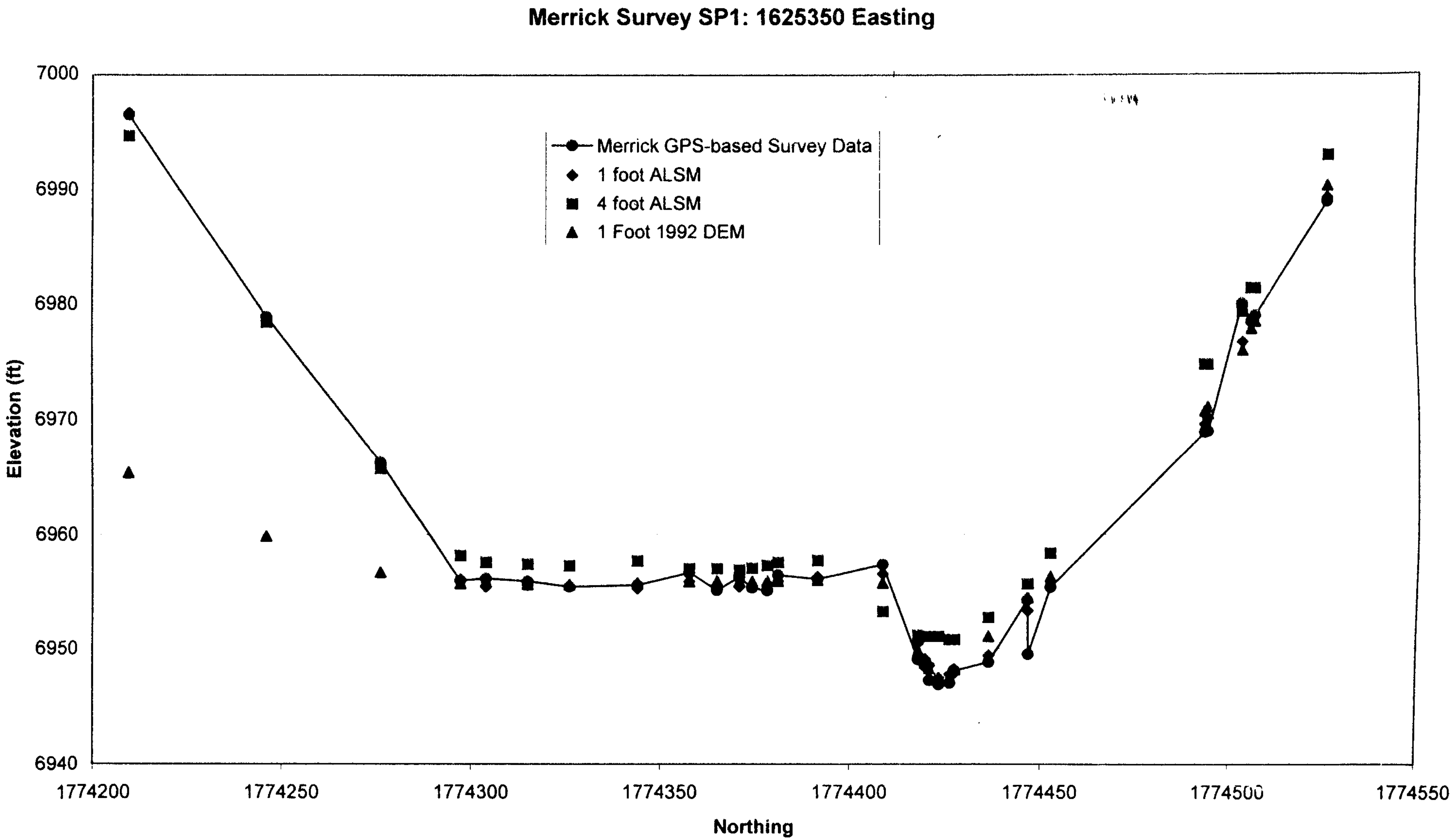


Figure 22. Comparison of GPS-based survey data with the 1' and 4' ALSM and the 1' 1992 DEM in a section of Los Alamos Canyon.

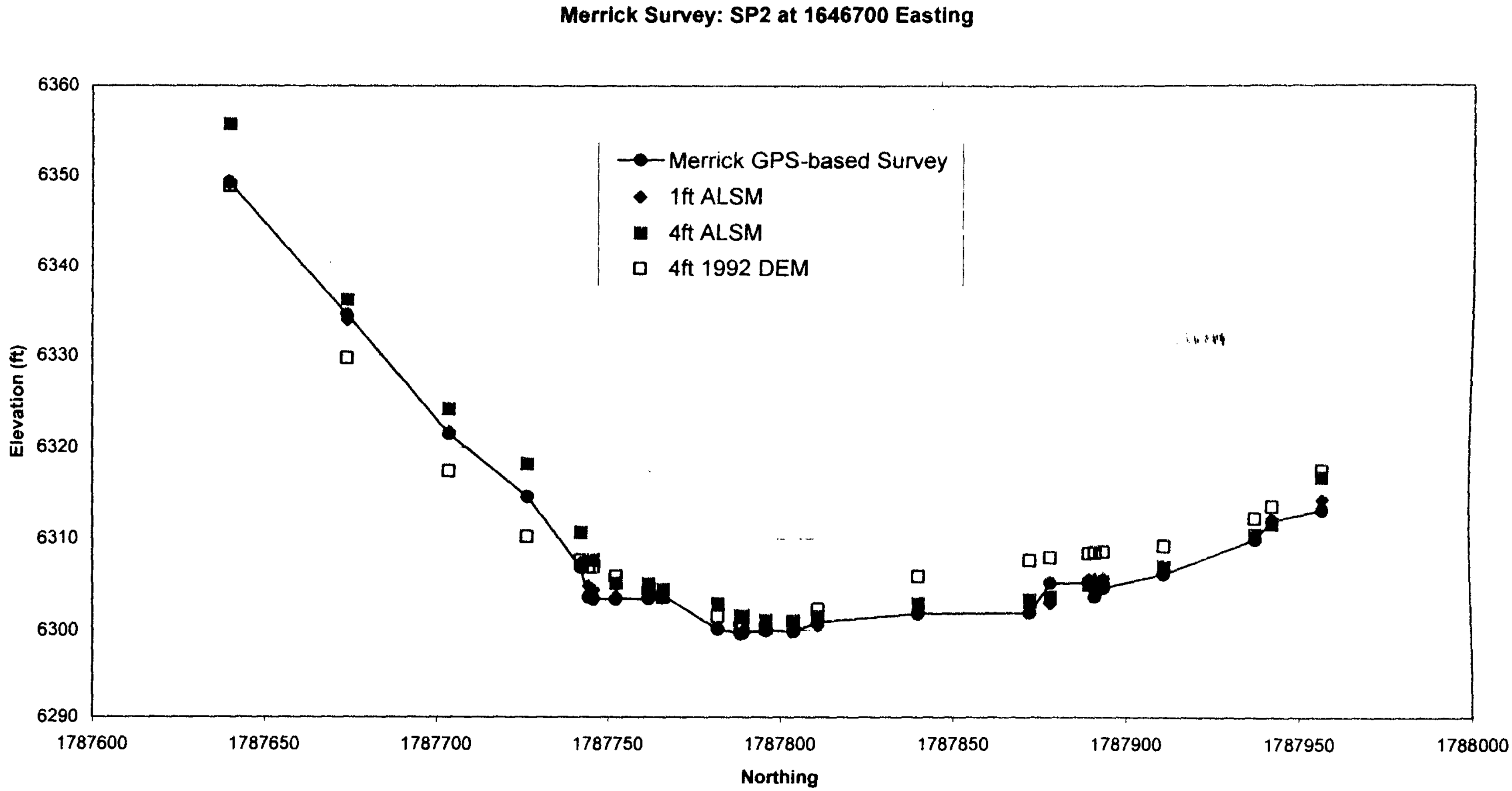


Figure 23. Comparison of GPS-based survey data with the 1' and 4' ALSM and the 1' 1992 DEM in a section of Guaje Canyon.

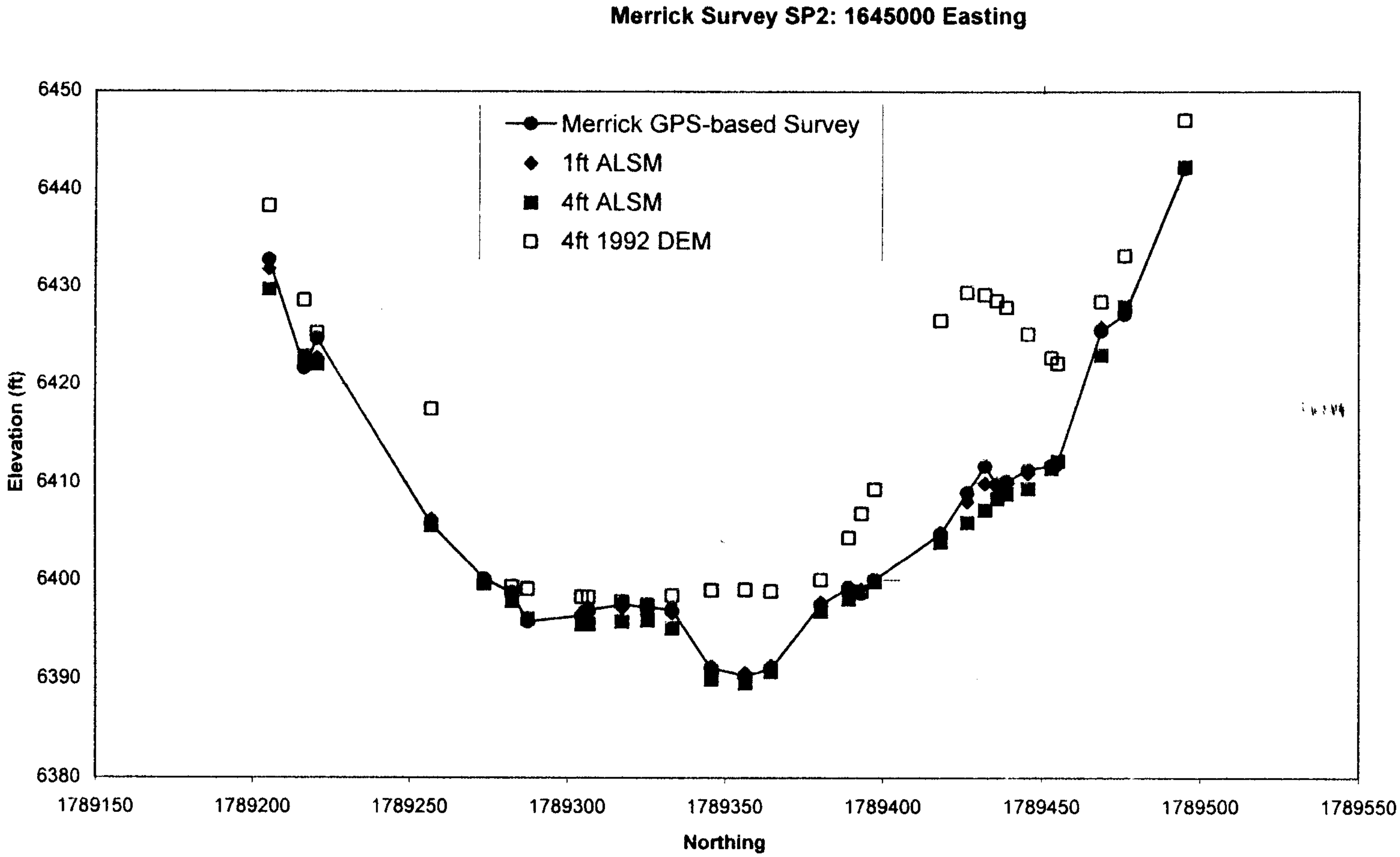


Figure 24. Comparison of GPS-based survey data with the 1' and 4' ALSM and the 1' 1992 DEM in a section of Guaje Canyon.

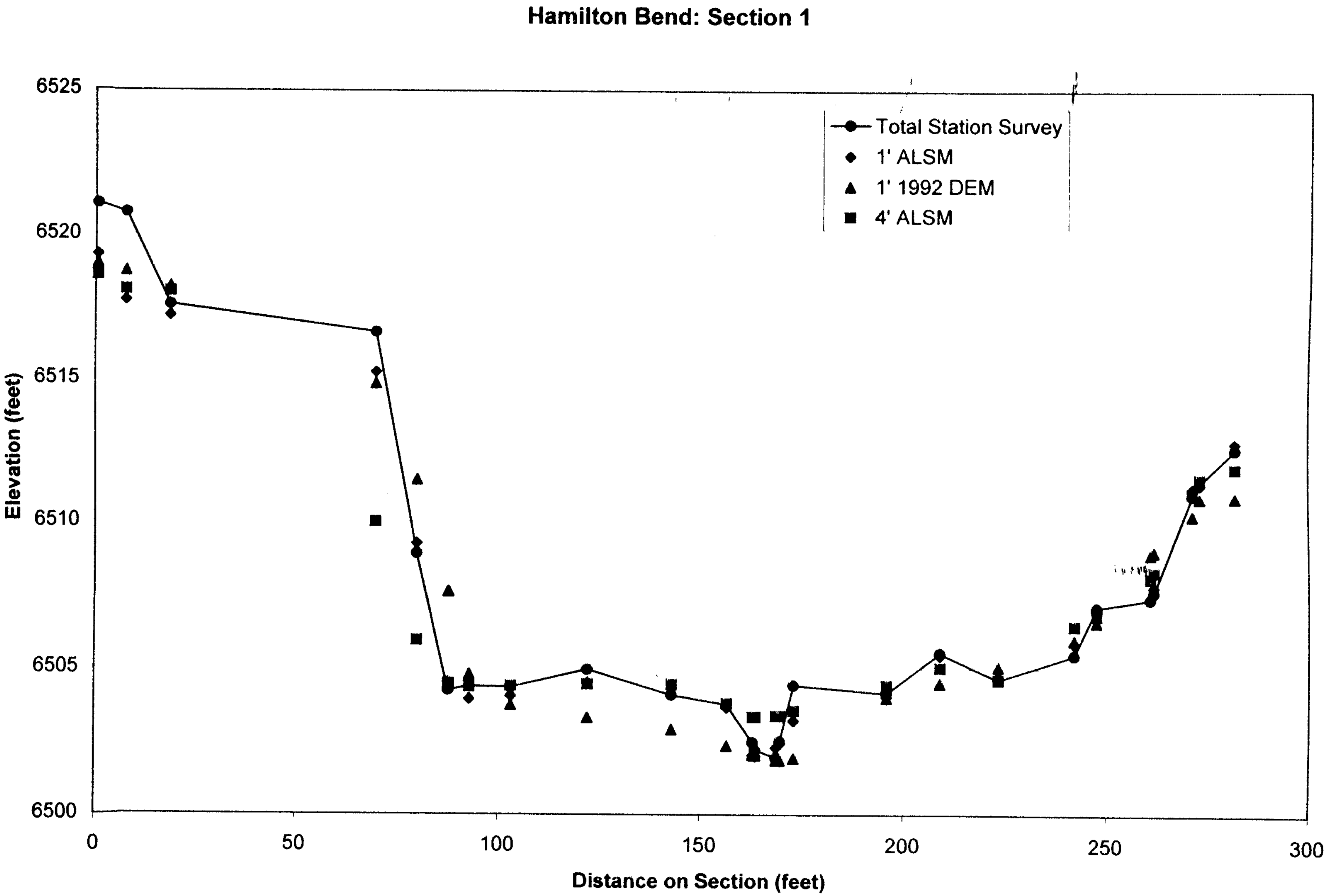
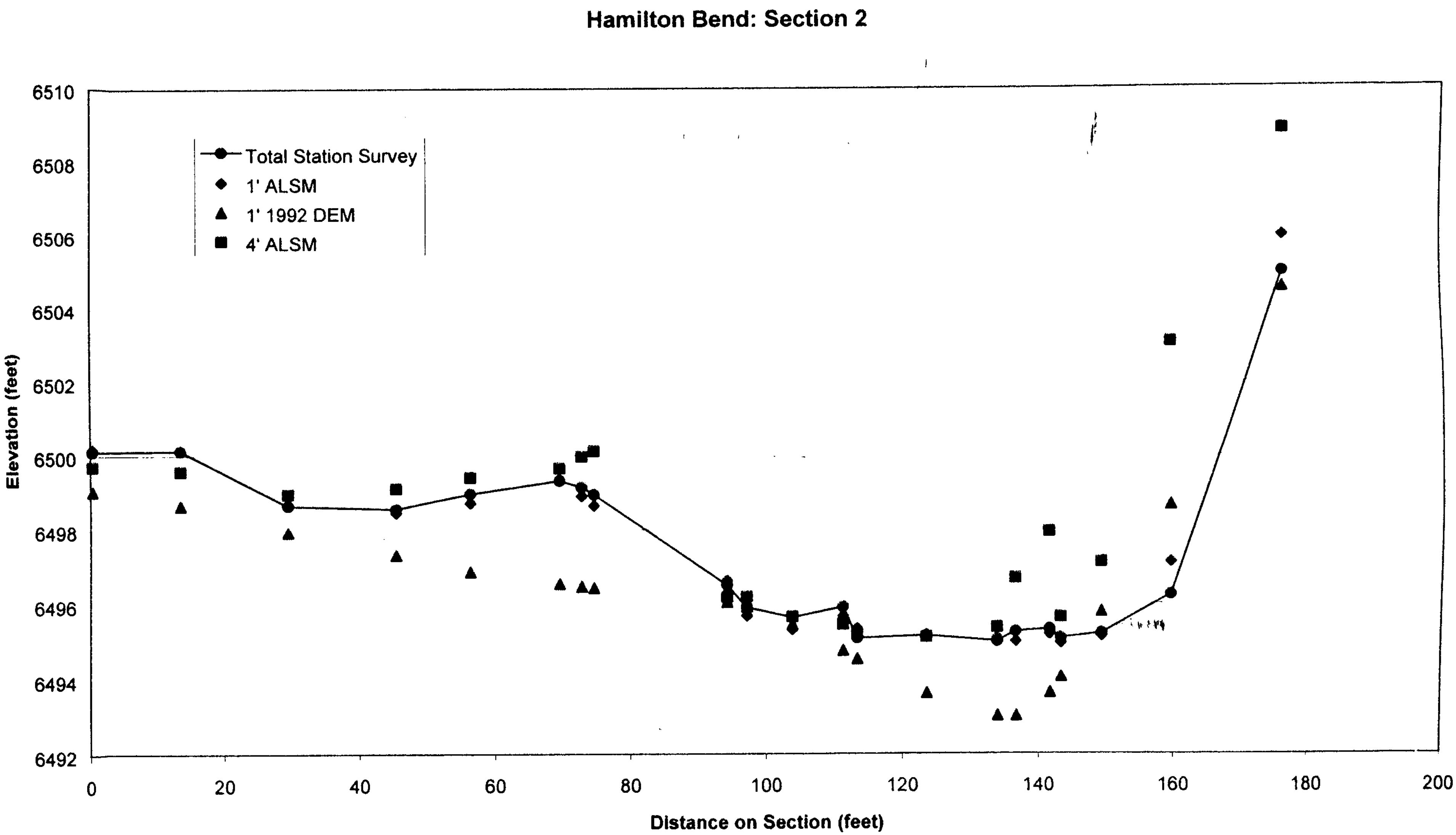


Figure 25. Comparison of total-station survey data with the 1' and 4' ALSM and the 1' 1992 DEM at Hamilton Bend in Pueblo



Canyon.

Figure 26. Comparison of total-station survey data with the 1' and 4' ALSM and the 1' 1992 DEM at Hamilton Bend in Pueblo Canyon.

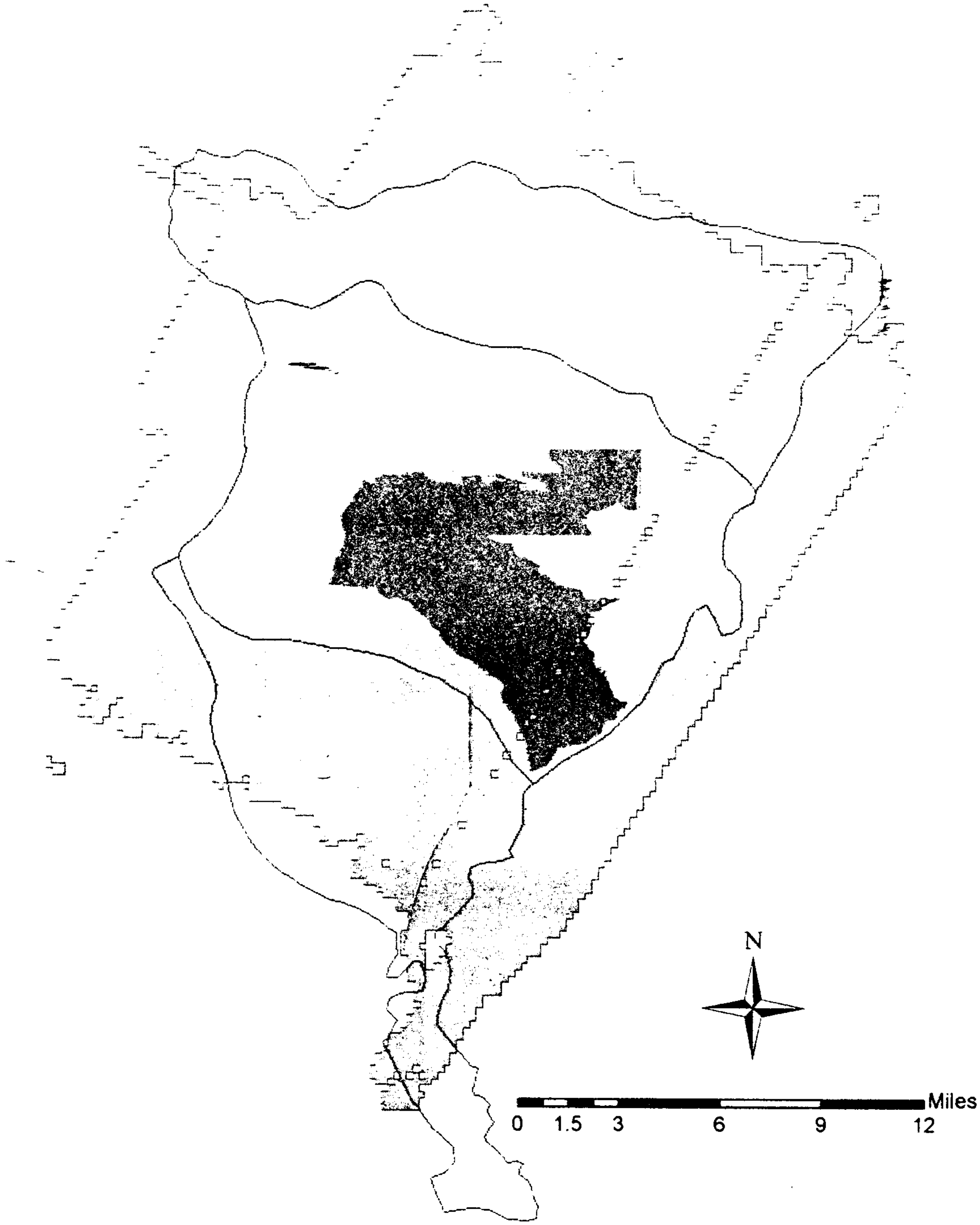


Figure 27. The lightly shaded region shows the area where high-resolution ALSM data was collected. The darker shaded region is the LANL site.

Frequency of 1 Foot Tiles Meeting Contract Criteria

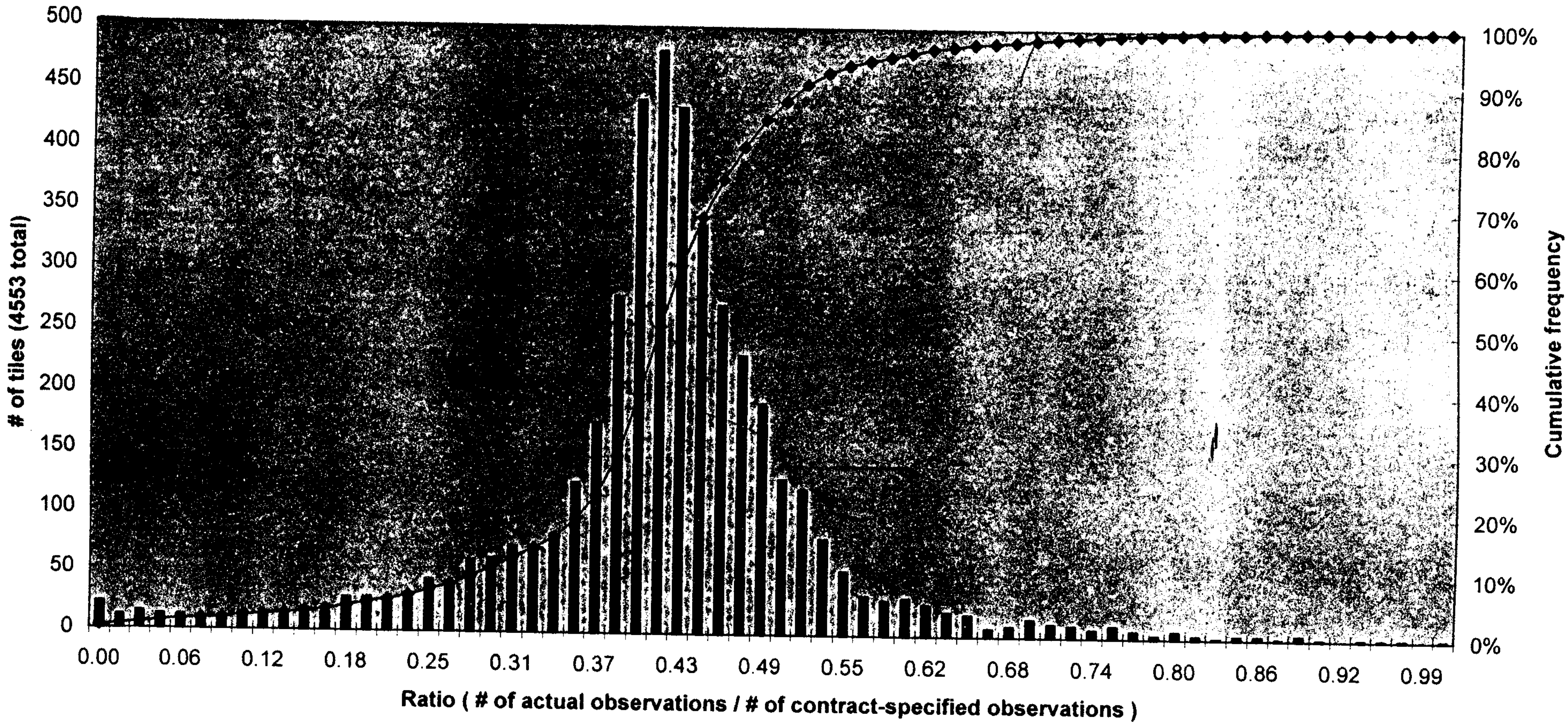


Figure 28. A histogram plot of the ratio of observed to contract-specified observations in each 1000 ft^2 tile within the contract-specified high-resolution region (see Figure 1, page 27).

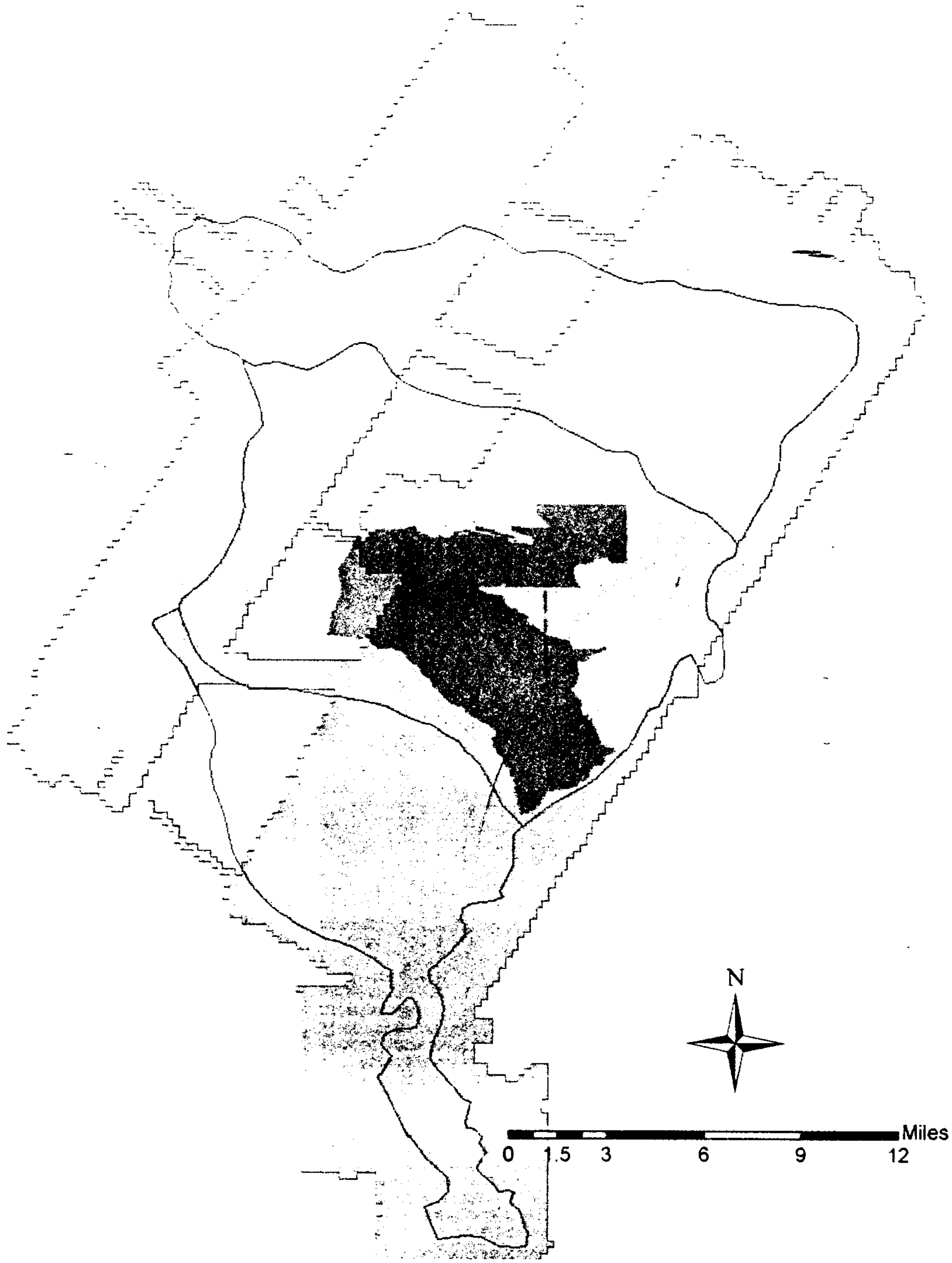


Figure 29. The lightly shaded region shows the area where low-resolution ALSM data was collected. The darker shaded region is the LANL site. The band of missing data west of LANL was never delivered (although DEMs for this region were delivered).

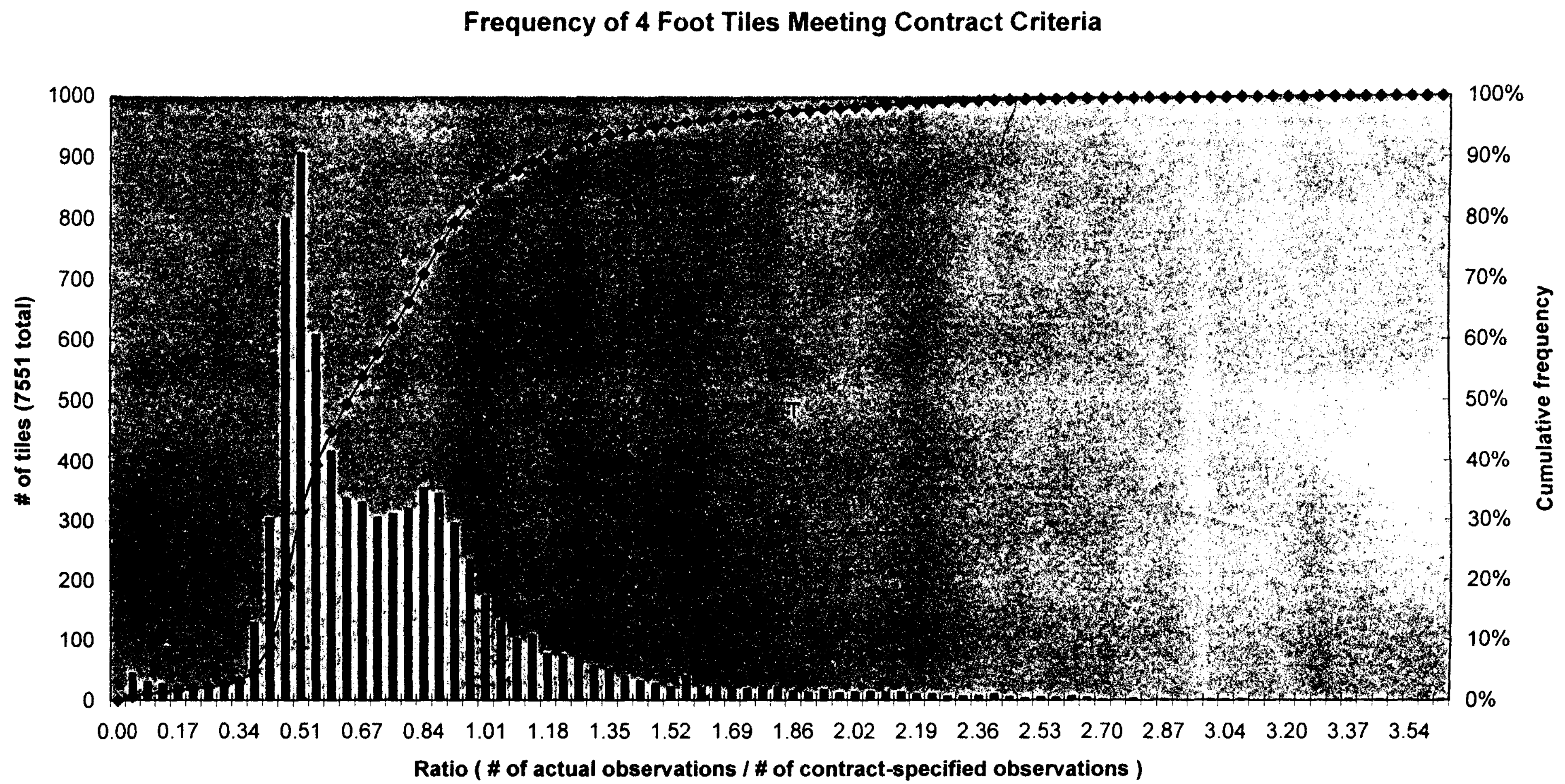


Figure 30. A histogram plot of the ratio of observed to contract-specified observations in each 1000 ft^2 tile within the entire study region (see Figure 1, page 27).

APPENDICES

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Appendix V: Merrick & Co. Conventional Survey Report for Cerro Grande Wildfire Project Los Alamos, N`ew Mexico

APPENDIX I

ALSM Flight Conditions

Appendix I. ALSM Flight Conditions

Low Resolution Flights

Flight Date	Time	Altitude AGL (m)	Weather condition	Ground Station Points	Tapes	SCAN RATE	SCAN FREQ	SCAN ANGLE	Aircraft Velocity (knots)	Expected Point Density (ft^2/pt)	Line Width (feet)
6/22/00	06:55AM-9:40AM	2000	CALM	228 & 434	NM17400A&B	25000	18	15	120	14.00	1728
6/22/00	11:55AM-1:05PM	2100	CALM	228 & 434	NM17400C	25000	18	15	125	15.31	1814
6/23/00	6:23AM-10:05AM	2100	CALM	434, Santair, Merr, 228	NM17500A&B	25000	18	15	125	15.31	1814
6/24/00	5:55AM-9:35AM	2000	CALM	434, 228, Merr, B0004	NM17600A&B	25000	18	15	127	14.81	1728
6/24/00	2:05PM-4:25PM	2000	CALM	434, 228, Merr, B0004	NM17600C	25000	18	15	127	14.81	1728
6/25/00	5:25AM-9:55AM	2000	LIGHT WINDS	434, 228, Merr	NM17700A,B&C	25000	18	15	130	15.16	1728

High Resolution Flights

Flight Date	Time	Altitude AGL (m)	Weather condition	Ground Station Points	Tapes	SCAN RATE	SCAN FREQ	SCAN ANGLE	Aircraft Velocity	Expected Point Density (ft^2/pt)	Line Width (feet)
7/1/00	3:25PM-6:05PM	1000	CALM	Merr,B004,434	NM18300A	25000	25	16	120	7.47	922
7/2/00	8:50AM-12:35PM	1000	CALM	Merr,B004,434	NM18400A&B	25000	25	16	118	7.35	922
7/3/00	11:15AM-2:20PM	1000	HIGH WINDS	Merr,B004,434	NM18500A&B	25000	25	16	122	7.60	922
7/4/00	6:10AM-10:35AM	1000	CALM	Merr,B004,434	NM18600A&B	25000	25	17	124	8.21	981
7/4/00	12:20PM-2:15PM	1000	HIGH WINDS	Merr,B004,434	NM18600C	25000	25	17	127	8.41	981
7/5/00	6:10AM-10:35AM	1000	CALM	Merr,B004,434	NM18700A&B	25000	25	17	130	8.61	981
7/5/00	2:00PM-3:15PM	1000	CALM	Merr,B004,434	NM18700C	25000	25	17	125	8.28	981
7/6/00	5:28AM-10:10AM	1000	CALM	Merr,B004,434	NM18800A&B	25000	25	17	117	7.75	981
7/6/00	5:13PM-6:40PM	1000	MODERATE WINDS	Merr,B004,434	NM18800C	25000	25	17	126	8.34	981
7/7/00	5:50AM-10:20AM	1000	CALM	Merr,B004,434	NM18900A&B	25000	25	17	125	8.28	981
7/8/00	6:25AM-11:50AM	1000	CALM	Merr,B004,434	NM19000A&B	25000	25	17	117	7.75	981
7/8/00	6:40PM-9:07PM	1000	CALM	Merr,B004,434	NM19100A	25000	25	17	121	8.01	981
7/9/00	5:40AM-10:25AM	1000	CALM	Merr,B004,434	NM19100B&C	25000	25	17	118	7.81	981

APPENDIX II

Statement of Work for ALSM Contract

STATEMENT OF WORK

PHOTOGRAMMETRIC AND LIDAR AERIAL MISSIONS

FOR

SUPPORT OF THE CERRO GRANDE FIRE DISASTER

Environmental Restoration Project
Environment, Safety & Health Division

I. Introduction

ESH Division and the ER Project propose to conduct photogrammetric and LIDAR aerial missions over approximately 321 square miles of Los Alamos National Laboratory, Los Alamos County, Bandelier National Monument, Santa Fe National Forest, Santa Clara Pueblo, the Pueblo of San Ildefonso, and Cochiti Pueblo in order to accurately document, inventory, model, and analyze the existing and potential damages resulting from the recent Cerro Grande fires. The services required are as follows:

- Low resolution LIDAR data acquisition for approximately 173 square miles (Areas A & C of Figure 1);
- High resolution LIDAR data acquisition for watershed and drainage study area approximately 148 square miles (Area B of Figure 1); and
- Color aerial photography at a scale of 1"=2,000' for approximately 320 square miles (Areas A, B, & C of Figure 1) to support 1"=400' digital ortho imagery.
- Analysis of LIDAR data to produce "bare-earth" DEMs, reflectance, and canopy data.
- Creation of ortho imager from aerial photography and DEMs.

II. Mapping Area

Figure 1 illustrates the extent of the mapping area. The map also shows the 1"=400' tiles using a 12,000 x 8,000' grid. The polygon indicates the extent of the Cerro Grande Fire.

Areas A, B, and C in Figure 1 reference the following study areas:

- A and C: Areas of low-resolution LIDAR.
- B: Area of high-resolution LIDAR
- A, B, and C: Areas of 1"=400' color ortho imagery.

III. Services and Specifications

The primary services required under this statement of work are as follows:

A. Aerial Photography

Photography is the source for collecting event (fire damage), physical, and cultural features as they are represented at the time of exposure.

1. Aerial photography shall be flown using natural color film at a negative scale of 1"=2,000' (1:24,000) sufficient to support 1"=400' digital ortho imagery. The flying altitude shall be approximately 12,000' above mean terrain.

2. All aerial photography shall be accomplished as to afford photographs meeting all precision requirements for aerotriangulation and GIS database compilation conforming to the USGS Map Accuracy Standards. These standards include:

- flying under optimal weather conditions such as cloud coverage and sun angle (there may be smoke/haze),
- Federal Aviation Administration (FAA) and Civil Aeronautics Board (CAB) safety regulations,
- state of the art film processing, and
- current USGS calibration report (within the past three years) meeting specifications for focal length (153 mm, ±3.0) and aerial weighted average resolution (AWAR of 90+ mm/inch).

B. Fully Analytical Aerotriangulation (FAAT)

FAAT is the process that merges the GPS control with the aerial photography. This process establishes a project-wide coordinate system for the photogrammetrist. FAAT specifications are as follows:

1. Fully analytical aerotriangulation (FAAT) for densifying the ABGPS control shall be accomplished by either conventional or digital methods.

2. Individual FAAT solutions shall be completed for both scales of aerial photography.

3. Following the completion of the adjustments for each scale, the FAAT solution shall be "tied" to both scales. The final results of the FAAT shall be delivered to LANL.

C. Survey Controls

Survey controls shall be utilized so that the LIDAR and aerial photography can be "referenced/tied" to a known coordinate system. When available, contractor shall utilize the control points established by LANL on previous projects.

1. Contractor shall use GPS technology to survey positions that will be used for the checkpoints supporting all mapping products. These points are used to verify the positional accuracy (horizontal and vertical) of the databases.

2. When applicable, contractor shall install a semi-permanent monument for each of the photo-control points. The monument shall be a #5 rebar, 24" long with an aluminum cap (LANL shall provide the survey cap). Additionally, a pre-mark shall be placed so that the control point will be visible in the aerial photography.

3. Horizontal coordinates shall be based on the New Mexico State Plane Coordinate System, North American Datum 1983. Elevations shall be based on National Geodetic Vertical Datum of 1988.

4. Upon completion of the survey, an ARC/INFO coverage all the GPS points shall be provided to LANL.

5. Airborne Global Positioning System (ABGPS) shall be used for the 1"=2000' aerial photography and to support the LIDAR acquisition.

D. LIDAR Elevation Mapping

LIDAR (Light Detection And Ranging) is a proven radar technology used for collecting elevation data (x, y, z). There are two resolutions of LIDAR data being requested; Approximately 173 square miles of Low resolution LIDAR in Areas A & C (see Figure 1), and approximately 148 square miles of High resolution LIDAR in Area B (see Figure 1).

1. <u>The following are the key data collection specifications for the Low Resolution (1" = 400') LIDAR mission</u>:

   a. The flying altitude of the aircraft shall be approximately 6,500 feet above mean ground level for the Low resolution LIDAR;

   b. The average DEM spot spacing shall not exceed 4';

   c. There shall be two GPS base stations on the ground during the LIDAR missions;

   d. The Low resolution LIDAR DEM shall be suitable for generating 10' contours.

   e. In order to accelerate the analysis of potential flooding and drainage problems, the contractor shall acquire a low resolution Digital Elevation Model (DEM) using the LIDAR "Bald Earth" model. The LIDAR DEM shall also be used to create digital ortho imagery and 1' contours. The positional accuracy of this data shall be 15 cm (.5') vertical and 4' horizontal.

   f. The integrity of the elevation data is increased using a "first and last pulse" procedure, as well as, evaluating the "intensity" of each posting;

   g. The aircraft is equipped with GPS and inertial reference systems that accurately determine the attitude and position of the sensor.

   h. The positional accuracy of the final contour data will comply with National Map Accuracy Standards.

   i. META data attributes shall be added to the LIDAR data.

   j. Reflectance and canopy data shall be generated from the LIDAR data.

2. <u>The following are the key data collection specifications for the High Resolution (1" = 100') LIDAR mission</u>:

   a. The flying altitude of the aircraft shall be approximately 3,000 feet above mean terrain for the High resolution LIDAR. The flight lines shall be parallel with about a 40% side overlap. The sensor-scanning angle shall be approximately 30°. Based on the target acquisition speed or through the use of a helicopter, a ground point density of 1.56 feet along and perpendicular to the flight path shall be obtained. As needed, Applied Geomatics shall acquire LIDAR profiles in order to maintain vertical accuracy in specific areas of the project.

b. There shall be two GPS base stations on the ground during the LIDAR missions;

c. The High resolution LIDAR DEM shall be suitable for generating 2' contours;

d. In order to accelerate the analysis of potential flooding and drainage problems, the contractor shall acquire a high resolution Digital Elevation Model (DEM) using the LIDAR "Bald Earth" model. The LIDAR DEM shall also be used to create digital ortho imagery and 2' contours. The positional accuracy of this data shall be 15 cm (.5') vertical and 1' horizontal.

e. The integrity of the elevation data is increased using a "first and last pulse" procedure, as well as, evaluating the "intensity" of each posting;

f. The aircraft is equipped with GPS and inertial reference systems that accurately determine the attitude and position of the sensor.

g. The positional accuracy of the final contour data will comply with National Map Accuracy Standards.

h. META data attributes shall be added to the LIDAR data.

i. Reflectance and canopy data shall be generated from the LIDAR data.

E. Color Digital Orthophoto Production

A digital ortho image shall be produced that uses survey control, FAAT, and LIDAR DEM (low and high-resolution data) to correct distortions inherent with aerial photography. The color ortho imagery will cover all three LANL mapping areas (A, B, C). The following specifications shall apply:

1. Contractor shall utilize digital mosaic technologies to create a "seamless" image database across the entire project. Contractor shall ensure that ground features on the digital ortho imagery shall edgematch within the specified National Map accuracy for each scale of photography. Tonal matching between different scale and dates of photography shall be accomplished to the best of the contractor's ability.

2. Contractor shall deliver the digital orthophoto in a TIFF (with a world file) format, compatible with ARC/INFO. The imagery will also be compressed using MrSID.

3. The low and high resolution LIDAR elevation data shall be used to control the 1"=400' color digital orthos;

IV. Deliverable Products and Databases

The following describes the products and databases requested by LANL.

Aerial Photography Products

1. One (1) set of labeled (titled) original 9" x 9" color negatives of each scale of aerial photography. The film will be delivered in an ASPRS approved canister.
2. Four (4) set of paper color 9" x 9" contact prints. One (1) set will be a "working" set used by the contractor. The remaining sets will be provided to LANL.
3. USGS certified Aerial Camera Calibration Report.
4. ARC/INFO point coverage of the ABGPS photo-centers.

Fully Analytical Aerotriangulation (FAAT) Products

1. Two (2) copies of the FAAT results and computations in a report form (both paper and electronic in WORD).

ARC/INFO Database Design and Definition

1. ARC/INFO database design documentation (both paper and electronic in WORD).

LIDAR Data Products

1. Two (2) sets of CD's Bald Earth LIDAR data in an ARC/INFO compatible ASCII file.
2. Two (2) sets of raw LIDAR data (i.e., filtered, uninterpolated, ground surface xyz points).
3. Two (2) sets of post-processed canopy data and reflectance imagery will be delivered.
4. Two (2) sets of the LIDAR data shall be delivered in an IEEE floating point (binary) format in column/row format suitable for input into ARC/INFO through the FLOATGRID command. This LIDAR dataset shall be delivered as an interpolated 1-foot grid.

Digital Ortho Data Products

1. Two (2) sets of CD's for the 1"=400' color digital ortho imagery in a TIFF format at a 2.0' pixel resolution in the LANL area. There are approximately 127 tiles in the 1"=400' mapping area. Partial tiles of data are acceptable on the edge of the project area. This delivery shall be uncompressed.

2. Two (2) sets of CD's for the 1"=400' color digital ortho imagery in a MrSID compressed format in the Burn Areas (not covered by the LANL area).

3. Eight (8) color wall mosaics of the digital ortho imagery. Each color mosaic will be in 2 pieces approximately 48" x 72". The mosaics will be delivered unframed on color paper.

4. Digital file for the color wall mosaics (Item #3 above).

V. Project Information Provided By LANL

1. Coordination with air traffic control to expedite the aerial photography and LIDAR missions. This support typically includes attending meetings, preparing an authorization letter and placing telephone calls.

2. Access (and escorts, if needed) to any areas where GPS control is needed for the LIDAR and photography missions.

3. Assistance with the design of the ARC/INFO coverage definition.

4. Provide the exact coordinates of the 1"=400' tile limits.

5. If applicable, provide subcontractor with the survey cap for the semi-permanent monument that is being installed during the survey task.

VI. Schedule of Deliveries

The following summarizes the delivery schedule the requested products:

Finalize scope of work	June 7, 2000
Notice to proceed	June 9, 2000
GPS surveyors mobilize to project	June 12, 2000
Flight and LIDAR Plan to LANL	June 13, 2000
Aerial and LIDAR missions	June 19-July 10, 2000
1"=400' digital ortho, LIDAR data	60 days following field acquisition

VII. Laboratory Implementation Requirements (LIRs)

The contractor shall comply with all of the applicable requirements of the *Aviation Safety* LIR (LIR 402-1320-02.0).

VIII. Additional Comments

1. LANL encourages the submittal of products as they become available (e.g., as sub-regions are completed). This will help insure that the deliverables are in the required format and will help LANL conduct analysis of the fire effects in a timely manner.

2. File formats of deliverables may be changed upon mutual agreement of LANL and subcontractor.

3. The total area of the work (i.e., A, B, and C) is subject to minor adjustment (by <1% of the area).

IX. Confidential and Proprietary Information

Each party will treat as confidential all Information that has been or may hereafter be made available to the other in connection with this agreement. Except as necessary for the project, each party agrees that under no circumstance will it make use of or disclose the Information to any third party.

APPENDIX III

Applied Geomatics International Inc.
Final Report
LIDAR Acquisition and Processing
Cerro Grande

1.1 Duration and Time Period

AGII was contracted by Merrick & Company to conduct an Airborne Laser Mapping project for the Cerro Grande Area, New Mexico.

Initial Data Acquisition was conducted in June and July 2000.

Additional acquisition was conducted in November/ December 2000 for a modified area added to the south of the initial project.

Data processing was conducted by AGII and was completed between August 2000 and May 2001. Initial data submissions were completed by January 2001.

1.2 Purpose of Survey

Data sets were collected following the fire that severely affected the Cerro Grande Survey Area. Data sets collected were to be utilized by the client for the following purposes:-

a. OrthoRectification of Photographic Data Collected
b. Terrain Modeling
c. Contour Generation

1.3 Project Location

The project was located in Northern New Mexico in the area surrounding the Los Alamos National Laboratory.

The project was clearly divided into three distinct areas.

1.	Northern Area	Low Resolution Survey	73 sq. miles
2.	Central Area	High Resolution Survey	148 sq. miles
3.	Southern Area	Low Resolution Survey	99 sq. miles

1.4 Project Scope

AGII was required to execute the survey and deliver the following data sets to the client.

1. Low Resolution Area

- First and Last Pulse Raw Data
- BEDEM Grid Files (4 ft Grid)
- Canopy Model (4 ft Grid)
- Reflectance Grid Sets

2. High Resolution Area

- First and Last Pulse Raw Data
- BEDEM Grid Files (1ft Grid)
- Canopy Model (1 ft Grid)
- Reflectance Grid Sets

1.5 CONDITIONS AFFECTING PROGRESS

In order to achieve the accuracy required for the survey, in particular, the High Resolution Survey, it was necessary to acquire data only during conditions of the best possible GPS conditions. This required that the PDOP during the acquisition period be less than 3. Additionally, due to the reliance on the inertial system to interpolate data between the 1-second GPS updates it was essentially that conditions of extreme turbulence were avoided. Initial acquisition was completed between the 22nd June 2000 and the 9th July 2000. Initial processing of LIDAR data to raw x,y,z format was completed by 14th August 2000. Of this data a portion had to be reprocessed several times. The last reprocessed dataset was received on the 9th December 2000.

1.6 OVERVIEW OF LIDAR TECHNOLOGY

Light Detection and Ranging (LIDAR) technology is an ongoing development of airborne laser mapping technology that has been developed commercially since the early 1980's. The system consists of a GPS Component, Inertial Component and Laser Component. Highly precise Post processed Airborne Kinematic positioning is combined with inertial positioning and laser ranging are combined to derive a 3-D position of all surface features.

The light source is generated in a control module and fed to the sensor head by means of fiber-optic transmission. A rotating mirror reflects this energy and directs it down to the ground. The frequency of this transmission and the angle under the aircraft can be adjusted for optimal acquisition. Returned energy from the laser transmissions is registered by an optical sensor co-located with the transmission module of the sensor. A two way travel time from the pulse transmission to its reception is measured. Additionally, the amount of returned energy is also measured and recorded as a reflectance value.

During the acquisition phase, airborne differential GPS is used in order to fly the aircraft along pre-programmed flight lines. Distances along and offline, as well as altitude, are displayed in the flight navigation system and corrections are made so as to ensure collection of data in accordance with pre-determined parameters. During the acquisition phase GPS ground base stations are established and raw GPS phase measurements are recorded. The Ground GPS receivers used for this project were dual frequency Trimble 4000 Ssi's. Data recording was set at 1 second. In the aircraft a Novatel Millennium Dual Frequency airborne GPS receiver also records measurements at a 1-second interval. All recorded measurements are synchronized by the use of the GPS 1PPS signal. Post mission a highly accurate GPS position is calculated on a 1-second interval.

Simultaneous, to the measurement of Laser and GPS information, three-dimensional measurements are recorded via an onboard inertial measurement unit. These measurements are typically recorded at 50 Hz. By combining these inertial measurements, the calculated GPS position, Mirror Angle, Time of travel and onboard system offsets an accurate 3D position is calculated.

The system offers a large number of user configurable parameters that can be adjusted pre mission or in flight so as to ensure collection of data in accordance with the survey acquisition parameters. The parameters include:-

- Flying Altitude
- Flying Speed
- Mirror Scan Angle
- Mirror Scan Rate
- Laser Pulse Rate

By adjusting any of these parameters the density of point survey on the ground can be manipulated so as to derive data at the required target point density.

The laser recording system is configured so as to enable the capture of both first and last return range and intensity data. The diagram below shows how this is applied so as to generate information for "bare earth" BEDEM data and also first return surface structures, which would include top of canopy, buildings and other structures.

1.7 THE OPTECH ALTM 1225

AGII utilized the Optech 1225 system owned and operated by Airborne 1 Corporation Inc, for the purpose of data capture. The key system characteristics are as follows:

- Operational Altitude 2000 m.
- First and Last Return data capture
- Dual Frequency Novatel Millennium GPS Receiver
- 25 kHz laser pulse frequency
- Litton Inertial Navigation System

The captured data is then processed to raw mass point files. Data delivered to AGII was in the 9-column "Calibration Format". This data format is as follows:

Column 1 GPS Time
Column 2 Last Return x
Column 3 Last Return y
Column 4 Last Return z
Column 5 First Return x
Column 6 First Return y
Column 7 First Return z
Column 8 Last Return Intensity
Column 9 First Return Intensity

1.8 TERRASCAN POST PROCESSING SYSTEM

TerraScan Post Processing Software™ is developed by TerraSolid of Finland and is part of an integrated product range that includes software for Terrain Modeling and Feature Extraction. AGII utilized the TerraScan software during the processing of Cerro Grande Dataset.

TerraScan software is designed to be able to perform the following functions:-

- Filtering of Erroneous points
- Classification of most likely ground points
- Classification of additional classes based upon the most likely ground classification
- Further filtering to generate Modal Keypoints (This is the minimum point density to preserve grid integrity given a stated accuracy objective of x ft)

Once the data had been filtered using TerraScan then various surface models were generated. The TerraModeler software developed by TerraSolid utilizes a Triangulation based algorithm for the generation of grid data.
This software module was used for the generation of the following DEM data sets:-

All Low Resolution Datasets
High Resolution Canopy
High Resolution Reflectance

Due to the nature of the terrain in this area the product generated for the High Resolution ground using simple triangulation was considered to be too coarse. Therefore for the purpose of the Terrain generation of this dataset another software DrDTM was utilized.
The datasets were gridded using an Iterative Least Curvature Gridding Method. This produced a dataset that better preserved the inherent integrity of the filtered ground points.

1.9 ARCVIEW PROCESSES

TerraModeler has the ability to generate an Arc ASCII Grid file. These files were generated using this software. Where the grid was generated from DrDTM then the grid data files were fed back into TerraModeler as raw datafiles and the Arc ASCII files generated in this manner.

AGII utilized ArcView 3.2 with the 3D-Analyst extension. Utilizing this software the ASCII files were then converted to the required Arc Binary Format. The files generated were then reviewed in 3D Analyst extension for completeness and data coverage.

2. Field and Office Procedures

2.1 Introduction.

This section describes the various field and office procedures that were established in order to ensure acquisition and processing to meet client requirements.

2.2 FIELD PROCEDURES

2.2.1 System Calibration.

AGII arranged for a system calibration to be conducted in Los Angeles prior to the mobilization of the system to Los Alamos. The system was mounted in Partenavia P-60 Observer owned by Aspen Helicopters from Oxnard California. This was a new platform for the mounting of Airborne 1's Optech 1225 System and Calibration and offset measurement was therefore essential to the integrity of the survey. AGII paid for three days of installation and calibration of the system prior to mobilization to the Cerro Grande Project. This calibration was conducted over the Clay Lacy Hanger in Riverside, North LA. This site was selected as it was an area that had been extensively surveyed by Airborne 1. The results of this initial calibration are held by Airborne 1.

Following demobilization from the project Airborne 1 requested that the system and aircraft be held on retainer by AGII so that additional post project calibration be conducted. This calibration was required so as to enhance the accuracy of the data collected by Airborne 1. AGII so agreed and a post project calibration was conducted. The details of this calibration are retained by Airborne 1.

2.2.2 Geodetic Base Station Observation.

AGII sent a survey crew to Los Alamos to occupy pre surveyed base stations. This primary network was controlled from an order B control point located at Santa Fe Airport. This network was established and tied into the existing Control Network at the Cerro Grande site. More details of this are contained in section 3.1.

Observations at the base stations were made using Trimble 4000 Ssi receivers. Standard survey quality control procedures were followed when setting up the base station receivers. These included the following:

- Optical centering of Tribrach's over control point
- Double Measurement of height of antenna above the control point using both feet and meters.
- Ensuring that no objects were within the field of view that could contribute to multi-path generation.
- All receivers were set up so as to log 1-second data with an elevation mask of 10 degrees and a PDOP mask of 7.

2.2.3 LIDAR Data Capture.

In order for the capture of the highest quality LIDAR data it was essential that all missions be flown during the best quality GPS conditions. Ideally, the data should be acquired during PDOP conditions less than 3 and in excess of 6 satellites visible. On a daily basis AGII downloaded an updated GPS Almanac and generated a GPS quality report showing SV's and PDOP. This report was provided on a daily basis to Airborne 1 and was used as the basis for the acquisition windows that were flown.

Preprogrammed flight lines were entered into the flight navigation system based upon an initial flight plan submitted to Airborne 1 by AGII. Due to the nature of the terrain, several of these flight lines had to be modified by Airborne 1 in order to ensure complete coverage an overlap in areas of rapidly changing terrain.

Prior to the commencement of flight operations a system check , GPS initialization and INS initialization were conducted. This was conducted in order to stabilize both GPS and inertial measurements prior to the aircraft and system being used in dynamic mode. The procedure consisted of initializing all systems and then leaving the aircraft in a static location for a period of approximately 10 minutes. This procedure was repeated at the end of each flight mission.

Where possible, AGII also requested that Airborne 1 over-fly the Los Alamos Runway prior to commencement of acquisition operations. This procedure was implemented in order to ensure that any gross blunder such as incorrect input of system offsets could be quickly identified at the processing stage.

2.3 Office Procedures

All initial processing of data to mass point cloud format was conducted by Airborne 1 utilizing proprietary Optech processing software. At the request of AGII this data was transmitted to AGII in the Optech Calibration format that consisted of the 9-column format described earlier. The data for each flight day typically consisted of 25 GB of processed data. Due to the volume of data transmission of processed data to AGII was on 40GB Hard Drive media.

2.3.1 Data Splitting

On receipt of the data the initial task was to parse the data in first and last return components. In order to achieve this AGII utilized in-house developed software called Splitter. Raw 9 column data was used as the base file and the program scanned the dataset and extracted information on both the First and Last Pulse data. It then output two separate files for each of these datasets. Raw data was received in UTM 13 coordinate system referenced to NAVD88. Following the data splitting all files were converted to the required client datum of New Mexico Central State Plane using NVGD27.

2.3.2 Initial Review

Following data splitting and conversion the data sets were fed into the TerraScan software. Initial data quality review was conducted to see if any gross errors existed in the data sets.

Of the data sets reviewed all initial submissions were returned to A1 for reprocessing due to various errors which were identified. A number of the sets were returned several times. Identified errors included:-

- Data sets Decimated during processing.
- Data sets which were generated using incorrect offsets
- Data sets which were submitted using only partial files from the flight day.

2.3.3 Data Filtering

Raw LIDAR data consists of a mass point cloud that includes all returns which are received from targets. The Optech ALTM 1225 is able to capture both first and last return data. By definition the Last Return data is the data set that contains the maximum likelihood of containing ground points. Data Post Processing and classification was conducted utilizing TerraScan Post Processing Software. This software was modified by TerraSolid at the request of AGII in order to include a project processing option. This option allowed the data set to be divided into predefined blocks with overlaps. Processing Macros were then defined and the data sets could be processed in batch mode. This modification was necessary because the post processing software conducts the majority of data processing in RAM. AGII was utilizing machines with a minimum of 768 Megs of RAM and several with 1 GB of RAM. This amount of RAM meant that upto 32 million data points could be loaded into RAM and processed.

In order to determine ground from non-ground points the software uses the following methodology:

1. Data Sets are first scanned for erroneous points. These consist of points that are abnormally high or abnormally low or that are outliers that fall outside the survey area. Typical examples of these are points that are reflected back by objects in the air such as birds. Typically this would be less than 0.01% of points in the data set but it is critical to remove these points prior to proceeding.

2. Once erroneous points have been removed then the next stage is to specify a building gate. This is a block area in the data set specified in terms of x meters. The software then divides the data set into this block area structure and scans through the data set to find a maximum likely ground point to begin constructing the model from. The size selection of this window is critical; too small an area will result in item such as building roofs or vegetation being selected as a base for the surface generation.

3. The next parameters that the software considers are the base terrain conditions. Prior to the commencement of ground generation the user will specify the following parameters:

a. Maximum Terrain Angle
b. Iteration Distance
c. Iteration Angle

Using these parameters the software will then classify a most likely surface by triangulating the mass data points. This results in an initial ground classification, satisfying the criteria specified. In areas of rapidly changing terrain and vegetation/building cover the classification can miss out points that should be included with the ground. For this reason additional manual review and processing is required.

4. Additional manual processing can be achieved in two ways. Firstly the user can choose block of defined areas by means of a fence within the MicroStation Software. The processing parameters can then be modified and either the whole area reprocessed or additional points added to ground by adding points to ground that fulfill the modified processing parameters. Individual points can also be selected and reclassified in or out of ground.

5. The manual review process was significantly enhanced by the provision by Merrick & Company of the OrthoRectified Image data sets.

   Due to the nature of the terrain in the survey area a large amount of experimentation was required in order to derive the optimal processing parameters. The final parameters utilized a three-stage process.

   a) Derivation of an initial coarse ground. This meant that certain canyon tops and other steep features were over filtered and removed.
   b) Reprocessing based upon this initial ground based upon significantly higher terrain angles. This meant that areas such as canyon walls etc were included.
   c) Manual Editing and review.

2.3.4 DEM Generation

Elevation grid sets were generated using the TerraModeller Software from TerraSolid. This software is able to grid large data sets utilizing a Triangulation methodology. Additionally the software is able to convert and output an ArcGrid ASCII File. This methodology was found to be suitable for all data sets except the high-resolution ground. Because of the need for the highest possible accuracy and preservation of feature integrity in the absence of breaklines it was necessary to use a slightly different grid method.

In order to achieve the above the datasets were processed using DrDTM which allowed for grid generation based upon a best fit Minimum Curvature methodology. This method significantly enhanced the data resolution and reduced the terrain roughness.

Datasets were then tiled in the client-required scheme.

2.3.5 ARC Generation

Following the generation of the Grid Data sets, TerraModeller was used to export the data in an ARC Grid ASCII Format. These data sets were then fed into 3D Analyst extension running on ArcView 3.2. The final stage was to export the data sets as ARC Grid Binary Files and associated headers.

2.3.6 QA/QC

Data Quality Control was conducted in the following manner.

- At all stages of the processing the points were reviewed by means of elevation coloring to identify outliers or erroneous inclusion of data such as buildings etc.
- Following Tile generation and gridding data sets were fed into 3-D Analyst and manually reviewed in two and three dimensions for integrity.
- Data sets were overlaid with the OrthoRectified Imagery to identify erroneous points
- A significant network of control points was established on the Cerro Grande project by the Merrick and AGII Survey teams. The coordinates of these points were compared to the reduced ground and grid data sets at various stages of the processing.

APPENDIX IV

Summary of Observations For Each Tile in the High-Resolution (1 foot) DEM

Appendix IV.

Summary of Observations For Each Tile in the High-Resolution (1 foot) DEM

Explanation:

The tiles were examined in shaded relief and, where available, difference maps were constructed with the 1992 DEM.

Key to Table:

Building Artifacts	Incomplete or inappropriate filtering of ALSM data from buildings creates bumps in the DEM
Mounds or other Artifacts	Incomplete or inappropriate filtering of ALSM data from vegetation creates bumps in the DEM
Flight line	Slight elevation differences between overlapping ALSM flight lines creates a step in the DEM with differing elevations and/or differing ground texture on either side of the line
Infill cliff faces	Areas lacking ALSM data are "infilled" with extrapolated elevations; especially common along
High/Low	Tiles that differ by > 1' in average elevation from the 1992 DEM
Pit	Pits are sharp depressions in the DEM, generally caused by multipath reflections of ALSM data (for example, reflections off windows) that are most commonly observed near buildings
Dimple and Pimple	A data processing artifacts that creates small raised mounds in some part of the tile and small depressions in other parts
Jigsaw	Two tiles have integer values for elevations, which creates step-like changes in elevation
Striping	ALSM data from overlapping flight lines can create undulating variations in topography
Comments	Miscellaneous comments on features observed in the tiles

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
728639				I						Linear infill zone (50x600'); partial tile
730636				I						Infill along canyon edge; partial tile
726639										Partial tile
728636		A	F							Partial tile
728642										Partial tile
730633										Partial tile
730639										OK
730642				I						Infill along sinuous elongated topographic breaks; partial tile
730645			F							
732633		A	F							Zone of mound artifacts
732636		A	F	I					S	Infill zones along canyon edge
732639										OK
732642				I						Small infill zones along topographic breaks
732645										OK
732648				I						Infill along linear topographic break
734633										OK
734636				I					S	
734639				I					S	Infill, 25x700'
734642										OK
734645										OK
734648				I						Infill along ridges
734651				I						Infill in linear zones; partial tile
736630										Partial tile
736633				I						Infill in round area and along topographic breaks; partial tile
736636		A		I	H					Infill on mesa nose, 30x30, uniformly high relative to 1992 DE, 1.33'
736639					H					Uniformly high relative to 1992 DEM, 1.43'

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
736642			F							
736645				I						Bands of infill along ledges, one large infill on east side, 500x500'
736648				I						Infill, 300x300' at east end
736651				I						Infill in linear areas along topographic break; partial tile
736654			F	I						Large amount of infill along linear topographic break
738630			F							Partial tile
738633				I		P				Infill, 150x150' on cliff, divot-like 100' diameter pit
738636		A			H					Uniformly high relative to 1992 DEM, 1.27'. One artifact mound
738639			F		H					Very high relative to 1992 DEM, 2.21'
738642					L				S	Uniformly low relative to 1992 DEM, 1.86'
738645				I						Three large, 400x700', infill patches
738648										OK
738651										OK
738654		A	F	I						One very large infill along topographic break; mound artifacts
740627			F	I						Partial tile with edge of tile having infilled topography
740630										OK
740633										OK
740636						P				Pit associated with building
740639					H				S	Uniformly high, 1.83', relative to 1992 DEM
740642										OK
740645										Hillshade appears blurry, possibly overfiltered
740648										OK
740651				I						2 infill zones, 100x100'
740654		A								One large mound artifact; partial tile
740657		A	F							
742624										Partial tile
742627			F	I						Partial tile; infill along cliff edge

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
742630			F		H					Uniformly high relative to 1992 DEM, 1.20'
742633										OK
742636										OK
742639		A			H					Uniformly high, 2.00', relative to 1992 DEM; a couple of mound artifacts
742642			F		H					Uniformly high, 1.79', relative to 1992 DEM
742645										OK
742648										OK
742651										OK
742654				I						Large infill at river
742657			F	I						Conspicuous infill along canyon wall and topography break
744618										Abundant minor artifacts
744621				I						One small infill along canyon wall
744624					H					Possibly high relative to 1992 DEM
744627			F							
744630			F							Textural affect across flight line
744633			F							Textural affect across flight line
744636										OK
744639										OK
744642				I	H					Uniformly very high, 3.21', relative to 1992 DEM; infill patch 250x700'
744645				I						Infill along ridge, 50x250'
744648										OK
744651		A								Six mound artifacts
744654								J		Jigsaw texture (elevations only integer valued)
744657				I						One patch of infill along canyon wall
746612										minor flight line
746615										OK
746618				I						Large infill along canyon wall

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
746621				I	H					Infill on canyon edge; appears uniformly high on level ground, average 0.67' relative to 1992 DEM
746624										OK
746627			F		H					Uniformly high relative to 1992 DEM, 1.36'
746630										OK
746633			F							Textural change across flight line
746636					H					Uniformly high, 1.04', relative to 1992 DEM
746639										OK
746642					H					Uniformly high relative to 1992 DEM, 2.4'
746645										OK
746648		A								Scattered, minor artifact mounds
746651										OK
746654						P				One small pit
746657										Minor flight line
746660				I						Infill patch; minor flight line
748594							D			
748597		A		I						Several scattered largish mound artifacts; small infill zone on north edge
748600		A		I						Several scattered artifact mounds; infill along canyon walls
748603		A								Numerous large mound artifact zones
748606		A								Numerous large mound artifact zones
748609		A								Numerous large mound artifact zones
748612										Part of tile corner missing; rough texture
748615										Scattered minor mound artifacts
748618										OK
748621					H					Uniformly high relative to 1992 DEM, 1.64', but features suggest possible problem in 1992 data
748624										OK

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
748627					H					Uniformly high relative to 1992 DEM, 1.23'
748630			F		H				S	Uniformly high relative to 1992 DEM, 1.29'
748633										OK
748636					H					Uniformly high relative to 1992 DEM, 1.87'
748639										OK
748642			F							
748645				I	H					Uniformly high relative to 1992 DEM, 1.11'; very large infill, 200x1000'
748648	A									Several building artifacts
748651	A		F							Several building artifacts
748654										OK
748657										OK
748660		A	F							Partial tile (part of corner missing); scattered artifacts
748663			F	I						Infill along canyon edge
750588		A					D			Large artifact mound
750591							D			
750594							D			(Over filtered?)
750597		A								Rough textured
750600										OK
750603		A								Numerous, significant mound artifacts
750606		A								
750609		A								Several mound artifacts
750612		A								Minor small artifacts
750615				I						Large, round infill (150' diameter)
750618		A								About 10 scattered mound artifacts
750621					H					Uniformly high relative to 1992 DEM, 1.16'
750624										OK
750627					H					Uniformly high relative to 1992 DEM, 1.26'

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
750630					H					Uniformly high relative to 1992 DEM, 1.61'
750633										Texture change across flight line
750636					H					Uniformly high relative to 1992 DEM: 1.24 '
750639					H					Uniformly high relative to 1992 DEM: 1.34 feet
750642		A								Artifact ridge and other features along road
750645			F		H					Uniformly high relative to 1992 DEM: 1.63
750648	A									
750651	A		F			P				3 pits
750654	A					P				one pit
750657										OK
750660										OK
750663										OK
750666			F							
750669				I						Partial tile with edge infilled (elevation control appears sparse)
750672										Partial tile
752585							D			
752588							D			
752591		A					D			A few mound artifacts
752594		A					D			a few small mound artifacts
752597										OK
752600										OK
752603		A								A few artifacts; rough texture
752606		A								Mound artifacts are abundant
752609		A								Scattered mound artifacts
752612										OK
752615										Vertical offset of elevation, probably a 1992 DEM feature
752618		A								Around 30 mound artifacts

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
752621										OK
752624										OK
752627										OK
752630					H					Uniformly high relative to 1992 DEM: 1.45
752633										OK
752636			F							Minor flight line effect
752639										OK
752642										Good
752645			F							Otherwise OK
752648	A		F		H					Uniformly high relative to 1992 DEM: 1.76
752651	A	A				P				One large mound artifact; scattered building artifacts; several small pits
752654	A					P				Scattered building artifacts; several small pits
752657	A					P				Scattered building artifacts; several small pits
752660										OK
752663										OK
752666			F							
752669			F							
752672										Partial tile
754585							D			
754588		A					D			About 5, smallish, cone-shaped artifacts
754591		A					D			Numerous mound artifacts
754594		A					D			Numerous mound artifacts
754597		A								Several mound artifacts
754600		A								Several mound artifacts
754603		A								Several mound artifacts
754606		A								Numerous mound artifacts
754609										OK

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
754612										OK
754615										OK
754618		A								Large number of artifacts
754621	A									Poorly removed building
754624										OK
754627				I						Infill along southern edge
754630					H					
754633			F							Minor flight line
754636										OK
754639										OK
754642										OK
754645		A								Several artifacts
754648	A	A			H					Very high relative to 1992, incomplete building removal, lots of mound artifacts
754651										OK
754654			F			P				2 pits
754657										Minor small divot artifacts
754660		A				P				1 pit; several small artifacts
754663										OK
754666			F							Tinned and over filtered
754669										OK
754672										Partial tile
756585							D			
756588							D			
756591		A					D			Several, diffuse mound artifacts
756594		A					D			Several mound artifacts
756597		A								Several mound artifacts; hash textured
756600		A								Several mound artifacts

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
756603		A								Several mound artifacts
756606										OK
756609										OK, with some textured zones
756612		A								Scattered artifact mounds
756615				I						Large infill zone
756618										OK
756621										Linear depressions (trenches?) in image
756624										OK
756627										OK
756630										OK
756633	A		F							Minor building and flight line affects
756636			F							Minor flight line, some textural affects
756639		A	F		H					Textural change across tile, linear artifact traces
756642										OK
756645			F	I		P				Small infill zone, a few pits
756648	A	A			H					Building artifact (?), lumps in stream channel
756651										OK
756654										One small artifact
756657		A							S	
756660		A		I						Infill along ridge; tinned appearance (sparse data control?)
756663										Looks tinned (sparse data control?)
756666			F							Looks tinned (sparse data control?)
756669			F							
756672			F							
758582										Rough textured
758585							D			
758588							D			

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
758591		A					D			Several smooth low mound artifacts
758594							D			
758597		A	F							Texture change across flight line; several mound artifacts
758600										OK
758603										OK
758606		A	F							Numerous mound artifacts
758609		A	F							Regularly distributed mound artifacts
758612										OK
758615										OK
758618	A									Building or possibly mound artifacts
758621										OK
758624										OK
758627										OK
758630				I						Huge infill zone
758633										OK
758636		A	F							Several small mound artifacts
758639			F							Flight line with texture changes
758642			F							Flight line with texture changes
758645					H					Slightly higher than 1992
758648										OK
758651										OK
758654										OK
758657		A								Hash and tinned textured (sparse data control?)
758660		A							S	Very rough texture
758663			F							Has a heavily tinned appearance (sparse data?)
758666			F							Heavily tinned appearance (sparse data?)
758669			F							

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
758672										Rough texture
760582		A								Very rough texture
760585		A					D			Abundant mound artifacts
760588							D			
760591		A					D			Scattered low mound artifacts
760594		A					D			Faint dimple and pimple; scattered low mound artifacts
760597										OK
760600			F							Texture change across flight line
760603										OK
760606										OK
760609		A	F							Texture change across flight line, scattered mound artifacts
760612	A	A								Several building artifacts; one large and many small mound artifacts; hashing texture
760615										OK
760618										OK
760621		A								
760624										OK
760627		A								3 small minor artifacts
760630										Possibly uniformly high relative to 1992 DEM, but not clearly high
760633				I		P				Infill zones at buildings; a few shallow pits along road
760636				I		P				Infill zones on mesa edge; one pit
760639					H					Uniformly high relative to 1992 DEM: 1.3 feet
760642			F							
760645					H					Uniformly high relative to 1992 DEM: 1.3'
760648										OK
760651			F							Flight line texture change, but not large apparent elevation change, scattered small artifacts; slightly high relative to 1992

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
760654			F							Apparent significant offset on flight line
760657				F	L					Uniformly low, -1.1' relative to 1992
760660										OK
760663		A								Scattered, abundant small mound artifacts
760666										Appears to have poor data density
760669										Partial tile; rough texture
762582										Rough texture
762585		A					D			
762588							D			
762591		A					D			Several low mound artifacts
762594		A					D			Several low mound artifacts
762597										OK
762600		A	F							Texture change across flight line; a line of small angular artifacts
762603										Minor artifacts
762606						P				Single deep pit
762609	A									Poor filtering of buildings
762612	A					P				Poor building filters, one pit associated with building
762615										Slightly low relative to 1992, a few artifacts
762618										OK
762621										OK
762624				I		P				Infill could be a building footprint, one pit
762627					H					Uniformly high relative to 1992, 2'
762633										OK
762630										OK
762636										OK
762639			F	I	H					Infill on cliff face, uniformly high relative to 1992, 1.7'
762642			F							

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
762645				I						Infill patch on cliff face
762648		A		I						Infill on cliff face, artifacts in stream channel
762651										OK
762654			F		H					Uniformly high to west of flight line
762657										OK
762660			F						S	
762663									S	Rough texture
762666										Rough texture
762669										Partial tile
764582										Rough texture
764585		A					D			Scattered mound artifacts
764588							D			
764591							D			
764594							D			
764597		A								Scattered, sharp artifacts
764600			F							Texture change across flight line
764603		A								Numerous large mound artifacts
764606		A								
764609	A									
764612	A		F							
764615					L					Slightly low
764618			F							Texture change across flight line
764621						P				1 small pit, a few artifacts
764624										OK
764627										OK
764630										OK
764633						P				1 small pit, slightly high relative to 1992 DEM

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
764636										OK
764639										OK
764642			F							
764645			F							Texture change across flight line
764648										OK
764651										OK
764654					H					High relative to 1992 DEM
764657										OK
764660			F							minor mound artifacts
764663										OK
764666			F						S	
764669		A	F	I						Partial tile; infill on ridge; flight effects minor; several mound artifacts
766585										Rough texture
766588			F							
766591							D			
766594							D			
766597		A								Rough texture; some larger artifacts
766600										OK
766603										Appears heavily tinned (sparse data?)
766606		A								A dozen large mound artifacts
766609										OK
766612	A									
766615			F							
766618	A									
766621		A								
766624					L					Low relative to 1992 DEM, 1.5'
766627		A								

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
766630	A	A			H					High relative to 1992 DEM, 1.2'
766633					H					High relative to 1992 DEM, 1.17'
766636				I						Infill on mesa edges
766639										OK
766642		A	F							
766645		A	F							Texture change across flight line, 1 mound artifact
766648		A								
766651			F							
766654										OK
766657										OK
766660			F							
766663			F							
766666										OK
766669				I						Large band of infill
768585										OK
768588			F							
768591		A					D			A few artifact mounds
768594		A					D			
768597										OK
768600										OK
768603		A								Scattered large artifacts
768606		A								
768609	A									
768612										OK
768615	A	A		I						Large infill zone, building and mound artifacts
768618		A	F		L					
768621										OK

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
768624	A									
768627	A					P				Pits at building artifacts
768630							D			Strange dimple texture in one area
768633					H					Uniformly high relative to 1992 DEM, 1.3'
768636				I						Narrow oval of infill along ridge top (about 75 x 200)
768639		A								About 8 artifacts along road
768642										OK
768645										OK
768648										OK
768651										OK
768654			F							Texture change across flight line
768657				I						A couple of infills on mesa edges
768660				I						Infill on mesa edge
768663			F							
768666										OK
768669			F							
770588										Coarse, tinned appearance (sparse data?)
770591		A					D			Scattered, low mound artifacts
770594		A					D			Scattered low mound artifacts
770597		A								Rough texture
770600										Minor artifacts
770603		A								Linear distortion in DEM runs across entire tile
770606			F							
770609		A								3-4 artifact mounds
770612				I						Circular infill patch, 100' across
770615			F							
770618	A				L	P				Pits at building, uniformly low relative to 1992 DEM

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
770621	A	A								Artifacts near road and buildings
770624		A						J		Jigsaw-like layering, 10-12 mound artifacts
770627	A									
770630			F							Texture effects across flight lines
770633	A									Artifacts at complex building geometries
770636	A					P				Complex building geometries creates pits and artifacts
770639	A									Somewhat high, 0.38'
770642					H					Uniformly high relative to 1992 DEM, 1.75'
770645		A	F							
770648										OK
770651				I		P			S	Infill on canyon wall
770654										OK
770657		A								
770660			F							
770663			F							
770666										OK
770669										OK
770672				I						Infill along cliff edge
772591		A					D			Low mound artifacts
772594		A					D			Low mound artifacts
772597		A								Rough texture
772600										Rough texture
772603										OK
772606			F							Texture change across flight line; rough textured
772609		A								Bumpy artifact texture
772612		A								Several artifacts
772615	A	A				P				1 pit, mound artifacts

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
772618	A					P				Several pits associated with buildings
772621				I						Large infill, some 200' across
772624										OK
772627				I						Infill patch, 30x60'
772630		A								A few artifacts
772633				I						Infill on canyon edge 100x200'
772636				I		P				300x900 infill zone, another smaller infill, and a pit
772639										OK
772642				I						Narrow infill along canyon edge
772645			F		H					High relative to 1992 DEM, 2.0'
772648		A	F		H					Several artifacts, uniformly high relative to 1992 DEM, 1.84'
772651			F							Texture change across flight line
772654				I						Infill on cliffs and ridges
772657			F	I						Infill on ridge
772660		A								
772663			F							
772666			F							
772669										Rough texture
772672										OK
774591							D			
774594		A					D			
774597										Rough texture
774600		A								Rough texture
774603		A								Horizontal linear distortion in DEM
774606		A	F							Horizontal linear artifact across entire tile
774609			F							Texture change across flight line
774612		A							S	Faint striping, artifacts in stream channel

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
774615										OK
774618	A		F			P				Bad artifacts and pits associated with buildings
774621										OK
774624	A									Building infill are not flat, but scalloped
774627	A					P				Artifacts associated with building
774630		A				P				
774633										OK
774636				I						2 small infill zones on mesa edge, 30x60'
774639										OK
774642										OK
774645		A			H					Several artifacts, uniformly high relative to 1992, 2.2'
774648					H					Uniformly high, especially north half, relative to 1992 DEM, 1.2'
774651										OK
774654		A								Horizontal linear artifact across entire tile
774657										OK
774660			F							
774663			F							
774666			F	I						Texture change across flight line; Infill at mesa tip
774669		A								Large artifacts
774672			F	I		P				3 small pits; circular infill (100x100')
776591		A					D			Hash texture
776594		A					D			Hash texture
776597		A								
776600		A								
776603										
776606										OK
776609			F							Texture change across flight line

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
776612									S	
776615				I		P				Large, tinned infill; 1 pit associated with building
776618	A					P				3 pits and small artifacts associated with buildings
776621										Small pits and artifacts associated with buildings
776624	A			I		P				Several pit and building artifacts; 2 large buildings with poor infill texture
776627	A			I		P				Pit in road; infill and artifacts associated with building
776630	A					P				2 pits and building artifacts
776633				I						Significant infill on canyon sides
776636				I						Infill along canyon edge
776639		A								Mound artifacts on flood plain (possibly real)
776642										OK
776645					H					Uniformly high relative to 1992 DEM: 2.08'. Also rough texture
776648			F	I	H					Small infill zone; uniformly high relative to 1992 DEM: 1.24'
776651										OK
776654										OK
776657		A								
776660			F						S	
776663			F	I						Infill along cliff edge
776666		A								
776669										Partial tile
778591		A					D			
778594		A					D			
778597		A	F							Poor quality with numerous artifacts, hash texture
778600		A				P				One small pit
778603										OK
778606										OK
778609		A	F						S	Hash texture

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
778612										Unusual rill pattern (real?)
778615	A					P				Large pit; bad building artifacts
778618	A			I		P				Pits and building artifacts; infill at buildings and along canyon edges
778621	A					P				Pits and building artifacts
778624	A									
778627				I						Infill along canyon
778630	A					P				2 pits and building artifacts
778633			F	I		P			S	Massive pit; infill along canyon
778636			F							
778639		A								About 6 mound artifacts
778642				I						Ridge-line infill
778645					H					Uniformly high relative to 1992 DEM: 2.34'
778648			F		H					Uniformly high relative to 1992 DEM: 2.1 feet
778651			F							
778654			F							
778657			F							Minor flight line
778660				I						Missing data long cliff slope
778663									S	
778666			F	I					S	Infill on cliff edge
778669										Partial tile
780594		A					D			
780597		A	F							
780600		A								
780603		A		I						Horizontal linear artifact across entire tile
780606		A								Horizontal linear artifact across entire tile
780609										Some hash texture
780612		A	F							

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
780615				I						Infill along east edge of tile
780618				I						Infill on west edge; 400' diameter infill zone
780621	A									Abundant building artifacts
780624	A			I		P				Large pit; poor infill of building footprints;
780627		A		I		P				Big pit; 3-4 prominent artifacts; 2 infill zones on mesa edges
780630										OK
780633										OK
780636						P				2 pits
780639				I						Large (100x450) infill zone on mesa
780642				I						Small bit of infill on mesa finger
780645										OK
780648		A	F							Scattered mound artifacts
780651		A	F							Scattered mound artifacts
780654		A	F	I						Infill on ridges
780657										OK
780660				I						Infill (50x50')
780663		A	F						S	
782594		A					D			
782597		A								Poor quality, abundant artifacts
782600		A								Poor quality, abundant artifacts
782603						P			S	One deep pit
782606										OK
782609		A								Hash texture
782612		A								Very poor texture
782615										OK
782618	A									One building incompletely removed
782621		A								Scattered, abundant mound artifacts

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
782624			F							Texture change across flight line
782627				I						Small infill on end of mesa
782630	A					P				Small pits and building artifacts
782633				I		P				One large, two small pits; circular (150' diameter) infill
782636				I		P				One pit; one very small infill
782639										OK
782642				I						
782645										OK
782648		A								Abundant mound artifacts
782651		A	F							Scattered large artifacts
782654			F							Hash texture
782657				I						Infill on cliff edge; hash texture
782660		A								
784594		A								Vertical linear artifact across entire tile
784597		A								
784600		A		I						Large infill (150x150'); Hash texture
784603										OK
784606										OK
784609										Sparse artifacts
784612										OK
784615										OK
784618										OK
784621	A					P				One pit; several building artifacts
784624	A	A								Numerous building and mound artifacts
784627	A					P				One pit; several building artifacts
784630	A									Several large building artifacts
784633				I						Infill on mesa (100x200')

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
784636										OK
784639										OK
784642										OK
784645										OK
784648										OK
784651		A	F	I						
784654										OK
784657		A	F	I						
786594		A								Vertical linear feature across entire tile
786597		A								
786600		A								
786603		A								Linear feature across entire tile; several mound artifacts
786606		A								Linear feature across entire tile
786609		A		I						Infill (50x50'); Hash texture
786612										Hash texture
786615		A							S	Hash texture
786618					L					Uniformly low relative to 1992 DEM: 2.37'
786621										Rather rough texture (possibly poorly filtered)
786624										Rough texture
786627		A								15 mound artifacts
786630										OK
786633										N-S elevation difference with 1992 DEM (problem with 1992 DEM?)
786636										OK
786639				I						2 ridge infill zones
786642				I						Several infill patches
786645										OK
786648										OK

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
786651		A								
786654		A							S	
786657		A								Partial tile
788594		A								
788597										OK
788600		A								
788603		A	F							
788606		A								
788609									S	
788612										OK
788615		A	F							Hash texture
788618		A	F							
788621		A								
788624										OK
788627		A								Couple of mound artifacts; rough texture
788630										Rough texture
788633										N-S elevation difference with 1992 survey (problem with 1992 DEM?)
788636										OK
788639										1992 DEM appears to have problems
788642				I						Infill (100x50')
788645										OK
788648										OK
788651										Partial tile
788654										Partial tile
790594										Partial tile
790597		A								One large artifact
790600		A								Very bumpy appearance

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
790603		A		I					S	Infill (75x75')
790606		A								Abundant artifacts
790609		A								
790612										OK
790615									S	
790618		A	F							Hash texture
790621										OK
790624		A							S	
790627		A							S	Abundant artifacts
790630		A								Minor artifacts
790633		A								
790636										OK
790639										OK
790642				I						Infill on ridge (50x100')
790645										OK
790648									S	Some striping
792597		A								
792600		A								
792603		A								
792606		A								Numerous artifacts
792609		A								
792612		A							S	
792615										OK
792618		A								
792621		A				P				Deep pit; linear mound artifacts
792624		A								
792627		A							S	

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
792630		A		I						Large infill regions on cliff edges
792633		A								Hash texture
792636		A	F							
792639										OK
792642		A								
792645		A								Minor artifacts
794594										Partial tile
794597		A								
794600		A								
794603		A								
794606		A							S	
794609		A								
794612		A								Abundant bad artifacts
794615		A								Abundant large mound artifacts
794618		A								
794621		A	F							
794624										OK
794627		A								
794630		A	F							Bad hash texture
794633			F							Hash texture
794636		A	F							
794639		A		I						Infill on mesa finger
794642										OK
796594		A								Partial tile
796597		A	F							
796600		A		I						
796603		A							S	

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
796606		A							S	
796609		A								
796612		A								
796615		A								
796618		A								
796621		A								Abundant mound artifacts
796624		A								
796627		A	F							Texture change across flight line
798594		A	F							Partial tile
798597		A		I						
798600		A								
798603		A							S	
798606		A	F							Hash texture
798609		A	F							Texture change across flight line; hash texture.
798612		A								
798615		A				P			S	One deep pit
798618		A								Partial tile
798621		A								Minor striping;
800591										Partial tile
800594		A	F							Partial tile
800597		A		I						Numerous tree artifacts; infill on cliff edge
800600		A								Numerous mound artifacts
800603		A							S	
800606		A							S	
800609		A								Numerous mound artifacts
800612									S	
800615		A							S	

Tile	Building Artifacts	Mounds or other Artifacts	Flight line	Infill	High/Low	Pit	Dimple and Pimple	Jigsaw	Striping	Comments
800618		A								
802591			F							Partial tile
802594										Partial tile
802597				I						Partial tile
802600										Partial tile
802606		A								Partial tile
802609		A	F							Partial tile; many mound artifacts
802612			F							
802615		A							S	Partial
804609		A							S	Partial tile
804612		A	F						S	Partial tile; textural change across flight line
804615										Partial tile

APPENDIX V

Merrick & Co. Conventional Survey Report for Cerro Grande Wildfire LIDAR Project Los Alamos, New Mexico

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Merrick & Co. Conventional Survey Report for
Cerro Grande Wildfire LIDAR Project
Los Alamos, New Mexico

INTRODUCTION

The Cerro Grande Wildfire and digital ortho project began in June of 2000 in order to support the planning of erosion that may evolve as a result of the wildfire. The database created consisted of aerial photography, (Light Detection and Ranging), natural color digital ortho imagery and GPS control. In order to validate the positional accuracy of these databases Merrick deployed conventional survey methods to check on the results of the different types of mapping methods. This report summarizes the sample locations of the conventional survey. It also, highlights the general procedure and equipment used during the ground survey. Please note, this report does not attempt to quantify the accuracy of the databases created for the Cerro Grande Wildfire.

LOCATIONS OF THE CONVENTIONAL SURVEY AREAS

The conventional ground survey checks were performed at strategic locations within the High Resolution project area. One of Merrick's objectives was to perform the conventional survey in areas where the may have difficulty penetrating the vegetation canopy. These were in areas of deep canyons with tree cover and steep slopes.

Three cross sectional areas were established in Los Alamos Canyon and two cross sectional areas were established in Guaje Canyon. The three cross section areas in Los Alamos Canyon were approximately 1.5 miles apart.

SURVEY EQUIPMENT

Cross sections and spot check points were established and surveyed using conventional survey methods utilizing a Sokkia Set5A Electronic Total Station (angle measurement accuracy = 5", distance measuring range = 2,200 meters, distance accuracy = +/-(3+2ppm x D)mm).
Trimble 4700 GPS receivers were used to survey the "accurate GPS points".

The Trimble 4700 GPS receiver is a dual frequency L1/L2 full cycle carrier phase receiver with an accuracy specification of 5 millimeters + 1 ppm for the horizontal and 10 millimeters + 1 ppm for the vertical in the Post processed Static mode of operation.

CONVENTIONAL SURVEY METHODS IN LOS ALAMOS CANYON

In Los Alamos Canyon three accurate static GPS control points were set at the areas to be analyzed (GPS points 240, 245, and 246). Two of the accurate static GPS control points were established close to the westerly cross section areas and one accurate GPS point was established at the easterly cross sectional area of Los Alamos Canyon.

These points are part of the Los Alamos National Laboratory ground control network (photo identifiable points). The horizontal accuracy of these GPS points is better than 2nd Order Class 1 and in reality they obtain better than 1st Order when using Geometric relative positioning accuracy standards that relate to the main ground control base station. Points 240, 245 and 246 all fall within three miles of the main ground control base station. Therefore using the relative accuracy specifications and recommended static GPS procedures these points should have less than 0.1 foot (one tenth of a foot) of error both horizontally and vertically.

Using conventional survey methods, a traverse, with 8 legs, was run, from the two westerly GPS points, down the Canyon for approximately 1.5 miles and checked into the accurate static GPS point located at the easterly cross sectional area. The conventional survey traverse checked both horizontally and vertically to within 0.1 foot (one tenth of a foot). This confirmed that the values on the GPS points were good and verified that the conventional survey traverse was good and matched the static GPS coordinate values. A conventional topographic survey was performed on the three areas in Los Alamos Canyon. Ground break points (tow of slope) and areas in the trees were of special interest. The conventional survey was done keeping short distances, accurate vertical angles and checking rod heights to maintain good horizontal positions and elevations. A topographical survey was done on the two westerly areas and the easterly area. These three areas in Los Alamos Canyon could now be compared with the results from the aerial photography and the results from the surveys.

CONVENTIONAL SURVEY METHODS IN GUAJE CANYON

Two accurate static GPS control points were also established in Guaje Canyon (Points 248 and 249). Points 248 and 249 fall within five miles of the main base station. Therefore, using the relative accuracy specifications and recommended static GPS procedures these points should have less than 0.1 foot (one tenth of a foot) of error horizontally and less than 0.2 feet (two tenth of a foot) vertically. A conventional type survey utilizing the Sokkia Set 5A Electronic Total Station (theodolite with electronic measuring system) was the survey equipment used to traverse between these two GPS points. The traverse had 4 legs between the two GPS points and the coordinates from the conventional survey traverse checked the GPS points also within 0.1 foot (one tenth of a foot) both horizontally and vertically. A cross section, perpendicular to the canyon, and feature point locations were surveyed, keeping distances relatively short (250 feet or less) and accurate horizontal and vertical angles were maintained to establish accurate positions and elevation values on the ground break points and features for comparisons with the results from the other methods (aerial photography and).

STAFF AND DATE OF CONVENTIONAL SURVEY

The conventional survey was performed by Roger Childs, a 20-year surveyor, and 17-year employee of Merrick & Company. Vertical target height measurements were made and checked by the survey Party Chief (Roger Childs). Conventional survey field observations were made on June 21, Through June 26, 2000.