Lower Columbia River Digital Terrain Model Development
Contract No. W9127N-09-D-0009, Task Order No. 0005
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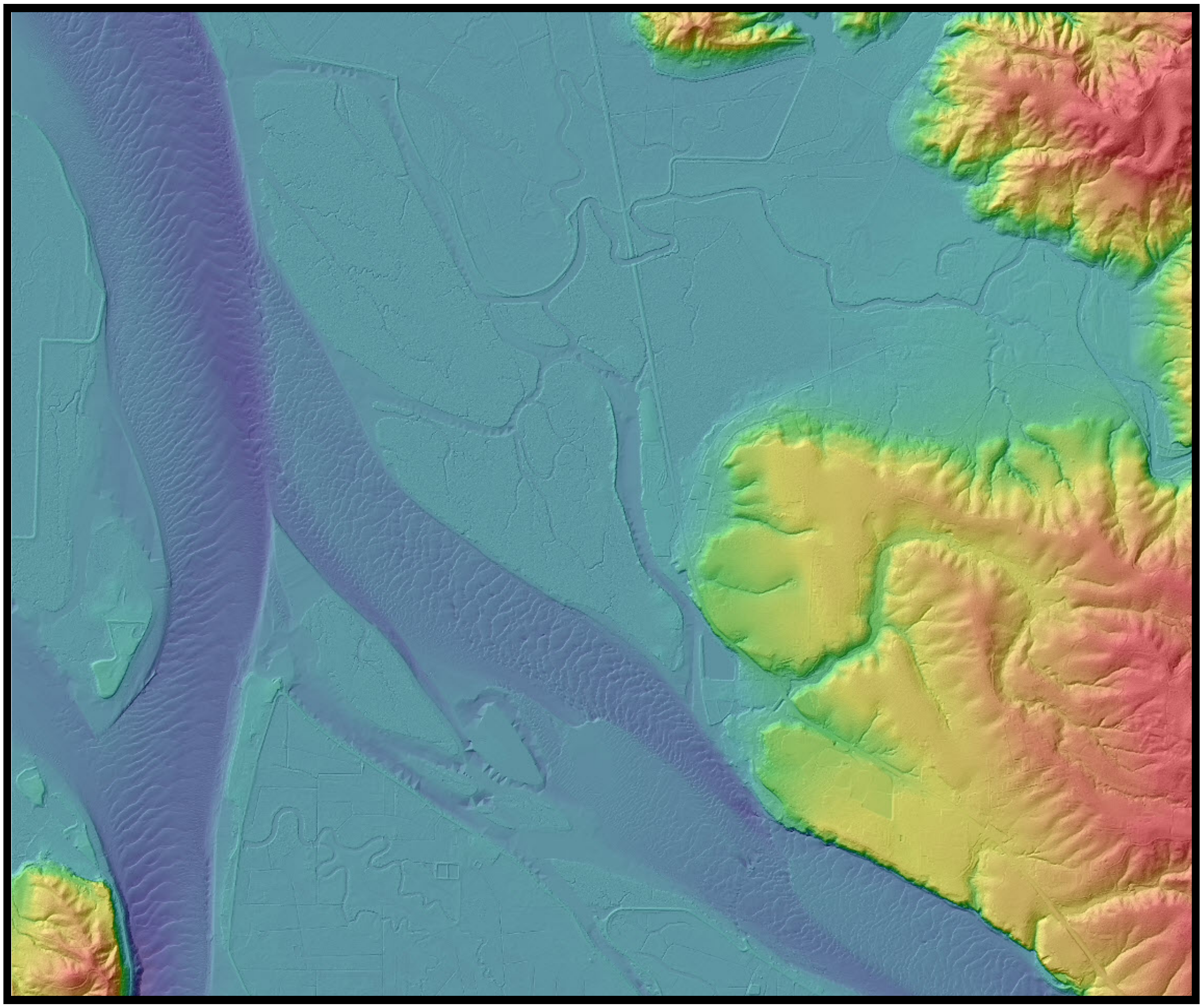

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Acronyms and Abbreviations

ASCII	American Standard Code for Information Interchange
CRD	Columbia River Datum
DEA	David Evans and Associates, Inc.
DSA	David Smith and Associates, Inc.
DTM	Digital Terrain Model
HIPS	Hydrographic Information Processing System
LCREP	Lower Columbia River Estuary Partnership
LiDAR	Light Detection and Ranging
MLLW	Mean Lower Low Water
NAD83	North American Vertical Datum of 1983
NAVD88	North American Vertical Datum of 1988
NOAA	National Oceanic and Atmospheric Administration
USACE	United States Army Corps of Engineers
UTM	Universal Transverse Mercator Projection

1.0 INTRODUCTION

This project was undertaken to provide a combined topographic and bathymetric digital terrain model (DTM) for the Lower Columbia River. The scope of the project covers the generation of a DTM combining bathymetric data that already exists in the study area with new LiDAR data that was acquired concurrently under a separate task order (W9127N-09-D-0009, Task Order No. 0006).

The purpose of the project is to support hydraulic modeling efforts related to the Columbia River Treaty negotiation of 2014. This model will be used to establish a base dataset and to identify areas of insufficient existing data coverage which may require additional future survey work.

The project team consisted of the Prime Contractor, David Smith and Associates, Inc. (DSA) and two subcontractors: David Evans and Associates, Inc. (DEA) and CC Patterson and Associates.

DSA was responsible for overall project management and for the technical role of using stereo photogrammetry tools to review, edit and merge the different data sets. DEA was responsible for acquiring, compiling and prioritizing the best available existing bathymetric data sets. CC Patterson and Associates was responsible for development of the final ArcGIS geodatabase and terrain deliverables.

Specific task responsibilities were as follows:

<u>DSA</u>

Overall project management
3D breaklines to "train" TIN legs for cross section and single beam datasets
3D polygons to blend and stitch multiple bathymetric datasets into a seamless dataset
Delineate gaps in coverage with a 3D polygon
Stitch and integrate bathymetric datasets with LiDAR data using 3D water polygons developed under separate task order (Task Order No. 6, Lower Columbia Basin LiDAR)

<u>DEA</u>

Research and compile best available data sets.
Complete Columbia River Datum model
Decimate LCREP single beam data and other data as appropriate
Convert all data sets to single final horizontal and vertical datums
Generate reporting information and metadata for bathymetry data and v-datum model

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Combine all data sets into a single geodatabase, maintaining and updating metadata for the process, priority and assumptions used.
Generate final terrains to be included in geodatabase, including a quality control review and edits to supplemental breaklines and breaklines between adjacent data sets as needed for correct TIN generation.

Specific assumptions, process steps and results are summarized in the remaining sections of this report.

2.0 BATHYMETRIC DATA

As a subcontractor to DSA, DEA compiled existing bathymetric datasets on the Lower Columbia River. The project area on the Columbia River extended from Bonneville Dam, at river mile 146.5, downstream to river mile 0.0 and extended into the Pacific Ocean over a 3 mile radius from river mile 0. On the Willamette River the project extended from Willamette Falls at river mile 27 downstream to river mile 0 at the confluence with the Columbia River.

2.1 Data Mining

No single data set exists to cover the extent of the project area. To obtain the maximum coverage over the project area an extensive data research effort was employed to mine data from a variety of sources. The data mining effort resulted in a wide array of surveys with varying accuracies, projections, units, and methodologies with dates ranging from 1851 to 2010. Sources of the data consisted of USACE single beam surveys, multibeam data collected by DEA for NOAA and the USACE, single beam surveys conducted by DEA on personal watercraft for the Lower Columbia Estuary Partnership (LCREP), NOAA historic smooth sheet data, and U.S. Bureau of Reclamation ADCP data collected on the Sandy River. The most comprehensive data set consisted of high resolution multibeam data collected by DEA for NOAA to update nautical charts of the Columbia from river mile 110 to 30. This data set consisted of a 0.5 meter grid of multibeam bathymetric data with some single beam bathymetric data in shallow water. Detailed descriptions of the various data sets are included in the imbedded metadata.

2.2 Datum Transformations

The horizontal datum for the final terrain model is the North American Datum of 1983 (NAD83) using the Universal Transverse Mercator Projection (UTM) Zone 10 North with positions in meters. The vertical datum is the North American Vertical Datum of 1988 (NAVD88) with elevations in meters. Original data files were in a variety of horizontal projections, vertical datums and units. The bulk of the bathymetric data was collected on chart datum which is Mean Lower Low water (MLLW) below Harrington Point and Columbia River Datum (CRD) above Harrington Point to Bonneville Dam and Willamette Falls. DEA, working with the Portland District and NOAA, compiled a model of chart datum relative to NAVD88 using CRD from Willamette Falls to the Columbia River on the Willamette and from Bonneville Dam to Harrington Point on the Columbia. Below Harrington Point, the NOAA VDatum model of the relationship between MLLW and NAVD88 was used. The model was smoothed to remove anomalies and blended into the CRD model for a comprehensive model of chart datum relative to NAVD88 for the Columbia and Willamette Rivers. A discussion about model development is incorporated in Appendix A.

Using CorpsCon 6.0.1, source data was converted to the UTM Zone 10 projection and units were converted to meters. DEA developed binary files from the chart datum model relative to NAVD88 that were compatible with CorpsCon. These binary files were used to simultaneously convert source data that was on chart datum to NAVD88 while also projecting coordinates to UTM Zone 10 with all resultant data in metric units using CorpsCon.

2.3 Compilation and Prioritization

Multibeam bathymetric data were provided as gridded datasets with a constant distance between successive points. Caris HIPS hydrographic information processing software was used to process all sounding data into a gridded surface. The gridded data was exported from HIPS as a comma delimited xyz ASCII file. Single beam bathymetric data were sorted in a variety of methods depending on the source data. When possible, a dense data set was used for single beam data. DEA acquired data for LCREP at a line spacing of 50-meters (164-feet) with data thinned to 2 meters (approximately 6-feet) along line. Typical USACE archived single beam data is thinned to every 75 feet for the 1:5000 dredging charts of the Columbia from cross-section lines spaced at 500 feet. When available, a denser data set along line was provided to DSA to supplement the sparse 75-foot spaced data.

The 75-foot spacing was found to be appropriate in most circumstances. Denser data sets produced more tin leg artifacts and only improved accuracy in localized areas. For that reason the 75-foot, final edited data sets were used as the primary data set. When denser data was available, a rough densification algorithm was used to evaluate the primary 75-foot spacing data and densify the data set where needed to capture significant terrain breaks. The densification process was as follows: A TIN was generated from the 75-foot spacing data. For each point in the denser data set, the difference between the point elevation and the elevation computed from the coarse data set TIN was computed. If the difference was great than a 0.5 meter tolerance, the denser point was added to the final data set and the evaluation TIN. The algorithm was run iteratively. This resulted in an over densification of points in a few locations. Additional thinning was not performed unless it caused unacceptable artifacts in the final TIN.

After transforming the bathymetric data to a common horizontal projection and vertical datum, bounding 3-D polygons for each dataset were created. Many of the surveys overlapped spatially making it necessary to prioritize surveys to be used in the merged bathymetric model. In areas with overlap the survey with highest priority was used and any portions of surveys with lower priority were clipped from the final model.

Priority was determined using three factors; date of acquisition, survey methodology, and spatial extent. Recent multibeam surveys were given priority over recent single beam surveys, which in turn were given priority over older single beam and lead line surveys. Spatial extent of a survey was also considered. If two surveys overlapped and had similar dates of acquisition and survey method, priority was given to the survey with a greater spatial extent to reduce the total number of surveys required in the model.

The river bed of the Lower Columbia River is dynamic with 15-foot high sand waves that can travel up to 3-feet per day. Further, dredging activities and runoff events can have significant impacts to the geomorphology of the river bed. That said, age of data is an important consideration and should be taken into account when decisions are made to update subsets of the final model.

3.0 TOPOGRAPHIC LIDAR

New topographic LiDAR within the project area was acquired under separate contract (Contract No. W9127N-09-D-009, Task Order NO. 0006) between 12/02/2009 and 2/22/2010. LiDAR acquisition targeted flows below average daily flow. Below Beaver, acquisition targeted low tide. In order to meet acquisition schedules given weather and leaf off requirements, maximum acceptable water levels were flows lower than the 75% exceedance. Maximum acceptable tide (below Beaver) was the lower of the two daily high tides.

The water/land interface was determined using stereo photogrammetry with LiDAR derived intensity images (LiDARgrammetry). 3D polygons were used to delineate all water areas. LiDAR points within the water were reclassified and excluded from the terrain models, relying on the 3D breaklines to define the water surface. These 3D water polygons were used as the basis for merging and integrating the LiDAR and bathymetric data sets.

Detailed information on the LiDAR acquisition and processing is provided in the LiDAR data set metadata and summarized in the Columbia River LiDAR Project summary report.

4.0 DATA INTEGRATION AND BREAKLINE PROCESS

Source bathymetric data from overlapping data sets were reviewed and merged using softcopy photogrammetry methods in a stereo 3D environment. Overlapping data sets were evaluated based on assigned priorities and clipped to create a seamless data set. In general, lower priority data was clipped to the extents of the higher priority data set. In some cases where this resulted in sharp breaks between data sets, the higher priority data sets were clipped back slightly in order to create a more seamless coverage. Data sets were considered to be seamless if the overlapping data fit within 1m. Elevation differences between overlapping data sets of greater than 1m were considered to be mis-matches and delineated with a "Dataset_mismatch" polygon.

The merged bathymetric datasets were then reviewed and merged for integration with the LiDAR shorelines using the same stereo 3D process. In areas of overlap, the bathymetric data was trimmed back to merge smoothly with the 3D LiDAR shorelines. The LiDAR was given precedence in all cases. For gap areas a TIN was generated and evaluated. If the transition appeared to reasonably match the trend of surrounding data, then the TIN was allowed to merge across the gap for development of the final terrain. The general target was to merge the data within a 1 meter tolerance, though this was largely subjective and the actual accuracy in no data areas could vary widely. If the gap introduced obvious artifacts or was so large that the transition did not appear to be a reasonable interpolation, then the gap was delineated as a "hole" polygon to be omitted from the terrain.

As additional quality control on the bathymetric data integration and TIN development, an initial TIN was generated and reviewed in stereo in conjunction with merging the datasets. The default TIN was evaluated and edited if it appeared to have erroneous TIN legs that would impact the terrain by more than an acceptable tolerance. For the 500' crossline data and other coarse datasets, a general criteria of 1 meter was used. For denser datasets a criteria of 1/2 meter was used. For erroneous TIN legs outside the target tolerances, breaklines were added to better shape the TIN. Breaklines were added where there were small gaps between data sets and within single beam cross section data sets to better model TIN connections between cross sections. In some cases, individual points or groups of points were deleted to improve the TIN development. This was particularly the case with "return" or "candy cane" pieces at the ends of the cross lines. This data was left in if it fit within the TIN and deleted if it introduced erroneous TIN legs outside tolerance.

No breaklines were required internally within the multibeam data sets. If observed in conjunction with the merge and breakline process, some individual points or outliers were deleted as necessary. Multibeam data sets were not thoroughly reviewed for outliers; it was assumed the data sets were final as delivered.

5.0 GEODATABASE

CC Patterson and Associates performed a final review of all data and metadata, compiled final geodatabases and metadata and prepared final terrains. The project area for the combined bathymetry/LiDAR datasets is a subset of CRT modeling Reach 1 and was delineated as CRT_Reach01 in the final GIS deliverables. All bathymetric and source LiDAR data was compiled into a single geodatabase as the source library datasets. A separate geodatabase was produced to store and manage the final blended terrain.

CRT_Reach01a_Terrain_v3.gdb is the completed version of the combined LiDAR/bathymetric terrain for the Columbia River Reach 1. It combines the LiDAR ground model with a mosaic of best-available bathymetric data to model the entire riverbed, adjacent floodplain, and bounding terrain. The LiDAR surface model (including structures and vegetation) is provided in CRT_Reach01b_LiDARDSM.gdb, a second geodatabase for Reach 1.

The final combined terrain model is tiled into 6 Terrain tiles (A, B, C1, C2, D, E) in order to most efficiently process, maintain, and update the combined bathymetric/LiDAR surface model for the entire Reach 1 modeling area. Each Terrain is contained in the geodatabase inside the Terrain Feature Datasets. DEMs and DEM hillshade images exported from each Terrain at 1m cell resolution are included as raster datasets in the final geodatabases.

CRT_LIB.gdb is the library database containing the complete (unclipped) version of all datasets contributing to the Columbia River terrain composite. The purpose of this library geodatabase is to manage and archive all bathymetric and LiDAR basic terrain data contributing to the CRT data model. As updated data become available for subareas of the model, these data should be added to the data archive library, and used to generate updated versions of the geodatabase terrain data models.

The geodatabase GIS deliverables are set up to allow best available current surface models to be extracted in a wide variety of data formats for any subarea of the river channel and floodplain below Bonneville Dam using standard GIS software and tools.