APPENDIX A

Lidar and Orthophoto Positional Accuracy Results

LIDAR AND ORTHOPHOTO POSITIONAL ACCURACY RESULTS

INTRODUCTION

Verification of the positional accuracy of lidar and orthophoto data was a key performance metric for the demonstration. To be useful in Wide Area Assessment, lidar and orthophotos must have positional accuracies that allow integration with other spatial data sets. Lidar and orthophotos must allow for meaningful measurement of object sizes in order to make conclusions about historic munitions use. The data must be sufficiently accurate to allow field verification of their results. Quality Assurance/Quality Control (QA/QC) methods for lidar and orthophotos have been well established, and standard methods were applied at both sites. At both sites, primary performance metrics for both technologies were met.

DISCUSSION

In the Demonstration Plan, performance specifications are established in Table 4-2, Performance Confirmation Methods, and Section 4.3, Data Analysis, Interpretation and Evaluation. Positional confirmation was accomplished through comparison of lidar and orthophoto positions to surveyed control points, vertical control structures, and comparison of lidar and orthophoto positions to each other.

RESULTS

Surveyed Control Points

Surveyed control points formed the basis for analysis of positional accuracy. At the Kirtland site, ESTCP established five control points on the site; TRSI established four additional control points and independently occupied two of the ESTCP control points. Both control point sets were referenced to NGS Q424, the local High Accuracy Reference Network (HARN) point, located approximately 6 km south of the study area.

At the Victorville site, TRSI established eight survey control points on the site. These were independently occupied by ESTCP. Control point locations and typical control points are shown in Section 3.4, and are available in the project QAQC reports.

Lidar vertical accuracies – Control points

Comparisons were made between the elevations of the control points and the lidar points, by comparing the surveyed elevations to the elevation of the modeled lidar surface at that point. All values were within the target accuracy of +/- 0.150 meters. Values for the Kirtland site were

calculated using both ESTCP and TRSI control point values. Values shown in the chart below were calculated using both sets of survey values. At the Victorville site, the ESTCP values were not used to calculate positional accuracies. This was because the TRSI and ESTCP surveyors had a vertical discrepancy in their surveyed values for the control points of approximately 1 meter (across all points) which could not be resolved. This discrepancy was probably the result of differences in survey datums used. All values were within the specified accuracy standard. At the Kirtland site, results followed the general industry expectation that lidar data flown at lower elevations will be more accurate than at higher elevations, however the correlation was not strong, and at the Victorville site the accuracy at the two elevations flown was essentially equivalent.

Kirtland

	Lowest Dz (m)	**Highest Dz (m)**	**Mean Dz (m)**
900 m flight	0.002	0.333	0.107
450 m flight	0.043	0.197	0.113
300 m flight 1	0.011	0.227	0.082
300 m flight 2	0.012	0.217	0.087

Victorville

	Lowest Dz (m)	**Highest Dz (m)**	**Mean Dz (m)**
300 m flight	0.021	0.333	0.107
450 m flight	0.021	0.197	0.113

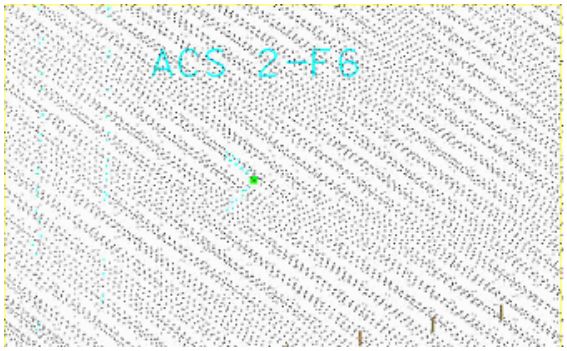
Lidar Horizontal Accuracy

The horizontal accuracy of the lidar data was evaluated by comparison with the control points. The method was slightly different at the two sites. At the Kirtland site, the control point positions were inferred from the lidar data by using the intensity value of the lidar returns. Intensity is the measured value of the strength of the lidar return signal, and this value varies directly with the reflectivity of the surface. Lidar points that returned from the white targets were distinguishable from those that reflected from the darker colored ground surface. These points were used to infer the position of the intersection of the two target legs, which was the location of the control point. This location was then compared to the surveyed location of the measured control point.

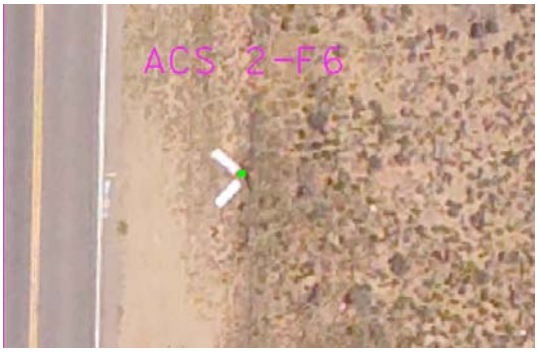
At the Victorville site, the lidar points reflected (by chance) from the antenna of the GPS base station at one control point, giving an excellent location for the control point. This location was used for the comparison and inference of the other control points was not needed.

The method is illustrated below.

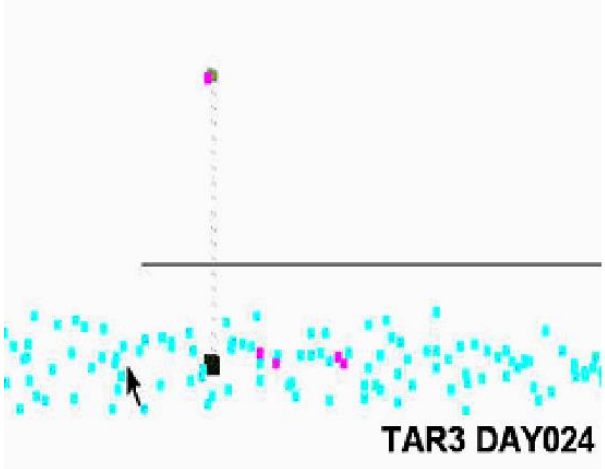
Figure A-1
Method for Evaluating Lidar Horizontal Accuracy



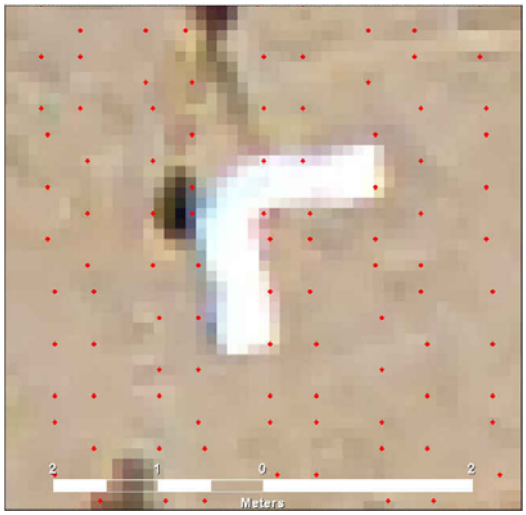
Lidar points classified by intensity, blue points are reflections from the target legs. Kirtland



Orthophoto image with lidar-derived point added.



Profile view of lidar points showing reflection from the antenna of the GPS base station and the fiberglass target legs.



Orthophoto view of the target showing the same lidar points.

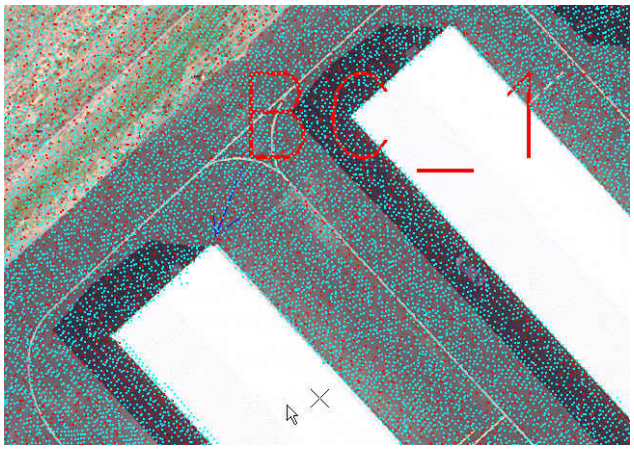
At the Kirtland site, the average x and y displacement (dx and dy) for all targets were both 0.08 m. At the Victorville site, the average x and y displacements were 0.03 m and 0.08 m for 300 m lidar flight and 0.06 m and -0.03 m for the 450 m flight. All values are well within the 0.65 m horizontal accuracy specification.

Lidar to Orthophoto Positional Alignment

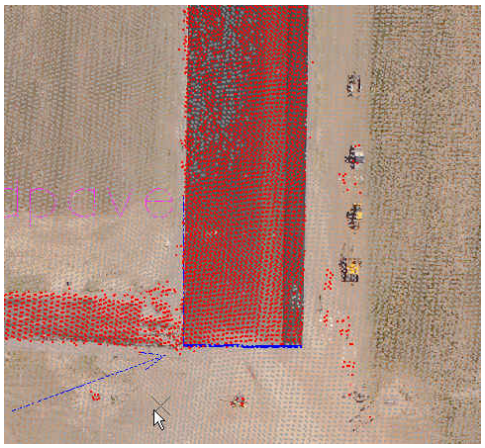
Lidar to orthophoto positional alignment was evaluated by comparing the locations of features with hard edges such as buildings and pavement in the lidar and orthophoto images. The edges of buildings and pavement were located visually on the orthophotos. In the lidar data, building

edges were located by examining the elevation values of the returns, and edges of pavement were located using the intensity values. The process is illustrated in the figures below:

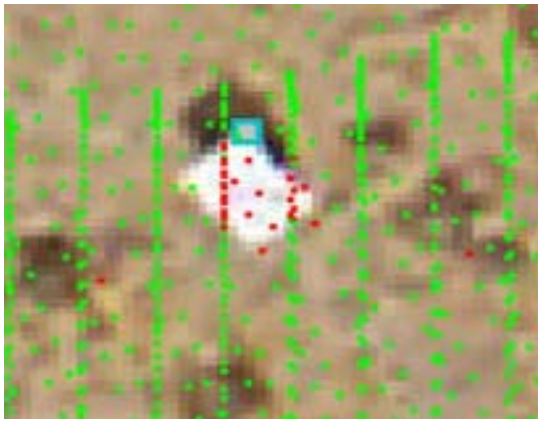
Figure A-2
Method for Evaluating Lidar Positional Alignment



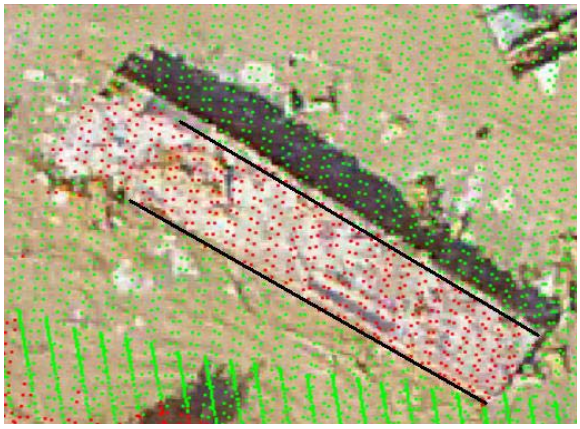
Kirtland site, Double Eagle Airport. Buildings in lidar are identified by elevation values of the lidar returns.



Kirtland site, Double Eagle Airport Runway. Pavement edges in lidar are identified by intensity value.



Victorville site, vertical control structure, lidar points classified by elevation.



Victorville site, old RV, lidar points classified by elevation.

At the Victorville site, this calculation was more difficult, since the site did not contain buildings or paved roads. The vertical control structures and an abandoned RV were examined. Results from this comparison are considered less reliable than for the Kirtland site. This is due partially to the fact that the vertical control structures are too small to reliably derive a corner location from the lidar data alone. (The example shown is the best case).

Results are shown for the two sites:

	Specification (m)	Average Dx (m)	Average Dy (m)
Kirtland 20 cm pixels	0.40	0.167	0.360
Kirtland 10 cm pixels	0.20	0.137	0.167
Victorville 10 cm pixels	0.20	0.10	0.10

Orthophoto Positional Accuracy

Orthophoto horizontal accuracy was evaluated by deriving the location of the surveyed control points in the orthophoto images, and then comparing these to their surveyed locations. The method is illustrated in the figure below.

Figure A-3
Orthophoto Comparison to Control Points

The red star represents the control point location in the orthophoto; the blue star is its surveyed location. The points are approximately 1 pixel width (10 cm) apart.

The established accuracy specification was 2 pixel widths; all orthophoto data met this specification, as shown below.

	Specification (m)	Maximum offset (m)	Mean offset (m)
Kirtland 20 cm pixels	0.60	0.561	0.210
Kirtland 10 cm pixels	0.30	0.279	0.146
Victorville 10 cm pixels	0.30	0.143	0.072

CONCLUSIONS

Lidar and orthophoto data at both sites met the established positional accuracy specifications.

APPENDIX B

Combining Lidar Data from Multiple Flights

COMBINING LIDAR DATA FROM MULTIPLE FLIGHTS

INTRODUCTION

When lidar data from different flights at the Kirtland site was combined, the resulting surface models showed serious degradation. Features that were clearly shown in the data from individual flights were obscured in the combined data. This effect was particularly pronounced when flights from different altitudes were combined. The cause of this effect has implications for the acquisition of lidar data, including appropriate contract specifications.

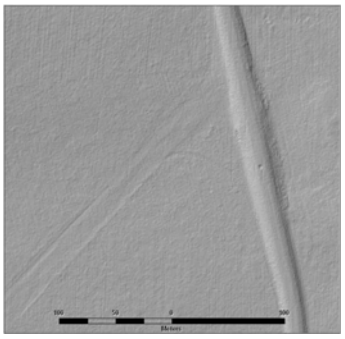
DISCUSSION

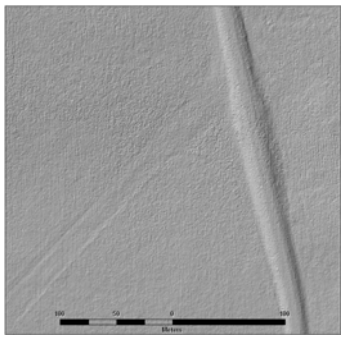
All lidar data acquisition contracts specify the vertical datum of the output data; normally the datum specified is the North American Vertical Datum of 1988 (NAVD 88). In the case of the Kirtland site, the lidar vendor was requested to deliver each of the four flights as a separate data set, each in NAVD 88. This specification was met.

However, this contract specifications, with adjustment of each individual flight to the contract vertical datum, is not standard industry practice. Rather, standard practice is to choose only one of the flights which will be calibrated to the specified vertical datum, after which data from the rest of the flights is calibrated, not to the vertical datum, but to data from the first flight. It is also more standard practice to deliver only one, combined data set. The contract specification used for the Kirtland site resulted from the decision to deliver the lidar at each elevation as a separate date file. Delivery of the Demonstration Plan appeared to be the most conservative approach and to introduce the fewest additional variables. In fact, this approach illustrated the wisdom of the standard industry practice.

The Kirtland data illustrates the results of specifying that each flight be adjusted only to the project vertical datum. Despite the fact that each flight's data set was correctly calibrated to the vertical datum, and each was well within contract specifications, small errors in the equipment lead to each flight being slightly out of alignment with the next. These slight misalignments create a "blurring" of the resulting ground surface in the combined data set.

Figure B-1
Kirtland Individual and Combined Lidar Data As Delivered


300 m lidar, single flight.


Combined 900 m and 450 m lidar flights.

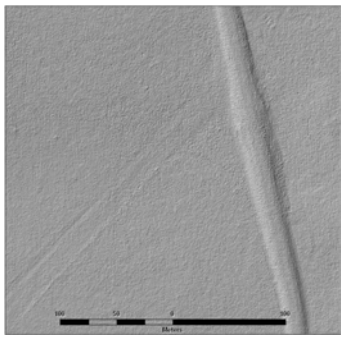
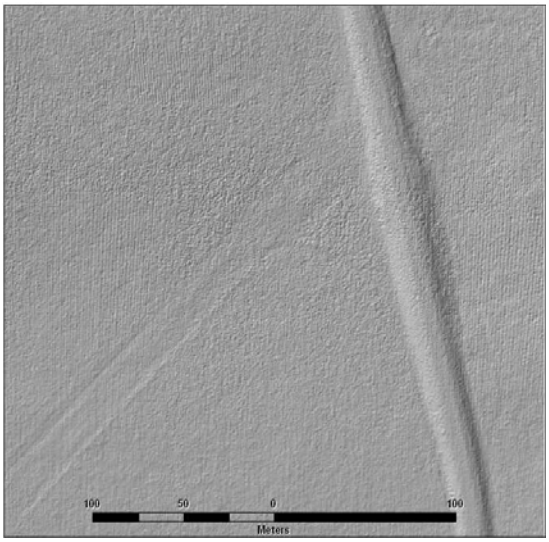
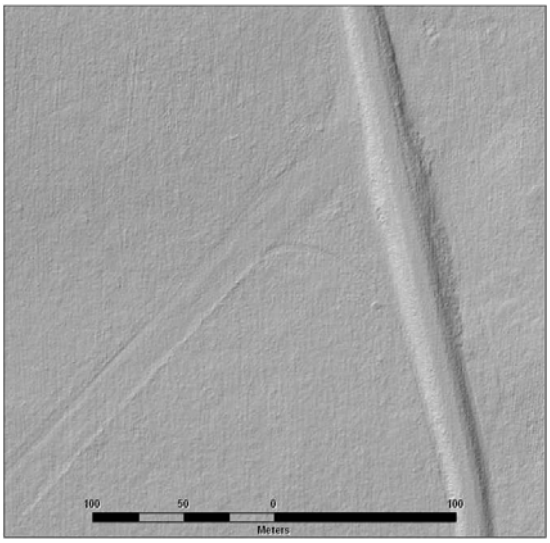

Combined lidar, all flights.

Figure B-2
Kirtland Combined Lidar Data Following Reprocessing

As a test, a small sample of the Kirtland data was reprocessed to achieve the best fit possible between the two data sets. Results were promising, with the reprocessed data yielding a much more useable surface model.



Combined 900 and 450 m lidar flights.

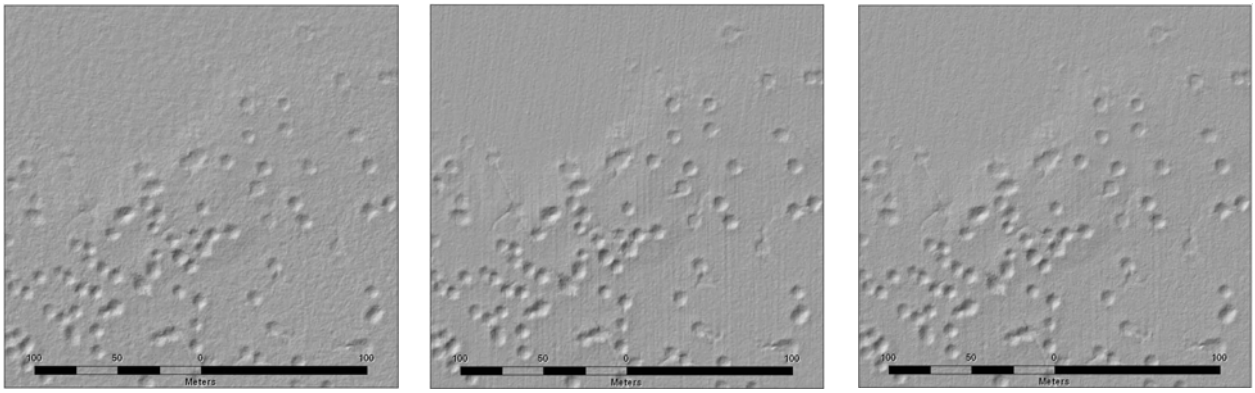


Combined 900 and 450 m lidar, following adjustment of the two flights for best fit.

At the Victorville site, contract specifications were changed. The two flights were delivered as separate data sets, as with the Kirtland data. However, the 900 m flight was calibrated to NAVD 88, and the 450 m flight was adjusted to the best possible fit with the 900 m data set. As a result, the 450 m data was not truly in NAVD 88. However, the two data sets could then be combined

to create a higher-density combined data set that could be used to examine the effects of higher overall point density.

Figure B-3
Victorville Individual and Combined Lidar Data



450 m lidar flight. 300 m lidar flight. Combined 300 m and 450 m flights.

CONCLUSIONS

In projects where multiple lidar flights will be conducted, acquisition specifications should be written to recognize current industry practice for combining lidar data sets. Contracts should not specify that each individual flight should be independently calibrated to the specified vertical datum. Rather, the vertical datum requirement should be applied to data from one flight, with subsequent data sets adjusted to the first.

APPENDIX C

Variation in Lidar Data Density and Potential Effect on Feature Identification

VARIATION IN LIDAR DATA DENSITY AND POTENTIAL EFFECT ON FEATURE DETECTION

INTRODUCTION

Lidar data density is generally expressed as either points per square meter or average spacing between lidar points, averaged over the entire site. In practice, lidar point density was found to vary considerably over the site depending on factors such as flight line overlap and wind conditions. These variations probably do not affect the ability of lidar to detect large features such as bombing targets, but may affect the ability to detect smaller objects, particularly those at or below 1 meter in size. Measures of overall density remain useful as general indicators of the effectiveness of lidar. However, data density specifications may need to be adjusted where detecting small objects is a priority.

DISCUSSION

Lidar data density is affected by at least five operational factors, including the following:

- flight altitude,
- flight speed,
- flight line overlap,
- laser pulse rate, and
- mirror rotation speed.

Data density is also affected by at least three site factors:
density of vegetation cover,
steepness of terrain, and
wind speed during data collection.

Finally, the density of lidar points used to create the ground surface model is very substantially affected by how lidar points are classified as ground or non-ground reflections.

At both demonstration sites, the intention of the demonstration was to vary only flight altitude, as a means to vary the overall lidar point density. Other parameters were held as constant as possible, including flight speed, flight line overlap, laser pulse rate and mirror rotation speed. Slopes on the site did not vary sufficiently to affect data density. Vegetation on the site was relatively sparse and also relatively constant throughout the site, and it was assumed that vegetation classification rates would be relatively constant.

Nevertheless, flight line overlap and vegetation classification had a very significant impact on lidar point density. In some cases these factors had a much larger impacts than flight altitude in determining lidar data density.

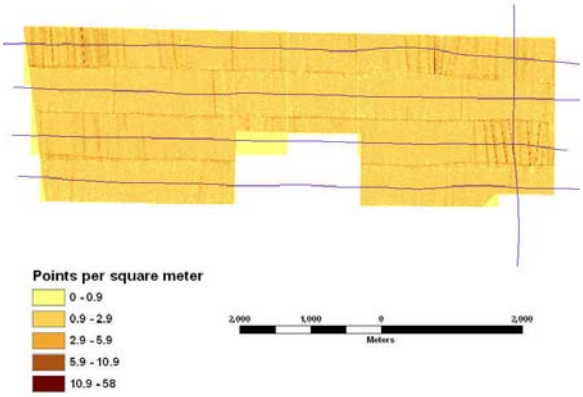
Lidar data densities achieved for the four Kirtland flights and two Victorville flights are given in the table below. These are overall densities, derived by dividing the number of lidar points by the area of the site, for the entire lidar point data set before classification as ground and non-ground returns.

Table C-1
Overall Lidar Data Densities

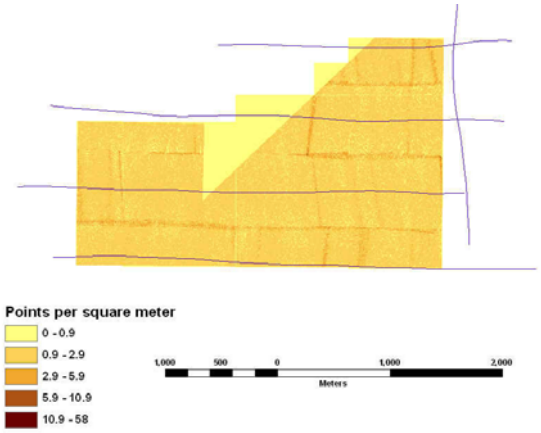
Demonstration Site	Flight	Point density (pts/m^2)
Kirtland	900 m North Block	1.4
	900 m South Block	1.6
	450 m north block	5.2
	450 m south block	4.1
	300 m east-west north block	5.2
	300 m north-south north block	6.5
	300 m flight 1 south block	5.9
	300 m flight 2 south block	6.1
Victorville	450 m flight	4.8
	300 m flight	6.4

When examined more closely, lidar point density was found to vary considerably within each flight. The following figures give a graphical illustration of some of the ways that lidar point density varied. In all of the following figures, darker colors indicate higher point density, and the fine blue lines indicate the lidar flight lines.

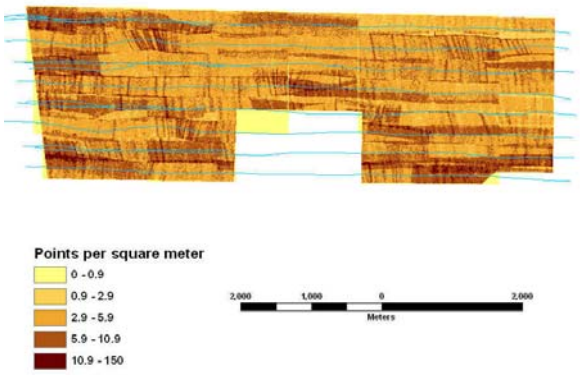
Figure C-1
Kirtland Site Lidar Point Density Maps – All Lidar Points



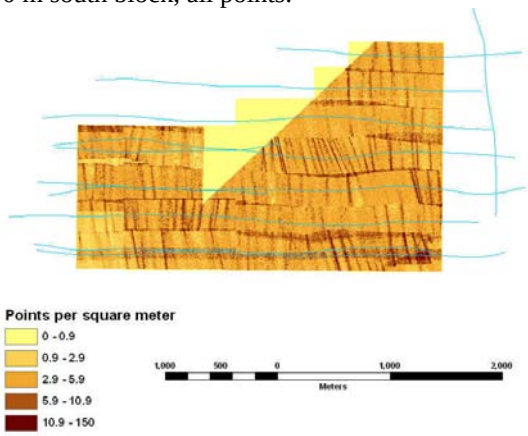
900 m north block, all points.



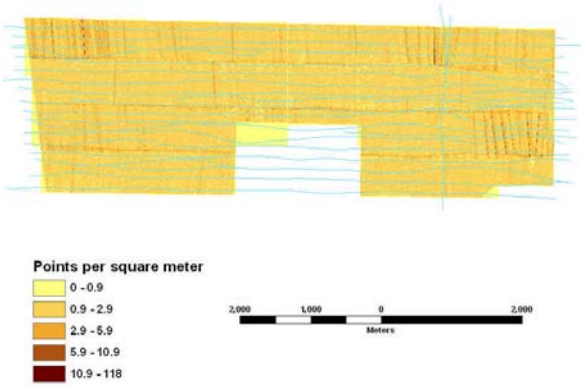
900 m south block, all points.



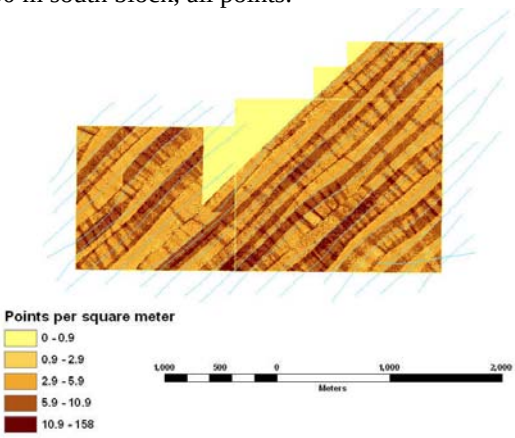
450 m north block, all points.



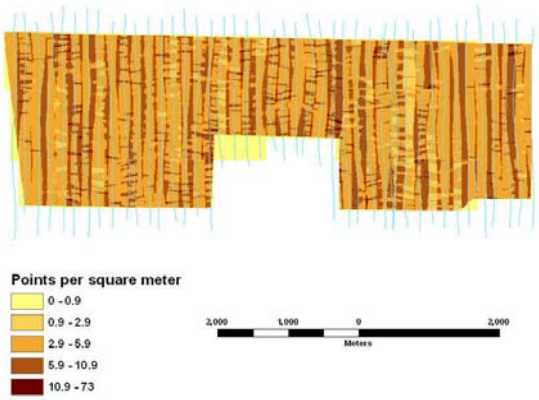
450 m south block, all points.



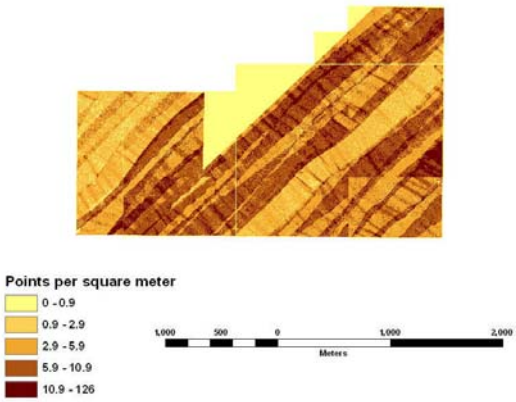
300 m north block East-West flight, all points.



300 m south block, Flight 1, all points.



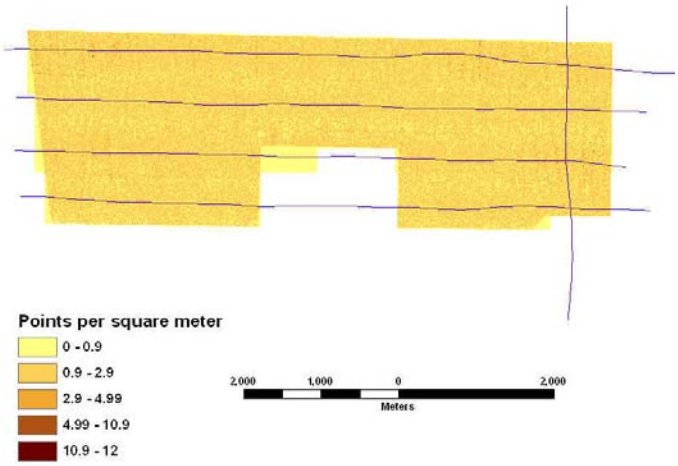
300 m north block North-South flight, all points.



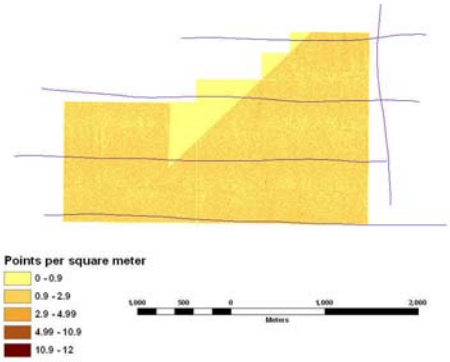
300 m south block, Flight 2, all points.

The images above are for all lidar points regardless of classification as ground or non-ground reflections. Once the points classified as vegetation are removed, both overall point density and the variability of the point density is reduced, as shown in the following figures.

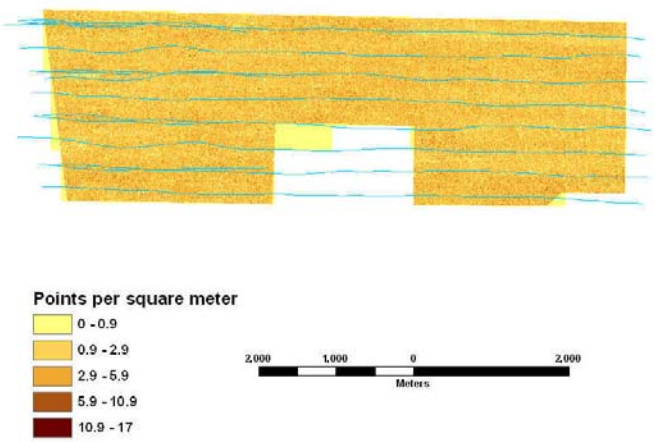
Figure C-2
Kirtland Site Lidar Point Density Maps – Ground Returns Only



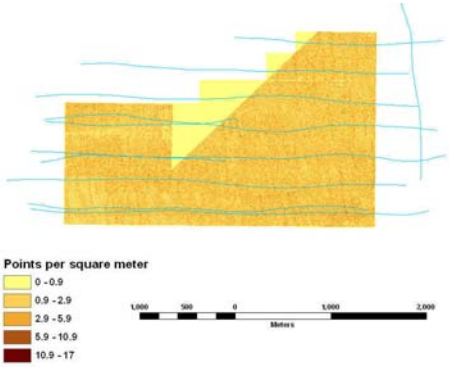
900 m north block, ground points.



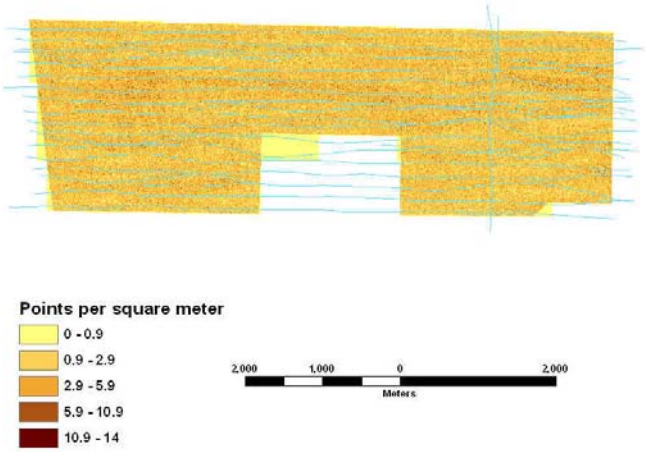
900 m south block, ground points.



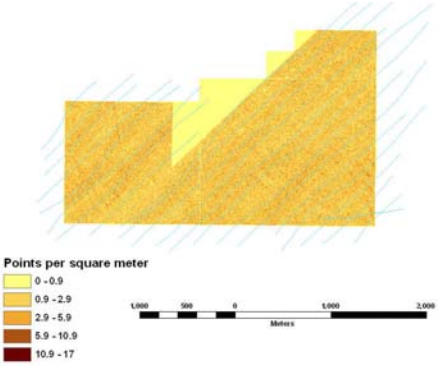
450 m north block, ground points.



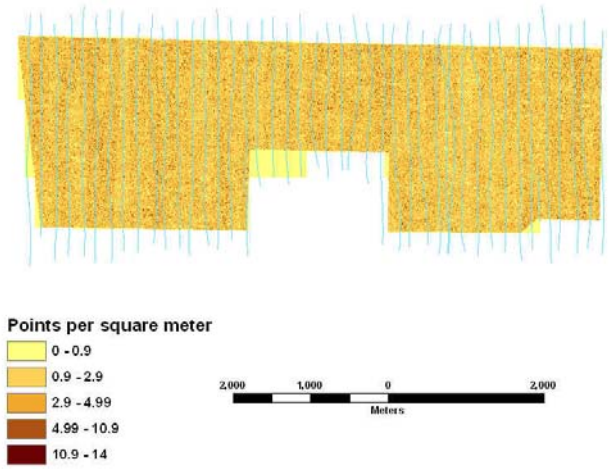
450 m south block, ground points.



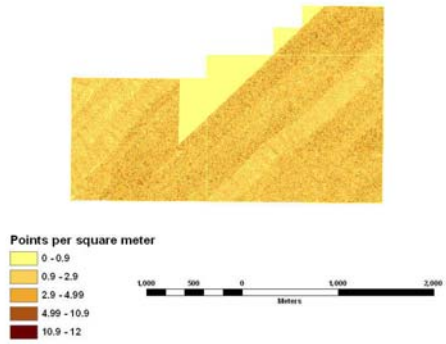
300 m north block EW, ground points.



300 m south block, Flight 1, ground points.



300 m north block NS, ground points.

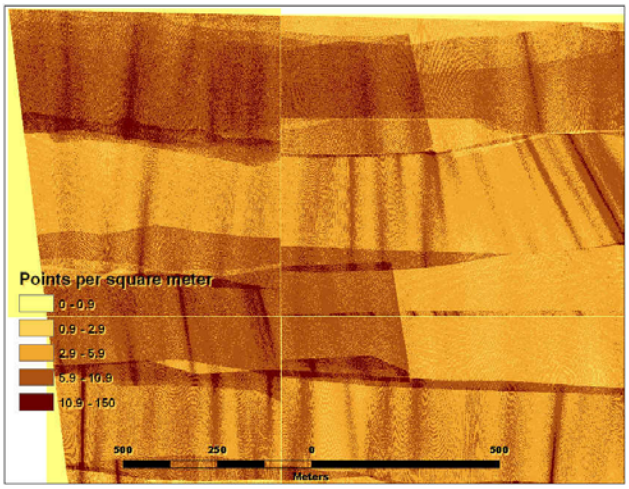


300 m south block F2, ground points.

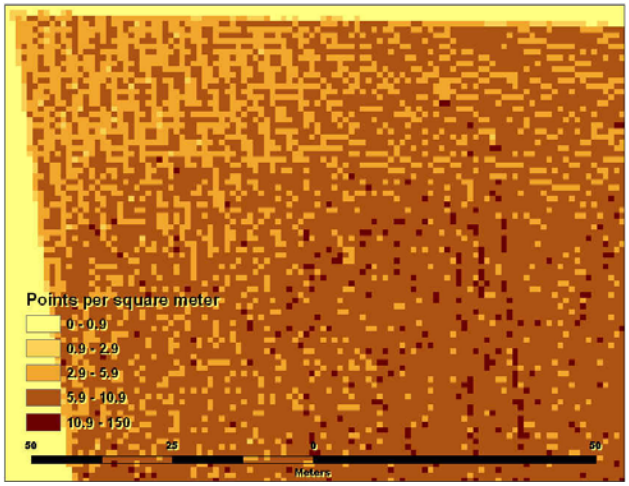
The following figures present close-up views of the point density maps for one of the 300 meter lidar data sets, including images for both all lidar points and ground points only.

These results illustrate one limitation of measuring lidar point density for the site as a whole: some areas of the site have a higher point density than specified, while other areas have a lower density.

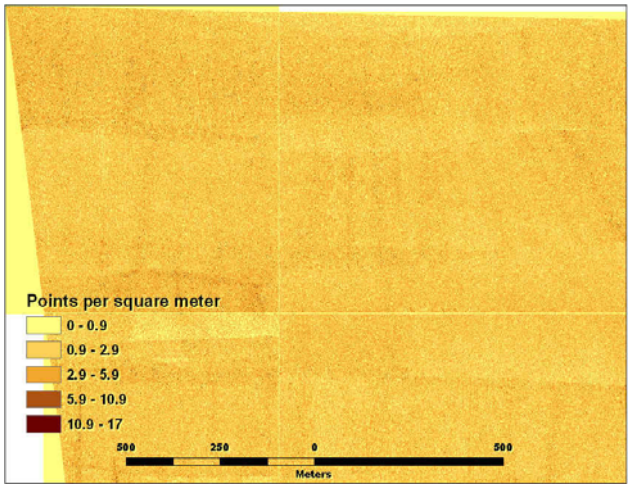
Figure C-3
Lidar Point Density Maps – Detailed Views



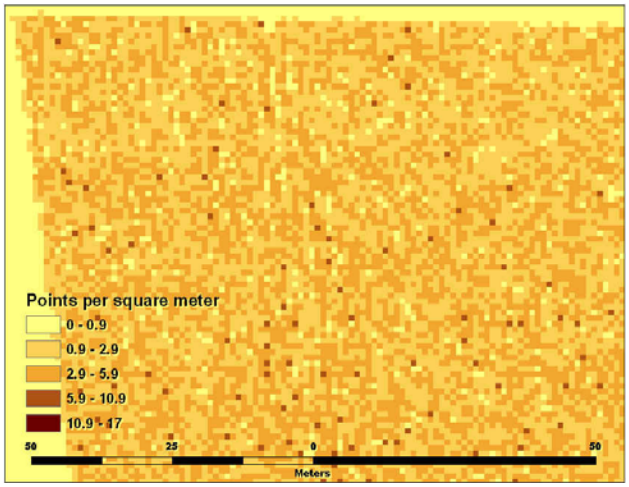
450 m all points, scale 1-6,000.



450 m all points, scale: 1-400.



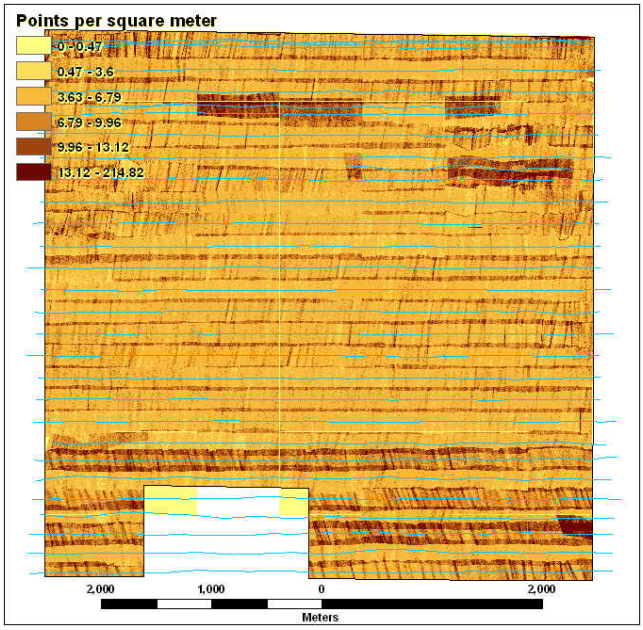
300 m east-west, ground points, scale 1-6,000.



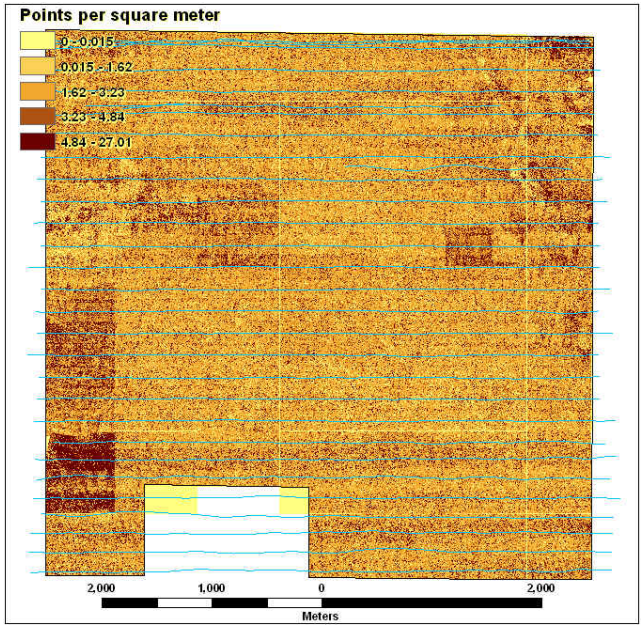
300 m east-west, ground points, scale: 1-400.

Similar results were obtained for the Victorville site, as shown below:

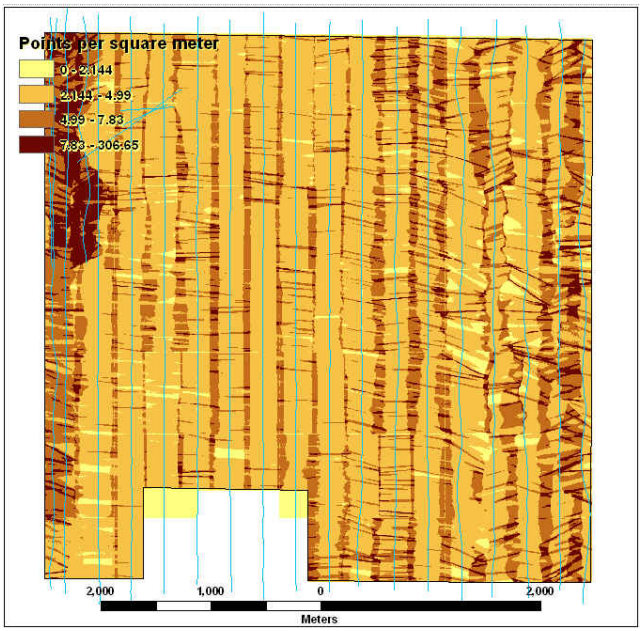
Figure C-4
Victorville Site Data Density Maps



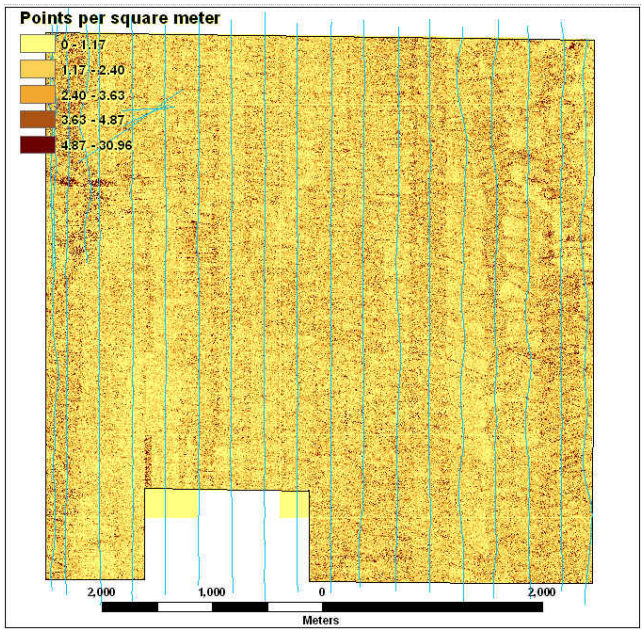
300 m all points.



300 m ground points only.



450 m all points.



450 m ground points only.

All of these figures show that lidar point density in the overall lidar data set is highly influenced by flight line overlap. Point density also varies along the flight line, with bands of higher and lower point density. These bands are the result of flight conditions such as wind gusts or sudden changes in pitch of the aircraft, which result in wider or narrower spacing between the lines of lidar points. This effect is particularly pronounced in the all points data set.

DATA DENSITY AND POINT CLASSIFICATION

Data density variation appears to fall significantly as vegetation is removed, even for these two relatively sparsely-vegetated sites. This result was unexpected: vegetation conditions were relatively uniform on both sites, so variation in data density caused by flight line overlap should theoretically be the same for either all points or ground points. This effect results from the methods used to classify points.

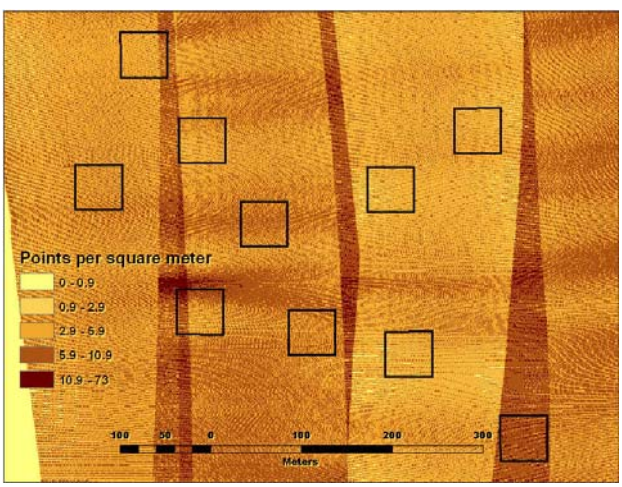
Classification of lidar points as ground or non-ground is performed using automated algorithms followed by operator inspection and editing. Standard point classification methods are aimed at creating an accurate ground surface model free of vegetation artifacts. As such, they are biased towards vegetation removal. The following table shows the percentages of points classified as ground and non-ground for the four lidar flights at the Kirtland demonstration site.

Table C-2
Percentages, Ground and Non-Ground Lidar Returns

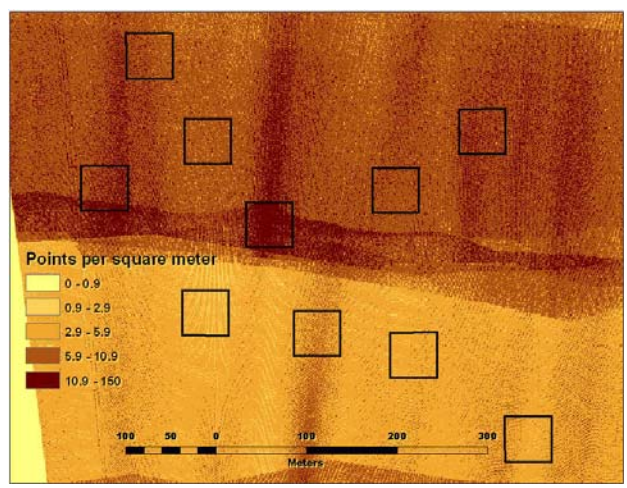
Lidar Flight	Total Points	Ground Points	Ground %	Non-Ground Points	Non-Ground %
900 m	31,212,625	22,503,996	72.1%	8,708,629	27.9%
450 n	102,136,027	42,849,155	42.0%	59,286,872	58.0%
300 m NS and SB F2	110,320,328	42,863,611	38.9%	67,456,717	61.1%
300 m EW and SB F1	129,953,682	45,906,149	35.3%	84,047,533	64.7%

This table shows that as the number of overall lidar points increased, the percentage classified as ground points decreased. That is, part of the increased overall data density was lost from the ground surface model. This finding is unexpected since vegetation was identical for each flight. In order to examine this phenomenon in more detail, ten sample blocks were selected, each 25 x 25 m, covering a range of data densities. The sample blocks are shown in the following figure.

Figure C-5
Data Density Analysis Blocks



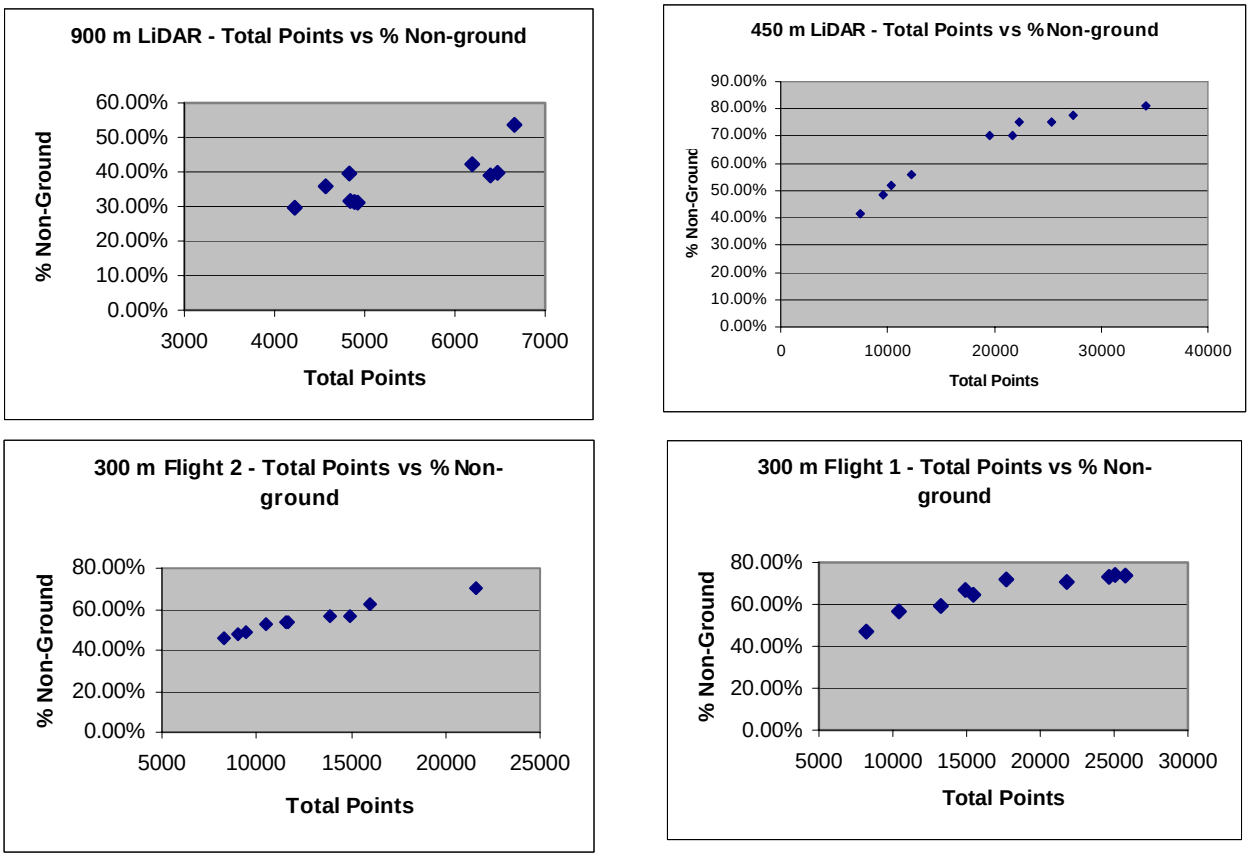
Point density test blocks with 300 m lidar point density map.



Point density test blocks with 450 m lidar point density map.

For each sample block, the total number of lidar points was calculated, along with the percentage of ground and non-ground returns. Similar calculations were performed for each of the four lidar flights. The data showed a strong correlation between overall data density (total number of points) and percentage of points classified as non-ground. As the total number of points increased, the percentage of non-ground points rose from around 30% to around 80%.

Figure C-6
Lidar Point Classification vs. Point Density



This result is significant since acquiring more lidar density raises the project costs. These results appear to indicate that at least a significant portion of the additional lidar points being acquired is not reaching the ground surface models.

The most likely explanation for this effect is based on the fact that, as shown in the point density maps, the highest areas of point density occur where flight lines overlap. In these areas, lidar points from the different flight lines are always very slightly misaligned, (even when the data is well within the vertical accuracy specification), with one data set slightly below and the other slightly above each other. This causes the surface in this overlap area to be “rough”, and it is this roughness that the automated point classification algorithm uses as an indicator of non-ground points such as low vegetation. This phenomenon deserves further investigation.

LIDAR DATA DENSITY DISTRIBUTION AND FEATURE DETECTION

Detecting MEC features using lidar requires that the lidar points be dense enough to reflect from both the feature and its surroundings. Variations in lidar point density should affect the size of features that can reliably be detected.

To examine this variation more closely, the lidar density maps shown above were queried to determine the number of lidar points in each square meter of the study area. The analysis was performed for both the entire point set and for ground returns only. Results were as follows:

Table C-3
Kirtland lidar Data Density Distribution – All Points

All values are in points per square meter.

Flight	Min	Max	Mean	Standard Deviation	% Value = 0
900 m all points	0	58	1.43	0.89	24.28
450 m all points	0	150	4.68	2.74	0.19
300 m north block east-west all points	0	118	6.22	3.25	0.14
300 m north block north-south all points	0	73	4.98	2.57	0.36
300 m south block flight 1 all points	0	158	5.34	3.20	0.12
300 m south block flight 2 all points	0	126	5.49	3.70	1.26

Table C-4
Kirtland lidar Data Density Distribution – Ground Points Only

All values are in points per square meter.

Flight	Min	Max	Mean	Standard Deviation	% Value = 0
900 m ground points	0	12	1.03	0.72	38.46
450 m ground points	0	17	1.98	1.23	11.10
300 m north block east-west ground points	0	14	2.21	1.38	10.20
300 m north block north-south ground points	0	14	2.03	1.38	12.59
300 m south block flight 1 ground points	0	17	1.86	1.32	14.51
300 m north block flight 2 ground points	0	12	1.83	1.35	16.62

Table C-5
Victorville lidar Data Density Distribution – All Points

All values are in points per square meter.

Flight	Min	Max	Mean	Standard Deviation	% Value = 0
450 m all points	0	346	4.48	2.80	1.60%
300 m all points	0	220	6.02	2.96	1.54%

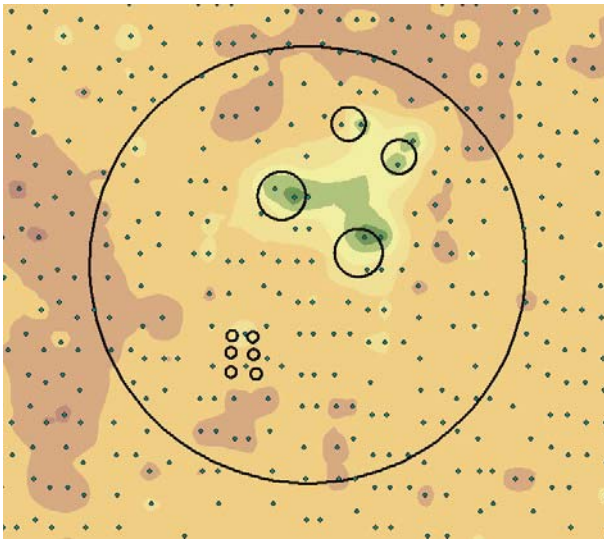
Table C-6
Victorville lidar Data Density Distribution – Ground Points Only

All values are in points per square meter.					
Flight	**Min**	**Max**	**Mean**	**Standard Deviation**	**% Value = 0**
450 m ground points	0	42	1.91	1.21	10.87%
300 m ground points	0	28	2.59	1.56	7.89%

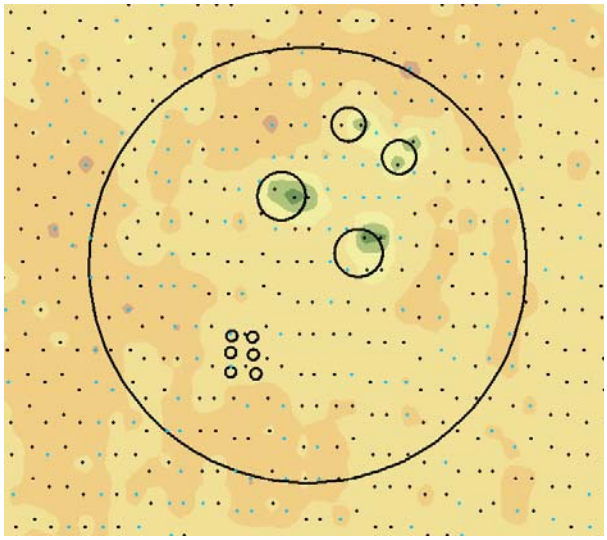
These tables illustrate that even at the highest overall data densities achieved; there are nevertheless one-meter grid cells where there are no lidar points. For ground points – the data most typically used to create surface models - the percentage of one-meter cells with no lidar points ranges from 7.89% to 38.46%. This is a potentially significant finding since one use of lidar is to detect small features in order to delineate MRS boundaries. An examination of the actual lidar point patterns on the ground demonstrates that in some circumstances, objects in the 1.0 – 1.5 m range could easily be missed in the 900 m flight.

The following figures show the Kirtland test crater area with surface models created from the various lidar data sets. Surfaces were created using both the full lidar data set and the points classified as ground reflections. This approach was taken in order to determine whether vegetation removal significantly affected the ability of the lidar data to distinguish the craters. Darker green colors represent lower elevations.

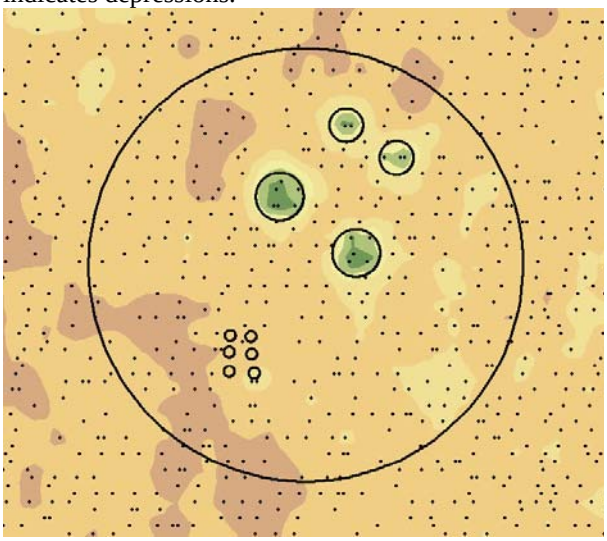
Figure C-7
Test Craters and lidar Data Density



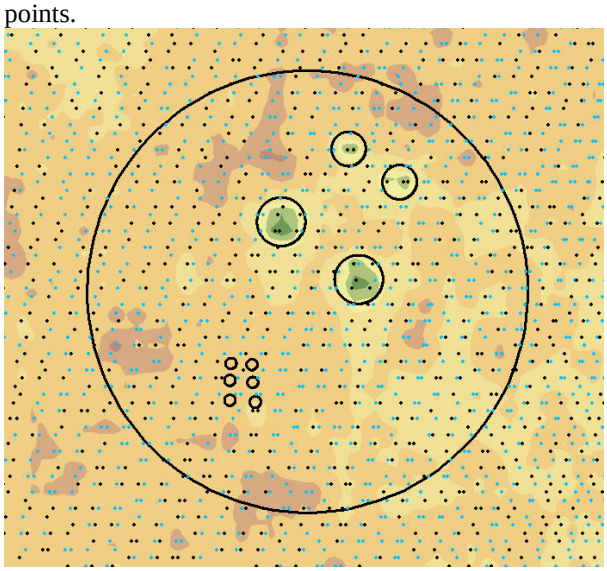
900 m lidar, ground points only. Darker green surface indicates depressions.



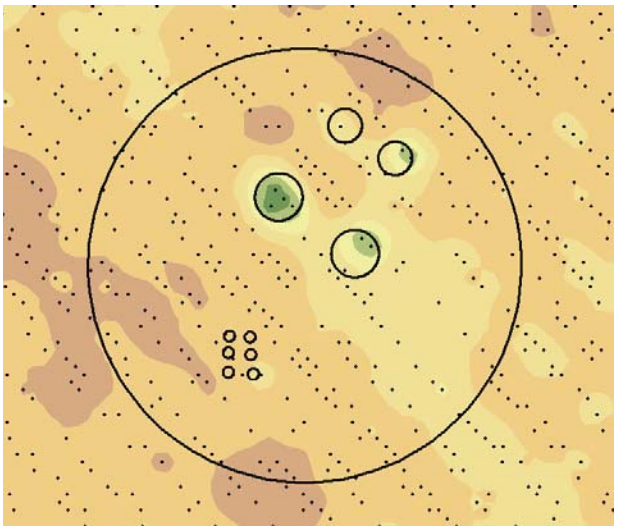
900 m lidar, ground (black) and non-ground (blue) points.



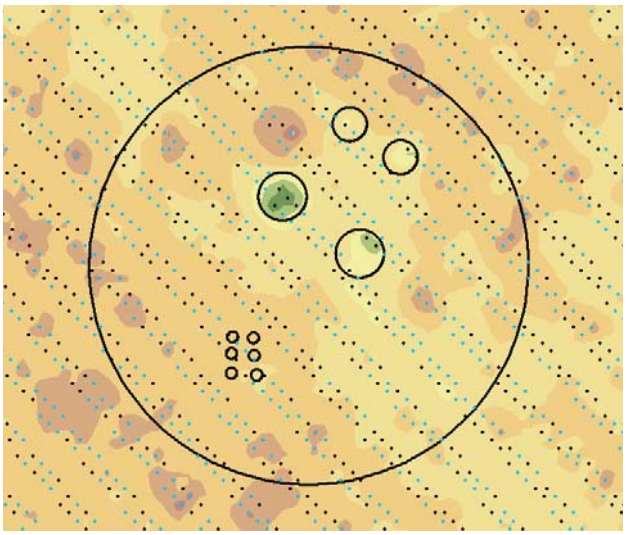
450 m lidar, ground points only.



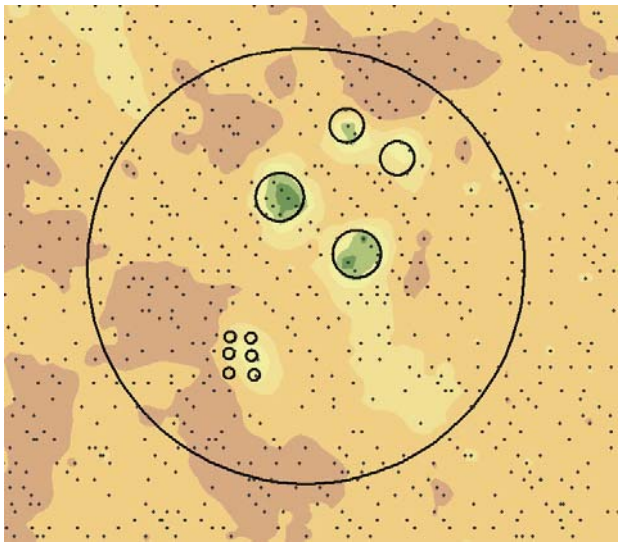
450 m lidar, ground (black) and non-ground (blue) points.



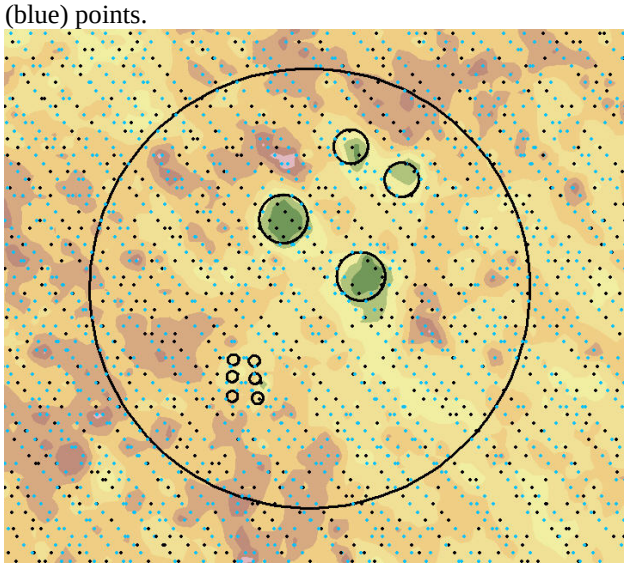
300 m lidar flight 1, ground points only.



300 m lidar flight 1, ground (black) and non-ground (blue) points.



300 m lidar flight 2, ground points only.



300 m lidar flight 2, ground (black) and non-ground (blue) points.

These figures illustrate several points:

- One of the 1.0 meter craters was missed completely using ground returns from both 300 m flights, despite the fact that these were the flights with the highest overall point densities.

- Data density in the test crater area was higher for the 450 m flight than for either 300 m flight, even though overall data density for the 450 m flight was lower.

- The 1.5 m craters were detected with roughly equal success, at all of the data densities tested. Nevertheless, there are areas in the 900 m and both 300 m ground point sets where a 1.5 m crater would not receive any lidar points.

CONCLUSIONS

Measures of overall lidar density such as points per square meter or average distance between points do not capture the actual variations of data density observed at the demonstration sites. Observed variation resulted primarily from flight line overlap and wind conditions, and was often a more important factor than flight altitude in affecting density for a particular area of the site.

Point classification methods had a strong effect on lidar density of the ground surface model. In effect, much of the extra point density achieved in the flight line overlap areas was removed by the point classification methods used.
Variations in lidar density did not affect the detection of the 1.5 m test craters at the Kirtland site, but three of the four lidar data sets nevertheless contained areas where a crater of this size could be missed. Detection of the 1.0 m test craters was affected by lidar density variations, and the 0.32 m craters were not detected at any of the densities tested.

APPENDIX D

GIS-Based Methods for Creating Ground Surface Models from Lidar Points

GIS-BASED METHODS FOR CREATING GROUND SURFACE MODELS FROM LIDAR POINTS

INTRODUCTION

Surface models can be created from lidar points in a variety of ways. All involve some level of interpolation from the random lidar points to a regularly-spaced array that can be analyzed using GIS methods. A limited comparison of some standard methods of creating surface models showed that the methods used to process the demonstration data gave the clearest definition of the Kirtland area test craters. However, the difference was not large, and the craters were visible using most of the methods tested.

DISCUSSION

There are two general approaches to creation of surface models, all result in a regularly-spaced grid with each cell assigned an elevation value.

The first approach is to interpolate the surface model directly from the lidar points. There are a variety of mathematical approaches to such interpolation. These include the following:

- **Inverse Distance Weighting** (IDW) interpolation determines cell values using a linearly weighted combination of a set of sample points. The weight is a function of inverse distance, and the surface being interpolated should be that of a locationally dependent variable. IDW interpolation allows the user to control the effect of known points on the interpolated values, based upon their distance from the output point. The characteristics of the interpolated surface can also be controlled by limiting the input points used to calculate each interpolated point. The input can be limited by the number of sample points to be used, or by a radius within which there are all points to be used in the calculation of the interpolated points.

- **Kriging** is an advanced geostatistical procedure that generates an estimated surface from a scattered set of points with z values. Kriging is based on a regionalized variable theory that assumes that the spatial variation in the phenomenon represented by the z values is statistically homogeneous throughout the surface (i.e., the same pattern of variation can be observed at all locations on the surface). This hypothesis of spatial homogeneity is fundamental to the regionalized variable theory.

- **Splining** performs a two-dimensional minimum curvature spline interpolation on a point data set resulting in a smooth surface that passes exactly through the input points. This basic minimum-curvature technique is also referred to as thin plate interpolation. It ensures a smooth (continuous and differentiable) surface together

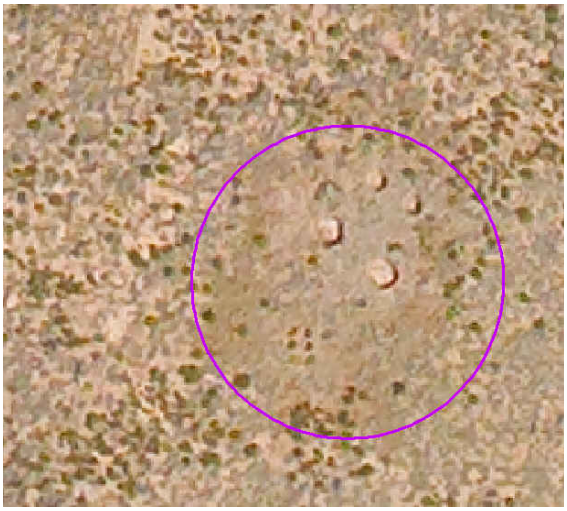
with continuous first-derivative surfaces. Rapid changes in gradient or slope (the first derivative) may occur in the vicinity of the data points; hence this model is not suitable for estimating second derivative (curvature).

The second approach is to create a Triangualted Irregular Network (TIN) using every individual lidar point. The TIN is then used to create the surface model, again using one of the interpolation methods described above. Either approach can be employed using the ground points only or both the ground and vegetation points.

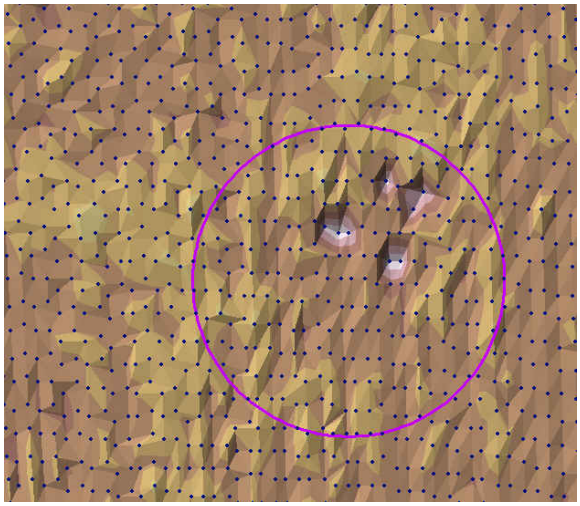
Both of the above approaches produce good surfaces, with each method having its own particular advantages and shortcomings. Every method uses one technique or other to interpolate (or guess at) the surface between the lidar points. However, by creating a TIN from the points before creating the grid surface model, we assure that each individual point is represented accurately in the final product, and in the TIN itself which can be examined in particular cases. Consequently, for this demonstration, the TIN method was used for all data sets.

A test of these alternative methods was conducted using the data from the Kirtland site. The points in the area surrounding the test craters was extracted and used to create a series of surfaces using the available methods.

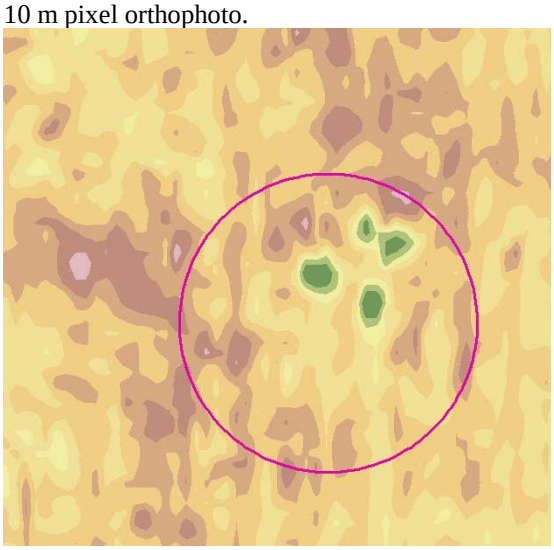
Figure D-1
Surface Model Examples



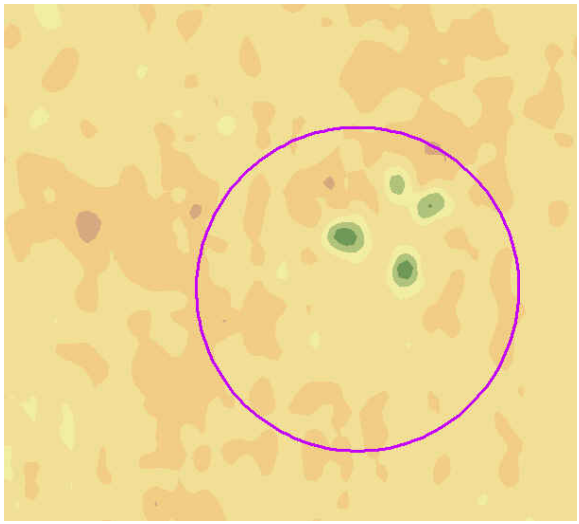
10 m pixel orthophoto.



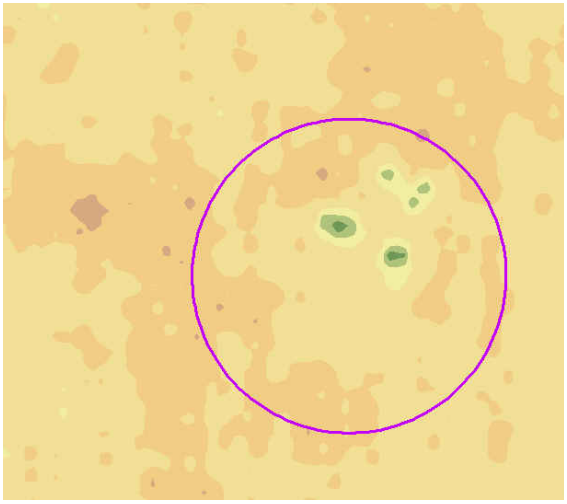
900 m TIN.



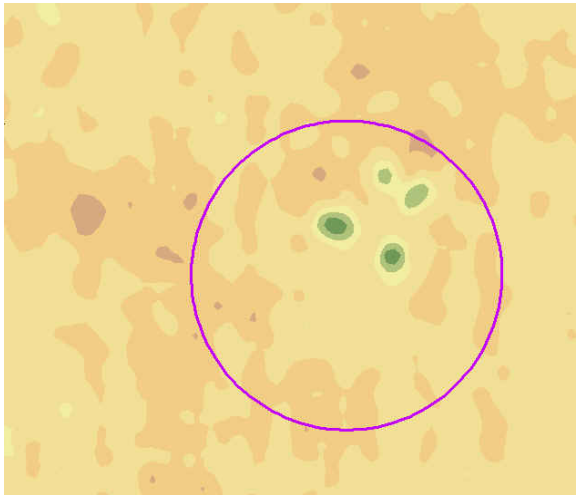
900 m TIN-derived IDW.



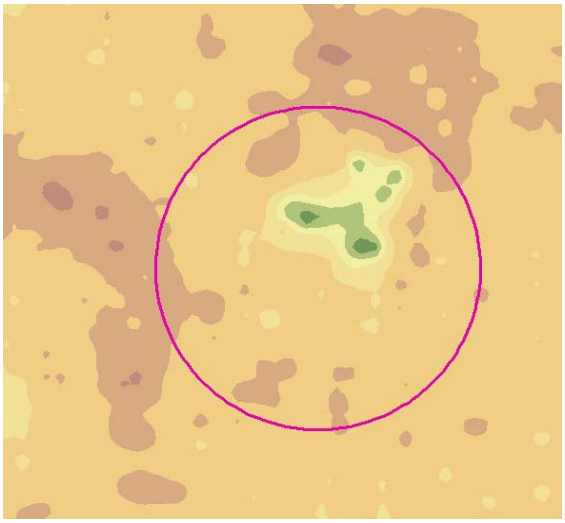
900 m spline.



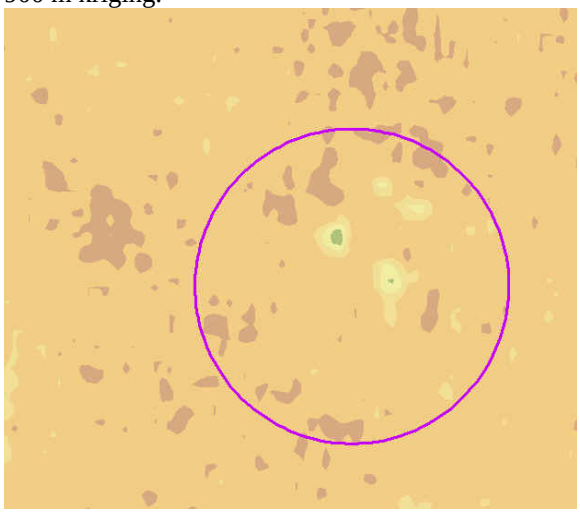
900 m IDW.



900 m kriging.

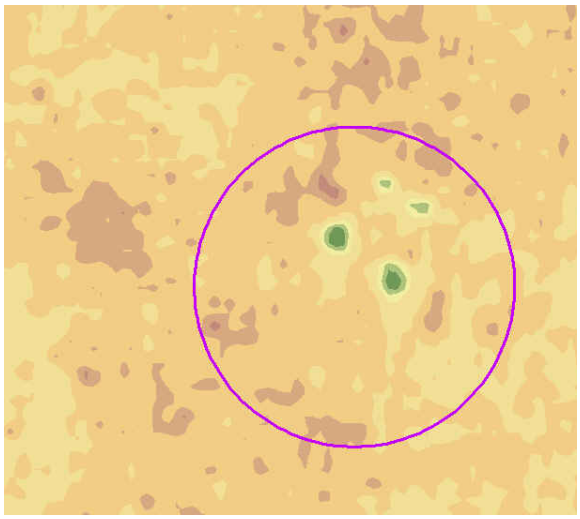


450 m TIN-derived IDW.



450 m spline.

450 m IDW.



450 m kriging.

These figures illustrate that the TIN-derived surface models give a slightly more clear representation of the 1.5 and 1.0 m test craters. However, all methods showed the presence of these four test craters.

CONCLUSIONS

Lidar surface interpolation methods tested appeared to have a weak effect on feature detection, with the TIN-to-surface model method used to process the demonstration data yielding the best results. However, the difference between the methods was not pronounced.

APPENDIX E

Automation of Lidar Data Processing in the ESRI GIS Environment

AUTOMATION OF LIDAR DATA PROCESSING IN THE ESRI GIS ENVIRONMENT

INTRODUCTION

Many standard lidar data processing steps can be successfully automated. This is important since lidar data sets are very large, often involving many hundreds of data files, all of which are processed using essentially the same steps. Automation, when successful, can reduce costs and increase the reliability of the resulting products. For this demonstration, all automation was accomplished using ESRI's ArcGIS program. This software was chosen because it is in wide use by federal land managers who may use lidar data.

DISCUSSION

ArcGIS provides several avenues for process automation, including the following:

- Arc Macro Language (AML). AML is a scripting language developed for the ArcInfo Workstation environment. It is used to automate data processing and analysis tasks, the creation of complex maps, and to develop custom interfaces to aid user with various tasks such as data creation, editing and analysis. .It is a robust, full-featured programming language that can be used to automate the commands that can be used at any of the ArcInfo command line prompts (i.e., ARC:, ARCEDIT:, ARCPLOT:).Its main disadvantage is that any non 3D spatial data processing must be done using the antiquated ArcInfo coverage format. Only in some very limited situations can ArcInfo shapefiles be used, and ArcGIS feature classes and geodatabases cannot be used at all. Another disadvantage is that the very steep learning curve required to become proficient in AML. Even though it is based on standard programming concepts, AML is a proprietary language unique to ArcInfo Workstation and is not easy to learn.

- Visual Basic. ESRI has written a library of programming objects called ArcObjects that allows the programmer to develop powerful applications relatively quickly using the very popular Visual Basic for Applications (VBA) programming language that comes bundled with ArcGIS. ArcObjects can also be used with the Visual Studio .NET languages, VB.NET, C++.NET and C#.NET. Applications written in VBA must be run from an ArcGIS application like ArcMap, ArcCatalog or ArcScene while Visual Studio.NET applications can be run independently of ArcGIS though access to the ArcGIS license server is still required.

- Python. Python is an open source, object oriented, programming language developed to handle the kind of tasks normally given to scripting languages like PERL, Ruby or

Tcl but without the steep learning curve usually associated with many powerful object oriented languages. ESRI has written its Geoprocessing object specifically to be used with Python. Python is a relatively easy language to learn, and ESRI also provides some pre-designed user interfaces that custom Python scripts can be linked to. Unfortunately, ESRI has made only the Geoprocessing object, and not all of its ArcObjects collection, available to Python developers. In order to use ESRI's more extensive ArcObjects library, the developer must use VBA or one of the .NET programming languages.

For this demonstration, automation was carried out using Python. The decision to use Python was based on its ease of use, combined with the need to develop the automation scripts quickly and start the processing of the raw lidar data as soon as possible. AML scripts had already been developed to automate lidar data processing, however the conversion to Python eliminated the need to convert the lidar data sets to coverages. Python was used to create a suite of tools that handles the processing of the lidar files delivered by the vendor, starting from the creation of the initial point shapefiles and continuing through the final surface models and data analysis. The processing scripts were designed to handle batch processing of input data files, which required that a consistent naming convention be established and followed input data.

While Python was the approach taken, automation results and process steps would have been essentially the same regardless of the scripting approach chosen.

1. The first step was to create point shapefiles from the ASCII files containing the lidar points in ArcGIS.

2. The second step was to generate a continuous surface model TINs using each point shapefile as an input.

3. The third step was to create DEMs, or surface model grids, from each of the TINs. For both Victorville and Kirtland, a 1 foot cell size was used for the DEMs as the highest resolution the lidar data would support.

These three steps were run as separate scripts. There would be no barrier to combining all three processes into one script. However, running each script separately allowed for QA/QC inspection between steps. This was significant since each processing step was relatively time-consuming, and it was important to catch any errors in the data at the earliest point possible.

APPENDIX F

Analytical Methods Supporting Experimental Design

ANALYTICAL METHODS SUPPORTING THE EXPERIMENTAL DESIGN

Analytical methods appropriate to lidar and orthophoto collection include calculations of target lidar point density, orthophoto pixel size, and along-flight-line swath width. Formulas for these calculations are given below.

Lidar point density. Point density is calculated using the following formula:
Pt Density = Pulse Rate / (Forward Flying Speed * Swath Width)
= 50 000 / (20 * 204)
= 12.25 shots/m

Pixel size. Pixel size is calculated using the following formula:
Pixel size = (Altitude * CCD Grid Size) / Focal Length
= (700 (m) * 0.000008 (m)) / 0.035 (m)
= 0.16 m@

Swath width. The swath width is calculated using flying height and maximum mirror angle in the following formula:
Swath Width = Tan(MirrorAngle)* Flying Height * 2
= Tan(27) * 200 * 2
= 204 m

Units. Units for all formulas are:
Flying Height: meters
Flying Speed: meters per second
Mirror Angle: degrees

APPENDIX G

Quality Assurance Project Plan

QUALITY ASSURANCE PROJECT PLAN
LiDAR AND ORTHOPHOTOGRAPHY
DEMONSTRATION PROJECT
KIRTLAND PRECISION BOMBING RANGE, NEW MEXICO

Approvals

Name: Thomas Tomczyk, P.G., L.G., C.Q.A.
Title: Principal Investigator
URS Group, Inc.

Signature: _____ Date: _____

Name: Dale Bennett
Title: Data Evaluation and GIS Lead
URS Group, Inc.

Signature: _____ Date: _____

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Terra Remote Sensing, Inc.

Signature: _____ Date: _____

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ABBREVIATIONS AND ACRONYMS

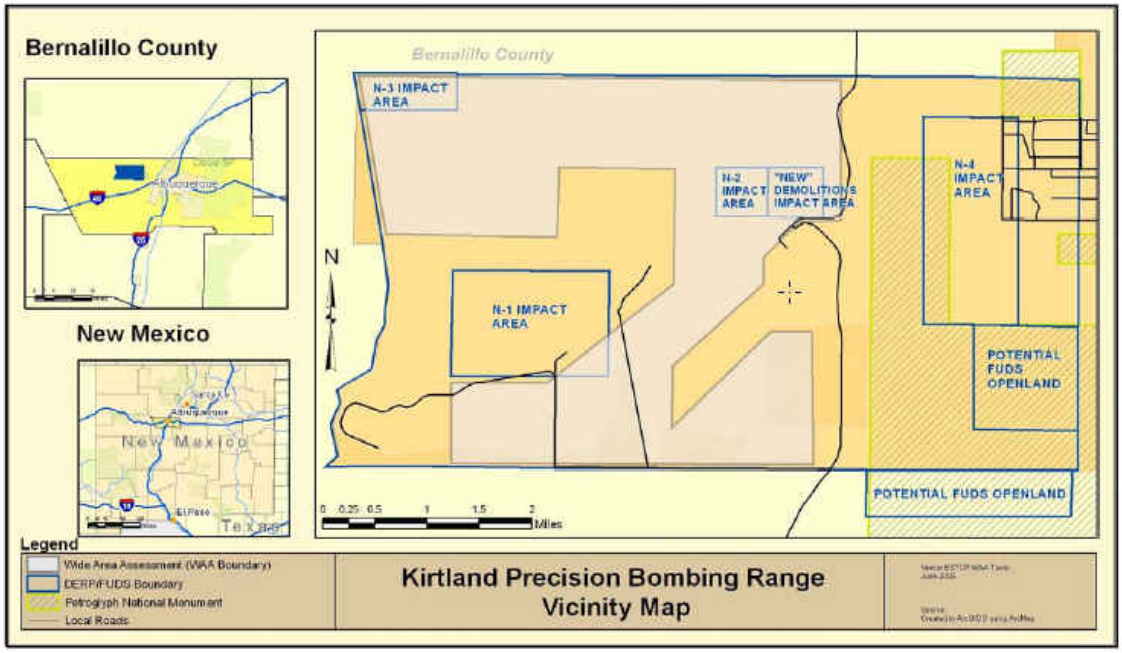
DoD	Department of Defense
DOPS	D
DQO	Data Quality Objective
ESTCP	Environmental Security Technology Certification Program
EPA	U.S. Environmental Protection Agency
GPS	Global Positioning System
HASP	Health and Safety Plan
IMU	Inertial Measurement Unit
MEC	Munitions and Explosives of Concern
MRS	Munitions Response Site
PBR	Precision Bombing Range
PI	Principal Investigator
PRF	Pulse Repetition Frequency
QA	Quality Assurance
QAO	Quality Assurance Officer
QAPP	Quality Assurance Project Plan
QC	Quality Control
SOP	Standard Operating Procedure
SOW	Statement of Work
TRSI	Terra Remote Sensing, Inc.
URS	URS Group, Inc.
URS PI	URS Principal Investigator

1.0 INTRODUCTION

This document serves as the quality assurance project plan (QAPP) for the Environmental Security Technology Certification Program (ESTCP) Demonstration Project entitled "High Density LiDAR and Orthophotography in UXO Wide Area Assessment", to be performed at the former Kirtland Precision Bombing Ranges (PBR), New Mexico (Figure 1-1). The QAPP serves as the primary guide for integrating quality assurance (QA) and quality control (QC) procedures and functions with data collection activities described in the Performance Plan to ensure that technically sound and defensible data are collected and meet project objectives. The QAPP was developed in conjunction with the Demonstration Plan, and health and safety plan (HASP).

By reference, this QAPP relies upon the management policies, objectives, principles, and general procedures presented in the URS Group, Inc. (URS) *Quality Management Plan* (URSG 1998). The quality management plan establishes the framework and general criteria for implementing the URS quality system.

Figure 1-1 Kirtland AFB PBS Vicinity Map



2.0 PROJECT DESCRIPTION

The WAA study area for project UX-0534 consists of 5,000 acres of the former Kirtland Precision Bombing Ranges located in the West Mesa area of Bernalillo County, New Mexico, about 10 miles west of Albuquerque. The WAA study area was selected to in accordance with WAA Pilot Program goals and includes several known WWII-era targets as well as undeveloped land surrounding the targets. Project UX-0534 explores the use of LiDAR and high-resolution orthophotography as a means to locate previously undocumented MRS, delineate the boundaries of MRS, identify site constraints on ground-based geophysical surveys, and identify munitions-related features such as craters, targets, burial pits, and ground and vegetation disturbances.

3.0 PROJECT ORGANIZATION AND QUALITY ASSURANCE RESPONSIBILITIES

3.1 PROJECT ORGANIZATION

The project-specific organization, shown in Figure 3-1, indicates key positions along with lines of authority and lines of communication and coordination. The names of individuals filling key roles on the project, along with their phone numbers, are provided in Table 3-1. The responsibilities and authorities of these key positions as they relate to project QA/QC are described in the following subsections.

It is essential that all individuals have defined responsibilities for their functional areas and that they are clearly aware of the entire project organization and the interrelationships of various roles. Because this discussion covers the project organization, those senior officials, corporate managers, and administrators whose positions are not functionally involved with data generation, data use, or decision making are not included.

QA personnel have sufficient authority, access to work areas, and organizational freedom to identify quality problems; to initiate, recommend, or provide solutions to problems through established channels; and to verify solution implementation. They ensure that all work, including any processing of information, delivery of products, and installation or use of equipment, is reviewed in accordance with the QC objectives and that all deficiencies and nonconformances are corrected. QA personnel have direct access to senior management so that the required authority is available, when needed, to carry out QA duties.

The project planning team will include the team members described below.

3.1.1 ESTCP Project Manager

The ESTCP-assigned Project Manager (ESTCP PM) is responsible for coordinating all project-related activities on behalf of ESTCP. A major component of this position involves directing the URS Principle Investigator (PI) in the execution of the work and the submission of deliverables as scheduled. Specific responsibilities of the ESTCP PM are as follows:

- Oversee all project activities.
- Provide the scope of work to the URS PI.
- Review and approve project plans and coordinate the review within ESTCP and other appropriate organizations, as necessary.
- Review and approve the QAPP and all other components of the project plan.

- Ensure that the QAPP and associated reports are transmitted to appropriate ESTCP personnel and organizations.

- Transmit to the URS PI review comments associated with the project plan from ESTCP and other organizations.

- Ensure that the URS PI addresses ESTCP and agency review comments and takes appropriate action.

3.1.2 URS Principle Investigator

The URS PI is responsible for providing senior leadership and expertise to the URS and subcontract staff and for maintaining a broad perspective of priorities. The URS PI reports to and obtains technical direction and assistance from the ESTCP PM and is responsible for monitoring and documenting the quality of all work produced by the project team, which includes the URS staff and subcontractors. The fundamental goal of this position is to produce a quality work product within the allotted schedule and budget. Duties include executing all phases of the project and efficiently applying the full resources of the project team in accordance with the project plans. Specific responsibilities of the URS PI are as follows:

- Identify the need for and expectations regarding services to be provided and, when necessary, negotiate acceptable scopes of work.

- Provide input and technical expertise to the ESTCP PM on developing or establishing project objectives, data quality objectives (DQOs), sampling rationale, and data analysis and assessment methods.

- Prepare and implement the Technology Demonstration Plan (which incorporates applicable QAPP elements) and prepare reports as required by ESTCP.

- Ensure that the QAPP and standard operating procedures (SOPs) are available and in use for activities that affect product quality and that assigned staff have been trained in the implementation of the QAPP and SOPs.

- Ensure that the best available technology is being applied to reduce potential waste and inefficiencies and that the best known processes are in use.

- Ensure that appropriate procedures for data collection, data processing, and data analysis are followed and that correct QC checks are implemented.

- Perform readiness reviews and monitor the progress of work in relation to scope, cost, and schedule.

- Monitor team and subcontractors for compliance with project and data quality requirements, records, costs, and progress of the work; replan and reschedule work tasks as appropriate.

- Review and approve calculations and data processing methods to ensure that data reduction is performed in a manner that produces quality products.

- Verify data quality, test results, equipment calibrations, and QC documentation; maintain and regularly review all QC records.

- Ensure that all key decisions and project deliverables are subjected to independent technical review by qualified personnel within the timeframe of the project schedule.

- Report QA problems to the Quality Assurance Officer (QAO) for review and/or resolution.

- Assess completion of work in accordance with ESTCP.

3.1.3 URS Quality Assurance Officer

The URS Quality Assurance Officer (QAO) communicates with the URS PI regarding the contract and additionally has direct reporting access to the URS Corporate QA Director on quality-related matters. The QAO is responsible for development, implementation, and maintenance of the comprehensive quality system. Responsibilities of this position include communicating with all levels of program and project management to ensure that a quality product is produced for delivery. Project-specific responsibilities of the QAO or designee are as follows:

- Respond to QA needs, resolve problems, and answer requests for guidance or assistance.

- Provide guidance to the URS PI in the development of project plans, including the QAPP.

- Review and approve the project plans.

- Together with the URS PI, assign competent, qualified independent reviewers to review the technical adequacy of deliverables.

- Track the progress and completion of the review and approval process.

- Ensure that ESTCP protocols and procedures, as well as SOPs, are being followed.

- Review the implementation of the Technology Demonstration Plan and the adequacy of the data or products generated based on quality objectives.

- Initiate field and office audits, if necessary.

- Review audit and nonconformance reports to determine areas of poor quality or failure to adhere to established procedures.

- Confer with the audited entity on the steps to be taken for corrective actions and track nonconformance until it has been corrected; evaluate the adequacy and completeness of the action taken; confer with the URS PI to resolve an inadequate corrective action; and confirm the adequacy and implementation of the response action.

- Upon detection and identification of an immediate adverse condition affecting the quality of results, suspend or stop work with the concurrence of the URS PI and the ESTCP PM.

3.1.4 URS Data Evaluation and GIS Lead

The URS Data Evaluation and GIS Lead is responsible for managing any project task requiring specialized technical expertise, related to the collection, assessment, analysis and reporting of LiDAR and orthophoto data. Specific responsibilities are as follows:

- Provide technical direction to URS technical staff in the specific area of LiDAR and orthophoto data collection and processing.

- Prepare a statement of work (SOW) for use in procurement of direct subcontracted services including LiDAR and orthophotography.

- Serve as a point of contact for direct subcontractors.

- Relay to the URS PI project information related to LiDAR and orthophoto data collection and processing.

- Coordinate data collection activities to be consistent with information requirements.

- Resolve problems with received data and/or analysis.

- Oversee evaluation of data received from subcontractors in accordance with the project requirements and DQOs.

- Supervise the creation of analytical products based on data provided by direct subcontractor(s).

- Ensure that data are correctly reported in appropriate data formats.

- Prepare or oversee the preparation of portions of the final report that summarize data results and present conclusions.

- Prepare and file required URS QA/QC review forms, documenting QA/QC activities related to data analysis performed by URS.

3.1.5 Subcontractor

One direct subcontractor, Terra Remote Sensing, Inc. (TRSI) will be used by URS during the demonstration. This subcontractor will collect LiDAR and photo image data in the field, and will also perform initial data processing to create LiDAR points and orthophotos. The subcontractor will be directed by the URS PI or their designee and apprised of project requirements as appropriate for their assigned tasks. In addition, the subcontractor will have the following responsibilities:

- Implement the data collection elements of the Technology Demonstration Plan and perform initial data processing elements of the Plan.

- Develop and maintain flight logs, calibration and accuracy reports, and other field activity files, forms, and logbooks as detailed in this QAPP.

- Implement technical procedures applicable to tasks, including calibration and maintenance of field equipment.

- Subcontract as necessary for specific equipment such as helicopter services, with the approval of URS.

- Provide a health and safety plan appropriate to their activities and to those of their subcontractors.

- Report any problems or deviations from project plans to URS PI.

Table 3-1
Project Contacts

Key Role	Name	Telephone
ESTCP		
ESTCP Contracting Officer	Lynn Harper	(703) 428-6551
ESTCP Project Manager (ESTCP PM)[1]	Herb Nelson	(202) 767-3686
On-Site Emergencies		
Any emergency		911
Ambulance		911
Kirtland PBR / Double Eagle Airport Manager		(505) 244-7888
Fire		911 or
University of New Mexico Hospital, Albuquerque		(505) 272-2111
URS Group, Inc.		
URS Principal Investigator	Tom Tomczyk	(206) 438-2137
URS Data Evaluation and GIS Lead	Dale Bennett	(206) 438-2026
URS Quality Assurance Officer	George Carlson	(503) 478-7661
URS Health and Safety Manager	Mark Litzinger	(206) 438-2199
TRSI.		
TRSI Technical Lead	Dave Neufeldt	(250) 656-0931

[1] In the event of an emergency, the URS PI and the ESTCP PM are to be notified immediately.

3.2 PROJECT SCHEDULE

The project schedule is provided in Table 3-2.

Table 3-2.
Project Schedule

Activity	Start Date	End Date
Mobilization	August 8, 2005	August 8, 2005
Field data collection	August 9, 2005	August 11, 2005
Complete initial data processing and deliver field data to URS	September 23, 2005	September 23, 2005
Completion of initial data deliverables and transfer to ESTCP	October 7, 2005	October 7, 2005
Data analysis. GIS-based analysis of LiDAR and image data for features; area classification.	November 30, 2005	November 30, 2006
Demonstration Report with Survey Data	February 1, 2006	February 1, 2006
Draft final report	June 1, 2006	June 1, 2006
Final report	August 1, 2006	August 1, 2006

4.0 DATA QUALITY PARAMETERS

Data Quality Objectives (DQOs) are qualitative or quantitative statements of the precision (a measure of the random error), bias (a measure of systematic error), representativeness, completeness, and comparability necessary for the data to serve the project objectives. During implementation of the demonstration, field and analytic data will be generated. These data will be evaluated to determine that DQOs have been met and that the data are usable for the project objectives.

4.1 ANALYTICAL OBJECTIVE AND RATIONALE

The objective of the demonstration is to accurately and systematically locate Munitions Response Sites (MRS) and ground features associated with the use of munitions and explosives of concern (MEC). A secondary objective is to develop realistic cost/benefit data regarding the appropriate densities of LiDAR and orthophotographs in the detection and characterization of MRS and MEC-related ground features. The primary means to achieve these objectives is through the development and analysis of detailed models of the ground surface based on several different densities of LiDAR points, and of orthophoto images at different pixel sizes. Consequently, analytical objectives are designed to ensure that LiDAR and orthophotography products created accurately reflect the capabilities of each technology, free of bias and error which will distort the experimental results.

Further, the products of the LiDAR and orthophotography demonstration will be used in subsequent phases of the overall ESTCP UXO pilot project. Consequently, a further analytic objective is to assure that the spatial coordinates of the LiDAR and orthophoto data are controlled, to the extent allowed by each technology, to on-site survey control points that will be used by other demonstrators.

4.2 QUALITY ASSURANCE MEASUREMENTS

The quality of the field data will be evaluated based on successful calibration of each instrument supplying the data based on the manufacturer's stated accuracy and precision of the instrument. The quality of data processing and data analysis steps will be evaluated based on the precision, bias, representativeness, completeness, and comparability of the data generated by each type of analysis. These data assessment parameters are described in the following subsections.

4.2.1 Precision

Precision is a measure of the scatter in the data due to random error. For airborne remote sensing technologies, the major sources of random error are the sampling rate of the sensors in relation to

the positional data provided by the Inertial Measurement Unit (IMU) and Global Positioning System (GPS). Sampling and analytical precision is expressed as the relative difference in position between the LiDAR and orthophoto data and ground-based survey control points, expressed in centimeters.

4.2.2 Bias

Bias is a measure of the difference between the analytical results for a parameter and the true value due to systematic errors. The primary source of systematic error is equipment calibration. Secondarily, systematic error can be created by improper flight line layout, which can result in uneven data collection in some types of terrain. Since the Kirtland PBR demonstration site is relatively flat, flight line layout is not expected to be a problem. Bias is expressed as positional differences in LiDAR data between one flight line and the next, or between LiDAR and orthophoto positions, that are beyond stated standards and cannot be adjusted out.

4.2.3 Representativeness

Representativeness is a qualitative parameter that expresses the degree to which sample data accurately and precisely represents a characteristic of a population, parameter variations at a sampling point, or an environmental condition. Representativeness of the environmental conditions at the time of sampling is achieved by selecting sampling locations, methods, and data collection times so that the data describe the site conditions that the project seeks to evaluate. In the context of LiDAR and orthophotography, representative sampling is influenced by proper choice of seasonal vegetative conditions (for more vegetated sites), and proper choice of sun angle to best reveal the features being sought. During data processing, representative LiDAR data is obtained by properly separating laser pulses that reflect from the ground surface from those that reflect from vegetation or buildings. Representative orthophotography data are obtained by performing appropriate color balancing on orthophoto mosaics to eliminate the effect of glare or different sun angles on images from flight lines in opposing directions, while still accurately representing the colors of the features being recorded.

4.2.4 Completeness

Completeness is a measure of the number of valid measurements obtained in relation to the total number of measurements planned. In the context of LiDAR and orthophotography, completeness is expressed in percentage of the target area for which data is successfully collected, and for which the data collected meets project specifications. For this demonstration, 100% coverage of the demonstration site is expected.

4.2.5 Comparability

Comparability is a qualitative parameter expressing the confidence with which one data set can be compared to another. During data collection the comparability goal is achieved by maintaining consistency in sampling conditions such as flight altitude, and equipment settings.

These are aimed at having data from each flight line and each flight mission be comparable to the next, and at having the LiDAR and orthophoto data positions be well controlled to ground survey control points to be used by other demonstrators.

During data processing and analysis, comparability is maintained through establishment and execution of appropriate data management and data format standards. This results in data that is organized in a consistent manner, with appropriate metadata to enable other users to understand the data processing steps used and their rationale, and in formats that have been agreed to by other demonstrators and ESTCP.

The following parameters in Table 4-1 will be subject to QA/QC review:

Table 4-1
Data Quality Parameters

Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result
Pre-flight Activities				
Study area boundary delineation	Site Boundary polygon characteristics agreed upon and documented to allow comparison with data collected.	Achieve stakeholder agreement to boundary parameters.	Once, start of program.	Document site boundary for measurement of future boundary metrics.
Survey control point confirmation measurement	Confirm coordinates of survey control points within at least 3rd order accuracy.	Perform and record GPS survey (static or kinematic).	Pre-flight (or during on-site acquisition).	
LiDAR Data Collection and Processing				
Sensor calibration	Resolve roll/pitch/heading for installation.	Perform opposing direction and orthogonal passes over baseline. Compare with nominal values from standard installation.	Prior to each flight day.	+/– 0.02 degrees
Sensor speed[1]	Laser pulse rate between 50-100 kHz.	Set laser pulse speed and the altitude of the low LiDAR passes depending on site conditions to achieve highest possible point density.	Prior to each flight day.	Achieve target sensor speed.
Flight altitude	Flight altitudes of 900, 450, and 200 to 300 m. The two higher altitudes are designed to achieve 10-cm and 20-cm pixel sizes; however, LiDAR will still be collected. The lowest flight altitudes will be adjusted to achieve the highest practical LiDAR point densities.	Establish and fly appropriate flight altitudes for the desired LiDAR point densities and orthophoto pixel sizes. Lay out a series of flight lines for high-density LiDAR collection to be able to respond to site conditions.	Each flight line.	+/– 50 m from planned flight altitudes[2].
Area coverage	100% coverage for each flight.	Establish and fly flight lines so as to cover the entire target area. Data from each day's flights will be examined and data gaps will be filled.	Each flight	100% coverage. 15% flightline overlap, 50m over area boundaries.

[1] Appropriate sensor speed is a site-specific determination based on site reflectivity. Higher speeds result in lower energy per laser pulse, and thus require more a reflective ground surface. Both ground material and flight altitude influence reflectivity.

[2] Flight altitudes significantly above the performance objective will fail the point density test and photo pixel size tests given below and will be repeated.

Table 4-1 (Continued)
Data Quality Parameters

Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result
Data collection rate	Accomplish 2 flights per day, each covering the full site. Reserve 1 additional day for QA/QC and re-flights	Establish and review flight lines and flight schedule prior to data collection.	N/A	Full data collection within planned schedule.
LiDAR point density	Achieve overall densities of: 200 m flights (2) – 8 pts/m^2 each 475 m flight (1) – 3 pts/m^2 950 m flight (1) – 1.5pts/m^2.	Plan and accomplish appropriate sensor speed, flight altitude, and air speed. Flights more than 10% below target point densities will be repeated.	Each flight.	Data collection within 10% of target densities.
LiDAR flight line alignment	The two 200 m flights will be orthogonal.	Appropriate flight lines will be designed and flown. Planned flight lines will be submitted in advance.	Each 200 m altitude flights	Flight lines within 10° of orthogonal.
LiDAR vertical accuracy	Vertical accuracy of +/– 15 cm compared to ground survey.	Steps: 1. Perform sensor calibration as described above 2. Obtain ground elevations on identifiable points using ground based GPS methods (static and/or kinematic) 3. Compare ground-based and airborne elevations.	Each flight	Achieve best possible match between LiDAR and ground-based elevations.
LiDAR horizontal accuracy	Horizontal accuracy of +/– 65 cm compared to ground survey.	Steps: 1. Perform sensor calibration as described above 2. Obtain ground positions on identifiable points using ground based GPS methods (static and/or kinematic) 3. Compare ground-based and airborne positions.	Each flight	Achieve best possible match between LiDAR and ground-based positions.
LiDAR data integration – flight lines	Achieve flight line to flight line edge match of +/– 12cm.	Review statistics from LiDAR processing software.	Line to line	Achieve best possible match between individual LiDAR flight lines.

Table 4-1 (Continued)
Data Quality Parameters

Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result
LiDAR point separation	Remove 100% of large features, (trees, buildings, vehicles) Remove small features (grass, low brush) to the level where remaining data cannot distinguish ground from non-ground features.	Operators remove non-ground laser returns through automated separation routines followed by hand cleaning and inspection.	LiDAR data set for each flight	Satisfactory visual inspection of surface model of the ground surface.
Orthophoto Data Collection and Processing				
Orthophoto area coverage	100% coverage for each flight.	Wireframes of "raw" images are compared to the project boundary to check for gaps or holes.	Each flight day as part of QA/QC checks.	100% coverage with sufficient image overlap for ortho-rectification.
Orthophoto flight altitude / pixel size	475 m (for 10 cm pixel flight) 950 m (for 20 cm pixel flight).	Orthophoto pixel size is directly related to flight altitude. Flight lines are designed for the desired pixel sizes. Flight data will be examined during and after each flight and flight lines outside of the range will be repeated.	Each flight	+/– 50m of design flying altitude.
Orthophoto image mosaicing	No obvious seams between images in the final orthophoto.	Creation of an image mosaic from individual small images is largely an operator controlled rather than an automated process.	Each orthophoto composite image (10 cm and 20 cm)	Line features are continuous with no visible discontinuity at mosaic seams.
Orthophoto image color balancing	No obvious color imbalances within data for each session.[34]	Color balancing is an operator controlled process based on viewing the mosaic to identify any areas of tonal imbalance.	Each orthophoto composite image (10 cm and 20 cm)	Continuity of tone such that individual images are not visible in mosaic.

[3] The final project area outline will determine the number of flight lines and turns necessary to cover the project area. This in turn will determine the duration of each acquisition period. In order to ensure relatively constant sun angle, if necessary, each image acquisition session will be split into two – one early in the day and one late in the day in which the sun-angle is the same with the exception of being in the opposite direction. Tonal balance between the early and late sessions may not be the same at the junction between the two collection areas.

Table 4-1 (Continued)
Data Quality Parameters

Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result
Orthophoto horizontal alignment to LiDAR	LiDAR and orthophotos aligned so that target features are not displaced in the two data sets.	Orthorectification is performed using the LiDAR data and fiducial locations are control data sources, followed by operator adjustment.	Each orthophoto composite image.	Orthophotos aligned to +/– 2 pixel widths.
Orthophoto horizontal alignment to fiducials	Orthophotos aligned to survey control points so that target features are not displaced.	Orthorectification is performed using the LiDAR data and fiducial locations are control data sources, followed by operator adjustment.	Each orthophoto composite image.	Orthophotos aligned to +/– 3 pixel widths.
MRS Identification and Analysis				
MRS identification[4]	Correctly identify all previously identified MRS.	Identify and document MRS from LiDAR and orthophoto data sets.	Each LiDAR and orthophoto data set and combinations.	All MRS
MRS false alarm rate	No areas incorrectly identified as MRS.	Identify and document MRS from LiDAR and orthophoto data sets.	Each LiDAR and orthophoto data set and combinations.	All MRS
MES boundary delineation	Correctly locate MRS boundaries to +/– 15% of ground-truthed area.	Identify and document MRS boundaries from LiDAR and orthophoto data sets for a selected set of test MRS.	Each LiDAR and orthophoto data set and combinations.	All MRS
MRS feature identification	Identify features presenting as human-made (anthropogenic) not including craters (e.g., walls, berms, pits, small buildings).	LiDAR and photo data sets will be examined for linear features.	Each LiDAR and orthophoto data set and combinations.	90% of features identified from selected field-identified features.
MRS feature identification	Identify craters. Count 90% of craters over 1.5 m diameter and .3 m depth.	Automated algorithms will be used to identify and count craters using LiDAR data.	Each LiDAR and orthophoto data set and combinations.	90% of craters identified outside of crater fields. 95% of craters identified inside crater fields.

[4] [4] The analysis described will be performed for each separate LiDAR data set and for the combined LiDAR data set, and for each orthophoto data set and for the combination of LiDAR and orthophotos. The "Desired Result" metric applies to the combination of all

Table 4-1 (Continued)
Data Quality Parameters

Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result
MRS feature identification	Identify vegetation patterns indicating previous disturbance.	Automated algorithms will be used to map vegetation heights and patterns from LiDAR data. Results will be examined for linearity or other regular shapes. Orthophotos will be examined for regular vegetation patterns.	Each LiDAR and orthophoto data set and combinations.	[COMING]
MRS feature identification	Identify established roads	LiDAR and photo data sets will be examined for linear features.	Each LiDAR and orthophoto data set and combinations.	100% of established roads.
MRS feature identification	Identify vehicle tracks	LiDAR and photo data sets will be examined for linear features.	Each LiDAR and orthophoto data set and combinations.	90% of field-identified vehicle tracks.
MRS feature identification	Identify topography that can limit access	LiDAR data sets will be used to map areas above designated slope.	Each LiDAR data set and combinations.	100% of areas.
Data management				
Data management	Data backup and storage to achieve redundancy and security.	Data will be backed up to separate redundant hard drives or tape drives.	Daily backup during field and data processing operations.	All data products.
Data transfer	Data transfer will be in appropriate formats and file sizes for ESTCP and Kirtland AFB ongoing use.	Data will meet US Government Spatial Data Standard (SDS) and fully comply with Versar EDD specifications.	Each data transfer.	All data products.
Data collection report	Standard flight reporting includes: calibration log, flight log, QA/QC log, and site photos.	The data collection report is a standard QA/QC product.	Calibration report: each flight day. Flight log: each flight. QA/QC log: each flight. Site photos: whole project.	Full reporting is a required part of contract performance.
Data processing report	Standard data processing report includes: GPS control ties, accuracy verification report, and QA/QC report.	The data processing report is a standard QA/QC product.	Each LiDAR and orthophoto data set.	Full reporting is a required part of contract performance.

Table 4-1 (Continued)
Data Quality Parameters

Analytical Objective	Metric	Action to Achieve Metric	Sampling Frequency or Timing	Desired Result
Metadata	Metadata to accurately describe data format and processing steps.	Data will meet US Government Spatial Data Standard (SDS) and fully comply with Versar EDD specifications including metadata standards.	Each data transfer.	All data products.
QA/QC	All data and derived products will be subject to appropriate QA/QC review.	Data processing will follow the QA/QC plan described herein.	Each data transfer.	All data products.
Data delivery	All data will be delivered in a timely and easy-to-transfer manner.	Data deliverables will be made using ftp where possible, but in all cases will be followed up with delivery on physical media, primarily external hard drives.	Each data transfer.	All data products.

5.0 CALIBRATION PROCEDURES, QUALITY CONTROL CHECKS, AND CORRECTIVE ACTION

Upon arrival at the site a suitable GPS base station will be established either at one of the survey control points or near the hanger. If a location near the hanger is chosen due to security or operational reasons, a GPS control survey will be conducted to tie the base station into the control points. Targets will also be placed on the survey control points to facilitate identification in the digital images and the intensity image of the LiDAR data. Positions of the survey control points will be verified and any discrepancies immediately noted and transmitted to the URS PI and ESTCP PM.

Initial equipment calibration will be performed following equipment installation to the helicopter. Calibration will be done by means of a calibration flight, during which test data will be collected to determine optimal system operation parameters for data acquisition. This will involve collecting data at varying heights above ground between 200m and 300m with variations in the laser pulse rate (PRF).

Equipment calibration will be checked prior to each day's flight missions. GPS data will be processed and checked each day for DOPS and quality of solution. The redundant base station will be processed to verify the solution and obtain the best-fit positions.

The following QA/QC checks will be made to verify equipment calibration and data quality:

a) LiDAR
Following each day's flights, the initial calibration values will be used to process the airborne data to obtain the LiDAR points. The points will be viewed visually to inspect the coverage with respect to the overall project boundary in order to verify complete coverage. Flight lines can be displayed in different colors to allow measurement of overlap as well as checking of height variations in the overlap region. Point densities will be calculated on sample areas throughout the project to verify compliance with specifications. Visualization tools are used to manipulate the points to check for comparison of features and general alignment of the data.

b) Imagery
Following each day's flights, "raw" images will be checked individually for completeness and exposure. Images with significantly abnormal exposure such as bright spots due sun glint off ground objects will be flagged for re-flight. Using an initial ground model from the LiDAR data, the wire frame outlines of the individual images will be draped onto the ground model to determine the true coverage of each photo image. The image coverage will be reviewed for gaps within the flight lines and extents to the project perimeter. Measurements are also made on the frames to validate compliance of end-lap and side-lap with project specifications.

Following return of the data to the office, field calibration will be reviewed and fine-tuned. Following QC checks, calibration factors will be applied to laser range, GPS, and INS data to

produce x,y,z values for each LiDAR point. Points are then transformed into the delivery datum and map projection. Subsequently, the points are separated into returns from ground, vegetation and buildings. Following point separation, separate x,y,z files (in ASCII comma-delimited format) will be created for ground, vegetation and building returns for each of the four flights and delivered to URS. Calibration of orthophoto images to the LiDAR surface model and the survey control points will be performed using standard orthorectification software methods.

6.0 DEMONSTRATION PROCEDURES

6.1 FIELD ANALYTICAL PROCEDURES

Technology startup includes setting out of GPS receivers over base stations and starting. The helicopter system is started including sub-systems of GPS, INS, navigation control, and logging systems. Checks are made to ensure correct operation, flight line data is uploaded and verified. Once ground operation is verified the helicopter commences flight to the lines to be flown, during this time while aloft, the LiDAR system operation is verified (this is done aloft to prevent damage to the system firing too close to the ground). Following verification of system operation, data collection is then undertaken.

During data collection all systems are monitored to verify continuous correct operation. Should a failure occur, airborne procedures to rectify the system will be implemented including resetting various portions of the system. Should these procedures not be effective, depending on the nature of the failure, the helicopter will land in the project area or return to the base for further corrective actions.

6.2 LABORATORY ANALYTICAL PROCEDURES

Laboratory procedures include a further review of all calibration data to refine the calibration for the system installation. Following this checks are made on the fiducials and any other available control points or ground data. If the checks meet specifications, the LiDAR data is passed on to the TM (Terrain Mapping) group for processing to extract the bare earth model while the image data is passed to the Ortho group for creation of the mosaic's.

Creation of the bare-earth model through classification of the raw LiDAR points includes both automated process and manual reviews of the data. Surfaces and contours may be created to identify areas that have not been correctly classified.

7.0 CALCULATION OF DATA QUALITY INDICATORS

This section outlines the procedures for verifying the accuracy of the data reduction and analysis process and the methods used to ensure that data transfer is error free (or has an admissible error rate), that no information is lost in the transfer process, and that the output is completely recoverable from the input. To reduce the risks associated with data transfer, this process is kept to a minimum. Data are reduced either manually on calculation sheets or by computer on formatted printouts. The following responsibilities will be delegated in the data reduction process:

- Technical personnel will document and review their own work and are accountable for its correctness.

- Major calculations will receive both a method and an arithmetic check by an independent checker. The checker is accountable for the correctness of the checking process. The checker is also responsible for becoming familiar with the project requirements and criteria; and bringing to the URS PI's attention any problems uncovered.

- The URS PI is responsible for ensuring that data reduction is performed in a manner that produces quality data through review and approval of calculations.

In general, any personnel performing review or oversight shall provide resumes or equivalent documentation demonstrating their qualifications and experience needed to perform their duties. In addition, each assessor shall be independent of the process under evaluation. Independent Technical Review for this project will be performed by ESTCP or its designated subcontractors.

7.1 DATA QUALITY CALCULATIONS

The following methods will be used to calculate data quality.

Table 7-1
Data Quality Metric Calculation

Analytical Objective	Metric	Action to Achieve Metric	Desired Result	Calculation Method
Survey control point confirmation measurement	Confirm coordinates of survey control points within at least 3rd order accuracy.	Perform and record GPS survey (static or kinematic).	3rd order accuracy	(x,y,z locations of confirmation survey) – (reported x,y,z locations)
Sensor calibration	Resolve roll/pitch/heading for installation.	Perform opposing direction and orthogonal passes over baseline. Compare with nominal values from standard installation.	+/– 0.02 degrees	(x,y,z locations of control points) – (x,y,z locations from sensors)
Sensor speed	Laser pulse rate between 50–100 kHz.	Set laser pulse speed and the altitude of the low LiDAR passes depending on site conditions to achieve highest possible point density.	Achieve target sensor speed.	Examination of sensor output, calculation of point densities
Flight altitude	Flight altitudes of 900, 450, and 200 to 300 m.	Establish and fly appropriate flight altitudes for the desired LiDAR point densities and orthophoto pixel sizes. Lay out a series of flight lines for high-density LiDAR collection to be able to respond to site conditions.	+/– 50 m from planned flight altitudes.	In-flight monitoring, examination of GPS flight line data,
Area coverage	100% coverage for each flight.	Establish and fly flight lines so as to cover the entire target area. Data from each day's flights will be examined and "holes" filled.	100% coverage. 15% flightline overlap, 15% flightline length over area boundaries.	(Area flown) – (Area of demonstration site) plus visual inspection
LiDAR point density	Achieve overall densities of: 200- to 300-m flights (2) – 8 pts/m^2 each 475-m flight (1) – 3 pts/ m^2 950-m flight (1) – 2 pts/ m^2.	Plan and accomplish appropriate sensor speed, flight altitude, and air speed. Flights more than 10% below target point densities will be repeated.	Data collection within 10% of target densities.	Density = (# of points)/(area in meters)
LiDAR flight line alignment	The two 200 m flights will be orthogonal.	Appropriate flight lines will be designed and flown. Planned flight lines will be submitted in advance.	Flight lines within 10° of orthogonal.	Angle of intersection will be measured.

Table 7-1) Continued)
Data Quality Metric Calculation

Analytical Objective	Metric	Action to Achieve Metric	Desired Result	Calculation Method
LiDAR vertical accuracy	Vertical accuracy of +/– 15 cm compared to ground survey.	Steps: 1. Perform sensor calibration as described above 2. Obtain ground elevations on identifiable points using ground based GPS methods (static and/or kinematic) 3. Compare ground-based and airborne elevations.	Achieve best possible match between LiDAR and ground-based elevations.	(z locations of control points) – (z locations from sensors)
LiDAR horizontal accuracy	Horizontal accuracy of +/– 65 cm compared to ground survey.	Steps: 1. Perform sensor calibration as described above 2. Obtain ground elevations on identifiable points using ground based GPS methods (static and/or kinematic) 3. Compare ground-based and airborne elevations.	Achieve best possible match between LiDAR and ground-based elevations.	(x,y locations of control points) – (x,y locations from sensors)
LiDAR data integration – flight lines	Achieve flight line to flight line edge match of +/– 12cm.	Review statistics from LiDAR processing software.	Achieve best possible match between individual LiDAR flight lines.	(x,y,z locations from flight lines compared visually and through automated software matching
LiDAR point separation	Remove 100% of large features, (trees, buildings, vehicles) Remove small features (grass, low brush) to the level where remaining data cannot distinguish ground from non-ground features.	Operators remove non-ground laser returns through automated separation routines followed by hand cleaning and inspection.	Satisfactory visual inspection of surface model of the ground surface.	Visual inspection following automated and operator implemented separation
Orthophoto area coverage	100% coverage for each flight.	Wireframes of "raw" images are compared to the project boundary to check for gaps or holes.	100% coverage with sufficient image overlap for ortho-rectification.	(Area flown) – (Area of demonstration site) plus visual inspection

Table 7-1) Continued)
Data Quality Metric Calculation

Analytical Objective	Metric	Action to Achieve Metric	Desired Result	Calculation Method
Orthophoto flight altitude / pixel size	475 m (for 10 cm pixel flight) 950 m (for 20 cm pixel flight).	Orthophoto pixel size is directly related to flight altitude. Flight lines are designed for the desired pixel sizes. Flight data will be examined during and after each flight and flight lines outside of the range will be repeated.	+/– 50m of design flying altitude.	In-flight monitoring, examination of GPS flight line data,
Orthophoto image mosaicing	No obvious seams between images in the final orthophoto.	Creation of an image mosaic from individual small images is largely an operator controlled rather than an automated process.	Line features are continuous with no visible discontinuity at mosaic seams.	Visual inspection
Orthophoto image color balancing	No obvious color imbalances.	Color balancing is an operator controlled process based on viewing the mosaic to identify any areas of tonal imbalance.	Continuity of tone such that individual images are not visible in mosaic.	Visual inspection.
Orthophoto horizontal alignment to LiDAR	LiDAR and orthophotos aligned so that target features are not displaced in the two data sets.	Orthorectification is performed using the LiDAR data and fiducial locations are control data sources, followed by operator adjustment.	Orthophotos aligned to +/– 2 pixel widths.	(x,y locations of LiDAR points) – (x,y locations of photo pixels) at target locations
Orthophoto horizontal alignment to fiducials	Orthophotos aligned to survey control points so that target features are not displaced.	Orthorectification is performed using the LiDAR data and fiducial locations are control data sources, followed by operator adjustment.	Orthophotos aligned to +/– 3 pixel widths.	(x,y locations of photo pixels) – (x,y locations of control points) at target locations
MRS identification[5]	Correctly identify all previously identified MRS.	Identify and document MRS from LiDAR and orthophoto data sets.	All MRS	
MRS false alarm rate	No areas incorrectly identified as MRS.	Identify and document MRS from LiDAR and orthophoto data sets.	All MRS	(# of MRS previously identified) – (# of MRS identified from demonstration data)

[5] The analysis described will be performed for each separate LiDAR data set and for the combined LiDAR data set, and for each orthophoto data set and for the combination of LiDAR and orthophotos. The "Desired Result" metric applies to the combination of all available data. It is currently unknown whether the metric can be achieved for some portion of the data rather than the combined data set.

Table 7-1) Continued)
Data Quality Metric Calculation

Analytical Objective	Metric	Action to Achieve Metric	Desired Result	Calculation Method
MES boundary delineation	Correctly locate MRS boundaries to +/– 15% of ground-truthed area.	Identify and document MRS boundaries from LiDAR and orthophoto data sets for a selected set of test MRS.	All MRS	(area of MRS previously identified) – (area of MRS identified from demonstration data), plus visual inspection
MRS feature identification	Identify features presenting as human-made (anthropogenic) not including craters (e.g. walls, berms, pits, small buildings).	LiDAR and photo data sets will be examined for linear features.	90% of features identified from selected field-identified features.	(# of features previously identified) – (# of features identified from demonstration data)
MRS feature identification	Identify craters. Count 90% of craters over 1.5 m diameter and .3 m depth.	Automated algorithms will be used to identify and count craters using LiDAR data.	90% of craters identified outside of crater fields. 95% of craters identified inside crater fields.	(# of craters identified from demonstration data) – (# of craters identified through field verification)
MRS feature identification	Identify vegetation patterns indicating previous disturbance.	Automated algorithms will be used to map vegetation heights and patterns from LiDAR data. Results will be examined for linearity or other regular shapes. Orthophotos will be examined for regular vegetation patterns.	[TBD]	Visual inspection
MRS feature identification	Identify established roads	LiDAR and photo data sets will be examined for linear features.	100% of established roads.	Comparison of roads located from demonstration data to roads identified by on-site inspection.
MRS feature identification	Identify vehicle tracks	LiDAR and photo data sets will be examined for linear features.	90% of field-identified vehicle tracks.	Comparison of tracks located from demonstration data to tracks identified by on-site inspection.
MRS feature identification	Identify topography that can limit access	LiDAR data sets will be used to map areas above designated slope.	100% of areas.	Comparison of slope data derived from demonstration data with reports of on-site inspection.

7.2 HAND CALCULATIONS

Hand calculations will be legibly recorded on calculation sheets and in a logical progression, with sufficient descriptions. Major calculations will be checked by a professional at a level equal to or higher than that of the originator. After completing the check, the checker will sign and date the calculation sheet immediately below the signature of the originator. Both the originator and checker are responsible for the correctness of calculations. A calculation sheet contains the following, at a minimum:

- Project title and brief description of the task
- Task number and date performed
- Signature of person who performed the calculation
- Basis for calculation
- Assumptions made or inherent in the calculation
- Complete reference for each source of input data
- Methods used for calculations
- Results of calculations, clearly annotated

7.3 COMPUTER ANALYSIS

Computer analysis includes the use of models, programs, and data management systems. For published software with existing documentation, test case runs are periodically performed to verify that the software is performing correctly. Both systematic analysis and random error analysis are investigated and appropriate corrective action measures are taken as needed.

8.0 QUALITY ASSURANCE AUDITS AND REPORTS

8.1 STATUS REPORTS

Status reporting will occur throughout the project. Status reporting is designed to verify and record quality assurance activities in order to ensure that data quality meets project specifications. During field data collection, status reporting will be made by the Operations Manager in charge of data collection for TRSI; these reports will be delivered to the URS PI and the URS QAO. During data processing and analysis by URS, status reporting will occur during each phase of the analysis, and will consist primarily of URS QA/QC forms documenting the design of analysis methods and review of resulting products for compliance with project specifications. These reports will be signed by the Assistant Investigator and delivered to the URS PI and the URS QAO.

Status reporting for each phase of the project will take place as follows:

Pre-flight—A report will be made to URS of pre-flight activities, including the following:

- Survey control point(s) established, their locations and ties to established control
- Confirmation of locations for established control points.
- Results of calibration flights and any adjustments made.
- Selection and documentation of sensor parameters for low-level LiDAR flights, and associated planned flight lines.

Data Collection Flights—A daily QA/QC report will be made to URS, including the following items:

- GPS solution quality. Results of daily GPS check.
- Flight logs showing time, orientation, and altitude for each flight line.
- Actual flight lines from GPS records during each flight.
- Area coverage for LiDAR and images.
- LiDAR point density.

INITIAL DATA PROCESSING TO CREATE LIDAR POINTS AND ORTHOPHOTO MOSAICS—A QA/QC REPORT WILL ACCOMPANY DELIVERY OF PRIMARY DATA TO URS, INCLUDING THE FOLLOWING ITEMS:

- Calibration factors for creation of LiDAR points.
- Horizontal and vertical positional accuracies for LiDAR points and orthophoto pixels.
- Final LiDAR point densities for each LiDAR flight.

Creation of Initial GIS Products—A URS QA/QC form will be completed for each of the following steps:

- Setup of project data directories. This report will document file locations, file types, data attribute types, and compliance with EDD standards.
- Finalizing of GIS-based analysis methods. This report will document analysis methods.
- Completion of each major phase of analysis, documenting results and comparison to project specifications.

Delivery of Data and GIS Products to ESTCP—A QA/QC report will accompany all data delivered to ESTCP, documenting review of data deliverable formats and compliance with EDD specifications.

8.2 AUDITS

Systems and performance audits and surveillances are conducted as the principal means to determine compliance with the project-specific documents. Audits and surveillances are used to formally review individual projects during their course and across all levels of management. The QAO has the primary responsibility for conducting audits and surveillances, portions of which may be delegated to an auditing team of senior technical specialists. No specific audits have been planned during the field and analysis activities due to their limited duration.

Technical specialists must be familiar with the technical and procedural requirements of both field and office operations, as well as the associated QA plans. In addition, auditors may not be directly involved with the actual tasks themselves to ensure no introduction of bias into the auditing process.

An audit or surveillance may be initiated (if required) prior to the award of a subcontract to determine the capability of a potential subcontractor, when reorganization or major revision has been made to the project-specific plans, at any time a nonconformance is suspected, or to verify that corrective actions for nonconformance have been implemented.

QA audits include auditor identification, audit notification, audit reporting, identification of nonconformances, establishment of corrective actions, and audit completion notification. In circumstances where corrective actions have not been completed as planned or scheduled, the auditing process provides for management intervention to resolve problems and for issuance of stop work orders, if necessary.

Two types of audits may be performed, a performance audit or a technical system audit. Performance audits will be conducted for this project to determine the status and effectiveness of field data collection and to provide a quantitative measure of the quality of data generated. Field performance will be evaluated by URS through review of the LiDAR and orthophoto data compared to project specifications. This review will include:

- Review of LiDAR point horizontal and vertical locations compared to survey control point locations.
- Review of LiDAR point density for each flight compared to project specifications.
- Review of LiDAR point separation to create bare-earth point sets without influence of vegetation.
- Review of orthophoto image quality.
- Review of orthophoto pixel locations in comparison to LiDAR and survey control points.

Technical system audits are used to confirm the adequacy of the data collection (field operation) and data generation (laboratory or office operation) systems. The on-site audits are conducted to determine whether the project-specific plans and field and laboratory SOPs are being properly implemented. Technical audits are not planned for this project; however, if substantial nonconformances are identified or if there is concern regarding the quality of data and related documentation, then technical system audits will be employed.

8.3 INDEPENDENT TECHNICAL REVIEW AND READINESS REVIEW

An independent technical review is a documented critical review of work of a substantive nature identified as a deliverable. These reviews will be conducted by experienced and qualified personnel to ensure the quality and integrity of tasks and products by allowing the work and/or deliverable to undergo objective, critical scrutiny. For this demonstration, independent technical review will be performed by ESTCP or is designated agents.

8.4 CORRECTIVE ACTIONS

Evaluation of QC data and review of audits conducted for field and analysis operations may indicate the need for a corrective action. Problems arising with QA data will be addressed by the URS QAO through communication of the identified problem and a potential corrective action to the URS PI. The URS PI will relay this information to the project staff for implementation. Project staff will then report back to the URS PI upon successful implementation of the corrective action. All corrective actions are required to be documented. This documentation shall include at a minimum the description of the problem, when the problem was discovered, how it was communicated, and specifics of the response action.

9.0 DATA FORMAT AND STORAGE

9.1 DATA FORMAT

Project data will be collected primarily by sensors in electronic formats. Some data, however, will be collected by hand.

Hand-collected data includes GPS survey data to establish control points, calibration checklists, records of equipment settings, and flight logs. All hand data entries will be made and dated on the day of entry and signed or initialed by the person entering the data. Any change to an entry will not obscure the original entry, will indicate the reason for the change, and will be dated and initialed by the person making the change.

Electronic data will be collected by the GPS, IMU, LiDAR sensor and digital camera. The person responsible for equipment operation for each flight will be identified and recorded through initials on the field data collection sheet at the conclusion of each flight. Changes are not made to automated data entries, which are preserved in their original form. Update of automated data is accomplished only through re-flight, which creates a new data set. All electronic data contains the date and time of collection, which is automatically recorded. Repeat data sets covering the same area can be distinguished from this time stamp, however all external hard drives will be labeled with the date of collection and the project number and area name.

Following each day's flight missions, data will be reviewed as describe above to verify that data has been accurately recorded. Unforeseen circumstances that may affect the integrity of the demonstration include weather problems, equipment malfunction and failure of hard drives used for data storage. Equipment function is monitored by the operator and through automated systems throughout each data collection flight, and the impact of hard drive failure is minimized through creating a duplicate copy of all data. Weather problems will be addressed through re-scheduling of data collection activities as needed. Unanticipated problems will also be addressed through scheduling of an extra flight day past the two flight days needed in order to repeat unsatisfactory flights.

9.2 DATA STORAGE AND ARCHIVING PROCEDURES

LiDAR and orthophotography both involve collection of large quantities of data, which limits the usefulness of data storage methods such as CDs or DVDs. Large project areas can sometimes involve too much data for network backup tapes, although this is not expected to be the case for the Kirtland PBR demonstration. The principle data storage method consists of redundant external hard drives. The standard URS and TRSI procedure is as follows:

- During data collection, LiDAR and camera image data is recorded directly to the hard drive of the sensor package. At the end of each flight this data is copied to external hard

drives. Two copies are made, one of which is sent to the TRSI office for processing, and one of which is retained as a backup.

- During data processing to create and calibrate the LiDAR points orthophoto mosaics, data is backed up nightly. Backup drives are stored off-site. [CONFIRM OFF-SITE STORAGE]

When data processing has been completed, data is transferred to the URS office for analysis. Transfer is either by external hard drive or ftp transfer depending on file sizes. A copy is retained as backup.

At the URS office, data is copied to external hard drive and to the URS corporate network. During processing and analysis, files are backed up nightly; backup tapes are stored off-site. Upon completion of analysis, data will be transferred to ESTCP and a copy retained on external hard drive as backup, in addition to the corporate network backup tapes.

Data availability following changes in key personnel is accomplished through two standard procedures. First, a file naming and location protocol is established at the beginning of the project, and this information is recorded in the project files. File naming conventions, which are recorded in writing, include metadata regarding the provenance of all data files including primary data, intermediate analytic products, and final products. Second, all GIS products include metadata that will meet the specifications of the Electronic Data Deliverable (EDD) specifications.

10.0 REFERENCES

URSG (URS Greiner, Inc.). 1998. *Quality Management Plan.* June 1998.

ATTACHMENT A

TECHNICAL REVIEW QA/QC FORM

Technical Review QA/QC Form

To be completed by technical reviewers. This form is used to document technical review of methods and products.

APPENDIX H

Health and Safety Plan

HEALTH AND SAFETY PLAN
LiDAR AND ORTHOPHOTOGRAPHY
DEMONSTRATION PROJECT
KIRTLAND PRECISION BOMBING RANGE, NEW MEXICO

Approvals

Name: Thomas Tomczyk, P.G., L.G., C.Q.A.
Title: Principal Investigator
URS Group, Inc.

Signature: _____ Date: _____

Name: Dale Bennett
Title: Assistant Investigator
URS Group, Inc.

Signature: _____ Date: _____

Name: Dave Neufeldt
Title: LiDAR / Orthophotography Technical Lead
Terra Remote Sensing, Inc.

Signature: _____ Date: _____

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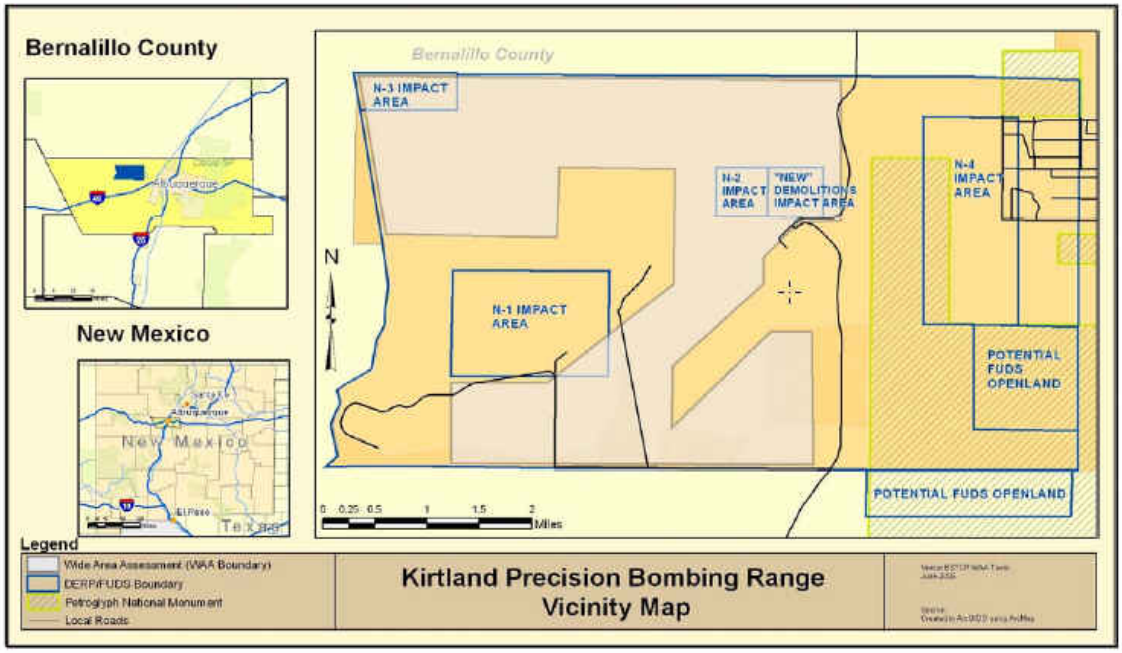
ABBREVIATIONS AND ACRONYMS

ESTCP	Environmental Security Technology Certification Program
EPA	U.S. Environmental Protection Agency
HASP	Health and Safety Plan
MEC	Munitions and Explosives of Concern
PBR	Precision Bombing Range
PI	Principal Investigator
SSR	Site Safety Representative
TRSI	Terra Remote Sensing, Inc.
URS	URS Group, Inc.
URS PI	URS Principal Investigator

1.0 INTRODUCTION

This document serves as the health and safety plan (HASP) for the Environmental Security Technology Certification Program (ESTCP) Demonstration Project entitled "High Density LiDAR and Orthophotography in UXO Wide Area Assessment", to be performed at the former Kirtland Precision Bombing Range (PBR), New Mexico (Figure 1-1). This HASP has been prepared to describe the procedures that will be implemented to manage the health and safety aspects of the demonstration. This HASP complies with, but does not replace, applicable Federal, State and local regulations. This HASP is to be used by URS and subcontract personnel as a supplement to these rules, regulations, and guidance. For URS employees, this HASP is to be augmented by applicable provisions of the Demonstration Plan, along with the URS Health and Safety Program and Management System; relevant standards from that program and system are required to be available on site during all activities.

Figure 1-1 Kirtland AFB PBS Vicinity Map



2.0 ORGANIZATION SAFETY RESPONSIBILITIES

2.1 RESPONSIBILITIES

The following subsections describe personnel with safety-related duties and their specific responsibilities.

2.1.1 URS Principle Investigator (PI)

The URS PI is responsible for all site operations and project implementation. In addition, the PI performs the following duties:

- Ensures adequate resources are available to implement and carry out all site safety activities
- Ensures that all personnel assigned to the site have received the necessary health and safety training
- Familiarizes all on-site personnel with the site safety requirements
- Assigns key safety duties and responsibilities to team members
- Ensures that all necessary personal protective equipment (PPE) is available and on site.

2.1.2 Subcontractor Safety Representative

Each subcontractor is requested to designate a Subcontractor's Safety Representative (SSR) who is the subcontractor supervisor. URS will consider the SSRs responsible for the safe and healthful performance of work by their work force and subcontractors. During subcontractor activities on site, the SSR will perform continuing work area inspections, and conduct safety meetings and safety orientations for all his subcontractor employees. The SSR will attend all safety meetings and will also investigate accidents and overexposures involving subcontractor personnel.

2.1.3 TRSI

Safety is an integral part of Terra Remote Sensing Inc.'s (TRSI) day-to-day activities. It is our first priority in the performance of our work. The protection of people, equipment, property and the public is an attitude that is emphasized and rewarded in all of our operations.

The economic benefits of working safely far outweigh the costs of non-compliance. The greatest cost is the human cost. By protecting our employees, TRSI is also protecting their friends, families, fellow workers, management, the public and the environment.

Protection of one's livelihood is first and foremost with our safety program. This program will also contribute to employee morale and pride because of their involvement in identifying safety needs and developing safe work procedures.

TRSI will ensure that recognized health and safety standards and legal requirements are met through the provision of adequate facilities, equipment, procedures, training and management systems.

Everyone employed by TRSI is responsible for maintaining our safety program. Supervisors and managers are responsible for identifying safety needs, communicating safety hazards, investigating hazardous conditions and accidents, providing training, supplying or wearing appropriate safety and personal protective equipment, and ensuring all equipment is properly maintained and meets legislated safety standards. Their role is supported by input from all employees.

All company employees, contractors and subcontractors on company worksites are responsible for obeying all safety rules, following recommended safe work procedures, wearing and using personal protective equipment when required, participating in safety training programs and informing party chiefs of any unsafe work conditions. Everyone has the right and responsibility to refuse to do work when unsafe conditions exist.

TRSI takes the approach that safety, and all of the implications of a health and safety program are part of an overall attitude expressed by all of its employees, supervisors and managers. An open and ongoing dialogue on all aspects of loss prevention is paramount to the well being of all concerned. By fulfilling our safety responsibilities, everyone who works for our company will share the benefits of a safe workplace.

2.1.4 AeroWest Helicopters

AeroWest Helicopters, Inc. is a full-service helicopter company based at the Double Eagle airport on the demonstration site. AeroWest is regulated under FAR 135, Operating Requirements: Commuter and On-Demand Operations and Rules Governing Persons On Board Such Aircraft, promulgated by the Federal Aviation Administration. AeroWest is certified under these regulations; a copy of the certification is attached and further information is available upon request. Additional material submitted by AeroWest includes that the company flies an average of 2500 hours per year and has never had a passenger hurt since operations were initiated in 1984.

Table 2-1.
Project Safety Contacts

Key Role	Name	Telephone
On-Site Emergencies		
Any emergency		911
Ambulance		911
Kirtland PBR / Double Eagle Airport Manager		(505) 244-7888
Fire		911 or
University of New Mexico Hospital, Albuquerque		(505) 272-2111
URS		
URS Principal Investigator	Tom Tomczyk	(206) 438-2137
URS Health and Safety Manager	Mark Litzinger	(206) 438-2199
TRSI		
TRSI Site Safety Officer		(xxx) xxx-xxxx

[1] In the event of an emergency, the URS PI and the ESTCP PM are to be notified immediately.

3.0 PERSONNEL MEDICAL QUALIFICATIONS AND TRAINING REQUIREMENTS

Team members performing critical functions, such as pilot, must have a physical examination prior to participation in field activities to verify that the worker is capable of performing those duties, and is free of medical conditions that may be aggravated while performing those duties. All site personnel will participate in an initial safety briefing, followed by daily briefings to discuss the effectiveness of controls and overall project safety. All necessary certifications and licenses will be produced prior to mobilization and a copy of the documentation will be kept on site.

4.0 SITE HAZARD ANALYSIS

This section describes the physical hazards that may be encountered during site operations.

4.1 LASER

TRSI uses a class 4 laser in their aerial survey equipment MPE (Maximum Permissible Exposure) and NHZ (Nominal Hazard Zone) have been calculated and demonstrate that the current laser is a potential hazard during indoor scenarios only. Indoor control measures have been implemented to reduce the possibility of exposure to the beam.

During the intended operation (outdoors) of the survey laser, the laser beam is fully enclosed except at the scanning mirror that disperses the laser down onto the earth's surface. The remote sensing pod is located on the underside of the aircraft where access is not possible during data collection. Therefore, immediately at the output aperture, the NHZ computation is not applicable. For distal outdoor targets, NHZ is not applicable as the beam is collimated at high altitude. Plus, the likelihood is very small that a subject on the ground will be exposed to more than one pulse of the laser because the laser is reflected in multiple directions at a high rate combined with the velocity of the aircraft. As standard safety precautions, the scanner is always running prior to laser initiation and the laser is not energized until the aircraft carrying the unit is 100m above ground.

4.2 AIRCRAFT

TRSI's aerial survey process requires the use of a helicopter or fixed wing aircraft. These aircrafts are chartered and the responsibility of flying the aircraft is with the subcontractor. Hazards associated with these transportation vehicles ranges from Class I to III and are: crash resulting in injury or fatality, struck by rotor or propeller, noise, stranded in remote location, hot exhaust, improper storage of equipment. TRSI employees working around aircraft follow general helicopter and fixed wing safety rules and guidelines, and follow instructions from the contracted pilot.

4.3 OTHER POTENTIAL HAZARDS

MEC. MEC may be present in the study area. Survey personnel are not expected to be on the ground outside of the airport for extended periods. If personnel do encounter MEC, avoid the item and contact the Site Safety Officer.

Heat Stress. Heat stress is considered an issue when the ambient temperature exceeds 70°F. Personnel are expected to keep hydrated by consistent intake of fluids, especially water. If

5.0 EMERGENCY RESPONSE

Injuries that occur at job sites must be handled quickly and competently. When serious injuries, breathing difficulties, intense pain, or unconsciousness occur, site personnel will immediately seek help from professional paramedics using a building phone or cellular phone and dialing **911**. For non-life-threatening injuries that do not impair driving ability, site personnel will drive to the hospital. If driving ability is affected by the injury, site personnel will use the designated phone to call **911** for assistance.

A first aid kit will be available at the site to treat minor injuries. First aid responders should protect themselves from contact with blood and other human body fluids by wearing latex gloves or establishing an equivalent barrier. Antiseptic wipes and latex gloves should be carried in the first aid kit. First aid responder's hands should be washed with hot, soapy water as soon as possible after first aid treatment is administered. All injuries will be reported to the PI as soon as possible.

After making initial contact with PI, and within 24 hours of a serious injury of fatality, a Contractor Significant Incident Report (CSIR) must be submitted. If the mishap is a lost-time or a recordable incident, submit the CSIR within 5 days of the incident.

symptoms of heat stress are observed, immediate rest and monitoring of the individual is imperative.

Traffic. Air and vehicle traffic at the site is expected to be moderate to heavy and personnel should exercise caution at the airport and on or near roadways. Communication with air traffic controllers and ground crews is vitally important and will be constantly monitored.

Noise. High noise levels may be encountered during flight operations. Noise and hearing conservation practices will be in effect.

Slip-Trip-Fall Hazards. Care will be taken to ensure proper footing and handholds, particularly if wet conditions make the ground surface or hand/sampling tools slippery. The sampling area will be kept uncluttered. Good housekeeping around equipment will be enforced.

Back Injuries. Workers will use proper lifting techniques, lifting with the legs and not the back. Lifting loads over 50 pounds require a second person or mechanical device. Whenever possible, mechanical devices should be used to lift or move heavy loads.

Hand Tools. Eye injuries, puncture wounds, cuts, or lacerations could result from use of hand tools while collecting samples or repairing equipment. Tools should be in good condition and the right tool should be selected for the job. Safety glasses with side shields or safety goggles should be worn whenever projectiles are a potential problem. Loose clothes or jewelry will not be worn because they could get caught in moving equipment. Steel-toed shoes should be worn when there is any risk that something could fall on the foot. Tools should be stored safely, with sharp edges protected.

Screwdrivers should not be used as chisels, because their tips could break or fly off. The head could fly off a hammer with a loose or cracked wooden handle. Impact tools such as chisels or wedges with mushroomed heads might shatter on impact, sending sharp fragments flying. Knives, saw blades, and scissors must be sharp.

APPENDIX I

Points of Contact

POINTS OF CONTACT

Name	Organization and Address	Phone/Fax/email	Role in Project
Jeffrey Marqusee	ESTCP 901 North Stuart St. Suite 303 Arlington, VA 22203	703-696-2120 703-696-2114	Director, ESTCP
Anne Andrews	ESTCP 901 North Stuart St. Suite 303 Arlington, VA 22203	703-696-3826 703-696-2114	Program Manager, Munitions Management
Herb Nelson	Naval Research Lab 1155 Herndon Parkway Suite 900 Herndon, WA 20170	202-767-3686 202-404-8119 Herb.nelson@nrl.navy.mil	Project Manager, ESTCP Wide Area Assessment Pilot Program
Dale Bennett	URS 1501 4th Ave Suite 1400 Seattle WA 98101-1616	206-438-2026 206-438-2699 dale_bennett@urscorp.com	Data Evaluation and GIS Lead
Rick Quinn	TRSI 1962 Mills Road Sidney BC Canada V8L 5Y3	250-656-0931 250-656-4604 rick.quinn@terraremote.com	Terra Remote Sensing Principle in Charge
Jim Vosberg	TRSI 1962 Mills Road Sidney BC Canada V8L 5Y3	250-656-0931 250-656-4604 jim.vosberg@terraremote.com	Terra Remote Sensing Operations Manager
Bill Rohrer	URS 1501 4th Ave Suite 1400 Seattle WA 98101-1616	206-438-2296 206-438-2699 bill_rohrer@urscorp.com	Senior QA/QC