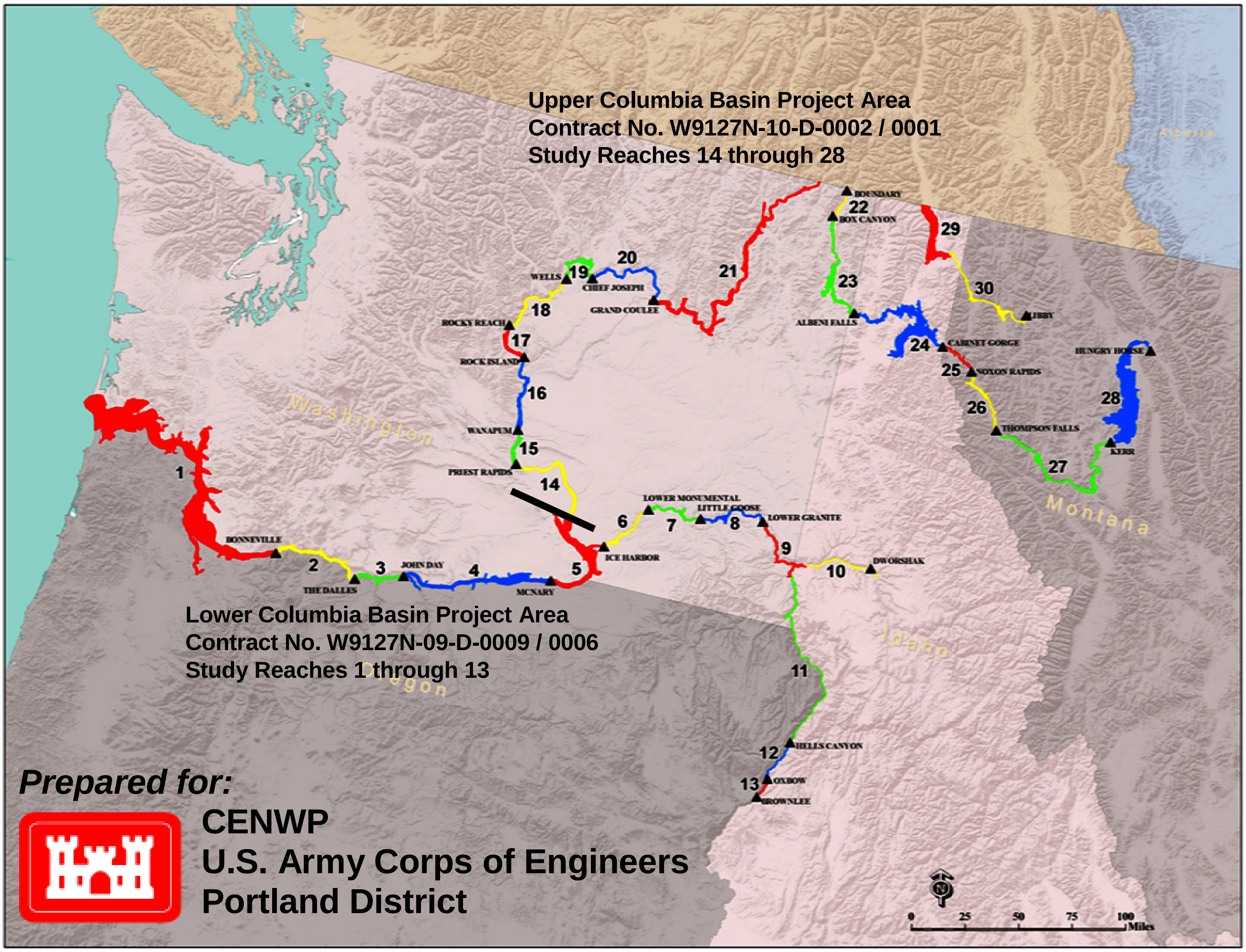
COLUMBIA RIVER LIDAR PROJECT

Contract No. W9127N-10-D-0002 / 0001 (Upper Basin Project Area)
Contract No. W9127N-09-D-0009 / 0006 (Lower Basin Project Area)



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1.1 Overview

The Columbia River Light Detection and Ranging (LiDAR) survey project was a collaborative effort to develop detailed high density LiDAR derived terrain data for the U.S. Army Corps of Engineers (USACE). The LiDAR data will be used to support hydraulic modeling work associated with proposed 2014 Columbia River treaty negotiations.

The survey area for this effort was divided into two project areas completed under two separate contracts. This report is a final combined summary for both project areas.

The Upper Columbia Basin survey area included the Columbia River between the Canadian border and the confluence with the Snake River, the Pend Oreille River between Hungry Horse Dam and the Canadian border, and the Kootenai River between Libby Dam and the Canadian border. The Lower Columbia Basin survey area included the remainder of the Columbia River downstream of the Snake River confluence to the Pacific Ocean, the Snake River up to Brownlee Dam and the Clearwater River up to Dworshak Dam. In total, the combined survey area between the two projects encompassed approximately 2,836 square miles of territory in four states (Oregon, Washington, Idaho, and Montana), under the jurisdiction of three Corps districts: Portland (CENWP), Seattle (CENWS), and Walla Walla (CENWW). CENWP was the project lead and primary contracting organization.

The two independent, but concurrent projects utilized the same project management and subcontractor project team. The Upper Columbia Basin project was completed under an on-call services contract held by AECOM. The Lower Columbia River Basin project was completed under an on-call services contract held by David C. Smith & Associates, Inc. Both contracts were managed by the CENWP and were carefully coordinated to ensure consistent and seamless work products.

1.2 Task Assignments

The Upper Basin project team consisted of the Prime Contractor, AECOM, and four subcontractors: David C. Smith and Associates, Inc. (DSA), David Evans and Associates, Inc. (DEA), Watershed Sciences, Inc., and CC Patterson and Associates. The Lower Basin project team consisted of Prime Contractor DSA and three subcontractors: DEA, Watershed Sciences and CC Patterson and Associates. The project teams worked collaboratively to manage and complete the tasks of LiDAR acquisition, data processing, and development of final deliverables. Task responsibilities, project workflow, and organization are summarized in Figure 1.1.

1.3 Scope of this Report

This report provides background information and serves as an overall summary report of work completed for the project. It does not include detailed technical reporting (metadata for ArcGIS deliverables, detailed LiDAR acquisition reports, and National Geodetic Survey [NGS] data sheets for all permanent control points), which was previously provided with project deliverables. Rather, it provides background and context for the detailed metadata and project reporting by providing a brief overview of key task items.

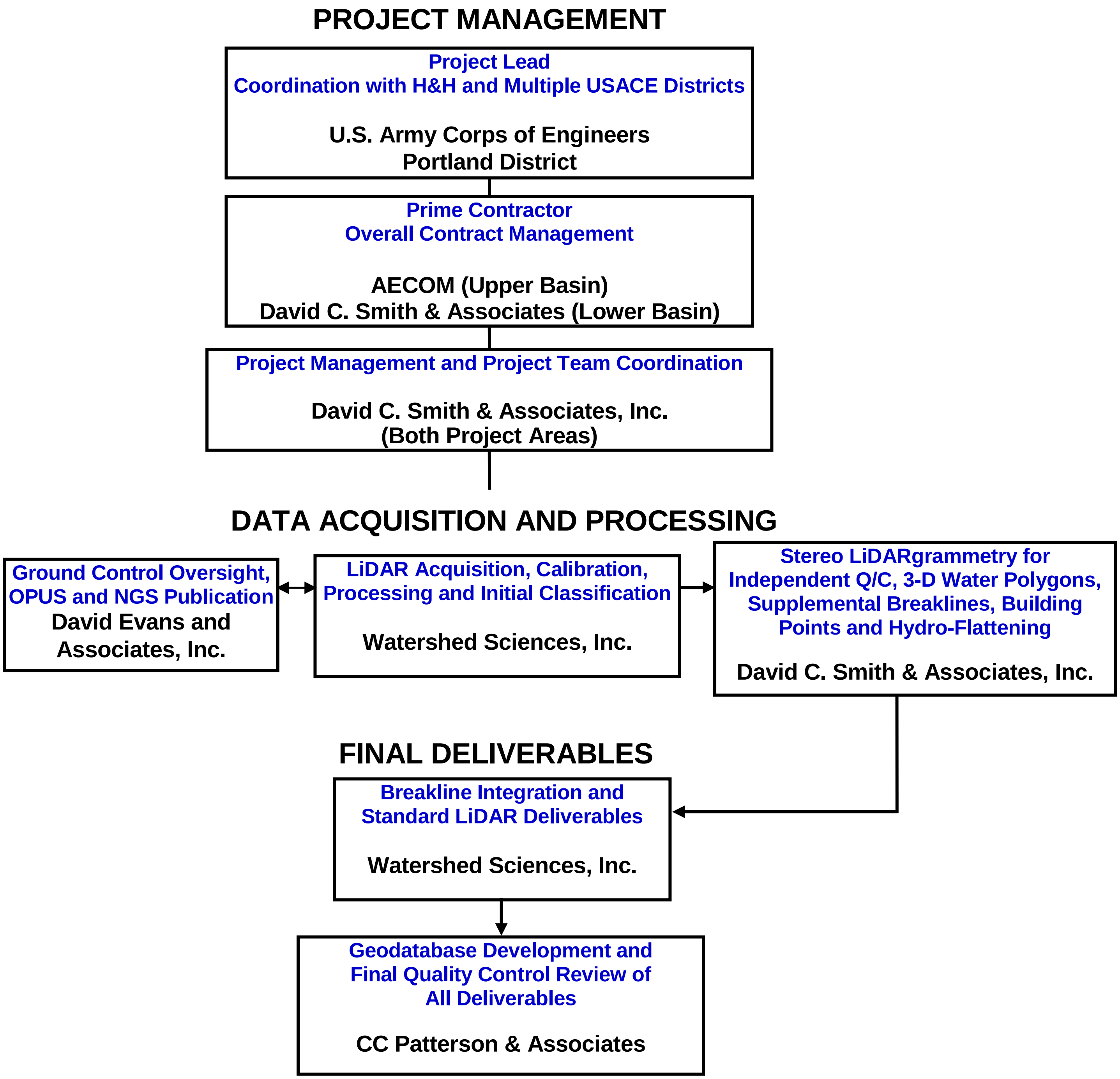

Figure 1-1 Project Organization and Workflow

2.0 Ground Control, Opus Solution, and NGS Publication

This task item was completed by Watershed Sciences and DEA. Watershed Sciences was responsible for control point field measurement and coordination of base station monitoring with the LiDAR flight missions. DEA was responsible for overall Professional Land Surveyor (PLS) supervision, NGS submittals, quality control, and oversight of ground control network for licensure compliance in all states. Specific DEA task items included the following:

1. Evaluation of all proposed points for consistency and suitability for proposed network.
2. Processing control network for Online Positioning User Service Database (OPUS-DB) solution for verification of base station results.
3. Preparation of data sheets and file control as required for compliance with State statutes.
4. Field survey quality checks on approximately 10% of the control points.
5. Final data sheet preparation for all points and submittal of new and upgraded points to NGS for publication. Final data sheets were provided in .pdf format as a contract deliverable, and were submitted previously.

All points (new and existing) were occupied, measured, and processed to NAVD ’88 with a Geoid ’09 solution and to meet requirements for publication in OPUS-DB. New points, where required, were established with cap and rebar. USACE caps provided by CENWP were used for this project.

Certification of the final primary control network and OPUS solution was performed by a PLS, registered in the state where the work was performed.

All primary points used for the survey were submitted to NGS for OPUS-DB publication. Additional secondary points were used for redundancy, but secondary points were not published.

All ground control (and subsequent LiDAR) data were established at NAD ’83 CORS 96 horizontal and NAVD ’88 Geoid ’99 vertical. As an exact transformation is not currently available in ESRI software, the horizontal datum may be represented by NAD ’83 HARN in ESRI deliverables.

3.0 LiDAR Data Acquisition and Initial Processing

Watershed Sciences was responsible for all aspects of LiDAR data acquisition and initial processing, including the following:

- Flight planning
- Base station monitoring
- Base station GPS measurements
- Field check accuracy / calibration checkpoints
- Data reduction
- LiDAR calibration
- Initial LiDAR data processing / edits for bare earth classification.

Flight missions for LiDAR data acquisition were planned on a weekly basis. Multiple aircraft and sensors were used, and planning of flight missions considered CENWP delivery priorities; GPS conditions; the overall acquisition schedule; and anticipated weather, vegetation and water level conditions within specific portions of the project area.

The preferred conditions for LiDAR data acquisition were leaf-off, snow-free and low water conditions. Preferred and acceptable conditions (if preferred conditions could not be achieved given GPS, mobilization, weather, schedule, or other considerations) were as follows:

- **Preferred water level –** Average daily flow or lower, as published by the U.S. Geological Survey (USGS)
- **Maximum acceptable water level –** Anything below the 75% exceedance, as published and indicated as “normal” flow on USGS water watch maps.
- **Preferred tide conditions (below Beaver)** – Low tide
- **Maximum acceptable tide conditions (below Beaver)** – Lower than the lowest of the two daily high tides.

In order to acquire data during preferred conditions while meeting other project needs, weekly phone calls were held that included Watershed Sciences project managers and flight planners, DSA project managers, the CENWP project lead, and the CENWP hydrologic and hydraulic (H&H) engineers responsible for overseeing future modeling work. The purpose of these calls was to discuss current conditions, determine the proposed acquisition schedule for that week, and to confirm that the proposed schedule priority and anticipated water level conditions were appropriate given the H&H modeling requirements.

Watershed Sciences prepared detailed reports for all aspects of the acquisition process, including calibration results and field survey accuracy checks, which were submitted with the Standard Contract Deliverables (see Section 5.0). For reporting, the project area was divided into 12 Delivery Areas, with a separate report prepared for each Delivery Area. Table 3.1 shows the final USACE geodatabase and model reaches that correspond to each report. Each report contains maps and data specific to a Delivery Area, as well as cumulative accuracy and density data appended from reports for lower numbered Delivery Areas. The final report (Delivery Area 12) contains complete, project-wide accuracy and density information.

Table 3-1 Acquisition Report and USACE Reach Cross Reference

Watershed Sciences Acquisition and Delivery Report	Project / Contract	USACE Geodatabase Reaches Affected
1, 2	Lower Columbia	1A (above Longview)
1, 2	Lower Columbia	5, 6, 7, 8, 9
3	Upper Columbia	14, 15, 16, 17, 18, 19
4	Lower Columbia	1B (below Longview)
5	Lower Columbia	5, 9, 10, 11
6, 6b	Upper Columbia	20, 21
7	Upper Columbia	22, 23, 24
8	Lower Columbia	2, 3, 4
9	Upper Columbia	25, 29
10	Upper Columbia	26, 27
11	Upper Columbia	28
12	Lower Columbia	11, 12, 13

Final Watershed Sciences delivery area indices and acquisition reports were included as a contract deliverable, submitted earlier.

4.0 LiDARgrammetry Quality Control Review and Breaklines

This task item was completed by DSA. The data produced by Watershed Sciences during LiDAR acquisition and initial processing (Section 3.0) were provided to DSA for review and editing. The resulting 3-D water polygons, classification edits and breakline edits were returned to Watershed Sciences for integration into the final data set and preparation of final deliverables.

LiDAR data acquisition and initial delivery of preliminary LiDAR data sets was phased into preliminary deliverable data blocks that were subsets of the 12 Delivery Areas discussed in Section 3.0. After a sufficient block of data within each acquisition area was calibrated, processed, and classified, preliminary data sets were provided to DSA for quality control review, water delineation, and breakline edits. The review and edit tasks were typically completed in one to two weeks, depending on block size and backlog.

The preliminary LiDAR data sets were processed by Watershed Sciences as complete through all calibration, accuracy verification, and standard bare earth processing steps, as would be typical for a LiDAR survey project that did not require water classification. In cases of obviously complex terrain or in shoreline/water areas, the review and edit phase of the initial processing was sometimes slightly less intensive in order to avoid redundant effort for areas that were to be addressed by later processes. But in general, the preliminary data sets were substantially complete through the standard level of processing consistent with Oregon LiDAR Consortium and other lidar projects in the region.

The primary purpose of this task was to meet the Statement of Work requirements for classification of water points and independent quality control review of the bare earth data. 3-D water polygons delineating all water bodies and 3-D stereo photogrammetry breaklines to improve terrain model accuracies and detail were value added benefits of choosing LiDARgrammetry as the preferred methodology to meet project requirements.

4.1 LiDARgrammetry

Softcopy photogrammetry with stereo imagery generated from LiDAR intensity data were used for the dual purpose of classifying water areas and as an independent quality control tool. This technology, often referred to as LiDARgrammetry, allows the classified LiDAR bare earth points to be superimposed on stereo three-dimensional (3-D) imagery generated from LiDAR intensities. Stereograms, or “pseudo” stereo images, were generated as overlapping left and right aerial views of the first return LiDAR intensity data. The LiDARgrammetry approach implements the same 3-D viewing screens, photogrammetry software, and technical expertise as conventional photogrammetric mapping from camera based imagery.

A LiDARgrammetry approach was selected for the following reasons:

1. Overall speed and efficiency.
2. The classified point data is viewed in a 3-D stereo environment directly on top of the raw points intensity imagery. This view of the data provides a much different perspective than the view during the initial processing phases, thus providing a truly independent review.
3. Missing ground features or classification issues could be quickly and efficiently corrected by digitizing 3-D breaklines, without having to go back and reclassify individual data points.

4. An accurate delineation between water and land is easier to interpret in complex shoreline situations (such as heavy vegetation or mud flats) than with automated methods or typical LiDAR data viewing tools that rely on shading and perspective views on a two-dimensional (2-D) viewing screen.
5. This approach facilitated the immediate value-added task of identifying scattered buildings and has the potential to facilitate future feature extraction tasks on a site-specific basis.

The following specific tasks were performed by DSA:

1. LiDAR stereograms were generated from first return intensities at a 0.3-meter pixel resolution. Pixel resolutions of 0.07 and 0.15 meters were evaluated and found to offer no accuracy or image clarity advantage.
2. Bare earth model key points (preserving an accuracy tolerance within ±0.07 meters of the original surface) were superimposed on the LiDARgrammetry imagery.
3. Water polygons for all water bodies greater than 2 meters in width were stereo-digitized as 3-D breaklines. Shorelines were digitized as depicted by the data for the date and time of acquisition. Shorelines were not artificially flattened. They were digitized within accuracies supported by the data to photogrammetric cartographic standards for 2' foot contours. Bare earth points and the first return intensity stereo imagery were used to interpret the shoreline; where obscured by vegetation or not accurately represented by bare earth points, the shoreline was interpolated at water level.
4. Supplemental digital terrain model breaklines were digitized for cliffs, hard breaks or other readily identifiable terrain features that were more than 0.5 meters in height and not sufficiently represented to within a 13-cm RMSE accuracy by the classified LiDAR ground points.
5. Concurrent photogrammetric review of the bare earth model was performed to identify any remaining ground classification edits required; vegetation misclassified as ground was delineated with a polygon for reclassification in the final deliverables.
6. Building points were digitized for scattered buildings; clustered buildings and dense developments were outlined with a polygon to facilitate digitizing their locations from orthophotographs later. This was a secondary task not specified in the original scope of work.
7. A final check of all water polygons was performed by comparing water polygons to Google Earth imagery; any water areas that appeared suspect based on the image comparison were double checked in the LiDARgrammetry imagery.

4.2 LiDARgrammetry Accuracy and Results

Comprehensive field checks for absolute accuracy of the breakline data and final bare earth model were not performed. However, the general overall suitability of the LiDARgrammetry process was assessed in two ways:

- The approximate relative accuracies of points read with the LiDARgrammetry process compared to the source LiDAR TIN were evaluated.
- Absolute accuracies for the bare earth model and the breakline data were compared to photogrammetric mapping from controlled photography at two test sites.

To evaluate the approximate relative accuracy of the LiDARgrammetry points compared to the source LiDAR data itself, 20 test points on hard, flat surfaces were measured. Points were from three separate regions of the project. The points were digitized photogrammetrically from the LiDARgrammetry imagery, and were not snapped to the LiDAR surface. To represent worst-case conditions for the test, bare earth points were not superimposed to provide a visual cue; however, during the actual mapping task these points would be present. The z value from the photogrammetric measurements was then compared to z values computed from the LiDAR points. The purpose of this test was to confirm that the process was sufficient to meet Request for Proposal (RFP) specified accuracies. A more comprehensive test would be required to compute a precise relative accuracy. It should also be noted that in areas of rough terrain or where obscured by vegetation, the ground surface would be harder to read from the imagery and slightly lower relative accuracies would be expected. The results of the accuracy evaluation are summarized in Table 4.1.

Table 4-1 Relative Accuracy of 20 LiDARgrammetry Test Points

Minimum error (absolute value)	0.01 m
Maximum error	0.13 m
Root mean square error	0.06 m
Average error (including ± results)	0.01 m

Spot-checking for absolute accuracies was also performed using controlled stereo imagery flown for independent engineering design accuracy photogrammetric projects at two different project sites. Due to uncertainties in the local vertical and horizontal datums used for the engineering work, a meaningful statistical analysis was not possible within the scope of this project. However, spot-checking several well-defined points and performing a general overall review indicated that the maximum absolute accuracies of the final bare earth model were consistently within the 13-cm value required for the RMSE to meet RFP specified accuracies.

The LiDARgrammetry approach was found to successfully meet project goals. While slightly less accurate than the LiDAR data points themselves, the digitized breaklines were found to be consistent with the relative accuracies of the LiDAR data, and within RFP specified accuracies. The process proved to be a very cost-effective means of delineating water boundaries for hydro-flattening and classification purposes. Added benefits included detailed 3-D breaklines as an improved interpretation of shoreline boundaries, the ability to provide an independent review of the data, and the ability to add 3-D breaklines to improve accuracies for features in rough terrain that could not be classified easily with the standard LiDAR classification tools.

5.0 Standard LiDAR Deliverables

Watershed Sciences incorporated the water polygon and supplemental breakline data provided by DSA to prepare the final set of "standard" lidar data deliverables. The format and content of the standard contract deliverables generally followed that of the Oregon LiDAR Consortium projects, with a few key exceptions: 1) All point data are in a single classified .LAS file, with classifications added for model key points (class 8) and bare earth water points (class 9); and 2) Final bare earth DEMs incorporate the 3-D vector breaklines for better representation of flattened or evenly sloped water surfaces and for improved accuracies for hard breaks and areas of rough terrain not depicted by the initial bare earth LiDAR classification.

Bare earth DEMs were generated from a TIN developed by combining the 3-D vector data with the Class 2 (ground) and Class 8 (model key) points from the .LAS files. Class 9 water points were not used in the bare earth DEMs. Breakline data was delivered as 3-D vectors in AutoCAD format and in geodatabase format. The 3-D vectors were not populated as points and were not incorporated into the final .LAS data sets. As such, producing bare earth DEMs requires using both the .LAS point data and the AutoCAD or geodatabase vector break line data.

The standard lidar deliverables produced by Watershed Sciences provided under this contract include the following:

- Detailed reporting
- Shape file indices
- Aircraft trajectories (as SBET attributed shape files)
- All returns LAS files (ASPRS v. 1.2) tile by 0.75 minute quadrangle boundaries with classifications for ground (2), unclassified (1), model key point (8) and water (9)
- Bare earth 1-meter ESRI grid format DEMs tiled by 7.5 minute quadrangle boundaries, generated from a TIN which included key supplemental breaklines and water polygons
- 1-meter ESRI grid format top surface DSMs tiled by 7.5 minute quadrangle boundaries
- 1-meter intensity images in GeoTIF format tiled by 0.75 minute quadrangle boundaries.

These deliverables were submitted in phases for the 12 Delivery Areas, as discussed in Section 3.0. At project completion, the final delivery was combined onto a single set of hard drives containing all deliverables for both the Lower and Upper Columbia Basin projects. One 2-TB hard drive contained all.las point data, and a second 2-TB drive contained all derived deliverables (DEMs, DSMs and intensity images).

Geospatial data were tiled based on USGS quad boundaries and delivered in UTM projections covering UTM Zone 10 and UTM Zone 11. For the Lower Basin Project area, all areas east of latitude 120 were delivered in UTM 11 and all areas west of latitude 120 were delivered in UTM 10. For the Upper Basin Project area all areas were delivered in UTM 11, even though some portions of those reaches extended slightly to the west of latitude 120. This was necessary in order to have a single datum within a full modeling reach.

6.0 Final Quality Control Checks and Geodatabase Development

To verify format, completeness, and overall quality, all standard lidar deliverables from the 12 Delivery Areas were segregated into final USACE modeling reaches (see Table 3.1) and loaded into an ArcGIS geodatabase. Each geodatabase includes all standard deliverables for that modeling reach, including overlap with adjacent reaches. The geodatabase methodology was selected as the best way to perform a final quality control check on the standard lidar deliverables because of the efficiency of the process and because it would produce a value-added deliverable that could be used to efficiently store, share and maintain the very large and complex lidar data sets.

Each modeling reach geodatabase includes the following components:

- All point data as a multipoint feature class (with the exception of water points classified as no data points)
- All water polygons
- All 3-D breakline data
- All derived DEM, DSM and intensity image data
- Point density images generated as a quality control check.

Dam sites were generally used to define the modeling reaches. Data for each modeling reach extended both above and below the dam to provide overlap between adjacent reached. Building point data were provided as an overall CAD file, but were not included in the geodatabase.

The specific final quality control check included the following steps:

1. Load/verify all .las data
2. Load/verify all raster data
3. Generate point density images as quality control check
4. Visually review all data for edge match and completeness
5. Perform an overall final review of the data by generating hillshades for selected areas and/or comparing to NAIP imagery.

The final geodatabase incorporated detailed metadata for all data sets and processes. The expectation and intent was for the geodatabase to be the primary deliverable for use in ArcGIS applications.

Geodatabase development for Modeling Reach 1 was a special case. The geodatabase for Modeling Reach 1B includes integrated bathymetric data sets as well as a final terrain. The bathymetric data integration, geodatabase development and terrain generation for Modeling Reach 1B was done under Contract No. W9127N-09-D-0009, Task Order No. 5 and is detailed in a separate project report.