Federal Emergency Management Agency

Kittitas County, Washington CID 53037C

Technical Support Data Notebook

Terrain Project Narrative

Elevation Data Acquisition

CASE NO. 11-10-0110S
Contract no. HSFEHQ-09-D-0370
Task Order No. HSFE01-10-J-0005

Date September 12, 2011

Prepared By:

Table of Contents

List of Tables

List of Figures

1. Introduction

Beginning in Fiscal Year 2010, FEMA initiated a five-year program for Risk Mapping, Assessment, and Planning (Risk MAP). The vision for Risk MAP is to deliver quality data that increases public awareness and leads to action that reduces risk to life and property. In order to realize the Risk MAP vision FEMA is acquiring high resolution terrain elevation and land cover elevation data to increase production efficiencies for NFIP regulatory products and support risk assessment data development. FEMA has made a commitment through Risk MAP to work closely with NDEP (National Digital Elevation Program) partners to obtain and support the collection of terrain data throughout the United States.

Terrain data, collected under the Risk MAP program, will be required to meet minimum specifications outlined in the *Draft Procedure Memorandum No. 61—Standards for LiDAR and Other High Quality Digital Topography dated August 1st, 2010*[1]. FEMA also requires all deliverables for topographic data collection be submitted in accordance with *Appendix M: Data Capture Standards March 2009*[2]. All relevant project materials have been reviewed to insure that these requirements are met.

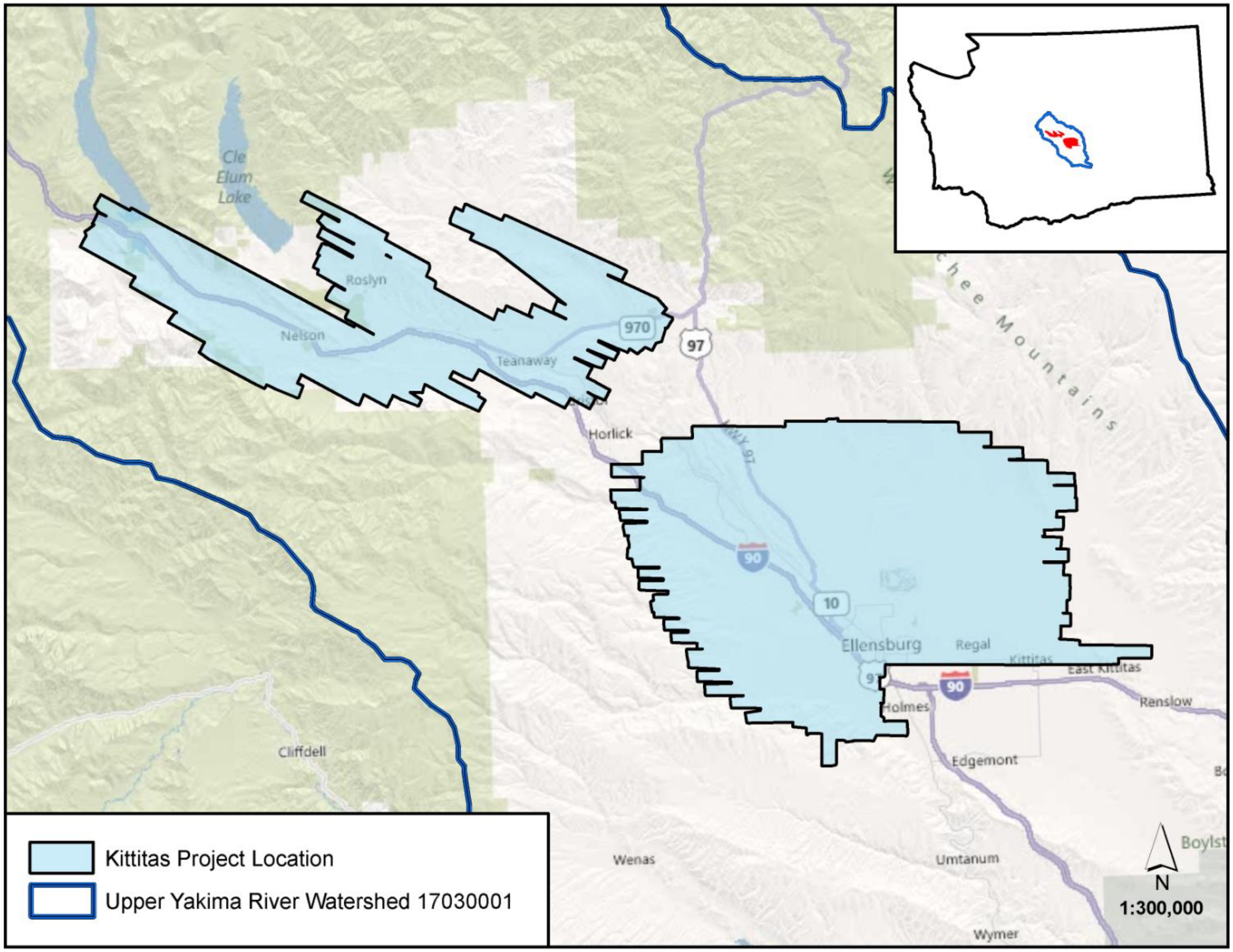
The objectives for elevation data acquisition for the portions of Kittitas County, Washington in the Upper Yakima River Watershed are as follows:

1. LAS point cloud files collected for 181 square miles
2. LAS point cloud files captured using the "Highest" vertical accuracy requirements
3. LAS point cloud files collected at equivalent of a 2-foot contour accuracy
4. LAS point cloud files collected using a nominal pulse spacing of 1-meter
5. LAS classified as Bare Earth processed for 181 square miles

Table 1. Vertical Accuracy Requirements

Contour Accuracy	Specification Level	$RMSE_z$	FVA	CVA
2ft	Highest	18.5 cm	24.5 cm	36.3 cm

Figure 1. Kittitas Project Location

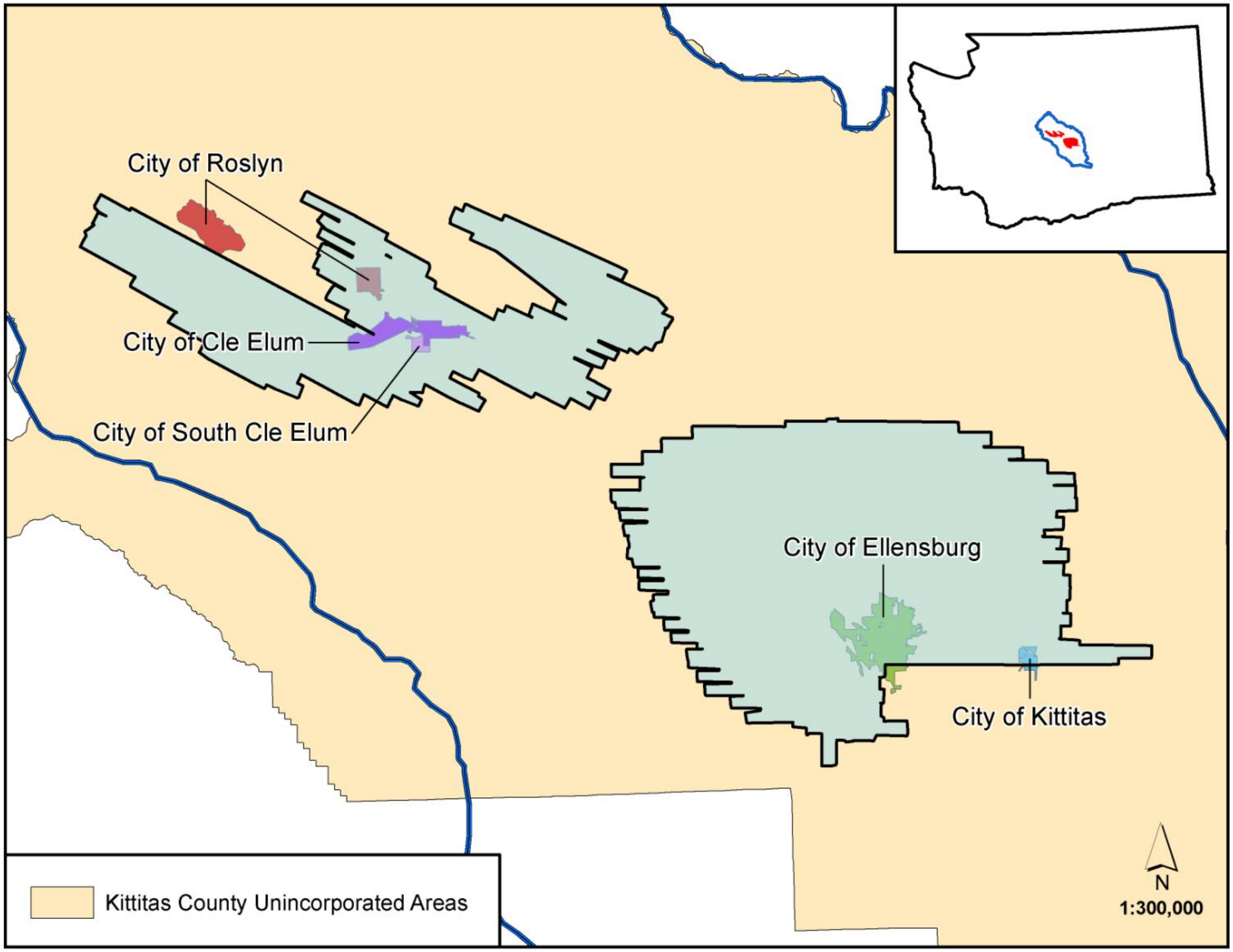


The LiDAR Acquisition area for this project covers portions of Kittitas County, Washington. The following communities are either partially or completely included within this Area of Interest:

Communities in Kittitas County, Washington:

City of Cle Elum
City of Ellensburg
City of Kittitas
City of Roslyn
City of South Cle Elum
County of Kittitas Unincorporated Areas

Figure 2 Kittitas Project Communities



2. Scope of Work

Statement of Priorities
PTS Elevation Data Acquisition
STARR – Contract # HSFEHQ-09-D-0370

The contractor shall acquire elevation data to support flood hazard data updates based on the minimum requirements shown of the attached ordering sheet. Elevation data shall comply with the draft FEMA Procedure Memorandum: Standards for LiDAR and Other High Quality Elevation Data.

The contractor shall respond with pricing for the minimum elevation collections and bare earth processing specified the attached ordering sheet. The contractor's proposal shall identify any breakline creation or other post-processing that is required to use the elevation data for the flood hazard data updates based on the risk, terrain type, anticipated engineering methods and other relevant factors. The proposal must explain the reasons this additional processing is needed.

The contractor will also be responsible for performing QA of the elevation data as specified in the Standards for LiDAR and Other High Quality Elevation Data procedure memo.

The contractor shall also propose collection and processing alternatives that group the collections into larger, more cost effective collection blocks or other collection and processing alternatives that may be more advantageous for the government as an alternative option.

Scope Details:

All data collected under this task order will adhere to the FEMA Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography.

STARR will be responsible for all phases of LiDAR collection (including ground control, acquisition, post-processing, and accuracy assessment of the data) as described below:

STARR is responsible for the collection of ground control required to control the LiDAR data and points to support a vertical test. These points must be located only in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation.

Checkpoints must be located on flat or uniformly sloping terrain and will be at least five (5) meters away from any break line where there is a change in slope. This criterion applies for all QA points for the Fundamental Vertical Accuracy (FVA) Assessment as well.

STARR will be responsible for the collection of blind vertical QA points for the Consolidated Accuracy Check (CVA). These points must be collected randomly across the three predominant land use types using the ASPRS NSSDA land cover types. The points will be located in flat areas with no substantial elevation breaks within a 3-5 meter radius. The CVA assessment may incorporate a representative sample of the FVA assessment into the dataset to save on the total number of points collected. A CVA point should not be collected for any land class comprising less than 10% of the total project area.

At least 20 points for the FVA and 15 additional points for the CVA in vegetated classes, supplemented by five FVA points to achieve 20 in total in the CVA must be collected. This number of points will give STARR the required RMSE to generate the 95% confidence required by the FEMA guidelines. All ground control points must have digital photos and a sketch (if practical) for each point. This collateral data may help with any discrepancies without further field work.

STARR must provide proof that the vertical accuracy assessment of the LiDAR data was a blind test via an independent check report. The spreadsheet with X and Y coordinates for at least 20 FVA and 15 CVA points, the elevation of each coordinate found in the LiDAR data, the comparison with the accuracy check point, the calculated difference and the overall RMSE must be included in this report. Independent check or calibration points will be three times as accurate as the surface being checked. Therefore, in order to validate a 24.5 cm surface, STARR must collect control data to 8 cm.

LiDAR acquisition of the Kittitas Project Areas, consisting of 181 square miles, captured to the “Highest” vertical accuracy requirement. This collection specification is the equivalent of a 2-foot contour accuracy and must be collected with a nominal pulse spacing of 1-meters. The areas will be post processed to bare earth.

DELIVERABLES

STARR will deliver the following:

- Ground control spreadsheet in x,y,z format, digital photograph and sketch of area (if practical) for each collected point.
- FVA Report. Assessment of initial vertical accuracy of point cloud to ensure that data has successfully completed preliminary processing. The data will be validated for positional accuracy using USGS LiDAR Guidelines and Base Specifications v13. Fundamental checkpoints will only consist of open area or bare earth areas (short grass, dirt, or rock).

  Listing of checkpoints will include any digital photographs and/or sketches for each point.
- CVA Report. Assessment of final vertical accuracy of LiDAR data to ensure that data has successfully completed bare earth processing. The data will be validated for positional accuracy using USGS LiDAR Guidelines and Base Specifications v13. Consolidated checkpoints will be collected over the five major ASPRS Land Classes.

  Listing of checkpoints will include any digital photographs and/or sketches for each point.
- Pre-Flight Operations Plan. MS Word file or PDF document that details planned flight lines, planned GPS stations, planned control, planned airport locations, calibration plans, quality procedures for flight crews, planned scanset, type of aircraft, re-flight procedures, and considerations for terrain, cover and weather in the project. This document is to be provided in accordance with the FEMA Procedure Memorandum No. 61– Standards for LiDAR and Other High Quality Digital Topography.
- Post Flight Aerial Acquisition Report. MS Excel, MS Word, and ESRI Shapefile formats (as appropriate) that details actual GPS base station information, GPS/IMU processing summary, coverage, flight data (as flown), flight logs, ground control to be used, and results of data verification (QC) process. This document is to be provided in accordance with the FEMA Procedure Memorandum No. 61 – Standards for LiDAR and Other High Quality Digital Topography.
- LAS Point Cloud Data. The initial processing and analysis of laser data (GPS/IMU/laser ranges) to fully calibrated point clouds in a mutually agreed upon tile format. This format will be proposed by Tuck Mapping to STARR. Consideration of optimum processing and use by floodplain modeling staff will be a basis for the format. All LiDAR data will be set to ASPRS LAS Class 1 (unclassified).
- LAS Bare Earth Data. The final processing and classification of LiDAR to the required ASPRS LAS classes in a mutually agreed upon tile format and compliant with USGS LiDAR Guidelines and Base Specifications v13, except as noted in the FEMA Procedure Memorandum No. 61 – Standards for LiDAR and Other

High Quality Digital Topography.

- LAS Model Key Points (ASPRS Class 8). LAS Bare Earth Data thinned to an average density of approximately 3-meter post spacing.
- Metadata. Metadata will be delivered for LAS Bare Earth Data using FGDC standards compliant with FEMA Procedure Memorandum N. 61 – Standards for LiDAR and Other High Quality Digital Topography, Attachment 2.

All data will be referenced to the NAD83 horizontal datum. The vertical datum will be referenced to NAVD88. Geoid 09 model for the National Geodetic Survey will be used to perform conversions from ellipsoidal heights to orthometric heights. The standard coordinate reference system and units will be UTM (meters).

A Certification of Compliance is also required. The Certification shall meet FEMA TSDN (Technical Support Data Notebook) requirements as stated in FEMA Guidelines and Specifications, Appendix M.

3. Issues

A. Special Problem Reports

None

B. Project Modifications

None

4. Information for the Next Mapping Partner

The Kittitas LiDAR collection Area of Interest (AOI) consist of two functional areas that cover 181 square miles. These areas are within Kittitas County in the Upper Yakima River Watershed. This project included both LiDAR point cloud development and Bare Earth post processing. The Point Cloud LiDAR data for this project are 308 partially classified LAS 1.2 binary files. The 308 Bare Earth LiDAR LAS 1.2 binary files for this project have been classified using ASPRS LiDAR classifications. Bare Earth classified as class 2 is considered to be Bare Earth and points classified as class 8 are Model Key. All data for this project has been collected using the following spatial reference information:

Projection: Universal Transverse Mercator
UTM Zone: 10
Linear units: Meter
Horizontal Datum: North American Datum 1983
Vertical Datum: North American Vertical Datum of 1988
Vertical units: Meters

LAS point files are named according to the UTM Coordinates at the southwest corner of the tile, following the zz_0xxxyyy convention, where z is the UTM zone number, x and y are the UTM coordinates.

Details about the storage of this dataset can be found within Appendix G of this document.

Ground control and quality control checkpoints were collected by CompassData, Inc. Photo Science, Inc. performed LiDAR acquisition flights, automated processing and Bare Earth manual edits. Independent QC of the point cloud and bare earth surface was performed by CompassData, Inc. Quality Assurance testing was conducted by Greenhorne & O'Mara, Inc. All firms were under contract to STARR, A Joint Venture which held the FEMA Professional Technical Services contract and task order for this work. All contact information for the project team can be found in Appendix A of this document.

A. Ground Control Survey

Ground Control is collected throughout the AOI for use in the processing of LiDAR data to ensure data accurately represents the ground surface. QA/QC checkpoints, also collected throughout the AOI, are used for independent quality checks of the processed LiDAR data.

GPS based surveys were utilized to support both processing and testing of LiDAR data within FEMA designated Areas of Interest (AOIs). Geographically distinct ground points were surveyed using GPS technology throughout the AOIs to provide support for three distinct tasks.

Task 1 was to provide Vertical Ground Control to support the aerial acquisition and subsequent bare earth model processing. To accomplish this, survey-grade Trimble R-8 GPS receivers were used to collect a series of control points located on open areas, free of excessive or significant slope, and at least 5 meters away from any significant terrain break. Most if not all control points were collected at street/road intersections on bare level pavement.

Task 2 was to collect Fundamental Vertical Accuracy (FVA) checkpoints to evaluate the initial quality of the collected point cloud and to ensure that the collected data was satisfactory for further processing to meet FEMA specifications. The FVA points were collected in identical fashion to the Vertical Ground Control Points, but segregated from the point pool to ensure independent quality testing without prior knowledge of FVA locations by the aerial vendor.

Task 3 was to collect Consolidated Vertical Accuracy (CVA) checkpoints to allow vertical testing of the bare-earth processed LiDAR data in different classes of land cover, including: Open (pavement, open dirt, short grass), High Grass and Crops, Brush and Low Trees, Forest, Urban. CVA points were collected in similar fashion as Control and FVA points with emphasis on establishing point locations within the predominant land cover classes within each AOI or Functional AOI Group. In order to successfully collect the Forest land cover class, it was necessary to establish a Backsight and Initial Point with the R8 receiver, and then employ a Nikon Total Station to observe a retroreflective prism stationed under tree canopy. This was necessary due to the reduced GPS performance and degradation of signal under tree canopy. The R-8 receivers were equipped with cellular modems to receive real-time correction signals from the Keystone Precision Virtual Reference Station (VRS) network encompassing the Region 1 AOIs. Use of the VRS network allowed rapid collection times (~3 minutes/point) at 2.54 cm (1 inch) initial accuracy.

All points collected were below the 8 cm specification for testing 24.5 cm, Highest category LiDAR data. To ensure valid in-field collections, an NGS monument with suitable vertical reporting was measured using the same equipment and procedures used for Control, FVA and CVA points on a daily basis. The measurement was compared to the NGS published values to ensure that the GPS collection schema was producing valid data and as a physical proof point of quality of collection. Those monument measurements are summarized in the Accuracy report included in the data delivered to FEMA.

In order to meet FEMA budgetary requirements, AOIs were consolidated into Functional Groups: if AOIs were contiguous, they were treated as one large AOI to allow collection of 20 FVA points and 15 additional CVA points across the group of AOIs. 20 FVA points are necessary to allow testing to CE95 – 1 point out of 20 may fail vertical testing and still allow the entire dataset to meet 95% accuracy requirements.
In similar fashion, 20 CVA points are necessary to test to CE95 as discussed above. 15 CVA points were collected with the intention at the outset that 5 of the collected FVAs would perform double –duty as Open-class CVA points, to total 20 CVAs.

The following software packages and utilities were used to control the GPS receiver in the field during data collection, and then ingest and export the collected GPS data for all points:

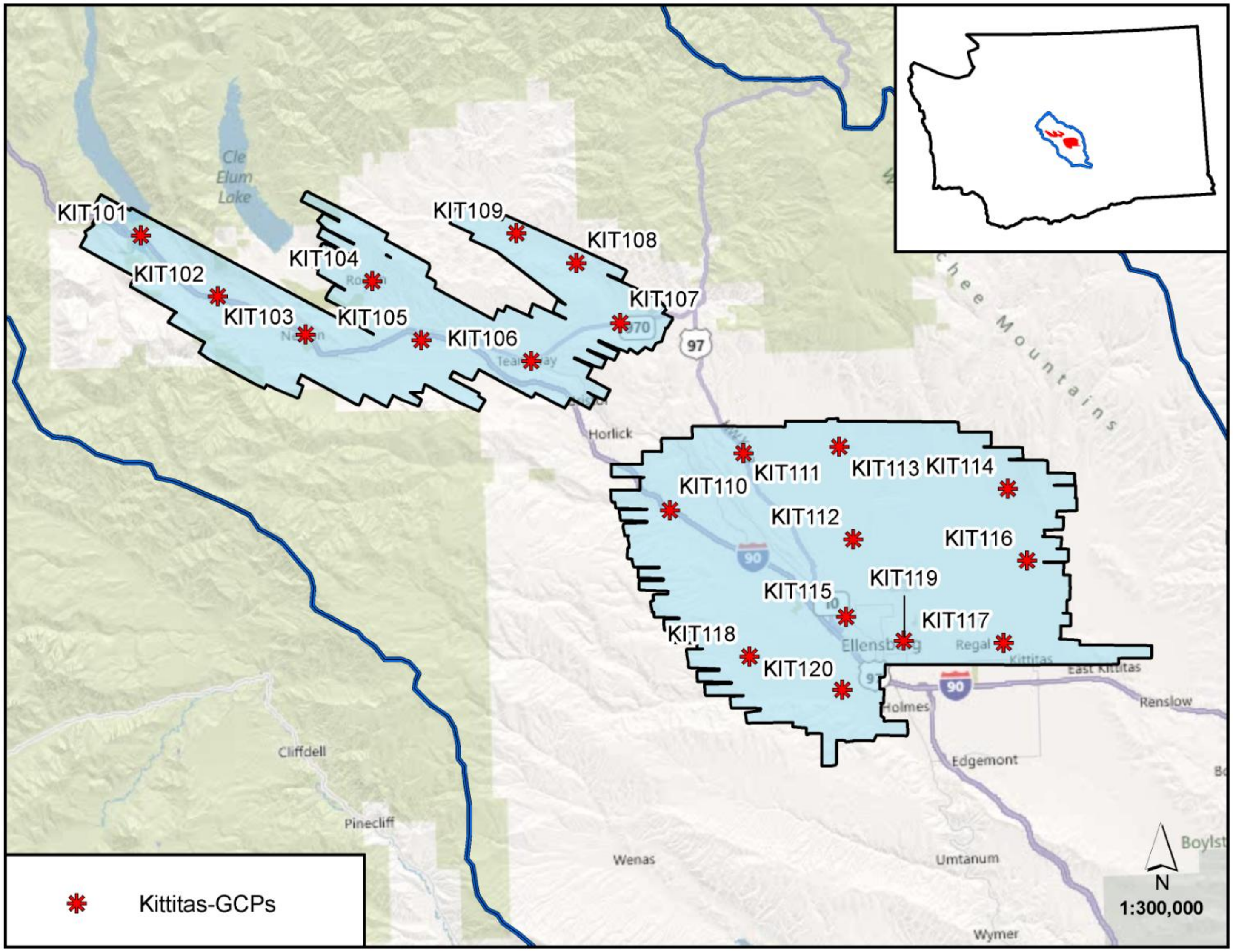
- Trimble Survey Controller
- Trimble Pathfinder Office

The following software utilities were used to translate the collected Latitude/Longitude Decimal Degree HAE GPS data for all points into Latitude/Longitude Degrees/Minutes/Seconds for checking the collected monument data against the published NGS Datasheet Lat/Long DMS values and into UTM NAD83 Northings/Eastings:

- U.S. Army Corps of Engineers CorpsCon
- National Geodetic Survey Geoid09NAVD88

MSL values were determined using the most recent NGS-approved geoid model to generate geoid separation values for each Lat/Long coordinate pair. In this fashion, Orthometric heights were determined for each Control, FVA and CVA point by subtracting the generated Geoid Separation value from the Ellipsoidal Height (HAE) for publication and use as MSL NAVD88(09).

Figure 3. Kittitas Project Ground Control Survey Coverage



B. Data Acquisition

LiDAR acquisition products include Pre- and Post- flight reports which contain information on the flight lines, equipment parameters, and other pertinent acquisition details. The LiDR product is considered to be point cloud data and consists of 1500mx1500m tiles of LAS points which are partially classified such that the bare earth points can be calibrated to the ground surface and tested via the independent QC to ensure the ground surface is accurately represented.

Using a Optech Gemini LiDAR system, 99 flight lines of highest density (Nominal Pulse Spacing of 1.0m) were collected over the Kittitas area. A total of four missions were flown: April 17, 2011, April 18, 2011, and April 19, 2011. Two airborne global positioning system (GPS) base stations were used to support the LiDAR data acquisition: 39471080.t01 and 82571071. Coordinates are available in the Post-Flight Aerial Acquisition Report.

Raw airborne GPS and IMU data were extracted from Applanix CARD. The GPS data was differentially processed in PosGPS and integrated with the IMU data in PosPAC. The GPS/IMU data is processed in Applanix to derive a smoothed best estimate of trajectory (SBET).The SBET was used to reduce the LiDAR slant range measurements to derive the Return measurement for each LiDAR pulse for all LiDAR pulses within for each flight line. The coverage was imported into TerraScan and tiled into 1500m x 1500m tiles. An initial accuracy assessment is done using the ground point survey data. The data then is classified to extract a bare earth digital elevation model (DEM). Once all project data was imported and classified, the survey ground control data was imported again and calculated against teh LAS Class 2 (Ground) data for an accuracy assessment. As a QC measure, a routine was used to generate accuracy statistical reports by comparison among LiDAR points, ground control, and triangulated irregular networks (TIN). Any systematic bias in the data is removed to meet or exceed the vertical accuracy requirements.

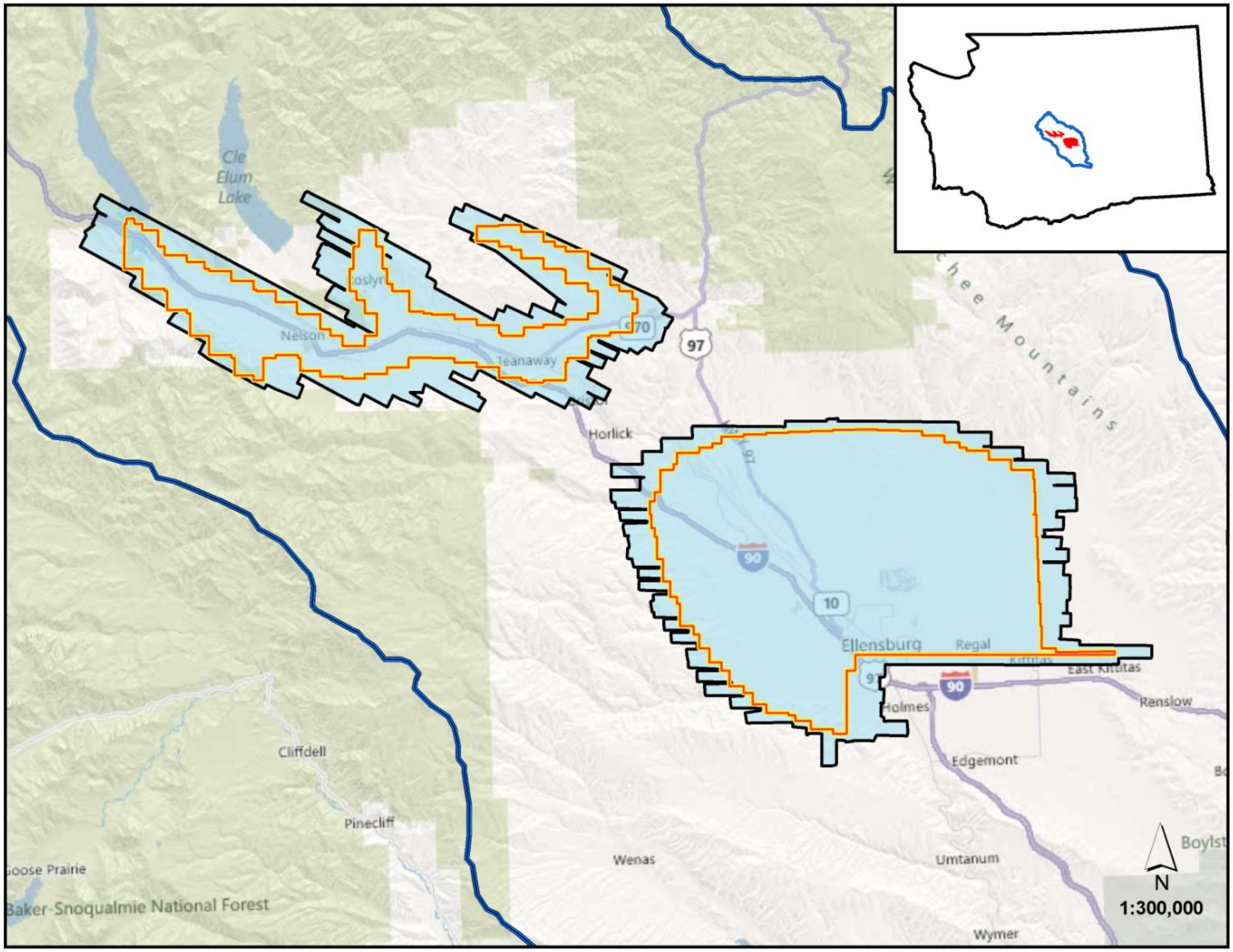
C. Post Processing

Point Cloud data is manually reviewed and any remaining artifacts are removed using functionality provided within the TerraScan and TerraModeler software packages. Additional project specific macros are created and run within GeoCue/TerraScan to ensure correct LAS classification prior to project delivery.

All points were placed in one of the following categories: 1 Unclassified, 2 Ground, 7 Noise, and 12 Overlap Points. Model Key points were then generated from the Ground points and placed in Category 8.

Final Classified LAS tiles are created within GeoCue to confirm correct LAS versioning and header information. In-house software is then used to check LAS header information and final LAS classification prior to delivery. LAS Class 2 is used to check the independent QC points against the Triangulated LiDAR surface.

Figure 4. Kittitas Project Point Cloud and Post Processing Areas



D. Quality Control

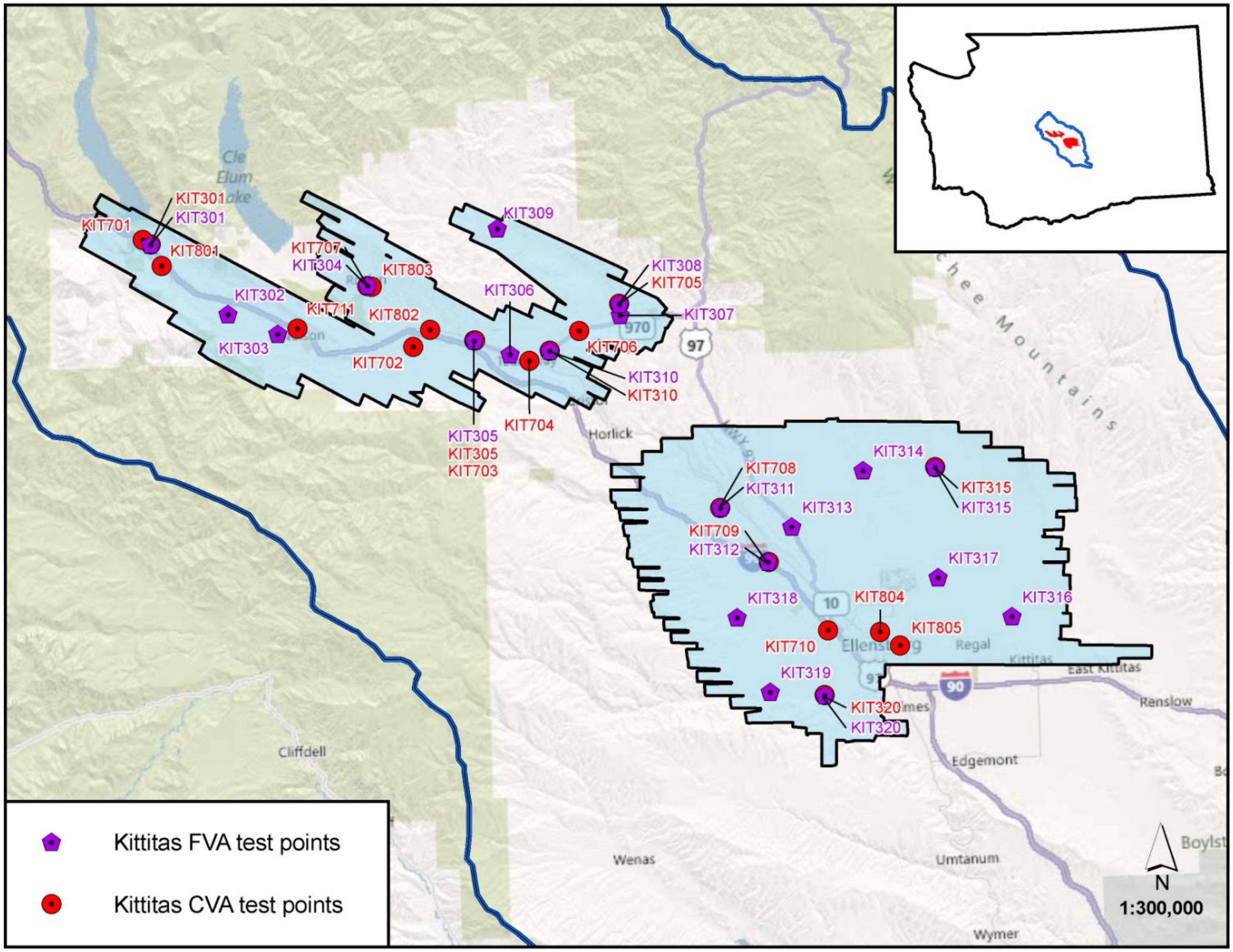
Fundamental Vertical Accuracy (FVA) checkpoints are located only in open terrain, where there is a high probability that the sensor will have detected the ground surface without influence from surrounding vegetation and/or buildings. Checkpoints are located on flat or uniformly sloping terrain and at least five (5) meters away from any break line where there is a change in slope. Checkpoints are located randomly across the acquisition area. At least 20 FVA points were collected for each test.

Consolidated Vertical Accuracy (CVA) checkpoints are collected randomly across different land use types using the ASPRS NSSDA land cover types. The points are located in flat areas with no substantial elevation breaks within a five meter radius. The CVA assessment incorporates a representative sample of the FVA assessment points into the dataset to save on the total number of points collected. CVA points were not collected for any land class comprising less that 10% of the total project area; this may have resulted in less than 4 land classes being collected in a particular area. At least 15 CVA points were collected and 5 FVA points used, for a total of at least 20 points for the CVA testing.

All checkpoints were collected by CompassData to ensure the 'independence' of the quality control check. All points were collected at three times the accuracy of the surface being checked. Thus to check a 24.5 cm surface the points were collected accurate to 8 cm.

Tests were conducted when processing by the LiDAR vendor was complete and points were called for. CompassData provided the point coordinates in an excel spreadsheet to the LiDAR vendor. The LiDAR vendor found the corresponding elevation from a surface created from the LiDAR points, filled in the spreadsheet and returned it to CompassData. CompassData compared the elevation of the LiDAR data with that of the accuracy check point, calculated the difference and reported their findings both in terms of $RMSE_z$ and at the 95% confidence level (computed as $RMSE_z$ x 1.9600). LiDAR datasets passing the quality control checks were delivered to STARR for quality assurance approval.

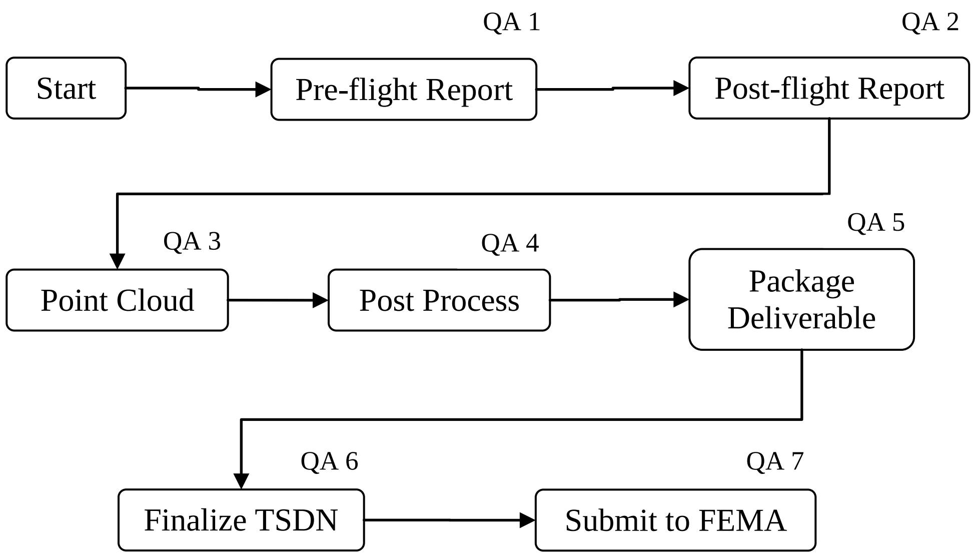
Figure 5. Kittitas Project FVA and CVA Points



E. Quality Assurance

Quality assurance for all elevation data collected for this project has been completed using *FEMA Draft PM61*$_1$, *FEMA Appendix M*$_2$, *USGS LiDAR Guidelines and Base Specifications v13*$_3$, and *FEMA Appendix A*$_4$ as guidance. Products generated during this project are checked for conformance to the aforementioned guidance and specifications before submittal to FEMA.

Figure 6. Quality Assurance Workflow



QA1: Preflight Planning and Reporting

Project preflight operations planning were delivered as a report. This report was reviewed for completeness based on: *Table 4.1 and checklists provided in section 4.2.1in PM61*$_1$. The report was reviewed and is compliant with FEMA guidance and specifications. This report is included within Appendix C of this document. Appendix G contains information about the location of report data on the MIP.

QA2: Post flight Report

Post flight reporting for this project has been reviewed for both content and completeness based upon: *Table 4.2 and checklists provided in section 4.2.1in PM61*$_1$. The report is included with Appendix E of this document. The report is complete and all content meets the guidance and specifications.

QA3: Raw Point Cloud Review

Fully calibrated raw point cloud data has been reviewed at both a macro and micro level using *Table 4.3 and checklists provided in section 4.2.1in PM61*[1], and USGS *LiDAR Guidelines and Base Specifications v13*[3]. 5% of the total number of project tiles was reviewed for compliance with USGS and FEMA specifications. All tiles reviewed for this project passed both the macro and micro reviews. Quality assurance results for the point cloud are contained within Appendix F of this document.

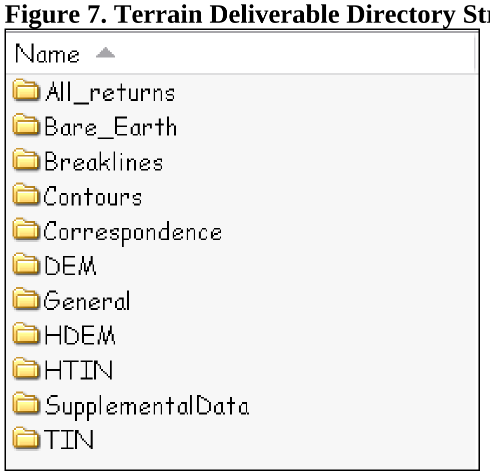
QA4: Bare Earth Review

Post-processed data has been reviewed at both a macro and micro level using *Table 4.4 and checklists provided in section 4.2.1in PM61*[1], and USGS *LiDAR Guidelines and Base Specifications v13*[3]. 10% of the total number of project tiles was reviewed for compliance with USGS and FEMA specifications. All tiles reviewed for this project passed both the macro and micro reviews. Quality assurance results for the bare earth are contained within Appendix F of this document.

QA5: Create Delivery Package

All deliverables have been organized in accordance with Appendix M: Data Capture Standards March 2009 Section M.4.2.8[2].

Figure 7. Terrain Deliverable Directory Structure



QA6: Finalization of Deliverables and TSDN

All data to be submitted for delivery has been reviewed for completeness based on the map activity statement, scope of work, and FEMA deliverable requirements. Quality assurance checklists are included in Appendix F of this document.

QA7: FEMA submission

All data for the elevation data acquisition task was delivered to FEMA on August 31, 2011. A transmittal of this submission is included in Appendix G of this document.

5. References

1. Draft Procedure Memorandum 61 included in Appendix H
2. FEMA Appendix M section M.4 included in Appendix H
3. USGS LiDAR Guidelines and Base Specifications v13 included in Appendix H
4. Appendix A: Guidance for Aerial Mapping and Surveying [includes guidance on Light Detection and Ranging Systems (LIDAR)] http://www.fema.gov/library/viewRecord.do?id=2206

Appendix A: Contact Information

STARR Contacts:

Project Management and Quality Assurance

Company	Greenhorne & O'Mara, Inc.
Name	Diane Rogers
Email	drogers@g-and-o.com
Phone	301-982-2800
Mailing Address	5565 Centerview Drive, Suite 107 Raleigh, NC 27606

LiDAR ground control and QC survey

Company	Compass Data, Inc.
Name	Hayden Howard
Email	haydenh@compassdatainc.com
Phone	303-627-4058
Mailing Address	12353 East Easter Avenue, Suite 200 Centennial, CO 80112

LiDAR data acquisition and Post Processing

Company	Aerometric, Inc.
Name	Robert Merry
Email	rmerry@aerometric.com
Phone	920-457-3631
Mailing Address	4020 Technology Parkway Sheboygan, WI 53081

Appendix B: FEMA Compliance Forms and Metadata

Project Name:	**Region 10: Kittitas, Washington – Elevation Data Acquisition**
Statement of Work No.:	FEMA TASK ORDER NUMBER: HSFEHQ-10-J-0005 WORK ORDER NUMBER: CP HQ 10 001
Interagency Agreement No.:	STARR PROJECT NUMBER: 400000058 STARR PARTNER TRACKING NUMBER: CP HQ 10 001
CTP Agreement No.:	N/A
Statement/Agreement Date:	10/ 10/10
Certification Date:	8/12/11

	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
☐	Topographic Data Development
X	Survey: Including Ground Control Points (GCPs), Fundamental Vertical Accuracy Testing (FVA), and Consolidated Vertical Accuracy Testing (CVA).
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping
	This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.

Name:	Philipp H. Hummel, PLS	COLORADO LICENSED PHILIPP H. HUMMEL 38155 August 12, 2011 PROFESSIONAL LAND SURVEYOR
Title:	Professional Land Surveyor, Geodesist	
Firm Represented:	Compass Data, Inc.	
Registration No.:	38155	
Signature:	Philipp Hummel	For and on behalf of Compass Data, Inc. Job. No.: 1508

This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

Project Name:	Kittatas, Washington AOI - Elevation Data Acquisition
Statement of Work No.:	HSFEHQ-09-D-0370
Interagency Agreement No.:	NA
CTP Agreement No.:	NA
Statement/Agreement Date:	30 September 2010
Certification Date:	31 August 2011

	Tasks/Activities Covered by This Certification (Check All That Apply)
☐	Base Map
X	Topographic Data Development
☐	Survey
☐	Hydrologic Analysis
☐	Hydraulic Analysis
☐	Alluvial Fan Analysis
☐	Coastal Analysis
☐	Floodplain Mapping
	This is to certify that the work summarized above was completed in accordance with the statement/agreement cited above and all amendments thereto, together with all such modifications, either written or oral, as the Regional Project Officer and/or Assistance Officer or their representative have directed, as such modifications affect the statement/agreement, and that all such work has been accomplished in accordance with the provisions contained in *Guidelines and Specifications for Flood Hazard Mapping Partners* cited in the contract document, and in accordance with sound and accepted engineering practices within the contract provisions for respective phases of the work. This is also to certify that data files submitted for the work summarized above are complete and final. Any revisions made to the already submitted data are included in the final submittal.

Name:	Sonja Ellefson
Title:	Lidar Technician II
Firm/Agency Represented:	Aero-Metric, Inc.
Registration No.:	Certified Photogrammetrist No.: 1450
Signature:	

This form must be signed by a representative of the firm or agency contracted to perform the work, who must be a registered or certified professional in the area of work performed, in compliance with Federal and State regulations.

Identification_Information:
  Citation:
    Citation_Information:
      Originator: Federal Emergency Management Agency
      Publication_Date: 20110822
      Title: TERRAIN, Kittitas, Washington
      Geospatial_Data_Presentation_Form: FEMA-DCS-Terrain
      Publication_Information:
        Publication_Place: Washington, DC
        Publisher: Federal Emergency Management Agency
      Online_Linkage: http://hazards.fema.gov
      Larger_Work_Citation:
        Citation_Information:
          Originator: Federal Emergency Management Agency
          Publication_Date: 20110822
        Title: FEMA CASE 11-017-0721S
  Description:
    Abstract: The Kittitas AOI consists of two areas. These areas were to be collected to the 'highest' accuracy requirement. Ground Control is collected throughout the AOI for use in the processing of LiDAR data to ensure data accurately represents the ground surface. QA/QC checkpoints, (FVA and CVA - see Ground Control process step for further information) are located throughout the area, and are used for independent quality checks of the processed LiDAR data.
LiDAR acquisition products include Pre- and Post- flight reports which contain information on the flightlines, equipment parameters, and other pertinant acquisition details. The LiDAR Point Cloud product consists of tiles of LAS points which are partially classified such that the bare earth points can be calibrated to the ground surface and tested via the independent QC to ensure the ground surface is accurately represented.
The LiDAR processing product consists of LAS points which are fully classified with the bare earth points tested via the independent QC to ensure the ground surface is accurately represented.
    Purpose: Provide high resolution terrain elevation and land cover elevation data. Terrain data is used to represent the topography of a watershed and/or floodplain environment and to extract useful information for hydraulic and hydrologic models.

  Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 2011822
    Currentness_Reference: ground condition
  Status:
    Progress: Complete
    Maintenance_and_Update_Frequency: Unknown
  Spatial_Domain:
    Bounding_Coordinates:
      West_Bounding_Coordinate: -121.233187
      East_Bounding_Coordinate: -120.303672
      North_Bounding_Coordinate: 47.365658
      South_Bounding_Coordinate: 46.887088
  Keywords:
    Theme:

```
  Theme_Keyword_Thesaurus: ISO 19115 Topic Category
  Theme_Keyword: elevation
Theme:
  Theme_Keyword_Thesaurus: FEMA NFIP Topic Category
  Theme_Keyword: Land Surface
  Theme_Keyword: Topography
  Theme_Keyword: Digital Terrain Model
  Theme_Keyword: Elevation Data
  Theme_Keyword: LIDAR
Theme:
  Theme_Keyword_Thesaurus: None
  Theme_Keyword: Ground Control
  Theme_Keyword: LAS point files
  Theme_Keyword: Point Cloud
  Theme_Keyword: All Returns
  Theme_Keyword: Bare Earth
Place:
  Place_Keyword_Thesaurus: None
  Place_Keyword: REGION X
  Place_Keyword: STATE WA
  Place_Keyword: COUNTY KITTITAS
  Place_Keyword: COUNTY-FIPS 037
  Place_Keyword: COMMUNITY KITTITAS COUNTY
  Place_Keyword: FEMA-CID 530095
Place:
  Place_Keyword_Thesaurus: None
  Place_Keyword: REGION X
  Place_Keyword: STATE WA
  Place_Keyword: COUNTY KITTITAS
  Place_Keyword: COUNTY-FIPS 037
  Place_Keyword: COMMUNITY CLE ELUM, CITY OF
  Place_Keyword: FEMA-CID 530096
Place:
  Place_Keyword_Thesaurus: None
  Place_Keyword: REGION X
  Place_Keyword: STATE WA
  Place_Keyword: COUNTY KITTITAS
  Place_Keyword: COUNTY-FIPS 037
  Place_Keyword: COMMUNITY ELLENSBURG, CITY OF
  Place_Keyword: FEMA-CID 530234
Place:
  Place_Keyword_Thesaurus: None
  Place_Keyword: REGION X
  Place_Keyword: STATE WA
  Place_Keyword: COUNTY KITTITAS
  Place_Keyword: COUNTY-FIPS 037
  Place_Keyword: COMMUNITY ROSLYN, CITY OF
  Place_Keyword: FEMA-CID 530299
Place:
  Place_Keyword_Thesaurus: None
  Place_Keyword: REGION X
  Place_Keyword: STATE WA
  Place_Keyword: COUNTY KITTITAS
  Place_Keyword: COUNTY-FIPS 037
```

Place_Keyword: COMMUNITY SOUTH CLE ELUM, CITY OF
Place_Keyword: FEMA-CID 530263

Access_Constraints: None
Use_Constraints: Acknowledgement of FEMA would be appreciated in products derived from these data. This digital data is produced for the purposes of updating/creating a DFIRM database.
Data_Set_Credit: Ground control and quality control checkpoints were collected by CompassData, Inc. AeroMetric, Inc. performed LiDAR acquisition flights,automated and manual processing. Independent QC of the bare earth surface was performed by CompassData, Inc. Quality Assurance testing was conducted by Greenhorne & O'Mara, Inc. All firms were under contract to STARR, A Joint Venture which held the FEMA contract and task order for this work.

Data_Quality_Information:
Logical_Consistency_Report: Survey data have been confirmed to be in proper units, coordinate systems and format. The terrain data have been confirmed as complete LAS format data files. Header files are in proper LAS format with content as specified by FEMA Procedural Memo No. 61.
Completeness_Report: Survey data have been checked for completeness, points have been collected in correct vegetation units, and distributed throughout the AOI. The terrain data have been checked for completeness against AOI polygons. No gaps as defined by FEMA Procedural Memo No. 61 are known to exist within the dataset.

Positional_Accuracy:
Vertical_Positional_Accuracy:
Vertical_Positional_Accuracy_Report: Deliverables were tested by for both vertical and horizontal accuracy. The vertical unit of the data file is in meters with 2-decimal point precision.
Quantitative_Vertical_Positional_Accuracy_Assessment:
Vertical_Positional_Accuracy_Value: .073
Vertical_Positional_Accuracy_Explanation: Consolidated Vertical Accuracy (CVA) equal to the 95th Percentile calculated against the bare earth surface in all ground cover classes. Reported in meters. Fundamental Vertical Accuracy (FVA) equal to the 95% confidence level (RMSE[z] x 1.9600) calculated against the point cloud (unclassified LAS) was 0.117meters.

Lineage:
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: GroundControl Kittitas
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110822
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other1

Source_Contribution: Control points for tying LiDAR data to the ground surface.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: FVA_CVA Kittitas
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110822
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other2
Source_Contribution: Quality Assurance points to confirm LiDAR data meets vertical accuracy requirements.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: Kittitas_Collection_Area
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110822
Source_Currentness_Reference: publication date
Source_Citation_Abbreviation: Other3
Source_Contribution: Shapefile of Kittitas LiDAR Acquisition Area.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: All_Returns
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
Single_Date/Time:
Calendar_Date: 20110822
Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other4
Source_Contribution: Point Cloud (All Returns) LAS point files named according to the Kittitas_Tile_Index.
Source_Information:
Source_Citation:
Citation_Information:
Originator: STARR
Publication_Date: 2011
Title: Kittitas_PreFlightReport
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:

```
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 20110822
        Source_Currentness_Reference: ground condition
      Source_Citation_Abbreviation: Other5
      Source_Contribution: document contains the operation plans for the
LiDAR acquisition.
     Source_Information:
      Source_Citation:
        Citation_Information:
          Originator: STARR
          Publication_Date: 2011
          Title: Kittitas_PostFlight_Report
      Type_of_Source_Media: DIGITAL
      Source_Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 20110822
        Source_Currentness_Reference: ground condition
      Source_Citation_Abbreviation: Other6
      Source_Contribution: Document contains the acquisition and
calibration report for the LiDAR acquisition.
     Source_Information:
      Source_Citation:
        Citation_Information:
          Originator: STARR
          Publication_Date: 2011
          Title: Kittitas_Tile_Index
      Type_of_Source_Media: DIGITAL
      Source_Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 20110822
        Source_Currentness_Reference: ground condition
      Source_Citation_Abbreviation: Other7
      Source_Contribution: shapefile of tile index used to populate and
reference the LAS tiled data.
    Source_Information:
      Source_Citation:
        Citation_Information:
          Originator: STARR
          Publication_Date: 2011
          Title: Region 10 Kittitas Testing Results FVA CVA
      Type_of_Source_Media: DIGITAL
      Source_Time_Period_of_Content:
    Time_Period_Information:
      Single_Date/Time:
        Calendar_Date: 20110822
        Source_Currentness_Reference: ground condition
      Source_Citation_Abbreviation: Other8
      Source_Contribution: document contains QC test results for both FVA
CVA blind checkpoint tests against the bare earth surface generated from
the bare earth LAS points.
    Source_Information:
```

Source_Citation:
  Citation_Information:
    Originator: STARR
    Publication_Date: 2011
    Title: R10_Kittitas_County_Terrain_TSDN
Type_of_Source_Media: DIGITAL
Source_Time_Period_of_Content:
Time_Period_Information:
  Single_Date/Time:
    Calendar_Date: 20110822
    Source_Currentness_Reference: ground condition
Source_Citation_Abbreviation: Other9
Source_Contribution: Technical Support Data Notebook contains complete narrative on the acquisition and processing of the LiDAR dataset, including area diagram, reports, metadata and other supporting documentation.
Source_Information:
  Source_Citation:
    Citation_Information:
      Originator: STARR
      Publication_Date: 2011
      Title: Bare_Earth
  Type_of_Source_Media: DIGITAL
  Source_Time_Period_of_Content:
Time_Period_Information:
  Single_Date/Time:
    Calendar_Date: 20110822
    Source_Currentness_Reference: ground condition
  Source_Citation_Abbreviation: Other10
  Source_Contribution: Fully Classified LAS point file named according to the UTM coordinates at the southwest corner of tile.

Process_Step:
  Process_Description: GPS based surveys were utilized to support both processing and testing of LiDAR data within FEMA designated Areas of Interest (AOIs). Geographically distinct ground points were surveyed using GPS technology throughout the AOIs to provide support for three distinct tasks.
Task 1 was to provide Vertical Ground Control to support the aerial acquisition and subsequent bare earth model processing. To accomplish this, survey-grade Trimble R-8 GPS receivers were used to collect a series of control points located on open areas, free of excessive or significant slope, and at least 5 meters away from any significant terrain break. Most if not all control points were collected at street/road intersections on bare level pavement.
Task 2 was to collect Fundamental Vertical Accuracy (FVA) checkpoints to evaluate the initial quality of the collected point cloud and to ensure that the collected data was satisfactory for further processing to meet FEMA specifications. The FVA points were collected in identical fashion to the Vertical Ground Control Points, but segregated from the point pool to ensure independent quality testing without prior knowledge of FVA locations by the aerial vendor.
Task 3 was to collect Consolidated Vertical Accuracy CVA) checkpoints to allow vertical testing of the bare-earth processed LiDAR data in

different classes of land cover, including: Open (pavement, open dirt, short grass), High Grass and Crops, Brush and Low Trees, Forest, Urban. CVA points were collected in similar fashion as Control and FVA points with emphasis on establishing point locations within the predominant land cover classes within each AOI or Functional AOI Group. In order to successfully collect the Forest land cover class, it was necessary to establish a Backsight and Initial Point with the R8 receiver, and then employ a Nikon Total Station to observe a retroreflective prism stationed under tree canopy. This was necessary due to the reduced GPS performance and degradation of signal under tree canopy.
The R-8 receivers were equipped with cellular modems to receive real-time correction signals from the Keystone Precision Virtual Reference Station (VRS) network encompassing the Region 1 AOIs. Use of the VRS network allowed rapid collection times (~3 minutes/point) at 2.54 cm (1 inch) initial accuracy.
All points collected were below the 8cm specification for testing 24cm, Highest category LiDAR data. To ensure valid in-field collections, an NGS monument with suitable vertical reporting was measured using the same equipment and procedures used for Control, FVA and CVA points on a daily basis. The measurement was compared to the NGS published values to ensure that the GPS collection schema was producing valid data and as a physical proof point of quality of collection. Those monument measurements are summarized in the Accuracy report included in the data delivered to FEMA.
20 FVA points and 15 additional CVA points across the group of AOIs were collected. 20 FVA points are necessary to allow testing to CE95 – 1 point out of 20 may fail vertical testing and still allow the entire dataset to meet 95% accuracy requirements.In similar fashion, 20 CVA points are necessary to test to CE95 as discussed above. 15 CVA points were collected with the intention at the outset that 5 of the collected FVAs would perform double–duty as Open-class CVA points, to total 20 CVAs per AOI.
The following software packages and utilities were used to control the GPS receiver in the field during data collection, and then ingest and export the collected GPS data for all points: Trimble Survey Controller, Trimble Pathfinder Office.
The following software utilities were used to translate the collected Latitude/Longitude Decimal Degree HAE GPS data for all points into Latitude/Longitude Degrees/Minutes/Seconds for checking the collected monument data against the published NGS Datasheet Lat/Long DMS values and into UTM NAD83 Northings/Eastings: U.S. Army Corps of Engineers CorpsCon, National Geodetic Survey Geoid09NAVD88.
MSL values were determined using the most recent NGS-approved geoid model to generate geoid separation values for each Lat/Long coordinate pair. In this fashion, Orthometric heights were determined for each Control, FVA and CVA point by subtracting the generated Geoid Separation value from the Ellipsoidal Height (HAE) for publication and use as MSL NAVD88(09).
  Process_Date: 2011
Process_Step:
  Process_Description: Using a Optech Gemini LiDAR system, 99 flight lines of highest density (Nominal Pulse Spacing of 1.0m) were collected over the Kittitas area. A total of four missions were flown: April 17, 2011, April 18, 2011, and April 19, 2011. Two airborne global

positioning system (GPS) base stations were used to support the LiDAR data acquisition: 39471080.t01 and 82571071. Coordinates are available in the Post-Flight Aerial Acquisition Report.
  Process_Date: 2011
Process_Step:
  Process_Description:Raw airborne GPS and IMU data were extracted from Applanix CARD. The GPS data was differentially processed in PosGPS and integrated with the IMU data in PosPAC. The GPS/IMU data is processed in Applanix to derive a smoothed best estimate of trajectory (SBET).The SBET was used to reduce the LiDAR slant range measurements to derive the Return measurement for each LiDAR pulse for all LiDAR pulses within for each flight line. The coverage was imported into TerraScan and tiled into 1500m x 1500m tiles. An initial accuracy assessment is done using the ground point survey data. The data then is classified to extract a bare earth digital elevation model (DEM). Once all project data was imported and classified, the survey ground control data was imported again and calculated against teh LAS Class 2 (Ground) data for an accuracy assessment. As a QC measure, a routine was used to generate accuracy statistical reports by comparison among LiDAR points, ground control, and triangulated irregular networks (TIN). Any systematic bias in the data is removed to meet or exceed the vertical accuracy requirements.
  Process_Date: 2011
Process_Step:
  Process_Description: The calibrated and filtered LiDAR point cloud was hand checked for accuracy. All points were placed in one of the following categories: 1 Unclassified, 2 Ground, 7 Noise, and 12 Overlap Points. Model Key points were then generated from the Ground points and placed in Category 8. Requested elevation values to were then provided to CompassData for their evaluation of the Consolidated Vertical Accuracy (CVA).
  Process_Date: 2011

Spatial_Reference_Information:
Horizontal_Coordinate_System_Definition:
Planar:
Grid_Coordinate_System:
Grid_Coordinate_System_Name: Universal Transverse Mercator
Universal_Transverse_Mercator:
UTM_Zone_Number: 10
Transverse_Mercator:
   Scale_Factor_at_Central_Meridian: 0.999600
   Longitude_of_Central_Meridian: -99.000000
   Latitude_of_Projection_Origin: 0.000000
   False_Easting: 500000.000000
   False_Northing: 0.000000
      Planar_Coordinate_Information:
        Planar_Coordinate_Encoding_Method: coordinate pair
        Coordinate_Representation:
          Abscissa_Resolution: 0.000010
          Ordinate_Resolution: 0.000010
        Planar_Distance_Units: meters
Geodetic_Model:
   Horizontal_Datum_Name: North American Datum 1983

Ellipsoid_Name: Geodetic Reference System 80
Semi-major_Axis: 6378137.00
Denominator_of_Flattening_Ratio: 298.257222
Vertical_Coordinate_System_Definition:
Altitude_System_Definition:
Altitude_Datum_Name: North American Vertical Datum of 1988
Altitude_Resolution: 0.01
Altitude_Distance_Units: meters
Altitude_Encoding_Method: Attribute Values

Entity_and_Attribute_Information:
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143612\SupplementalData\GroundControl
Entity_Type_Definition: Ground Control Survey for LiDAR collection
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143612\SupplementalData\FVA_CVA
Entity_Type_Definition: Survey for Horizontal and Vertical LiDAR QC
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143612\SupplementalData\Kittitas_Collection_Area
Entity_Type_Definition: Area Spatial File
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143612\All_Returns
Entity_Type_Definition: LAS 1.2 files
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at http://www.fema.gov/fhm/dl_cgs.shtm)
Detailed_Description:
Entity_Type:
Entity_Type_Label: Terrain\2143612\SupplementalData\Kittitas_PreFlightReport
Entity_Type_Definition: Digital Document
Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and

Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
      Entity_Type:
        Entity_Type_Label:
Terrain\2143612\SupplementalData\Kittitas_PostFlightReport
        Entity_Type_Definition: Digital Document
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
      Entity_Type:
        Entity_Type_Label:
Terrain\2143612\SupplementalData\Kittitas_Tile_Index
        Entity_Type_Definition: Area Spatial File
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
      Entity_Type:
        Entity_Type_Label: Terrain\2143612\SupplementalData\Region 10 Kittitas Testing Results FVA CVA
        Entity_Type_Definition: Digital Document
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
      Entity_Type:
        Entity_Type_Label:
Terrain\2143612\General\R10_Kittitas_County_Terrain_TSDN
        Entity_Type_Definition: Digital Document
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Detailed_Description:
      Entity_Type:
        Entity_Type_Label: Terrain\2143612\Bare_Earth
        Entity_Type_Definition: LAS 1.2 files
        Entity_Type_Definition_Source: FEMA Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix M: Data Capture Standards and Data Capture Guidelines (available at
http://www.fema.gov/fhm/dl_cgs.shtm)
    Overview_Description:
      Entity_and_Attribute_Overview: The Terrain data package is made up of several data themes containing primarily spatial information. These data supplement the Elevation datasets by providing additional information to aid flood risk evaluation and flood hazard area delineations.
      Entity_and_Attribute_Detail_Citation: Appendix M of FEMA Guidelines and Specifications for FEMA Flood Hazard Mapping Partners contains a

detailed description of the data themes and references to other relevant information.

Distribution_Information:
  Distributor:
    Contact_Information:
      Contact_Organization_Primary:
        Contact_Organization: Federal Emergency Management Agency Engineering Library
      Contact_Address:
        Address_Type: mailing address
        Address: Marie Sparrow, Zimmerman Associates, Inc.
        Address: 847 South Pickett Street
        City: Alexandria
        State_or_Province: Virginia
        Postal_Code: 22304
        Country: USA
      Contact_Voice_Telephone: 1-877-336-2627
      Contact_Electronic_Mail_Address: miphelp@mapmodteam.com

Distribution_Liability: No warranty expressed or implied is made by FEMA regarding the utility of the data on any other system nor shall the act of distribution constitute any such warranty.
  Standard_Order_Process:
    Digital_Form:
      Digital_Transfer_Information:
        Format_Name: FEMA-DCS-Terrain
      Digital_Transfer_Option:
        Online_Option:
          Computer_Contact_Information:
            Network_Address:
              Network_Resource_Name: http://hazards.fema.gov
    Fees: Contact Distributor

Metadata_Reference_Information:
  Metadata_Date: 20110131
  Metadata_Contact:
    Contact_Information:
      Contact_Person_Primary:
        Contact_Person: FEMA Representative
        Contact_Organization: Federal Emergency Management Agency
      Contact_Address:
        Address_Type: mailing address
        Address: 500 C Street, S.W.
        City: Washington
        State_or_Province: District of Columbia
        Postal_Code: 20472
        Country: USA
      Contact_Voice_Telephone: 1-877-336-2627
      Contact_Electronic_Mail_Address: miphelp@mapmodteam.com
  Metadata_Standard_Name: FGDC Content Standards for Digital Geospatial Metadata
  Metadata_Standard_Version: FGDC-STD-001-1998
Metadata_Extensions:

Online_Linkage: http://hazards.fema.gov
Online_Linkage: http://www.epsg.org
Profile_Name: FEMA NFIP Metadata Content and Format Standard

Appendix C: Pre Flight Planning Report

the precision and accuracy of the LiDAR mapping. All steps and QA/QC results will be documented in a report.

Procedure for Tracking, Executing, and Checking for Re-flights

Checking Coverage

Aero-Metric plans all missions using a DEM to minimize the potential of gaps in the collection. The DEM is brought into the ALTM_planner software and potential gaps are identified by red. Once this is determined the flight altitude will be adjusted to eliminate the gap and maintain the required point density. The DEM is also used to plan the flights according to terrain and the flight parameters will be adjusted per flight line to account for terrain so we are still optimizing the NPS to meet the USGS NGS specifications required. Although, this usually eliminates the gaps certain flight conditions could exist that potentially cause a gap. The following is the process is used in the field to verify coverage and data usability. The ALTM_NAV software provides an output of the swath coverage and in addition the flight can be brought into Optech's Zinview software if a potential gap is identified.

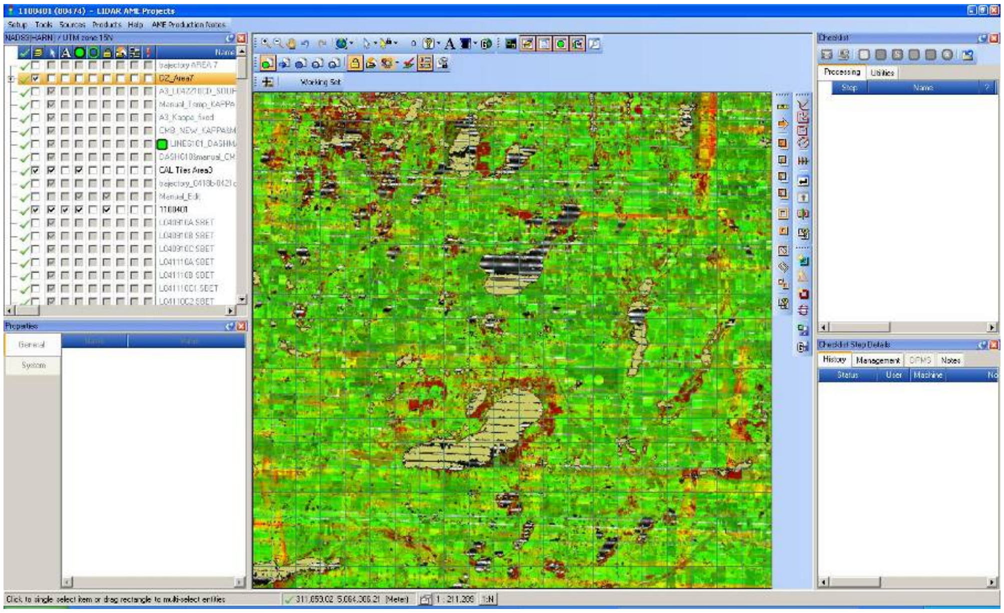
The GPS and IMU data will be processed to validate the data. This data is combined with the Laser Data and analyzed for usability. The swath data is saved and verified in the field. The data is transmitted to the office of operation on a regular basis and again verified in the office during collection.

Tracking and execution

The tracking of the flights are done using the swath data and log sheets. The log sheets are completed on a mission by mission basis and are tied to the flight plans generated for ALTM_NAV as provided in the flight plan section. The swath data from a previous mission loaded prior to a mission and verify the next line to be flown until all missions for the project are completed. The previous days logs will be referenced as well to verify at all lines are being flown for a project area. All the data will be saved on two separate Disk drives for redundancy to make sure that all data has been transmitted to the office of operation.

Re-flights

In the event that a re-flight is necessary, the line will be identified and logged as a re-flight. The line re-flown will be indicated as such on the flight log so the processing department will know that it is a re-flown line for a specific line.



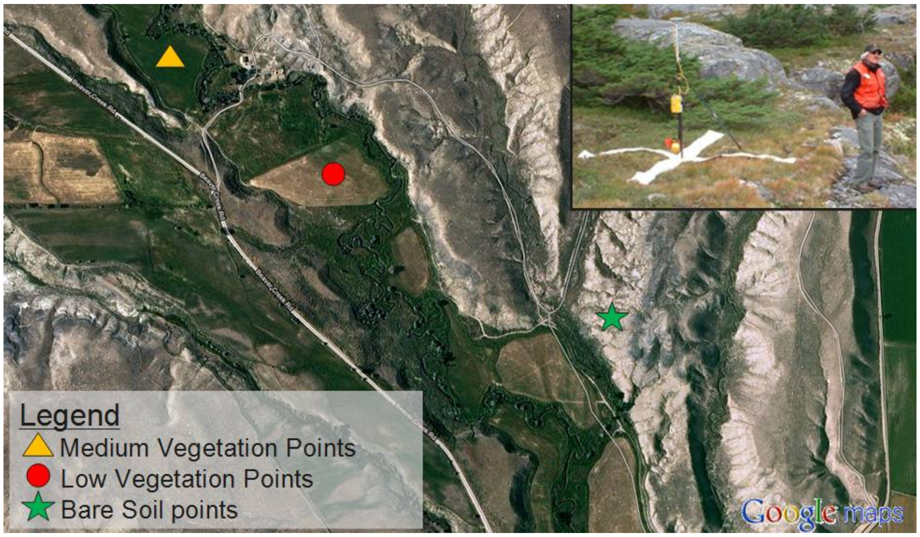
DZ ortho Validating Calibration of LiDAR data

Field QA/QC

Aero-Metric QA/QC procedures are designed with the intent that a project is complete the first time, without re-flights. Field QA/QC will consist of several steps to maintain accuracy of our mapping deliverables. When placed in a new platform, the LiDAR unit will be "surveyed in" to provide accurate offset information relating to the GPS and the LiDAR unit. Before starting a project, several test scans will be flown over a fixed object to verify calibration of the operating system. On the day of a survey flight, the flight time will be synchronized with GPS receivers on the ground to ensure a common observation "session." Ground GPS receivers will be set up on the primary control monument at the local airport, which will be free of significant obstructions that may block GPS satellite signals. On-board information displayed on a laptop computer will provide information regarding navigation and overall operation of the LiDAR system, including real-time updates of scan coverage and ranging. Issues with the LiDAR system will be identified immediately while the plane is in flight. Aero-Metric will use multiple ground GPS base stations during a LiDAR survey, increasing redundancy in the data and decreasing the potential of an unrecoverable mishap in data collection. We will maintain a reasonably short distance from the ground GPS stations to the LiDAR system to ensure a fixed-integer solution at all times during the flight. It is our policy to acquire LiDAR only when there is a minimum of six NAVSTAR satellites visible with a positional dilution of precision (PDOP) value below four.

Office QA/QC

Data collected in the field will be processed in an Aero-Metric field office. Several methods will be used to verify the data captured in the field. For example, the instrument height and receiver/antennae combinations will be checked to verify the accuracy of each GPS setup. Field notes will be checked and verified in the office. During the processing phase, all data will be solved using least-squares, which will aid us in identifying and fixing problem data sets. Aero-Metric will confirm that all GPS vectors have achieved fixed-integer solutions. Using proprietary software, we will process the IMU data to verify and validate all roll, pitch, heading, trajectory, and offset measurements. After successful processing, the resulting data will then be independently compared against both the higher-order ground control survey and the precise photogrammetric survey. Further, a system of test patch areas scattered throughout the project, as well as kinematic GPS profiles along area roads to check the validity of the LiDAR data, will be used to validate the LiDAR data. These ground comparisons will be automated, giving statistics indicating



Ground Check Point Verification

LiDAR QA/QC Procedures

As with all Aero-Metric production processes, extensive QA/QC testing will be applied to the data throughout the work flow. These tests will be designed in the project planning stage to ensure the efficacy of the critical processes necessary to meet final deliverable specifications. Any issues discovered by these QA/QC tests will be immediately addressed to ensure a satisfactory outcome and the generation of deliverables that will meet or exceed all project specifications.

Based on the tiling scheme agreed upon, each tile in the delivery will be examined for compliance with the established specifications. This testing will include, at a minimum, the following:

- Validate proper projection coordinate system and datum
- Verify interpolated elevations from DEM using field-derived blind QA point elevations
- Inspect LAS files for proper format
- Check for disjoints, overlap, or underlap
- Statistically sample files for compliance
- View TIN file and look for spikes
- Validate conformance with intended extent and naming convention
- Verify there is a smooth-edge match with adjacent tiles (slope and elevation)
- Confirm there are no voids in dataset

Aero-Metric employs a variety of methods to provide QA/QC for LiDAR projects. It is our policy to provide multiple QA/QC processes throughout the life of the project. The following are a representative sample of some of the QA/QC procedures used.

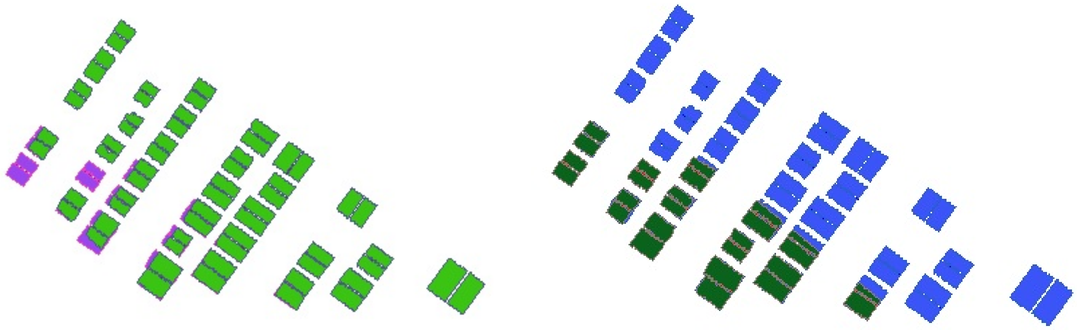


Figure 5: Roof lines prior to calibration correction and after calibration correction

The roof lines are analyzed and corrected in the calibration process as depicted in figure 5 above.

It is imperative that the calibration of the sensor is precise in all aspects of the complexity of the sensor. If the calibration of the system is not exact, then the impact to the collection of the Nebraska project will be significant. The Aero-Metric team understands the importance of calibration and takes major steps to insure the stability of all our sensors.

LiDAR In-Situ Data Calibration

In addition to the system calibration, Aero-metric performs project calibrations to further define the system parameters and improve the accuracies as they relate to the project location. During every mission a series of cross flight lines are flown perpendicular to the collection flight lines. This process enables the Aero-Metric LiDAR group to check and analyze the flight line matching and if necessary apply a least squares adjustment to minimize or eliminate flight line differences which will improve the overall accuracy of the LiDAR data. The In-Situ calibration is as extensive as the system calibration and it is preformed on every mission as indicated. The following figure is a representation of an In-Situ calibration for a mission and the same configuration will be utilized on every mission during the collection of the Nebraska LiDAR campaign.

Figure 6: In-Situ Calibration

Planned Control

Aero-Metric has determined 40 check points disturbed throughout the Kittitas LiDAR project location which will be collected to verify the accuracy of the LiDAR collection per the FEMA guidelines and specifications for this project. The following is an example of check point locations and classes to meet FEMA specification.

The system calibration is preformed to validate and maintain the error budget associated with the Inertial Measurement Unit (IMU), mirror angle encoding, and pulse gate timing. In simple terms we correct the variations in roll, pitch, heading, scale scan factor and Z- bias as a result of the changes in the system information. The results of the calibration contribute to the tuning of the sensor prior to deployment of the LiDAR and aircraft to a project location.

Aero-Metric uses an innovative approach to calibration. The variables showing historic stability are held in the calibration process and variables such as roll are floated and redefined using the planar surfaces, or tie planes. The least squared adjustment is applied to the differences associated with the LiDAR data and the results are analyzed to provide consistence throughout the calibration and resulting data sets. In addition roof lines and roof surfaces are evaluated to further refine the calibration. The representation in Figure 2 depicts the tie planes of the calibration referenced above in figure 1.

Figure 2: Tie plane depiction of calibration

ALS-ID	scan-offset value [deg]	scan-offset std.dev. [deg]	scan-scale value [-]	scan-scale std.dev. [-]	scan-lag value [deg]	scan-lag std.dev. [deg]
SC1	-	-	0.000090	0.000018	0.000335	0.000056

ALS-ID	Ex-correction value [deg]	Ex-correction std.dev. [deg]	Ey-correction value [deg]	Ey-correction std.dev. [deg]	Ez-correction value [deg]	Ez-correction std.dev. [deg]
SC1	0.002468	0.000331	-0.002754	0.000402	0.008868	0.003494

(c) GPS position corrections

GPS-ID	X-correction value [m]	X-correction std.dev. [m]	Y-correction value [m]	Y-correction std.dev. [m]	Z-correction value [m]	Z-correction std.dev. [m]
PC1	0.000	0.0001	0.000	0.0001	0.019	0.0114
PC2	-0.000	0.0001	-0.000	0.0001	-0.050	0.0114
PC3	0.000	0.0001	0.000	0.0001	0.031	0.0114

Figure 3: example of calibration parameters

The statistics in figure 3 indicate an example of some of the corrections made in the system calibration. In addition to the historic calibration corrections, additional validation of the GPS information is performed and evaluated to make sure that with a PDOP of 3 or better the GPS data is usable and has integrity. The figure below (figure 4) indicates the correction of the tie planes.

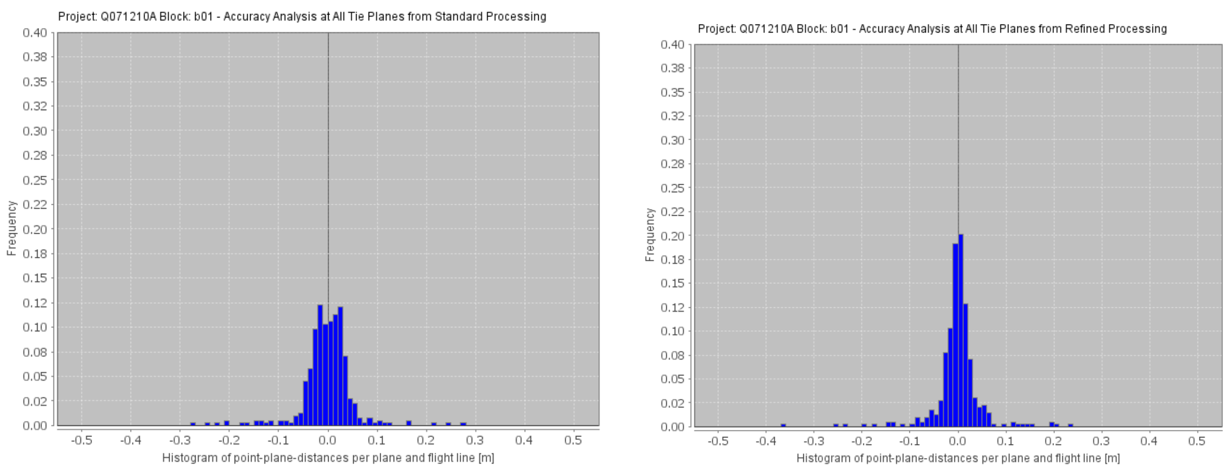


Figure 4: Tie planes before calibration correction and after calibration correction

GPS Stations (base stations)

The GPS stations will be selected based on the list of points provided below. The exact points for this collection are not detailed since the current recovery data may not be valid. Therefore the location of base stations will be assessed once on site based on the reliability of the given point(s). All points on the list are suitable for GPS observations and will be provided to the field staff.

PID	LATITUDE	LONGITUDE	Horizontal	Vertical
Kittitas				
CO6017	47 00 01.19035	120 32 18.54665	A	H
AH2506	47 00 01.19017	120 32 18.54694	A	H
AJ7207	46 57 03.31176	120 43 28.53658	A	H
DL3300	46 36 17.85473	120 30 18.17383	A	H
SX1079	47 00 43.35100	120 31 16.2824	0	1
AI3654	47 00 15.32732	120 31 39.47645	0	1
AD9543	47 02 26.02395	120 32 05.79785	0	
SX1547	47 01 51.11424	120 31 14.92835	0	
AA6011	47 02 11.64953	120 29 52.47812	0	

In the event that Aero-Metric has to establish a new point the information of the new point or points will be provided.

LiDAR System Calibration

As part of every LiDAR project, Aero-Metric performs system calibration upon sensor installation and at three month intervals in the event the LiDAR system remains in the aircraft. The system calibration is performed to identify inconsistencies between the software corrections as they relate to the sensor hardware and its relationship to the GPS antenna location on the aircraft. Typically, a series of calibration lines (*figure 1*) are flown over a test range at verified attitudes to validate the calibration of the LiDAR sensor. The Aero-Metric team's main calibration sites include the following locations: Sheboygan County Airport in Sheboygan, Wisconsin, Boeing Field in Seattle, Washington and Merrill Field in Anchorage, Alaska.

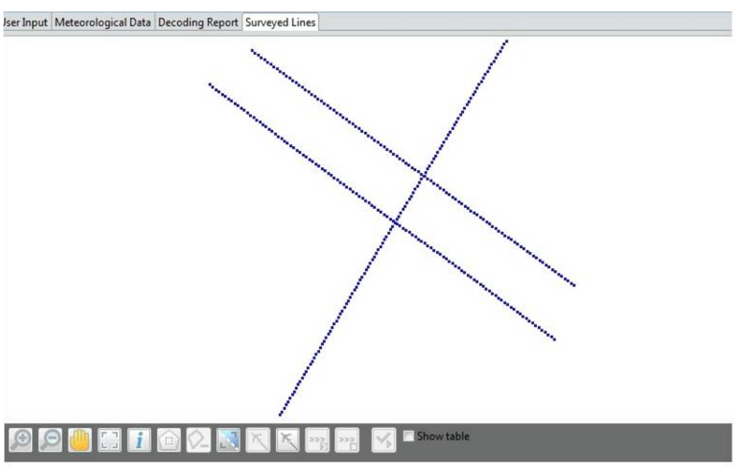


Figure 1: System LiDAR Calibration Configuration

Introduction

The following is the Pre-Flight Operations Plan for the Washington (FEMA Region 10) Kittitas project area. The report will cover GPS, control plans, airport locations and Aircraft used, calibration procedures as preformed by Aero-Metric, quality procedures, and procedures for tracking, executing and checking for re-flights. The planning of the project was based on the scope of work provided, FEMA Procedure Memorandum No. 61, and the USGS NGP V 13 specifications.

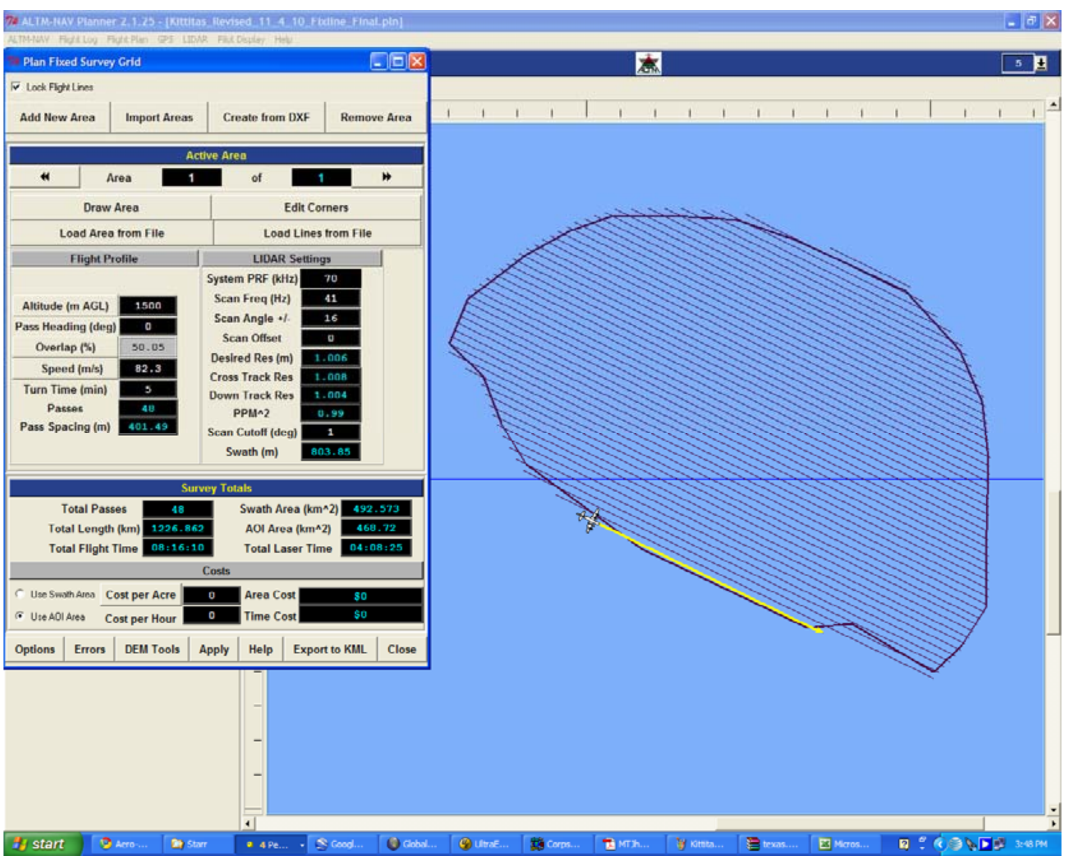
Airport Locations and Type of Aircraft Used

The airport locations for the Kittitas project area are Bower Field (KELN), Pangborn Memorial (KEAT), Yakima (KYKM), Grand County (KMWH), Richland (KRLD), Ephrata Municipal (KEPH) airports. All airports should be suitable for base of operation and have suitable SAC\PAC GPS points. The exact location for base of operation will be determined based on the requirements of the aircraft selected for the collection. In addition, the airport hours of operation will be an important determining factor for planning the LiDAR collection.

Aero-Metric has 4 LiDAR Aircraft used for LiDAR. The aircraft used by Aero-Metric use for LiDAR are an Aztec, Navaho and Twin Commander 500s which are twin engine aircraft and a Cessna 210 which is a single engine aircraft. The tail numbers for these aircraft are N3443Q, N73TM, N280MB and N69WA, respectively.

Project Flight Plans

The following are the flight plans for the Kittitas Project area. The plans below detail the LiDAR collection parameters and flight lines as represented in the ALTM_NAV software used during collection of the project areas.



Strategic Alliance for Risk Reduction

Kittitas

Pre-Flight Operations Plan

November 2010

Appendix D: Ground Control Survey and Vertical Testing Quality Control

CompassData

FEMA Region 10 Kittitas, WA
Ground Control Project Report for Aerometric
April 14th, 2010

Project Information

CDI Project Number: CDI1564
Geographic Location: Kittitas, Washington
Number of GCPs Requested: 20
Number of GCPs Collected: 20

Project Specifications

Precision (Horizontal/Vertical): 5 cm vertical
Coordinate System: UTM
Datum: NAD 83
Zone: 10 North
Altitude Reference: MSL (Geoid09)
Units: Meters

RTK GPS

All Ground Control Points for this project were collected within the boundaries of the state wide Virtual Reference Station System of Washington (Washington State Reference Network (WSRN)), which provides continuous real-time broadcast correction signals within a network of over 100 base stations distributed evenly in the state of Washington.

All Control Points were observed for 180 epochs to determine a coordinate < 8 cm in both Horizontal and Vertical to support subsequent LiDAR post-processing and bare earth deliverables generation.

All data collected were well within the confines of the Washington State Reference Network with multiple base locations providing position and correction data for each point collected.

Summary

The purpose of this project was to locate and survey ground control points (GCPs) in the area of interest as defined by FEMA-supplied shape and kml files. The GCP coordinates were to be used to control the vertical aspect of all newly-flown LiDAR data during post-processing and subsequent deliverables creation. CompassData visited the project area, found suitable GCPs, and determined accurate coordinates for each GCP according to the customer's specifications.

Equipment

CompassData used a Trimble R8 antenna to perform the survey. This device is accurate to within 1 cm on a position-by-position basis per Trimble specifications. Operating within the VRS network provided accurate coordinate values at or around 3 cm H/V within a 3 minutes observation times. CompassData has consistently demonstrated this level of accuracy on many GCP collection jobs across North and South America and Africa. Specifications for the Trimble R8 are available upon request.

Survey Methodology

CompassData has met the required precision for this project by using a high-quality GPS receiver with differential corrections provided by a GPS base station close to the project area. The GPS antenna sat atop a bubble-leveled, fixed-height range pole that was placed over the center of the desired GCP. At least 180 positions (captured at a rate of one per second) were geometrically averaged to calculate a single coordinate for each GCP. All required field documentation was filled out and the points were marked on the supplied image chips (when available) and diagrammed on the CompassData-supplied sketch sheets. Digital pictures of each GCP location were collected in the field.

Quality Control Procedures

CompassData selects GCPs with an unobstructed view of the sky to ensure proper GPS operation. CompassData works to avoid potential sources of multipath error such as trees, buildings, and fences that may adversely affect the GPS accuracy. Additional quality control comes from the fact that at least 480 GPS positions are collected for each GCP. While operating within a VRS, valid solutions are reached within seconds; however, we continue to collect additional data to ensure meeting collection specifications. To ensure accuracy, a GCP will be retaken or moved to a more suitable location if it does not meet these standards.

In addition to the aforementioned procedures, CompassData "surveys" existing geodetic control monuments to see if our coordinates match the published coordinates to the required accuracy. These monuments are usually established by the National Geodetic Survey (NGS) in the United States. If it is found that our coordinates are outside the acceptable accuracy, the reason for the difference will be found or the GCPs will be retaken and/or adjusted by the necessary amounts. There are certain geodetic considerations that must be taken into account that affect whether a GPS-derived coordinate will line up with a survey monument, especially when these monuments reference local coordinate systems or the systems of another country. Sometimes the published coordinates for a monument are not accurate, although this is very infrequent.

CompassData visited one or more survey monuments during the course of this project. The results of those monuments are summarized in the Accuracy Report.

Deliverables

Deliverables for this project include:

- Coordinates (in spreadsheet format)
- Image Chips (when available)
- Sketch Sheets
- Digital Pictures
- QA/QC Data
- A Copy of the Project on CD

Project Notes

All collected points were retrieved from the Trimble Survey Controller in Northing, Easting, NAD83, MSL (Geoid09), Meters.

CorpsCon was used to generate files in the following format:
Degrees Minutes Decimal Seconds, NAD83 Hae
UTM Meters, NAD83, MSL

Geoid09 was then used to generate the geoid separation at every Lat/Long location. NAVD88(09) orthometric heights were then generated in spreadsheet form using the formula HAE – Geoid =Orthometric Height. Those values were then included into the final delivery coordinate CVS files and have been tested against NGS monuments collected during the course of this survey and are showing agreement.

The Horizontal and Vertical accuracies reported in the Final Coordinates file were obtained from the Survey Report generated by Trimble Survey Controller. The report contains all points collected during each daily survey deployment, including CVAs, FVAs and Ground Control. Copies of these reports can be provided upon request once CVA and FVA data has been redacted.

Contact Information

Hayden Howard Phone: (303) 627-4058 E-mail: haydenh@compassdatainc.com

KITTITAS, WASHINGTON								
GCP	**Date**	**Vert_Prec**	**Horz_Prec**	**Latitude**	**Longitude**	**Easting**	**Northing**	**NAVD88**
KIT101	4/18/2011	0.009	0.013	47.25646036	121.19704840	5235240.723	636411.427	675.004
KIT102	4/18/2011	0.008	0.010	47.21843694	121.13009575	5231134.592	641578.210	637.716
KIT103	4/18/2011	0.007	0.010	47.19428292	121.05263510	5228593.904	647509.878	620.452
KIT104	4/18/2011	0.008	0.011	47.22543273	120.99203021	5232171.732	652011.404	706.443
KIT105	4/18/2011	0.008	0.013	47.18902401	120.95010314	5228208.349	655291.617	585.482
KIT106	4/19/2011	0.016	0.027	47.17462940	120.85288788	5226806.721	662699.975	560.364
KIT107	4/19/2011	0.022	0.036	47.19590324	120.77301590	5229340.267	668684.708	618.593
KIT108	4/21/2011	0.014	0.030	47.23295413	120.81039535	5233377.423	665737.945	628.850
KIT109	4/21/2011	0.026	0.031	47.25205895	120.86300102	5235390.030	661698.036	664.869
KIT110	4/20/2011	0.013	0.021	47.08196019	120.73347332	5216764.821	672047.111	562.128
KIT111	4/20/2011	0.008	0.012	47.11528566	120.66679190	5220616.868	676998.028	637.786
KIT112	4/20/2011	0.014	0.023	47.06111240	120.57184238	5214816.498	684387.584	531.603
KIT113	4/20/2011	0.009	0.013	47.11728369	120.58180273	5221034.876	683438.193	660.139
KIT114	4/20/2011	0.008	0.013	47.08878788	120.43358572	5218226.992	694784.993	677.220
KIT115	4/20/2011	0.008	0.013	47.01455405	120.58045301	5209622.664	683893.721	472.986
KIT116	4/20/2011	0.014	0.023	47.04490336	120.41876460	5213387.592	696070.782	599.261
KIT117	4/20/2011	0.012	0.018	46.99568666	120.44158315	5207861.745	694516.342	503.569
KIT118	4/20/2011	0.019	0.021	46.99230258	120.66696710	5206950.479	677392.294	591.064
KIT119	4/20/2011	0.080	0.015	46.99895335	120.53011768	5208008.602	687773.906	508.745
KIT120	4/20/2011	0.010	0.014	46.97052481	120.58586744	5204717.453	683633.058	490.535
Survey Control								
NGS_SX0450	4/18/2011	0.013	0.021	47.12997409	120.76493510	5222031.499	669506.446	588.745
NGS_SX0450	4/21/2011	0.017	0.027	47.12997437	120.76493500	5222031.530	669506.453	588.725
NGS_SX0503	4/20/2011	0.008	0.015	47.01555733	120.58332163	5209727.387	683672.253	473.356
Metadata								
UTM 10 North, NAD83, NAVD88								
All units in meters where applicable.								
HAE - GEOID09 = NAVD88								

KIT101_C


9/10/2009
Kachess Dam Rd
W Sparks Rd
KIT101
Old US Hwy 10
90
Image USDA Farm Service Agency
© 2011 Google
© 2011 Europa Technologies
©2010 Google

KIT102_C


9/10/2009
Lavender Lake
Lavender Rd
KIT102
Pine Glen Dr
Pine Glen Ct
Spruce Dr
90
Old Milwaukee Rd Railroad Grde
Nelson Siding Rd
Cresto Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT103_C


9/10/2009
Prairie Ln
Golf Course Rd
KIT103
Old Milwaukee Rd Railroad Grde
Hundley Rd
90
Little Creek Rd
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT104_C

9/10/2009
1994
2009
W Nevada Ave
E Nevada Ave
E Utah Ave
W Utah Ave
E Arizona Ave
N A St
N B St
N C St
N D St
N E St
KIT104
W 3rd St
N 3rd St
E Idaho Ave
W Idaho Ave
903
W Arizona Ave
N 1st St
E Washington Ave
N 2nd St
W Washington Ave
Roslyn
W Pennsylvania Ave
S 1st St
W 4th St
Whitehead Rd
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT105_C


9/10/2009
1994
2009
4th St
Grant St
KIT105
Washington Ave
Washington St
S Cle Elum Way
Broadway Ave
5th St
6th St
7th St
Main St
3rd St
Lincoln Ave
Lincoln St
Cleveland Ave
Cleveland St
2nd St
Image USDA Farm Service Agency
© 2011 Google
South Cle Elum
Google

KIT106_C


9/10/2009
1994
2009
Lambert Rd
KIT106
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT107_C


9/10/2009
1994
2009
Teanaway Rd
KIT107
970
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT108_C


9/10/2009
KIT108
Teanaway Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

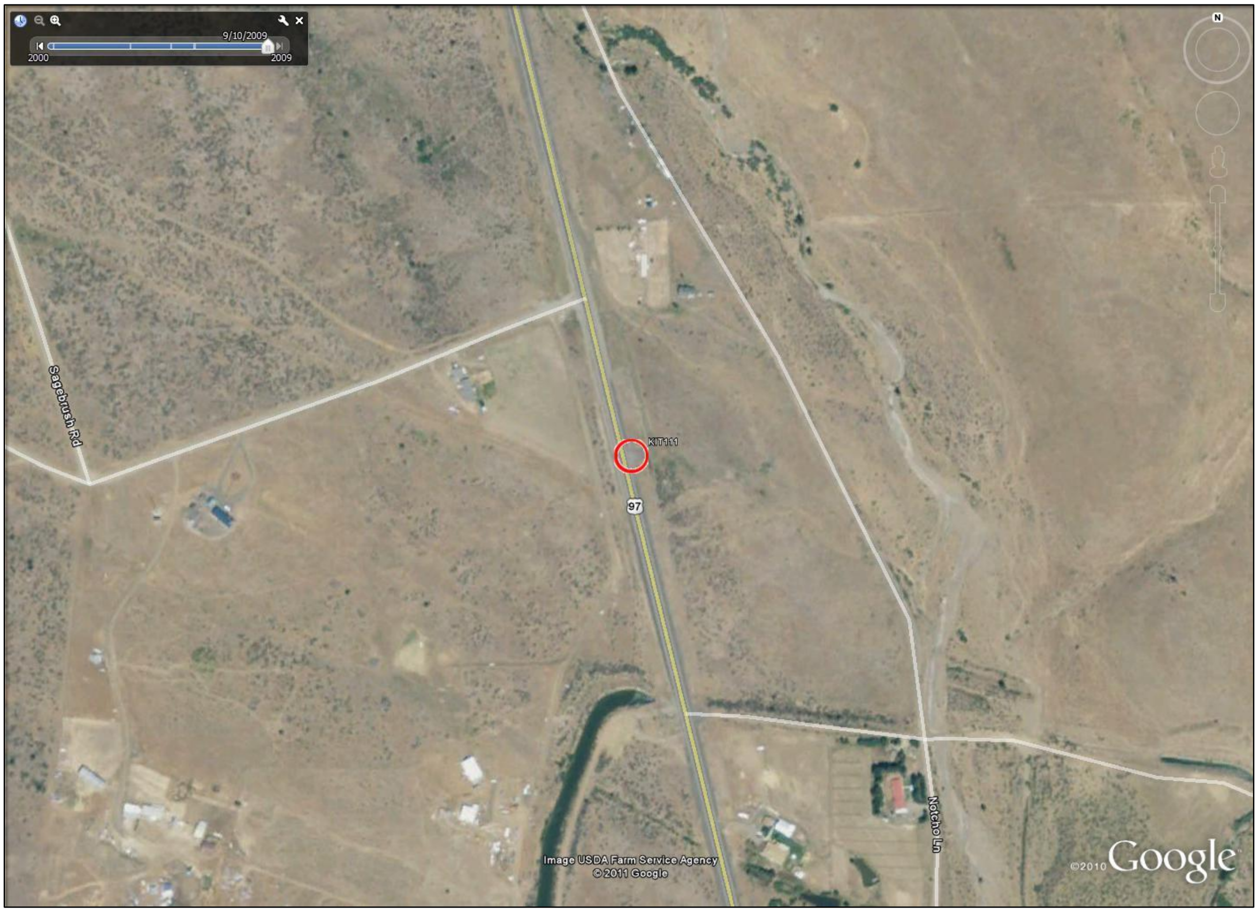
KIT109_C


9/10/2009
1994
2009
Teanaway Rd
Teanaway Meadows
KIT109
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT110_C


9/10/2009
1994
2009
KIT110
90
Thorp Cemetery Rd
Watt Rd
E Taneum Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT111_C


9/10/2009
2000
2009
Sagebrush Rd
KIT111
97
Notcho Ln
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT112_C


9/10/2009
2000
2009
Reecer Creek Rd
KIT112
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT113_C


9/10/2009
1998
2009
Pheasant Ln
Reecer Creek Rd
KIT113
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT114_C

9/10/2009
Schneebly Rd
KIT114
Thomas Rd
Fairview Hall Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

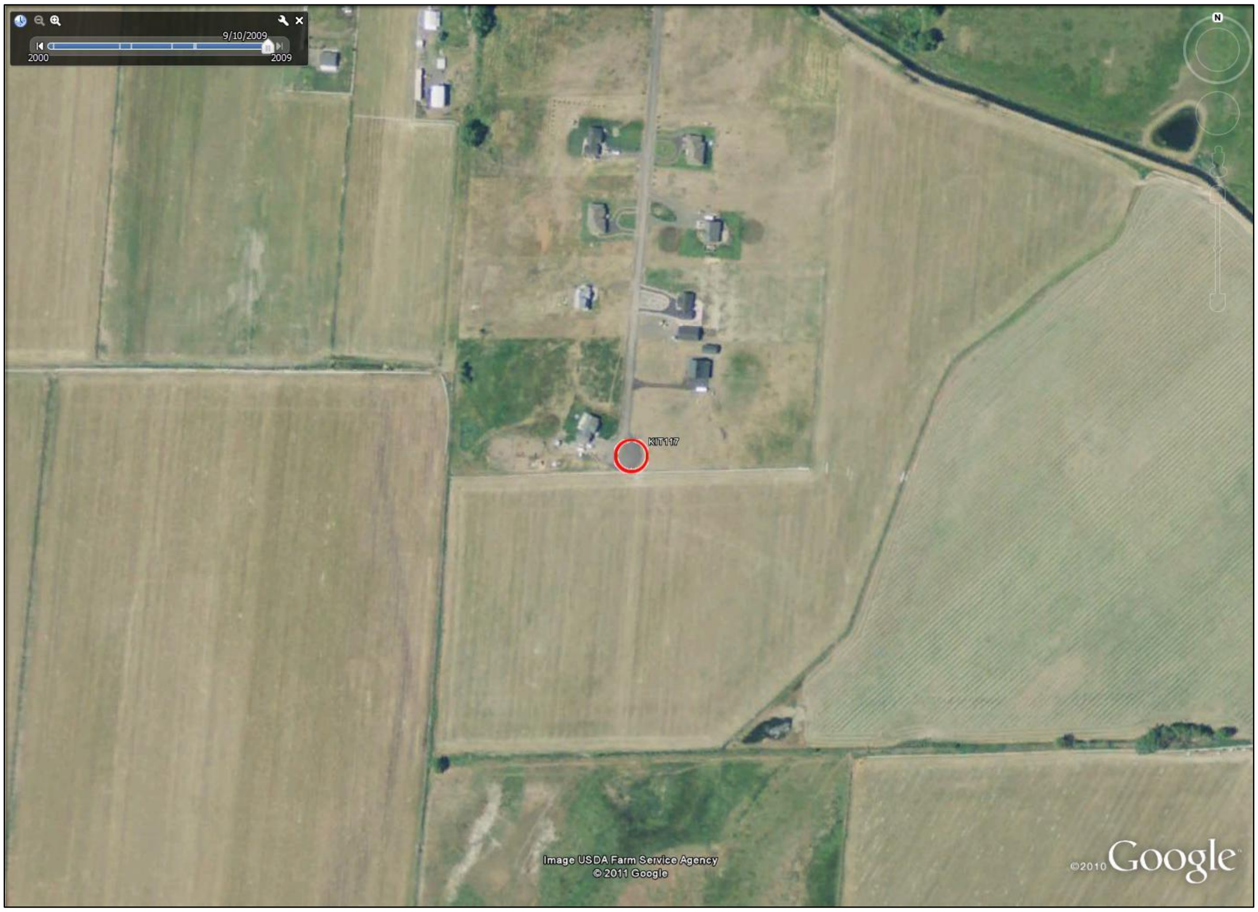
KIT115_C

9/10/2009
2000
2009
Dry Creek Rd
Dry Creek Con
KIT115
Image USDA Farm Service Agency
© 2011 Google
Reecer Creek Rd
2010
Google

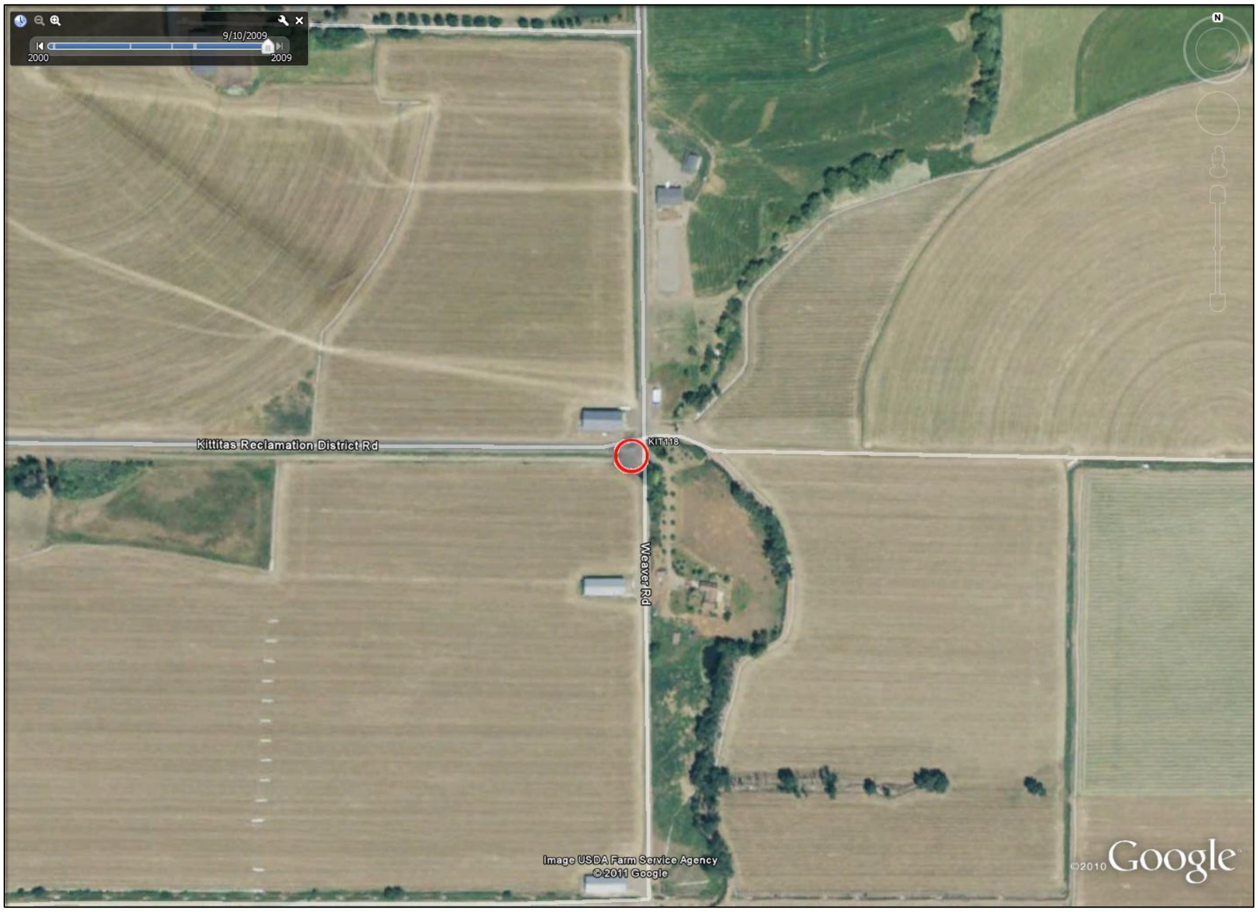
KIT116_C


9/10/2009
Schmebly Rd
Brick Mill Rd
KIT116
Number 8 1 Rd
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT117_C


9/10/2009
2000
2009
KIT117
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

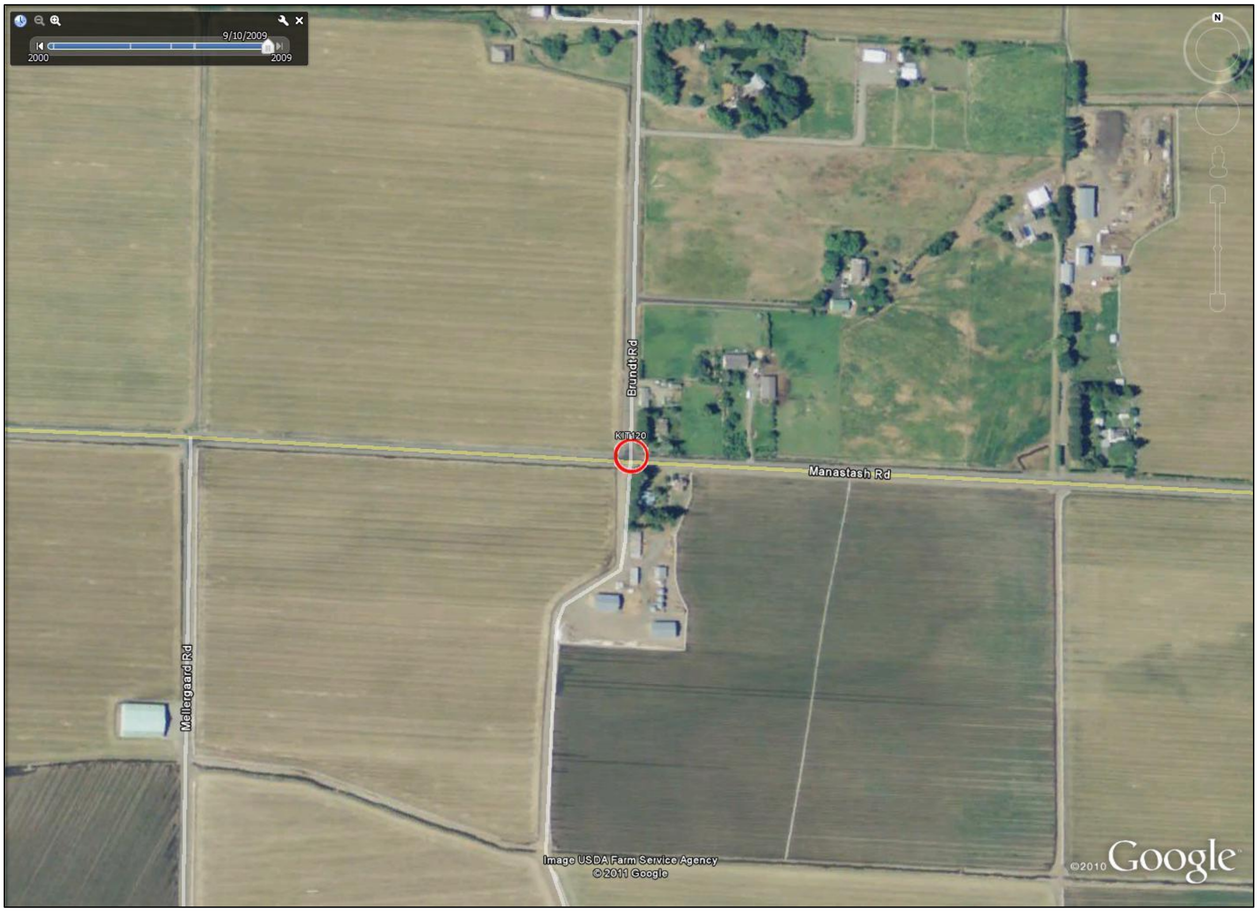
KIT118_C


9/10/2009
2000
2009
Kittitas Reclamation District Rd
KIT118
Weaver Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT119_C

9/10/2009
2000
2009
E 10th Ave
E University Way
N Maple St
E 9th Ave
N Chestnut St
Iron Horse Trail
Chamith
E 7th Ave
KIT119
Rodeo Grandstands
Craig Ave
E 6th Ave
N Willow St
Angford Dr
E 5th Ave
Franklin St
Linda Ln
E 4th Ave
N Alder St
Image USDA Farm Service Agency
© 2011 Google
Cliff Ave
©2010
Google

KIT120_C

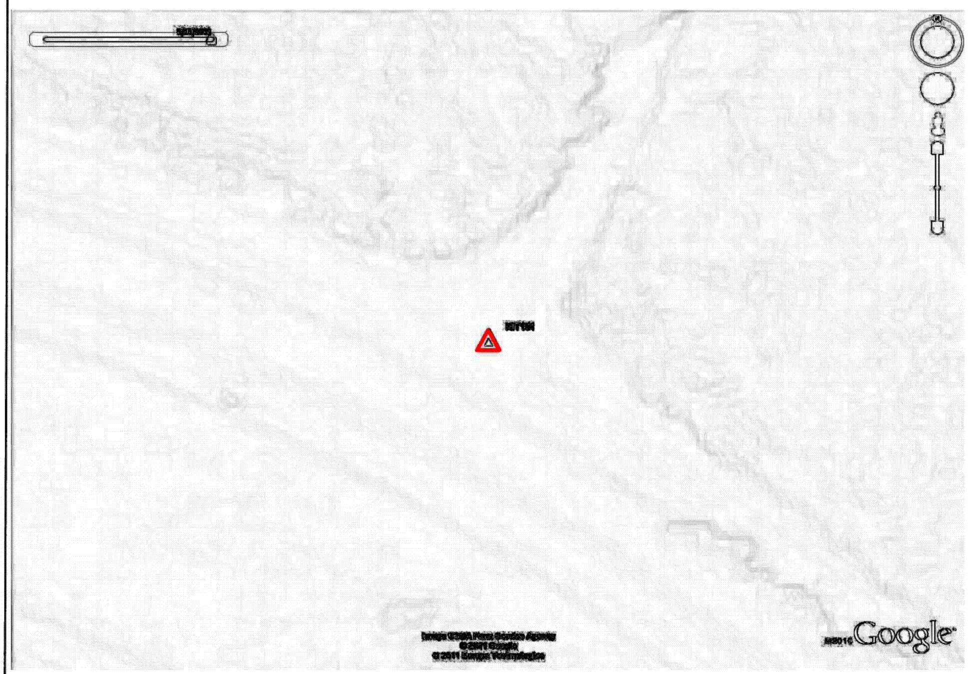

9/10/2009
2000
2009
N
Brundt Rd
KIT120
Manastash Rd
Mellergaard Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT101_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT101
CDI Project Number: 1564	**Date:** 4/18/2011



GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Kachess Dam Rd and W Sparks Rd
Kittitas County, Washington USA

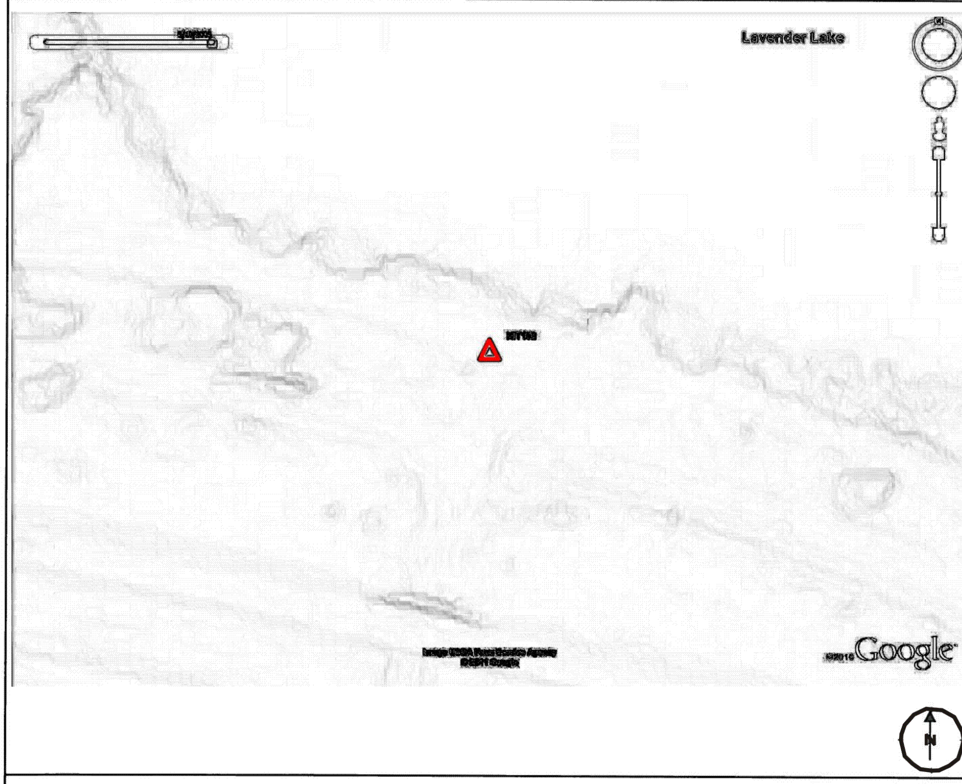
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT102_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT102
CDI Project Number: 1564	**Date:** 4/18/2011



GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Lavender Rd and Nelson Siding Rd
Kittitas County, Washington USA

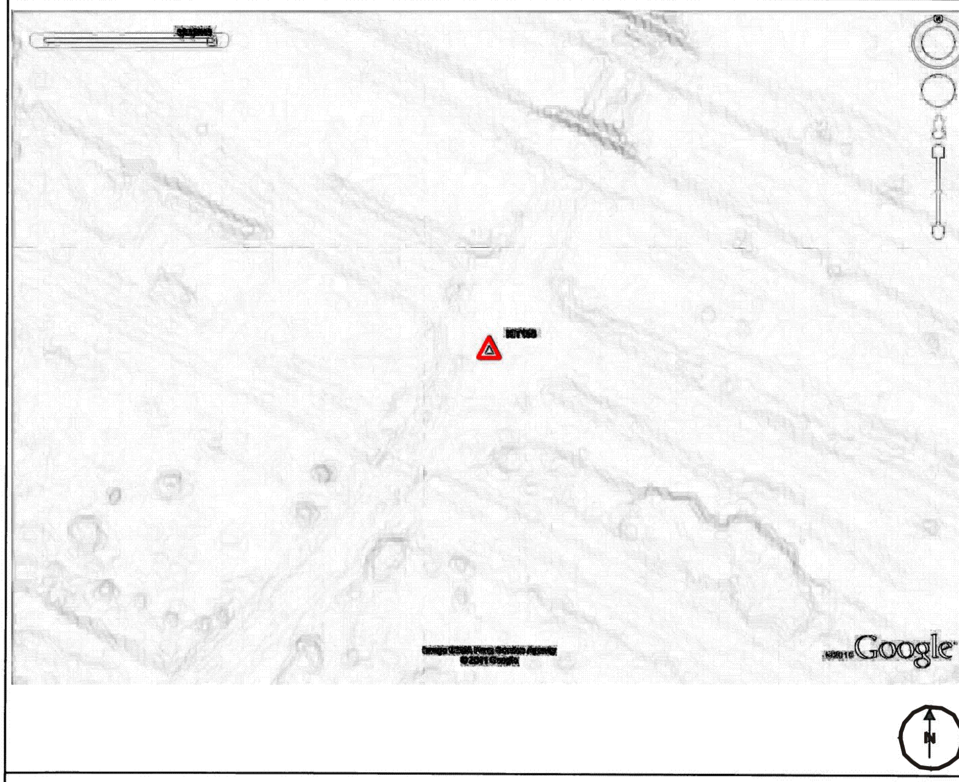
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT103_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT103
CDI Project Number: 1564	**Date:** 4/18/2011



GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Golf Course Rd and the on/off ramps of I-90 Kittitas County, Washington USA

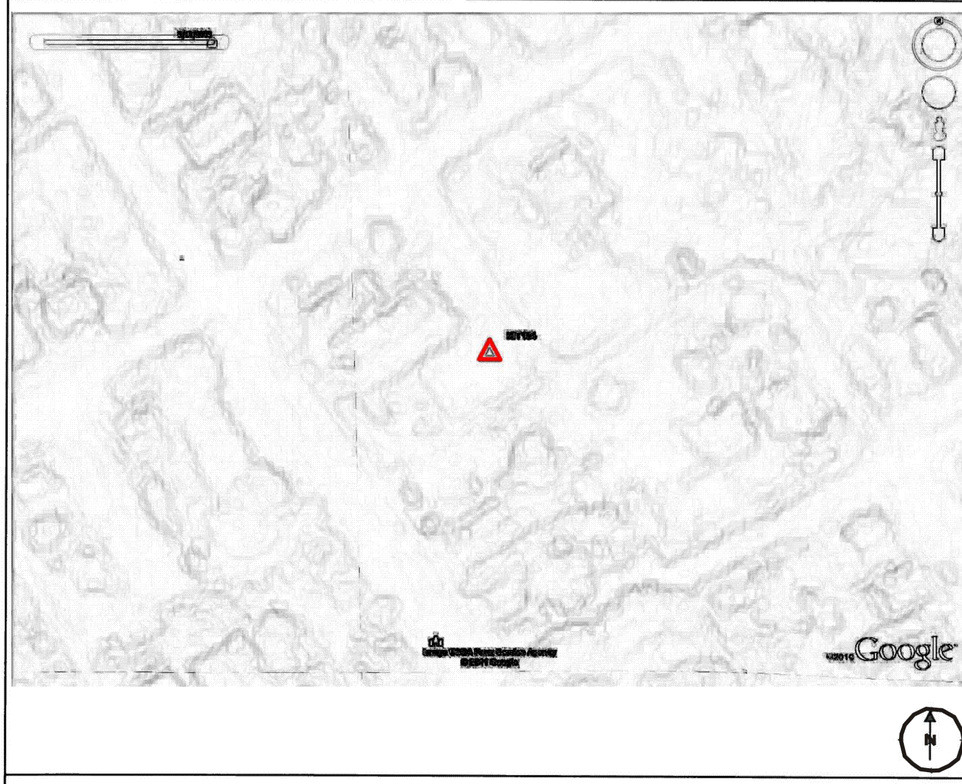
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT104_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	GCP Number: KIT104
CDI Project Number: 1564	Date: 4/18/2011



GPS Antenna Height: 2m

Comments:

Point collected in a parking lot of Church on the east corner of N B Street and E Idaho Ave in the town of Roslyn.
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	Sketch 1 of 1
Collected By: Bryan Frazier	Checked By:

LiDAR

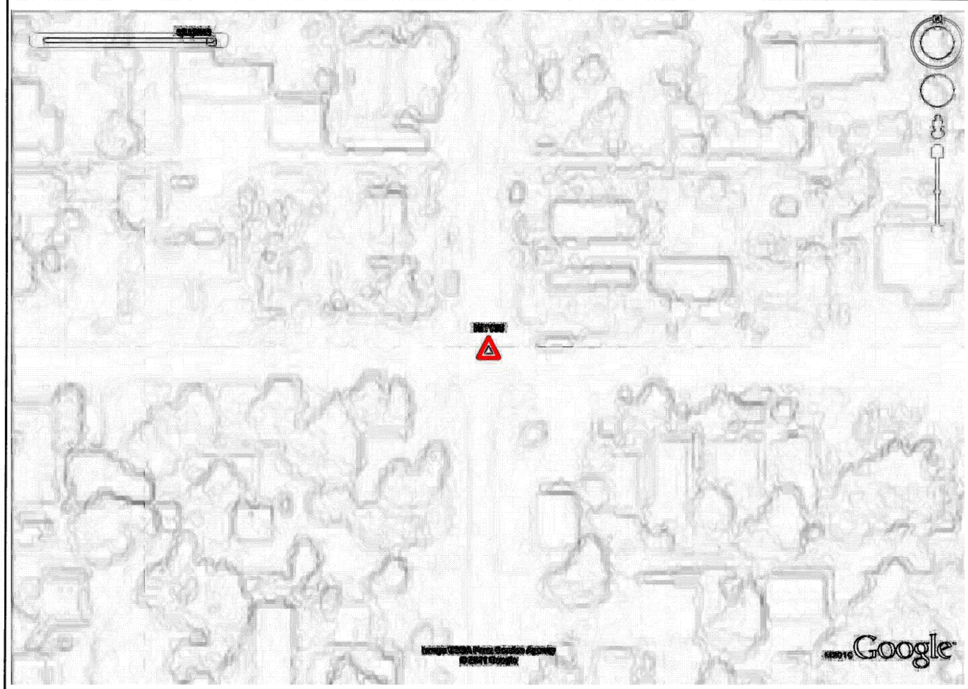
LiDAR

KIT105_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT105
CDI Project Number: 1564	**Date:** 4/18/2011



LiDAR

LiDAR

GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Washington Ave and 5th Street in the Town of South Cle Elum.
Kittitas County, Washington USA

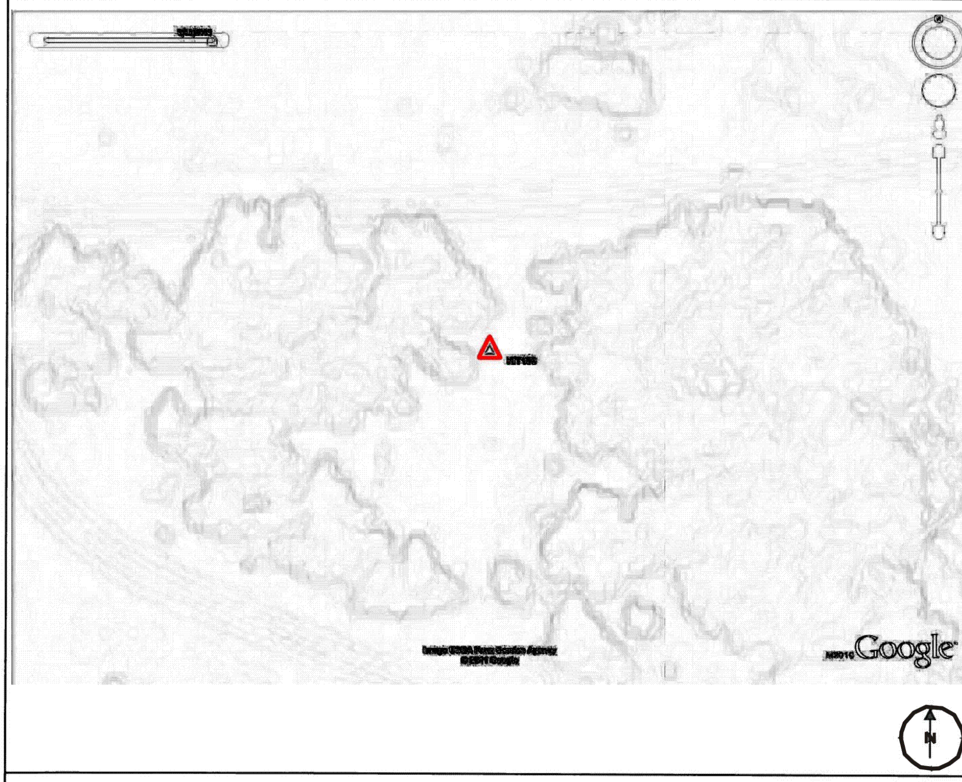
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT106_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	GCP Number: KIT106
CDI Project Number: 1564	Date: 4/19/2011



GPS Antenna Height: 2m

Comments:

Point collected in a vancant lot approximately 35.30 meters south of State HWY 970 and approximately 125 meters east of the intersection of State Highways 10 and 970.
Kittitas County, Washington USA

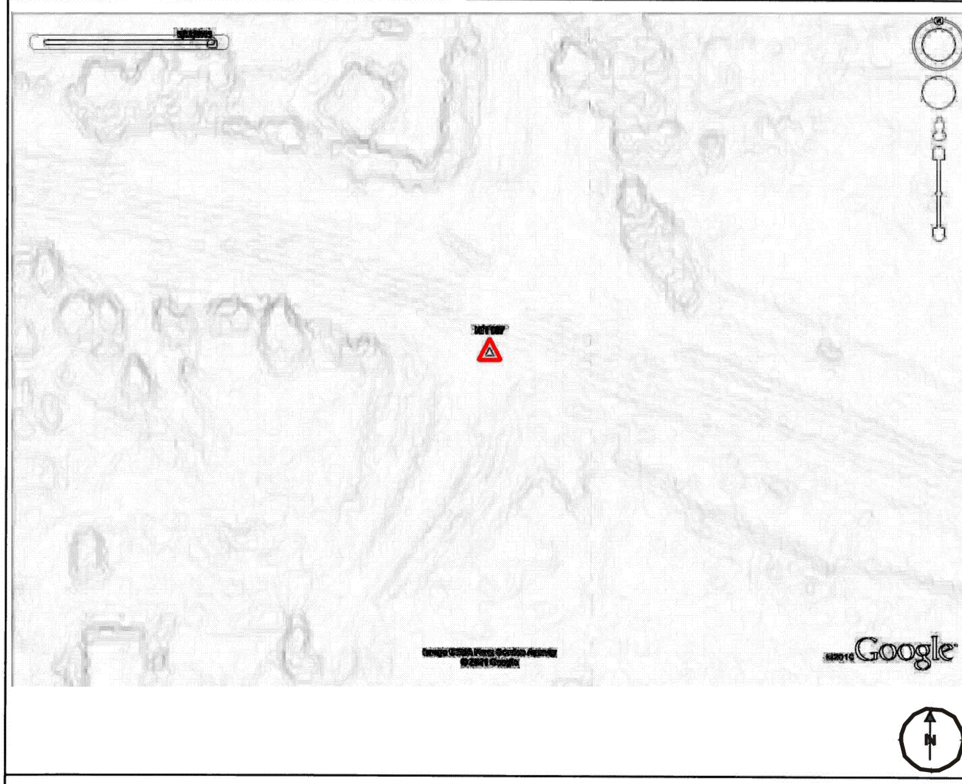
Disk (Roll) / Frame Number:	Sketch 1 of 1
Collected By: Bryan Frazier	Checked By:

LiDAR LiDAR

KIT107_D

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT107
CDI Project Number: 1564	**Date:** 4/19/2011



GPS Antenna Height: 2m

Comments:

Point collected at the intersection of State HWY 970 and Teanaway Rd.
Kittitas County, Washington USA

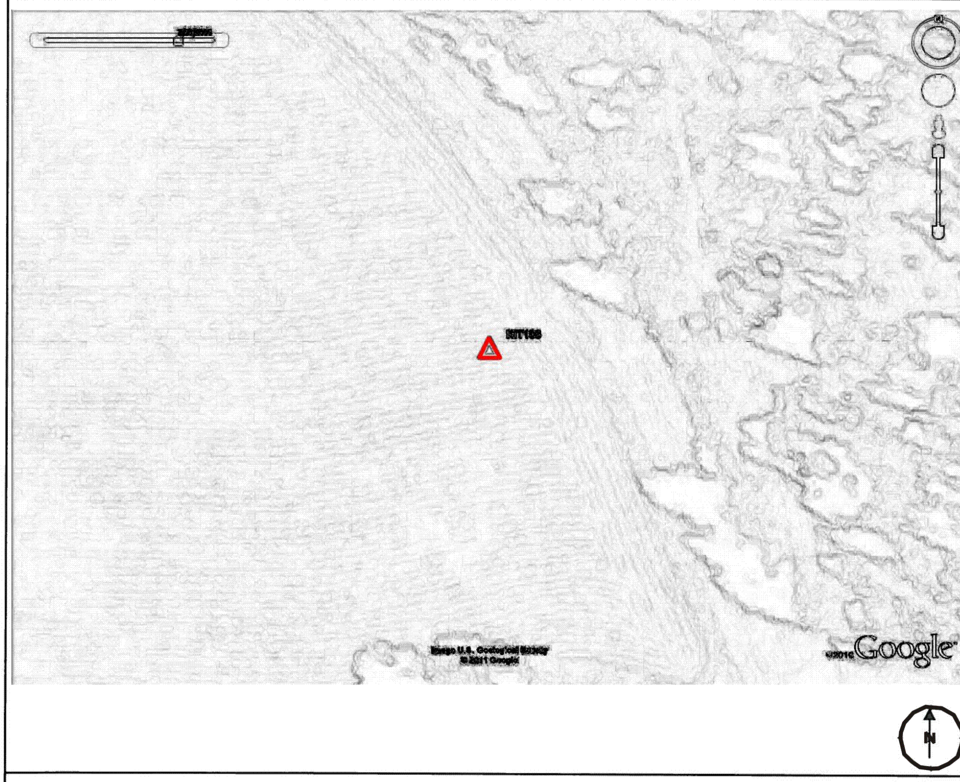
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT108_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	GCP Number: KIT108
CDI Project Number: 1564	Date: 4/21/2011



GPS Antenna Height: 2m

Comments:

Point collected in a field approximately 25 meters west of Teanaway Rd and approximately 5 km north of State HWY 970
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	Sketch 1 of 1
Collected By: Bryan Frazier	Checked By:

LiDAR

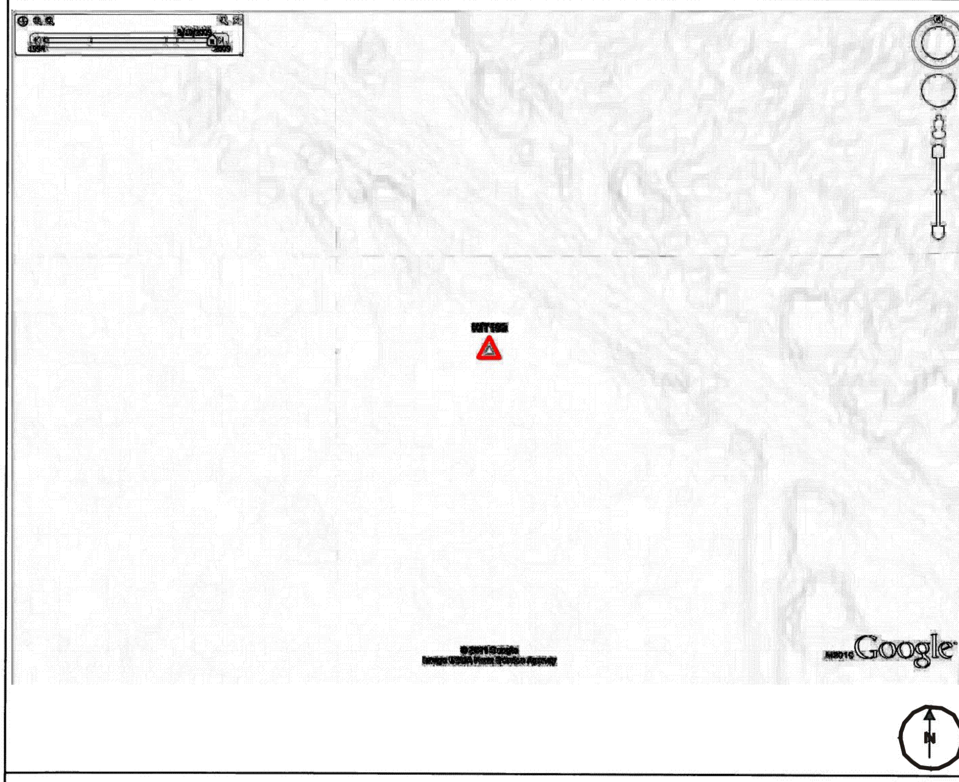
LiDAR

KIT109_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT109
CDI Project Number: 1564	**Date:** 4/21/2011



GPS Antenna Height: 2m

Comments:

Point collected in a field approximately 18 meters southwest of Teanaway Rd and approximately .32 km southeast of Teanaway Meadows Rd.
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

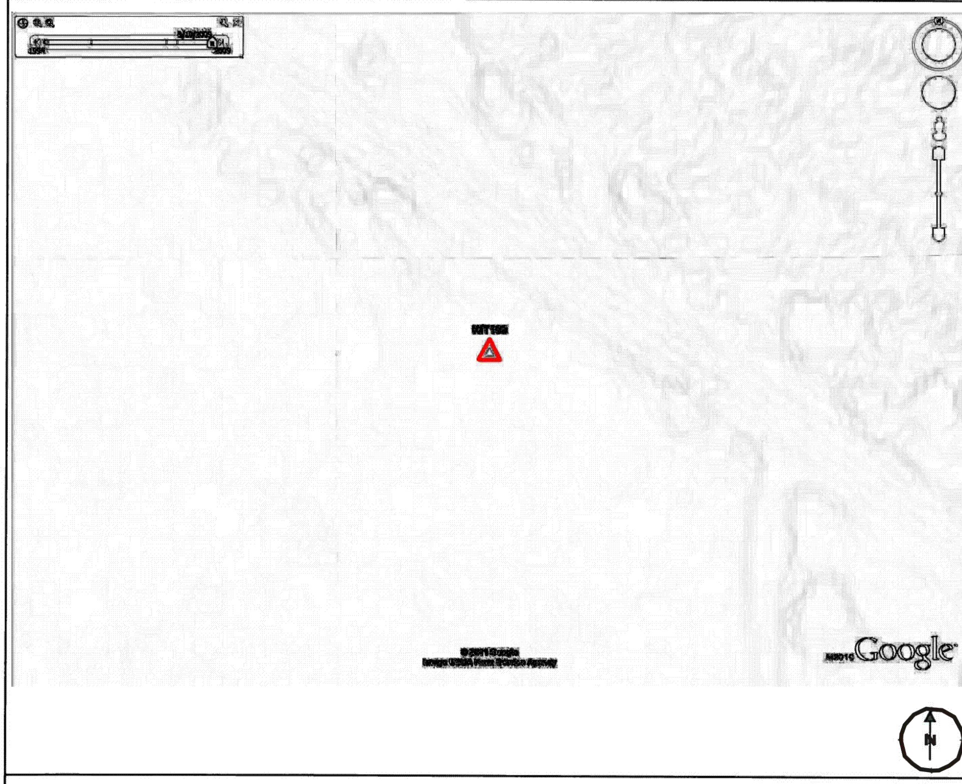
LiDAR

KIT110_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT110
CDI Project Number: 1564	**Date:** 4/20/2011



GPS Antenna Height: 2m

Comments:

Point collected in a gravel lot just southeast of the creek off E Taneum Rd and approximately .68 km southeast of Thorp Prairie Rd.
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

LiDAR

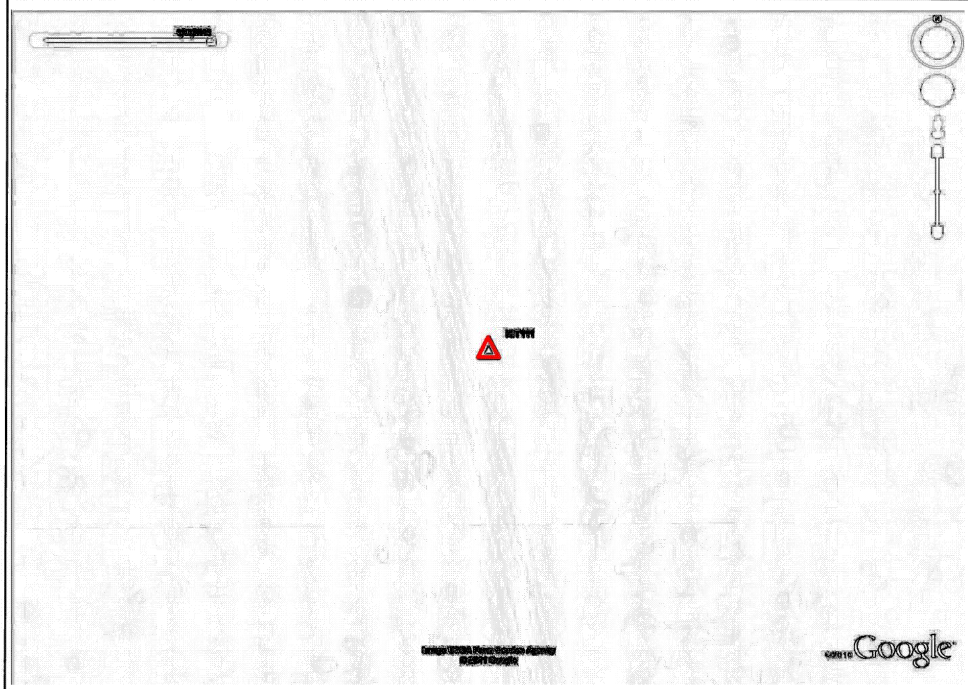
KIT111_D

CompassData

GCP Station Diagram for LiDAR

LiDAR

Project Name: Kittitas	**GCP Number:** KIT111
CDI Project Number: 1564	**Date:** 4/20/2011



GPS Antenna Height: 2m

Comments:

Point collected in a gravel lot just off tot he east of State HWY 97 approximately .15 km south of Ellensburg Ranches Rd.
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

KIT112_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT112
CDI Project Number: 1564	**Date:** 4/20/2011

GPS Antenna Height: 2m

Comments:

Point collected at an entrance to a private residence off Reecer Creek Rd
approximately .41 km north of Clarke Rd
Kittitas County, Washington USA

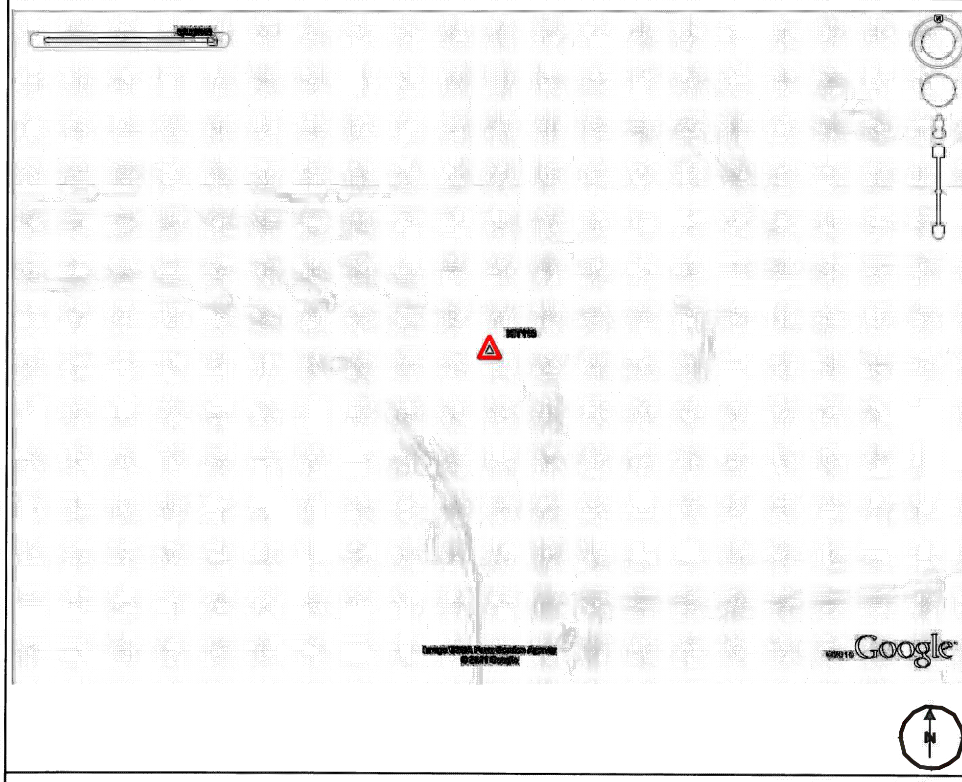
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT113_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT113
CDI Project Number: 1564	**Date:** 4/20/2011



GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Reecer Creek Rd and Pleasant Ln
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT114_D

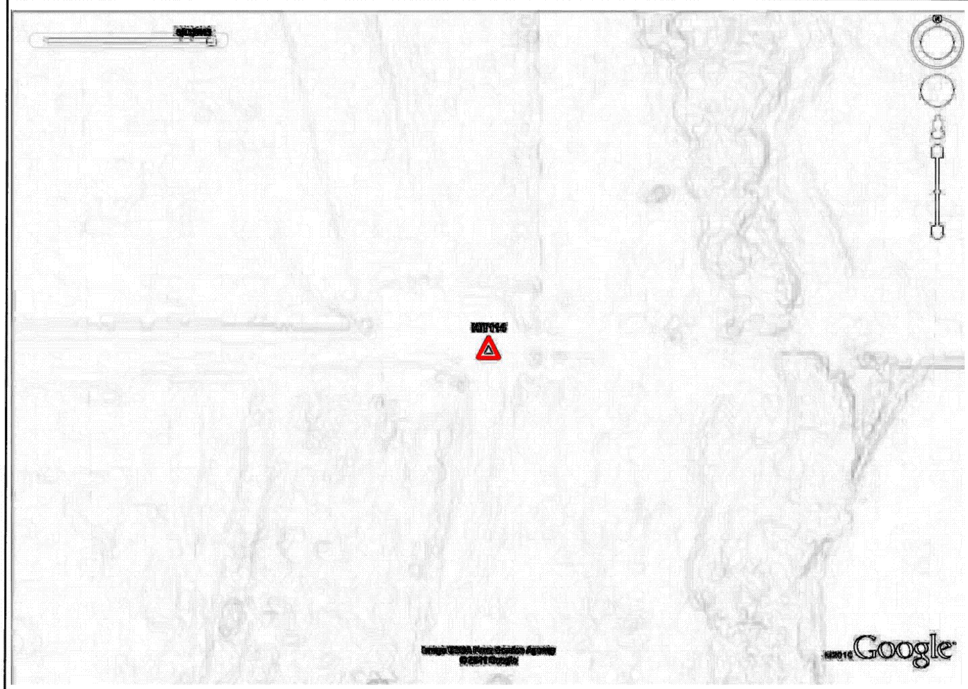
CompassData

GCP Station Diagram for LiDAR

LiDAR

LiDAR

Project Name: Kittitas	**GCP Number:** KIT114
CDI Project Number: 1564	**Date:** 4/20/2011



GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Thomas Rd and Fairview Hall Rd
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT115_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT115
CDI Project Number: 1564	**Date:** 4/20/2011

GPS Antenna Height: 2m

Comments:

Point collected at the intersection/entrance to a subdivision just northeast of Dry Creek Connector Rd and W Clearview Drive
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT116_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT116
CDI Project Number: 1564	**Date:** 4/20/2011

GPS Antenna Height: 2m

Comments:

Point collected at the intersection of Brick Mill Rd and Schnebly Rd
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT117_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT117
CDI Project Number: 1564	**Date:** 4/20/2011

GPS Antenna Height: 2m

Comments:

Point collected at the south end of cul-de-sac on unnamed road
approximately .63 miles west of Fairview Rd
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT118_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT118
CDI Project Number: 1564	**Date:** 4/20/2011

GPS Antenna Height: 2m
Comments: Point collected at the intersection of Kittitas Reclamation District Rd and Weaver Rd Kittitas County, Washington USA

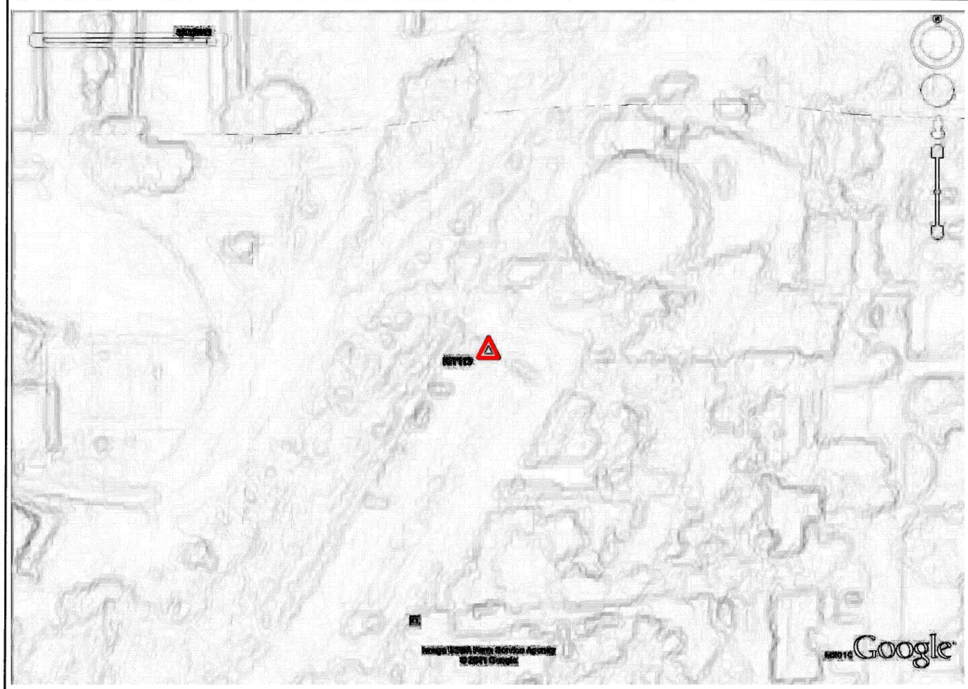
Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

KIT120_D

CompassData

GCP Station Diagram for LiDAR

Project Name: Kittitas	**GCP Number:** KIT119
CDI Project Number: 1564	**Date:** 4/20/2011



GPS Antenna Height: 2m

Comments:

Point collected at the end of a E Craig Ave near the entrance to a
water storage tank in Reed Park
Kittitas County, Washington USA

Disk (Roll) / Frame Number:	**Sketch** 1 **of** 1
Collected By: Bryan Frazier	**Checked By:**

LiDAR

LiDAR

KIT101_E

KIT101_N

KIT101_S

KIT101_W

KIT102_E

KIT102_N

KIT102_S

KIT102_W

KIT103_E

KIT103_N

KIT103_S

KIT103_W

KIT104_E

KIT104_N

KIT104_S

KIT104_W

KIT105_E

KIT105_N

KIT105_S

KIT105_W

KIT110_E

KIT110_N

KIT110_S

KIT110_W

KIT111_E

KIT111_N

KIT111_S

KIT111_W

KIT112_E

KIT112_N

KIT112_S

KIT112_W

KIT113_E

KIT113_N

KIT113_S

KIT113_W

KIT114_E

KIT114_N

KIT114_S

KIT114_W

KIT115_E

KIT115_N

KIT115_S

KIT115_W

KIT116_E

KIT116_N

KIT116_S

KIT116_W

KIT117_E

KIT117_N

KIT117_S

KIT117_W

KIT118_E

KIT118_N

KIT118_S

KIT118_W

KIT119_E

KIT119_N

KIT119_S

KIT119_W

KIT120_E

KIT120_N

KIT120_S

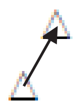
KIT120_W

CompassData

Accuracy Report

ΔH = 0.037m

ΔV = 0.019m



NGS_SX0450

Lat/Long
WGS 1984

N

Scale 1:4.00

0 0.150

Meters

5/25/2011

GPS Pathfinder® Office

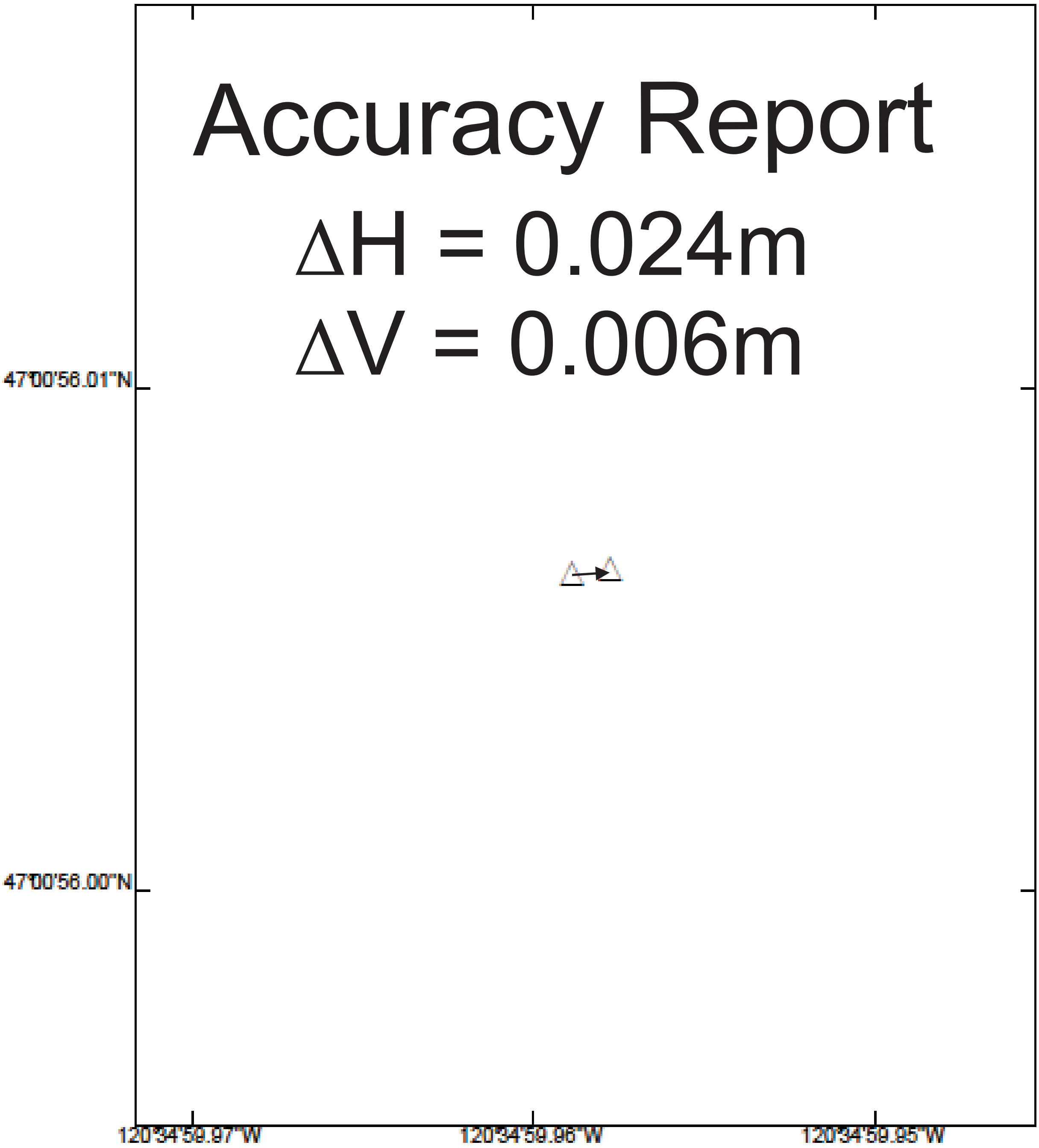
Trimble

CompassData

Accuracy Report

$\Delta H = 0.024m$

$\Delta V = 0.006m$



NGS_0503

Lat/Long
WGS 1984

N

Scale 1:4.00
0 0.150
Meters

5/24/2011

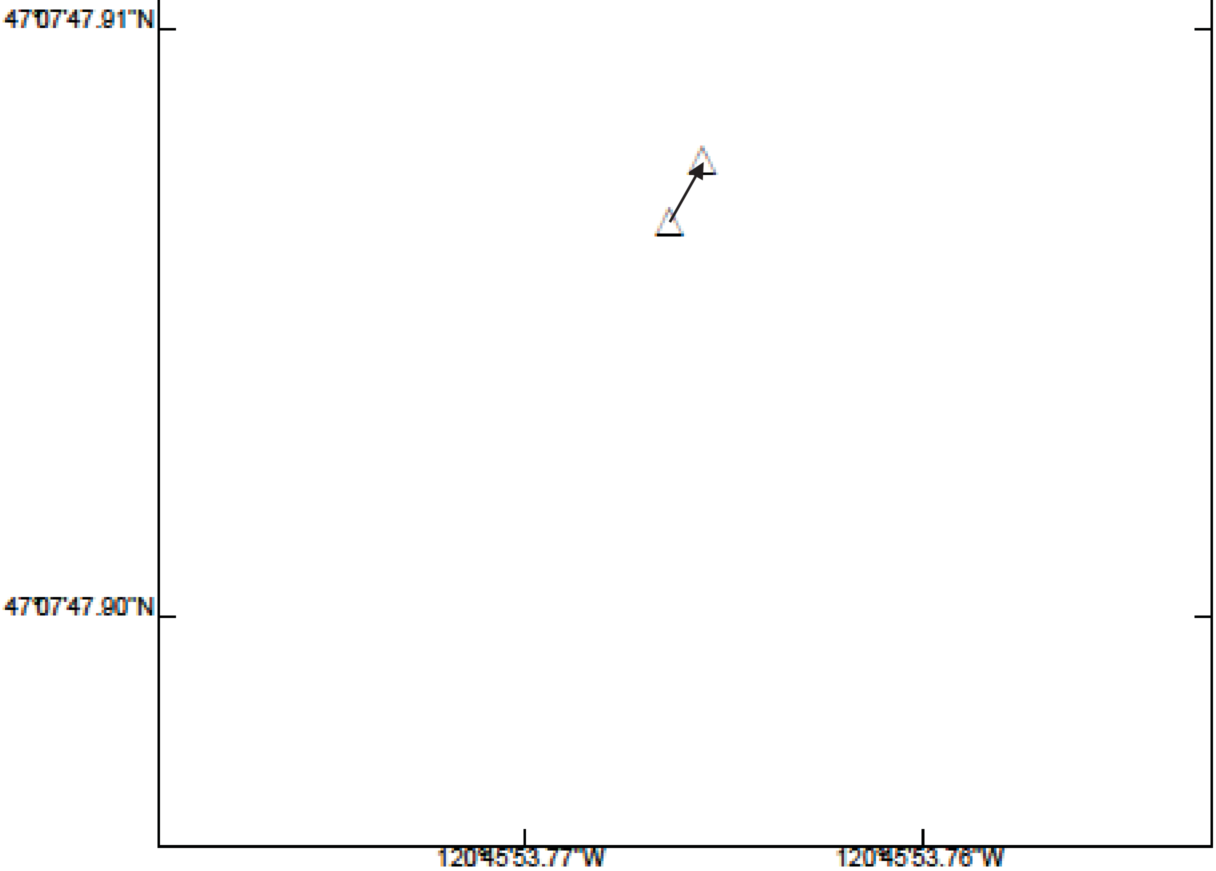
GPS Pathfinder® Office
Trimble

CompassData

Accuracy Report

ΔH = 0.010m

ΔV = 0.001m



NGS_SX0450

Lat/Long
WGS 1984

N

Scale 1:4.00
0 0.150
Meters

5/25/2011

GPS Pathfinder Office
Trimble

CompassData

FEMA Region 10 Kittitas, ID
Ground Control Project Report for Aerometric
September 6th, 2011

Project Information

CDI Project Number: CDI1565
Geographic Location: Kittitas, WA
Number of FVAs/CVAs Requested: 20/15
Number of FVAs/CVAs Collected: 20/15

Project Specifications

Precision (Horizontal/Vertical): 8 cm vertical
Coordinate System: UTM
Datum: NAD 83
Zone: 10 North
Altitude Reference: MSL (Geoid09)
Units: Meters

RTK GPS

All Ground Control Points for this project were collected within the boundaries of the state wide Virtual Reference Station System of Washington (Washington State Reference Network (WSRN)) which provides continuous real-time broadcast correction signals within a network of over 100 base stations distributed evenly in the state of Washington.

All Control Points were observed for 180 epochs to determine a coordinate < 8 cm in both Horizontal and Vertical to support subsequent LiDAR post-processing and bare earth deliverables generation.

All data collected were well within the confines of the Washington State Reference Network with multiple base locations providing position and correction data for each point collected.

CompassData

Summary

The purpose of this project was to locate and survey ground control points (GCPs) in the area of interest as defined by FEMA-supplied shape and kml files. The GCP coordinates were to be used to control the vertical aspect of all newly-flown LiDAR data during post-processing and subsequent deliverables creation. CompassData visited the project area, found suitable GCPs, and determined accurate coordinates for each GCP according to the customer's specifications.

Equipment

CompassData used a Trimble R8 antenna to perform the survey. This device is accurate to within 1 cm on a position-by-position basis per Trimble specifications. Operating within the VRS network provided accurate coordinate values at or around 3 cm H/V within a 3 minutes observation times. CompassData has consistently demonstrated this level of accuracy on many GCP collection jobs across North and South America and Africa. Specifications for the Trimble R8 are available upon request.

Survey Methodology

CompassData has met the required precision for this project by using a high-quality GPS receiver with differential corrections provided by a GPS base station close to the project area. The GPS antenna sat atop a bubble-leveled, fixed-height range pole that was placed over the center of the desired GCP. At least 180 positions (captured at a rate of one per second) were geometrically averaged to calculate a single coordinate for each GCP. All required field documentation was filled out and the points were marked on the supplied image chips (when available) and diagrammed on the CompassData-supplied sketch sheets. Digital pictures of each GCP location were collected in the field.

Quality Control Procedures

CompassData selects GCPs with an unobstructed view of the sky to ensure proper GPS operation. CompassData works to avoid potential sources of multipath error such as trees, buildings, and fences that may adversely affect the GPS accuracy. Additional quality control comes from the fact that at least 480 GPS positions are collected for each GCP. While operating within a VRS, valid solutions are reached within seconds; however, we continue to collect additional data to ensure meeting collection specifications. To ensure accuracy, a GCP will be retaken or moved to a more suitable location if it does not meet these standards.

In addition to the aforementioned procedures, CompassData "surveys" existing geodetic control monuments to see if our coordinates match the published coordinates to the required accuracy. These monuments are usually established by the National Geodetic Survey (NGS) in the United States. If it is found that our coordinates are outside the acceptable accuracy, the reason for the difference will be found or the GCPs will be retaken and/or adjusted by the necessary amounts. There are certain geodetic considerations that must be taken into account that affect whether a GPS-derived coordinate will line up with a survey monument, especially when these monuments reference local coordinate systems or the systems of another country. Sometimes the published coordinates for a monument are not accurate, although this is very infrequent.

CompassData visited one or more survey monuments during the course of this project. The results of those monuments are summarized in the Accuracy Report.

Deliverables

Deliverables for this project include:

- Coordinates (in spreadsheet format)
- Image Chips (when available)
- Sketch Sheets
- Digital Pictures
- QA/QC Data
- A Copy of the Project on CD

CompassData

Project Notes

All collected points were retrieved from the Trimble Survey Controller in Northing, Easting, NAD83, MSL (Geoid09), Meters.

CorpsCon was used to generate files in the following format:
Degrees Minutes Decimal Seconds, NAD83 Hae
UTM Meters, NAD83, MSL

Geoid09 was then used to generate the geoid separation at every Lat/Long location. NAVD88(09) orthometric heights were then generated in spreadsheet form using the formula HAE – Geoid =Orthometric Height. Those values were then included into the final delivery coordinate CVS files and have been tested against NGS monuments collected during the course of this survey and are showing agreement.

The Horizontal and Vertical accuracies reported in the Final Coordinates file were obtained from the Survey Report generated by Trimble Survey Controller. The report contains all points collected during each daily survey deployment, including CVAs, FVAs and Ground Control. Copies of these reports can be provided upon request once CVA and FVA data has been redacted.

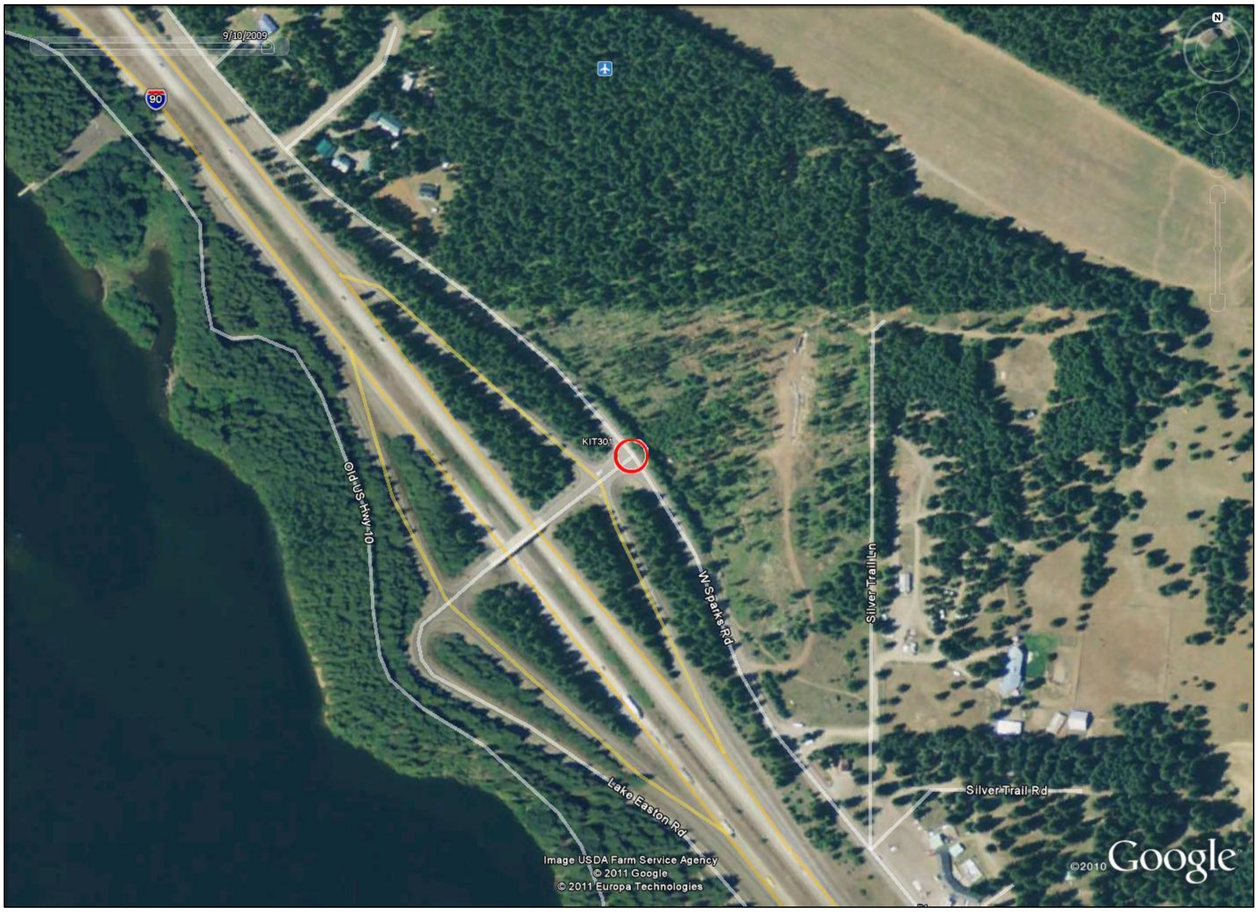
Contact Information

Hayden Howard Phone: (303) 627-4058 E-mail: haydenh@compassdatainc.com

KITTITAS, WASHINGTON								
FVA	**Date**	**Vert_Prec**	**Horz_Prec**	**Latitude**	**Longitude**	**Easting**	**Northing**	**NAVD88**
KIT301	4/18/2011	0.011	0.007	47.25079167	-121.1883827	5234625.971	637081.69	678.396
KIT302	4/18/2011	0.01	0.009	47.20763976	-121.1212467	5229950.836	642277.072	650.309
KIT303	4/18/2011	0.01	0.007	47.19503029	-121.0772947	5228630.657	645639.963	636.586
KIT304	4/18/2011	0.017	0.011	47.22288208	-120.9966322	5231879.335	651670.302	687.507
KIT305	4/18/2011	0.011	0.006	47.18789302	-120.9031615	5228177.11	658850.98	572.721
KIT306	4/19/2011	0.012	0.007	47.17899088	-120.8715629	5227252.645	661271.694	564.182
KIT307	4/19/2011	0.035	0.024	47.20090824	-120.7729263	5229896.635	668675.622	606.1
KIT308	4/19/2011	0.012	0.011	47.20762856	-120.773046	5230643.165	668645.252	611.651
KIT309	4/21/2011	0.028	0.014	47.25522473	-120.8799119	5235706.906	660408.943	675.735
KIT310	4/20/2011	0.015	0.012	47.18057355	-120.8364374	5227501.666	663928.184	571.812
KIT311	4/20/2011	0.03	0.016	47.08285782	-120.6888107	5216963.799	675434.272	506.97
KIT312	4/20/2011	0.014	0.011	47.04915797	-120.6479205	5213311.586	678650.594	490.246
KIT313	4/20/2011	0.015	0.01	47.07006742	-120.6260387	5215685.258	680242.028	539.909
KIT314	4/20/2011	0.014	0.008	47.10280627	-120.5613283	5219474.39	685041.462	620.308
KIT315	4/20/2011	0.013	0.01	47.10329015	-120.4973614	5219681.573	689893.199	703.675
KIT316	4/20/2011	0.017	0.01	47.01180123	-120.4336529	5209672.107	695060.55	532.155
KIT317	4/20/2011	0.019	0.011	47.03663904	-120.4977745	5212274.286	690098.83	554.66
KIT318	4/20/2011	0.012	0.009	47.01633875	-120.6770793	5209598.525	676544.196	586.987
KIT319	4/20/2011	0.014	0.011	46.97073345	-120.6495462	5204593.335	678788.773	578.491
KIT320	4/20/2011	0.016	0.013	46.96753029	-120.601749	5204347.598	682435.246	511.672
Survey Control								
NGS_SX0450	4/18/2011	0.021	0.013	47.12997409	120.76493510	5222031.499	669506.446	588.745
NGS_SX0450	4/21/2011	0.027	0.017	47.12997437	120.76493500	5222031.530	669506.453	588.725
NGS_SX0503	4/20/2011	0.015	0.008	47.01555733	120.58332163	5209727.387	683672.253	473.356
Metadata								
UTM 10 North, NAD83, NAVD88								
All units in meters where applicable.								
HAE - GEOID09 = NAVD88								

KITTITAS, WASHINGTON								
CVA	**Date**	**Vert_Prec**	**Horz_Prec**	**Latitude**	**Longitude**	**Easting**	**Northing**	**NAVD88**
KIT701	4/18/2011	0.050	0.050	47.25353688	-121.1956153	5234918.352	636527.366	667.562
KIT702	4/18/2011	0.050	0.050	47.1849207	-120.9574322	5227737.817	654748.347	588.831
KIT703	4/18/2011	0.050	0.050	47.18778237	-120.902396	5228166.371	658909.297	572.009
KIT704	4/19/2011	0.050	0.050	47.1746917	-120.854703	5226809.863	662562.244	560.573
KIT705	4/19/2011	0.050	0.050	47.20762566	-120.7735367	5230641.783	668608.1	610.675
KIT706	4/19/2011	0.050	0.050	47.19184255	-120.8097765	5228810.241	665913.012	578.67
KIT707	4/18/2011	0.050	0.050	47.22257471	-120.996891	5231844.675	651651.587	688.401
KIT708	4/20/2011	0.050	0.050	47.08253672	-120.6889663	5216927.768	675423.517	506.068
KIT709	4/20/2011	0.050	0.050	47.04900014	-120.6472617	5213295.553	678701.158	488.547
KIT710	4/20/2011	0.050	0.050	47.00659523	-120.5969367	5208699.691	682668.107	468.896
KIT711	4/20/2011	0.050	0.050	47.19774616	-121.0599093	5228965.039	646949.322	620.763
KIT801	4/18/2011	0.019	0.008	47.23753208	-121.1791266	5233168.784	637816.456	661.999
KIT802	4/18/2011	0.010	0.008	47.19495186	-120.9420908	5228883.048	655881.213	582.833
KIT803	4/18/2011	0.011	0.007	47.22200849	-120.9928337	5231789.647	651960.371	681.279
KIT804	4/20/2011	0.014	0.008	47.00478769	-120.5509786	5208607.094	686167.733	480.622
KIT805	4/20/2011	0.032	0.023	46.9961437	-120.533389	5207688.556	687535.046	497.322
Survey Control								
NGS_SX0450	4/18/2011	0.021	0.013	47.12997409	120.76493510	5222031.499	669506.446	588.745
NGS_SX0450	4/21/2011	0.027	0.017	47.12997437	120.76493500	5222031.530	669506.453	588.725
NGS_SX0503	4/20/2011	0.015	0.008	47.01555733	120.58332163	5209727.387	683672.253	473.356
Metadata								
UTM 10 North, NAD83, NAVD88								
All units in meters where applicable.								
HAE - GEOID09 = NAVD88								

KIT301_C


9/10/2009
90
KIT301
Old US Hwy 10
W Sparks Rd
Silver Trail Ln
Silver Trail Rd
Lake Easton Rd
Image USDA Farm Service Agency
© 2011 Google
© 2011 Europa Technologies
©2010 Google

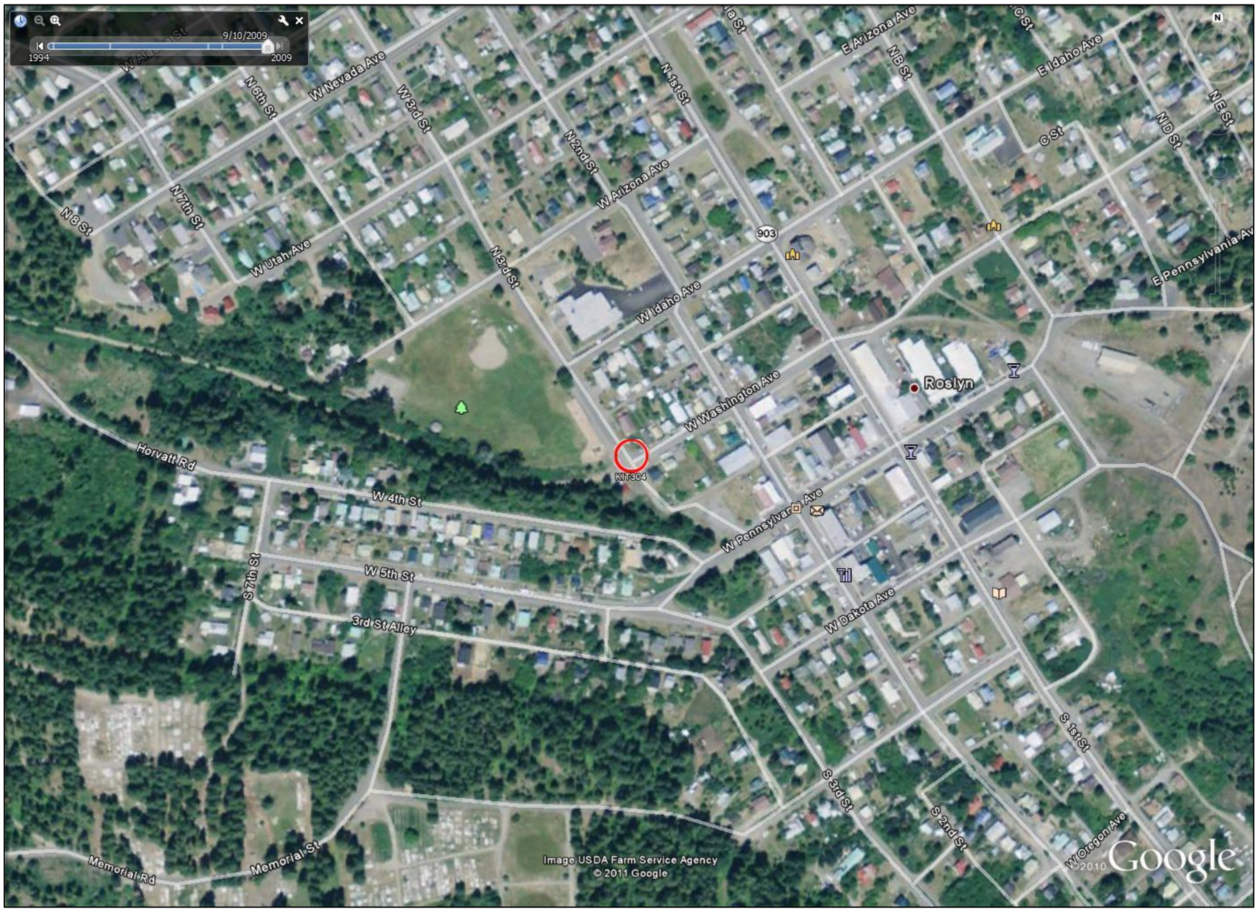
KIT302_C

9/10/2009
Pioneer Trail Rd
KIT302
Nelson Siding Rd
Filbert Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT303_C


9/10/2009
KIT303
Timber Valley Rd
Hugh Banks Rd
Secret Valley Rd
Nelson Siding Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT304_C



9/10/2009
1994
2009
W Nevada Ave
N 6th St
W 3d St
N 1st St
E Arizona Ave
N B St
E Idaho Ave
C St
N D St
N E St
N 2nd St
W Arizona Ave
N 7th St
N 8 St
W Utah Ave
903
N 3rd St
W Idaho Ave
E Pennsylvania Ave
Roslyn
W Washington Ave
KIT304
Horvatt Rd
W 4th St
W Pennsylvania Ave
S 7th St
W 5th St
W Dakota Ave
3rd St Alley
S 1st St
S 3rd St
S 2nd St
Memorial Rd
Memorial St
Image USDA Farm Service Agency
© 2011 Google
W Oregon Ave
©2010
Google

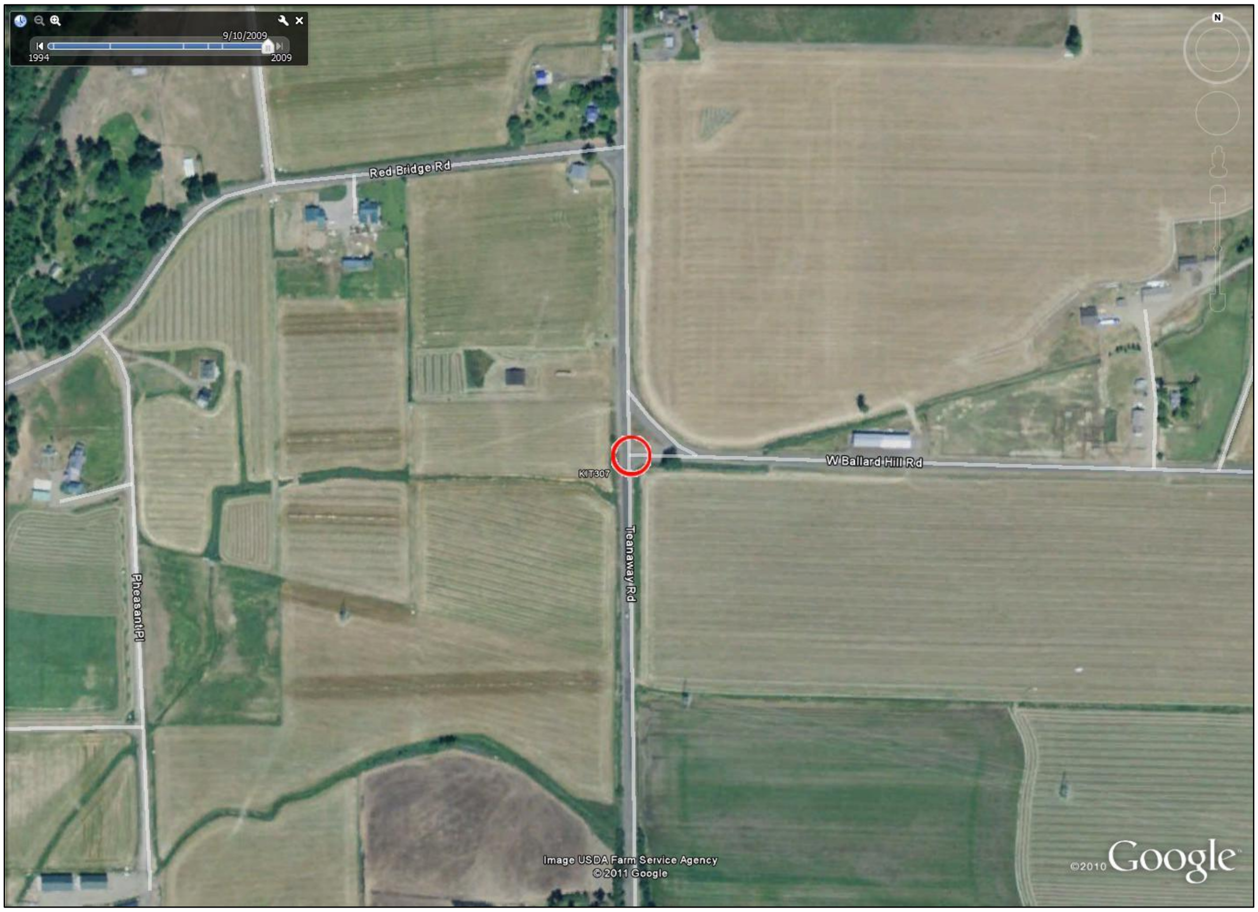
KIT305_C


9/10/2009
1994
2009
E 1st St
Airport Rd
Cle Elum Airport Rd
White Rd
10
KIT305
90
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

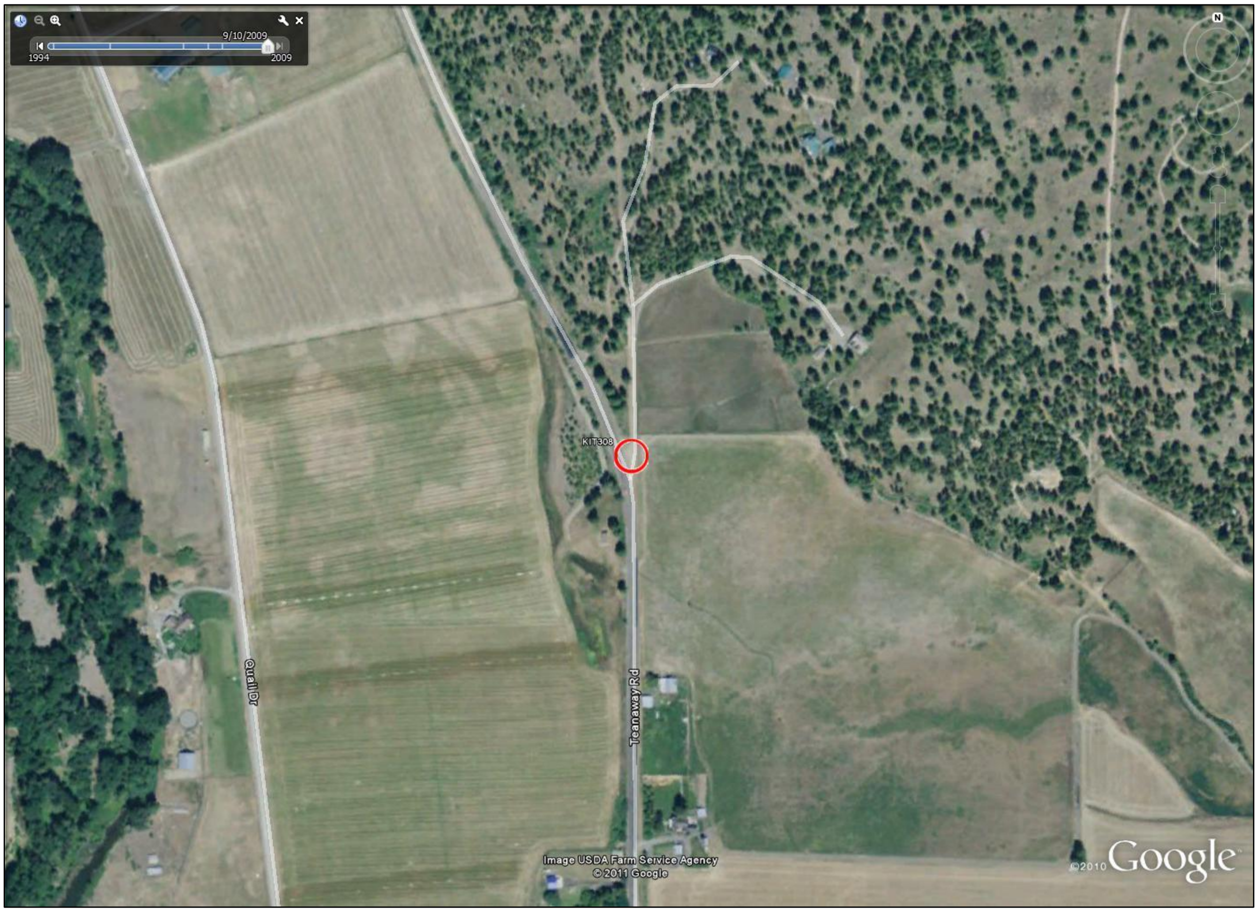
KIT306_C


9/10/2009
1994
2009
KIT306
10
Image USDA Farm Service Agency
© 2011 Google
© 2011 Europa Technologies
©2010
Google

KIT307_C


9/10/2009
1994
2009
Red Bridge Rd
W Ballard Hill Rd
KIT307
Teanaway Rd
Pheasant Pl
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT308_C



9/10/2009
1994
2009
KIT308
Quail Dr
Teanaway Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT309_C


9/10/2009
W Fork Teanaway Rd
Storm Creek Rd
KIT309
© 2011 Google
Image USDA Farm Service Agency
©2010
Google

KIT310A_C


9/10/2009
1994
2009
Red Bridge
Seaton Rd
970
KIT310_A
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

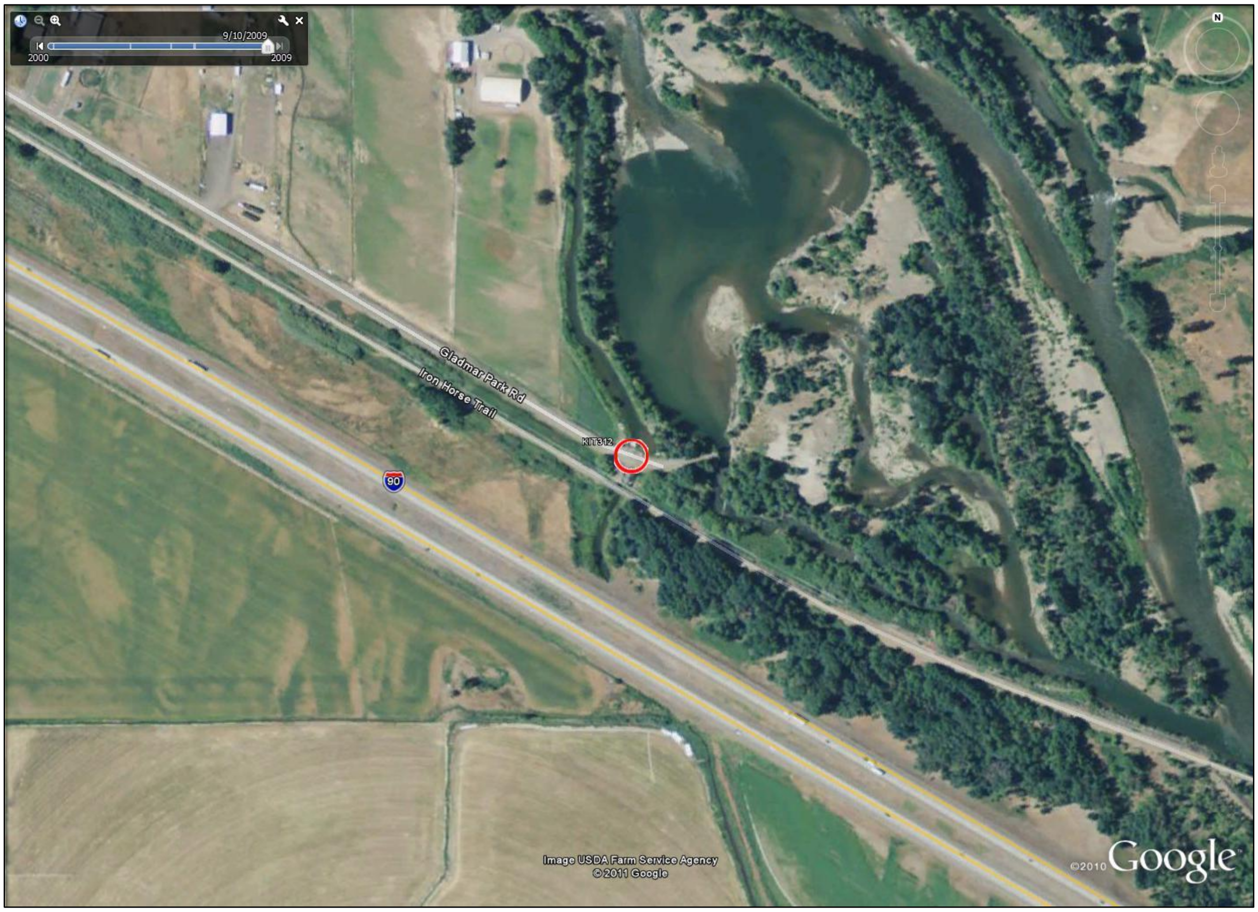
KIT310_C

9/10/2009
W Fork Teanaway Rd
Storm Creek Rd
Teanaway Rd
KIT310
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT311_C


9/10/2009
2000
2009
KIT311
Iron Horse Trail
Thorp Hwy
Bruton Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

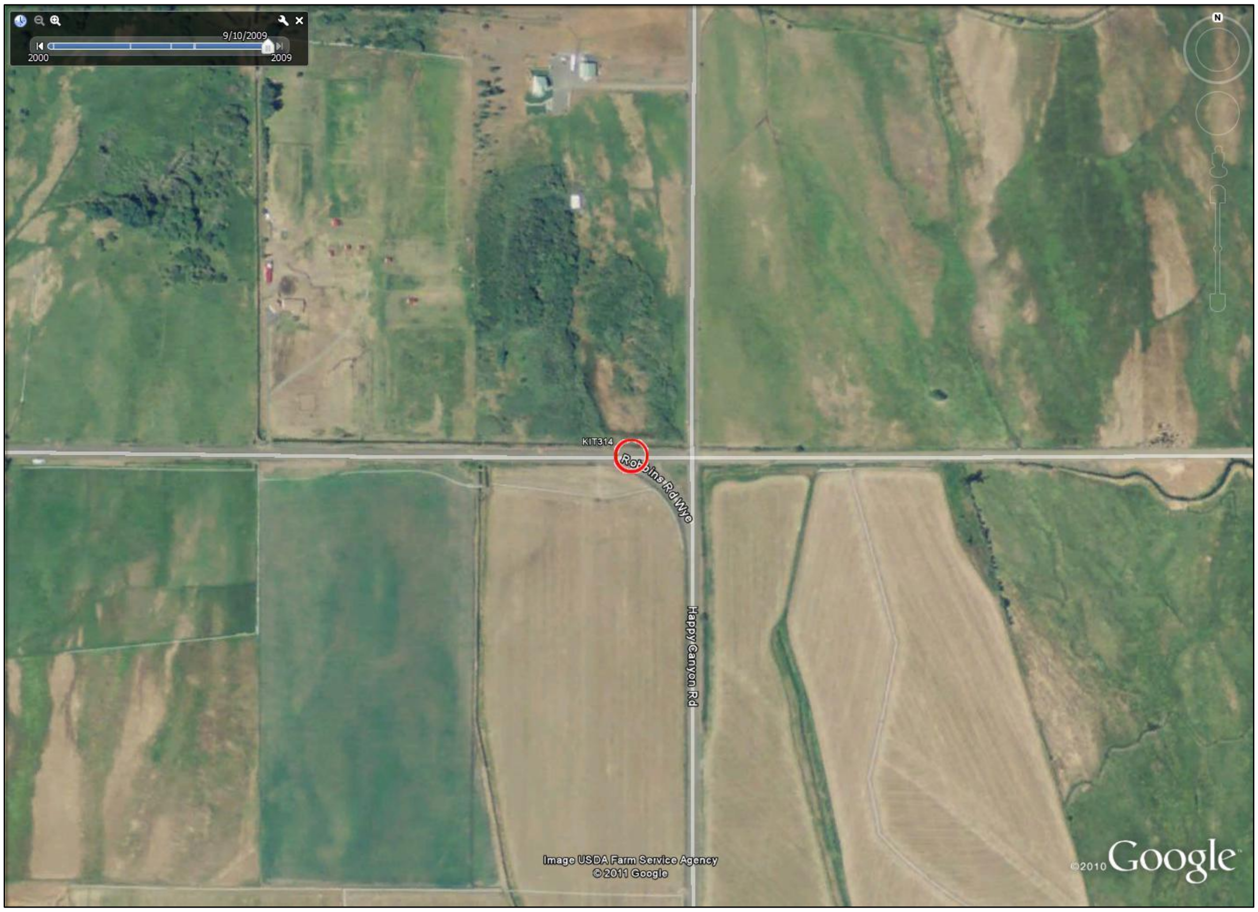
KIT312_C


9/10/2009
2000
2009
Gladmar Park Rd
Iron Horse Trail
KIT312
90
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT313_C


9/10/2009
2000
2009
KIT313
97
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

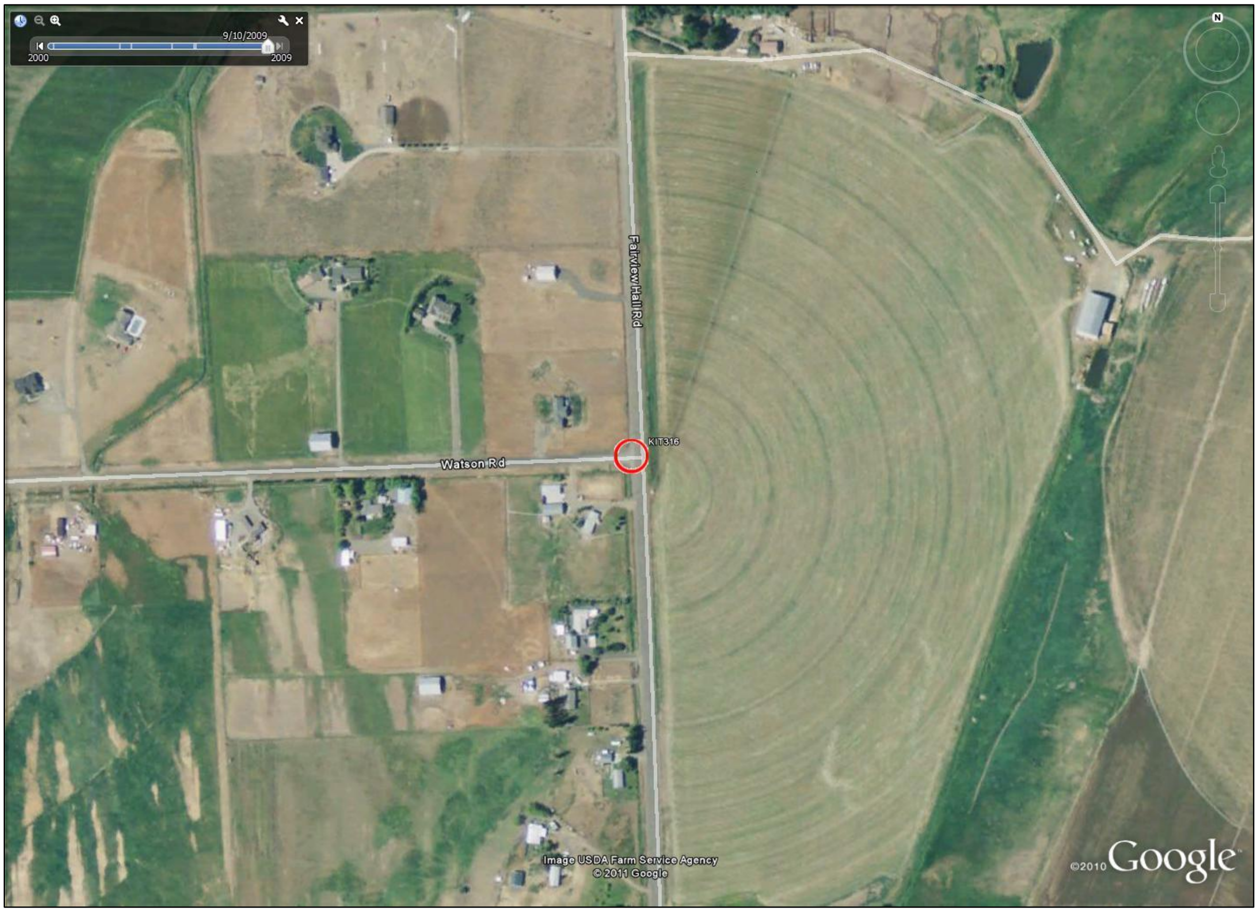
KIT314_C


9/10/2009
2000
2009
KIT314
Robbins Rd Wye
Happy Canyon Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT315_C


9/10/2009
N
KIT315
Charlton Rd
Wilson Creek Rd
Image USDA Farm Service Agency
© 2011 Google
©2010
Google
Frontier R

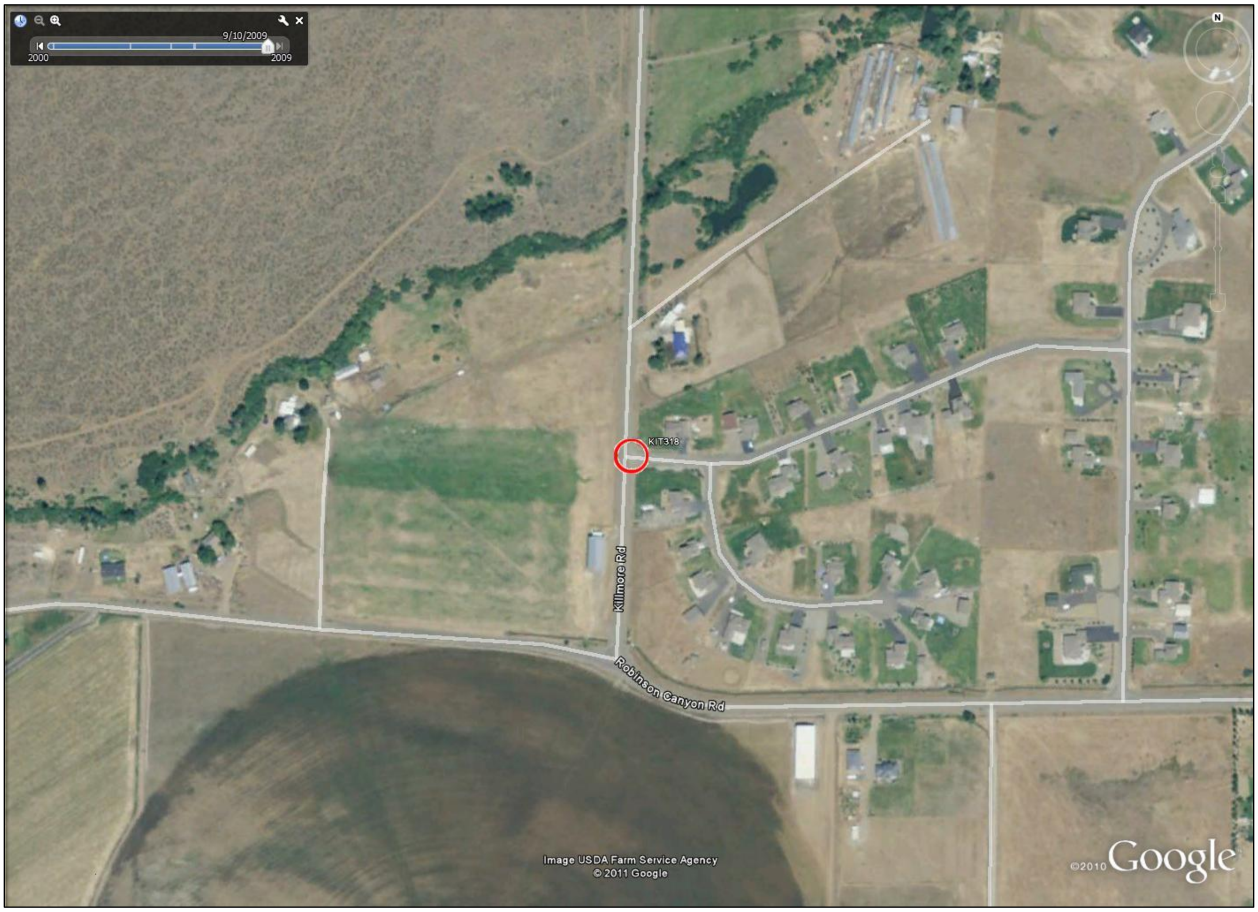
KIT316_C


9/10/2009
2000
2009
Fairview Hall Rd
KIT316
Watson Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT317_C


9/10/2009
KIT317
Brick Mill Rd
Wilson Creek Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

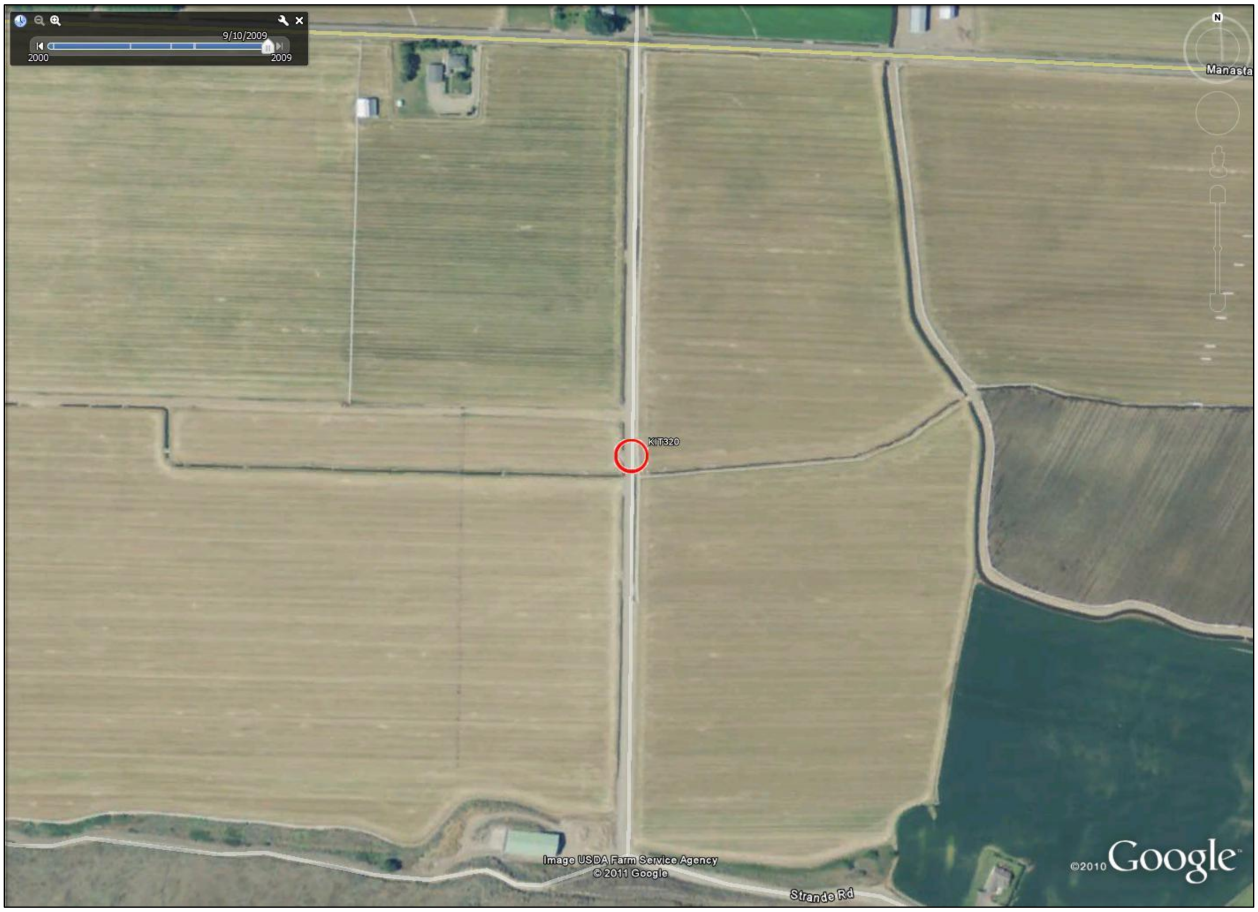
KIT318_C


9/10/2009
2000
2009
KIT318
Killmore Rd
Robinson Canyon Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

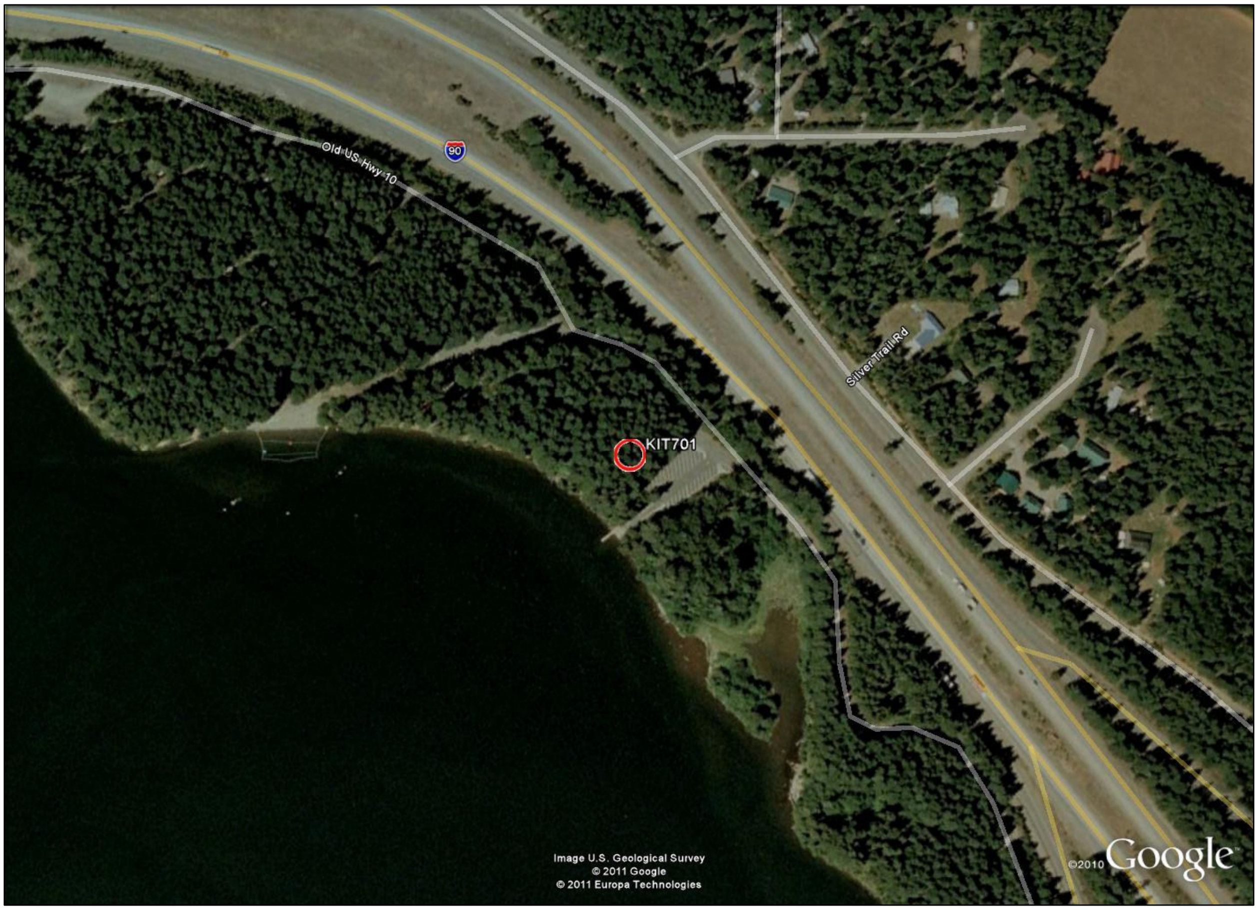
KIT319_C


9/10/2009
2000
2009
KIT319
Manastash Rd
Cove Ln
Aspen Dr
Cove Rd
Orrion Rd
Image USDA Farm Service Agency
© 2011 Google
©2010 Google

KIT320_C


9/10/2009
2000
2009
Manasta
KIT320
Image USDA Farm Service Agency
© 2011 Google
Strande Rd
©2010 Google

KIT701_C


Old US Hwy 10
90
Silver Trail Rd
KIT701
Image U.S. Geological Survey
© 2011 Google
© 2011 Europa Technologies
©2010 Google

KIT702_C


Broadway Ave
Lincoln Ave
Cleveland Ave
Madison Ave
Garfield Ave
Milwaukee Ave
Garfield Pl
Old Milwaukee Rd Railroad Grde
N Milwaukie Ave
Main St
7th St
6th St
5th St
Westside Rd
Dunnagan Rd
KIT702
Image U.S. Geological Survey
© 2011 Google
©2010 Google

KIT703_C

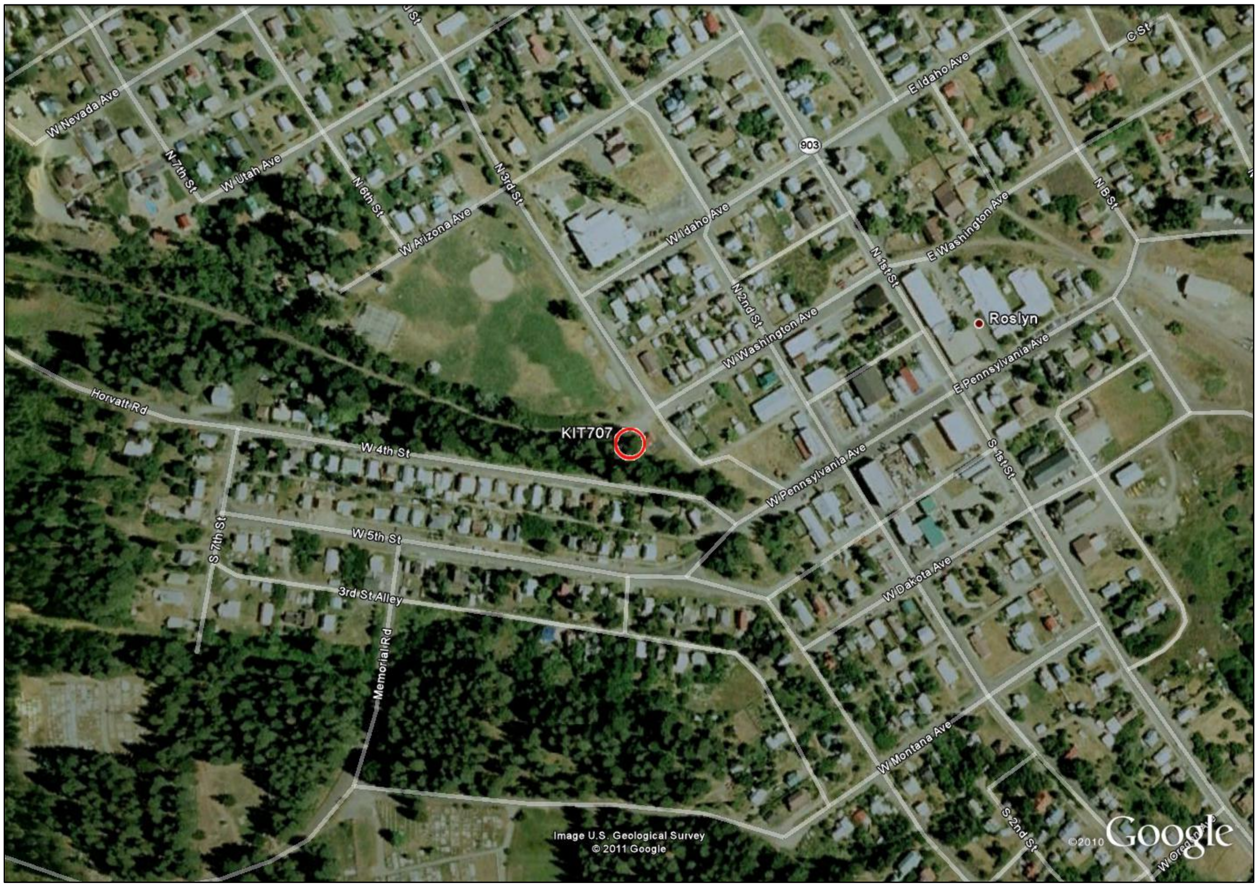
KIT704_C

KIT705_C

KIT706_C


Red Bridge Rd
970
KIT706
Image U.S. Geological Survey
© 2011 Google
©2010 Google

KIT707_C



W Nevada Ave
N 7th St
W Utah Ave
N 6th St
W Arizona Ave
N 3rd St
W Idaho Ave
E Idaho Ave
903
C St
N B St
E Washington Ave
N 1st St
N 2nd St
W Washington Ave
Roslyn
E Pennsylvania Ave
KIT707
Horvatt Rd
W 4th St
S 1st St
W Pennsylvania Ave
S 7th St
W 5th St
W Dakota Ave
3rd St Alley
Memorial Rd
W Montana Ave
S 2nd St
Image U.S. Geological Survey
© 2011 Google
©2010
Google

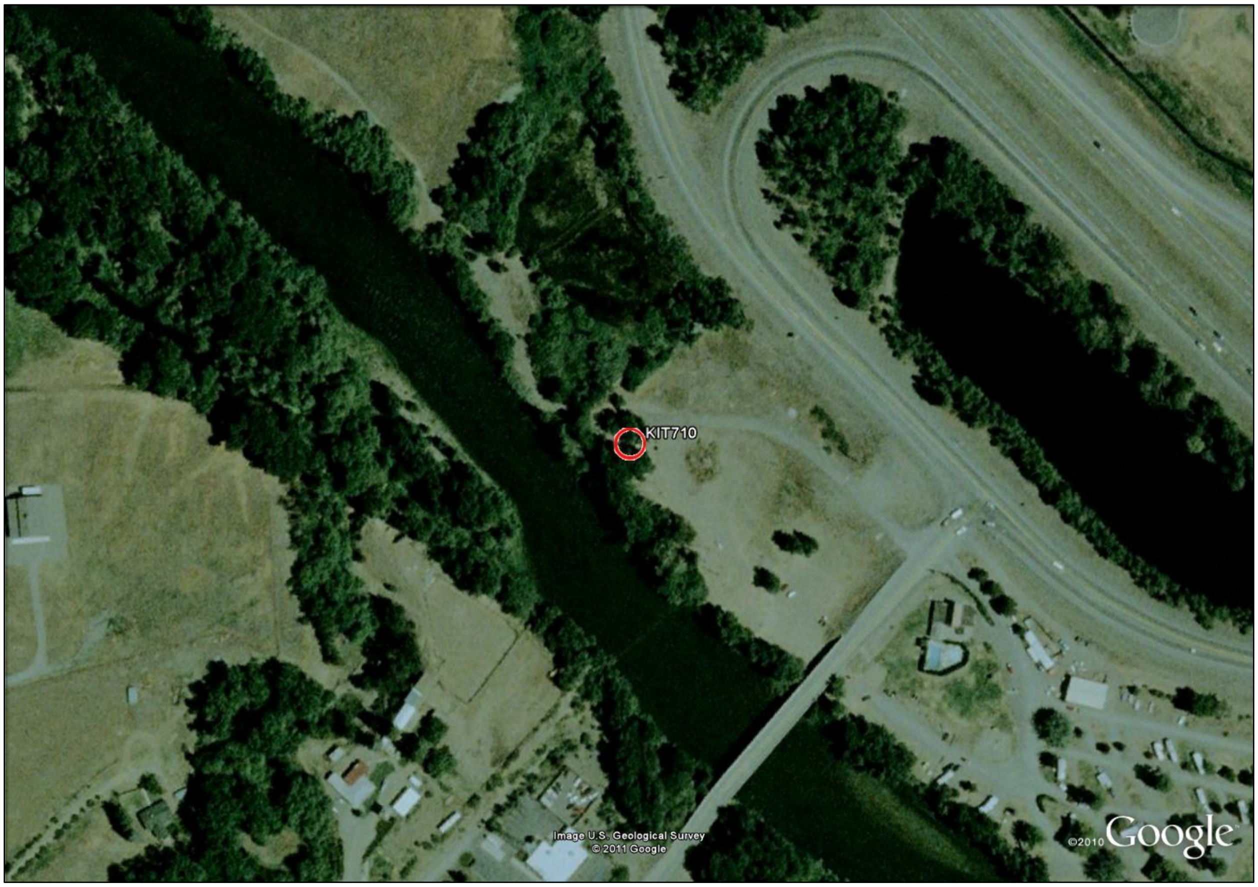
KIT708_C

Thorp Hwy
KIT708
Image U.S. Geological Survey
© 2011 Google
©2010 Google

KIT709_C

Gladmar Park Rd
KIT709
Iron Horse Trail
90
Image U.S. Geological Survey
© 2011 Google
©2010 Google

KIT710_C



KIT711_C


90
KIT711
Image U.S. Geological Survey
© 2011 Google
©2010 Google

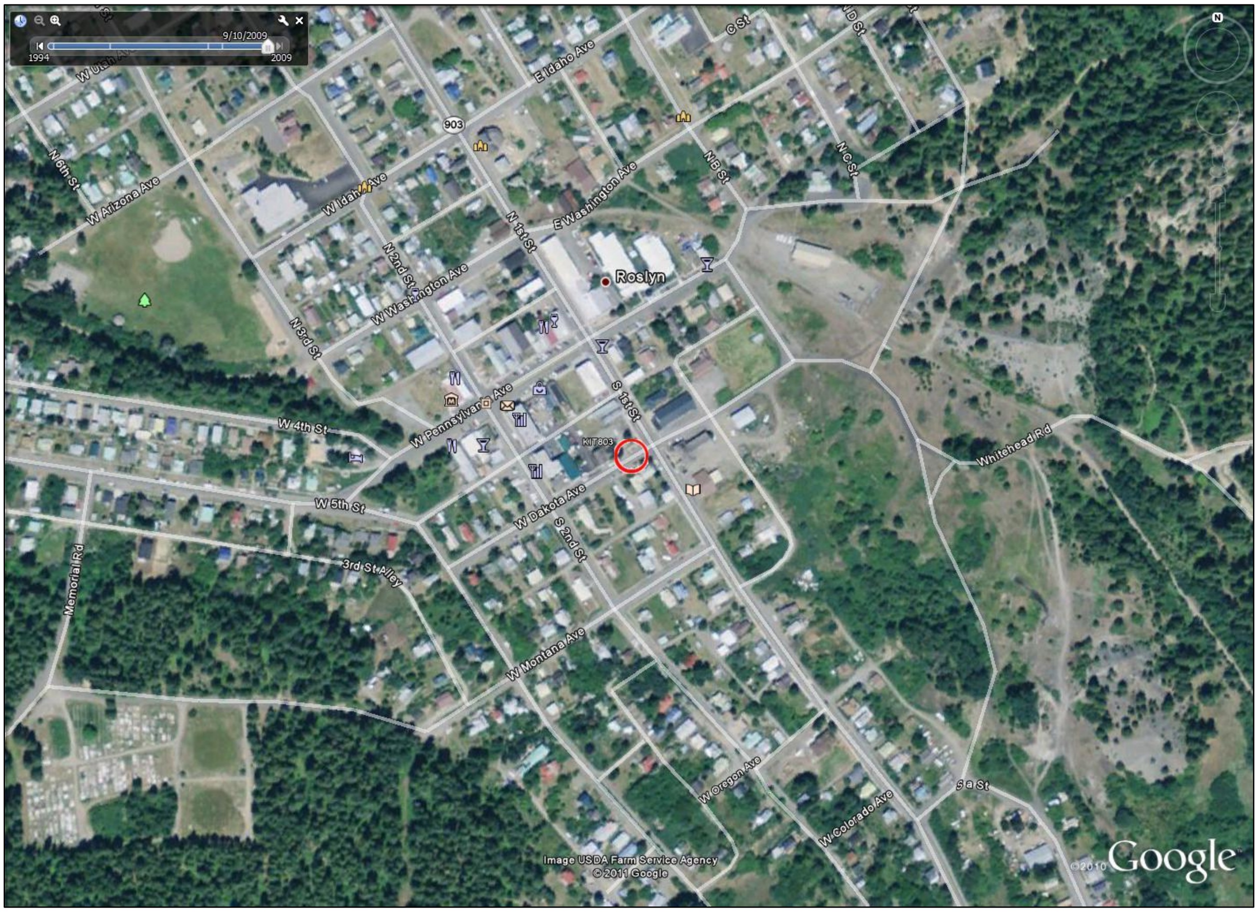
KIT801_C


9/10/2009
90
Hawthorn Rd
Lake Easton Rd
Kachess Ave
KIT801
Depot St
1st St
Easton
Old Milwaukee Rd Railroad Grde
Iron Horse Trail
Cross St
Alley St
No 277 Rd
Railroad St
Cabin Creek Rd
Image USDA Farm Service Agency
© 2011 Google
© 2011 Europa Technologies
©2010
Google

KIT802_C

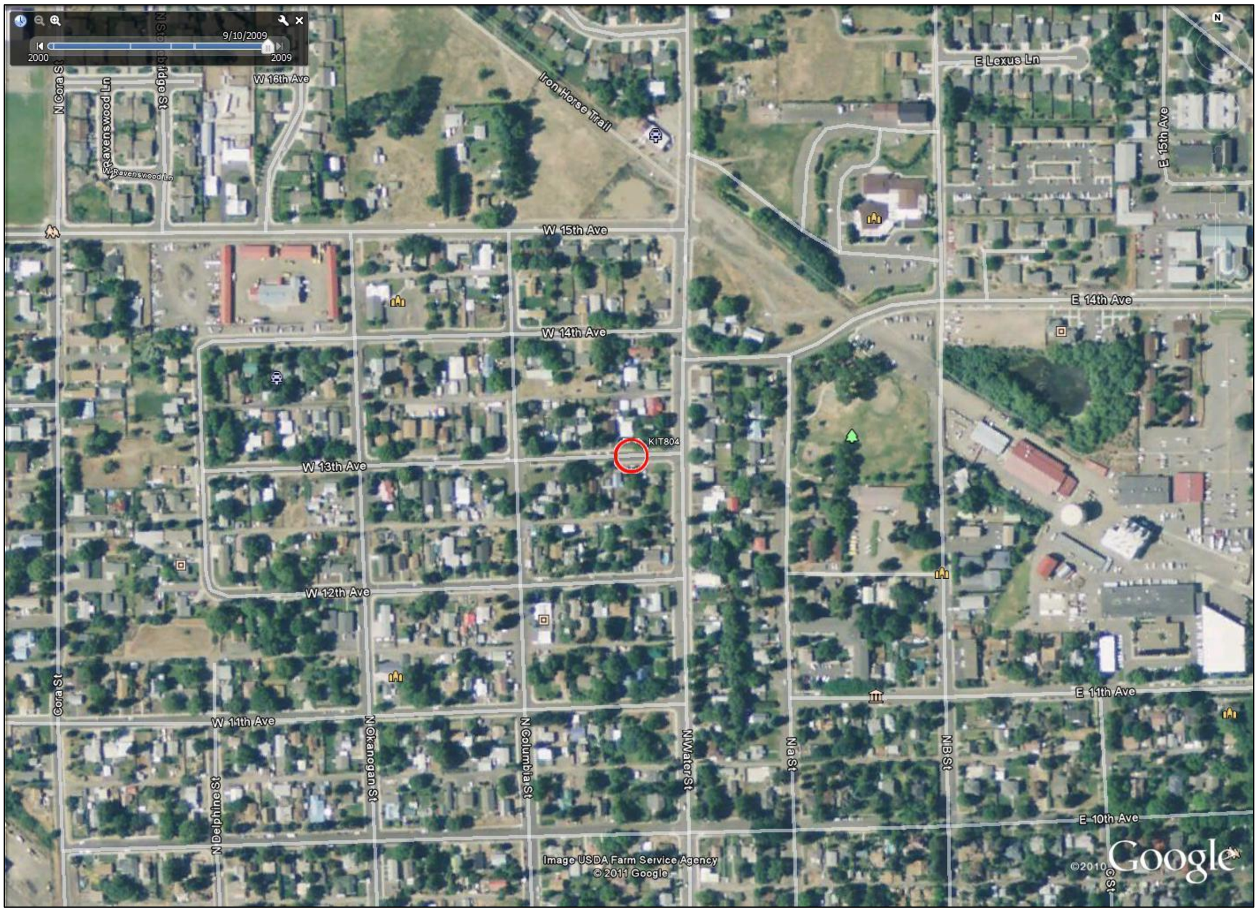

9/10/2009
1994
2009
W 4th St
E 5th St
W 3rd St
E 3rd St
E 4th St
Shober Way
Reed St
2nd Pl
Mine Heritage Trail
Stafford St
W 2nd St
E 2nd St
N Oaks Ave
Billings Ave
Cle Elum
W 1st St
E 1st St
970
KIT802
N Harris Ave
N Wright Ave
N Oakes Ave
W Railroad Ave
E Railroad Ave
S Oaks Ave
W Russ St
E Russ St
Oakes Ave S
90
4th St
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT803_C



9/10/2009
1994
2009
903
E Idaho Ave
W Idaho Ave
W Arizona Ave
N 6th St
E Washington Ave
W Washington Ave
N 1st St
N 2nd St
N 3rd St
N B St
N C St
C St
D St
Roslyn
W Pennsylvania Ave
W 4th St
W 5th St
KIT803
S 1st St
W Dakota Ave
S 2nd St
3rd St Alley
Memorial Rd
W Montana Ave
Whitehead Rd
W Oregon Ave
W Colorado Ave
S a St
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT804_C



9/10/2009
2000
2009
W 16th Ave
N Cora St
Ravenswood Ln
Ravenswood Ln
Iron Horse Trail
E Lexus Ln
E 15th Ave
W 15th Ave
E 14th Ave
W 14th Ave
KIT804
W 13th Ave
W 12th Ave
E 11th Ave
W 11th Ave
Cora St
N Okanogan St
N Columbia St
N Water St
N A St
N B St
N Delphine St
E 10th Ave
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT805_C


E University Way
9/10/2009
2000
2009
E 7th Ave
Rodeo Grandstands
Craig Ave
E 6th Ave
E 5th Ave
KIT805
N Willow St
Franklin St
Linda Ln
Angford Dr
E 4th Ave
Cliff St
Cliff Ave
E 3rd Ave
E 2nd Ave
N Sampson St
N Walnut St
N Chestnut St
N Poplar St
N Maple St
N Alder St
Image USDA Farm Service Agency
© 2011 Google
©2010
Google

KIT301_E

KIT301_N

KIT301_S

KIT301_W

KIT302_E

KIT302_N

KIT302_S

KIT302_W

KIT303_E

KIT303_N

KIT303_S

KIT303_W

KIT304_E

KIT304_N

KIT304_S

KIT304_W

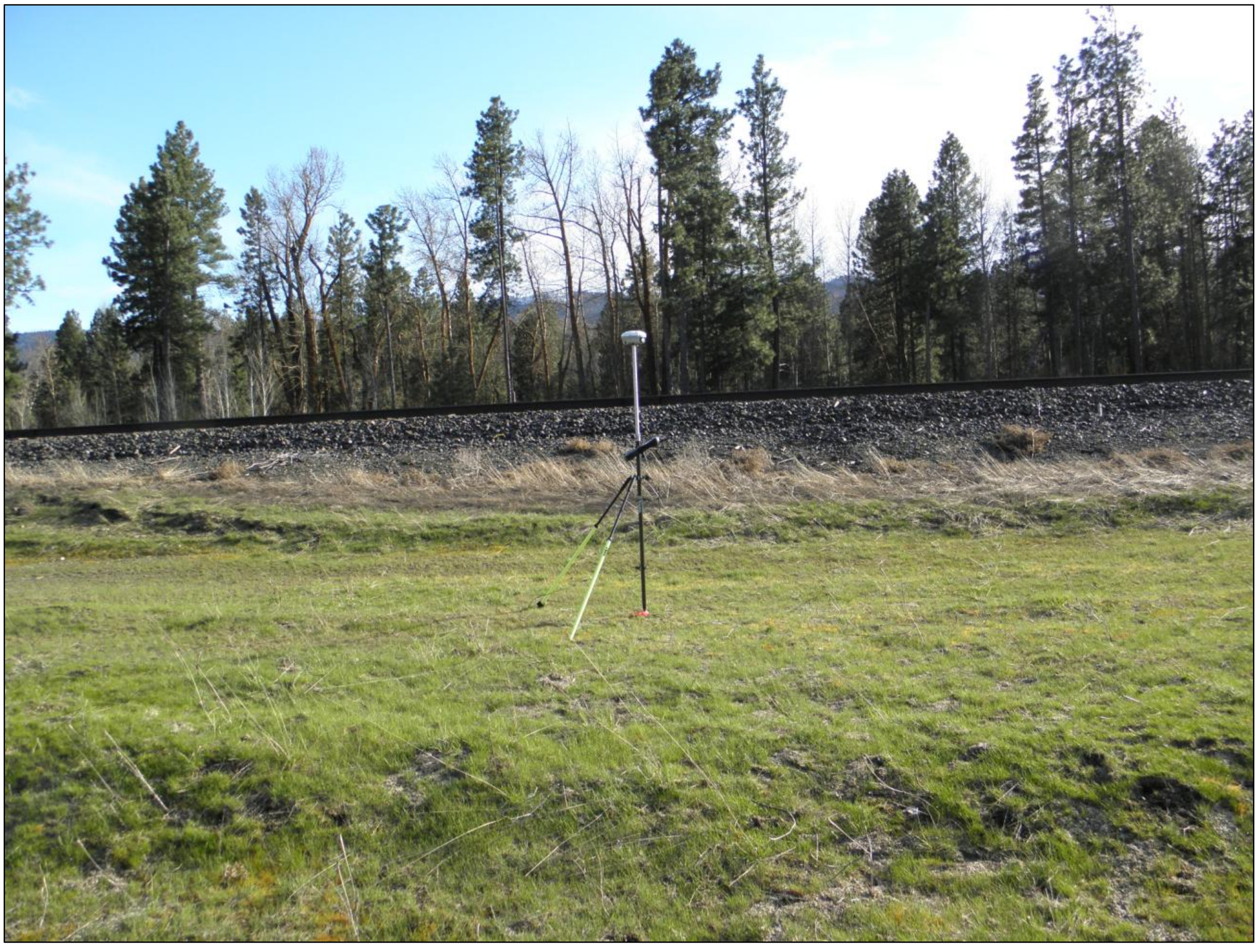
KIT305_2

KIT305_3

KIT305_E

KIT305_N

KIT305_S



KIT305_W

KIT310_A_E

KIT310_A_N

KIT310_A_S

KIT310_A_W

KIT311_E

KIT311_N

KIT311_S

KIT311_W

KIT312_E

KIT312_N

KIT312_S

KIT312_W

KIT313_E

KIT313_N

KIT313_S

KIT313_W

KIT314_E

KIT314_N

KIT314_S

KIT314_W

KIT315_E

KIT315_N

KIT315_S

KIT315_W

KIT316_E

KIT316_N

KIT316_S

KIT316_W

KIT317_E

KIT317_N

KIT317_S

KIT317_W

KIT318_E

KIT318_N

KIT318_S

KIT318_W

KIT319_E

KIT319_N

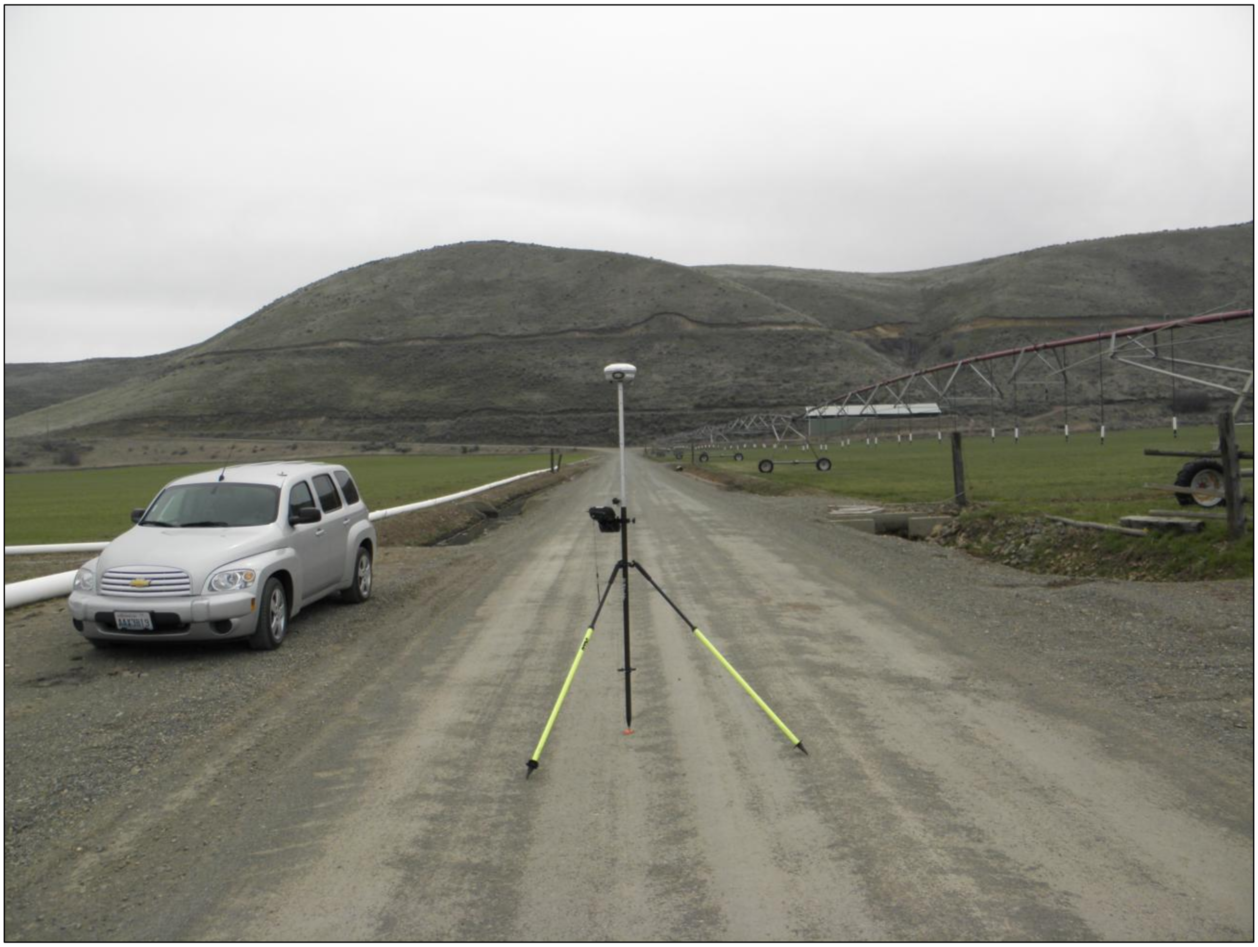
KIT319_S

KIT319_W

KIT320_E

KIT320_N

KIT320_S



KIT320_W

KIT701_1

KIT701_2

KIT702_1

KIT702_2

KIT702_3

KIT703_1

KIT703_2

KIT703_3

KIT707_1

KIT707_2

KIT707_3

KIT708_1

KIT708_2

KIT708_3

KIT710_1

KIT710_2

KIT710_3

KIT711_1 (2)

KIT711_2

KIT711_3

KIT712_1

KIT712_2

KIT712_3

KIT801_E

KIT801_N

KIT801_S

KIT801_W

KIT802_E

KIT802_N

KIT802_S

KIT802_W

KIT803_E

KIT803_N

KIT803_S

KIT803_W

KIT804_E

KIT804_N

KIT804_S

KIT804_W

KIT805_E

KIT805_N

KIT805_S

KIT805_W

NGS_SX0450_CAP

NGS_SX0450_E

NGS_SX0450_N

NGS_SX0450_S

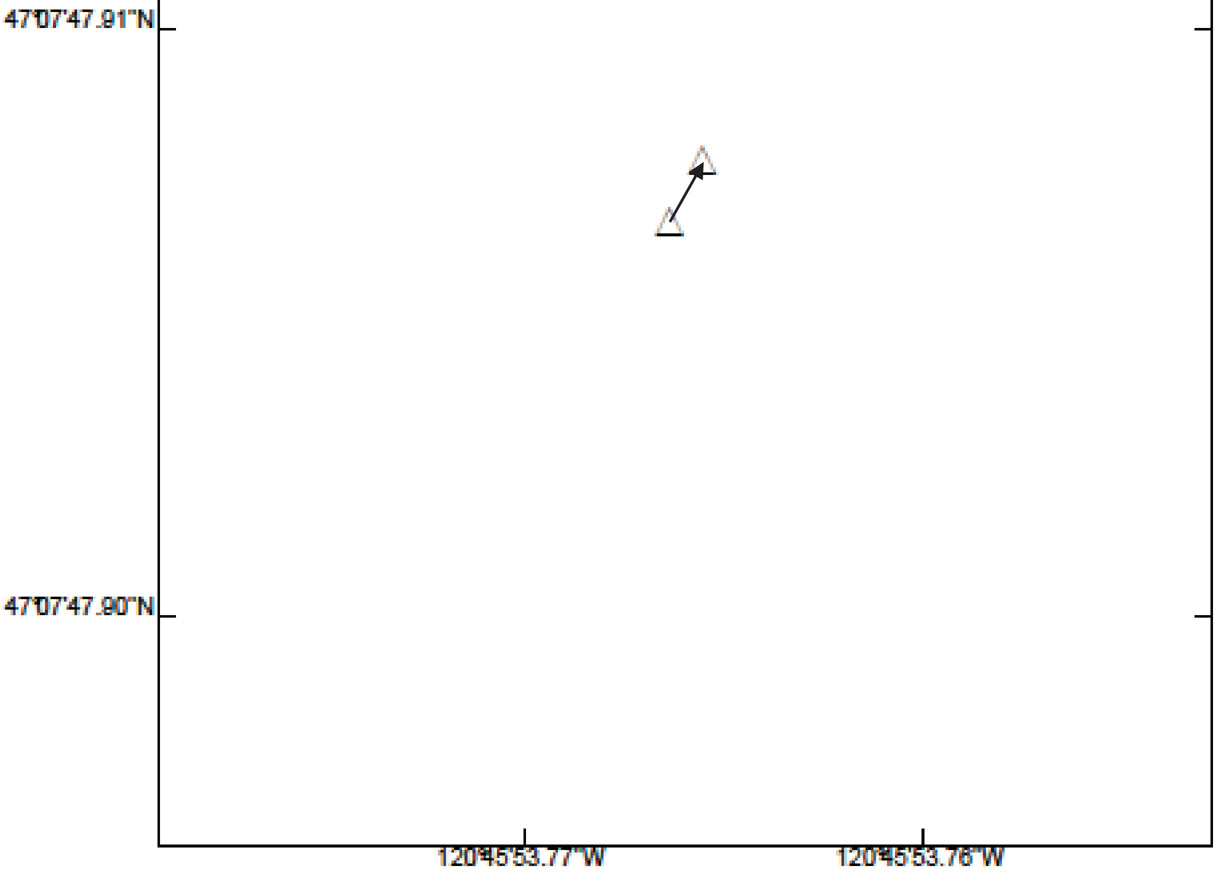
NGS_SX0450_W

CompassData

Accuracy Report

$\Delta H = 0.037m$

$\Delta V = 0.019m$



NGS_SX0450

Lat/Long
WGS 1984

N

Scale 1:4.00

0 0.150

Meters

5/25/2011

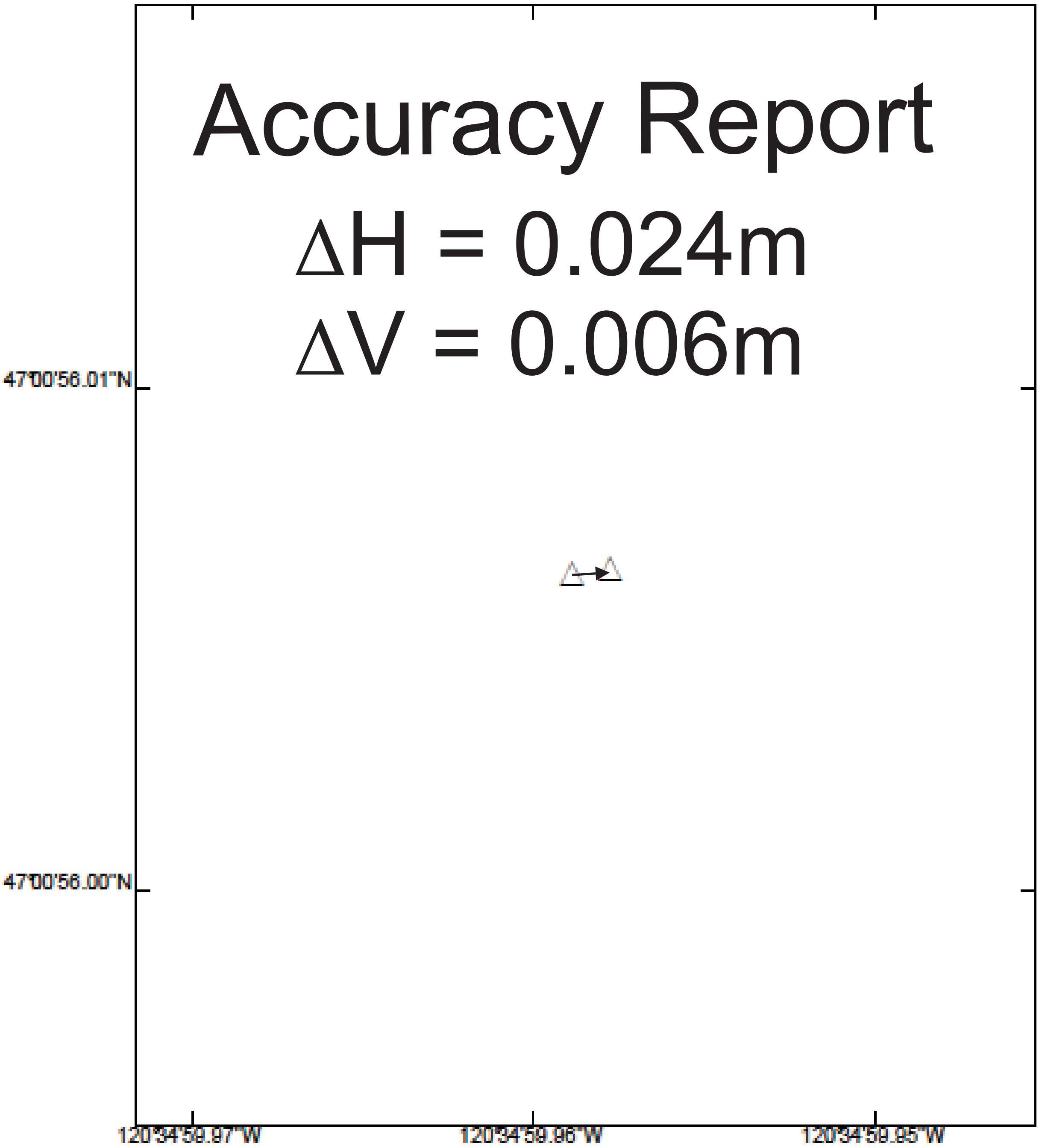
GPS Pathfinder® Office

Trimble

CompassData

Accuracy Report

ΔH = 0.024m
ΔV = 0.006m



NGS_0503

Lat/Long
WGS 1984

N

Scale 1:4.00
0 0.150
Meters

5/24/2011

GPS Pathfinder® Office
Trimble

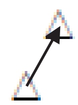
CompassData

Accuracy Report

$\Delta H = 0.010m$

$\Delta V = 0.001m$

47°07'47.91"N



47°07'47.90"N

120°45'53.77"W 120°45'53.76"W

NGS_SX0450

Lat/Long
WGS 1984

N

Scale 1:4.00

0 0.150

Meters

5/25/2011

GPS Pathfinder® Office

Trimble

CompassData

Region 10: Test results for Kittitas, WA

Summary

In FEMA-Region 10 the Kittitas area is split up in multiple parts. This test encompasses total about 210 square miles. A LiDAR data acquisition was ordered for a 2’ equivalent contour accuracy, which equals the highest specification level. The area was flown and post-processed by Aerometric. CompassData performed the quality control of the collected and processed LiDAR data with a fundamental vertical accuracy (FVA) and a consolidated vertical accuracy (CVA) assessment, respectively. The planning, data collection, data processing, and data testing were successfully accomplished by the STARR members.

Index

Final Test Results

The vertical accuracy requirements based on flood risk and terrain slope are met with 11.7 cm and 15.2 cm for both FVA and CVA testing. The mandatory requirements for the highest specification for vertical accuracy, 95% confidence levels are for FVA < 24.5 cm and CVA < 36.3 cm.

FVA Test

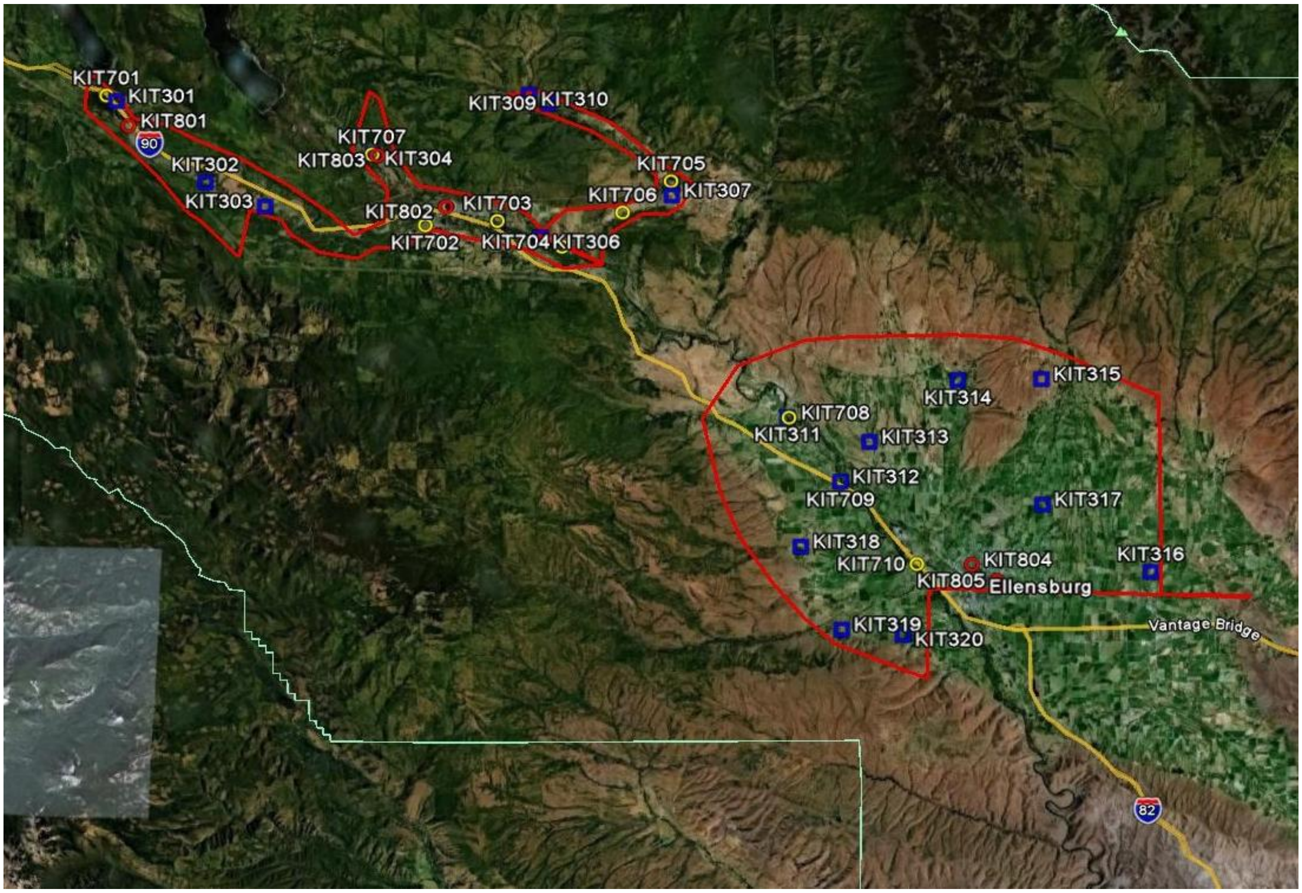
Tested 11.7 cm fundamental vertical accuracy at 95% confidence level in open terrain using $RMSE_{(z)}$ x 1.9600. The Root Mean Square Error for the elevation differences between GPS control points and LiDAR points is 6.0 cm calculated with 20 FVA points.

CVA Test

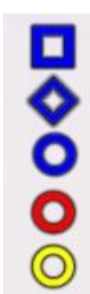
Tested 15.2 cm consolidated vertical accuracy at 95th percentile in: open terrain, forest terrain, and urban terrain. The Root Mean Square Error for the elevation differences between GPS control points and LiDAR points is 7.3 cm calculated with 20 supplemental vertical accuracy points (SVA).

Distribution of Testing Points

Region 10, Kittitas, WA



<u>Legend:</u>



FVA points in open terrain on hard surface

FVA points in open terrain used as well in CVA test

SVA points in open terrain

SVA points in urban terrain

SVA points in forest terrain

According to the area to be tested the 20 FVA points are evenly distributed. Additional 15 SVA points are distributed in respect to the available major land classes.

CompassData

FVA Test Details

FVA	Latitude(GPS)	Longitude(GPS)	Northing(GPS)	Easting(GPS)	MSL (GPS)	MSL (LiDAR)	Δ Z
KIT301	47.250792	-121.188383	5234625.971	637081.690	678.396	678.380	**0.02**
KIT302	47.207640	-121.121247	5229950.836	642277.072	650.309	650.350	**-0.04**
KIT303	47.195030	-121.077295	5228630.657	645639.963	636.586	636.600	**-0.01**
KIT304	47.222882	-120.996632	5231879.335	651670.302	687.507	687.470	**0.04**
KIT305	47.187893	-120.903161	5228177.11	658850.980	572.721	572.760	**-0.04**
KIT306	47.178991	-120.871563	5227252.645	661271.694	564.182	564.200	**-0.02**
KIT307	47.200908	-120.772926	5229896.635	668675.622	606.100	606.070	**0.03**
KIT308	47.207629	-120.773046	5230643.165	668645.252	611.651	611.610	**0.04**
KIT309	47.255225	-120.879912	5235706.906	660408.943	675.735	675.600	**0.13**
KIT310	47.180574	-120.836437	5227501.666	663928.184	571.812	571.760	**0.05**
KIT311	47.082858	-120.688811	5216963.799	675434.272	506.970	506.800	**0.17**
KIT312	47.049158	-120.647921	5213311.586	678650.594	490.246	490.210	**0.04**
KIT313	47.070067	-120.626039	5215685.258	680242.028	539.909	539.920	**-0.01**
KIT314	47.102806	-120.561328	5219474.39	685041.462	620.308	620.320	**-0.01**
KIT315	47.103290	-120.497361	5219681.573	689893.199	703.675	703.700	**-0.03**
KIT316	47.011801	-120.433653	5209672.107	695060.550	532.155	532.070	**0.08**
KIT317	47.036639	-120.497774	5212274.286	690098.830	554.660	554.630	**0.03**
KIT318	47.016339	-120.677079	5209598.525	676544.196	586.987	586.970	**0.02**
KIT319	46.970733	-120.649546	5204593.335	678788.773	578.491	578.440	**0.05**
KIT320	46.967530	-120.601749	5204347.598	682435.246	511.672	511.700	**-0.03**

ΔZ Mean	**0.04**	**RMSE:**	**0.060**
ΔZ Min	**-0.04**	***1.96**	**0.117**
ΔZ Max	**0.17**		

Metadata

UTM 10 North, NAD83, NAVD88

All units in meters where applicable.

HAE - GEOID09 = NAVD88

Note:

All 20 of the FVA points (open terrain) passed. 100% of the points are within the 24.5 cm confidence level. The FVA test is passed.

CVA Test Details

SVA	Latitude(GPS)	Longitude(GPS)	Northing(GPS)	Easting(GPS)	MSL (GPS)	MSL (LiDAR)	Δ Z
KIT301	47.250792	-121.188383	5234625.971	637081.690	678.380	678.396	**-0.02**
KIT305	47.187893	-120.903161	5228177.110	658850.980	572.760	572.721	**0.04**
KIT310	47.180574	-120.836437	5227501.666	663928.184	571.760	571.812	**-0.05**
KIT315	47.103290	-120.497361	5219681.573	689893.199	703.700	703.675	**0.03**
KIT320	46.967530	-120.601749	5204347.598	682435.246	511.700	511.672	**0.03**
KIT701	47.253537	-121.195615	5234918.352	636527.366	667.562	667.52	**0.04**
KIT702	47.184921	-120.957432	5227737.817	654748.347	588.831	588.81	**0.02**
KIT703	47.187782	-120.902396	5228166.371	658909.297	572.009	572.2	**-0.19**
KIT704	47.174692	-120.854703	5226809.863	662562.244	560.573	560.69	**-0.12**
KIT705	47.207626	-120.773537	5230641.783	668608.100	610.675	610.74	**-0.07**
KIT706	47.191843	-120.809776	5228810.241	665913.012	578.670	578.82	**-0.15**
KIT707	47.222575	-120.996891	5231844.675	651651.587	688.401	688.45	**-0.05**
KIT708	47.082537	-120.688966	5216927.768	675423.517	506.068	506.02	**0.05**
KIT709	47.049000	-120.647262	5213295.553	678701.158	488.547	488.59	**-0.04**
KIT710	47.006595	-120.596937	5208699.691	682668.107	468.896	468.94	**-0.04**
KIT711	47.197746	-121.059909	5228965.039	646949.322	620.763	620.78	**-0.02**
KIT801	47.237532	-121.179127	5233168.784	637816.456	661.999	661.97	**0.03**
KIT802	47.194952	-120.942091	5228883.048	655881.213	582.833	582.84	**-0.01**
KIT803	47.222008	-120.992834	5231789.647	651960.371	681.279	681.33	**-0.05**
KIT804	47.004788	-120.550979	5208607.094	686167.733	480.622	480.55	**0.07**
KIT805	46.996144	-120.533389	5207688.556	687535.046	497.322	497.26	**0.06**

ΔZ Mean	**0.04**	**RMSE:**	**0.073**
ΔZ Min	**-0.19**	***1.96**	**0.143**
ΔZ Max	**0.07**	**95 Percentile**	**0.152**

Metadata

UTM 10 North, NAD83, NAVD88
All units in meters where applicable.
HAE - GEOID09 = NAVD88

Note:

All 20 of the SVA points (open, forest, and urban terrain) passed. 100% of the points are within the 36.3 cm confidence level. The CVA test is passed.

Appendix E: Post Flight Reports

Kittitas

Post-Flight Aerial Acquisition Report

August 2011

Post-Flight Aerial Acquisition and Calibration Report

FEMA REGION 10

Kittitas County, WA

August 2011

Contents

1.0 Overview

1.1. Contact Information:

Questions regarding the technical aspects of this report should be addressed to:

AeroMetric, Inc.
4020 Technology Parkway
Sheboygan, WI 53081

Attn: Robert Merry (Geomatics Manager)
Telephone: 920-457-3631
FAX: 920-457-0410
Email: rmerry@aerometric.com

1.2. Purpose and Location

AeroMetric, Inc acquired highly accurate Light Detection and Ranging (LiDAR) data for an area that comprised of approximately 185 square miles of Kittitas County, Washington for STARR as a part of FEMAs RiskMAP program. A graphic of the location is provided in Figure 1.1.

Figure 1.1 Project Area - Kittitas County, WA

2.0 LiDAR Acquisition

2.1 System Parameters

LiDAR was collected to the 'Highest' FEMA specification which is equivalent to the 2 foot contour equivalency accuracy requirement. This requires a nominal post spacing of 1 meter. The LiDAR system parameters to meet this requirement are found in Table 2.1.

Table 2.1 LiDAR System Specifications

Flying Height	1500 meters
Laser Pulse Rate	70 kHz
Mirror Scan Frequency	41 Hz
Scan Angle	(+/-) 16°
Side Lap	50%
Ground Speed	160 knots
Nominal Point Spacing	1 meter

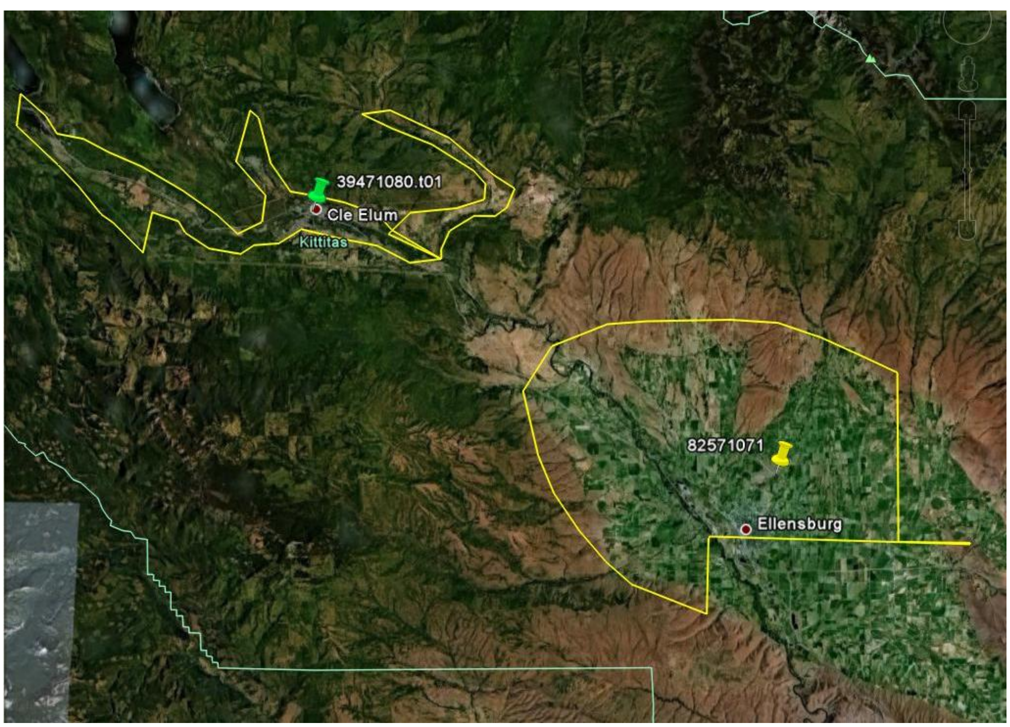
2.2 Base Station Information:

All missions originated and terminated at Bowers Airport in Ellensburg, WA. A GPS base station was operating at the airport during every lift. Table 2.1 is the Base Station information for the project area. Figure 2.1 provides a graphic representation of the Base Station locations. In the figure the Green Stick Pin represents Base Station 39471080.t01. The maximum extent of the collection area was approximately 22 km from Base Station 39471080.t01. The Yellow Stick Pin represents Base Station 82571071. The maximum extent of the collection area was approximately 20 km from Base Station 82571071. Shapefiles of the Base Stations can be found in the Control.zip file attached to this report.

Table 2.2 Base Station Locations

POINT ID	LAT	LONG	HEIGHT (M)
39471080.t01	47 11 39.9373	120 56 33.6098	584.027
82571071	47 01 51.11424	120 31 14.92835	513.293

Figure 2.1 Base Station Location Map



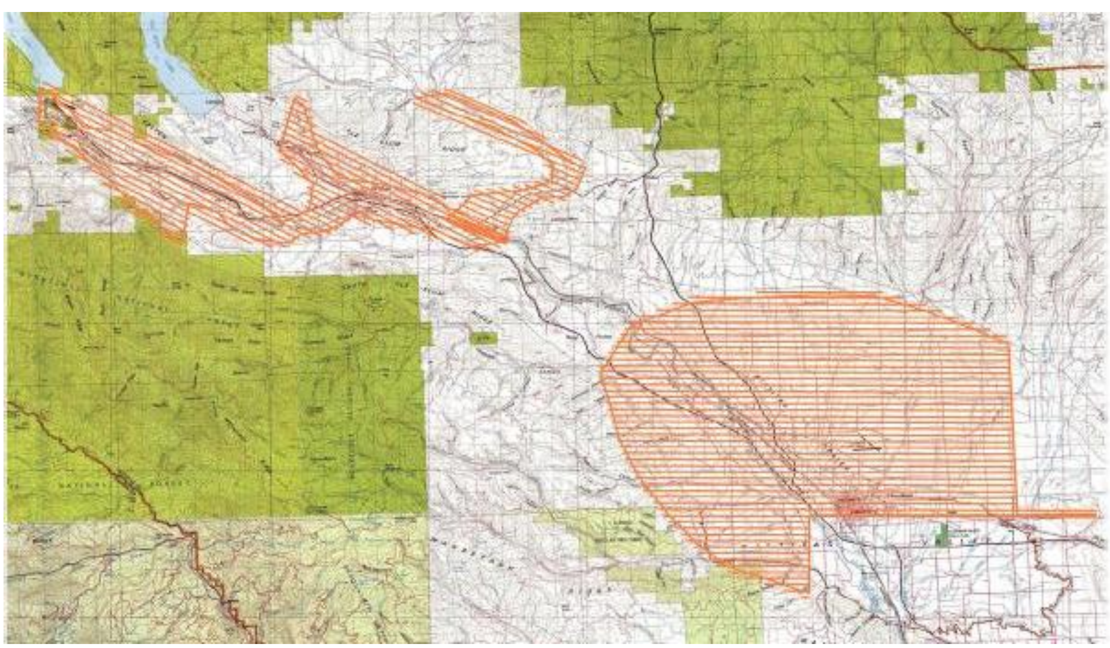
2.3 Time Period:

LiDAR data acquisition was completed between April 17, 2011 and April 19, 2011. A total of 4 flight missions were required to cover the project area. Table 2.3 provides the acquisition parameters. Figure 2.2 depicts the flightlines over the project area. Shapefiles of the flightline swath can be found in the Coverage.zip file attached to this report.

Table 2.3 LiDAR Acquisition Flight Summary

Acquisition Date, Mission, and Time	20110417 107B 12:15-17:00 PDT 20110418 108A 09:15-12:15 PDT 20110419 109A/109B 07:55-17:00 PDT
Area of Acquisition	185 square miles
Aircraft	PA 31 Navajo N59984
Planned Altitude	1,500 meters AGL
Planned Airspeed	160 knots
Planned Number of Flight Lines	Block 1 - 49 lines; Block 2 - 20 lines; Block 3 – 30 Lines
Flight Line Spacing	430 meters
Flight Line Coverage	860 meters
Sidelap	50%
System PRF	70 kHz
Mirror Scan Half Angle	16 degrees
Mirror Scan Rate	42 Hz
Nominal Point Density	0.7 points per square meter per pass
Datum	NAD83(NSRS2007) Epoch of 2007.0
	NAVD88 via Geoid09
Projection and Units	U.S. State Plane WA North Zone, U.S. Survey Foot

Figure 2.2 Flight Line Map



2.4 PDOP

The maximum planned PDOP for the LiDAR collection was set at ≤ 3.0. The PDOP plots are provided in Figures 2.3-2.6

PDOP Plots

Figure 2.3

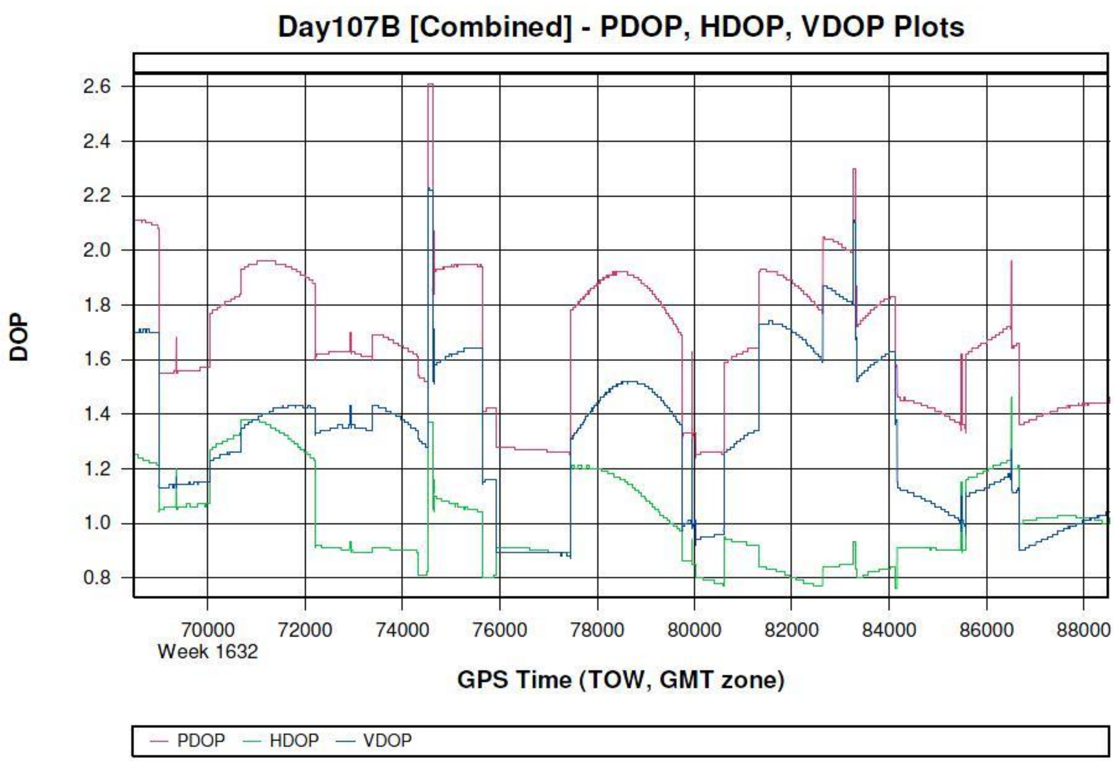


Figure 2.4

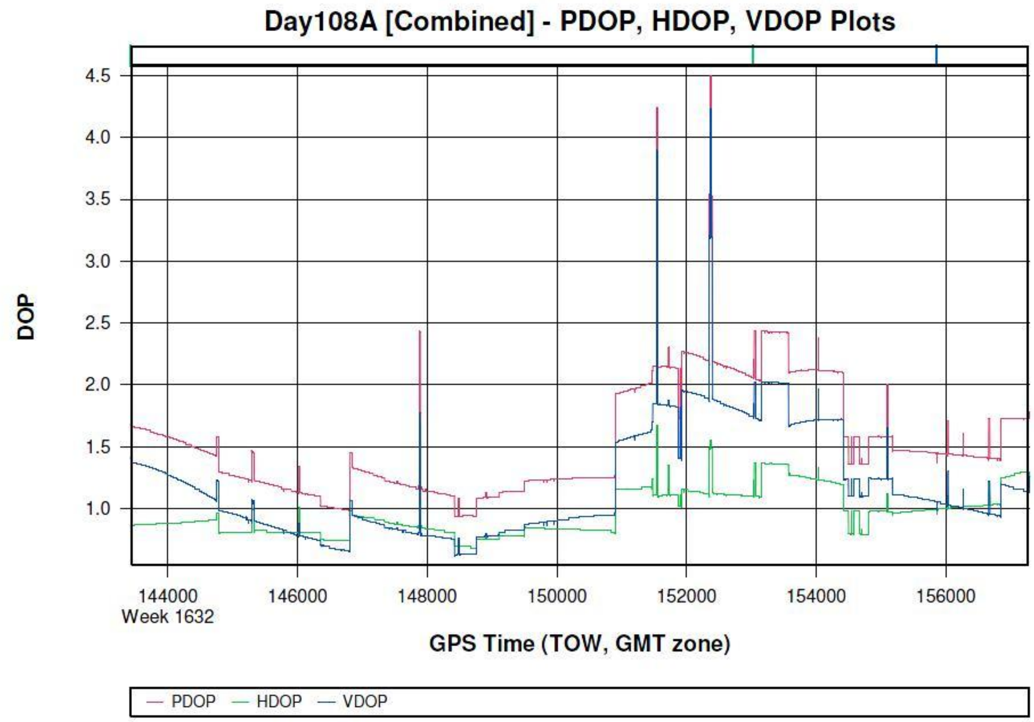


Figure 2.5

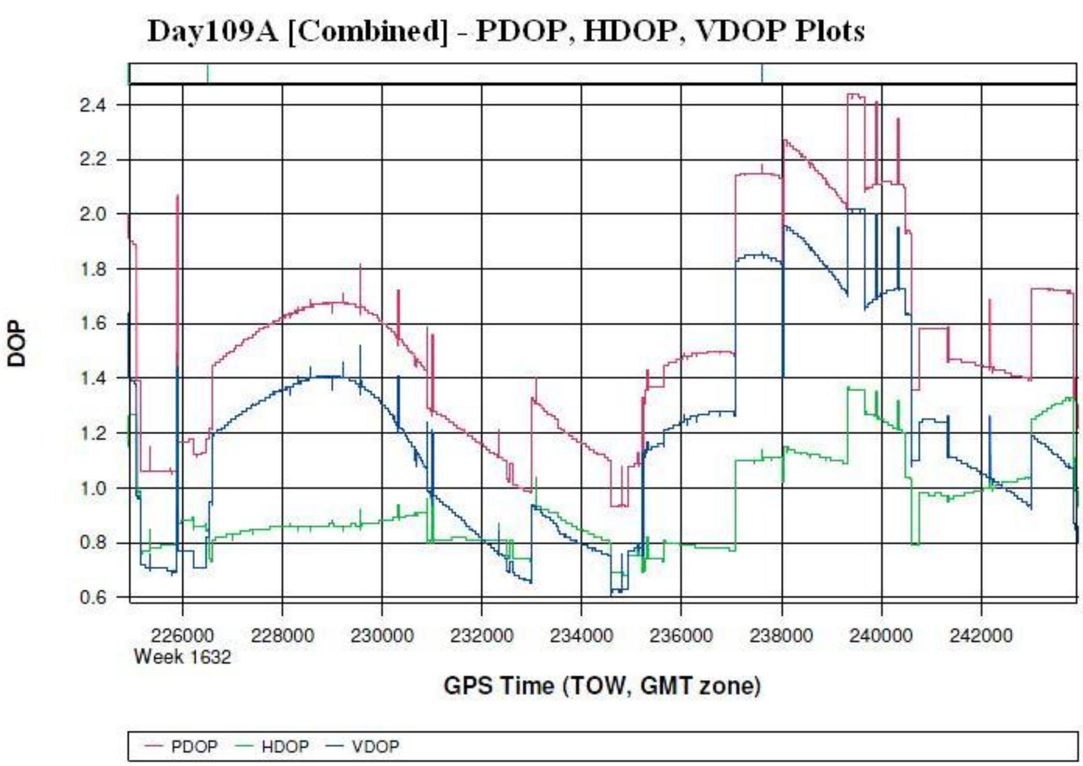
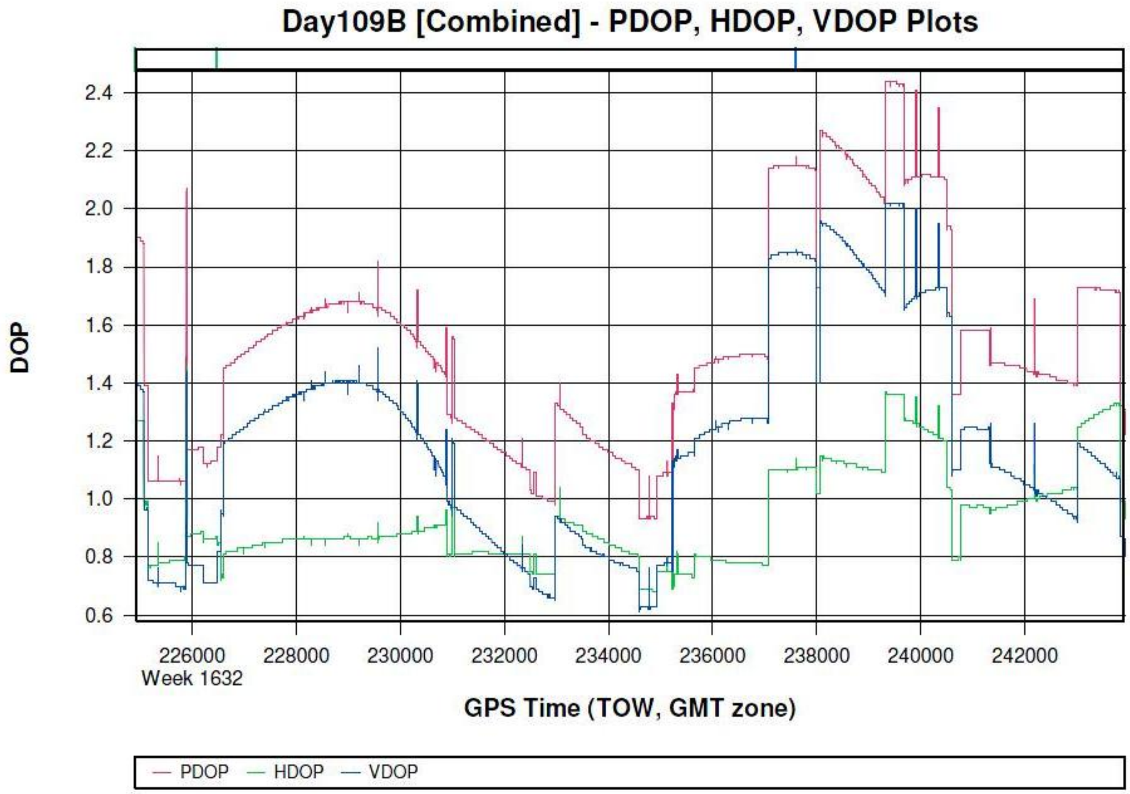


Figure 2.6



3.0Processing Summary

3.1 Airborne GPS

Applanix - POSGPS

Utilizing carrier phase ambiguity resolution on the fly (i.e., without initialization), the solution to sub-decimeter kinematic positioning without the operational constraint of static initialization as used in semi-kinematic or stop-and-go positioning was utilized for the airborne GPS post-processing.

The processing technique used by Applanix, Inc. for achieving the desired accuracy is Kinematic Ambiguity Resolution (KAR). KAR searches for ambiguities and uses a special method to evaluate the relative quality of each intersection (RMS). The quality indicator is used to evaluate the accuracy of the solution for each processing computation. In addition to the quality indicator, the software will compute separation plots (Figures 3.1-3.4)between any two solutions, which will ultimately determine the acceptance of the airborne GPS post processing.

GPS Separation Plots

Figure 3.1

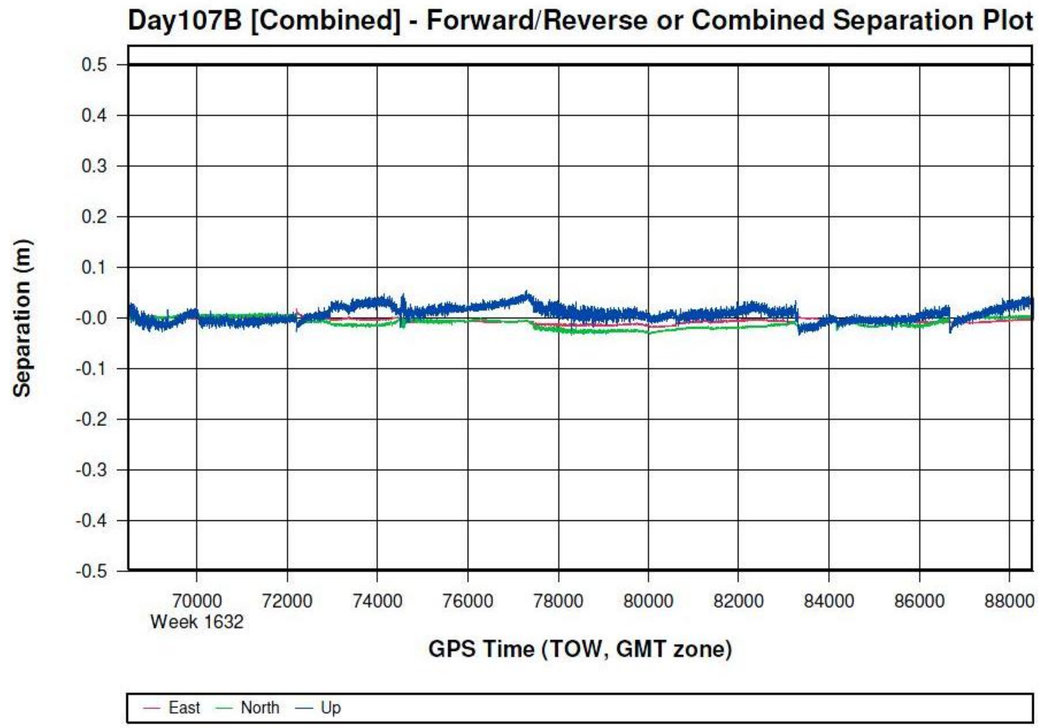


Figure 3.2

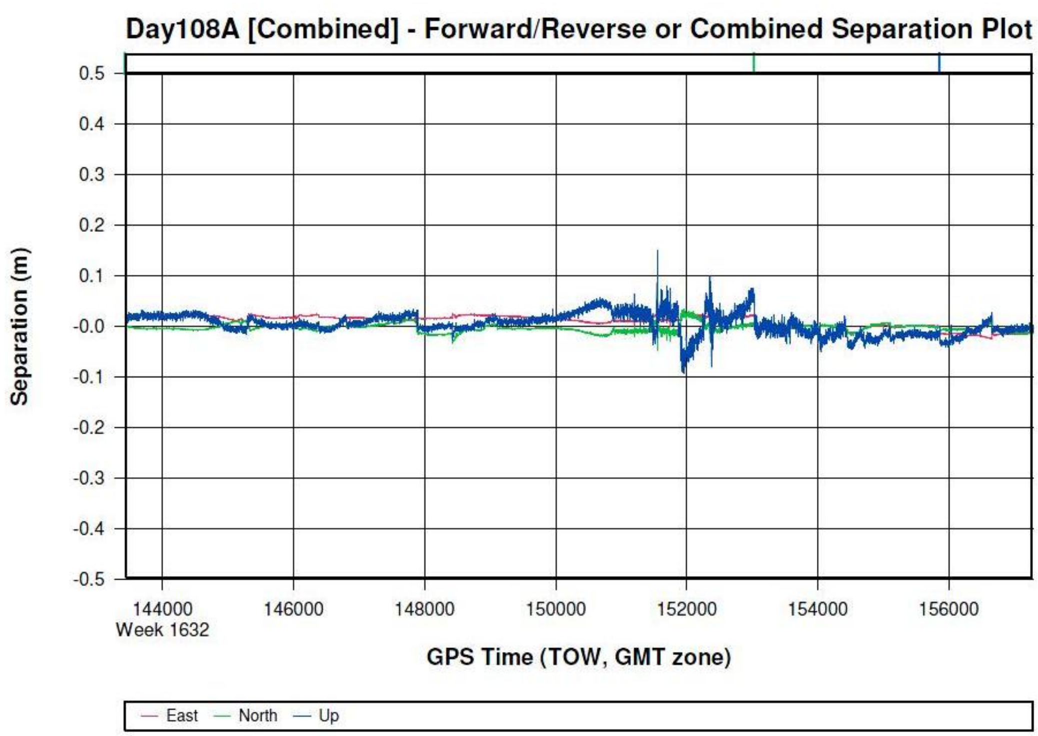


Figure 3.3

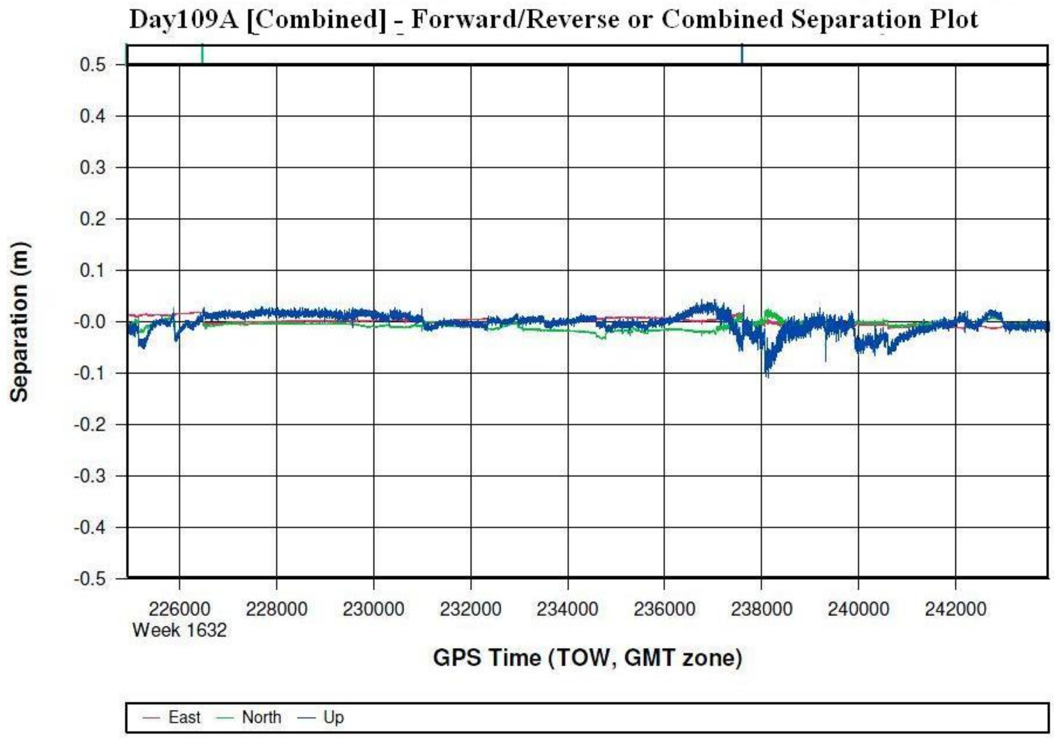
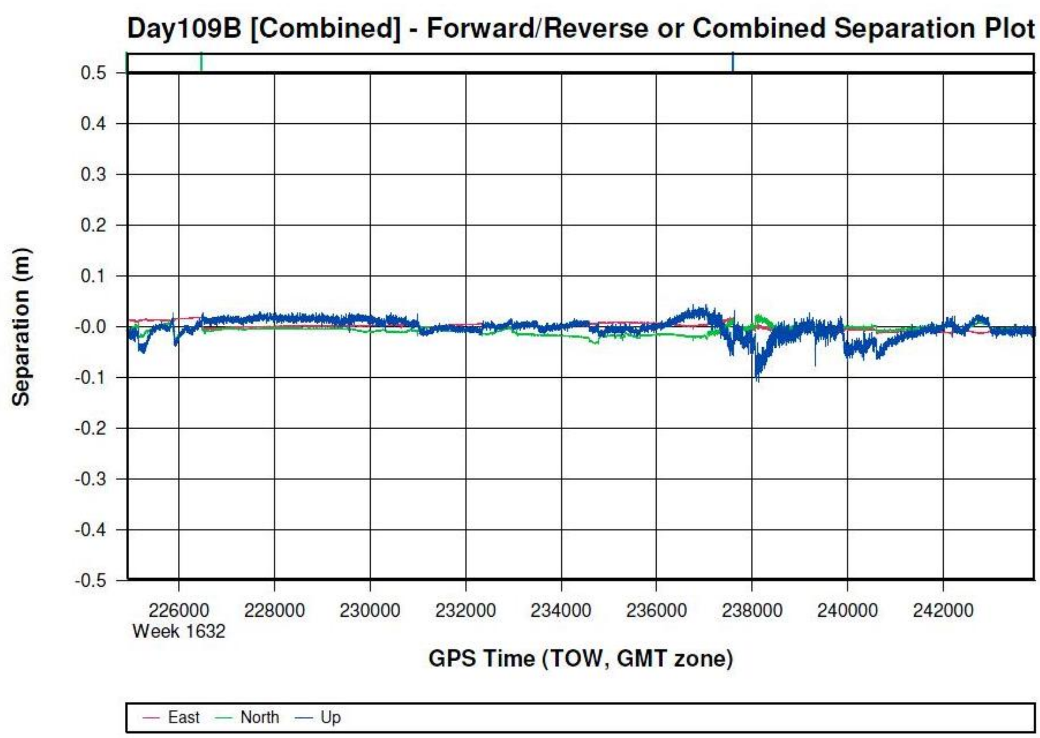


Figure 3.4



Inertial Data

The post-processing of inertial and aiding sensor data (i.e. airborne GPS post processed data) is to compute an optimally blended navigation solution. The Kalman filter-based aided inertial navigation algorithm generates an accurate (in the sense of least-square error) navigation solution that will retain the best characteristics of the processed input data. An example of inertial/GPS sensor blending is the following: inertial data is smooth in the short term. However, a free-inertial navigation solution has errors that grow without bound with time. A GPS navigation solution exhibits short-term noise but has errors that are bounded. This optimally blended navigation solution will retain the best features of both, i.e. the blended navigation solution has errors that are smooth and bounded. The GPS Altitude Plots are presented in Figures 3.5 – 3.8.

GPS Altitude Plots

Figure 3.5 107B GPS Altitude Plot

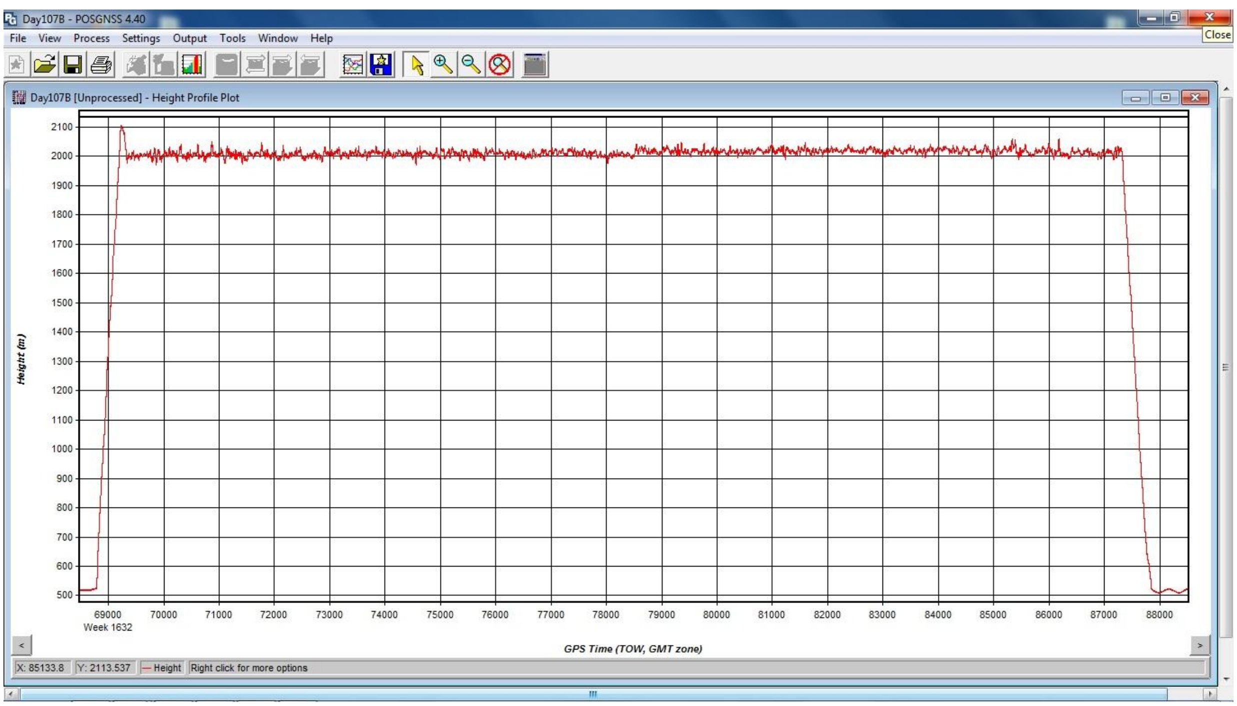


Figure 3.6 108A GPS Altitude Plot

Figure 3.7 109A GPS Altitude Plot

Figure 3.8 109B GPS Altitude Plot

The resultant processing generates the following data:

- Position: Latitude, Longitude, Altitude
- Velocity: North, East, and Down components
- 3-axis attitude: roll, pitch, true heading
- Acceleration: x, y, z components
- Angular rates: x, y, z components

The airborne GPS and blending of inertial and GPS post-processing were completed in multiple steps.

1. The collected data was transferred from the field data collectors to the main computer. Data was saved under the project number and separated between LiDAR mission dates. Inside each mission date, a sub-directory was created with the aircraft's tail number and an A or B suffix was attached to record which mission of the day the data is associated with. Inside the tail number sub-directory, five sub-directories were also created: EO, GPS, IMU, PROC, and RAW.

2. The aircraft raw data (IMU and GPS data combined) was run through a data extractor program. This separated the IMU and GPS data. In addition to the extraction of data, it provided the analyst the first statistics on the overall flight. The program was POSPac (POS post-processing PACkage).

3. Executing POSGPS program to derive accurate GPS positions for all flights:

   Applanix POSGPS

   The software utilized for the data collected was PosGPS, a kinematic on-the-fly (OTF) processing software package. Post processing of the data is computed from each base station (Note: only base stations within the flying area were used) in both a forward and backward direction. This provides the analyst the ability to Quality Check (QC) the post processing, since different ambiguities are determined from different base stations and also with the same data from different directions.

The trajectory separation program is designed to display the time of week that the airborne or roving antenna traveled, and compute the differences found between processing runs. Processed data can be compared between a forward/reverse solution from one base station, a reverse solution from one base station and a forward solution from the second base station, etc. For the Applanix POSGPS processing, this is considered the final QC check for the given mission. If wrong ambiguities were found with one or both runs, the analyst would see disagreements from the trajectory plot, and re-processing would continue until an agreement was determined.

Once the analyst accepts a forward and reverse processing solution, the trajectory plot is analyzed and the combined solution is stored in a file format acceptable for the IMU post processor.

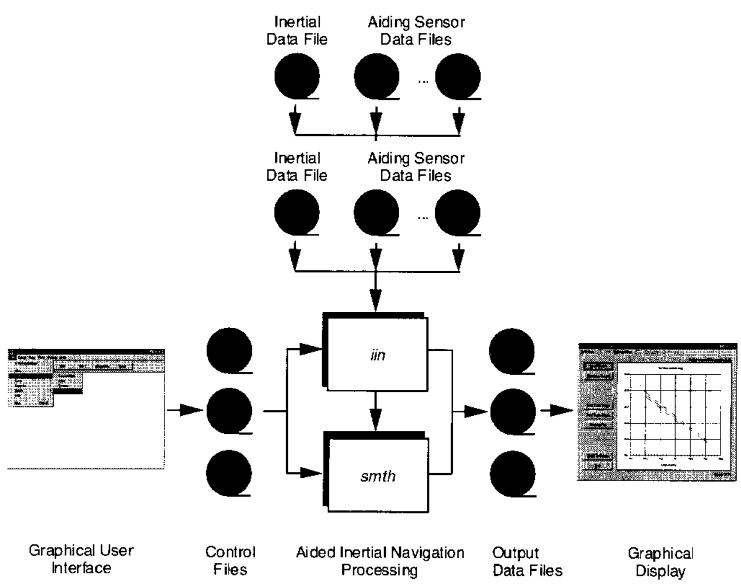
4. When the processed trajectory (either through POSGPS) data was accepted after quality control analysis, the combined solution is stored in a file format acceptable for the IMU post processor (i.e. POSProc). Shapefiles of the trajectories are found in the Coverage.zip attachment to this document.

5. Execute POSProc.

   POSProc comprises a set of individual processing interface tools that execute and provide the following functions:

Figure 3.9 shows the organization of these tools, and the function of the POSProc processing components.

Figure 3.9 POSProc Processing Components



Integrated Inertial Navigation (*iin*) Module.

The name *iin* is a contraction of Integrated Inertial Navigation. *iin* reads inertial data and aiding data from data files specified in a processing environment file and computes the aided inertial navigation solution. The inertial data comes from a strapdown IMU. *iin* outputs the navigation data between start and end times at a data rate as specified in the environment file. *iin* also outputs Kalman filter data for analysis of estimation error statistics and smoother data that the smoothing program *smth* uses to improve the navigation solution accuracy.

iin implements a full strapdown inertial navigator that solves Newton's equation of motion on the earth using inertial data from a strapdown IMU. The inertial navigator implements coning and sculling compensation to handle potential problems caused by vibration of the IMU.

Smoother Module (*smth*)

smth is a companion processing module to *iin*. *smth* is comprised of two individual functions that run in sequence. *smth* first runs the *smoother function* and then runs the *navigation correction function*.

The *smth* smoother function performs backwards-in-time processing of the forwards-in-time blended navigation solution and Kalman filter data generated by *iin* to compute smoothed error estimates. *smth* implements a modified Bryson-Frazier smoothing algorithm specifically designed for use with the *iin* Kalman filter. The resulting smoothed strapdown navigator error estimates at a given time point are the optimal estimates based on all input data before and after the given time point. In this sense, *smth* makes use of all available information in the input data. *smth* writes the smoothed error estimates and their RMS estimation errors to output data files.

The *smth* navigation correction function implements a feedforward error correction mechanism similar to that in the *iin* strapdown navigation solution using the smoothed strapdown navigation errors. s*mth* reads in the smoothed error estimates and with these, corrects the strapdown navigation data. The resulting navigation solution is called a Best Estimate of Trajectory (BET), and is the best obtainable estimate of vehicle trajectory with the available inertial and aiding sensor data.

The above mentioned modules provide the analyst the following statistics to ensure that the most optimal solution was achieved: a log of the *iin* processing, the Kalman filter Measurement Residuals, Smoothed RMS Estimation Errors, and Smoothed Sensor Errors and RMS.

3.2 LIDAR Calibration

The purpose of the LiDAR system calibration is to refine the system parameters in order for the post-processing software to produce a "point cloud" that best fits the actual ground.

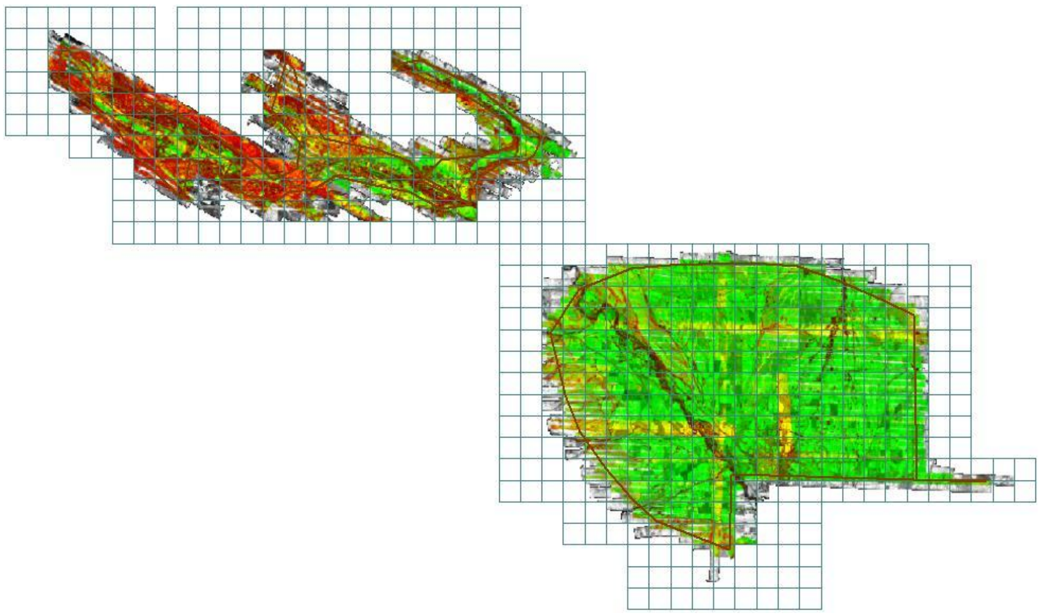
For each mission, LiDAR data for at least one cross flight is acquired over the mission's acquisition site. The processed data of the cross flight is compared to the perpendicular flight lines using either the Optech proprietary software or TerraSolid's TerraMatch software to determine if any systematic errors are present. In this calibration, the data of individual flight lines are compared against each other and their systematic errors are corrected in the final processed data.

3.3 LIDAR Processing

The LAS files were then imported, verified, and parsed into manageable, tiled grids using GeoCue.

The first step after the data has been processed and calibrated is to perform a relative accuracy assessment on the flightline to flightline comparisons and also a data density test prior any further processing. To determine a proper accuracy assessment between flightlines, Aerometric uses GeoCue to create Orthos by elevation differences. The generated orthos have assigned elevation ranges that allow the technician to evaluate if the data passes the accuracy assessment and also determine if additional calibration efforts are needed based on the bias trends. Figure 3.10 is the screen capture of the elevation orthos where green indicates a flightline comparison of less than 0.2 feet; yellow is 0.2-0.4 feet; orange is 0.4-0.6 feet, and red is greater than 0.6 feet.

Figure 3.10 DZ Raster Image



3.4Flight Log Overview:

-Post Spacing – 1 meter
-AGL (Above Ground Level) average flying height – 1500 meters
-MSL (Mean Sea Level) average flying height – 2100 meters
-Average Ground Speed – 160 knots
-Field of View – 30°
-Pulse Rate – 70 kHz
-Scan Rate – 41 Hz
-Side Lap (Average) – 50%

Flight logs are located in Appendix A of this document.

4.0 Data Verification

The data was verified using the ground control data collected by Compass Data, Inc. 21 points were distributed throughout the project area and the points were compared to the LIDAR data using TerraScan. TerraScan computes the vertical differences between the surveyed elevation and the LiDAR derived elevation for each point. Table 4.1 provides this vertical accuracy test. RMSE = 0.1feet.

The Fundamental Vertical Accuracy (FVA) was tested by Compass Data, Inc. This test consisted of 20 vertical checkpoints reported at the 95% confidence level RMSE. FVA= 0.117 meters

The Supplemental Vertical Accuracy (SVA) was tested by Compass Data, Inc. This test consisted of 20 vertical checkpoints reported at the 95th Percentile RMSE. CVA= 0.152 meters

Table 4.1 Vertical Accuracy Test Results

Point	Surveyed Elev. (U.S. Survey Foot)	Lidar Elev. (U.S. Survey Foot)	Difference (U.S. Survey Foot)
CP50	1734.91	1734.85	-0.06
CP51	1923.59	1923.64	0.05
CP52	1823.89	1823.87	-0.02
CP53	1678.68	1678.85	0.17
CP54	2078.41	2078.55	0.15
CP55	1714.18	1714.17	-0.01
CP56	2310.98	2311.15	0.17
CP57	1995.45	1995.23	-0.22
CP58	1685.77	1685.75	-0.02
CP59	1540.66	1540.69	0.03
CP70	2303.73	2303.72	-0.01
CP71	2205.49	2205.35	-0.14
CP72	2092.45	2092.39	-0.06
CP73	2038.72	2038.79	0.07
CP74	1841.34	1841.16	-0.18
CP75	1910.75	1910.73	-0.02
CP76	2193.97	2193.99	0.02
CP77	2048.34	2048.29	-0.05
Cleelum	1916.10	1916.18	0.08
SX0873	2076.54	2076.52	-0.02
SX1547	1750.17	1750.25	0.08

Average dz	0.00
Standard deviation	0.10
Root mean square (RMS)	0.10

Original Flight Logs

Flight Log 107B Page 1

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-17-11
Mission: 107B

Survey Information		Base Station Data	
Project Name:	ELN 13652-101	Station Name:	SX1547
Flight Vendor / Tail No:	Marc Inc. N59984	Receiver Type & SN:	R7 # 8257
METs: temp, press, humid)	9.7° 950 mb 37.5%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.357
Planned Parameters: (scan angle, freq., height)	16 42 1500	Antenna Height – feet:	4451 → 13566 (Checks?)

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
Test	1908	1908				
Test	1915	1915				
c1	1916	1917	1500	356		Cal @ KELN
c2	1920	1926	1500	176		
49	1923	1923	1500	272		aborted
49	1927	1928	1500	272		
48	1931	—	1500	92		Error
48	1935	1936	1500	272		
47	1939		1500	92		Error Eye-Safety Alarm
47	1944	1946	1500	272		

Page 1 of 3

Flight Log 107B Page 2

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-17-11
Mission: 107B

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
46	1947	1950	1500	92		
45	1954	1956	1500	272		
44	1959	2001	1500	92		
43	2005	2007	1500	272		
42	2011	2013	1500	92		
41	2016	2019	1500	272		
40	2023	2025	1500	92		
39	2029	2032	1500	272		
37	2035	2041	1500	92		
36	2045	2052	1500	272		
38	2055	2058	1500	92		
35	2104	2109	1500	272		
34	2113	2118	1500	92		
33	2123	2129	1500	272		
32	2133	2138	1500	92		
31	2143	2149	1500	272		

Flight Log 107B Page 3

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-17-11
Mission: 107B

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
30	2153	2158	1500	92		
29	2203	2209	1500	272		
28	2213	2218	1500	92		
27	2223	2229	1500	272		
26	2233	2239	1500	92		
25	2244	2250	1500	272		
24	2254	2300	1500	92		
23	2305	2312	1500	272		
22	2315	2321	1500	92		
21	2325	2332	1500	272		
20	2335	2341	1500	92		
19	2346	2353	1500	272		
18	2358	0003	1500	92		
c3	0007	0008	1500	176		
c4	0013	0014	1500	356		

Flight Log 108A Page 1

LIDAR FLIGHT LOG

TOWILL | Surveying, Mapping and GIS Services

Date:	4-18-11
Mission:	108A

Survey Information		Base Station Data	
Project Name:	ELN 13652_101	Station Name:	SX 1547
Flight Vendor / Tail No:	Marc. Inc N59984	Receiver Type & SN:	R7 #8257
METs: temp, press, humid)	12.5° 950.1 mb 46.2%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.398
Planned Parameters: (scan angle, freq., height)	16 42 1500	Antenna Height – feet:	4.585 → 13975 Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
test	1559	1559				
c1	1603	1604	1500	176		Col @ KELN
c2	1609	1610	1500	356		" Ellensburg
S0	1616	1619	1400	296		
S1	1622	1625	1400	116		trace amounts of snow
S2	1628	1631	1400	296		
S3	1635	1638	1400	116		
S4	1642	1646	1400	296		cloud - east
S5	1644	1650	1400	116		
S4	1655	1656	1400	296		Reflight ☆

Flight Log 108A Page 2

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-18-11
Mission: 108A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
56	1700	1701	1400	116		clouds ☆ Refly
17	1705	1711	1500	92		possible cloud - Big box
16	1715	1721	1500	272		
15	1725	1731	1500	92		
14	1735	1742	1500	272		
13	1746	1752	1500	92		
12	1756	1802	1500	272		
56	1805	1806	1400	296		Reflight
57	1807	1810	1400	116		
58	1815	1816	1400	296		
59	1820	1821	1400	116		
60	1826	1827	1400	296		
61	1831	1832	1400	116		
62	1837	1839	1400	296		possible cloud
63	1842	1844	1400	116		"
64	1849	1850	1400	296		"

Flight Log 108A Page3

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date:	4-18-11
Mission:	108A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
65	1854	1855	1500	116		cloud possible
66	1900	1902	1500	296		
67	1906	1907	1500	116		
68	1911	1913	1500	296		
69	1917	1918	1500	116		
11						abort
c3	1924	1925	1500	176		
c4	1929	1930	1500	356		

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109A

Survey Information		Base Station Data	
Project Name:	ELN 13657-101	Station Name:	SX1547
Flight Vendor / Tail No:	Mare Inc N59984	Receiver Type & SN:	R7 #8257
METs: temp, press, humid)	11.5° 956.6 mb 55%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.334
Planned Parameters: (scan angle, freq., height)	16 42 1500	Antenna Height – feet:	4.378 → 1.3344 Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
test	1437	1437				
c1	1441	1442	1500	176		Cal @ KELN
c2	1446	1447	1500	356		" Ellensburg
86	1455	1459	1100	300		Snow - abort - clouds
85	1502	1503	1400	120		
84	1507	1508	1400	300		
83	1512	1514	1400	120		
82	1518	1520	1450	300		
81	1523	1526	1400	170		
80	1530	1533	1400	300		possible cloud

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
74	1538	1542	1200	120		66 reflight
75	1546	1550	1500	300		
76	1554	1558	1400	120		possible clouds
77	1603	1607	1400	300		
78	1611	1614	1400	120		
79	1619	1623	1400	300		cloud at West ☆
70	1625	1625	1400	120		aborted Snow
61	1628	1629	1500	116		Reflight
57	1632	1635	1500	296		Reflight + 53
64	1637	1638	1500	116		Reflight
90	1642	1643	1500	300		Aborted
12	1649	1655	1500	92		Reflight
1	1658	1701	1500	277		
2	1706	1709	1500	92		
3	1714	1718	1500	272		
4	1722	1726	1500	92		

Flight Log 109A Page 3

TOWILL Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109A

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
5	1730	1735	1500	272		
6	1739	1744	1500	92		
7	1749	1754	1500	272		
87	1757	1802	1200	300		1200 meter plan abort
8	1809	1815	1500	92		
9	1819	1825	1500	272		
10	1829	1835	1500	92		
13	1840	1841	1500	272		Reflight
11	1846	1853	1500	272		
20	1856	1857	1500	92		Reflight
21	1904	1905	1500	92		Reflight
24	1910	1913	1500	92		
Cross	1918	1923	1500	2		Crossline
c3	1926	1927	1500	176		
c4	1931		1500	356		

Flight Log 109B Page 1

LIDAR FLIGHT LOG

TOWILL | Surveying, Mapping and GIS Services

Date: 4-19-11
Mission: 109B

Survey Information		Base Station Data	
Project Name:	ELN 13652_101	Station Name:	JX 1547
Flight Vendor / Tail No:	Move Inc N59984	Receiver Type & SN:	R7 # 8257
METs: temp, press, humid)	14° 956 mb 23.2%	Antenna & Measurement Type:	Zephyr Geodetic
Airport Start/End:	KELN	Antenna Height – meters:	1.334
Planned Parameters: (scan angle, freq., height)	19.50 42 1200	Antenna Height – feet:	4.378 → 13344 Checks?

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
test	2110					
87	2117	2125	1200	300		1200m plan
88	2128	2133	1200	170		
89	2134	2141	1200	300		
90	2146	2150	1200	120		
91	2155	2200	1200	300		
92	2204	2208	1200	120		Snow in Air - west
93	2212	2218	1200	300		
94	2220	2224	1266	120		
95	2229	2233	1200	300		

Flight Log 109B Page 2

TOWILL | Surveying, Mapping and GIS Services

LIDAR FLIGHT LOG

Date: 4-19-11
Mission: 109B

Line Number	Start Time (UTC)	End Time (UTC)	Average Range	Approximate Heading	Range Strip Number	Comments
96	2236	2238	1200	120		
97	2242	2244	1200	300		
98	2246	2248	1200	120		
99	2251	2252	1200	300		
100	2256	2257	1200	120		
92	2259	2302	1700	300		Reflight - Bad line
70	2306	2307	1400	120		1500m plan
71	2311	2312	1500	300		
72	2315	2316	1700	120		
73	2319	2321	1700	300		
92	2326	2330	1700	120		Reflight
80	2333	2337	1500	300		Reflight
79	2340	2343	1500	120		Reflight
77	2347	2352	1500	300		Reflight
76	2355	2359	1500	120		Reflight
C3	0005	0005	1500	176		Cal
C4	0008	0009	1500	356		

Appendix F: Quality Assurance

Project Information	
Project Name:	**Kittitas County Washington**
Project Description:	Region10 LiDAR Acquisition
State:	WA
HUC-8:	17030001
Provider Name:	Aerometric, Inc.
Collection Area:	181 Square Miles (Includes all overlapping tiles and all no data voids at edges.)
Specification Level:	HIGHEST
Contour Accuracy:	2 ft
Point Cloud	
NPS	0.65 m
Date Delivered:	8/15/2011
Date QC:	8/18/2011
Media:	Hard Drive
Contents of Media:	308 version 1.2 las files
Tiles Reviewed	20
QC tiles with NPS > Spec Level	Pass-only at edges where including no data voids
Voids or Gaps	Pass-Voids only over open water
Reviewed By:	Dan Hoff
Bare Earth	
NPS	0.65 m
Date Delivered:	8/15/2011
Date QC:	8/18/2011
Media:	Hard Drive
Contents of Media:	308 version 1.2 las files
Tiles Reviewed	31
QC tiles with NPS > Spec Level	Pass-only at edges where including no data voids
Voids or Gaps	Pass-Voids only over open water
Artifact QA	Pass
Reviewed By:	Dan Hoff

Pre-Flight Report		
	Included	Comments
Planned flight lines (sufficient coverage, spacing, length)	Pass	
Planned GPS stations	Pass	
Planned Control (sufficient to control and boresight)	Pass	
Planned airport locations	Pass	
Calibration plans	Pass	
Quality procedures for flight crew	Pass	
Planned scanset (proper scan angle, sidelap, design pulse)	Pass	
Type of aircraft	Pass	
Aircraft utilizes ABGPS	Pass	
Re-flight procedure (tracking, documenting, processing)	Pass	
project design supports accuracy requirements of project	Pass	
Project design accounts for land cover and terrain types	Pass	

Non-Classified Point Cloud		
Macro Review		
	Pass/Fail	Comments
LAS Point Cloud Files		
Projection	Pass	NAD_1983_UTM_Zone_10N
Datum	Pass	
Units	Pass	X,Y, and Z in Meters
Area covered 100m buffer	Pass	
Data Voids	Pass	
Correct Header	Pass	
Correct NPS	Pass	
Returns Contain		
GPS time stamp	Pass	
GPS second in microsec	Pass	
Easting	Pass	
Northing	Pass	
Elevation	Pass	
Intensity	Pass	
Return #	Pass	
Classification	Pass	
Classification is correct	Pass	
Cloud file structure conforms to layout	Pass	
Cloud file naming conforms to project	Pass	
Tiles checked for gaps and voids	Pass	
Micro Review		
Total Number of Tiles:	308	
Number of tiles to be reviewed:	**20**	
Excessive Noise	Pass	
Elevation Steps	Pass	
LP360 Scan and profile	Pass	

Post Flight Report		
	Included	Comments
GPS Base Station INFO		
GPS base station - names	Pass	
GPS base station - lat/longs	Pass	
GPS base station - heights	Pass	
GPS base station - Maximum PDOP	Pass	
GPS base station - map	Pass	
GPS base station - spatial data	N/A	
GPS/IMU		
GPS quality - Max horizontal variance (cm).	Pass	
GPS quality - Max vertical variance (cm).	Pass	
GPS quality - Notes on GPS quality	Pass	
GPS quality - GPS separation plot	Pass	
GPS quality - GPS altitude plot	Pass	
GPS quality - PDOP plot	Pass	
GPS quality - Plot of GPS distance from base stations	Pass	
Coverage		
Coverage - Verification of AOI coverage	Pass	
Coverage - Spatial data	Pass	
Flights		
Flights - Calibration lines	Pass	
Flights - As-flown trajectories	Pass	
Flights - Spatial data	Pass	
Control		
Control - Ground control and base station layout	Pass	
Control - Spatial data	N/A	
Data verification/QC		
Data verification process documented	Pass	
Flight logs		
Incorporated as appendix		
Job # / name	Pass	
Lift #	Pass	
Block or AOI designator	Pass	
Date	Pass	
Aircraft tail number, type	Pass	
Pilot name	Pass	
Operator name	Pass	
Airport of operations	Pass	
GPS base station names	Pass	
Flight lines		
Flight line	Pass	
Line #	Pass	
Direction	Pass	
Start/stop	Pass	

Altitude	Pass	
Scan angle/rate	Pass	
Speed	Pass	
Conditions	Pass	
Comments	Pass	
Settings		
AGC switch setting	N/A	
Laser pulse rate	Pass	
Mirror rate	N/A	
Field of view	Pass	
Comments	Pass	

Classified Point Cloud		
Macro Review		
	Pass/Fail	**Comments**
LAS Bare Earth		
Projection	Pass	NAD_1983_UTM_Zone_10N
Datum	Pass	
Units	Pass	X,Y, and Z in Meters
Area covered 100m buffer	Pass	
Data Voids	Pass	
Correct Header	Pass	
Correct NPS	Pass	
Returns Contain		
GPS time stamp	Pass	
GPS second in microsec	Pass	
Easting	Pass	
Northing	Pass	
Elevation	Pass	
Intensity	Pass	
Return #	Pass	
Classification	Pass	
Classification is correct	Pass	
Cloud file structure conforms to layout	Pass	
Cloud file naming conforms to project	Pass	
Tiles checked for gaps and voids	Pass	
Micro Review		
Total Number of Tiles:	308	
Number of tiles to be reviewed:	**31**	
Excessive Noise	Pass	
Elevation Steps	Pass	
2% Artifacts	Pass	
LP360 Scan and profile	Pass	

Appendix G: Deliverables

MIP Locations for Kittitas County Wahington, FEMA case number 11-10-0110S, LiDAR* data acquisition and post processing supporting data:

All supporting data
J:\FEMA\R10\WASHINGTON_53\KITTITAS_53037\KITTITAS_037C\11-10-0110S\SubmissionUpload\Terrain\2143612

*All LAS data is available upon request from the FEMA Engineering Library. Due to the size of the dataset it has not been uploaded to the MIP.

Please Contact:

Marie Sparrow, Zimmerman Associates, Inc.
Federal Emergency Management Agency Engineering Library
847 South Pickett Street
Alexandria, Virginia 22304
1-877-336-2627
miphelp@mapmodteam.com

8<----------------8<----------------8<----------------8<----------------8<----------

MIP Locations for Kittitas County Wahington, FEMA case number 11-10-0110S, LiDAR derived topographic products:

Contours
J:\FEMA\R10\WASHINGTON_53\KITTITAS_53037\KITTITAS_037C\11-10-0110S\SubmissionUpload\Terrain\2141404\Contours\

DEMs
J:\FEMA\R10\WASHINGTON_53\KITTITAS_53037\KITTITAS_037C\11-10-0110S\SubmissionUpload\Terrain\2141404\DEM

Mass Points, Tile Index, LiDAR coverage, and ESRI terrain
J:\FEMA\R10\WASHINGTON_53\KITTITAS_53037\KITTITAS_037C\11-10-0110S\SubmissionUpload\Terrain\2141404\TIN

STARR

Date: September 12, 2011

Contract # HSFEHQ-090D-0370

Task Order # HSFEHQ -10-J-0005

Subject:

STARR Elevation Data (LiDAR)

Transmittal:

To: **Kelly Stone**
FEMA Region X
Federal Regional Center
20700 44th Avenue W
Suite 400
Lynwood, WA 98036

From: **James Huffines**
Greenhorne & O'Mara, Inc
5565 Centerview Drive
Ste 107
Raleigh, NC 27606

Transmitted:

- ☒ For Your Use
- ☐ For Your Approval/Signature
- ☐ For Your Information
- ☐ For Your Review
- ☐ As Requested
- ☒ For Storage

The following:

COPIES	DATE	DESCRIPTION
1	9/12/11	Hard Drive Containing: Kittitas County Washington LiDAR data and terrain products Please see readme.txt included on hard drive for directory structure information.
		Includes: Ground Control data, QC Checkpoint (FVA/CVA) data, PreFlight Report, PostFlight Report, Tile Index shapefile, Collection Area shapefile, Point Cloud (All Returns) LAS files, QC Testing Results, QA Review spreadsheet, Compliance Certificates for Survey, Point Cloud (Bare Earth LAS files and LiDAR, Metadata for Survey and Point Cloud Data, ESRI file geodatabase (contains LAS multipoint, LiDAR extent, LAS Information grid, and ESRI terrain), 5ft floating point DEMs in ESRI grid format, ESRI file geodatabase that contains 2ft contours, and FEMA FGDC compliant terrain metadata record and TSDN.

Remarks:

If you have any questions or require additional information please feel free to contact me at 919-532-2332.
Please sign this transmittal upon receipt and mail to address shown above or fax to 919-851-8393.

Printed Name and Date: JAMES L. HUFFINES 9/12/2011

Signature: [signature]

From: trackingupdates@fedex.com
Sent: Monday, September 12, 2011 2:17 PM
To: HUFFINES, James
Subject: FedEx Shipment Notification

This tracking update has been requested by:
Company Name:
GREENHORNE & O'MARA
Name:
Kelly Aldrich
E-mail:
kaldrich@g-and-o.com

Kelly Aldrich of GREENHORNE & O'MARA sent Kelly Stone of FEMA Region X 1 FedEx Standard
Overnight package(s).
This shipment is scheduled to be sent on 09/12/2011.
Reference information includes:
Reference:
110558.009.QA12.EXP Huffines
Special handling/Services:
Deliver Weekday

Status:
Shipment information sent to FedEx

Tracking number:
795175947036

To track the latest status of your shipment, click on the tracking number above, or visit us at fedex.com.
To learn more about FedEx Express, please visit our website at fedex.com.
This tracking update has been sent to you by FedEx on the behalf of the Requestor noted above. FedEx does not validate the authenticity of the requestor and does not validate, guarantee or warrant the authenticity of the request, the requestor's message, or the accuracy of this tracking update. For tracking results and fedex.com's terms of use, go to fedex.com.
Thank you for your business.

Appendix H: Guidance Documents

U.S. Department of Homeland Security
500 C Street, SW
Washington, DC 20472

FEMA

DATE

MEMORANDUM FOR: Mitigation Division Directors Regions I-X, CTPs, Mapping Partners

FROM: Doug Bellomo, Director
Risk Analysis Division

SUBJECT: Procedure Memorandum No. XX—Standards for Lidar and Other High Quality Digital Topography

EFFECTIVE DATES: August 1, 2010

Background: Beginning in Fiscal Year (FY) 2010, Federal Emergency Management Agency (FEMA) initiated a five-year program for Risk Mapping, Assessment, and Planning (Risk MAP). FEMA's vision for the Risk MAP program is to deliver quality data that increases public awareness and leads to mitigation actions that reduce risk to life and property. To achieve this vision, FEMA will transform its traditional flood identification and mapping efforts into a more integrated process of accurately identifying, assessing, communicating, planning for, and mitigating flood risks.

Under Risk MAP, FEMA seeks to:

- Deliver new data and products that expand risk awareness and promote mitigation planning that leads to risk reduction actions.
- Increase production efficiencies for Flood Insurance Rate Maps (FIRMs) and Flood Insurance Studies (FISs).

Issue: To implement FEMA's Risk MAP vision and provide the high quality topographic data necessary to meet Risk MAP's goals, FEMA Regions and Mapping Partners need upgraded guidance concerning the accuracy, and processing of high quality topographic data including Light Detection and Ranging (lidar) data. To that end, this Procedure Memorandum will supersede Appendix A: Guidance for Aerial Mapping and Surveying of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (Guidelines) in key areas (defined in the Procedure Memorandum Attachments), and must be implemented beginning with all topographic data collected by FEMA beginning in FY 2010.

Actions Taken: When procuring topographic data under the Risk MAP Program the Mapping Partner assigned to obtain topographic data or perform independent QA of topographic data must meet the specifications detailed in this Procedure Memorandum's attachments. The attachments align FEMA's high quality topographic specifications, found in Appendix A of the Guidelines, with the United States Geological Survey (USGS) *Lidar Guidelines and Base Specifications* v13 so that data procured and used by the Federal government is consistent across agencies and is updated to industry standards. Further, adherence to these specifications will support the Risk MAP Program by closing gaps in existing flood hazard data; supporting risk assessments; and better communicating risks to community officials and the public.

Existing elevation data, not acquired by FEMA, but planned for use on a new flood hazard analysis must comply with the accuracy, density and the final product metadata requirements detailed in the attachments and, but is not required to comply with the other specifications included and referenced below.

Consistent with FEMA's overall approach to flood hazard identification, this Procedure Memorandum aligns FEMA topographic data specifications to level of risk, and accounts for different slopes in the terrain that can affect the accuracy of base flood elevations and the delineation of mapped floodplains. These specifications represent the minimum requirements. Where funding partners are involved or where the engineering requirements dictate, projects may use higher specification levels or include additional processing. Quality assurance requirements for high quality topographic data are also provided.

Attachments:
Attachment 1 – Definitions
Attachment 2 – Alignment of FEMA Appendix A to USGS *Lidar Guidelines and Base Specification* v13
Attachment 3 – Topographic Breakline and Hydro-Enforcement Specifications
Attachment 4 – Topographic Data Quality Review Process

Distribution List:

Attachment 1 – Definitions

Digital Elevation Data – Includes all of the following terms: mass points, point clouds, breaklines, contours, TINs, DEMs, DTMs or DSMs.

- **Breakline –** A linear feature demarking a change in the smoothness or continuity of a surface such as abrupt elevation changes or a stream line. The two most common forms of breaklines are as follows:
  - A **soft breakline** ensures that known elevations, or z-values, along a linear feature are maintained (e.g., elevations along a pipeline, road centerline or drainage ditch), and ensures the boundary of natural and man-made features on the Earth's surface are appropriately represented in the digital terrain data by use of linear features and polygon edges They are generally synonymous with 3-D breaklines because they are depicted with series of x/y/z coordinates.
  - A **hard breakline** defines interruptions in surface smoothness, e.g., to define streams, shorelines, dams, ridges, building footprints, and other locations with abrupt surface changes. Although some hard breaklines are three dimensional (3-D) breaklines, they are often depicted as two dimensional (2-D) breaklines because features such as shorelines and building footprints are normally depicted with a series of horizontal coordinates only which are often digitized from digital orthophotographs that include no elevation data.
- **Contours –** Lines of equal elevation on a surface. An imaginary line on the ground, all points of which are at the same elevation above or below a specified vertical datum.
- **Digital Elevation Model (DEM) –** An elevation model created for use in computer software where bare-earth elevation values have regularly spaced intervals in latitude and longitude (x and y). The Δx and Δy values are normally measured in feet or meters to even units; however, the National Elevation Dataset (NED) defines the spacing interval in terms of arc-seconds of latitude and longitude, e.g., 1/3rd arc-second.
- **Digital Surface Model (DSM) –** An elevation model created for use in computer software that is similar to DEMs or DTMs except that DSMs depict the elevations of the top surfaces of buildings, trees, towers, and other features elevated above the bare earth.
- **Digital Terrain Model (DTM) –** An elevation model created for use in computer software of bare-earth mass points and breaklines. DTMs are technically superior to a gridded DEM for many applications because distinctive terrain features are more clearly defined and precisely located, and contours generated from DTMs more closely approximate the real shape of the terrain.
- **Mass Points –** Irregularly spaced points, each with latitude and longitude location coordinates and elevation values typically used to form a TIN.
- **Metadata –** Project descriptive information about the elevation dataset.
- **Point Cloud –** Often referred to as the "raw point cloud", this is the first data product of a lidar instrument. In its crudest form, a lidar raw point cloud is a collection of range measurements and sensor orientation parameters. After initial processing, the range and orientation of each laser value is converted to a position in a three dimensional frame of reference and this spatially coherent cloud of points is the base for further processing and analysis. The raw point cloud typically includes first, last, and intermediate returns for each laser pulse. In addition to spatial information, lidar intensity returns provide texture or color information. The combination of three dimensional spatial information and spectral information contained

in the lidar dataset allows great flexibility for data manipulation and extraction. As used in this procedure memorandum, two additional lidar data processing terms are defined as follows:

- **Lidar Preliminary Processing –** The initial processing and analysis of laser data (GPS/IMU/laser ranges) to fully "calibrated point clouds" in some specified tile format. All lidar data will be set to ASPRS LAS Class 1 (unclassified) and must include testing for Fundamental Vertical Accuracy (FVA). The tile format can change later, if necessary.
- **Lidar Post-Processing –** The final processing and classification of lidar data to the required ASPRS LAS classes, per project specifications. This must include testing for Consolidated Vertical Accuracy (CVA). At this point, the datasets are referred to as the "classified point cloud."

- **Triangulated Irregular Network (TIN) –** A set of adjacent, non-overlapping triangles computed from irregularly-spaced points with lattitude, longitude, and elevation values. The TIN data structure is based on irregularly-spaced point, line, and polygon data interpreted as mass points and breaklines and stores the topological relationship between triangles and their adjacent neighbors. The TIN model may be preferable to a DEM when it is critical to preserve the precise location of narrow or small features, such as levees, ditch or stream centerlines, isolated peaks or pits in the data model.
- **Z-Values –** The elevations of the 3-D surface above the vertical datum at designated x/y locations.

Geospatial Accuracy Standard – A common accuracy testing and reporting methodology that facilitates sharing and interoperability of geospatial data. Published in 1998, the National Standard for Spatial Data Accuracy (NSSDA) is the Federal Geographic Data Committee (FGDC) standard relevant to digital elevation data when assuming that errors follow a normal error distribution. However, after it was learned that lidar datasets do not necessarily follow a normal distribution in vegetated terrain, the National Digital Elevation Program (NDEP) published its "Guidelines for Digital Elevation Data" and the American Society for Photogrammetry and Remote Sensing (ASPRS) published the "ASPRS Guidelines: Vertical Accuracy Reporting for Lidar Data," both of which were published in 2004 and use newer terms defined below as Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA). All of these standards, designed for digital elevation data, replace the National Map Accuracy Standard (NMAS) that is applicable only to graphic maps defined by map scale and contour interval.

Accuracy – The closeness of an estimated value (e.g., measured or computed) to a standard or accepted (true) value of a particular quantity. Note: With the exception of GPS Continuously Operating Reference Stations (CORS), assumed to be known with zero errors relative to established datums, the true locations of 3-D spatial coordinates or other points are not known, but only estimated. Therefore, the accuracy of other coordinate information is unknown and can only be estimated. Other accuracy definitions are as follows.

- **Absolute Accuracy –** A measure that accounts for all systematic and random errors in a data set. Absolute accuracy is stated with respect to a defied datum or reference system.
- **Accuracy_r –** The NSSDA reporting standard in the horizontal component that equals the radius of a circle of uncertainty, such that the true or theoretical horizontal location of the

point falls within that circle 95-percent of the time. $Accuracy_r = 1.7308 \times RMSE_r$. Horizontal accuracy is defined as the positional accuracy of a dataset with respect to a horizontal datum.

- **$Accuracy_z$ —** The NSSDA reporting standard in the vertical component that equals the linear uncertainty value, such that the true or theoretical vertical location of the point falls within that linear uncertainty value 95-percent of the time. $Accuracy_z = 1.9600 \times RMSE_z$. Vertical accuracy is defined as the positional accuracy of a dataset with respect to a vertical datum.
- **Consolidated Vertical Accuracy (CVA) –** The result of a test of the accuracy of vertical checkpoints (z-values) consolidated for two or more of the major land cover categories, representing both open terrain and other land cover categories. Computed by using the 95^{th} percentile, CVA is always accompanied by Fundamental Vertical Accuracy (FVA).
- **Fundamental Vertical Accuracy (FVA) –** The value by which vertical accuracy can be equitably assessed and compared among datasets. The FVA is determined with vertical checkpoints located only in open terrain, where there is a very high probability that the sensor will have detected the ground surface. FVA is calculated at the 95% confidence level in open terrain only, using $RMSE_z \times 1.9600$,
- **Local Accuracy –** A value that represents the uncertainty in the coordinates of a control point relative to the coordinates of other directly-connected, adjacent control points at the 95-percent confidence level. The reported local accuracy is an approximate average of the individual local accuracy values between this control point and other observed control points used to establish the coordinates of the control point.
- **Network Accuracy –** A value that represents the uncertainty in the coordinates of a control point with respect to the geodetic datum at the 95-percent confidence level. For National Spatial Reference System (NSRS) network accuracy classification in the U.S., the datum is considered to be best expressed by the geodetic values at the CORS supported by the National Geodetic Survey (NGS). By this definition, the local and network accuracy values at CORS sites are considered to be infinitesimal, i.e., to approach zero.
- **Percentile –** Any of the values in a dataset of errors dividing the distribution of the individual errors in the dataset into one hundred groups of equal frequency. Any of those groups can specify a specific percentile, e.g., the 95^{th} percentile as defined below.
- **Precision –** A statistical measure of the tendency of a set of random numbers to cluster about a number determined by the dataset. *Precision* relates to the quality of the method by which the measurements were made and is distinguished from *accuracy* which relates to the quality of the result. The term "precision" not only applies to the fidelity with which required operations are performed, but, by custom, has been applied to methods and instruments employed in obtaining results of a high order of precision. Precision is exemplified by the number of decimal places to which a computation is carried and a result stated.
- **Positional Accuracy** – The accuracy of the position of features, including horizontal and/or vertical positions.
- **Relative Accuracy** – A measure that accounts for random errors in a data set. Relative accuracy may also be referred to as point-to-point accuracy. The general measure of relative accuracy is an evaluation of the random errors (systematic errors and blunders removed) in determining the positional orientation (e.g., distance, azimuth) of one point or feature with respect to another.
- **Root Mean Square Error (RMSE) –** The square root of the average of the set of squared differences between dataset coordinate values and coordinate values from an independent

source of higher accuracy for identical points. The vertical RMSE ($RMSE_z$), for example, is calculated as the square root of $\sum(Z_n - Z'_n)^2/N$, where:

  - Z_n is the set of N z-values (elevations) being evaluated, normally interpolated (for TINs and DEMs) from dataset elevations of points surrounding the x/y coordinates of checkpoints
  - Z'_n is the corresponding set of checkpoint elevations for the points being evaluated
  - N is the number of checkpoints
  - n is the identification number of each of the checkpoints from 1 through N.

- **Supplemental Vertical Accuracy (SVA) –** The result of a test of the accuracy of z-values over areas with ground cover categories or combination of categories other than open terrain. Computed by using the 95th percentile, SVA is always accompanied by Fundamental Vertical Accuracy (FVA). SVA values are computed individually for different land cover categories. Each land cover type representing 10% of more of the total project area is typically tested and reported as an SVA. SVA specifications are normally target values that may be exceeded so long as overall CVA requirements are satisfied.
- **95% Confidence Level** – Accuracy reported at the 95% confidence level means that 95% of the positions in the dataset will have an error with respect to true ground position that is equal to or smaller than the reported accuracy value. The reported accuracy value reflects all uncertainties, including those introduced by geodetic control coordinates, compilation, and final computation of ground coordinate values in the product. Where errors follow a normal error distribution, $Accuracy_z$ defines vertical accuracy at the 95% confidence level (computed as $RMSE_z$ x 1.9600), and $Accuracy_r$ defines horizontal (radial) accuracy at the 95% confidence level (computed as $RMSE_r$ x 1.7308).
- **95th Percentile –** Accuracy reported at the 95th percentile indicates that 95% of the errors will be of equal or lesser value and 5% of the errors will be of larger value. This term is used when errors may not follow a normal error distribution, e.g., in forested areas where the classification of bare-earth elevations may have a positive bias. Vertical accuracy at the 95% confidence level and 95th percentile may be compared to evaluate the degree to which actual errors approach a normal error distribution.

Resolution – In the context of elevation data, resolution is synonymous with the horizontal density of elevation data points for which two similar terms are used:

- **Nominal Pulse Spacing (NPS)** – The estimated average spacing of irregularly-spaced lidar points in both the along-track and cross-track directions resulting from: the laser pulse repetition frequency (e.g., 100,000 pulses of laser energy emitted in one second from a 100 kHz sensor); scan rate (sometimes viewed as the number of zigzags per second for this common scanning pattern); field-of-view; and flight airspeed. Lidar system developers currently provide "design NPS" as part of the design pulse density, although the American Society for Photogrammetry and Remote Sensing (ASPRS) is currently developing standard procedures to compute the "empirical NPS" which should be approximately the same as the "design NPS" when accepting statistically insignificant loss of returns and disregarding void areas, from water for example. The NPS assessment is made against single swath first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track pulse spacing should be comparable. When point density is increased by relying on overlap or double-coverage it should be documented in metadata and not by changing the project's reported NPS. The NPS should be equal to or less than the Digital Elevation Model (DEM) post spacing when gridded DEMs are required as part of project specifications. This same definition for NPS could similarly apply to irregularly-spaced mass points from photogrammetry or Interferometric Synthetic Aperture Radar (IFSAR) data. NPS pertains to lidar only and is not intended to pertain to photogrammetry or IFSAR.

- **DEM Post Spacing –** Sometimes confused with Nominal Pulse Spacing, the DEM Post Spacing is defined as the constant sampling interval in x- and y-directions of a DEM lattice or grid. This is also called the horizontal resolution of a gridded DEM or the DEM grid spacing. It is standard industry practice to have:
  - 1-meter DEM post spacing for elevation data with 1-foot equivalent contour accuracy;
  - 2-meter DEM post spacing for elevation data with 2-foot equivalent contour accuracy;
  - 5-meter DEM post spacing for elevation data with 5-foot equivalent contour accuracy.

Attachment 2 – Alignment of FEMA Appendix A to USGS Lidar Specification v13

FEMA is aligning Appendix A of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (Guidelines) to the USGS *Lidar Guidelines and Base Specification* v13 to modernize the FEMA specifications to current industry practice, leverage the expertise of the USGS Geography discipline, maintain Federal standards across agencies, and support the use of elevation products acquired as part of Risk MAP by other agencies for other purposes thus maximizing the Government's investment.

Overall, new elevation data purchased by FEMA must comply with the USGS *Lidar Guidelines and Base Specification* v13, except where specifically noted in this Procedure Memorandum.

Because FEMA's needs for elevation are specific to floodplain mapping, FEMA has some unique requirements that differ from the USGS specifications. To supplement the existing USGS specifications, FEMA-specific items such as cross section surveys, bridges, and other features in Appendix A of the Guidelines remain valid except where superseded by more current information provided in this attachment. Table 1 summarizes the sections in Appendix A that are fully superseded, partially superseded or not superseded by this Procedure Memorandum.

Table 2.1 Currency of Major Sections within FEMA's Appendix A: Guidance for Aerial Mapping and Surveying

Section	Name	Status
A.1	Introduction	Is not superseded and remains valid.
A.2	Industry Geospatial Standards	Remains valid but is appended by additional standards which use newer standards from the National Digital Elevation Program (NDEP) and American Society for Photogrammetry and Remote Sensing (ASPRS) to test elevation data for Fundamental Vertical Accuracy (FVA), Supplemental Vertical Accuracy (SVA), and Consolidated Vertical Accuracy (CVA).
A.3	Accuracy Guidelines	Partly superseded, especially Table 2, below, that specifies variable vertical accuracy standards and nominal pulse spacing (NPS), depending on the risk level and terrain slope within the floodplain being mapped.
A.4	Data Requirements	Major portions are superseded. Subsection A.4.2.3 pertaining to breaklines, subsection A.4.3 pertaining to elevation data vertical accuracy, and subsection A.4.5 pertaining to mapping area, are superseded. Subsection A.4.11 pertaining to other digital topographic data requirements, including Table A-3, Digital Topographic Data Requirements Checklist, is now superseded by other FEMA procurement guidelines. Subsection A.4.9 on data formats is partially superseded by the addition of lidar LAS formatted datasets. Subsections pertaining to cross sections (A.4.6) and hydraulic structures (A.4.7) remain valid.
A.5	Ground Control	Is not superseded and remains valid.
A.6	Ground Surveys	Is not superseded and remains valid.

Section	Name	Status
A.7	Photogrammetric Surveys	Remains valid but is appended by additional standards which require low confidence areas to be delineated for photogrammetry as well as lidar and interferometric synthetic aperture radar (IFSAR). The vast majority of section A.7 remains valid and unchanged.
A.8	Airborne LiDAR	Superseded with references the USGS *Lidar Guidelines and Base Specification* v13; and by NDEP and ASPRS guidelines for accuracy testing and reporting of lidar data.

2.1Elevation Specifications Based on Risk Levels

FEMA maintains a national dataset that estimates flood risk. The basic data is calculated at the Census Block Group level, and is also aggregated to the sub-watershed, watershed and county levels. These data assign a risk value and a risk rank to each area. The areas are grouped into 10 classes with an equal number of members based on risk rank. These 10 classes are called risk deciles.

The table below provides the minimum elevation standards for new engineering analyses produced by FEMA. The highest and high specifications are suitable for either basic or enhanced engineering analyses. The medium and low specifications are suitable for basic engineering analyses. Where more than 20% of the project area covered by the new elevation will have enhanced engineering analyses, the next higher elevation specification level may be appropriate. When the scope of the enhanced engineering analyses is not sufficient to justify increasing the overall project specification level, the bulk elevation data collection may be enhanced by field survey in areas of enhanced engineering analyses if necessary.

Table 2.2. Vertical Accuracy Requirements based on Flood Risk and Terrain Slope within the Floodplain being mapped

Level of Flood Risk	Typical Slopes	Specification Level	Vertical Accuracy, 95% Confidence Level FVA/CVA	Lidar Nominal Pulse Spacing (NPS)
High (Deciles 1,2,3)	Flattest	Highest	24.5 cm/36.3 cm	≤1 meter
High (Deciles 1,2,3)	Rolling or Hilly	High	49.0 cm/72.6 cm	≤2 meters
High (Deciles 2,3,4,5)	Hilly	Medium	98.0 cm/145 cm	≤3.5 meters
Medium (Deciles 3,4,5,6,7)	Flattest	High	49.0 cm/72.6 cm	≤2 meters
Medium (Deciles 3,4,5,6,7)	Rolling	Medium	98.0 cm/145 cm	≤3.5 meters

Medium (Deciles 4,5,6,7)	Hilly	Low	147 cm/218 cm	≤5 meters
Low (Deciles 7,8,9,10)	All	Low	147 cm/218 cm	≤5 meters

Whereas contour lines are for visual interpretation and are unnecessary for FEMA's automated H&H analyses, the term "equivalent contour accuracy" is used to show the accuracy of contour lines that could be produced from a DEM if needed for manual analysis; this is also for the benefit of those who do not understand NSSDA terminology that defines vertical accuracy at the 95% confidence level. Table 3 explains "equivalent contour accuracy" for various standard contour intervals, referenced also in terms of vertical root mean square error ($RMSE_z$), National Standard for Spatial Data Accuracy (NSSDA) $Accuracy_z$, SVA and CVA.

Table 2.3. Accuracy Terms that Equal "Equivalent Contour Accuracy"

Equivalent Contour Accuracy	FEMA Specification Level	$RMSE_z$	NSSDA $Accuracy_z$ 95% confidence level	SVA (target)	CVA (mandatory)
1 ft		0.30 ft or 9.25 cm	0.60 ft or18.2 cm	0.60 ft or18.2 cm	0.60 ft or18.2 cm
2 ft	Highest	0.61 ft or 18.5 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm	1.19 ft or 36.3 cm
4 ft	High	1.22 ft or 37.1 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm	2.38 ft or 72.6 cm
5 ft		1.52 ft or 46.3 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm	2.98 ft or 90.8 cm
8 ft	Medium	2.43 ft or 73.9 cm	4.77 ft or 1.45 m	4.77 ft or 1.45 m	4.77 ft or 1.45 m
10 ft		3.04 ft or 92.7 cm	5.96 ft or1.82 m	5.96 ft or1.82 m	5.96 ft or1.82 m
12 ft	Low	3.65 ft or 1.11m	7.15 ft or 2.18 m	7.15 ft or 2.18 m	7.15 ft or 2.18 m

FEMA's requirements for elevation data are specific to flood risk analysis. As a result, FEMA's requirements diverge from the USGS specification which is intended to serve a different purpose. Two of the key differences with the FEMA specifications are the requirements for vertical accuracy and nominal pulse spacing. The FEMA requirements in these areas are only similar to the USGS requirements in the highest specification level, but otherwise differ for the lower accuracy levels.

All data collected must go through lidar preliminary processing and the unclassified point cloud must be tested as specified in the USGS specification. Where the Mapping Activity Statement (MAS) requires bare earth post-processing of the floodplain area of interest (AOI), the elevation data must be tested and comply with both the FVA and CVA requirements. Where no bare earth post-processing is specified, only the FVA requirements apply for lidar preliminary processing.

Many other organizations require higher-accuracy lidar data for diverse applications and combine their resources to solve multiple needs with lidar. FEMA prefers to acquire elevation data through partnerships so that the resulting data will meet a broader variety of end user needs and be more consistent with the overall USGS specification. These partnership elevation collection activities will frequently utilize specifications that exceed the minimums described above in Table 2. Before committing funds to a new elevation mapping project, FEMA Regional staff should first determine whether funds could be spent more effectively by cooperating with other agencies to more cost-effectively acquire elevation data. FEMA is a member of the National Digital Elevation Program (NDEP) which was formed, in part, to avoid duplication of effort among state and federal government agencies acquiring digital elevation data. USGS maintains state geospatial liaisons that are a good source of information regarding the status of existing and/or planned mapping activities in their states.

2.2 Light Detection and Ranging (lidar)

Lidar is capable of delivering 1- foot equivalent contour accuracy with sub-meter NPS used to produce DEMs with 1-meter DEM gridded post spacing. Therefore, lidar could satisfy FEMA's requirements for elevation data in high risk, moderate risk, and low risk areas. Lidar is often the best technology for mapping the elevations of the bare earth terrain in dense vegetation.

If this technology is selected for high risk areas, lidar will be collected in accordance with the USGS *Lidar Guidelines and Base Specification*, v13, for the National Geospatial Program except as noted. FEMA does not require the data to be hydro-flattened, as specified in v13. Also, FEMA does not require all data to be processed to the bare earth terrain, but instead limits the area to be processed to areas in the vicinity of floodplains that will require hydraulic modeling. See FEMA's Procurement Guidelines for specifics on this topic.

The following USGS specifications are most relevant to FEMA and are consistent with FEMA requirements:

- Fundamental Vertical Accuracy (FVA) pertains only to open, non-vegetated terrain. The FVA is specified at a higher level of accuracy than other land cover categories. The FVA is a mandatory specification that must be satisfied in order to be usable by FEMA for flood risk mapping within the specified level of flood risk.
- Supplemental Vertical Accuracy (SVA) pertains to other major land cover categories representative of the floodplain being mapped. SVA values are target values, where one SVA category can test higher and another lower than the target SVA value so long as the overall CVA is satisfied for the consolidated equivalent contour accuracy.
- Consolidated Vertical Accuracy (CVA) pertains to all land cover categories combined. Compliance with the CVA specification is mandatory in order for an elevation dataset to qualify for satisfaction of a specified equivalent contour accuracy.
- For the highest specification level equivalent to 2 foot contour accuracy, the relative accuracy should be ≤ 7 cm $RMSE_z$ within individual swaths; ≤ 10 cm $RMSE_z$ within swath overlap (between adjacent swaths). These relative accuracy specifications double to 14 and 20 cm, respectively, for risk areas that utilize the high elevation specification with 4 foot equivalent contour accuracy. This specification is not applicable to lower risk areas.
- Consistent with USGS *Lidar Guidelines and Base Specification*, v13, a regular grid, with cell size equal to the design NPS*2 will be laid over the first return data within the geometrically usable center portion of each swath. At least 90% of the cells in the grid shall contain at least one lidar point.
- All data collected will be delivered consistent with the USGS Raw Point Cloud deliverable requirements.

- Where lidar post-processing is performed, the deliverables must also include the classified point cloud deliverable. The data will be delivered in full compliance with LAS classes 1 (processed, but unclassified), 2 (bare-earth ground), 7 (noise), 9 (water), 10 (ignored), and 11 (withheld). All points not identified as "withheld" are to be classified. "Overlap" classification (Class 12) shall not be used.
- The horizontal datum shall be referenced to the latest adjustment of the North American Datum of 1983 (NAD83 [NSRS2007]).
- The vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD88) whenever available. Areas outside of the continental U.S. where NAVD88 is not available should be referenced to a reproducible local datum that can be used to support floodplain management.
- The most recent approved Geoid model from the National Geodetic Survey (NGS) shall be used to perform conversions from ellipsoidal heights to orthometric heights.
- The standard coordinate reference system and units shall be Universal Transverse Mercator (UTM), meters. Considerations for other standard coordinate systems such as State Plane can be made for projects which are contributed to by mapping partners.
- The single non-overlapped tiling scheme shall be established and agreed upon by the data producer and FEMA prior to collection, consistent with the USGS *Lidar Guidelines and Base Specifications,* v13.
- Specifications for breaklines and hydro-enforcement are addressed in Attachment B.
- Specifications for lidar accuracy testing by land cover categories within the floodplain being mapped are addressed in Attachment C.

Lidar dataset deliverables shall include the following:

1. Metadata should comply with the requirements in the USGS *Lidar Guidelines and Base Specification*, v13. In addition, the finished elevation product for hydraulic modeling should be documented by a FGDC-compliant metadata file that complies with the FEMA Elevation Metadata Profile. Project documentation must also include a Pre-flight Operations Plan and Post-flight Aerial Survey and Calibration Report as described in Attachment 4.
2. Raw point cloud data shall comply with the requirements in the USGS Lidar Guidelines and Base Specification, v13.
3. Classified point cloud data shall comply with requirements in the USGS Lidar Guidelines and Base Specification, v13.
4. Optional breaklines, when produced, shall be delivered in compliance with guidance in Attachment 3
5. Optional digital bare earth elevation data product(s) (e.g., DEM, DTM, contours) in file formats specified in the Statement of Work.

2.3 Photogrammetry

Photogrammetry is also capable of delivering 1-foot equivalent contour accuracy and a DEM with 1-meter post spacing. Therefore, photogrammetry could also satisfy FEMA's requirements for elevation data in high risk, moderate risk, and low risk areas. Except for the new requirement to delineate areas of low confidence, existing guidance published in section A.7, Photogrammetric Surveys, in Appendix A of FEMA's Guidelines, remain current for new aerial image acquisition with either film or digital cameras.

The USGS annually contracts for leaf-off orthoimagery of selected areas under the National Geospatial Program, typically producing digital orthophotographs with pixel resolution of 30 cm (~1 foot) or 15 cm (~6 inches), as do many states and local governments; and the USDA contracts for leaf-on orthoimagery of major areas of the U.S. annually under the National Agricultural Imagery Program (NAIP) with pixel resolution of 1 meter. Although intended for production of digital orthophotos, those same images could be reused for production of digital elevation data because the aerotriangulation (AT) solution for production of orthophotos can be reused for establishing stereo models from which DEMs can be produced by photogrammetric auto-correlation and/or manual compilation. Elevation accuracies typically achievable by reuse of digital imagery and AT metrics are as follows:

- Typically acquired at an elevation of approximately 4,800 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 6-inch pixel resolution should be acceptable for elevation data with 2.5-foot equivalent contour accuracy
- Typically acquired at an elevation of approximately 9,600 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 1-foot pixel resolution should be acceptable for elevation data with 5-foot equivalent contour accuracy
- Typically acquired at an elevation of approximately 30,000 feet above mean terrain, imagery and AT solutions used to produce digital orthophotos with 1-meter pixel resolution should be acceptable for elevation data with 15-foot equivalent contour accuracy.

Photogrammetric dataset deliverables shall include the following:

1. Metadata shall include:
    - Collection Report detailing mission planning and flight logs, flying heights, camera parameters, forward overlap and sidelap.
    - Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
    - Aerial triangulation (AT) report detailing compliance with relevant accuracy statistics.
    - Processing Report detailing photogrammetric processed used to manually compile elevation data or to semi-automatically compile elevation data with automated image correlation or other techniques.
    - QA/QC reports.
    - Geo-referenced extents of each delivered dataset.
2. Digital bare earth elevation data product (DEM, DTM, mass points, breaklines, contours) specified in the Statement of Work.
3. Optional breaklines, when produced, shall be delivered in compliance with guidance in Attachment 3

2.4 Ground Surveys

All ground surveys must be performed in accordance with procedures in Section A.5, Ground Control, and Section A.6, Ground Surveys, in Appendix A of FEMA's Guidelines. Cross-section surveys and hydraulic structure surveys shall also be performed in accordance with sections A.4.6 and A.4.7, respectively, of Appendix A.

2.5 Low Confidence Areas

Regardless of technology used, FEMA requires that low confidence areas be delineated by the data provider to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the specified nominal pulse spacing was met or exceeded in those areas. The metadata must explain steps taken to minimize the areas delineated as low confidence areas. Accuracy test points are normally retained within such areas and are not discarded. The data provider must take reasonable steps to minimize areas delineated as low confidence areas, taking into consideration the density of the vegetation in the floodplain being mapped and other factors.

These low confidence areas must be delivered as polygons in accordance with a database schema. The database schema for polygons defining low confidence areas is as follows.

Feature Dataset: TOPOGRAPHIC **Feature Class:** CONFIDENCE
Feature Type: Polygon
Contains M Values: No **Contains Z Values:** No
Annotation Subclass: None
XY Resolution: Accept Default Setting **Z Resolution:** Accept Default Setting
XY Tolerance: 0.003 **Z Tolerance:** N/A

2.5.1 Description

This polygon feature class will depict areas where the ground is obscured by dense vegetation, meaning that the resultant bare-earth digital terrain model (DTM) may not meet the required accuracy specifications in these obscured areas. Low confidence areas can pertain to lidar, photogrammetry or IFSAR.

2.5.2 Table Definition

Field Name	Data Type	Allow Null Values	Default Value	Domain	Precision	Scale	Length	Responsibility
OBJECTID	Object ID							Assigned by Software
SHAPE	Geometry							Assigned by Software
DATESTAMP_DT	Date	Yes			0	0	8	Assigned by Contractor
SHAPE_LENGTH	Double	Yes			0	0		Calculated by Contractor
SHAPE_AREA	Double	Yes			0	0		Calculated by

								Contractor
TYPE	Long Integer	No	1	Obscure	0	0		Assigned by Contractor

2.5.3 Feature Definition

Code	Description	Definition	Capture Rules
1	Low Confidence Area	“Low confidence areas” are defined by the data provider to indicate areas where the vertical data may not meet the data accuracy requirements due to heavy vegetation even though the nominal pulse spacing was met or exceeded in those areas.	Capture as closed polygon. Compiler does not need t z-values of vertices; feature class will be 2-D only.

Attachment 3 – Topographic Breakline and Hydro-Enforcement Specifications

FEMA has no minimum breakline requirements; breaklines are optional and depend upon the procedures used to perform hydrologic and hydraulic modeling. The FEMA Project Manager should specify the breaklines requirements if desired based on the planned approach for hydraulic analysis or the mapping partner may propose breakline requirements based on the anticipated hydraulic modeling approach.

When optional breaklines are produced, the following breakline topology rules must be followed for the applicable feature classes. The topology must be validated by each contractor prior to delivery to FEMA.

Name: BREAKLINES_Topology			Cluster Tolerance: 0.003 Maximum Generated Error Count: Undefined State: Analyzed without errors	
Feature Class	**Weight**	**XY Rank**	**Z Rank**	**Event Notification**
COASTALSHORELINE	5	1	1	No
HYDROGRAPHICFEATURE	5	1	1	No
PONDS_AND_LAKES	5	1	1	No
HYDRAULICSTRUCTURE	5	1	1	No
ISLAND	5	1	1	No

Topology Rules

Name	Rule Type	Trigger Event	Orgin (FeatureClass::Subtype)	Destination (FeatureClass::Subtype)
Must not intersect	The rule is a line-no intersection rule	No	HYDRAULICSTRUCTURE::All	HYDRAULICSTRUCTURE::All
Must not intersect	The rule is a line-no intersection rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not intersect	The rule is a line-no intersection rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All
Must not intersect	The rule is a line-no intersection rule	No	PONDS_AND_LAKES::All	PONDS_AND_LAKES::All
Must not intersect	The rule is a line-no intersection rule	No	ISLAND::All	ISLAND::All
Must not overlap	The rule is a line-no overlap line rule	No	HYDROGRAPHICFEATURE::All	COASTALSHORELINE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDRAULICSTRUCTURE::All	HYDRAULICSTRUCTURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	HYDROGRAPHICFEATURE::All	HYDROGRAPHICFEATURE::All
Must not self-intersect	The rule is a line-no self intersect rule	No	COASTALSHORELINE::All	COASTALSHORELINE::All

Name	Rule Type	Trigger Event	Orgin (FeatureClass::Subtype)	Destination (FeatureClass::Subtype)
Must not self-intersect	The rule is a line-no self intersect rule	No	PONDS_AND_LAKES::All	PONDS_AND_LAKES::All
Must not self-intersect	The rule is a line-no self intersect rule	No	ISLAND::All	ISLAND::All

Attachment 4 – Topographic Data Quality Review and Reporting Process

To complement the topographic data specifications in this procedure memorandum, this attachment describes data quality review processes and reporting obligations to be performed on new topographic data procured by FEMA as part of a flood hazard study or Risk MAP project. The mapping partner responsible for producing the elevation data is responsible for the quality of the product. In addition, FEMA may assign another mapping partner to perform Independent QA/QC of Topographic Data

Existing topographic data leveraged by FEMA should be certified to meet or tested for the vertical accuracy requirements specified in this procedure memo. In addition, the quality reviews described here are best practices that may be applied to existing topographic data. However, some of the documentation needed to perform some of these reviews may not be readily available for existing data..

4.1 Quality Reviews and Reporting Performed by Data Provider

The mapping partner responsible for producing new elevation data must submit copies of QA reports as specified in USGS Lidar Guidelines and Base Specification version 13. Unless the responsibility for checkpoint surveys and vertical accuracy testing is specifically assigned to a different mapping partner performing Independent QA/QC, the mapping partner responsible for producing the elevation data must test the unclassified point cloud data for Fundamental Vertical Accuracy (FVA) and, when lidar post-processing is performed must also test the bare earth product for Supplemental Vertical Accuracy (SVA) and Consolidated Vertical Accuracy (CVA).

4.1.1 Ground Survey of Quality Review Checkpoints

Quality review checkpoint surveys shall be performed in accordance with procedures in Section A.6.4, Checkpoint Surveys and A.6.5 Survey Records, in Appendix A of FEMA's Guidelines.

Checkpoints surveyed for accuracy reporting shall not be used by the data provider in the calibration or adjustment of the topographic data.

4.1.2 Assessment of Initial Vertical Accuracy

Assessment of the fully calibrated, raw point cloud initial vertical accuracy is required to ensure data has successfully completed preliminary processing. The absolute and relative accuracy of the data, relative to known control, shall be verified prior to classification and subsequent product development , by calculating FVA, measured in open, non-vegetated terrain. The spatial distribution of checkpoints for FVA testing should be based on the entire project collection area, distributed to avoid clustering, and support vertical accuracy reporting that is representative of the whole project.

If the project area exceeds 2,000 square miles it must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas. In addition, the division of large project areas should apply the following rules if applicable:

- Divide areas by vendor used
- Divide areas by sensor type (manufacturer)
- Divide areas by flight dates if significant temporal difference is present
- Other logical project divisions based factors that might have a systematic relationships to data quality.

Reporting of positional accuracy shall be in accordance with ASPRS/NDEP standards as well as the USGS *Lidar Guidelines and Base Specification*, v13, Section II.13 and shall use the following statement:

Tested ____ (meters) fundamental vertical accuracy at 95% confidence level

Reporting on the assessment of the point cloud initial vertical accuracy shall include the following at a minimum:

- ***A description of the process used to test the points***
- A graphic depicting the spatial distribution of the ground survey checkpoints
- Descriptive statistics and RMSEz in FVA calculations

4.1.3 Assessment of Bare Earth Vertical Accuracy

When bare earth post-processing is included in the project, assessment of the vertical accuracy for the delivered bare earth elevation product is required to ensure data has successfully completed post processing. Reporting of positional accuracy shall be in accordance with ASPRS/NDEP standards for FVA and CVA. Testing should be performed on the bare earth deliverable as specified in the mapping activity statement, along with the following guidance:

- If an assessment of initial vertical accuracy (FVA) was conducted prior to the processing of the data (section 4.1.2), the FVA checkpoints can again be used in the CVA computations if located within the area to be processed
- The SVA for up to three significant land cover categories, in terms of percentage of the project area covered, shall be tested in addition to the open/bare ground areas already tested for FVA Land cover categories making up 10% or more of the project area should be included in the SVA testing
- For smaller projects less than 1,000 square miles, fewer check points for SVA testing is acceptable. The number of checkpoints shall be reduced to control the QA cost to about 10% of the acquisition and processing cost. The checkpoints should be distributed evenly across the SVA land cover types.
- Processing areas greater than 2,000 square miles must be divided into smaller blocks of 2,000 square miles or less and tested as individual areas. In addition,

the division of large processing areas should apply the following rules if applicable:

- Divide areas by vendor used
- Divide areas by sensor type (manufacturer)
- Divide areas by flight dates if significant temporal difference is present
- Other logical project divisions based factors that might have a systematic relationships to data quality.

1.

- Each block of 2,000 square miles or less shall be tested for FVA, SVA, and CVA

Checkpoints used for testing SVA of the bare earth elevation product must be located in the areas where bare earth post-processing was performed, distributed to avoid clustering, and support vertical accuracy reporting that is representative of the post processed areas. The SVA results will then be combined with the FVA results to compute CVA for the entire project area.

Reporting on the assessment of the vertical accuracy of the post-processed, delivered elevation data shall include the following at a minimum:

- ***A description of the process used to test the points***
- A graphic depicting the spatial distribution of the ground survey checkpoints
- An analysis of checkpoints that have errors exceeding the 95th percentile in SVA and CVA calculations
- Descriptive statistics and RMSEz in FVA calculations

4.1.4 Aerial Data Acquisition and Calibration

The mapping partner responsible for producing new elevation data must also submit a pre-flight Operations Plan and a post-flight Aerial Acquisition and Calibration Report will be provided to FEMA and/or their representatives by the data acquisition provider and uploaded to the MIP by the data provider. This information will aid future quality review efforts. The required reporting includes the following, outlined in Tables 4.1 and 4.2.

Table 4.1. Pre-flight Operations Plan

Item	Contents	Format
Flight Operations	• Planned flight lines	MS Word or

Plan	• Planned GPS stations • Planned control • Planned airport locations • Calibration plans • Quality procedures for flight crew (project-related for pilot and operator) • Planned scanset (sensor settings and altitude) • Type of aircraft • Procedure for tracking, executing, and checking reflights • Considerations for terrain, cover, and weather in project	PDF

Table 4.2. Post-flight Aerial Acquisition and Calibration Report

Item	Contents	Format
GPS Base station info	• Base station name • Latitude/Longitude (ddd-mm-ss.sss) • Base height (Ellipsoidal meters) • Maximum Position Dilution of Precision PDOP • Map of locations	Excel, TXT, MS Word, or PDF for data; ESRI shape file for map of locations (data and info may be in attribute table)
GPS/IMU processing summary	• Max Horizontal GPS Variance (cm) • Max Vertical GPS Variance (cm) • Notes on GPS quality (High, Good, etc.) • GPS separation plot • GPS altitude plot • PDOP plot • Plot of GPS distance from base station/s	MS Word or PDF with screenshots
Coverage	• Verification of project coverage	ESRI shape files reflecting the actual coverage area and not the applicable tiles.
Flights	• As-flown trajectories • Calibration lines	ESRI shape files

Item	Contents	Format
Flight logs	• Incorporated as appendix Should include: • Job # / name • Lift # • Block or AOI designator • Date • Aircraft tail number, type • Flight line, line #, direction, start/stop, altitude, scan angle/rate, speed, conditions, comments • Pilot name • Operator name • AGC switch setting • Laser pulse rate • Mirror rate • Field of view • Airport of operations • GPS base station names or numbers Comments	
Control	• Ground control and base station layouts	ESRI shape files
Data verification/QC	• Description of data verification/QC process • Results of verification and QC steps	MS Word, Excel or PDF

4.2 Quality Reviews and Reporting Performed by Independent QA/QC

When a mapping partner is assigned to perform *Independent QA of Topographic Data* macro and micro reviews of the submitted reports and data shall be performed. Macro reviews are automated processes or are checks required to establish overall data quality and shall be applied to the entire project area. Micro reviews are typically manual in nature and shall be used to check no less than 3 project tiles or 5% of the total number of project tiles, whichever is the greater amount.

Tables 4.3 and 4.4 outline macro and micro reviews to be conducted on the raw point cloud and for data that is post-processed. Some reviews are duplicated between the raw point cloud and post-processing phases due to the potential for errors to be introduced into the data during post-processing.

Table 4.3. Review of fully calibrated raw point cloud

Macro Reviews	
Product	**Reviewed for**
Pre-flight Operations Plan	• Compliance with section 4.1.4 and checklists in 4.2.1 • Compliance with the specifications outlined in the Mapping Activity Statement
Post-flight Aerial Acquisition and Calibration Report	• Compliance with section 4.1.4 and checklists in 4.2.1 • Compliance with the specifications outlined in the Mapping Activity Statement

Macro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Project area coverage – buffered by a minimum of 100 meters • Data voids • Inclusion of GPS time stamp • Correct projection, datum and units • Multiple Discrete Returns (at least 3 returns per pulse) • Correct header information • Other LAS attributes required by Mapping Activity Statement such as intensity values • Correct nominal pulse spacing as required by specific risk and/or level of study and buy-up options.
Metadata	• Compliance with the FEMA Terrain Metadata Profile
Micro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Excessive noise • Elevation steps • Other anomalies present in the point cloud

Table 4.4. Review of post-processed data

Macro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Compliance with checklists in section 4.2.1 • Project area coverage – buffered by a minimum of 100 meters • Data voids • Inclusion of GPS time stamp • Correct projection, datum and units • Multiple Discrete Returns (at least 3 returns per pulse) • Correct header information • Other LAS attributes required by Mapping Activity Statement such as intensity values • Correct nominal pulse spacing as required by specific risk and/or level of study and buy-up options. • Easting, northing and elevation reported to nearest 0.01m or 0.01 ft • Correct file-naming convention
Metadata	• Compliance with the FEMA Terrain Metadata Profile

Macro Reviews	
Product	**Reviewed for**
Micro Reviews	
Product	**Reviewed for**
LAS Point Cloud Files	• Excessive noise • Elevation steps • Other anomalies present in the point cloud • Correct classification and cleanliness: no more than 2% of the project area classified to bare ground shall contain artifacts such as buildings, trees, overpasses or other above-ground features in the ground point classification (Class 2). In addition, no more than 2% of the project area shall contain incorrect classifications of points. (USGS *Lidar Guidelines and Base Specification*, v13, Section IV.14. •
Optional - Breaklines	• Correct topology • Horizontal placement • Completeness • Continuity *See Attachment 3 for breakline topology rules to be checked against*

If the mapping partner responsible *Independent QA of Topographic Data* is tasked to perform assessment of vertical accuracy of the elevation data as described above in sections 4.1.2 and 4.1.3:

- Assessment of FVA only for pre-processed data to be stored and FVA, SVA, and CVA for post-processed data
- Review of data provider vertical accuracy assessment reports

4.2.1 Recommended Checklists

The following checklists are recommended for use during Independent QA/QC review to facilitate the process.

Pre-flight review checklist

Checklist	Pass / Fail	Comments
Planned lines – sufficient coverage, spacing, and length		
Planned GPS stations		
Planned ground control – sufficient to control and boresight		
Calibration plans		
Vendor quality procedures		
Lidar sensor scan set – planned for proper scan angle, sidelap, design pulse.		
Aircraft utilizes ABGPS		

Sensor supports project design pulse density		
Type of aircraft – supports project design parameters		
Reflight procedure – tracking, documenting, processing		
Project design supports accuracy requirements of project		
Project design accounts for land cover and terrain types		

Post-flight review checklists

Checklist for QA of Flight Logs		
Checklist	Included Yes/No	Comments
Flight logs – job #/name		
Flight logs – block or AOI		
Flight logs – date		
Flight logs – aircraft tail #		
Flight logs – lines - #		
Flight logs – lines - direction		
Flight logs – lines – start/stop		
Flight logs – lines – altitude		
Flight logs – lines – scan angle		
Flight logs – lines – speed		
Flight logs – conditions		
Flight logs – comments		
Flight logs - pilot name		
Flight logs - operator name		
Flight logs - AGC switch		
Flight logs – GPS base stations		

Checklist for Aerial Acquisition Report		
Checklist	Included? Yes/No	Comments
GPS base station – names		
GPS base station – lat/longs		
GPS base station – heights		
GPS base station – map		
GPS quality – separation plot		
GPS quality – PDOP plot		

GPS quality - horizontal Acc.		
GPS quality - vertical Acc.		
Sensor calibration process		
Verification of AOI coverage		
As-flown trajectories		
Ground control layout		
Data verification process documented		

Final terrain product review checklists

Checklist for QA of Terrain Products		
Checklist	**Pass/Fail**	**Comments**
Vertical datum correct		
Horizontal datum correct		
Projection correct		
Vertical units correct		
Horizontal units correct		
Each return contains – GPS week, GPS second, easting, northing, elevation, intensity, return # and classification		
No duplicate entries		
GPS second reported to nearest microsecond		
Easting, northing, and elevation reported to nearest 0.01 m or 0.01 ft		
Classifications correct – 1. Unclassified; 2. Bare-earth ground; 7. Noise; 9. Water; 10. Ignored ground; 11. Withheld		
Cloud file structure conforms to project tile layout		
Naming conforms project requirements		
Deliverable tiles checked for significant gaps not covered by aerial acquisition checks and/or caused by data post-processing/filtering		

M.4 Terrain Submittal Standards

M.4.1 Overview

This section describes the format and type of terrain data required to be submitted to FEMA for FISs. All data must be submitted in digital format. The Mapping Partner performing "Develop Topographic Data" is required to submit the data in this section.

The Mapping Partner should refer to Appendix A of these Guidelines for guidance on terrain data production. This section is not intended to detail the specifications and procedures for coastal hydrographic surveys. The reader is referred to the following additional sources for details on coastal surveys:

- National Oceanic and Atmospheric Administration (NOAA) NOS Hydrographic Survey Specifications and Deliverables (April 2007);
- NOAA Office of Coast Survey Hydrographic Surveys Division Field Procedures Manual (March 2007); and
- U.S. Army Corps of Engineers (USACE) National Coastal Mapping Program Joint LiDAR Bathymetry Technical Center for Expertise.
- Appendix D of the *Guidelines and Specifications for Flood Hazard Mapping Partners* (February 2007).

The submitting Mapping Partner must retain copies of all Project-related data for a period of 3 years. The submitting Mapping Partner will need these data for responding to the following:

- Questions from FEMA or the receiving Mapping Partner during the review of the final draft materials;
- Comments and appeals submitted to FEMA during the 90-day appeal period following the issuance of preliminary maps; and
- Other concerns and issues that may develop during the processing of the new or revised FIS report and FIRM.

M.4.2 Requirements

M.4.2.1 Data Files

The minimum data required for the terrain data submission are the source terrain and topographic maps from the terrain data used in the study. These data can be contained in a single file or in tiled files. When tiled files are submitted, they must be accompanied by a tiling index file. If any processing has been performed, the original and final files must be submitted as well. For instance, if terrain data were blended from three different sources to create the final terrain data, the original of the three sources and the final terrain file that results from the blending process must be submitted. This information is required to be a georeferenced, digital submittal. The following information must be submitted when it is used to perform a study:

- LiDAR data (bare earth and all returns);
- Tiling index for data files;
- Breaklines and Mass Points;
- Contours;
- Bathymetry;
- Digital Elevation Models (DEMs);
- Hydro-corrected DEMs;
- Triangulated Irregular Networks (TINs);
- Hydro-corrected TINs;
- USGS topographic data;
- All other terrain data; and
- LiDAR data generated as part of the project must be submitted as two separate files: one for bare earth only, and one for all returns if bare earth processing was performed as part of this project. For existing LiDAR data not processed as part of the project, the bare earth data must be submitted, and the submittal of the all returns data (if available) is optional.

A project narrative describing the SOW, direction from FEMA, issues, information for next Mapping Partner, etc. (see DCS User Guide for additional details).

M.4.2.2 General Correspondence

A file that compiles general correspondence must be submitted by the Mapping Partner assigned to "Develop Topographic Data." General correspondence is the written correspondence generated or received by the Mapping Partner to fulfill the requirements of developing topographic data. Correspondence includes any documentation generated during this task such as letters; transmittals; memoranda; general status reports and queries; SPRs; technical issues that need to be documented; and direction given by FEMA.. Contractual documents, such as a signed SOW or MAS, are not to be submitted as a part of this appendix.

M.4.2.3 Certification of Work

FEMA-funded (including CTP-funded projects if they are a part of FEMA's flood mapping program) terrain data development must be certified using the Certification of Compliance Form provided in Figure M-11 in section M.10. Submittal of this certification at "Develop Topographic Data" workflow step is required if this is the only task performed by the Mapping Partner. Mapping Partners that are contracted to perform multiple mapping tasks can submit one certification form to certify all the work performed. A PDF file of this form with the original signature, data, and seal affixed to the form must be submitted digitally in the general directory identified in section M.4.2.8. This form must be signed by a registered or certified professional from the firm contracted to perform the work, or by the responsible official of a government agency. A digital version of this form is available at www.fema.gov.

M.4.2.4 Acceptable File Formats

Terrain data used to perform the study must be submitted in a georeferenced, digital format as listed below. These data can be contained in a single file or in a tiled set of files. Any tiled data must have an accompanying index spatial file.

- Contours, Masspoints, and breaklines – Personal geodatabase, DXF, or shapefile
- DEMs – ESRI grid, GeoTIFF, or ASCII grid
- LiDAR – LAS file, ASCII x, y, z file
- Terrain – ESRI ArcGIS
- Word – project narrative
- PDF – correspondence and certification

PDF files must be created using the source file (e.g., Word file), if the source file is created by the Mapping Partner, rather than raster scans of hard copy text documents. PDF files created must allow copying of text and pasting to another document. In addition, ESRI shapefiles must include .PRJ files.

M.4.2.5 Metadata

A metadata file in XML format that complies with the NFIP Terrain Metadata Profiles (provided in Section M.14) must be included with the submittal. The profiles follow the FGDC Content Standard for metadata and define additional domains and business rules for some elements that are mandatory for FEMA, based on the specific submittal type. For each spatial data source in the metadata file, the Mapping Partner must assign a Source Citation Abbreviation.

If metadata is available from an agency or organization that provided data for use in the study, it should be included in the metadata submittal in addition to the NFIP Terrain Metadata Profiles. Reference the data providers' original metadata record in the Lineage section of the NFIP metadata profile. If there is a Web-accessible metadata record for the original data set, the URL to the metadata may be provided in the optional Source Citation - Online Linkage element. Otherwise, the Source Contribution [free text] element may include information on how to access the metadata record for the data sets obtained.

M.4.2.6 Transfer Media

Mapping Partners must submit files via the internet by uploading to the MIP (http://www.hazards.fema.gov) or by mailing the files to FEMA on one or more of the following electronic media:

- CD-ROM;
- DVD; or
- External Hard Drive (for very large data submissions with a return label for shipment back to the partner).

In special situations or as technology changes, other media may be acceptable if coordinated with FEMA.

When data is mailed to FEMA, all submitted digital media must be labeled with at least the following information:

- Mapping Partner's name;
- Community name and State for which the FIS was prepared;
- Terrain Data;
- Date of submission (formatted mm/dd/yyyy); and
- Disk [*sequential number*] of [*number of disks*]. The media must be numbered sequentially, starting at Disk 1. [Number of disks] represents the total number of disks in the submission.

M.4.2.7 Transfer Methodology

Terrain artifacts can be uploaded to the MIP by following the guidelines for Data Submission and Validation located on the MIP (https://hazards.fema.gov) under "User Guidance" in the "Guides & Documentation" tab of "MIP User Care".

M.4.2.8 Directory Structure and Folder Naming Conventions

The files presented in section M.4.2 Requirements must be submitted to the MIP or mailed to FEMA within the following directory structure. Data files must be organized under an applicable 8-digit Hydrologic Unit Code (HUC-8). The following folders can be created either on a local work space (i.e., a personal computer) or within the work space for the community on the MIP. If the following folders are generated locally, these newly created folders and their contents must be uploaded to the MIP. Terrain files are arranged into appropriate directories based on data type.

- \HUC-8\General
  - Project narrative
  - Certification
- \HUC-8\Correspondence
  - Letters; transmittals; memoranda; general status reports and queries; SPRs; technical issues; direction by FEMA; and internal communications, routing slips, and notes.
- \HUC-8\All_Returns
  - LIDAR data – All Returns
  - LIDAR Tile Index spatial file (if used)
- \HUC-8\Bare_Earth
  - LIDAR data – Bare Earth Points
  - LIDAR Tile Index spatial file (if used)
- \HUC-8\Breaklines
  - 3D breakline spatial files
  - 3D breakline Tile Index spatial file (if used)

  - 2D breakline spatial files
  - 2D breakline Tile Index spatial file (if used)
  - Mass Points
- \HUC-8\Contours
  - Contour spatial files
  - Contour Tile Index spatial file (if used)
  - Bathymetric files
  - Bathymetric Tile Index spatial file (if used)
- \HUC-8\DEM
  - Uncorrected DEM files
  - Tile Index spatial file (if used)
- \HUC-8\HDEM
  - Hydrologically correct DEM files
  - Tile Index spatial file (if used)
- \HUC-8\TIN
  - Uncorrected TIN files
  - Terrain (ESRI ArcGIS format)
  - Tile index spatial file (if used)
- \HUC-8\HTIN
  - Hydrologically corrected TIN files
  - Terrain (ESRI ArcGIS format)
  - Tile Index spatial file (if used)
- \HUC-8\Supplemental Data
  - As-built drawings
  - GIS representation of structures

U.S. Geological Survey
National Geospatial Program
Lidar Guidelines and Base Specification

Version 13 – ILMF 2010

The U.S. Geological Survey National Geospatial Program (NGP) has cooperated in the collection of numerous lidar datasets across the nation for a wide array of applications. These collections have used a variety of specifications and required a diverse set of products, resulting in many incompatible datasets and making cross-project analysis extremely difficult. The need for a single base specification, defining minimum collection parameters and a consistent set of deliverables, is apparent.

Beginning in late 2009, an increase in the rate of lidar data collection due to American Reinvestment and Recovery Act (ARRA) funding for The National Map makes it imperative that a single data specification be implemented to ensure consistency and improve data utility. Although the development of this specification was prompted by the ARRA stimulus funding, the specification is intended to remain durable beyond ARRA funded NGP projects.

The primary intent of this specification is to create consistency across all NGP funded lidar collections, in particular those undertaken in support of the National Elevation Dataset (NED). Unlike most other “lidar specs” which focus on the derived bare-earth DEM product, this specification places unprecedented emphasis on the handling of the source lidar point cloud data. This is to assure that the complete source dataset collected remains intact and viable to support the wide variety of non-DEM science and mapping applications that benefit from lidar technology. In the absence of other comprehensive specifications or standards, it is hoped that this specification will, to the highest degree practical, be adopted by other USGS programs and disciplines, and by other Federal agencies.

Adherence to these minimum specifications ensures that bare-earth Digital Elevation Models (DEMs) derived from lidar data is suitable for ingestion into the NED (National Elevation Dataset) at the 1/9 arc-second resolution, and can be resampled for use in the 1/3 and 1 arc-second NED resolutions. It also ensures that the point cloud source data are handled in a consistent manner by all data providers and delivered to the USGS in clearly defined formats. This allows straight-forward ingest into CLICK (Center for Lidar Information, Coordination, and Knowledge) and simplifies subsequent use of the source data by the broader scientific community, particularly with regard to cross-collection analysis.

It must be stressed that this is a **base specification,** defining minimum parameters. It is expected that local conditions in any given project area, specialized applications for the data, or the preferences of cooperators, may mandate more stringent requirements. The

USGS encourages the collection of more detailed, accurate, or value-added data. A list of common upgrades to the minimum requirements defined here is provided in Appendix 1.

In addition, it is recognized that the USGS NGP also employs lidar technology for specialized scientific research and other projects whose requirements are incompatible with the provisions of this Specification. In such cases, and with properly documented justification supporting the need for the variance, waivers of any part or all of this Specification may be granted.

It is conceivable that in some cases, based on specific topography, land cover, intended application, or other factors, the USGS-NGP may require specifications more rigorous than those defined in this document. It is expected that this would be highly uncommon.

Lidar is still a relatively new technology; adolescent but not fully matured.. Advancements and improvements in instrumentation, software, processes, applications, and understanding are constantly being made. It would not be possible to develop a set of guidelines and specifications that address all of these advances. The current document is based on our understanding of and experience with the industry and technology at the present time. Furthermore, we acknowledge that there is a lack of commonly accepted "best practices" for numerous processes and technical assessments (i.e., measurement of NPS, point clustering, classification accuracy, etc.). The USGS encourages the development of such best practices through the appropriate industry and professional governance organizations, and we eagerly await the opportunity to include them in future revisions to this and other similar documents.

It is not the intention of the USGS to stifle the development of the lidar industry, nor to discourage innovation within the technology. Technical alternatives to any part of this document may be submitted with any proposal and will be given due professional consideration.

I. COLLECTION

1. Multiple Discrete Return, capable of at least 3 returns per pulse

   Note: Full waveform collection is both acceptable and welcomed; however, waveform data is regarded as supplemental information. The requirement for deriving and delivering multiple discrete returns remains in force in all cases.

2. Intensity values for each return.

3. Nominal **Pulse** Spacing (NPS) of 1-2 meters, dependent on the local terrain and landcover conditions. Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath. Average along-track and cross-track point spacings should be comparable.

4. Collections designed to achieve the NPS through swath overlap or multiple passes are generally discouraged. Such collections may be permitted with prior approval.

5. Data Voids [areas => $(4*NPS)^2$, measured using 1^{st}-returns only] within a single swath are not acceptable, except:

   - where caused by water bodies
   - where caused by areas of low near infra-red (NIR) reflectivity such as asphalt or composition roofing.
   - where appropriately filled-in by another swath

6. The spatial distribution of geometrically usable points is expected to be uniform and free from clustering. In order to ensure uniform densities throughout the data set:

   - A regular grid, with cell size equal to the design NPS*2 will be laid over the data.
   - At least 90% of the cells in the grid shall contain at least 1 lidar point.
   - Assessment to be made against single swath, first return data located within the geometrically usable center portion (typically ~90%) of each swath.
   - Acceptable data voids identified previously in this specification are excluded.

   Note: This requirement may be relaxed in areas of significant relief where it is impractical to maintain a consistent NPS.

7. Scan Angle: Total FOV should not exceed 40^o ($+/-20^o$ from nadir) USGS quality assurance on collections performed using scan angles wider than 34^o will be particularly rigorous in the edge-of-swath areas. Horizontal and vertical accuracy shall remain within the requirements as specified below.

   Note: This requirement is primarily applicable to oscillating mirror lidar systems. Other instrument technologies may be exempt from this requirement.

8. Vertical Accuracy of the lidar data will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

   http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

   Vertical accuracy requirements using the NDEP/ASPRS methodology are:

   FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz)
   CVA <= 36.3cm, 95th Percentile
   SVA <= 36.3cm, 95th Percentile

   - Accuracy for the lidar point cloud data is to be reported independently from accuracies of derivative products (i.e., DEMs). Point cloud data accuracy is to be tested against a TIN constructed from bare-earth lidar points.
   - Each landcover type representing 10% or more of the total project area must be tested and reported as an SVA.
   - For SVAs, the value is provided as a target. It is understood that in areas of dense vegetation, swamps, or extremely difficult terrain, this value may be exceeded. Overall CVA requirements must be met in spite of "busts" in individual SVAs.

   Note: These requirements may be relaxed in cases:

   - *where there exists a demonstrable and substantial increase in cost to obtain this accuracy.*
   - *where an alternate specification is needed to conform to previously contracted phases of a single larger overall collection effort, i.e., multi-year statewide collections, etc.*
   - *where the USGS agrees that it is reasonable and in the best interest of all stakeholders to use an alternate specification.*

9. Relative accuracy <=7cm $RMSE_Z$ within individual swaths; <=10cm RMSEz within swath overlap (between adjacent swaths).
10. Flightline overlap 10% or greater, as required to ensure there are no data gaps between the usable portions of the swaths. Collections in high relief terrain are expected to require greater overlap. Any data with gaps between the geometrically usable portions of the swaths will be rejected.
11. Collection Area: Defined Project Area, buffered by a minimum of 100 meters.
12. Collection Conditions:
    - Atmospheric: Cloud and fog-free between the aircraft and ground
    - Ground:
      - Snow free. Very light, undrifted snow may be acceptable in special cases, with prior approval.

- No unusual flooding or inundation, except in cases where the goal of the collection is to map the inundation.

- Vegetation: Leaf-off is preferred, however:
  - As numerous factors will affect vegetative condition at the time of any collection, the USGS NGP only requires that penetration to the ground must be adequate to produce an accurate and reliable bare-earth surface suitable for incorporation into the 1/9 (3-meter) NED.
  - Collections for specific scientific research projects may be exempted from this requirement, with prior approval.

II. DATA PROCESSING and HANDLING

1. All processing should be carried out with the understanding that all point deliverables are required to be in fully compliant LAS format, v1.2 or v1.3. Data producers are encouraged to review the LAS specification in detail.
2. If full waveform data is collected, delivery of the waveform packets is required. LAS v1.3 deliverables with waveform data are to use external “auxiliary” files with the extension “.wdp” for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
3. GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse. Adjusted GPS Time is defined to be Standard (or satellite) GPS time minus $1*10^9$. See the LAS Specification for more detail.
4. Horizontal datum shall be referenced to the North American Datum of 1983/HARN adjustment. Vertical datum shall be referenced to the North American Vertical Datum of 1988 (NAVD 88). The most recent NGS-approved Geoid model shall be used to perform conversions from ellipsoidal heights to orthometric heights.
5. The USGS preferred Coordinate Reference System for the Conterminous United States (CONUS) is: UTM, NAD83, Meters. Each discrete project is to be processed using the predominant UTM zone for the overall collection area.

   State Plane Coordinate Reference Systems that have been accepted by the European Petroleum Survey Group (EPSG) and that are recognized by ESRI GIS software may be used by prior agreement with the USGS.

   Alternative projected coordinate systems for collections in Alaska, Hawaii, and other areas Outside the Conterminous United States (OCONUS) must be approved by the USGS prior to collection.
6. All references to the Unit of Measure “Feet” or “Foot” must specify either “International” or “U.S. Survey”
7. Long swaths (those which result in a LAS file larger than 2GB) should be split into segments no greater than 2GB each. Each segment will thenceforth be

regarded as a unique swath and shall be assigned a unique File Source ID. Other swath segmentation approaches may be acceptable, with prior approval. Renaming schemes for split swaths are at the discretion of the data producer. The Processing Report shall include detailed information on swath segmentation sufficient to allow reconstruction of the original swaths if needed.

8. Each swath shall be assigned a unique File Source ID. The Point Source ID field for each point within each LAS swath file shall be set equal to the File Source ID prior to any processing of the data. See the LAS Specification.

9. Point Families (multiple return "children" of a single "parent" pulse) shall be maintained intact through all processing prior to tiling. Multiple returns from a given pulse shall be stored in sequential (collected) order.

10. All collected swaths are to be delivered as part of the "Raw Data Deliverable". This includes calibration swaths and cross-ties. All collected points are to be delivered. No points are to be deleted from the swath LAS files. This in no way requires or implies that calibration swath data are to be included in product generation. Excepted from this are extraneous data outside of the buffered project area (aircraft turns, transit between the collection area and airport, transit between fill-in areas, etc.). These points may be permanently removed.

11. Outliers, blunders, noise points, geometrically unreliable points near the extreme edge of the swath, and other points deemed unusable are to be identified using the "Withheld" flag, as defined in the LAS specification.

    - This applies primarily to points which are identified during pre-processing or through automated post-processing routines.
    - If processing software is not capable of populating the "Withheld" bit, these points may be identified using Class=11.
    - "Noise points" subsequently identified during manual Classification and Quality Assurance/Quality Control (QA/QC) may be assigned the standard LAS classification value for "Noise" (Class=7), regardless of whether the noise is "low" or "high" relative to the ground surface.

12. The ASPRS/LAS "Overlap" classification (Class=12) shall not be used. ALL points not identified as "Withheld" are to be classified.

    - If overlap points are required to be differentiated by the data producer or cooperating partner, they must be identified using a method that does not interfere with their classification, such as:
        - Overlap points are tagged using Bit:0 of the User Data byte, as defined in the LAS specification. (SET=Overlap).
        - Overlap points are classified using the Standard Class values + 16.
        - Other techniques as agreed upon in advance
    - The technique utilized must be clearly described in the project metadata files.

Note: A standard bit setting for identification of overlap points has been planned for a future version of LAS.

13. Positional Accuracy Validation: The absolute and relative accuracy of the data, both horizontal and vertical, and relative to known control, shall be verified prior to classification and subsequent product development. This validation is obviously limited to the Fundamental Vertical Accuracy, measured in clear, open areas. A detailed report of this validation is a required deliverable.

14. Classification Accuracy: It is expected that due diligence in the classification process will produce data that meets the following test:

    Within any 1km x 1km area, no more than 2% of non-withheld points will possess a demonstrably erroneous classification value.

    This includes points in Classes 0 and 1 that should correctly be included in a different Class as required by the contract.

    Note: This requirement may be relaxed to accommodate collections in areas where the USGS agrees classification to be particularly difficult.

15. Classification Consistency: Point classification is to be consistent across the entire project. Noticeable variations in the character, texture, or quality of the classification between tiles, swaths, lifts, or other non-natural divisions will be cause for rejection of the entire deliverable.

16. Tiles:

    Note: This section assumes a projected coordinate reference system.

    - A single non-overlapped tiling scheme will be established and agreed upon by the data producer and the USGS prior to collection. This scheme will be used for **all** tiled deliverables.
    - Tile size must be an integer multiple of the cell size of raster deliverables.
    - Tiles must be sized using the same units as the coordinate system of the data.
    - Tiled deliverables shall conform to the tiling scheme, without added overlap.
    - Tiled deliverables shall edge-match seamlessly and without gaps in both the horizontal and vertical.

III. HYDRO-FLATTENING REQUIREMENTS

Note: Please refer to Appendix 2 for reference information on hydro-flattening.

Hydro-flattening pertains only to the creation of derived DEMs. No manipulation of or changes to originally computed lidar point elevations are to be made. Breaklines may be used to help classify the point data.

1. Inland Ponds and Lakes:
   - ~2-acre or greater surface area (~350' diameter for a round pond) at the time of collection.
   - Flat and level water bodies (single elevation for every bank vertex defining a given water body).
   - The entire water surface edge must be at or below the immediately surrounding terrain.
   - Long impoundments such as reservoirs, inlets, and fjords, whose water surface elevations drop when moving downstream, should be treated as rivers.
2. Inland Streams and Rivers:
   - 100' **nominal** width: This should not unnecessarily break a stream or river into multiple segments. At times it may squeeze slightly below 100' for short segments. Data producers should use their best professional judgment.
   - Flat and level bank-to-bank (perpendicular to the apparent flow centerline); gradient to follow the immediately surrounding terrain.
   - The entire water surface edge must be at or below the immediately surrounding terrain.
   - Streams channels should break at road crossings (culvert locations). These road fills should not be removed from DEM. However, streams and rivers should **not** break at elevated bridges. Bridges should be removed from DEM. When the identification of a feature as a bridge or culvert cannot be made reliably, the feature should be regarded as a culvert.
3. Non-Tidal Boundary Waters:
   - Represented only as an edge or edges within the project area; collection does not include the opposing shore.
   - The entire water surface edge must be at or below the immediately surrounding terrain.
   - The elevation along the edge or edges should behave consistently throughout the project. May be a single elevation (i.e., lake) or gradient (i.e., river), as appropriate.

4. Tidal Waters:

   - Water bodies such as oceans, seas, gulfs, bays, inlets, salt marshes, very large lakes, etc. Includes any water body that is affected by tidal variations.
   - Tidal variations over the course of a collection or between different collections, will result in discontinuities along shorelines. This is considered normal and these "anomalies" should be retained. The final DEM should represent as much ground as the collected data permits.
   - Variations in water surface elevation resulting in tidal variations during a collection should NOT be removed or adjusted, as this would require either the removal of valid, measured ground points or the introduction of unmeasured ground into the DEM. The USGS NGP priority is on the ground surface, and accepts there may be occasional, unavoidable irregularities in water surface.
   - Scientific research projects in coastal areas often have very specific requirements with regard to how tidal land-water boundaries are to be handled. For such projects, the requirements of the research will take precedence.

Cooperating partners may require collection and integration of single-line streams within their lidar projects. While the USGS does not require these breaklines be collected or integrated, it does require that if used and incorporated into the DEMs, the following guidelines are met:

1. All vertices along single-line stream breaklines are at or below the immediately surrounding terrain.
2. Single-line stream breaklines are not to be used to introduce cuts into the DEM at road crossings (culverts), dams, or other such features. This is hydro-enforcement and as discussed in Section VI, creates a non-traditional DEM that is not suitable for integration into the NED.
3. All breaklines used to modify the surface are to be delivered to the USGS with the DEMs.

The USGS does not require any particular process or methodology be used for breakline collection, extraction, or integration. However, the following general guidelines must be adhered to:

1. Bare-earth lidar points that are in close proximity breaklines should be excluded from the DEM generation process. This is analogous to the removal of masspoints for the same reason in a traditional photogrammetrically compiled DTM.

   The proximity threshold for reclassification as "Ignored Ground" is at the discretion of the data producer, but in general should be approximately equal to the NPS.

2. These points are to be retained in the delivered lidar point dataset and shall be reclassified as "Ignored Ground" (class value = 10) so that they may be subsequently identified.

3. Delivered data must be sufficient for the USGS to effectively recreate the delivered DEMs using the lidar points and breaklines without significant further editing.

IV. DELIVERABLES

The USGS shall have unrestricted rights to all delivered data and reports, which will be placed in the public domain. This specification places no restrictions on the data provider's rights to resell data or derivative products as they see fit.

1. Metadata

Note: "Metadata" refers to all descriptive information about the project. This includes textual reports, graphics, supporting shapefiles, and FGDC-compliant metadata files.

- Collection Report detailing mission planning and flight logs.
- Survey Report detailing the collection of control and reference points used for calibration and QA/QC.
- Processing Report detailing calibration, classification, and product generation procedures including methodology used for breakline collection and hydro-flattening *(see Sections III and Appendix 1 for more information on hydro-flattening).*
- QA/QC Reports (detailing the analysis, accuracy assessment and validation of:
  - o The point data (absolute, within swath, and between swath)
  - o The bare-earth surface (absolute)
  - o Other optional deliverables as appropriate
- Control and Calibration points: All control and reference points used to calibrate, control, process, and validate the lidar point data or any derivative products are to be delivered.
- Geo-referenced, digital spatial representation of the precise extents of each delivered dataset. This should reflect the extents of the actual lidar source or derived product data, exclusive of Triangular Irregular Network (TIN) artifacts or raster NODATA areas. A union of tile boundaries or minimum bounding rectangle is not acceptable. ESRI Polygon shapefile or geodatabase is preferred.
- Product metadata (FGDC compliant, XML format metadata). One file for each:

  - Project
  - Lift
  - Tiled deliverable product group (classified point data, bare-earth DEMs, breaklines, etc.). Metadata files for individual tiles are not required.
- FGDC compliant metadata must pass the USGS metadata parser ("mp") with no errors or warnings.

2. Raw Point Cloud

- All returns, all collected points, fully calibrated and adjusted to ground, by swath.
- Fully compliant LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in all LAS file headers
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution)
- 1 file per swath, 1 swath per file, file size not to exceed 2GB, as described in Section II, Paragraph 7.

3. Classified Point Cloud

Note: Delivery of a classified point cloud is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Fully compliant LAS v1.2 or v1.3, Point Record Format 1, 3, 4, or 5
- LAS v1.3 deliverables with waveform data are to use external "auxiliary" files with the extension ".wdp" for the storage of waveform packet data. See the LAS v1.3 Specification for additional information.
- Georeference information included in LAS header
- GPS times are to be recorded as Adjusted GPS Time, at a precision sufficient to allow unique timestamps for each pulse.
- Intensity values (native radiometric resolution)
- Tiled delivery, without overlap (tiling scheme TBD)

- Classification Scheme (minimum):

Code	Description
1	Processed, but unclassified
2	Bare-earth ground
7	Noise (low or high, manually identified, if needed)
9	Water
10	Ignored Ground (Breakline Proximity)
11	Withheld (if the "Withheld" bit is not implemented in processing software)

Note: Class 7, Noise, is included as an adjunct to the "Withheld" bit. All "noise points" are to be identified using one of these to methods.

Note: Class 10, Ignored Ground, is for points previously classified as bare-earth but whose proximity to a subsequently added breakline requires that it be excluded during Digital Elevation Model (DEM) generation.

4. **Bare Earth Surface (Raster DEM)**

Note: Delivery of a bare-earth DEM is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement.

- Cell Size no greater than 3 meters or 10 feet, and no less than the design Nominal Pulse Spacing (NPS).
- Delivery in an industry-standard, GIS-compatible, 32-bit floating point raster format (ERDAS .IMG preferred)
- Georeference information shall be included in each raster file
- Tiled delivery, without overlap
- DEM tiles will show no edge artifacts or mismatch. A quilted appearance in the overall project DEM surface, whether caused by differences in processing quality or character between tiles, swaths, lifts, or other non-natural divisions, will be cause for rejection of the entire DEM deliverable.
- Void areas (i.e., areas outside the project boundary but within the tiling scheme) shall be coded using a unique "NODATA" value. This value shall be identified in the appropriate location within the file header.
- Vertical Accuracy of the bare earth surface will be assessed and reported in accordance with the guidelines developed by the NDEP and subsequently adopted by the ASPRS. The complete guidelines may be found in Section 1.5 of the Guidelines document. See:

  http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf

Vertical accuracy requirements using the NDEP/ASPRS methodology are:
FVA <= 24.5cm ACCz, 95% (12.5cm RMSEz)
CVA <= 36.3cm, 95th Percentile
SVA <= 36.3cm, 95th Percentile

All QA/QC analysis materials and results are to be delivered to the USGS.

- Depressions (sinks), natural or man-made, are **not** to be filled (as in hydro-conditioning and hydro-enforcement).
- Water Bodies (ponds and lakes), wide streams and rivers (“double-line”), and other non-tidal water bodies as defined in Section III are to be hydro-flattened within the DEM. Hydro-flattening shall be applied to all water impoundments, natural or man-made, that are larger than ~2 acre in area (equivalent to a round pond ~350’ in diameter), to all streams that are nominally wider than 100’, and to all non-tidal boundary waters bordering the project area regardless of size. The methodology used for hydro-flattening is at the discretion of the data producer.

  Note: Please refer to the Sections III and VI for detailed discussions of hydro-flattening.

5. **Breaklines**

Note: Delivery of the breaklines used in hydro-flattening is a standard requirement for USGS NGP lidar projects. Specific scientific research projects may be exempted from this requirement. If hydro-flattening is achieved through other means, this section may not apply.

- All breaklines developed for use in hydro-flattening shall be delivered as an ESRI feature class (PolylineZ or PolygonZ format, as appropriate to the type of feature represented and the methodology used by the data producer). Shapefile or geodatabase is preferred.
- Each feature class or shapefile will include properly formatted and accurate georeference information in the standard location. All shapefiles must include the companion .prj file.
- Breaklines must use the same coordinate reference system (horizontal and vertical) and units as the lidar point delivery.
- Breakline delivery may be as a continuous layer or in tiles, at the discretion of the data producer. Tiled deliveries must edge-match seamlessly in both the horizontal and vertical.

APPENDIX 1

COMMON DATA UPGRADES

1. Independent 3rd-Party QA/QC by another AE Contractor (encouraged)
2. Higher Nominal Pulse Spacing (point density)
3. Increased Vertical Accuracy
4. Full Waveform collection and delivery
5. Additional Environmental Constraints
    - Tidal coordination, flood stages, crop/plant growth cycles, etc.
    - Shorelines corrected for tidal variations within a collection
6. Top-of Canopy (First-Return) Raster Surface (tiled). Raster representing the highest return within each cell is preferred.
7. Intensity Images (8-bit gray scale, tiled)
8. Detailed Classification (additional classes):

Code	Description
3	Low vegetation
4	Medium vegetation (use for single vegetation class)
5	High vegetation
6	Buildings, bridges, other man-made structures
n	additional Class(es) as agreed upon in advance

9. Hydro-Enforced and/or Hydro-Conditioned DEMs
10. Breaklines (PolylineZ and PolygonZ) for single-line hydrographic features (narrow streams not collected as double-line, culverts, etc.), including appropriate integration into delivered DEMs
11. Breaklines (PolylineZ and PolygonZ) for other features (TBD), including appropriate integration into delivered DEMs
12. Extracted Buildings (PolygonZ): Footprints with maximum elevation and/or height above ground as an attribute.
13. Other products as defined by requirements and agreed upon in advance of funding commitment.

APPENDIX 2

HYDRO-FLATTENING REFERENCE

The subject of modifications to lidar-based DEMs is somewhat new, and although authoritative references are available, there remains significant variation in the understanding of the topic across the industry. The following material was developed to provide a definitive reference on the subject only as it relates to the creation of DEMs intended to be integrated into the USGS NED. The information presented here is not meant to supplant other reference materials and it should not be considered authoritative beyond its intended scope.

The term "**hydro-flattening**" is also new, coined for this document and to convey our specific needs. It is not, at this time, a known or accepted term across the industry. It is our hope that its use and acceptance will expand beyond the USGS with the assistance of other industry leaders.

Hydro-flattening of DEMs is predominantly accomplished through the use of breaklines, and this method is considered standard. Although other techniques may exist to achieve similar results, this section assumes the use of breaklines. The USGS does not require the use of any specific technique.

The Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition (Maune *et al.*, 2007) provides the following definitions related to the adjustment of DEM surfaces for hydrologic analyses:

1. **Hydrologically-Conditioned (Hydro-Conditioned)** – Processing of a DEM or TIN so that the flow of water is continuous across the entire terrain surface, including the removal of all spurious sinks or pits. The only sinks that are retained are the real ones on the landscape. Whereas "hydrologically-enforced" is relevant to drainage features that are generally mapped, "hydrologically-conditioned" is relevant to the entire land surface and is done so that water flow is continuous across the surface, whether that flow is in a stream channel or not. The purpose for continuous flow is so that relationships/links among basins/catchments can be known for large areas. This term is specifically used when describing EDNA (see Chapter 4), the dataset of NED derivatives made specifically for hydrologic modeling purposes.
2. **Hydrologically-Enforced (Hydro-Enforced)** – Processing of mapped water bodies so that lakes and reservoirs are level and so that streams flow downhill. For example, a DEM, TIN or topographic contour dataset with elevations removed from the tops of selected drainage structures (bridges and culverts) so as to depict the terrain under those structures. Hydro-enforcement enables hydrologic and hydraulic models to depict water flowing under these structures, rather than appearing in the computer model to be dammed by them because of road deck elevations higher than the water levels. Hydro-enforced TINs also utilize breaklines along shorelines and stream centerlines, for example, where these breaklines form the edges of TIN triangles along the alignment of drainage features. Shore breaklines for streams would be 3-D breaklines

> with elevations that decrease as the stream flows downstream; however, shore breaklines for lakes or reservoirs would have the same elevation for the entire shoreline if the water surface is known or assumed to be level throughout. See figures 1.21 through 1.24. See also the definition for "hydrologically-conditioned" which has a slightly different meaning.

While these are important and useful modifications, they both result in surfaces that differ significantly from a traditional DEM. A "hydro-conditioned" surface has had its sinks filled and may have had its water bodies flattened. This is necessary for correct flow modeling within and across large drainage basins. "Hydro-enforcement" extends this conditioning by requiring water bodies be leveled and streams flattened with the appropriate downhill gradient, and also by cutting through road crossings over streams (culvert locations) to allow a continuous flow path for water within the drainage. Both treatments result in a surface on which water behaves as it physically does in the real world, and both are invaluable for specific types of hydraulic and hydrologic (H&H) modeling activities. Neither of these treatments is typical of a traditional DEM surface.

A traditional DEM such as the NED, on the other hand, attempts to represent the ground surface more the way a bird, or person in an airplane, sees it. On this surface, natural depressions exist, and road fills create apparent sinks because the road fill and surface is depicted without regard to the culvert beneath. Bridges, it should be noted, are removed in most all types of DEMs because they are man-made, <u>above-ground</u> structures that have been added to the landscape.

Note: DEMs developed <u>solely</u> for orthophoto production may include bridges, as their presence can prevent the "smearing" of structures and reduce the amount of post-production correction of the final orthophoto. These are "special use DEMs" and are not relevant to this discussion.

For years, raster Digital Elevation Models (DEMs), have been created from a Digital Surface Model (DSM) of masspoints and breaklines, which in turn were created through photogrammetric compilation from stereo imagery. Photogrammetric DSMs inherently contain breaklines defining the edges of water bodies, coastlines, single-line streams, and double-line streams and rivers, as well as numerous other surface features.

Lidar technology, however, does not inherently collect the breaklines necessary to produce traditional DEMs. Breaklines have to be developed separately through a variety of techniques, and either used with the lidar points in the generation of the DEM, or applied as a correction to DEMs generated without breaklines.

In order to maintain the consistent character of the NED as a traditional DEM, the USGS NGP requires that all DEMs delivered have their inland water bodies flattened. This does not imply that a complete network of topologically correct hydrologic breaklines be developed for every dataset; only those breaklines necessary to ensure that the conditions defined in Section III exist in the final DEM.

APPENDIX 3

SAMPLE METADATA TEMPLATE

[to be added]

APPENDIX 4

REFERENCES

Maune, D.F., 2007. Definitions, in *Digital Elevation Model Technologies and Applications: The DEM Users Manual, 2nd Edition* (D.F. Maune, editor), American Society for Photogrammetry and Remote Sensing, Bethesda, MD pp. 550-551

National Digital Elevation Program, 2004. *Guidelines for Digital Elevation Data—Version 1*, 93 p., available online at: http://www.ndep.gov/NDEP_Elevation_Guidelines_Ver1_10May2004.pdf (last date accessed: 29 September 2009)

FEMA, 2003. *Guidelines and Specifications for Flood Hazard Mapping Partners, Appendix A: Guidance for Aerial Mapping and Surveying*, 59 p., available online at: http://www.fema.gov/library/viewRecord.do?id=2206 (last date accessed 29 September 2009)

USGS NED Website: www.ned.usgs.gov

USGS CLICK Website: www. lidar.cr.usgs.gov

MP-Metadata Parser: http://geology.usgs.gov/tools/metadata

Appendix I: Topographic Data Products

Federal Emergency Management Agency

Kittitas County, Washington

Technical Support Data Notebook

Terrain Project Narrative

Topographic Data Development

CID 53037C

CASE NO. 11-10-0110S
CONTRACT NO. HSFEHQ-09-D-0370
TASK ORDER NO. HSFE10-09-J-00002

Date September 6, 2011

Prepared By:

STARR
Strategic Alliance for Risk Reduction

TABLE OF CONTENTS

1. Introduction

1.1 Purpose

Terrain data, as defined in FEMA Guidelines and Specifications, Appendix M: Data Capture Standards describes the digital topographic data that was used to create the elevation data representing the terrain environment of a watershed and/or floodplain. Terrain data requirements allow for flexibility in the types of information provided as sources used to produce final terrain deliverables. Once this type of data is provided, FEMA will be able to account for the origins of the flood study elevation data.

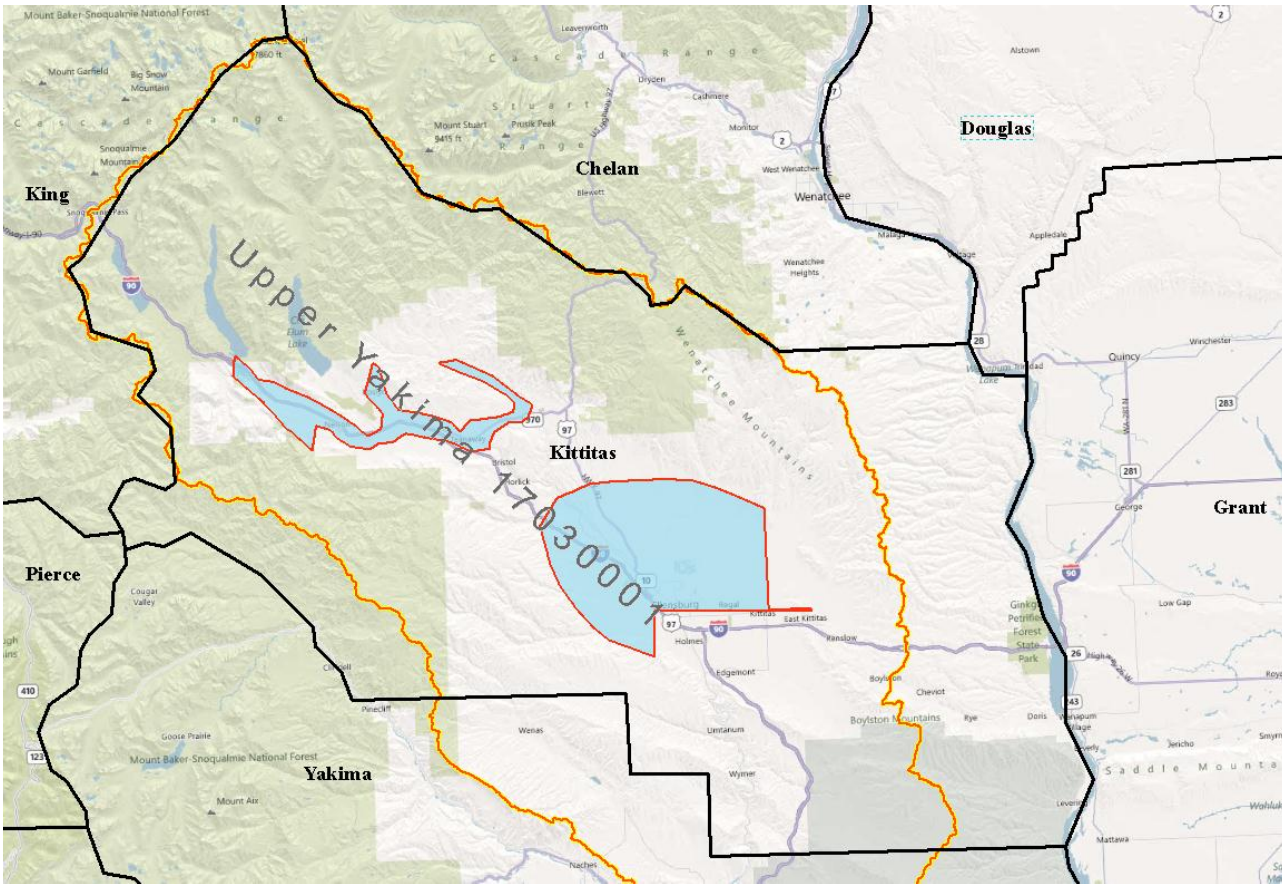
The purpose of these terrain datasets are to represent the topography of a watershed and/or floodplain environment for for riverine hydraulic and hydrologic modeling in Kittitas County Washington. All terrain data collected for hydrologic analysis, hydraulic analysis, floodplain boundary delineation, and/or testing of floodplain boundary standard compliance meets the requirements outlined in FEMA Appendix A: Guidance for Aerial Mapping and Survey and FEMA Procedural Memorandum 61: Standards for LiDAR and Other High Quality Digital Topography.

1.2 Project Synopsis

Base LiDAR point cloud data provided for this project is compliant with FEMA Guidelines and Specifications procedure memorandum 61. LiDAR acquisition and post processing was completed for the Concord River Watershed under FEMA Task Order No. HSFE01-10-J-0006 for FEMA case number 11-01-0110S. The LiDAR acquisition for an area of interest within Kittitas County Washington, consisting of 181 square miles, was captured to the “Highest” vertical accuracy requirement. This collection specification is the equivalent of a 2-foot contour accuracy with a nominal pulse spacing of 1-meter. Topographic datasets delivered to FEMA for Task Order No. HSFE01-10-J-0006 was used as the basis for topographic data development for the watershed under FEMA Task Order Number HSFE01-10-J-00002 to support riverine H&H analysis and floodplain boundary delineation.

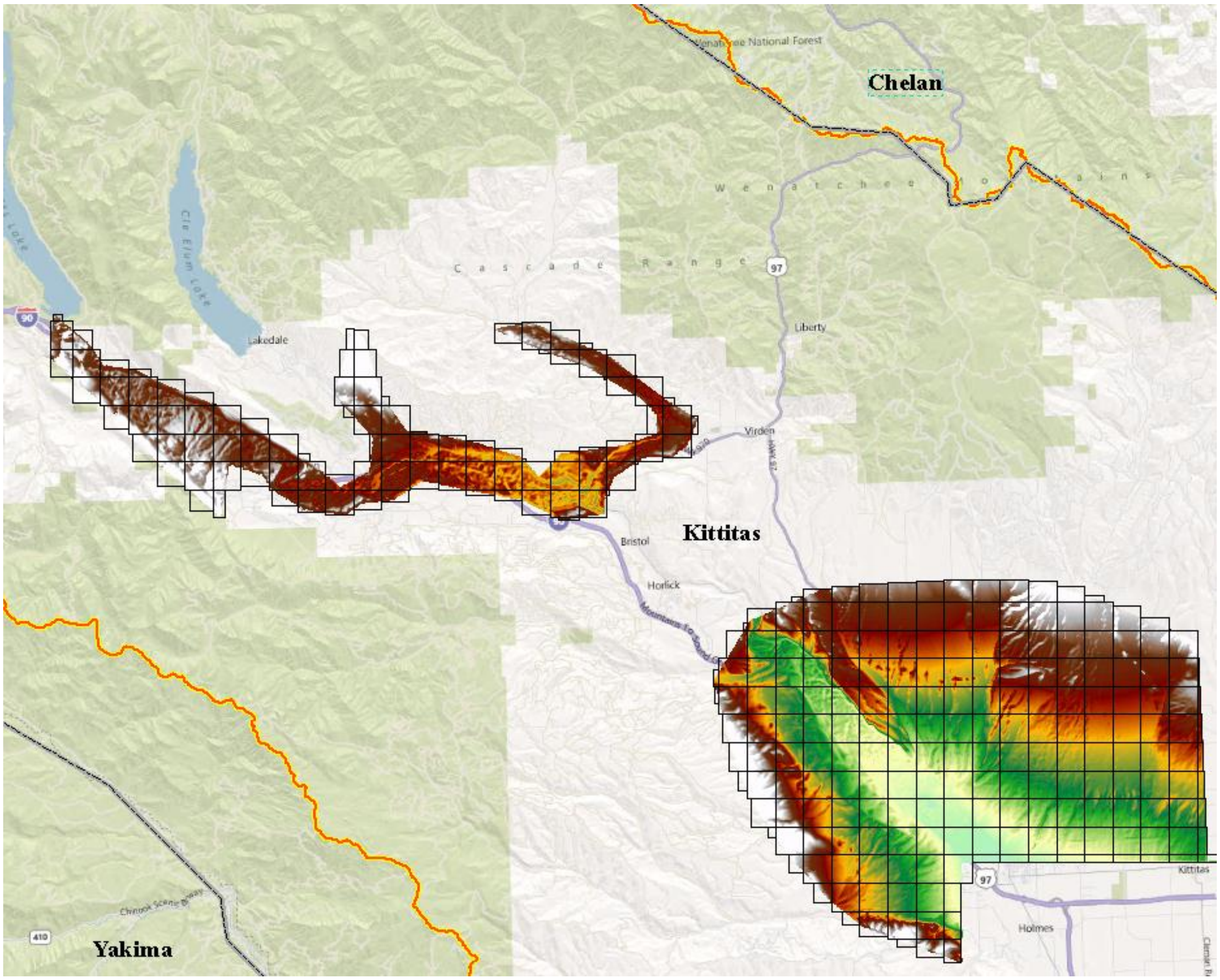
Kittitas is bordered by Chelan and Douglas Counties to the north, King County to the northwest, Yakima County to the south, Pierce County to the southwest and the Grant Countyto the east.   Towns located within Kittitas County are: City of Cle Elum, City of Ellensburg, City of Kittitas, City of Roslyn, and the City of South Cle elum in the Upper Yakima River HUC8 (17030001) watershed.

Figure 1- Kittitas County, WA Location



Fully classified LAS Bare Earth tiles were processed and provided to FEMA under Task Order No. HSFE01-10-J-00002. The LiDAR LAS tiles and derived products cover the entire 40 square miles collected.

Figure 2- Kittitas LiDAR/Products Coverage



2 Scope of Work

Topographic Data Development

Responsible PTS Contractor: STARR

- STARR will gather any available and existing topography from the communities and review the
- Certification documents to determine if it meets FEMA specifications for the level of study required.
- For counties in Table 1.0 listed as having LiDAR we will obtain the data and certification

Scope: STARR shall obtain additional topographic data of the overbank areas of the flooding sources and coastal floodplains studied. These data will be used for hydrologic analysis, hydraulic analysis, floodplain boundary delineation, and/or testing of floodplain boundary standard compliance as required in the SOP. STARR shall gather information on what topographic data is available for the given community and what accuracy and currency it meets. STARR shall use this topographic data when it is better than that of the original study. In coordination with the partner who performed scoping, ensure that the FEMA Geospatial Data Coordination Policy and Implementation Guide is followed and the data obtained or to be produced are documented properly. (If necessary, describe additional steps that may need to be taken to use the available data.)

For this activity, STARR also shall generate the data collected under this Topographic Data Development task and via field surveys to create a best available digital elevation model for the subject flooding sources. STARR shall confirm with the FEMA Regional Project Officer the automated appropriate data model(s) (i.e., contours, Digital Elevation Models (DEMs), Triangulated Irregular Network (TIN), mass points, and breaklines) for the intended use of the data.

For this activity, STARR also shall develop topographic maps and/or DEMs for the subject flooding sources using the data collected under this Topographic Data Development process and via field surveys.

Standards: All Topographic Data Development work shall be performed in accordance with the standards specified in Section 4 - Standards.
Deliverables:

In accordance with the G&S, STARR shall make the following products available to FEMA by uploading the digital data to the MIP and submitting in TSDN format in accordance with the schedule outlined in Section 5 - Schedule.

A metadata file complying with the NFIP Metadata Profiles Specifications, must accompany the uploaded G&S compliant digital data. Additionally, the TSDN format described in the G&S must be delivered in accordance with Section 2 – Technical and Administrative Support Data Submittal.

Where paper documentation is required by state law for professional certifications, you may submit the paper in addition to a scanned version of the paper for the digital record.

- Digital contour data;
- Report summarizing methodology and results;
- Mass points and breaklines data;
- Gridded DEM data;
- TIN data if needed;
- Checkpoint analyses to assess the accuracy of data, including RMSE calculations to support vertical accuracy;
- Identification of data voids and methods used to supplement data voids;
- National Geodetic Survey data sheets for Network Control Points used to control remote-sensing and ground surveys;
- Other supporting files consistent with the DCS in the G&S; and
- A Summary Report that describes and provides the results of all automated or manual QA/QC
- review steps taken during the preparation of the topographic data as outlined in the approved
- QA/QC Plan.

Independent QA/QC Review of Topographic Data

Responsible PTS Contractor: STARR

Scope: STARR shall perform an internal and impartial review of the mapping data generated by STARR under Topographic Data Development for the applicable projects listed in Table A.1 to ensure that these data are consistent with FEMA standards and standard engineering practice, and are sufficient to prepare the DFIRM. FEMA may audit or assist in these activities if deemed to be necessary by the Regional Project Officer.

Please note FEMA will also be performing periodic audits and overall study/project management to ensure study quality. STARR will be responsible for addressing comments resulting from periodic audits.

Standards: All Topographic Data Development work shall be reviewed in accordance with the standards specified in Section 4 - Standards.

Deliverables: In accordance with the G&S, STARR shall make the following products available to FEMA by uploading the digital data to the MIP. Additionally, the TSDN format described in the G&S must be delivered in accordance with Section 2 – Technical and Administrative Support Data Submittal.

This submittal will occur in accordance with the schedule outlined in Section 5 - Schedule.

- A Summary Report that describes the findings of the independent QA/QC review; and
- Recommendations to resolve any problems that are identified during the independent QA/QC review.

3 Information for the next Mapping Partner

LiDAR collected under FEMA Task Order No. HSFE01-10-J-0006 was collected and processed by STARR. Compass Data, Inc. performed the ground control survey and RMSE vertical quality control. Photoscience, Inc. performed the LiDAR Acquisition and LiDAR post processing. Greenhorne and O'Mara, Inc. performed Independent Quality Assurance of the base LiDAR products and produced the LiDAR derived products.

All LiDAR derived products for this project has been collected using the following spatial reference information:

Projection: Washington State Plane South
State Plane FIPS Zone: 4602
Linear units: US Survey Foot
Horizontal Datum: North American Datum 1983
Vertical Datum: North American Vertical Datum of 1988
Vertical units: US Survey Foot

3.1 LAS processing

Classified LAS data for KittitasCounty was used as the basis for topographic products. Due to automated processing procedures and quality reviews the LAS was selected as the base LiDAR product. LAS header files were checked to insure data consistency. By spot checking several tiles it was determined that the LAS files had a standard projection, linear units were identical, ASPRS classifications are present, and the elevation minimum and maximum values meet expectations for the project area.

Using the Point File Information tool in ArcGIS 3D analyst a LiDAR boundary grid was created that contains the file name, point count, point spacing, elevation minimum, and elevation maximum for each LAS file. This is compared with the header files to insure data reliability between the information in the header files and the actual spatial information. This grid is also used to determine the average point spacing by viewing the statistics of the point spacing field. The mean value is captured and compared with LAS metadata.

Once it is determined that the LAS files are ready to be used in terrain processing they are converted to a multipoint feature class and stored within a file geodatabase featuredataset. The featuredataset has the projection information that matched the LiDAR collection. The ArcGIS 3D Analyst tool LAS to multipoint is used to accomplish this. Once this is complete the LAS tiles are only used as a back up in the event of errors in processing.

3.2 DEM processing

Once all of the LAS files have been converted to a multipoint feature class digital elevation modeling can proceed. The first step in creating a DEM for the project is to determine the actual LiDAR extent. This area represents the actual area covered by points and not the LAS boundary. LAS files may not include "full" point coverage. ArcGIS Spatial Analyst is used to accomplish this by converting the multipoint feature class to a raster. From there a series of Spatial analyst tools are used to create the LiDAR coverage polygon. Once the extent has been created the next process is to create an ESRI terrain dataset. The terrain is composed of the multipoint feature class as mass points, the breaklines as hard lines, and the LiDAR collection extent as a soft clip. After the terrain has been created it is reviewed. This terrain is then converted to a floating point raster with a cell size of 5ft.

3.3 Contour processing

Once the DEM has been created the next step in the data processing is to generate contours. In order to create accurate cartographic contours an automated routine to reduce the noise is run on the DEM. Two foot contours created from the DEM are reviewed and given an integer contour value.

3.4 Quality Assurance

All products created under the develop topographic information are carefully reviewed to make sure datasets meet the needs for detailed coastal analysis. Datasets are organized and stored in Appendix M data capture standards formatting for delivery to FEMA.

3.5 Deliverables

Products delivered under this task order include:

- ESRI file geodatabase that contains LAS multipoint, LiDAR extent, LAS Information grid, and ESRI terrain.
- 5ft floating point DEM in ESRI grid format
- ESRI file geodatabase that contains 2ft contours.
- FEMA FGDC compliant terrain metadata record

Data will be uploaded to the MIP at this location:
J:\FEMA\R10\WASHINGTON_53\KITTITAS_53037\KITTITAS_037C\11-10-0110S\SubmissionUpload\Terrain\2141404\