Appendix A
Lower Columbia River Chart Datum Modeling

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1.0 Vertical Datum's of the Lower Columbia River

Upland topographic surveys are referenced to the National Spatial Reference System, which currently uses the North American Vertical Datum of 1988 (NAVD88) for orthometric heights and the North American Datum of 1983 (NAD83) as the reference ellipsoid. NAVD88 is a fixed datum derived from a simultaneous, least squares, and minimum constraint adjustment of Canadian/Mexican/United States leveling observations. Local mean sea level observed at Father Point/Rimouski, Canada was held fixed as the single initial constraint. NAVD88 supersedes the National Geodetic Vertical Datum of 1929 (NGVD29) as the national standard geodetic reference for heights. NAVD88 is referenced by vertical bench marks along high order level runs. Discrepancies were found while comparing elevations of reference NAVD88 bench marks derived from independent level runs along the Oregon and Washington shorelines of the Columbia River. These discrepancies became more apparent with the use of GPS technology which allowed for differential height observations across bodies of water. GPS technology uses a Geoid separation model, currently GEOID09, to obtain the height difference between the NAD83 ellipsoid and NAVD88. All elevation data in the Lower Columbia digital terrain model are referenced to NAVD88 using GEOID 09.

Chart Datum is the vertical reference for navigation surveys and nautical chart products. Chart Datum in the Pacific Ocean and in the Lower Columbia River seaward of Harrington Point, at Columbia River Mile (CRM) 22, is referenced to Mean Lower Low Water (MLLW). MLLW is a tidal datum determined over a 19-year National Tidal Datum Epoch (NTDE) and is defined and maintained by the National Oceanic and Atmospheric Administration (NOAA) Center of Operational Oceanographic Products and Services (CO-OPS). In the Lower Columbia River the CO-OPS reference water level gauge used to determine MLLW is at Tongue Point in Astoria (Station ID 9439040) and is part of the National Water Level Observation Network. The current NTDE is 1983 to 2001.

Columbia River Datum (CRD) is a non-tidal gradient datum developed and maintained by the US Army Corps of Engineers, Portland District and is the Chart Datum extending from Harrington Point at CRM 22 to Bonneville Dam at CRM 145.5 continuing up the Willamette River from mile 0 to Willamette Falls at river mile 26.6. CRD was defined as a profile by river mile relative to NGVD29 until recently. Thanks to the recent efforts by the Portland District, CRD has been redefined as a profile relative to NAVD88 at every mile along the Columbia and Willamette rivers. This was accomplished by obtaining NAVD88 orthometric heights on historic CRD bench marks. Due to the known discrepancies in the level runs between Oregon and Washington and the need to have a uniform datum that could be readily referenced after bench mark monuments have been destroyed, NAVD88 elevations were obtained by GPS observations using the National Geodetic Survey Online Positioning User Service (OPUS) and GEOID 09.

To integrate hydrographic data collected for navigation purposes and referenced to Chart Datum into the Lower Columbia digital terrain model, a spatial model of Chart Datum relative to NAVD88 was developed.

2.0 Model Development

The Portland District provided the profile of CRD relative to NAVD 88 along the centerline of the federal navigation channel in mile increments upstream of Harrington Point on the Columbia River to Bonneville Dam and up the Willamette River to Willamette Falls.

The first step in the generation of the model was to expand the profile into a spatial model spanning the river, behind islands and partially up tributaries of CRD relative to NAVD 88. TerraModel software was used to offset the river profile at 2,000-foot intervals perpendicular to the profile and model the back channels of the islands. A Triangular Irregular Network (TIN) model was developed to provide spatial coverage of CRD relative to NAVD88. Figure 1 presents 1 centimeter contours of NAVD88 elevations of CRD from the resultant spatial model.

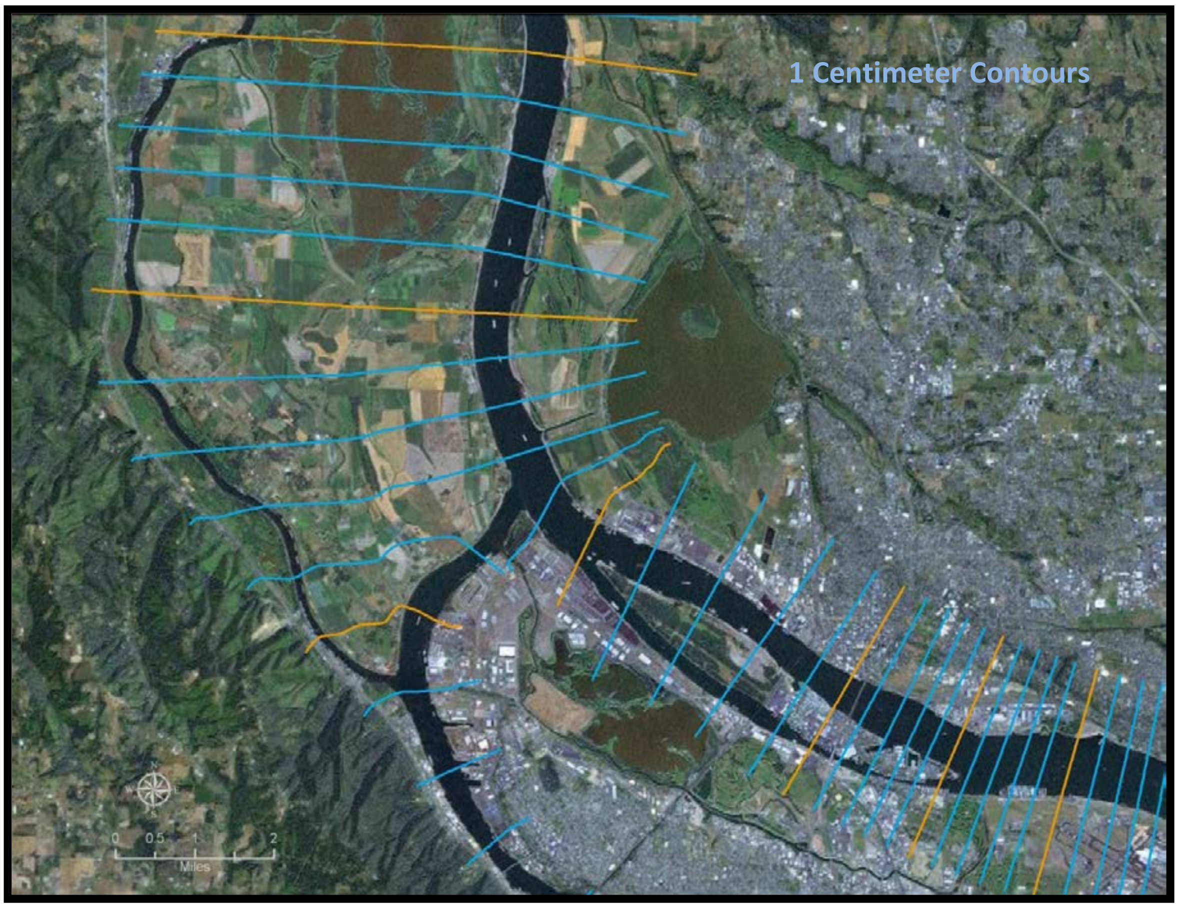
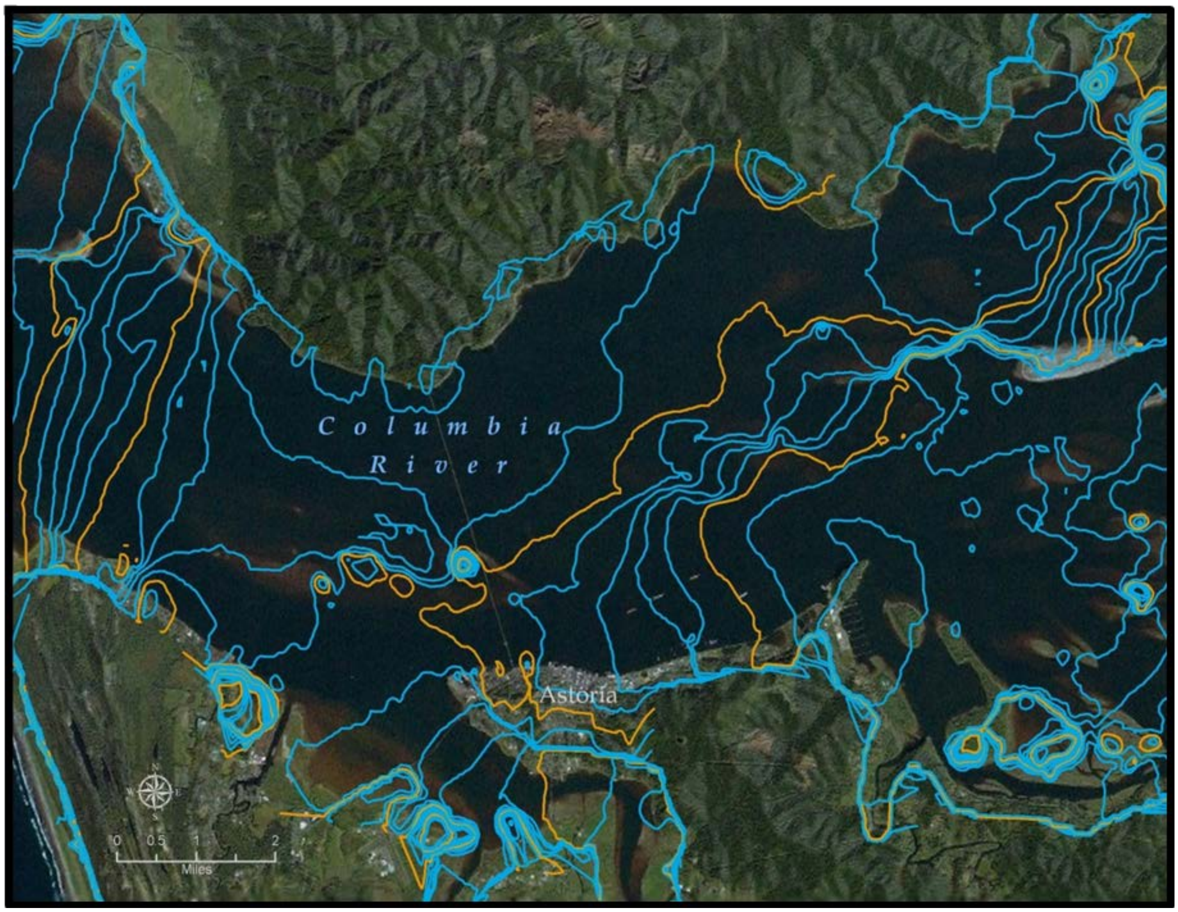


Figure 1: CRD model relative to NAVD88 at the confluence of the Willamette River

NOAA has developed a Vertical Datum Transformation tool (VDatum) which was used to provide separation values between MLLW and NAVD88 from Harrington Point, seaward to approximately three miles beyond the Columbia River Jetties. VDatum version 2.2.7 with transformation models for the Columbia River and Southwest Washington dated October 1, 2009 were used. To model MLLW seaward of Harrington Point (CRM 22) a gridded point file with a 3-arc second resolution (roughly 100-meter grid) and 0.0 assigned as the MLLW value was used for VDatum input. The output file consisted of an ASCII xyz file defining the NAVD88 elevation of MLLW. The ASCII data points were loaded into TerraModel software and a TIN model was generated. Review of 1 centimeter contours of the resultant model revealed 5 to 15



centimeter anomalies in the VDatum derived values (Figure 2).

Figure 2: VDatum model with 5 to 15 centimeter anomalies

The anomalies in the NOAA VDatum model are artifacts from a circulation model used to spatially distribute MLLW values and from use of conflicting old water level observations. Further, a 15-cm step was noted when comparing VDatum results to Portland District CRD values at Harrington Point. In the final MLLW TIN model, anomalous values were removed; data from the Portland District were held at Harrington Point and smoothed to match VDatum values at the NOAA water level station at Tongue Point. The refinements resulted in a more uniform model of MLLW with corrections of more than 15cm in some areas (Figure 3).

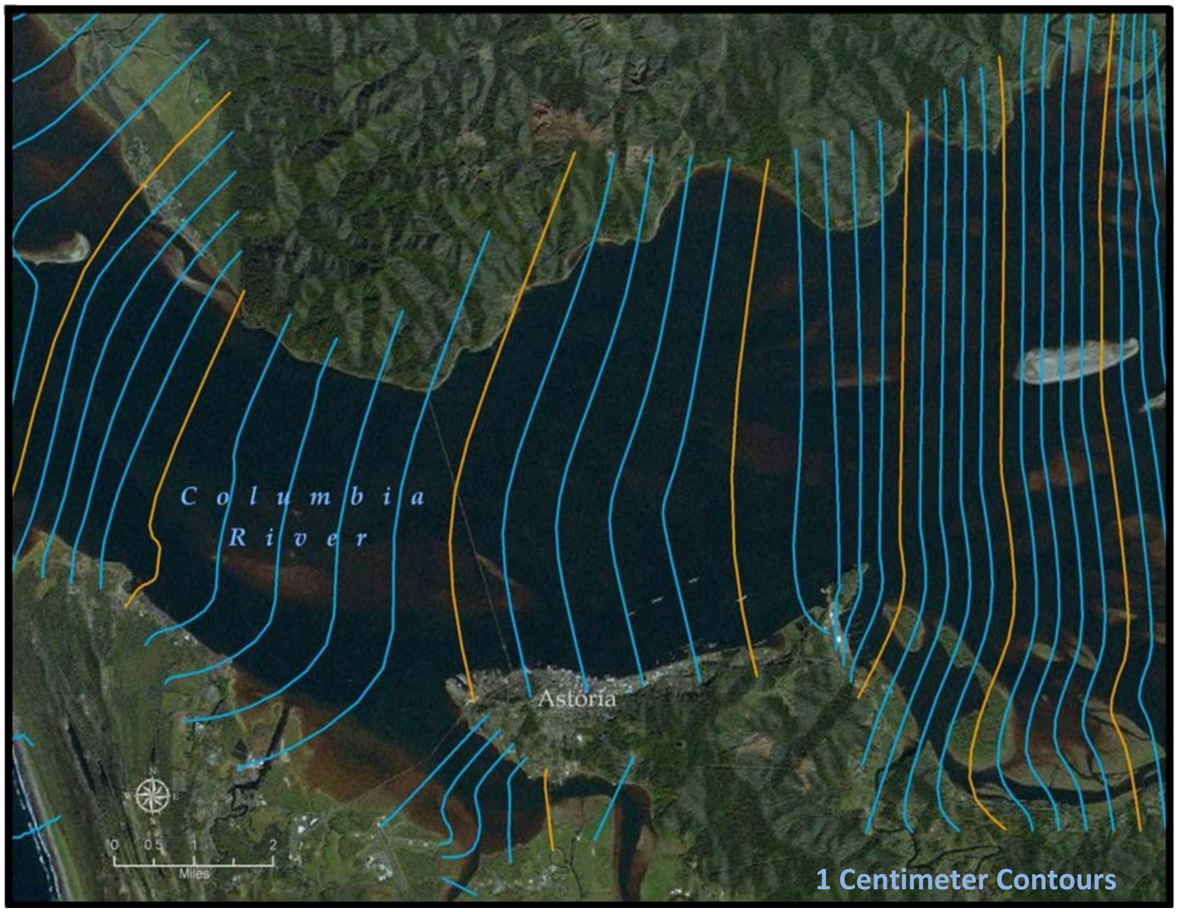


Figure 3: Modified model of MLLW relative to NAVD88

No anomalous values were noted seaward of CRM 1 and the VDatum values were unchanged in this area.

The CRD and MLLW TIN models were merged into a single TIN model defining Chart Datum relative to NAVD88 inside TerraModel. As numerous break lines were used in the TIN model, which would be difficult to replicate in ARCGIS, a 3-arc second high resolution grid (approximate 100-meter grid) was interpolated over the resultant TIN. A polyline defining the boundary of the Chart Datum model was also developed and exported to dxf.

1 Centimeter Contours

To combine the data to ArcGIS, a file based geodatabase was created and the gridded separation model was imported as points along with the 2d polyline, bounding the model as a polygon. An ArcGIS Terrain dataset using these files was generated. The terrain model was subsequently converted to an ArcGIS compatible TIN model and 75-meter resolution ArcGIS GRID as shown in Figures 4 and 5.

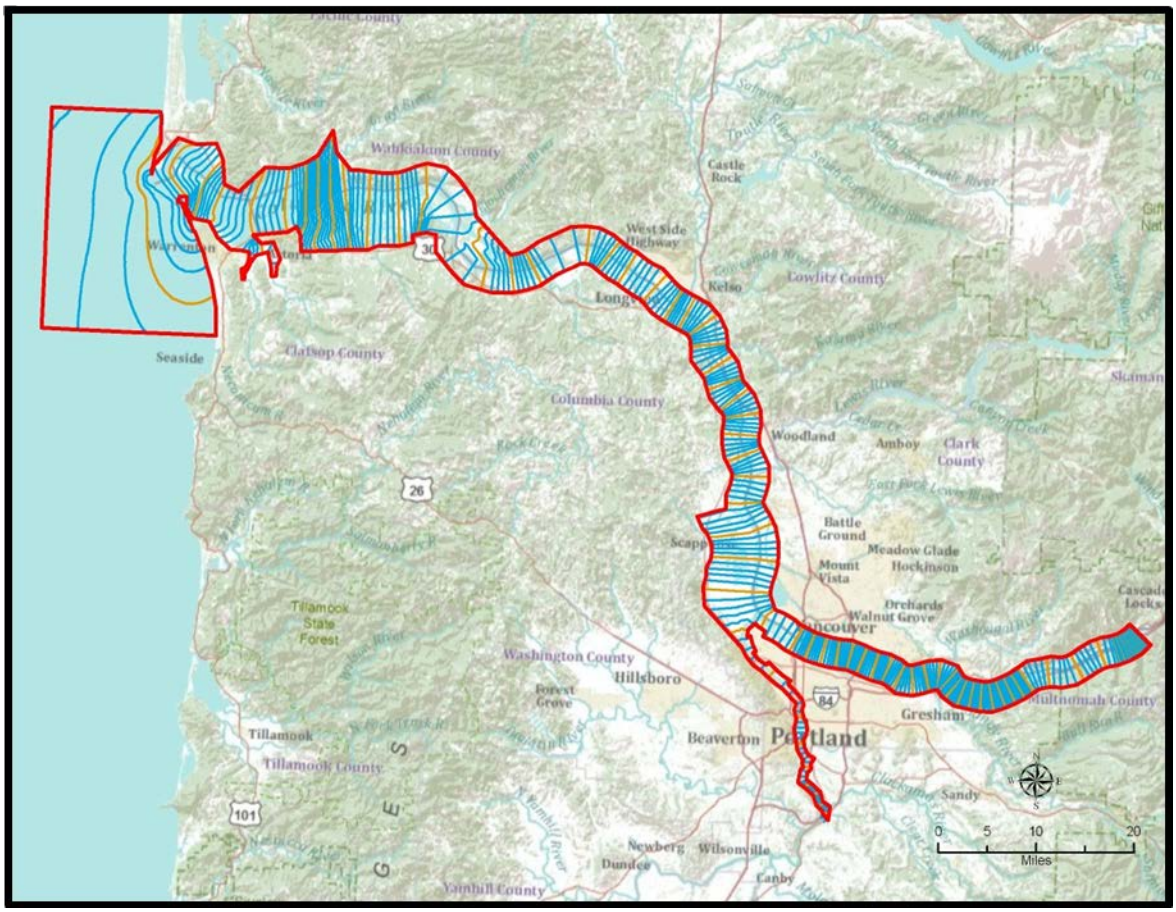


Figure 4: Chart Datum model relative to NAVD88 bounding polygon and 1cm contours

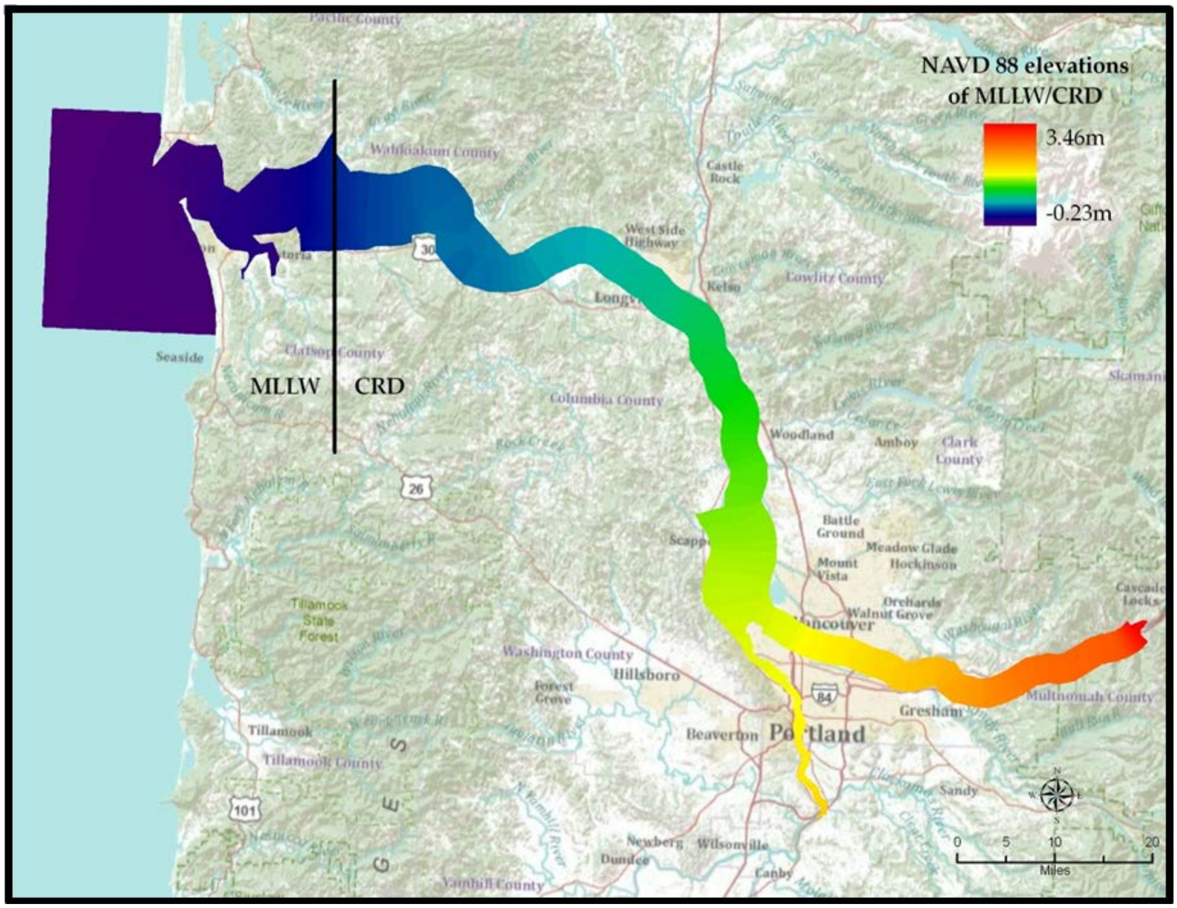


Figure 5: ArcGIS Terrain of Chart Datum relative to NAVD88

3.0 Conversion Process

To convert bathymetric datasets from MLLW or CRD to NAVD88 elevations the user will need to make sure bathymetric data is converted to positive up (most bathymetric data is positive down) and add the value obtained at the same position in the ArcGIS Terrain dataset "CRD_MLLW_to_NAVD88_GEOID09" to the z value of the source dataset.

File index:

SepModel.gdb – File based ArcGIS geodatabase

SepModel – Feature class housing ArcGIS Terrain model.

CRD_MLLW_to_NAVD88_GEOID09 – 3-arc second gridded model for NAVD 88 elevations of MLLW/CRD in meters

CRD_MLLW_to_NAVD88_GEOID09 – ArcGIS Terrain NAVD 88 elevations of MLLW/CRD in meters.

ModelBnd2D – 2d polygon defining the limits of the separation model.

TIN_crd_mllw_to_navd88_geoid09 – ArcGIS TIN model exported from ArcGIS Terrain model with xml metadata.