in alignment offsets due to sensor remounting and sonar strikes on submerged objects. Additional discussion on calibration tests can be found in the OPR-N338-KR-08 DAPR.

B4. Data Processing (Data Representation)

CUBE surface resolutions and depth ranges were set in accordance with the NOS *Hydrographic Surveys Specifications and Deliverables* (April 2007). Final CUBE surfaces were created at a 50-centimeter resolution to meet Object Detection requirements. Some data gaps exist in the 50-centimeter grids, however the grids still meet coverage requirements for the survey. Near shore coverage, in some areas less than 4 meters used, Set Line spacing and gaps are present between survey lines. Additionally, coverage outside of the maintained channel only required a one meter resolution and small data gaps may be visible in the 50-centimeter surfaces, but still meet requirements in these areas.[14] Complete Coverage requirements were met and all data gaps, three nodes or greater, were filled prior to ceasing survey operations.

In order to keep CUBE surfaces at a manageable size, the main survey area was broken up into six Field Sheets organized by corresponding Columbia River mile (H11856_CRM_61-63, etc.). When combined the Fields Sheets encompass the entire area of acquired multibeam bathymetry. A BAG was created for each finalized CUBE surface and both the CUBE and BAG surfaces have been included with the digital data.

C. HORIZONTAL AND VERTICAL CONTROL

Due to the CRD, the project chart datum, being a non-tidal gradient datum and the complex hydrodynamics of the Columbia River, the project chart datum, OPR-N338-KR-08 was approved as a pilot project for the use of GPS water levels acquired directly at the survey vessel. With the exception of tide reduction of baring features, traditional zoning from water level stations was not used for this project though zoning provided by Center for Operational Oceanographic Products and Services (CO-OPS) and verified water level files for the survey have been included with the digital deliverables

Prior to survey acquisition, three GPS base stations with a dual frequency (L1/L2) receiver were established in Washington at Kalama and Longview and in Oregon at the Beaver Army Terminal. The base stations logged raw dual frequency (L1/L2) GPS observables at one second epochs as well as broadcast real-time kinematic (RTK) corrections to the survey vessels. The base station closest to the area surveyed broadcast the RTK correctors. This base station was later used to post-process the navigation data. Base station positions relative to the North American Datum of 1983 (NAD83) (CORS96) (Epic 2002) were derived from the NGS (National Geodetic Survey) On-line Positioning User Service (OPUS) and were based on a 24-hour data file, with one second-epoch logging prior to commencement of survey operations.

A separation model of CRD relative to NAD83 was created and formatted to allow for direct integration with Hypack and Caris HIPS. The model input used a river profile of CRD relative to NAVD88 provided by the U.S. Army Corps of Engineers, Portland District (the designated stewards of CRD). GEOID 03 was used to transfer the NAVD88 to CRD relationship directly to the NAD83 ellipsoid, which allowed direct computation of GPS water levels from ellipsoid

heights recorded at the survey vessel. The model file (.bin) used to compute GPS water levels in HIPS, has been included with the digital deliverables.

RTK navigation was logged during acquisition and applied during preliminary data processing, but ultimately overwritten with a post-processed Inertially-Aided Kinematic Ambiguity Resolution (IAKAR) navigation solution. The HIPS Load Attitude and Navigation tool was used to load position, GPS height, and attitude data from a smoothed best estimate trajectory (SBET) file create from Applanix POSPac.

A complete description of horizontal and vertical control for survey H11856 can be found in the OPR-N338-KR-08 *Horizontal and Vertical Control Report*, submitted under separate cover.[15] A summary of horizontal and vertical control for this survey follows.

C1. Vertical Control

The vertical datum for this project is the CRD, an adopted low-water gradient datum relative to NAVD88. There are known problems in the NGS level lines between Oregon and Washington due to the long level runs without the ability to run tie lines across the Columbia River. GPS observations have documented large vertical differences in published bench mark elevations across the Columbia River. Whereas CO-OPS water level gauges are located in Oregon and Washington and are directly referenced to NGS published bench mark elevations, and the known issue with the level lines between Oregon and Washington, a decision was jointly made by the US Army Corps of Engineers and NOAA to use NGS OPUS solutions to establish vertical consistency in the relationship of CRD relative to NAVD88. The U. S. Army Corps of Engineers, Portland District (designated stewards of CRD) conducted surveys that established OPUS derived NAVD88 elevations on historic bench marks referencing CRD. A result of these surveys was a profile of Columbia River Datum relative to OPUS derived NAVD 88 elevations which were consistent across the Columbia River. The profile defined CRD relative to NAVD88 for each River Mile (RM) from RM 23 to RM 145 on the Columbia River and RM 0 to RM 26 on the Willamette River. This profile is used by the Portland District for hydrographic surveys and dredging operations to maintain the Federal Channel on the Columbia and Willamette rivers.

To improve vertical accuracy of this survey, soundings were reduced to CRD using GPS water levels measured at the survey vessel. Water levels were derived from post processed GPS heights and application of a separation model of the CRD to NAD83 ellipsoid relationship. Data reduction procedures, including detailed discussions of the CRD model generation and GPS water levels computations, for survey H11856 are detailed in the *OPR-N338-KR-08 Data Acquisition and Processing Report*.

To verify GPS water levels, a comparison was made by vessel static observations adjacent to the CO-OPS water level station 9440422 located in Longview, WA. . To obtain water levels relative to the CO-OPS defined CRD, the hydrographer selected Station Datum when downloading data from the CO-OPS web site. This is consistent with obtaining CRD values for any CO-OPS station on the Columbia River above river mile 23. Adjustments were required to correct CO-OPS water level data to CRD based on the updated USACE CRD profile used to maintain the Columbia and Willamette rivers. An additional adjustment was applied to correct local tidal

bench marks with orthometric heights based on NGS level lines to OPUS derived NAVD88 elevations to match the USACE profile and eliminate errors from distorted level lines. As a result of these comparisons, the hydrographer discovered a large deviation from the CO-OPS data reported from station 9440422 in Longview, WA. After running digital levels and recording a 1-hour series of water level observations with an optical level, it has been determined that the CO-OPS water level station in Longview, WA (9440422) is incorrectly reporting water levels relative to the station tidal bench marks and should be corrected by -0.071 meters to match CO-OPS tidal bench marks. CO-OPS is aware of this issue and is working toward resolving the problem. It should be noted that these adjustments were applied to CO-OPS water level data for comparison purposes of water level data relative to the revised USACE profile relative to OPUS derived NAVD88 elevations. This method was approved for project OPR-N388-KR-08 by the Office of Coast Survey, Hydrographic Surveys Division Chief as it is consistent with the USACE, Portland District, methods for maintaining the Federal Channel in the Columbia and Willamette rivers. Further, CO-OPS should adjust water level stations on Columbia River Datum and part of the Columbia PORTS® system to be consistent with the defined CRD profile by the Portland District. Table 5 lists corrections to be applied to CO-OPS data to be consistent with the Portland District CRD profile.

Table 5. Corrections Applied to 9440422 Longview, Washington

Description of Adjustment	Adjustment (m)
Revised CRD Value to 0.804m NAVD88 from CO-OPS 0.764m NAVD88	-0.040
Adjustment to OPUS elevation for Tidal Bench Mark SA 89 MON 4	-0.052
CO-OPS Gauge Correction Based on Optical Level Water Surface Observations	-0.071
Total Adjustment to CO-OPS Data in Longview, WA	**-0.163**

Water level observations, OPUS position results and gauge comparison data may be found in Appendix IV. No configurations used during data acquisition deviated from those described in the OPR-N338-KR-08 *Data Acquisition and Processing Report*.

C2. Discussion of GPS Tides

The coordinates of the GPS base stations used during acquisition and processing of H11856 are included in Table 6. The reference base stations used for both RTK and post processing are listed in the survey acquisition logs and POSPac processing logs included in Separate I *Acquisition and Processing Logs*.

Table 6. H11856 NAD83 Base Station Positions

RTK Base Station	Latitude (N)	Longitude (W)	Ellipsoid Height
KLMA	46/00/20.45579	122/50/50.13183	-11.153 m
PLVW	46/07/26.23898	122/58/49.89723	-11.143 m
BEVR	46/10/13.97257	123/09/26.40353	-15.766 m

As discussed in the OPR-N338-KR-08 DAPR, the use of GPS water levels eliminated large errors associated with discrete zoning and significantly reduced vertical uncertainty for this survey. Typical tide zoning artifacts for the survey area could exceed 30 centimeters, but as a result of using GPS water levels there are no visual tidal artifacts present in this survey.