UPPER JAMES RIVER WATERSHED
LIDAR MAPPING INITIATIVE

3RD PARTY QUALITY ASSESSMENT REPORT
Block J

PREPARED FOR:
TED STANTON MVS
CARTOGRAPHER
USACE, ST. LOUIS DISTRICT

March 2012

PREPARED BY:
KADRMAS, LEE & JACKSON, INC.
128 SOO LINE DRIVE
BISMARCK, ND 58501

Kadrmas
Lee &
Jackson
Engineers Surveyors
Planners

Project # 50610128

CERTIFICATION

I hereby certify this survey plan, or report, was prepared by me or under my direct supervision, and that I am a duly licensed professional Land Surveyor under the laws of the State of North Dakota.

___________________________	______________________________
Ross R Wamre	Daniel Wagner
NDPLS ND 4626	NDPLS ND 7193

Quality assurance oversight has been provided by me during project completion. I certify I have reviewed the work products in accordance with the specifications and criteria contained in herein.

____
Jeff Price
GIS Analyst II

PREPARED BY:
KADRMAS, LEE & JACKSON
128 SOO LINE DRIVE
BISMARCK, ND 58501
PHONE 701-355-8400
FAX 701-355-8781

APPROVED BY:

KL&J Project No. 50610128

Kadrmas
Lee &
Jackson
Engineers Surveyors
Planners

TABLE OF CONTENTS

1 Introduction 1
  1.1 Project Overview 1
  1.2 Project Specific Area Overview 1
2 Quality Assurance Consideration 4
  2.1 References 4
  2.2 Performance Specifications for LiDAR Products Established by the Contract 4
  2.3 Chain of Custody 5
  2.4 Quality Assurance Unit 5
  2.5 Collection of Known Elevations in the Field 5
  2.6 Computing the $\text{RMSE}_{(z)}$ 7
  2.7 Visual Assessment 8
3 Quality Assurance Results and Conclusions for Block J 8
  3.1 Results 8
    3.1.1 Vertical Accuracy 8
    3.1.2 Visual Assessment 10
    3.1.3 Concurrence with the Specification 10
4 Tables 11
5 Appendix A – Chain of Custody 13
6 Appendix B – Screen Captures of LiDAR Anomalies/Artifacts/Errors 14
7 Appendix C – Federal Geodetic Standard Guidelines for GPS Accuracy 17
8 Appendix D – CD Enclosure of KL&J Survey Checkpoints 27

1 INTRODUCTION

1.1 Project Overview

The DOI US Fish and Wildlife Service (USFWS) and the USDA Natural Resources Conservation Service (NRCS) in North and South Dakota contracted Fugro Horizons, Inc. to acquire detailed surface elevation data for use in conservation planning, design, research, delivery, floodplain mapping and hydrologic modeling utilizing LiDAR technology.

Fugro Horizon's, Inc. has retained Kadrmas, Lee & Jackson, Inc. (KL&J) as an independent contractor to provide quality assurance including completeness, qualitative and quantitative reviews for final acceptance of the LiDAR data.

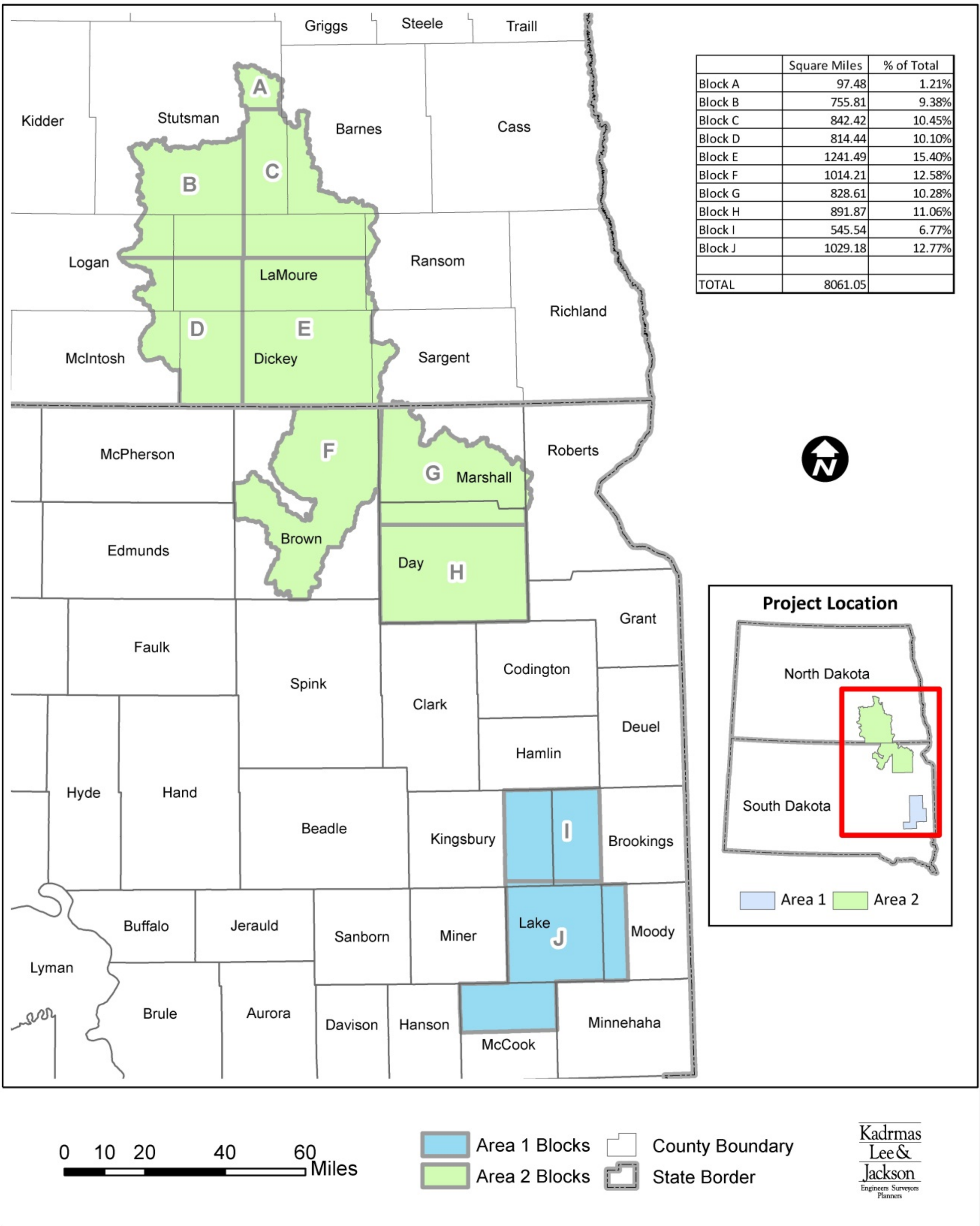
LiDAR data for the Upper James River Watershed and adjacent watersheds in North and South Dakota was collected by Fugro Horizons, Inc. between fall 2010 and spring 2011. The project is divided into two areas (Area 1 and Area 2) as shown in Figure 1, totaling approximately 8,061 square miles. Data was delivered to KL&J via hard drive in standard version 1.2 LAS format. The data will be processed and delivered by blocks for the quality assessment check.

1.2 Project Specific Area Overview

This report is the quality assurance check for Block J (Figure 2). Block J covers approximately 1029 square miles and lies within the counties of Kingsbury, Brookings, Lake, Moody and McCook in South Dakota.

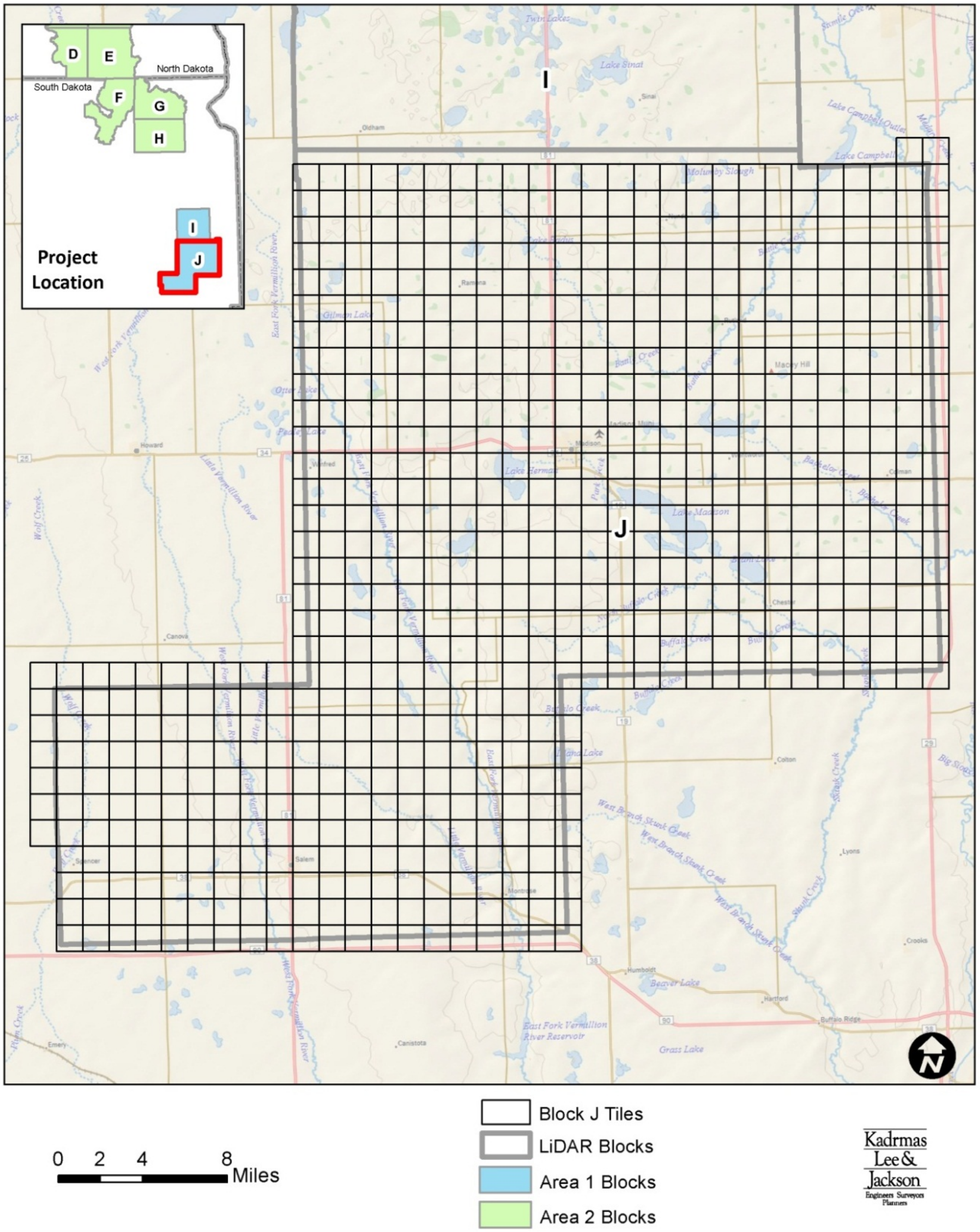
Block J was covered by 718 tiles of LAS format files, version 1.2, collected at a nominal point spacing of 1.4 meters.

Figure 1. LiDAR Project Areas and Blocks



	Square Miles	% of Total
Block A	97.48	1.21%
Block B	755.81	9.38%
Block C	842.42	10.45%
Block D	814.44	10.10%
Block E	1241.49	15.40%
Block F	1014.21	12.58%
Block G	828.61	10.28%
Block H	891.87	11.06%
Block I	545.54	6.77%
Block J	1029.18	12.77%
TOTAL	8061.05	

Figure 2. Block J Tiles



2 QUALITY ASSURANCE CONSIDERATION

2.1 References

The following documents were used as guidance for Quality Assurance/Quality Control (QA/QC):

- Guidelines and Specifications for Flood Hazard Mapping Partners - Appendix A: Guidance for Aerial Mapping and Surveying, 2003; Federal Emergency Management Agency (FEMA)
- USGS National Geospatial Program LiDAR Guidance and Base Specification, v13
- National Digital Elevation Program (NDEP) Guidelines for Digital Elevation Data, v1.0, May 10, 2004
- Federal Geodetic Control Committee, 1984, Standards and Specifications for Geodetic Control Networks, pages 2-1 to 2-5

2.2 Performance Specifications for LiDAR Products Established by the Contract

The Statement of Work (SOW) from Fugro Horizons, Inc. specifies the following requirements:

> *For all three project areas the FEMA Guidelines and Specifications for Flood Hazard Mapping (Appendix A) will define the technical requirements but will be superseded based on the required accuracies for each project area. Unless otherwise noted, the specifications outlined in this document will follow the USGS National Geospatial Program LiDAR Guidance and Base Specification, v13. LiDAR vertical accuracy will be tested and is required to meet both FEMA/NSSDA and ASPRS/NDEP standards.*
>
> *For Areas 1 and 2, the vertical accuracy will meet or exceed 15.0 centimeters root mean square error (RMSE) and the horizontal accuracy will meet or exceed 0.6 meter RMSE.*

The data deliverables must be in full compliance with the specifications set by the St. Louis District of the USACE.

Mandatory deliverables include:

- LiDAR mass point data
    - LAS version 1.2
    - 1.4 meter Ground Sample Distance (GSD) minimum
    - Projection shall be UTM, Zone 14, meter units
    - Horizontal datum of NAD83 (NSRS 2007)

    - Vertical datum of NAVD88 (Geoid03 for height conversion)
- Intensity image
    - .img format

- Digital Elevation Model (DEM)
    - .img (Imagine) format
    - 1-meter resolution
    - Projection shall be UTM, Zone 14, meter units
    - 32-bit floating point
    - Cells aligned and fully contained within each tile
    - Water bodies must be hydro-flattened

- Tile scheme
    - 2,000 x 2,000 meter size

- Metadata for LiDAR .las files, intensity image and DEM

- Survey Control Report

2.3 Chain of Custody

In order to meet LiDAR product specifications, a Chain of Custody form was used and is included in this report as Appendix A.

2.4 Quality Assurance Unit

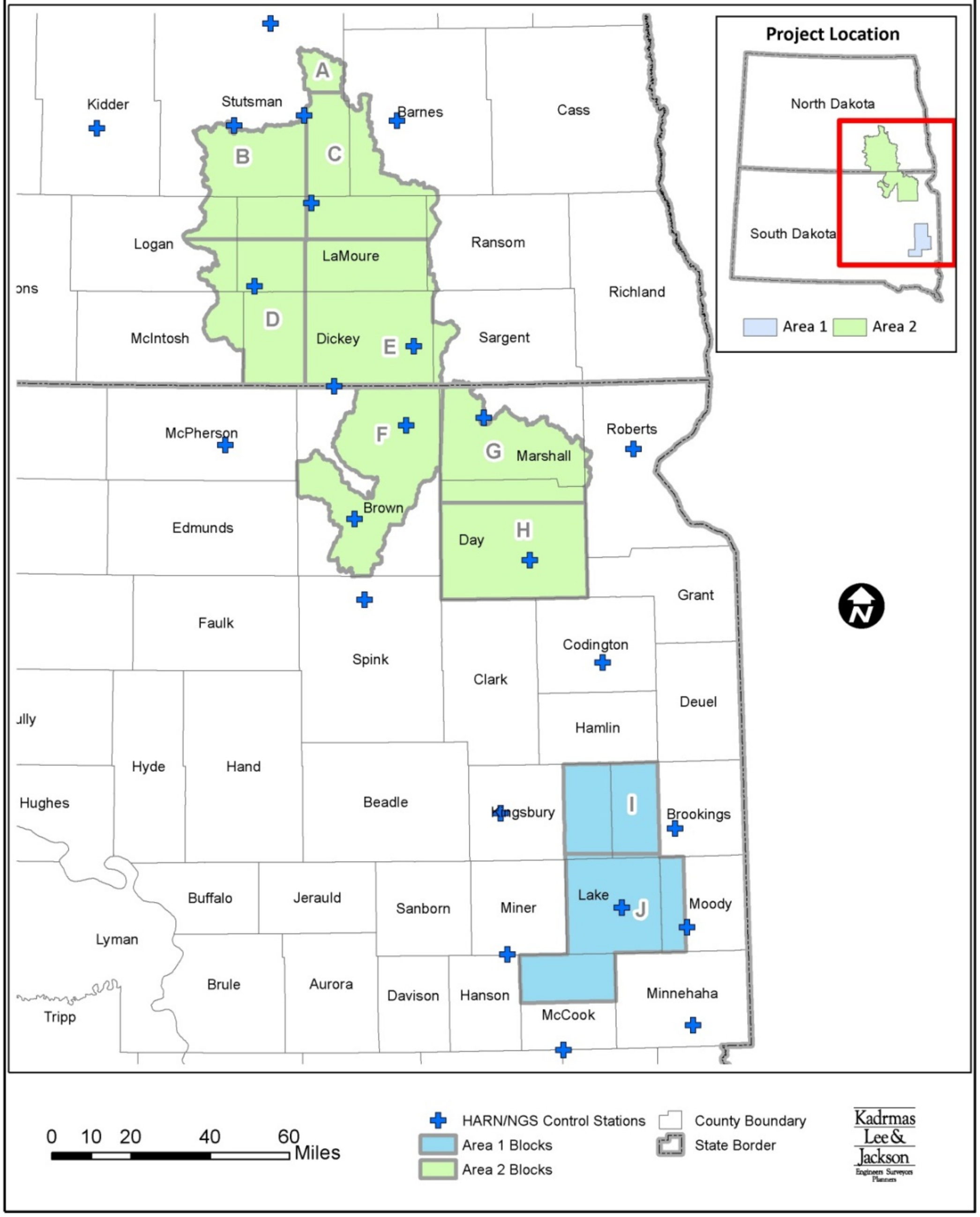
A Quality Assurance (QA) process was applied to Block J, which was subdivided into tiles of 2,000 x 2,000 meters. Survey elevations were acquired to assess vertical accuracy of the LiDAR data.

2.5 Collection of Known Elevations in the Field

KL&J performed a ground survey to assess the accuracy of the LiDAR data. Survey grade Global Positioning Systems (GPS) were utilized for checkpoint collection as part of a post-processed and adjusted control network. The network was based on control stations from the High Accuracy Reference Network (HARN) or National Geodetic Survey (NGS) for North Dakota and South Dakota (See **Figure 3**). HARN/NGS station network accuracies are established from the Federal Geodetic Control Committee for Geodetic Control Networks (http://www.ngs.noaa.gov/FGCS/tech_pub/1984-stds-specs-geodetic-control-networks.pdf). Each checkpoint was occupied by a GPS unit for a pre-determined period of time to reach vertical and horizontal accuracy specifications consistent with the type of equipment used.

Quality Control (QC) check points utilized the same control network points as the LiDAR collection. Checkpoints were located in the field inside of each chosen classification area on ground that was flat, open and consistent with the National Digital Elevation Program (NDEP) guidelines (http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf).

Figure 3. HARN/NGS Control Stations used to Establish Checkpoints



Within Block J, 50 checkpoints were collected in four different land cover types: bare ground/earth, low vegetation, medium vegetation and high vegetation (See **Figure 4**). The difference in elevation between surveyed checkpoints and LiDAR data was used to calculate the root mean square error (RMSE) of the data. RMSE will be calculated for the bare ground/earth class and must meet the contract specifications, which specifies vertical elevation must meet or exceed 15.0 cm RMSE (Accuracyz=0.30m at the 95 percent confidence level). RMSE of the three vegetation types will also be calculated and reported.

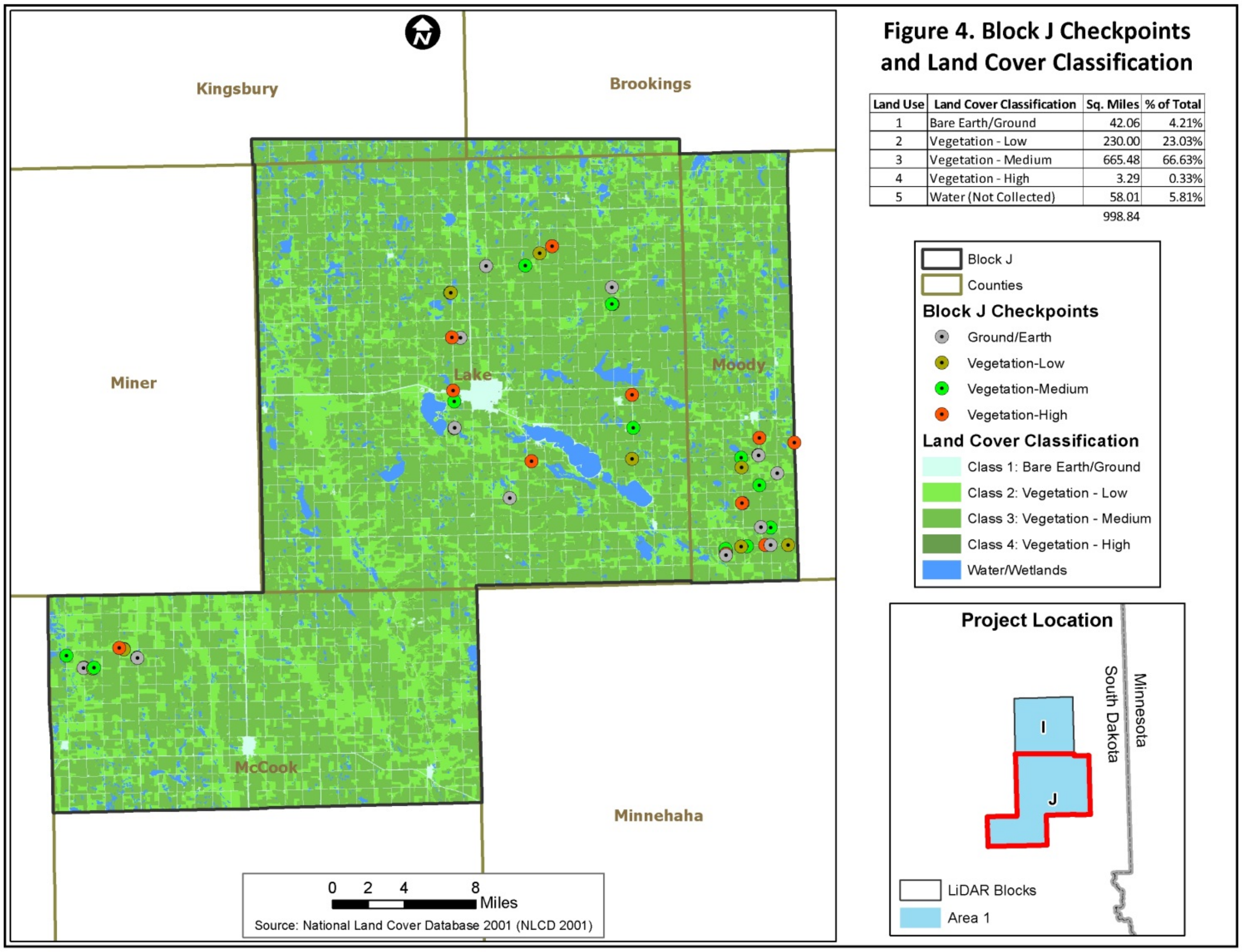


Figure 4. Block J Checkpoints and Land Cover Classification

Land Use	Land Cover Classification	Sq. Miles	% of Total
1	Bare Earth/Ground	42.06	4.21%
2	Vegetation - Low	230.00	23.03%
3	Vegetation - Medium	665.48	66.63%
4	Vegetation - High	3.29	0.33%
5	Water (Not Collected)	58.01	5.81%
		998.84	

Source: National Land Cover Database 2001 (NLCD 2001)

2.6 Computing the RMSE$_{(z)}$

RMSE$_z$ is the root mean square error for the comparison of LiDAR data and survey checkpoints. It is calculated using the following equation:

$$\mathrm{RMSE}_{(z)} = \sqrt{\left(\sum_i^n [(LiDAR_z - checkpoint_z)^2/n]\right)}$$

where n is the number of checkpoints and i is any particular checkpoint.

To determine the vertical accuracy of the LiDAR data, KL&J used QCoherent Software's LP360 program running within the ESRI ArcGIS environment. This tool provides *quantitative* quality control, whereas *qualitative* quality control (visual assessment) will be addressed in section 2.6.

The KL&J collected checkpoint survey data which was received in excel format and converted to shapefile format. The LiDAR data was converted to a Triangulated Irregular Network (TIN) surface. The interpolated surface was compared to the checkpoint shapefile and an error result report was generated.

2.7 Visual Assessment

Using the QCoherent LP360 QA/QC Toolbar, a systematic visual inspection of the entire Block J LiDAR dataset was completed to verify the project area was completely covered, no data gaps/voids existed and was free of artifacts. The contract specifies that voids not caused by classification are not allowed to exceed three times the point spacing. LiDAR data was displayed as a TIN and checked for anomalies (spikes and dips). The most current 1-meter National Agricultural Imagery Program (NAIP) image was used to verify these anomalies and if no reason was seen for their occurrence, they were flagged for further follow-up.

3 QUALITY ASSURANCE RESULTS AND CONCLUSIONS FOR BLOCK J

For the qualitative assessment of Block J, the LiDAR data elevation network was compared to the surveyed checkpoints.

LiDAR elevations were derived from a TIN surface generated by QCoherent's LP360 software.

3.1 Results

3.1.1 Vertical Accuracy

Table 1 shows the numerical and statistical results of the elevation comparison by land class. **Figure 4** is a graphical representation of the $RMSE_{(Z)}$ for each of the individual land classes.

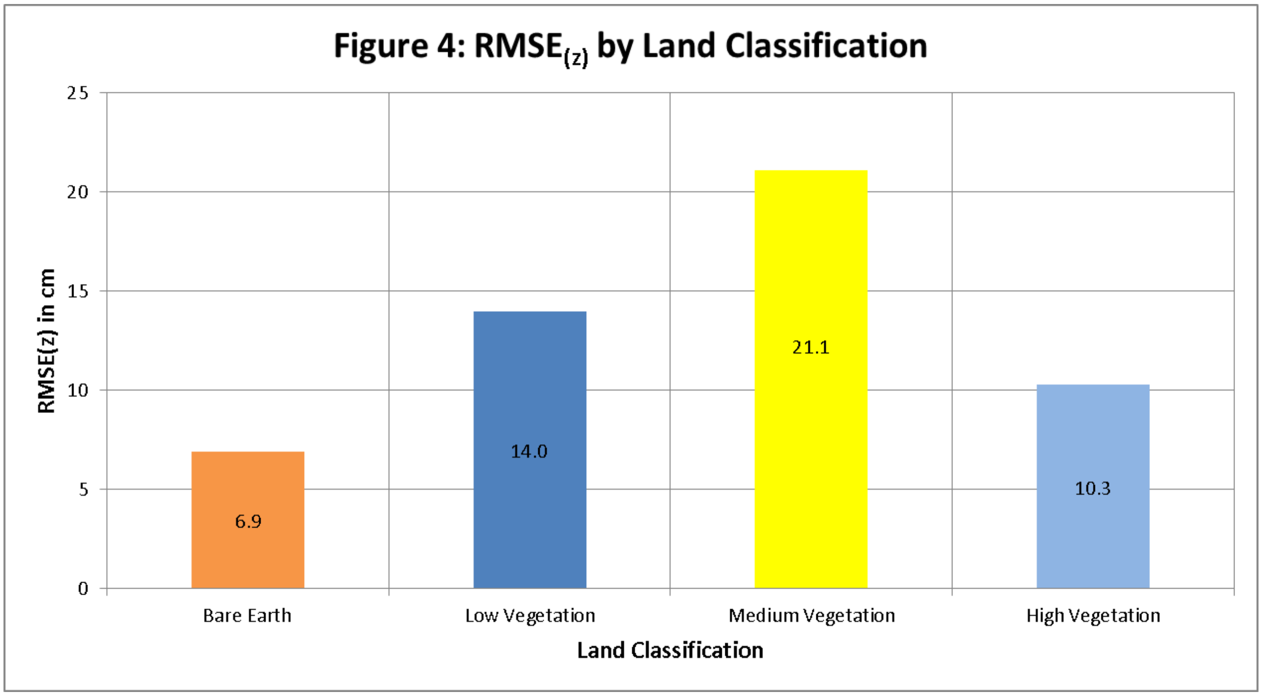
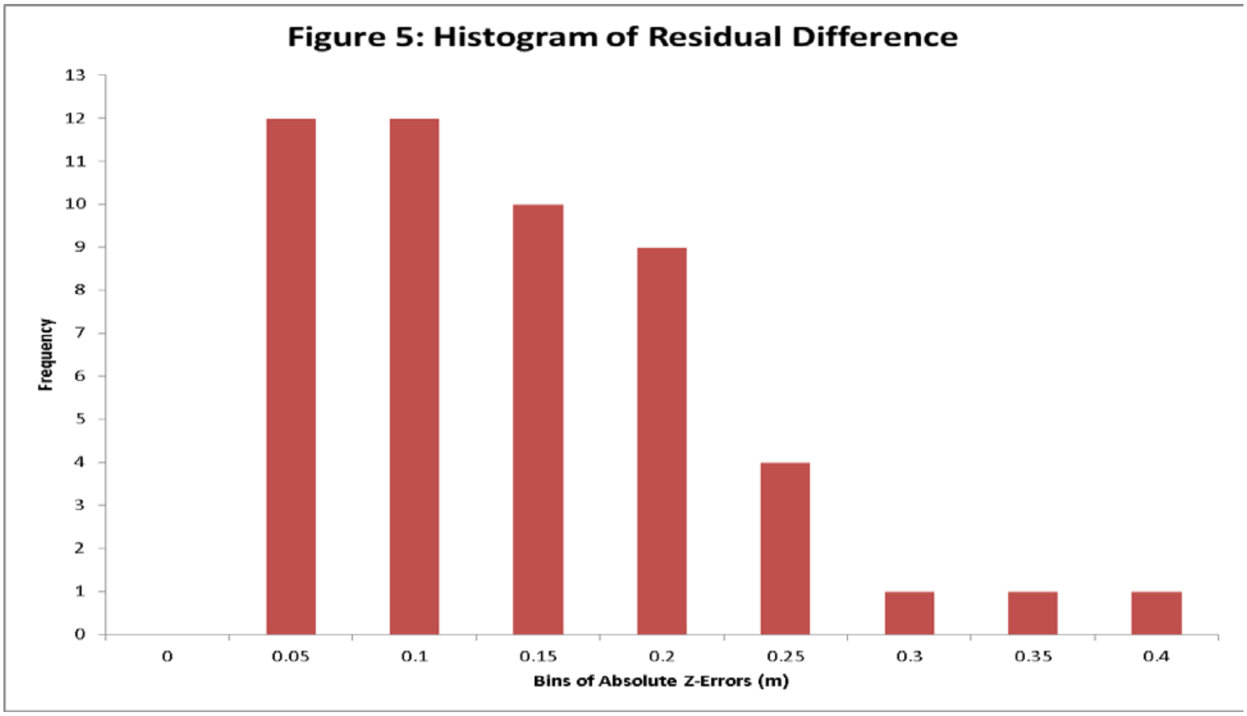


Table 2 compares the elevation difference, or residual, at each checkpoint. **Figure 5** is a chart of the residuals (in absolute values).



In addition, the data were absolute accuracy tested in accordance with the ASPRS/NDEP method and the NSSDA/FEMA method. The NSSDA/FEMA method assumes a normal error distribution and yielded the following results:

- Tested 0.276 (meters) vertical accuracy at 95 percent confidence level
- Compiled to meet 1.04 (meters) horizontal accuracy at the 95 percent confidence level

(KL&J did not perform independent horizontal accuracy testing on the LiDAR. The LiDAR vendor states the LiDAR meets or exceeds horizontal accuracy of 0.6m RMSE.)

The ASPRS/NDEP method takes into account the possibility that normal error distribution in vegetative areas is not always the case so it uses the Fundamental Vertical Accuracy (FVA), the Supplemental Vertical Accuracy (SVA) and the Consolidated Vertical Accuracy (CVA). Results are:

- Tested 0.135 (meters) fundamental vertical accuracy at 95 percent confidence level in open terrain using RMSEz X 1.9600
- Tested 0.275 (meters) supplemental vertical accuracy at 95th percentile in low, medium and high vegetation classifications
- Tested 0.258 (meters) consolidated vertical accuracy at 95th percentile in all land classifications

3.1.2 Visual Assessment

Block J contained 718 tiles. A minimum of 5% of the tiles were randomly selected for review. No bare earth data voids were noted and the project area was fully covered. No major anomalies/artifacts were found. Some classification errors were noticed (**Appendix B**, example 1). Other anomalies included strips of Low Vegetation classification running east-west (examples 2 and 3) throughout most of the inspected tiles and Low Vegetation classification points located in water (examples 4 and 5). No bare earth anomalies were found in the inspected tiles. Note: LiDAR point colors are optimized for best visibility.

3.1.3 Concurrence with the Specification

Project specifications require the final $RMSE_{(z)}$ for the bare earth LiDAR data to be equal to or less than 15 cm. Block J achieves the requirement by posting an $RMSE_{(z)}$ of 6.9 cm.

4 TABLES

Table 1

Land Class	# of Check Points	Mean Absolute Difference (cm)	Median Absolute Difference (cm)	Min Absolute Difference (cm)	Max Absolute Difference (cm)	Skew	Standard Deviation (cm)	Mean Difference (cm)	95% Confidence Interval Value (cm)	95th Percentile Value	RMSE(z) (cm)
Bare Ground	13	5.9	5.3	2.2	13.8	0.188	3.7	-1.3	± 13.5	13.0	6.9
Low Vegetation	12	12.0	12.9	3.4	24.7	-0.435	7.6	-12.0	± 27.4	24.5	14.0
Medium Vegetation	13	19.5	16.0	9.0	36.0	-0.544	8.3	-19.5	± 41.3	32.9	21.1
High Vegetation	12	8.6	9.7	1.3	18.4	-0.016	5.9	-8.4	± 20.2	17.5	10.3
ALL POINTS	50	11.5	10.3	1.3	36.0	-0.284	8.3	-7.0	± 27.7	25.8	14.1

Table 2

KL&J Surveyed Checkpoints for Block J					**LiDAR**	**Results**	
Point ID	Landuse Class	X Coordinate	Y Coordinate	Elevation (m)	LiDAR Elevation derived from TIN	Elevation Difference	Absolute Difference (cm)
5020	Bare Ground	648975.470	4879239.728	530.237	530.259	-0.022	2.2
5028	Bare Ground	662597.573	4883783.031	507.133	507.110	0.023	2.3
5061	Bare Ground	615076.673	4849537.664	430.869	430.892	-0.023	2.3
601	Bare Ground	618686.808	4851234.520	451.535	451.562	-0.027	2.7
605	Bare Ground	619926.451	4850458.385	454.579	454.540	0.039	3.9
5056	Bare Ground	676863.735	4860601.113	493.482	493.534	-0.052	5.2
5037	Bare Ground	648449.138	4871155.413	534.319	534.372	-0.053	5.3
5024	Bare Ground	651267.754	4885719.822	530.256	530.201	0.055	5.5
5059	Bare Ground	676009.079	4862195.726	499.919	499.860	0.059	5.9
5035	Bare Ground	653403.921	4864829.654	542.193	542.258	-0.065	6.5
5046	Bare Ground	677472.073	4867078.677	488.104	488.189	-0.085	8.5
5042	Bare Ground	675799.471	4868653.780	494.734	494.610	0.124	12.4
5054	Bare Ground	672862.574	4859685.330	498.928	499.066	-0.138	13.8
5029	Low Vegetation	662650.231	4882277.499	500.109	500.143	-0.034	3.4
5023	Low Vegetation	648092.069	4883287.154	535.887	535.929	-0.042	4.2
5026	Low Vegetation	656105.844	4886852.361	539.730	539.776	-0.046	4.6
5048	Low Vegetation	674366.333	4864389.150	512.431	512.483	-0.052	5.2
5062	Low Vegetation	615909.840	4849511.759	437.889	437.946	-0.057	5.7
5036	Low Vegetation	648415.101	4871118.974	533.220	533.348	-0.128	12.8
5051	Low Vegetation	674229.231	4860471.267	492.520	492.649	-0.129	12.9
5057	Low Vegetation	678440.003	4860610.372	496.901	497.030	-0.129	12.9
5033	Low Vegetation	664406.880	4868368.295	511.142	511.303	-0.161	16.1
602	Low Vegetation	618689.506	4851218.829	450.900	451.068	-0.168	16.8
5044	Low Vegetation	674271.303	4867583.046	506.037	506.281	-0.244	24.4
5041	Low Vegetation	675768.131	4868697.824	493.708	493.955	-0.247	24.7

KL&J Surveyed Checkpoints for Block J					**LiDAR**	**Results**	
Point ID	Landuse Class	X Coordinate	Y Coordinate	Elevation (m)	LiDAR Elevation derived from TIN	Elevation Difference	Absolute Difference (cm)
5022	Medium Vegetation	648033.752	4883308.148	535.095	535.185	-0.090	9.0
604	Medium Vegetation	619894.499	4850468.254	453.437	453.535	-0.098	9.8
5058	Medium Vegetation	676878.753	4862180.763	495.076	495.192	-0.116	11.6
5043	Medium Vegetation	674232.919	4868466.331	508.159	508.311	-0.152	15.2
5050	Medium Vegetation	674732.811	4860506.902	488.883	489.037	-0.154	15.4
5025	Medium Vegetation	654806.011	4885749.988	530.131	530.288	-0.157	15.7
5047	Medium Vegetation	675859.291	4865968.130	512.842	513.002	-0.160	16.0
5038	Medium Vegetation	648418.859	4873506.450	508.638	508.825	-0.187	18.7
5064	Medium Vegetation	613538.176	4850651.177	422.876	423.114	-0.238	23.8
5052	Medium Vegetation	672822.013	4860250.010	493.224	493.472	-0.248	24.8
5032	Medium Vegetation	664508.572	4871133.434	517.541	517.807	-0.266	26.6
5063	Medium Vegetation	615997.868	4849581.257	436.834	437.143	-0.309	30.9
5030	Medium Vegetation	662593.174	4882296.878	499.762	500.122	-0.360	36.0
5039	High Vegetation	648320.079	4874496.792	530.296	530.309	-0.013	1.3
5060	High Vegetation	615102.556	4849571.211	432.644	432.629	0.015	1.5
603	High Vegetation	618286.883	4851349.631	449.866	449.886	-0.020	2.0
5027	High Vegetation	657215.604	4887503.997	541.854	541.887	-0.033	3.3
5021	High Vegetation	648203.465	4879298.728	536.559	536.613	-0.054	5.4
5055	High Vegetation	676394.010	4860611.970	493.785	493.877	-0.092	9.2
5031	High Vegetation	664424.359	4874116.712	509.451	509.553	-0.102	10.2
5053	High Vegetation	672843.671	4859844.887	496.280	496.383	-0.103	10.3
5049	High Vegetation	674301.246	4864388.010	513.265	513.384	-0.119	11.9
5034	High Vegetation	655373.231	4868141.355	496.473	496.605	-0.132	13.2
5045	High Vegetation	678990.116	4869826.022	515.380	515.548	-0.168	16.8
5040	High Vegetation	675870.824	4870225.271	509.063	509.247	-0.184	18.4

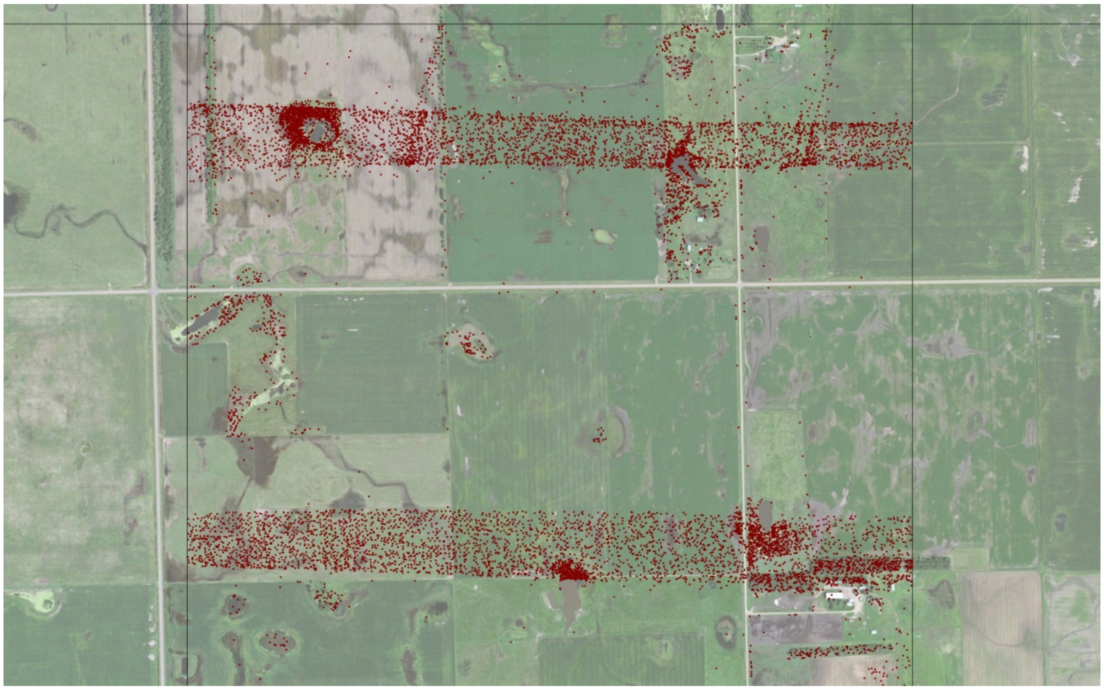
5 APPENDIX A – CHAIN OF CUSTODY

Appendix A - Chain of Custody Form

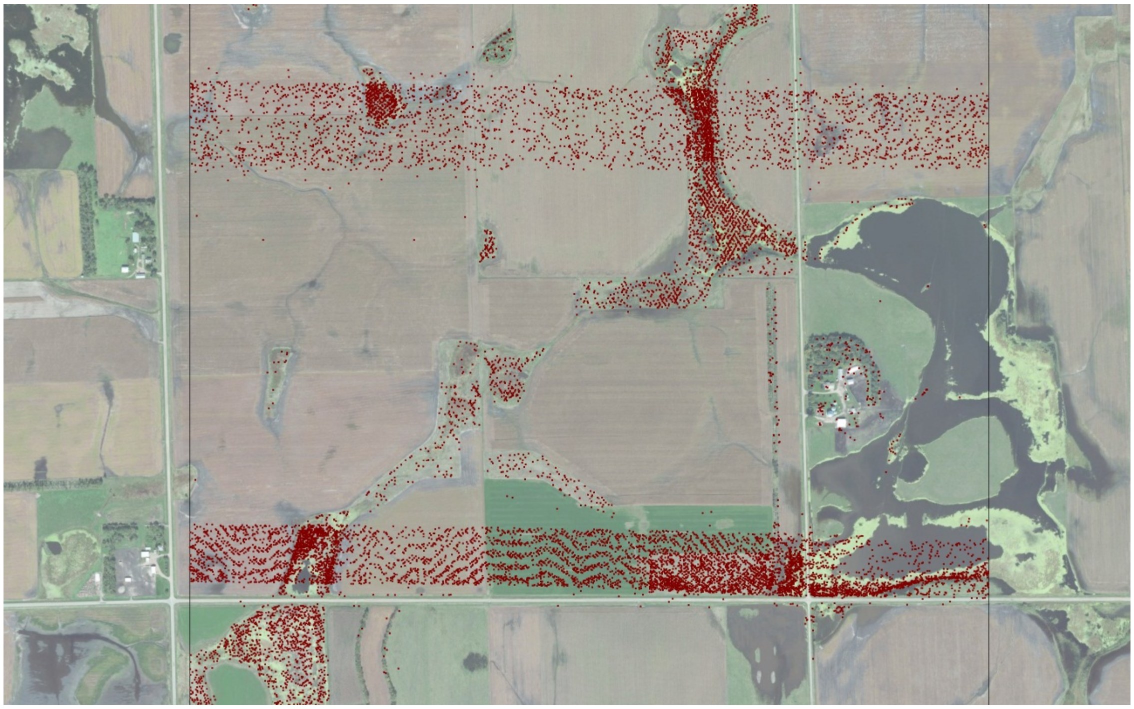
James River LiDAR				
Project Name: James River LiDAR QA / QC	**Priority Area: 1 Block: J # Tiles in Block: 718**			
LiDAR Production Company: Fugro-Horizons , Inc.	**Horizontal Coord: UTM 14 NAD83 Vertical Datum: NAVD 88**			
Correspondence Note	**Recd./Checked By:**	**Date**	**Notes**	**Pass**
Initial Delivery of LiDAR products	DW	3/12/2012	via FedEx from Fugro, Inc.	Y
Delivery to Bismarck Office for QAQC	JP	3/13/2012	via FedEx from Daniel Wagner	Y
QAQC check for file completeness	JP	3/13/2012		Y
QAQC check for data adherence to format/specifications				
Filtered Bare Earth Data (LAS Files)				
Version 1.2	JP	3/22/2012		Y
1.4 meter GSD minimum	JP	3/22/2012		Y
Header contains day, year	JP	3/22/2012		Y
Projection info in VLR	JP	3/22/2012		Y
Metadata	JP	3/22/2012		Y
Bare Earth DEM 1meter (IMG Format)				
1-meter	JP	3/22/2012		Y
UTM, Z14, meters projection	JP	3/22/2012		Y
32-bit floating point	JP	3/22/2012		Y
Cells aligned/contained	JP	3/22/2012		Y
Hydro-flattened	JP	3/22/2012		Y
Metadata	JP	3/22/2012		Y
Intensity Images (.IMG format)				
8-bit	JP	3/22/2012		Y
Metadata	JP	3/22/2012		Y
Tile Scheme (2000x2000m)	JP	3/22/2012		Y
LIDAR Report	JP	3/22/2012		Y
Flight Logs and JPEGs	JP	3/22/2012		Y
Vertical Accuracy Assessment	JP	3/22/2012	RMSE(z) of 6.9 cm	Y
Qualitative (visual) Assessment				
Data Voids	JP	3/22/2012		Y
Classification Issues	JP	3/26/2012	None in Bare Earth class	Y
Anomalies	JP	3/27/2012		Y
Flight Line Seams	JP	3/27/2012		Y
Metadata Review	JP	3/27/2012		Y
LIDAR Report Review	DW/RW			
Pass/Fail Notice Given to LiDAR Vendor TBD				
Final LiDAR Products Archived on External Hard Drive TBD				
Final LiDAR Products Sent to USACE for Dissemination TBD				

6 APPENDIX B – SCREEN CAPTURES OF LIDAR ANOMALIES/ARTIFACTS/ERRORS

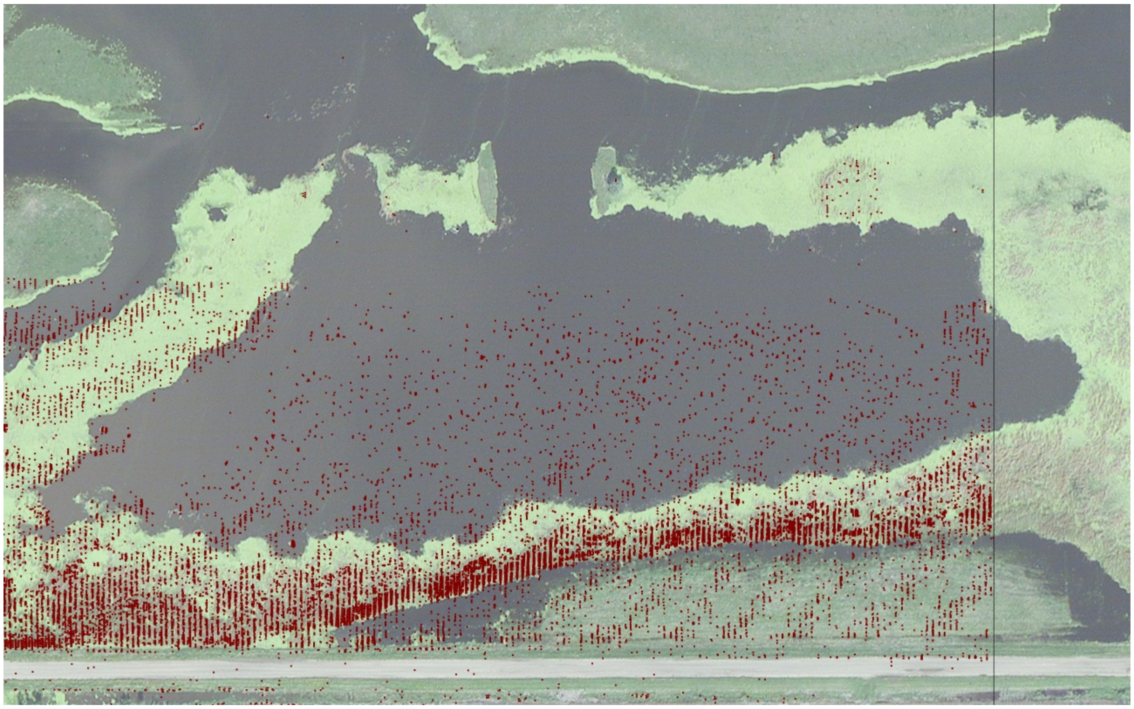
Example 1: Manmade structures classified as High Vegetation in tile 06684892.



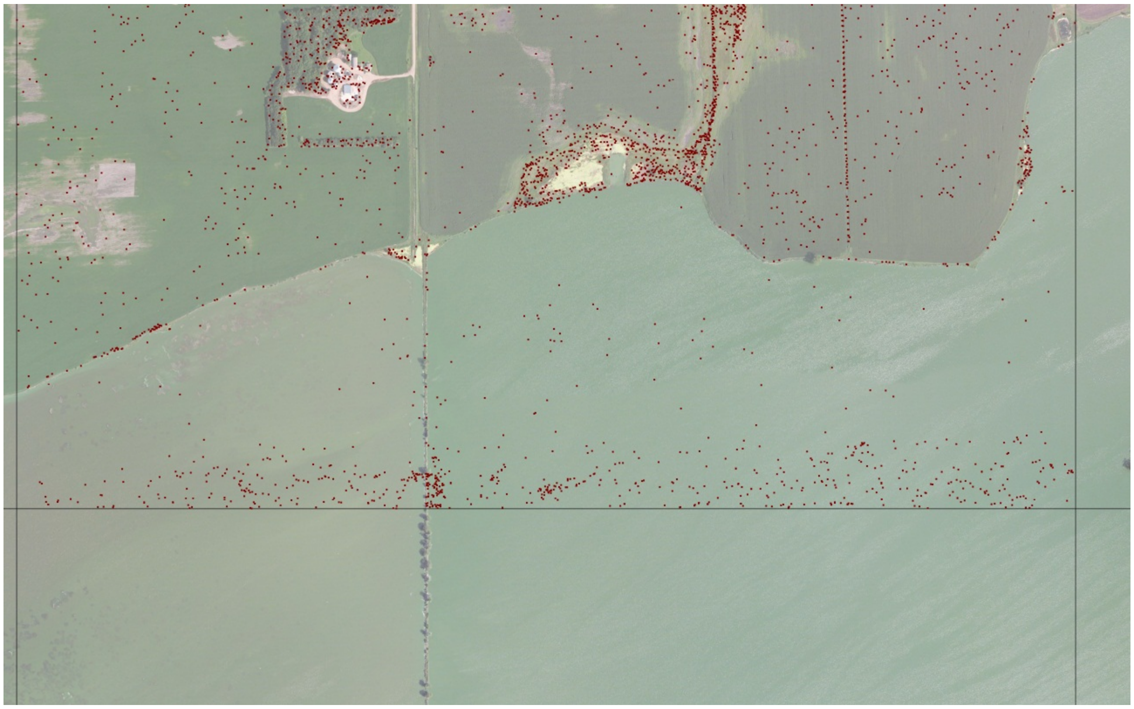
Example 2: Strips of Low Vegetation running east-west throughout project area.



Example 3: Strips of Low Vegetation running east-west throughout project area.



Example 4: Low Vegetation in water feature (tile 06404890).



Example 5: Low Vegetation in water feature (tile 06624876).

7 APPENDIX C – FEDERAL GEODETIC STANDARD GUIDELINES FOR GPS ACCURACY

2. Standards

The classification standards of the National Geodetic Control Networks are based on accuracy. This means that when control points in a particular survey are classified, they are certified as having datum values consistent with all other points in the network, not merely those within that particular survey. It is not observation closures within a survey which are used to classify control points, but the ability of that survey to duplicate already established control values. This comparison takes into account models of crustal motion, refraction, and any other systematic effects known to influence the survey measurements.

The NGS procedure leading to classification covers four steps:

1. The survey measurements, field records, sketches, and other documentation are examined to verify compliance with the specifications for the intended accuracy of the survey. This examination may lead to a modification of the intended accuracy.

2. Results of a minimally constrained least squares adjustment of the survey measurements are examined to ensure correct weighting of the observations and freedom from blunders.

3. Accuracy measures computed by random error propagation determine the provisional accuracy. If the provisional accuracy is substantially different from the intended accuracy of the survey, then the provisional accuracy supersedes the intended accuracy.

4. A variance factor ratio for the new survey combined with network data is computed by the Iterated Almost Unbiased Estimator (IAUE) method (appendix B). If the variance factor ratio is reasonably close to 1.0 (typically less than 1.5), then the survey is considered to check with the network, and the survey is classified with the provisional (or intended) accuracy. If the variance factor ratio is much greater than 1.0 (typically 1.5 or greater), then the survey is considered to not check with the network, and both the survey and network measurements will be scrutinized for the source of the problem.

2.1 Horizontal Control Network Standards

When a horizontal control point is classified with a particular order and class, NGS certifies that the geodetic latitude and longitude of that control point bear a relation of specific accuracy to the coordinates of all other points in the horizontal control network. This relation is expressed as a distance accuracy, 1:a. A distance accuracy is the ratio of the relative positional error of a pair of control points to the horizontal separation of those points.

Table 2.1 - Distance accuracy standards

Classification	*Minimum distance accuracy*
First-order	1:100,000
Second-order, class I	1: 50,000
Second-order, class II	1: 20,000
Third-order, class I	1: 10,000
Third-order, class II	1: 5,000

A distance accuracy, l:a, is computed from a minimally constrained, correctly weighted, least squares adjustment by:

$$a = d/s$$

where

a = distance accuracy denominator
s = propagated standard deviation of distance between survey points obtained from the least squares adjustment
d =distance between survey points

The distance accuracy pertains to all pairs of points (but in practice is computed for a sampling of pairs of points). The worst distance accuracy (smallest denominator) is taken as the provisional accuracy. If this is substantially larger or smaller than the intended accuracy, then the provisional accuracy takes precedence.

As a test for systematic errors, the variance factor ratio of the new survey is computed by the Iterated Almost Unbiased Estimator (IAUE) method described in appendix B. This computation combines the new survey measurements with existing network data, which are assumed to be correctly weighted and free of systematic error. If the variance factor ratio is substantially greater than unity then the survey does not check with the network, and both the survey and the network data will be examined by NGS.

Computer simulations performed by NGS have shown that a variance factor ratio greater than 1.5 typically indicates systematic errors between the survey and the network. Setting a cutoff value higher than this could allow undetected systematic error to propagate into the national network. On the other hand, a higher cutoff value might be considered if the survey has only a small number of connections to the network, because this circumstance would tend to increase the variance factor ratio.

In some situations, a survey has been designed in which different sections provide different orders of control. For these multi-order surveys, the computed distance accuracy denominators should be grouped into sets appropriate to the different parts of the survey. Then, the smallest value of a in each set is used to classify the control points of that portion, as discussed above. If there are sufficient connections to the network, several variance factor ratios, one for each section of the survey, should be computed.

Horizontal Example

Suppose a survey with an intended accuracy of first-order (1:100,000) has been performed. A series of propagated distance accuracies from a minimally constrained adjustment is now computed.

Line	***s (m)***	***d (m)***	***1:a***
l-2	0.141	17,107	1:121,326
l-3	0.170	20,123	1:118,371
2-3	0.164	15,505	1: 94,543

Suppose that the worst distance accuracy is 1:94,543. This is not substantially different from the intended accuracy of 1:100,000, which would therefore have precedence for classification. It is not feasible to precisely quantify "substantially different." Judgment and experience are determining factors.

Now assume that a solution combining survey and network data has been obtained (as per appendix B), and that a variance factor ratio of 1.2 was computed for the survey. This would be reasonably close to unity, and would indicate that the survey checks with the network. The survey would then be classified as first-order using the intended accuracy of 1:100,000.

However, if a variance factor of, say, 1.9 was computed, the survey would not check with the network. Both the survey and network measurements then would have to be scrutinized to find the problem.

Monumentation

Control points should be part of the National Geodetic Horizontal Network only if they possess permanence, horizontal stability with respect to the Earth's crust, and a horizontal location which can be defined as a point. A 30-centimeter-long wooden stake driven into the ground, for example, would lack both permanence and horizontal stability. A mountain peak is difficult to define as a point. Typically, corrosion resistant metal disks set in a large concrete mass have the necessary qualities. First-order and second-order, class I, control points should have an underground mark, at least two monumented reference marks at right angles to one another, and at least one monumented azimuth mark no less than 400 m from the control point. Replacement of a temporary mark by a more permanent mark is not acceptable unless the two marks are connected in timely fashion by survey observations of sufficient accuracy. Detailed information may be found in C&GS *Special Publication 247,*"Manual of geodetic triangulation."

2.2 Vertical Control Network Standards

When a vertical control point is classified with a particular order and class, NGS certifies that the orthometric elevation at that point bears a relation of specific accuracy to the elevations of all other points in the vertical control network. That relation is expressed as an elevation difference accuracy, b. An elevation difference accuracy is the relative elevation error between a pair of control points that is scaled by the square root of their horizontal separation traced along existing level routes.

Table 2.2-Elevation accuracy standards

Classification	***Maximum elevation difference accuracy***
First-order, class I	0.5
First-order, class II	0.7
Second-order, class I	1.0
Second-order, class II	1.3
Third-order	2.0

An elevation difference accuracy, b, is computed from a minimally constrained, correctly weighted, least squares adjustment by

$$b = S/\sqrt{d}$$

where

d = approximate horizontal distance in kilometers between control point positions traced along existing level routes.
S = propagated standard deviation of elevation difference in millimeters between survey

control points obtained from the least squares adjustment. Note that the units of b are (mm)/ √ (km).

The elevation difference accuracy pertains to all pairs of points (but in practice is computed for a sample). The worst elevation difference accuracy (largest value) is taken as the provisional accuracy. If this is substantially larger or smaller than the intended accuracy, then the provisional accuracy takes precedence.

As a test for systematic errors, the variance factor ratio of the new survey is computed by the Iterated Almost Unbiased Estimator (IAUE) method described in appendix B. This computation combines the new survey measurements with existing network data, which are assumed to be correctly weighted and free of systematic error. If the variance factor ratio is substantially greater than unity, then the survey does not check with the network, and both the survey and the network data will be examined by NGS.

Computer simulations performed by NGS have shown that a variance factor ratio greater than 1.5 typically indicates systematic errors between the survey and the network. Setting a cutoff value higher than this could allow undetected systematic error to propagate into the national network. On the other hand, a higher cutoff value might be considered if the survey has only a small number of connections to the network, because this circumstance would tend to increase the variance factor ratio.

In some situations, a survey has been designed in which different sections provide different orders of control. For these multi-order surveys, the computed elevation difference accuracies should be grouped into sets appropriate to the different parts of the survey. Then, the largest value of b in each set is used to classify the control points of that portion, as discussed above. If there are sufficient connections to the network, several variance factor ratios, one for each section of the survey, should be computed.

Vertical Example

Suppose a survey with an intended accuracy of second-order, class II has been performed. A series of propagated elevation difference accuracies from a minimally constrained adjustment is now computed.

Line	***s***	***d***	***b***
	(mm)	(km)	(mm)/√(km)
l-2	1.574	1.718	1.20
l-3	1.743	2.321	1.14
2-3	2.647	4.039	1.32

Suppose that the worst elevation difference accuracy is 1.32. This is not substantially different from the intended accuracy of 1.3 which would therefore have precedence for classification. It is not feasible to precisely quantify "substantially different." Judgment and experience are determining factors.

Now assume that a solution combining survey and network data has been obtained (as per appendix B), and that a variance factor ratio of 1.2 was computed for the survey. This would be reasonably close to unity and would indicate that the survey checks with the network. The survey would then be classified as second-order, class II, using the intended accuracy of 1.3.

However, if a survey variance factor ratio of, say, 1.9 was computed, the survey would not check with the network. Both the survey and network measurements then would have to be scrutinized to find the problem.

Monumentation

Control points should be part of the National Geodetic Vertical Network only if they possess permanence, vertical stability with respect to the Earth's crust, and a vertical location that can be defined as a point. A 30-centimeter- long wooden stake driven into the ground, for example, would lack both permanence and vertical stability. A rooftop lacks stability and is difficult to define as a point. Typically, corrosion resistant metal disks set in large rock outcrops or long metal rods driven deep into the ground have the necessary qualities. Replacement of a temporary mark by a more permanent mark is not acceptable unless the two marks are connected in timely fashion by survey observations of sufficient accuracy. Detailed information may be found in *NOAA Manual NOS NGS 1,*"Geodetic bench marks."

2.3 Gravity Control Network Standards

When a gravity control point is classified with a particular order and class, NGS certifies that the gravity value at that control point possesses a specific accuracy.

Gravity is commonly expressed in units of milligals (mGa1) or microgals (Gal) equal, respectively, to (10^{-5}) meters/sec^2, and (10^{-8}) meters/sec^2. Classification order refers to measurement accuracies and class to site stability.

Table 2.3-Gravity accuracy standards

Classification	***Gravity accuracy (µGal)***
First-order, class I	20 (subject to stability verification)
First-order, class II	20
Second-order	50
Third-order	100

When a survey establishes only new points, and where only absolute measurements are observed, then each survey point is classified independently. The standard deviation from the mean of measurements observed at that point is corrected by the error budget for noise sources in accordance with the following formula:

$$c^2 = \Sigma^n_{i+1}((x_i - x_m)^2 / (n - 1)) + e^2$$

where

c =gravity accuracy
x_i= gravity measurement
n = number of measurements
x_m= ($\Sigma^n_{i=1}(x_i)$ / (n)
e = external random error

The value obtained for c is then compared directly against the gravity accuracy standards table.

When a survey establishes points at which both absolute and relative measurements are made, the absolute determination ordinarily takes precedence and the point is classified accordingly. (However, see Example D below for an exception.)

When a survey establishes points where only relative measurements are observed, and where the survey is tied to the National Geodetic Gravity Network, then the gravity accuracy is identified with the propagated gravity standard deviation from a minimally constrained, correctly weighted, least squares adjustment.

The worst gravity accuracy of all the points in the survey is taken as the provisional accuracy. If the provisional accuracy exceeds the gravity accuracy limit set for the intended survey classification, then the survey is classified using the provisional accuracy.

As a test for systematic errors, the variance factor ratio of the new survey is computed by the Iterated Almost Unbiased Estimator (IAUE) method described in appendix B. This computation combines the new survey measurements with existing network data which are assumed to be correctly weighted and free of systematic error. If the variance factor ratio is substantially greater than unity, then the survey does not check with the network, and both the survey and the network data will be examined by NGS.

Computer simulations performed by NGS have shown that a variance factor ratio greater than 1.5 typically indicates systematic errors between the survey and the network. Setting a cutoff value higher than this could allow undetected systematic error to propagate into the national network. On the other hand, a higher cutoff value might be considered if the survey has only a minimal number of connections to the network, because this circumstance would tend to increase the variance factor ratio.

In some situations, a survey has been designed in which different sections provide different orders of control. For these multi-order surveys, the computed gravity accuracies should be grouped into sets appropriate to the different parts of the survey. Then, the largest value of c in each set is used to classify the control points of that portion, as discussed above. If there are sufficient connections to the network, several variance factor ratios, one for each part of the survey, should be computed.

Gravity Examples
Example A. Suppose a gravity survey using absolute measurement techniques has been performed. These points are then unrelated. Consider one of these survey points.

Assume $n = 750$
$\Sigma^{750}{}_{i=1}((x_i - x_m)^2 = .169\ \text{mGal}^2$
$e = 5\ \mu\text{Gal}$
$c^2 = (0.169) / (750 - 1) + (.005)^2$
$c = 16\ \mu\text{Gal}$

The point is then classified as first-order, class II.

Example B. Suppose a relative gravity survey with an intended accuracy of second-order (50 µGal) has been performed. A series of propagated gravity accuracies from a minimally constrained adjustment is now computed.

Station	***Gravity standard deviation (µGal)***
1	38
2	44
3	55

Suppose that the worst gravity accuracy was 55 µGal. This is worse than the intended accuracy of 50 µGal. Therefore, the provisional accuracy of 55 µGal would have precedence for classification, which would be set to third-order.

Now assume that a solution combining survey and network data has been obtained (as per appendix B) and that a variance factor of 1.2 was computed for the survey. This would be reasonably close to unity, and would indicate that the survey checks with the network. The survey would then be classified as third-order using the provisional accuracy of 55 µGal.

However, if a variance factor of, say, 1.9 was computed, the survey would not check with the network. Both the survey and network measurements then would have to be scrutinized to find the problem.

Example C. Suppose a survey consisting of both absolute and relative measurements has been made at the same points. Assume the absolute observation at one of the points yielded a classification of first-order, class II, whereas the relative measurements produced a value to second-order standards. The point in question would be classified as first-order, class II, in accordance with the absolute observation.

Example D. Suppose we have a survey similar to Case C, where the absolute measurements at a particular point yielded a third-order classification due to an unusually noisy observation session, but the relative measurements still satisfied the second-order standard. The point in question would be classified as second-order, in accordance with the relative measurements.

Monumentation

Control points should be part of the National Geodetic Gravity Network only if they possess permanence, horizontal and vertical stability with respect to the Earth's crust, and a horizontal and vertical location which can be defined as a point. For all orders of accuracy, the mark should be imbedded in a stable platform such as flat, horizontal concrete. For first-order, class I stations, the platform should be imbedded in stable, hard rock, and checked at least twice for the first year to ensure stability. For first-order, class II stations, the platform should be located in an extremely stable environment, such as the concrete floor of a mature structure. For second and third-order stations, standard bench mark monumentation is adequate.

Replacement of a temporary mark by a more permanent mark is not acceptable unless the two marks are connected in timely fashion by survey observations of sufficient accuracy. Detailed information is given in NOAA *Manual NOS NGS 1*, "Geodetic bench marks." Monuments should not be near sources of electromagnetic interference.

It is recommended, but not necessary, to monument third-order stations. However, the location associated with the gravity value should be recoverable, based upon the station description.

8 APPENDIX D – CD ENCLOSURE OF KL&J SURVEY CHECKPOINTS