NOAA Technical Memorandum NESDIS NGDC-22

DIGITAL ELEVATION MODEL OF ASTORIA, OREGON: PROCEDURES, DATA SOURCES AND ANALYSIS

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Digital Elevation Model of Astoria, Oregon: Procedures, Data Sources and Analysis

1. Introduction

In May 2008, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed an integrated bathymetric–topographic digital elevation model (DEM) of Astoria, Oregon (Fig. 1) for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research (http://nctr.pmel.noaa.gov/). The 1/3 arc-second[1] coastal DEM will be used as input for the Method of Splitting Tsunami (MOST) model developed by PMEL to simulate tsunami generation, propagation and inundation. The DEM was generated from diverse digital datasets in the region (grid boundary and sources shown in Fig. 3) and will be used for tsunami inundation modeling, as part of the tsunami forecast system SIFT (Short-term Inundation Forecasting for Tsunamis) developed by PMEL for the NOAA Tsunami Warning Centers. This report provides a summary of the data sources and methodology used in developing the Astoria DEM.

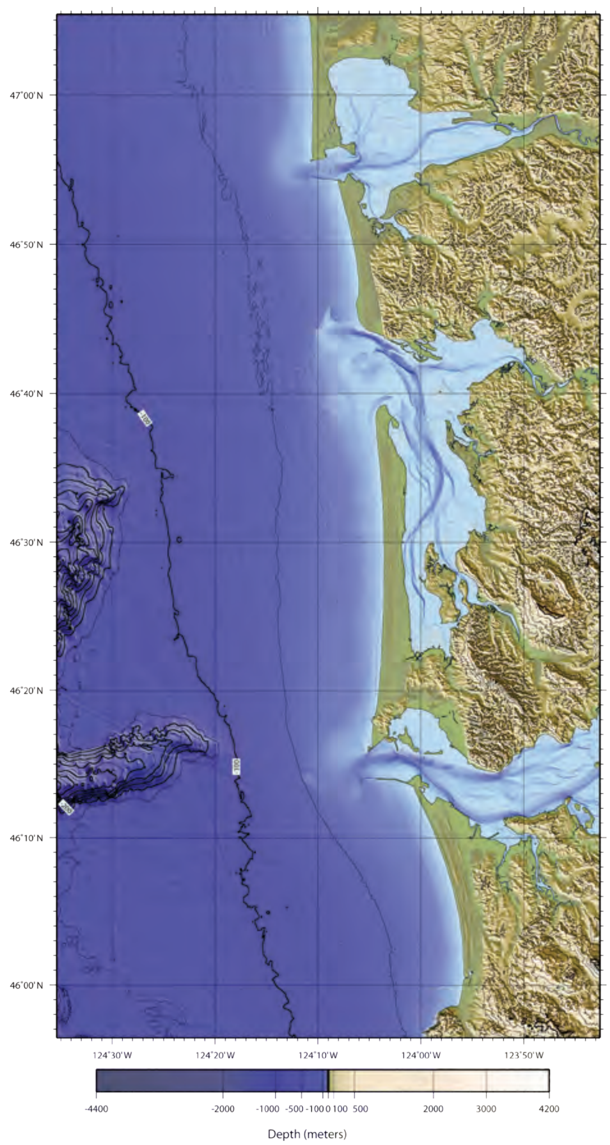

Figure 1. *Shaded-relief image of the Astoria, Oregon DEM. Contour interval is 50 meters in water and 100 meters on land. Image is in Mercator projection.*

1. The Astoria DEM is built upon a grid of cells that are square in geographic coordinates (latitude and longitude), however, the cells are not square when converted to projected coordinate systems, such as UTM zones (in meters). At the latitude of Astoria, Oregon (46°11.33′ N, 123°49.27′ W) 1/3 arc-second of latitude is equivalent to 10.29 meters; 1/3 arc-second of longitude equals 7.15 meters.

2. Study Area

The Astoria DEM covers the coastal area of the Willapa Hills physiographic province stretching from Seaside, Oregon north to Ocean Shores, Washington (Fig. 2). Formed from the Columbia River Basalt Group and coastal sediments, the region is characterized more by weathering than from deformation creating more rounded topography compared to the Olympic Mountains to the north. Encompassing the mouth of the Columbia River, the DEM region also includes two large estuaries, Willapa Bay and Grays Harbor. Willapa Bay is largely an intertidal zone with much of the water entering and retreating with the tide. Grays Harbor, to the north, also contains large areas of mud flats.

Astoria was founded in 1810 as a fur trading port on the southern bank of the Columbia River. Tourism and light manufacturing have replaced the once booming fishing and lumber industries as the main economic sources. Currently, Astoria has a population of approximately 10,000 over about a six square mile area.

Figure 2. *NASA World Wind i-cubed Landsat 7 image of Astoria DEM boundary shown in red (http://worldwind.arc.nasa.gov/).*

3. Methodology

The Astoria, Oregon DEM was constructed to meet PMEL specifications (Table 1), based on input requirements for the development of Reference Inundation Models (RIMs) and Standby Inundation Models (SIMs) (V. Titov, pers. comm.) in support of NOAA's Tsunami Warning Centers use of SIFT to provide real-time tsunami forecasts in an operational environment. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: North America Datum 1983 (NAD 83) and Mean High Water (MHW), respectively, for modeling of maximum flooding[2]. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1: PMEL specifications for the Astoria, Oregon DEM.

Grid Area	Astoria, Oregon
Coverage Area	123.71º to 124.59º W; 45.94º to 47.09º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean High Water (MHW)
Vertical Units	Meters
Grid Spacing	1/3 arc-second
Grid Format	ESRI Arc ASCII grid

2. The horizontal difference between the North American Datum of 1983 (NAD 83) and World Geodetic System of 1984 (WGS 84) geographic horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEM. Most GIS applications treat the two datums as identical, so do not actually transform data between them, and the error introduced by not converting between the datums is insignificant for our purposes. NAD 83 is restricted to North America, while WGS 84 is a global datum. As tsunamis may originate most anywhere around the world, tsunami modelers require a global datum, such as WGS 84 geographic, for their DEMs so that they can model the wave's passage across ocean basins. This DEM is identified as having a WGS 84 geographic horizontal datum even though the underlying elevation data were typically transformed to NAD 83 geographic. At the scale of the DEM, WGS 84 and NAD 83 geographic are identical and may be used interchangeably.

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 3) were obtained from several U.S. federal, state and local agencies including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS) and Coastal Services Center (CSC); the U.S. Geological Survey (USGS); the U.S. Army Corps of Engineers (USACE); Washington State Department of Ecology; and the Puget Sound LiDAR Consortium (PSLC). Safe Software's (http://www.safe.com/) *FME* data translation tool package was used to shift datasets to NAD 83 horizontal datum and to convert them into ESRI (http://www.esri.com/) *ArcGIS* shape files[3]. The shape files were then displayed with *ArcGIS* to assess data quality and manually edit datasets. Vertical datum transformations to MHW were accomplished using *FME* and *ArcGIS*, based upon data from the NOAA tide stations. Applied Imagery's *Quick Terrain Modeler* software (http://www.appliedimagery.com/) was used for editing data and to evaluate processing and gridding techniques.

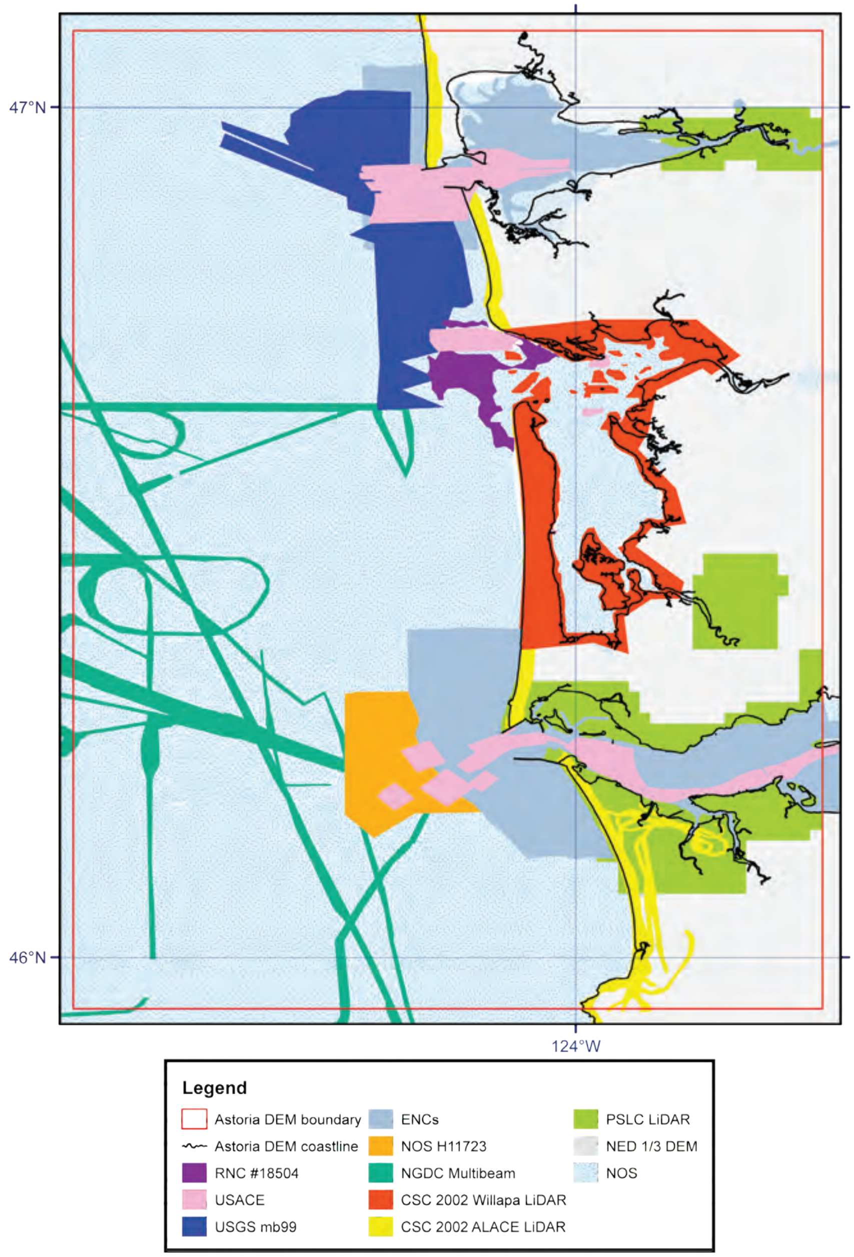

Figure 3. *Source and coverage of datasets used to compile the Astoria DEM.*

3. *FME* uses the North American Datum Conversion Utility (NADCON; http://www.ngs.noaa.gov/TOOLS/Nadcon/Nadcon.html) developed by NOAA's National Geodetic Survey (NGS) to convert data from NAD 27 to NAD 83. NADCON is the U.S. Federal Standard for NAD 27 to NAD 83 datum transformations.

3.1.1 Shoreline

Coastline datasets of the Astoria region were obtained from NOAA's Office of Coast Survey as Electronic Navigational Charts (ENCs) and Raster Nautical Charts (RNCs); the USGS; and the Washington State Department of Ecology (WASDOE). The coastlines varied in distance up to 500 meters from the most recent topographic LiDAR datasets, particularly at the inlets to the bays and at the mouth of the Columbia River. The ENC and RNC varied the least from the LiDAR datasets in most areas and were used to develop a complete coastline for the DEM region (Table 2; Fig. 4).

Table 2: Shoreline dataset used in the Astoria DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
OCS ENC extracted shoreline	2005 to 2007	vector	1:40,000 to 1:185,238	WGS 84 geographic (meters)	Mean High Water	http://chartmaker.ncd.noaa.gov/MCD/enc/index.htm
OCS RNC derived coastline	2007	derived from raster data	1:20,000 to 1:40,000	WGS 84 geographic (meters)	Mean High Water	http://nauticalcharts.noaa.gov/mcd/Raster/Index.htm
NGDC Garibaldi DEM coastline	2007	vector		WGS 84 geographic	Mean High Water	http://www.ngdc.noaa.gov/dem/showdem.

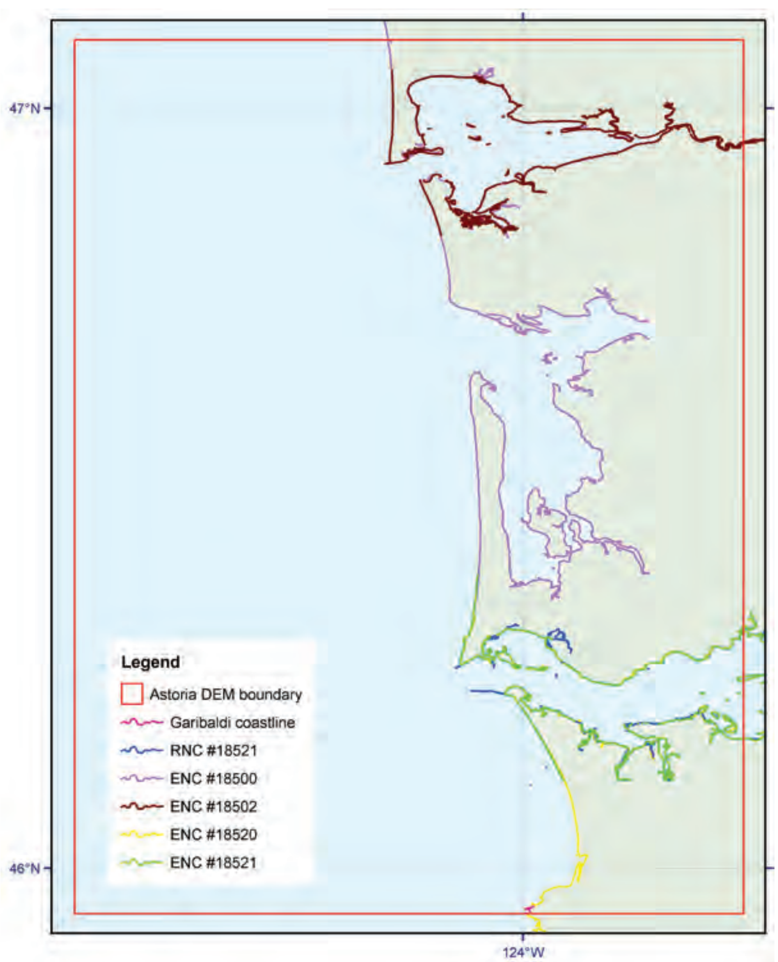

Figure 4. *Digital coastline datasets used for developing a coastline for the Astoria DEM*

1) OCS Raster Nautical Charts

Five raster nautical charts (RNCs) were available for the Astoria area (Table 3) and downloaded from NOAA's Office of Coast Survey website (http://nauticalcharts.noaa.gov/mcd/enc/index.htm). The RNCs are provided online as georeferenced raster images and cover the entire coastline within the DEM boundaries. A 'derived coastline' was generated using *ArcGIS* Spatial Analyst to extract the coastline from the raster image of the nautical chart based on pixel values. The resulting data were then resampled and converted to polylines. Further editing of the RNC coastline dataset was done to remove stray line segments in the open ocean using *ArcMap* editing tools.

2) OCS Electronic Navigational Charts

Four electronic navigational charts (ENCs) were available for the Astoria area (Table 3) and downloaded from the NOAA's Office of Coast Survey website (http://chartmaker.ncd.noaa.gov/MCD/enc/index.htm). The coastline data were extracted from the ENC S-57 format to vector line shapefiles. The ENC coastline dataset covers the entire DEM area except the Chehalis River on the eastern DEM boundary.

Table 3: Digital nautical chart data available in the Astoria, Oregon region.

Chart	*Title*	*Edition*	*Edition Date*	*Format*	*Scale*
18500	Columbia River to Destruction Island	29	2004	ENC and RNC	1:180,789
18502	Greys Harbor - Westhaven Cove	86	2007	ENC and RNC	1:40,000
18504	Willapa Bay – Toke Point	66	2006	RNC	1:40,000
18520	Yaquina Head to Columbia River – Netarts Bay	26	2005	ENC and RNC	1:185,238
18521	Columbia River Pacific Ocean to Harrington Point – Ilwaco Harbor	72	2005	ENC and RNC	1:40,000

3) NGDC Garibaldi DEM coastline

The southern Astoria DEM boundary overlaps the Garibaldi DEM (http://www.ngdc.noaa.gov/dem/showdem.jsp?dem=Garibaldi&state=OR&cell=1/3%20arc-second) northern boundary by approximately 2 kilometers. The coastline used in the Garibaldi DEM was clipped to the Astoria DEM boundary and merged with the OCS chart coastline datasets using ArcCatalog tools.

Figure 5. *Levee at Toke Point. Photo from Washington State Department of Ecology (http://apps.ecy.wa.gov/shorephotos/).*

Figure 6. *South Jetty at Clatsop Point. Photo from US Coast Guard (http://www.uscg.mil/d13/units/gruastoria/cd_aor_photo_gallery3.htm).*

The merged coastline datasets were visually compared to *Google Earth* satellite imagery (http://earth.google.com/userguide/v4/#imagery_dates), the Washington State Department of Ecology aerial photo collection (http://apps.ecy.wa.gov/shorephotos/), and USGS topographic maps available on *NASA World Wind* (http://worldwind.arc.nasa.gov/index.html) to ensure features such as jetties and levees were present in the coastline (Figs. 5 and 6). Finally, to represent the most recent topographic LiDAR data, the coastline was adjusted to match the LiDAR data available from the Puget Sound LiDAR Consortium (PSLC) where present and the Coastal Services Center 2002 ALACE LiDAR in the remaining areas along the coast.

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Astoria DEM include 73 NOS hydrographic surveys, 34 hydrographic channel line surveys from USACE, 11 multibeam swath sonar surveys downloaded from the NGDC multibeam sonar database, one multibeam sonar survey from the USGS, extracted ENC sounding data, and digitized RNC soundings (Table 4; Fig. 7).

Table 4: Bathymetric datasets used in compiling the Astoria DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/ Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1851 to 2005	Hydrographic survey soundings	Ranges from 10 m to 1 km (varies with scale of survey, depth, traffic, and probability of obstructions)	NAD 27 or NAD 83 geographic	Mean Lower Low Water	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
NOS	2007	Multibeam Survey	1:20,000	NAD 83 UTM Zone 10 North	Mean Lower Low Water	
USACE	2006 to 2007	Hydrographic channel line surveys	various, from 3 to 40 meter point spacing	NAD 83 Oregon State Plane North (feet) or NAD 83 Washington State Plane South	Mean Lower Low Water	https://www.nwp.usace.army.mil/op/nwh/xyzcoastal.asp
NGDC	1998 to 2003	Multibeam sonar swath files	raw MB files gridded to 1 arc-second	WGS 84 geographic	assumed Mean Sea Level	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
USGS	1999	Multibeam	~ 10 meters	NAD 83 State Plane Washington South (meters)	MLLW	http://walrus.wr.usgs.gov/swces/data.html#era4
OCS RNC	2003 to 2005	digitized soundings from RNC	1:20,000	WGS 84 geographic	Mean Lower Low Water	http://nauticalcharts.noaa.gov/mcd/Raster/Index.htm
OCS ENC	2005	extracted soundings from ENC	1: 191,730	WGS 84 geographic	Mean Lower Low Water	http://chartmaker.ncd.noaa.gov/MCD/enc/index.htm

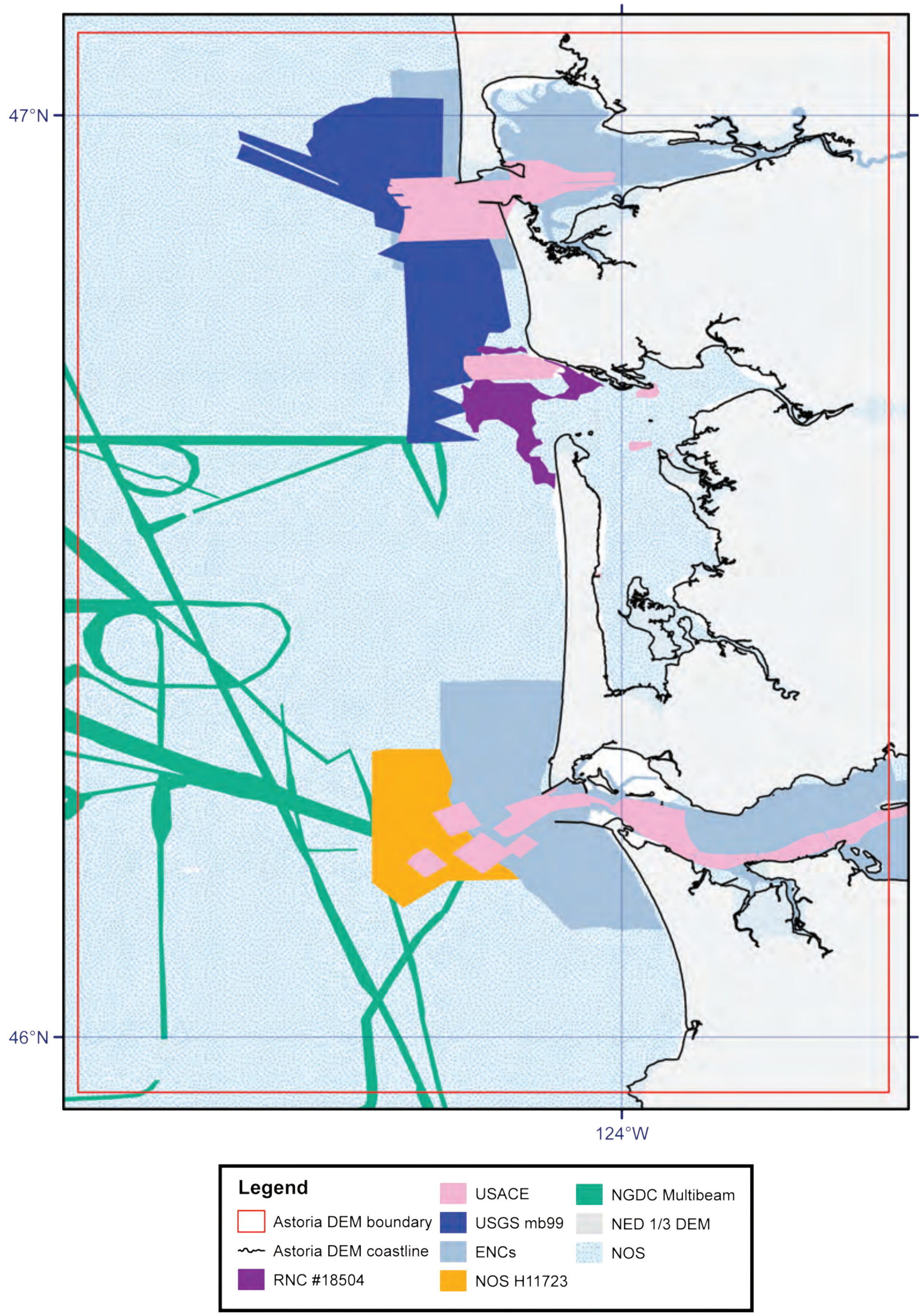

Figure 7. *Spatial coverage of bathymetric datasets used to compile the Astoria DEM.*

1) NOS hydrographic survey data

A total of 73 NOS hydrographic surveys conducted between 1851 and 2005 were available for use in developing the Astoria DEM. The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to either NAD 1913, NAD 27, or NAD 83 datums if the datum was known and recorded (Table 5; Fig. 8).

Data point spacing for the NOS surveys varied by collection date. In general, earlier surveys had greater point spacing than more recent surveys. All surveys were extracted from NGDC's online NOS hydrographic database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) referenced to NAD 83. The surveys were subsequently clipped to a polygon 0.05 degree (~5%) larger than the Astoria DEM area to support data interpolation along grid edges.

After converting all NOS survey data to MHW, the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and edited as necessary. The surveys were also compared to the topographic and other bathymetric datasets, the Astoria coastline, and NOS raster nautical charts (RNCs). The surveys were clipped to remove soundings that overlap the more recent multibeam surveys, USACE surveys, and where soundings from older surveys have been superseded by more recent NOS surveys.

Table 5: Digital NOS hydrographic surveys used in compiling the Astoria DEM.

NOS Survey ID	*Year of Survey*	*Survey Scale*	*Original Vertical Datum*	*Original Horizontal Datum of Digital Records*
H00250	1851	20,000	Mean Lower Low Water	unknown
H00335	1852	20,000	Mean Lower Low Water	unknown
H00809	1862	20,000	Mean Lower Low Water	NAD 27
H01019	1868	20,000	Mean Lower Low Water	unknown
H01378	1877	40,000	Mean Lower Low Water	NAD 1913
H01379	1877	40,000	Mean Lower Low Water	NAD 1913
H01589A	1883/91	20,000	Mean Lower Low Water	NAD 27
H01800	1887	40,000	Mean Lower Low Water	NAD 27
H02103	1891	20,000	Mean Lower Low Water	undetermined
H03297	1911	20,000	Mean Lower Low Water	NAD 1913
H04363	1924	20,000	Mean Lower Low Water	NAD 1913
H04611	1926	20,000	Mean Lower Low Water	NAD 1913
H04612	1926	20,000	Mean Lower Low Water	NAD 1913
H04618	1926	20,000	Mean Lower Low Water	NAD 1913
H04619	1926	20,000	Mean Lower Low Water	NAD 1913
H04620	1926	20,000	Mean Lower Low Water	NAD 1913
H04621	1926	20,000	Mean Lower Low Water	NAD 1913
H04633A	1926	120,000	Mean Lower Low Water	NAD 1913
H04635	1926	40,000	Mean Lower Low Water	NAD 27
H04636	1926	80,000	Mean Lower Low Water	NAD 27
H04639	1926	120,000	Mean Lower Low Water	NAD 27
H04634	1926/27	40,000	Mean Lower Low Water	NAD 1913
H04710	1927	20,000	Mean Lower Low Water	NAD 27
H04715	1927	20,000	Mean Lower Low Water	NAD 1913
H04728	1927	40,000	Mean Lower Low Water	NAD 27
H04729	1927	40,000	Mean Lower Low Water	NAD 1913
H04735	1927	80,000	Mean Lower Low Water	NAD 27
H04658	1927/28	15,000	Mean Lower Low Water	NAD 27
H05927	1935	10,000	Mean Lower Low Water	NAD 27

H05928	1935	10,000	Mean Lower Low Water	NAD 27
H05975	1935	10,000	Mean Lower Low Water	NAD 27
H05976	1935	10,000	Mean Lower Low Water	NAD 27
H06237	1935/37	2,500	Mean Lower Low Water	NAD 27
H06178	1936	10,000	Mean Lower Low Water	NAD 27
H06179	1936	10,000	Mean Lower Low Water	NAD 27
H06180	1936/37	10,000	Mean Lower Low Water	NAD 27
H06514	1939	10,000	Mean Lower Low Water	NAD 27
H06515	1939	10,000	Mean Lower Low Water	NAD 27
H06516	1939	10,000	Mean Lower Low Water	NAD 27
H06517	1939	10,000	Mean Lower Low Water	NAD 27
H06518	1939	10,000	Mean Lower Low Water	NAD 27
H06519	1939	10,000	Mean Lower Low Water	NAD 27
H06520	1939	10,000	Mean Lower Low Water	NAD 27
H06521	1939	10,000	Mean Lower Low Water	NAD 27
H06646	1940	10,000	Mean Lower Low Water	NAD 27
H06647	1940	10,000	Mean Lower Low Water	NAD 27
H06665	1941	10,000	Mean Lower Low Water	NAD 27
H07178	1947	10,000	Mean Lower Low Water	NAD 27
H07179	1947	5,000	Mean Lower Low Water	NAD 27
H07180	1947	5,000	Mean Lower Low Water	NAD 27
H07817	1950	10,000	Mean Lower Low Water	NAD 27
H07940	1951	10,000	Mean Lower Low Water	NAD 27
H08136	1954	10,000	Mean Lower Low Water	NAD 27
H08137	1954	10,000	Mean Lower Low Water	NAD 27
H08138	1954	15,000	Mean Lower Low Water	NAD 27
H08335	1954	10,000	Mean Lower Low Water	NAD 27
H08252	1955	20,000	Mean Lower Low Water	NAD 27
H08250	1956	10,000	Mean Lower Low Water	NAD 27
H08251	1956	10,000	Mean Lower Low Water	NAD 27
H08292	1956	10,000	Mean Lower Low Water	NAD 27
H08293	1956	10,000	Mean Lower Low Water	NAD 27
H08423	1956/58	10,000	Mean Lower Low Water	NAD 27
H08416	1958	20,000	Mean Lower Low Water	NAD 27
H08417	1958	20,000	Mean Lower Low Water	NAD 27
H08419	1958	10,000	Mean Lower Low Water	NAD 27
H08420	1958	10,000	Mean Lower Low Water	NAD 27
H08436	1958	5,000	Mean Lower Low Water	NAD 27
B00115	1987	50,000	Mean Lower Low Water	NAD 83
B00116	1987	50,000	Mean Lower Low Water	NAD 83
F00430	1996/97	10,000	Mean Lower Low Water	NAD 83
H11282	2005	10,000	Mean Lower Low Water	NAD 83
H11299	2005	10,000	Mean Lower Low Water	NAD 83
H11300	2005	10,000	Mean Lower Low Water	NAD 83

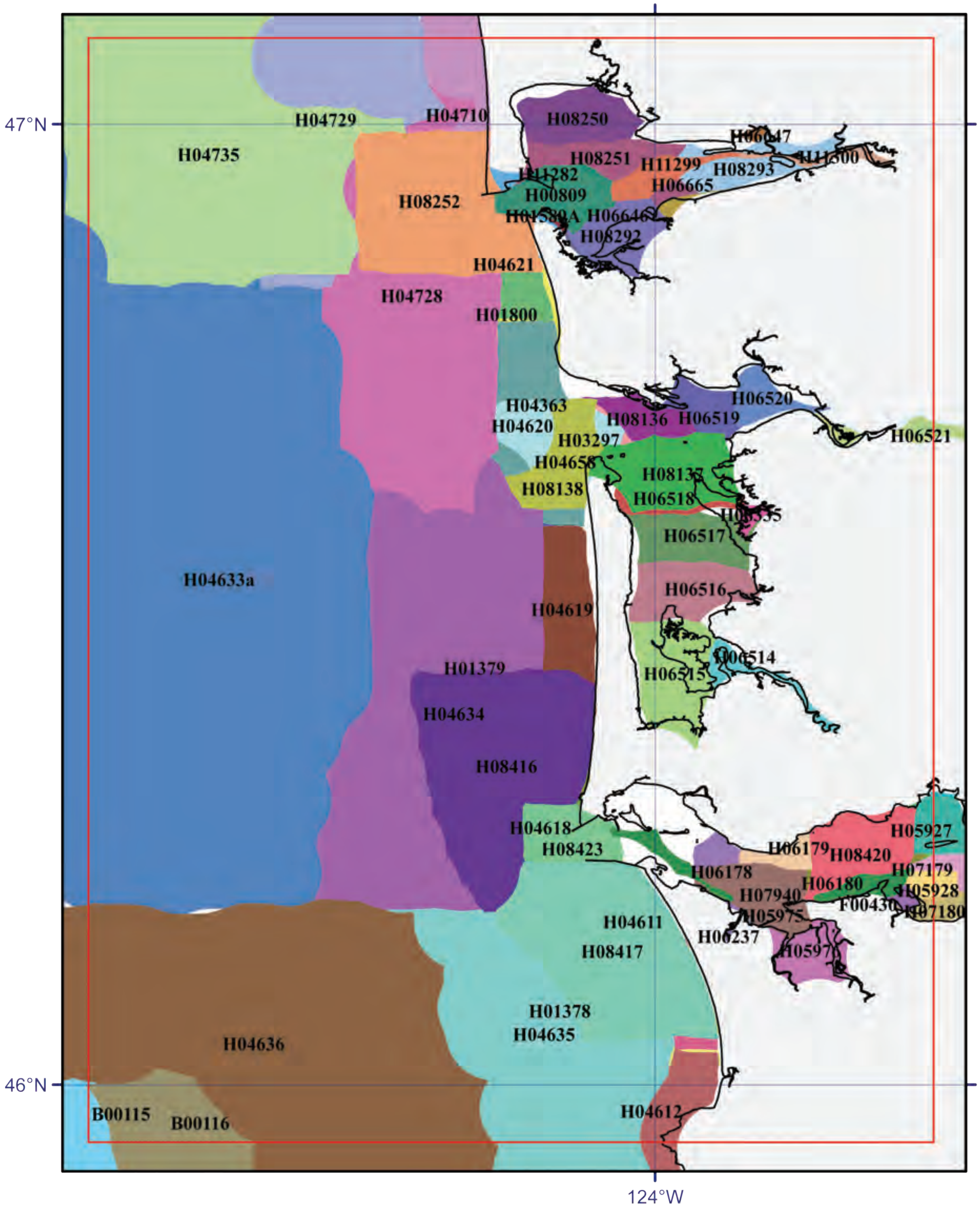

Figure 8. *Digital NOS hydrographic survey coverage in the Astoria region. Some older surveys were not used as they have been superseded by more recent surveys. DEM boundary in red.*

2) NOS hydrographic survey H11723 data

The most recent available NOS survey, H11723, was completed in 2007 and is located just outside the mouth of the Columbia River (Fig. 9). This multibeam survey was provided to NGDC in *CARIS* BAG gridded format by the NOS Pacific Hydrographic Branch directly after processing. The grid was converted to xyz data using *CARIS* and transformed from NAD 83 UTM Zone 10 and MLLW to NAD 83 and MHW using *FME*.

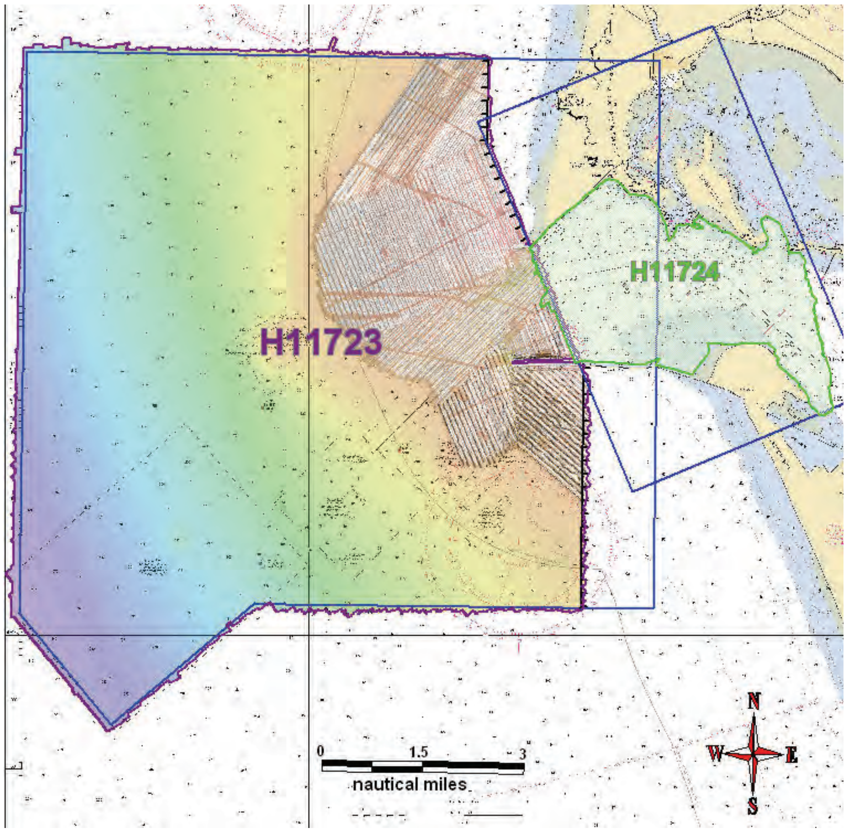

Figure 9. *Spatial coverage of NOS hydrographic survey H11723 from descriptive report available online (http://www.ngdc.noaa.gov/nndc/servlet/ShowDatasets?dataset=101523&search_look=2&display_look=1,2). Adjacent survey H11724 is currently unavailable.*

3) USACE hydrographic channel line surveys

Thirty-four hydrographic channel line surveys (survey lines that run parallel to the channel, 7 lines across, spaced 150 feet apart) and cross line surveys (survey lines that run perpendicular, bank-to-bank and are spaced approximately 500 feet apart) were available for use in the Astoria DEM (Table 6, Fig. 10). The surveys along the Columbia River were downloaded in xyz format from the USACE Portland District website (https://www.nwp.usace.army.mil/op/nwh/xyzcoastal.asp). Surveys located in Grays Harbor and Willapa Bay were obtained directly from the USACE Seattle District office. The data were transformed to NAD 83 and MHW, changed to shape files using *FME* and quality checked in *ArcMap* against other bathymetric datasets.

Table 6: USACE hydrographic surveys used in compiling the Astoria DEM.

Survey ID	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Survey Format*
Columbia River - Deep water site	2007	MLLW	NAD 83 State Plane Oregon North (feet)	Line spacing ~150 meters apart with ~50 meter point spacing
Columbia River - North Jetty site	2007	MLLW	NAD 83 State Plane Oregon North (feet)	Line spacing ~30 meters apart with ~60 meter point spacing
Columbia River - Shallow water site	2007	MLLW	NAD 83 State Plane Oregon North (feet)	Line spacing ~60 meters apart with ~60 meter point spacing
Columbia River - Site A	2005	MLLW	NAD 83 State Plane Oregon North (feet)	Line spacing ~75 meters apart with ~50 meter point spacing
Columbia River - Site B	2005	MLLW	NAD 83 State Plane Oregon North (feet)	Line spacing ~75 meters apart with ~60 meter point spacing
Columbia River - Site F	2005	MLLW	NAD 83 State Plane Oregon North (feet)	Line spacing ~125 meters apart with ~50 meter point spacing
Columbia River - Flavel FLV022708	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Flavel FLVX010908	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Cross line survey
Columbia River - Lower Desdemona LDS0022108	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Lower Desdemona ldsx	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Cross line survey
Columbia River - Mouth of Columbia River MCR110807	2007	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Miller Sands MLN022508	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Miller Sands mlnx	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Cross line survey
Columbia River - Tongue Point TNG022208	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Tongue Point tngx	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Cross line survey
Columbia River - Upper Desdemona UDS022108	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Upper Desdemona udsx	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Cross line survey
Columbia River - Upper Sands USN022208	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Channel line survey
Columbia River - Upper Sands USNX010808	2008	MLLW	NAD 83 State Plane Oregon North (feet)	Cross line survey
Grays Harbor - 0626	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Grays Harbor - 0628	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Grays Harbor - 0723	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Grays Harbor - 0724	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Grays Harbor - 0725	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey

Grays Harbor - 0726	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Grays Harbor - 0820	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Willapa Bay - 2007wi003a	2007	MLLW	NAD 83 State Plane Washington South (feet)	Cross line survey
Willapa Bay - 2007wi003b	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Willapa Bay - 10131	2007	MLLW	NAD 83 State Plane Washington South (feet)	Cross line survey
Willapa Bay - 20201	2007	MLLW	NAD 83 State Plane Washington South (feet)	Cross line survey
Willapa Bay - 210501		MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Willapa Bay - allp	2007	MLLW	NAD 83 State Plane Washington South (feet)	Channel line survey
Willapa Bay - allx	2007	MLLW	NAD 83 State Plane Washington South (feet)	Cross line survey
Willapa Bay - r420830	2007	MLLW	NAD 83 State Plane Washington South (feet)	Cross line survey

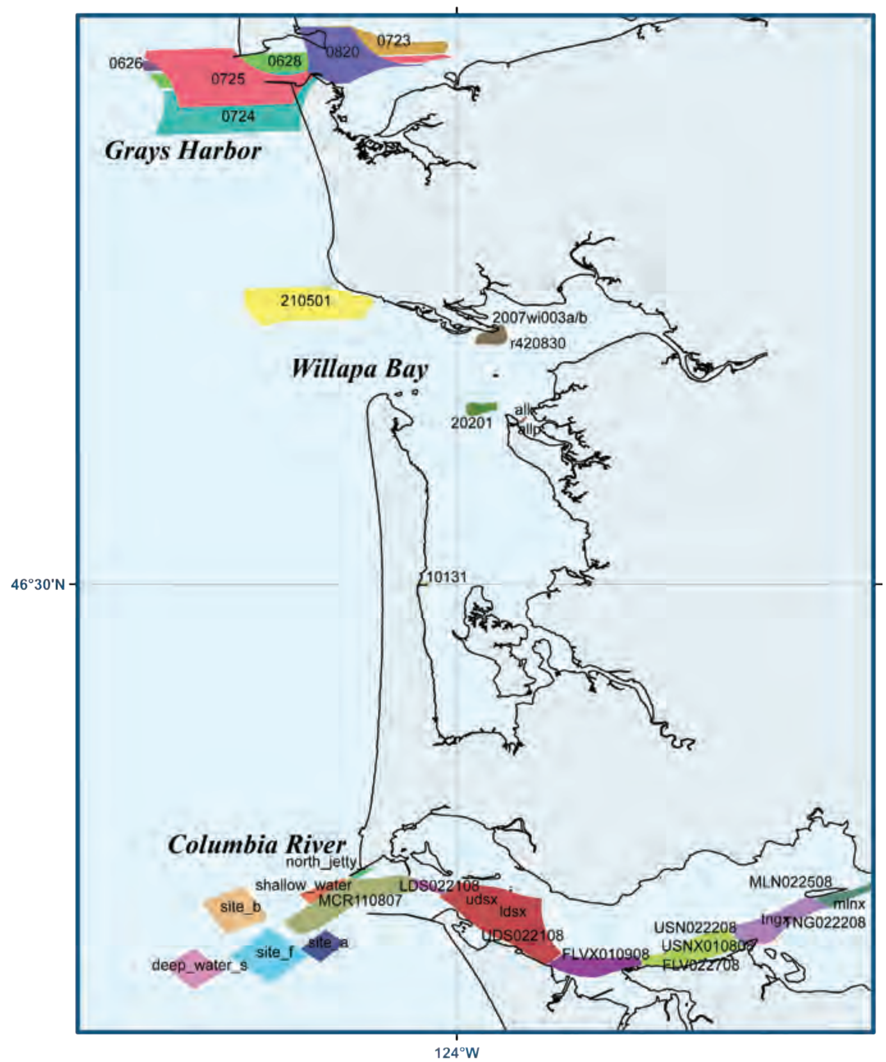

Figure 10. *Spatial coverage of USACE hydrographic channel line and cross line surveys for the Astoria DEM.*

4) Multibeam swath sonar files

Eleven multibeam swath sonar surveys were available from the NGDC multibeam database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html) for use in the Astoria DEM (Fig. 11, Table 7). This database is comprised of the original swath sonar files of surveys conducted mostly by the U.S. academic fleet. The downloaded data were gridded to 1/3 arc-second resolution using *MB-System*. *MB-System* is an NSF-funded free software application specifically designed to manipulate submarine multibeam sonar data (http://www.ldeo.columbia.edu/res/pi/MB-System/).

Most of the multibeam swath surveys offshore were transits rather than dedicated sea-floor surveys. All have a horizontal datum of WGS 84 geographic and undefined vertical datum, and were assumed to be referenced to mean sea level (MSL).

Table 7: Multibeam swath sonar files used in compiling the Astoria DEM.

Cruise ID	*Ship*	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
AT3L23	Atlantis	1998	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AT03L24	Atlantis	1998	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AT03L36	Atlantis	1999	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AT03L37	Atlantis	1999	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AT03L38	Atlantis	1999	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AT3L53	Atlantis	1997	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AT3L56	Atlantis	2000	assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institution (WHOI)
AVON09MV	Melville	1999	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
REM-01MV	Melville	1993	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
REM-02MV	Melville	1993	assumed Mean Sea Level	WGS 84 geographic	University of California, Scripps Institution of Oceanography (UC/SIO)
SO108	Sonne	1996	assumed Mean Sea Level	WGS 84 geographic	University of Kiel, Germany, GEOMAR Forshungszentrum

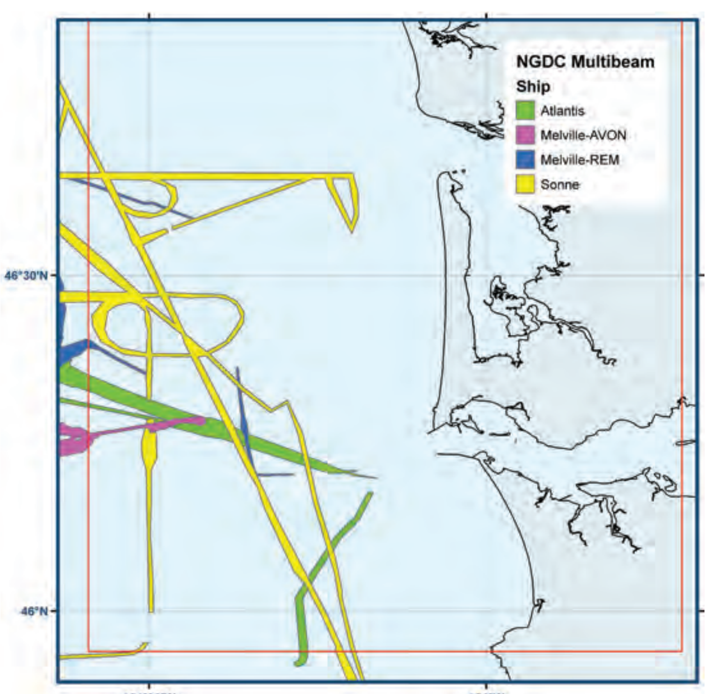

Figure 11. *Spatial coverage of multibeam swath sonar files from NGDC multibeam database used in the Astoria region.*

After assessing individual survey quality, the gridded data were transformed to MHW in xyz format using *FME*, displayed in *QT Modeler* and edited using *ArcMap* and *QT Modeler*. Figure 12 shows a band of anomalous data spikes in survey SO108, which were removed before use in the DEM. Another error in the multibeam data collection included swath edge rolling, "smiles and frowns". These errors were manually edited at the edges where most pronounced, before creating a gridded bathymetric surface.

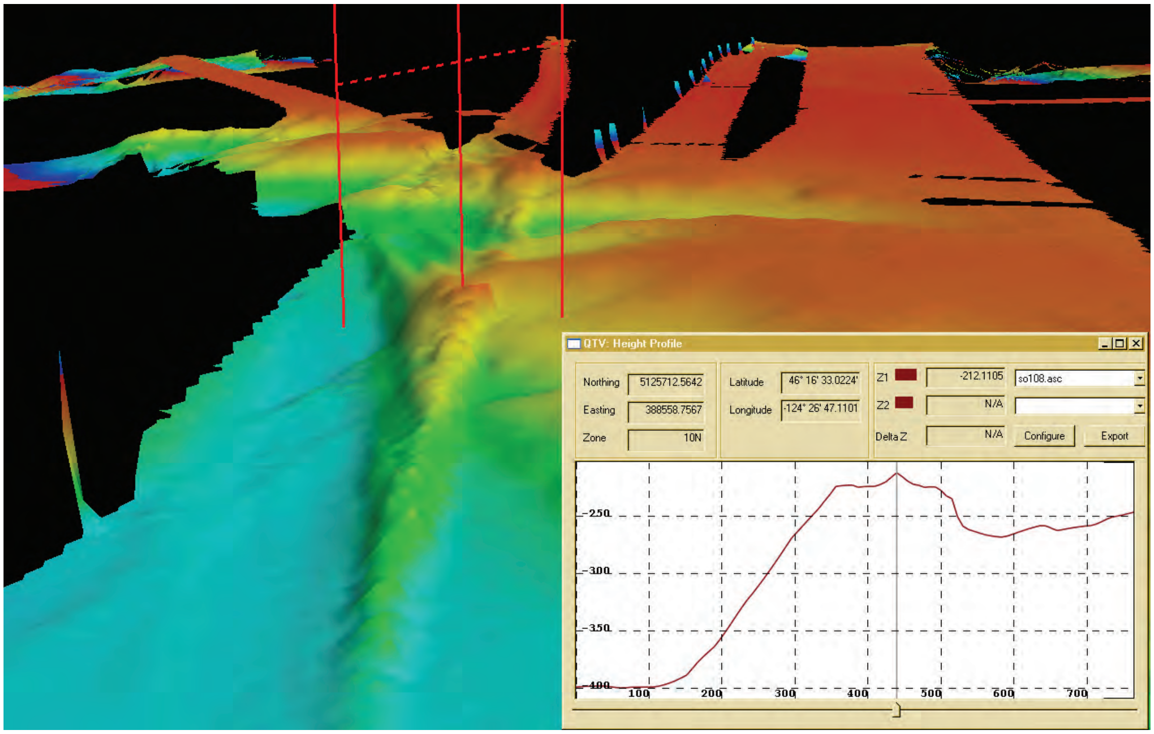

Figure 12. *QT Modeler image of anomalous data spikes in the NGDC multibeam sonar surveys. These spikes were removed by clipping out this section of trackline.*

5) USGS Multibeam survey

The USGS multibeam survey, mb99, covered the offshore area between Willapa Bay and Grays Harbor and was downloaded from the USGS Southwest Washington Coastal Erosion Study website (http://walrus.wr.usgs.gov/swces/data.html#era4). The survey was exported to a coverage from an .E00 file and changed to a shapefile using *ArcCatalog*. Vertical and horizontal datums were transformed using *FME*. When displayed for analysis, the data revealed horizontal lines across the entire dataset and anomalous low data points not consistent with surrounding elevations or adjacent bathymetric data (Fig. 13). The lines and low data points were removed using *ArcMap* editing tools and *QT Modeler*.

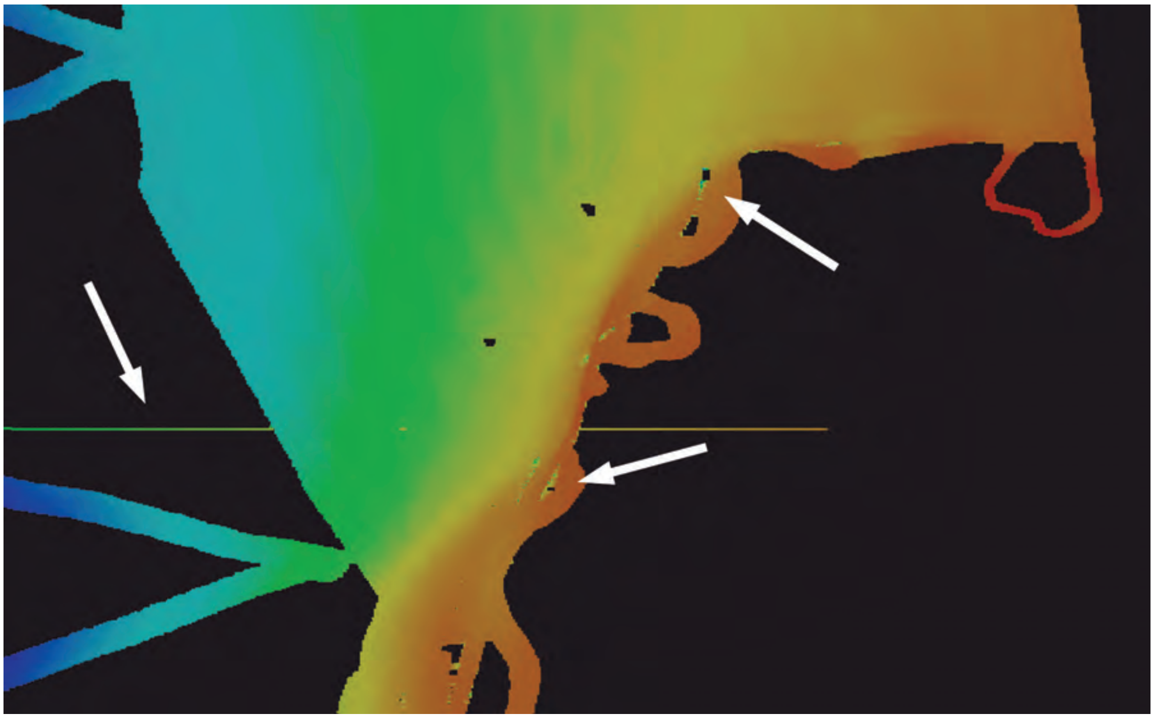

Figure 13. *QT Modeler image of USGS multibeam survey mb99. White arrows point to errors in data, which were removed before incorporation into bathymetric surface and final DEM.*

6) Office of Coast Survey extracted ENC soundings

The OCS electronic navigational chart (ENC) sounding data were extracted from chart #18502 at Grays Harbor and #18521 at Ilwaco Harbor in Baker Bay where there was either no other bathymetric data available or existing data points were sparse. Soundings were transformed to MHW and clipped to the multibeam sonar surveys, the USACE hydrographic surveys, and the more recent NOS hydrographic surveys. Additional soundings were added to the ENC #18521 dataset at the head of the southern jetty at Clatsop Point to fill in the submerged portion of the eroded jetty. Elevation values assigned to the points were determined by averaging the existing neighboring point elevations in NOS survey H08417.

7) Office of Coast Survey digitized RNC soundings

At the entrance to Willapa Bay, soundings from RNC #18504 were digitized to ensure negative elevations in the bathymetric surface where no other digital sounding data were available.

Inconsistencies were identified while merging the bathymetric datasets due to the range in ages of the NOS hydrographic surveys and differences in resolution. In areas where more recent data were available, the older NOS surveys were either edited or removed. Figure 14 illustrates the large amount of morphologic change that has occurred at Leadbetter Point since survey H04658 was completed. Soundings originally taken ~500 meter from the shoreline are now on land. This survey was not used in generating the bathymetric surface for the Astoria DEM.

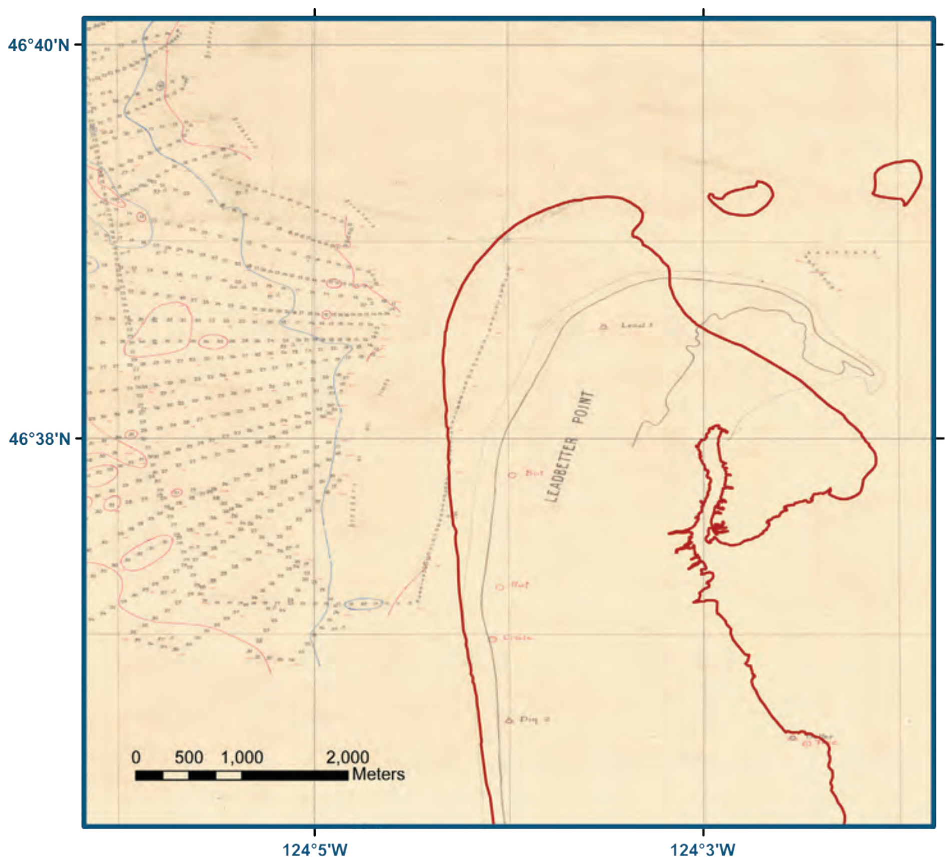

Figure 14. NOS hydrographic survey smooth sheet from survey H04658 shown with Astoria coastline in red.

3.1.3 Topography

Six topographic datasets in the Astoria region were obtained and used to build the Astoria DEM (Table 8; Fig. 15). The USGS NED 1/3 arc-second provided full coverage for the DEM area and the 2002 CSC ALACE LiDAR dataset covered the entire coastline. The 2002 CSC Willapa Bay LiDAR provided higher resolution data for the inland area of Willapa Bay. Two datasets were downloaded from the Puget Sound LiDAR Consortium (PSLC) website covering the shoreline along the Columbia River and the Chehalis River. NGDC created an additional topographic dataset representing a coastal feature not fully resolved in the NED or CSC dataset. NGDC evaluated but did not use the Shuttle Radar Topography Mission (SRTM) Elevation 1 arc-second DEM available from USGS, as the higher-resolution 1/3 arc-second NED DEMs provided complete coverage.

Table 8: Topographic datasets used in compiling the Astoria DEM.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS	1999-2006	NED DEM	1/3 arc-second	NAD 83 geographic	NAVD88 (meters)	http://ned.usgs.gov/
CSC ALACE	2002	LiDAR	~2 meters	NAD 83 geographic	NAVD88 (meters)	http://maps.csc.noaa.gov/TCM/
CSC Willapa Bay	2002	LiDAR	~2 meters	NAD 83 geographic	NAVD88 (meters)	http://maps.csc.noaa.gov/TCM/
PSLC Columbia River	2005	LiDAR Bare earth DEMs	~1 meter grid	NAD 83 UTM Zone 10 North (meters)	NAVD88 (meters)	http://pugetsoundlidar.ess.washington.edu/
PSLC Chehalis River	2002	LiDAR Bare earth	~1 meter	NAD 83 State Plane Washington North (feet)	NAVD88 (feet)	http://pugetsoundlidar.ess.washington.edu/
NGDC		digitized elevation points	5 meters	WGS 84 (geographic)	MHW	

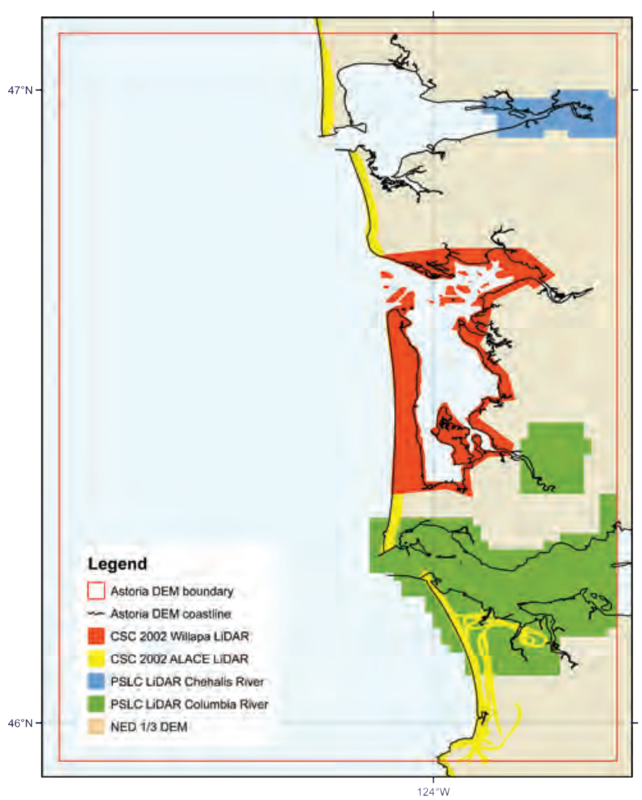

Figure 15. *Spatial coverage of topographic datasets used in the Astoria DEM.*

1) **USGS NED topographic 1/3 arc-second DEMs**

The U.S. Geological Survey (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 1/3 arc-second coverage of the Astoria region[4]. Data are in NAD 83 geographic coordinates and NAVD88 vertical datum (meters), and are available for download as raster DEMs. The bare-earth elevations have a vertical accuracy of +/- 7 to 15 meters depending on source data resolution. See the USGS Seamless web site for specific source information (http://seamless.usgs.gov/). The dataset was derived from USGS quadrangle maps and aerial photographs based on topographic surveys; it has been revised using data collected in 1999 and 2000. The NED DEM included "zero" elevation values over the open ocean, which were removed from the dataset by clipping to the combined coastline. The clipping process also removed artifacts shown in Figure 16.

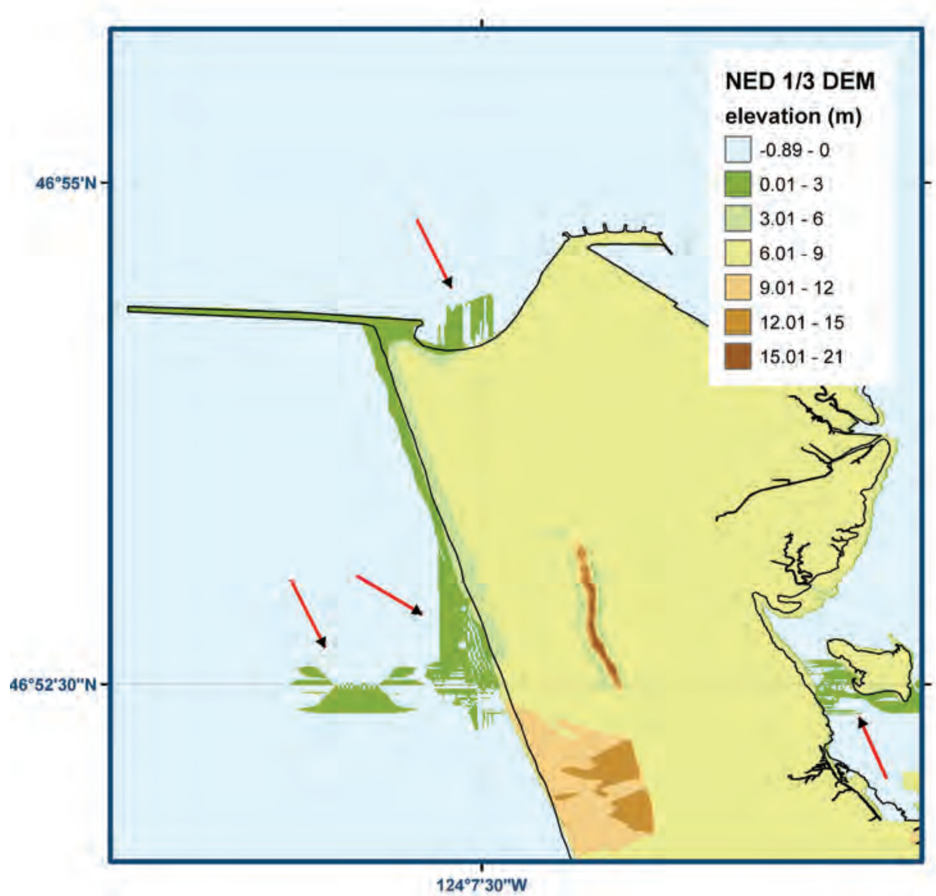

Figure 16. *NED topographic data at Chehalis Point. Red arrows point to artifacts present in the raw dataset.*

4. The USGS National Elevation Dataset (NED) has been developed by merging the highest-resolution, best quality elevation data available across the United States into a seamless raster format. NED is the result of the maturation of the USGS effort to provide 1:24,000-scale Digital Elevation Model (DEM) data for the conterminous U.S. and 1:63,360-scale DEM data for Georgia. The dataset provides seamless coverage of the United States, HI, AK, and the island territories. NED has a consistent projection (Geographic), resolution (1 arc second), and elevation units (meters). The horizontal datum is NAD 83, except for AK, which is NAD 27. The vertical datum is NAVD88, except for AK, which is NGVD29. NED is a living dataset that is updated bimonthly to incorporate the "best available" DEM data. As more 1/3 arc second (10 m) data covers the U.S., then this will also be a seamless dataset. [Extracted from USGS NED website]

2) CSC LiDAR ALACE topography

The 2002 NASA/USGS Airborne LiDAR Assessment of Coastal Erosion (ALACE) Project topographic LiDAR dataset was downloaded from the NOAA CSC website (http://maps.csc.noaa.gov/TCM/) and transformed to NAD 83 and MHW using *FME*. As this dataset was not processed to bare earth and contained elevation values over open water as well as vegetation and buildings, NGDC processed the data using *FME* to simulate bare earth. The data were compared to the USGS NED topographic DEM and points were retained where the difference in elevation between the NED and the LiDAR data points was less than 12 meters. Most tall buildings and vegetation were eliminated while the high sand dunes and berms along the beaches remain (Figs. 17 and 18). This technique also created a smoother seam between the topographic datasets. The data were then clipped to the Astoria coastline and filtered to remove elevation points below zero.

Figure 17. *NASA World Wind image of area north of Seaside, OR. Elevation of sand dunes reach 67 feet.*

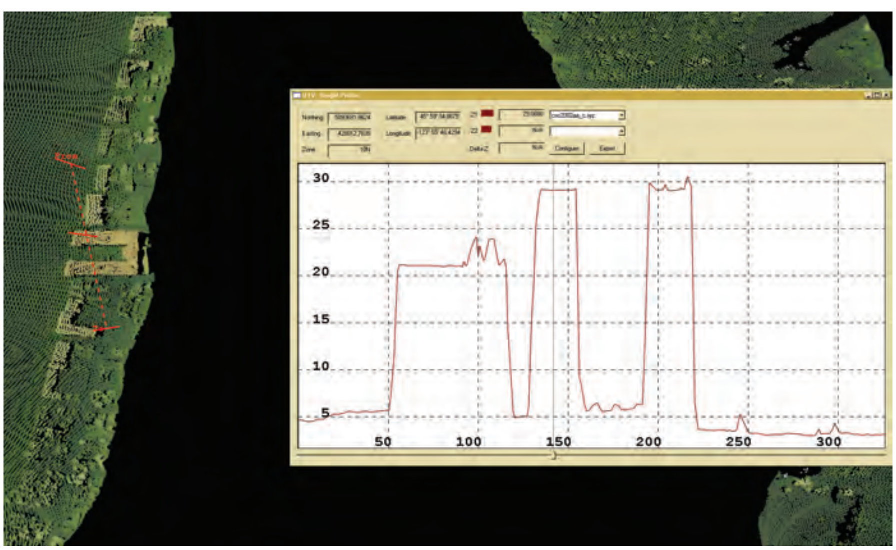

Figure 18. *QT Modeler image of non-bare earth CSC ALACE LiDAR data before filtering process.*

3) CSC LiDAR Willapa Bay topography

The 2002 Willapa Bay LiDAR Project data were downloaded from the CSC website as points in NAD 83 and NAVD88 datums. This project was flown at low tide to capture topographic surface elevation of the exposed intertidal flats and surrounding land areas. The dataset is not designated as bathymetric–topographic because the returns are from land surface at low tide as opposed to returns below water line. The data were transformed to NAD 83 and MHW using *FME* before editing. Visualizing the point data in *QT Modeler* revealed some processing artifacts in the form of horizontal lines along the flight lines throughout the dataset (Fig. 19). This required manual editing in *QT Modeler* before converting to xyz format for final gridding. Data points close to shore and on shoal areas in the bay were retained for use in creating a bathymetric surface.

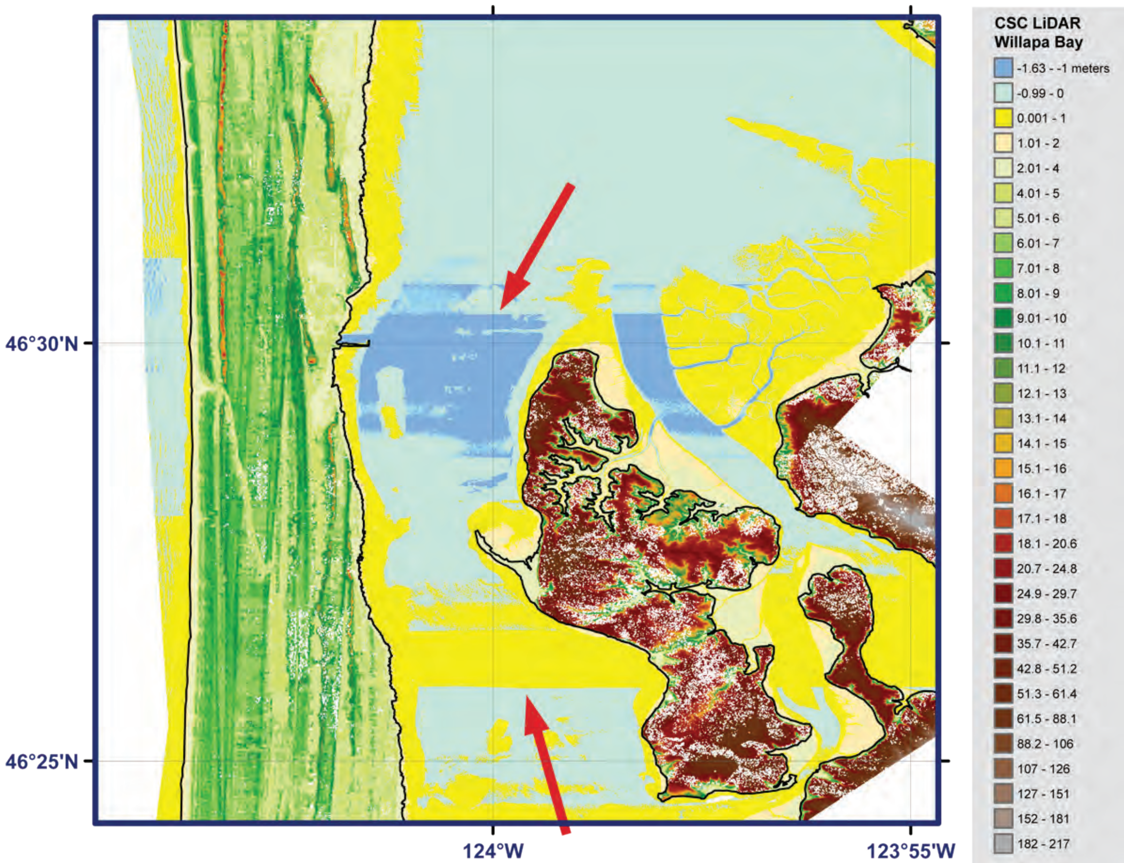

Figure 19. *CSC Willapa Bay LiDAR. Red arrows point to linear artifacts that were clipped from data before final gridding.*

4) PSLC LiDAR Chehalis River bare earth topography

The PSLC Chehalis River LiDAR data were downloaded from the PSLC website (http://pugetsoundlidar.ess.washington.edu/) in ~1 meter resolution point file format and processed to bare earth. The data were converted from NAD 83 State Plane Washington North (feet) and NAVD88 to NAD 83 and MHW using *FME*. Data points over water, shown below in Fig. 20 as darker blue, were removed by clipping to the Astoria coastline using ArcCatalog tools.

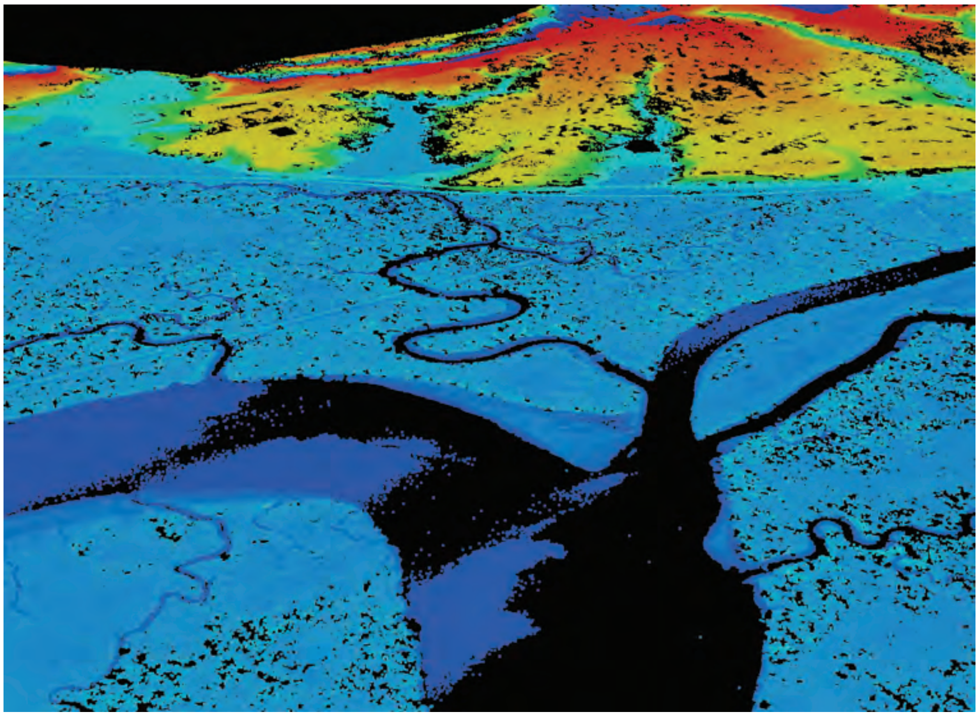

Figure 20. *QT Modeler image of PSLC Chehalis River LiDAR data points. Darker blue points in rivers were removed from dataset before final gridding process.*

5) PSLC LiDAR Columbia River bare earth DEMs

The PSLC Columbia River bare earth DEMs were downloaded from the PSLC website (http://pugetsoundlidar.ess.washington.edu/) as ESRI interchange files and converted to raster format using ArcCatalog tools. *FME* was then used to transform to NAD 83 and MHW, convert to xyz format, and filter out elevation points below -1 meter. Data tiles along the coastline were converted to point shapefiles and clipped to the coastline before final gridding. The green band in the upper right corner of Figure 21 illustrates a section of positive elevation points over the Columbia River that were removed by clipping to the coastline.

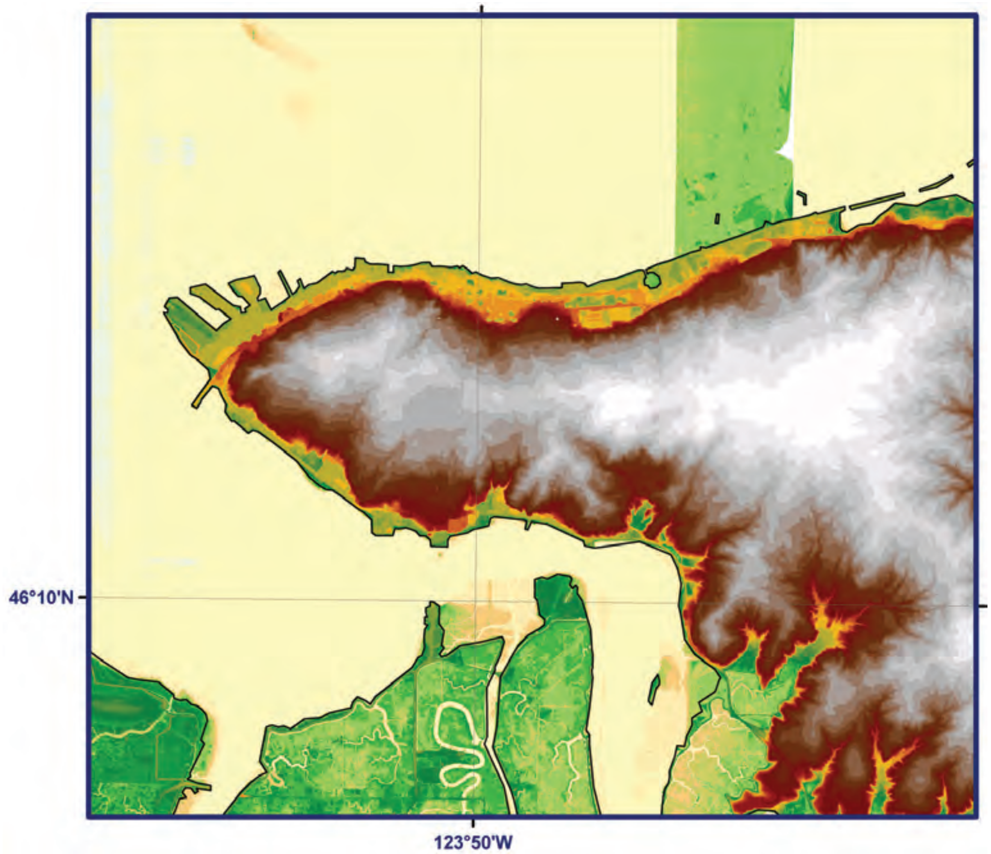

Figure 21. *PSLC Columbia River LiDAR DEM tiles before processing steps. Data are in UTM coordinates and referenced to NAVD88.*

6) NGDC digitized jetty

The southern jetty on Clatsop Spit was not resolved in any of the topographic datasets. In order to ensure the feature was represented in the final DEM, a row of points was created along the jetty with an elevation of 3 meters. The USACE web site for jetties located at the mouth of the Columbia River provided the elevation information used (https://www.nwp.usace.army.mil/issues/jetty/documents.asp). The web site also provides updates on jetty reconstruction for this area. The diagram in Figure 22 shows a comparison of the cross sections of the south jetty from 2005, in blue, and the proposed structure, in green.

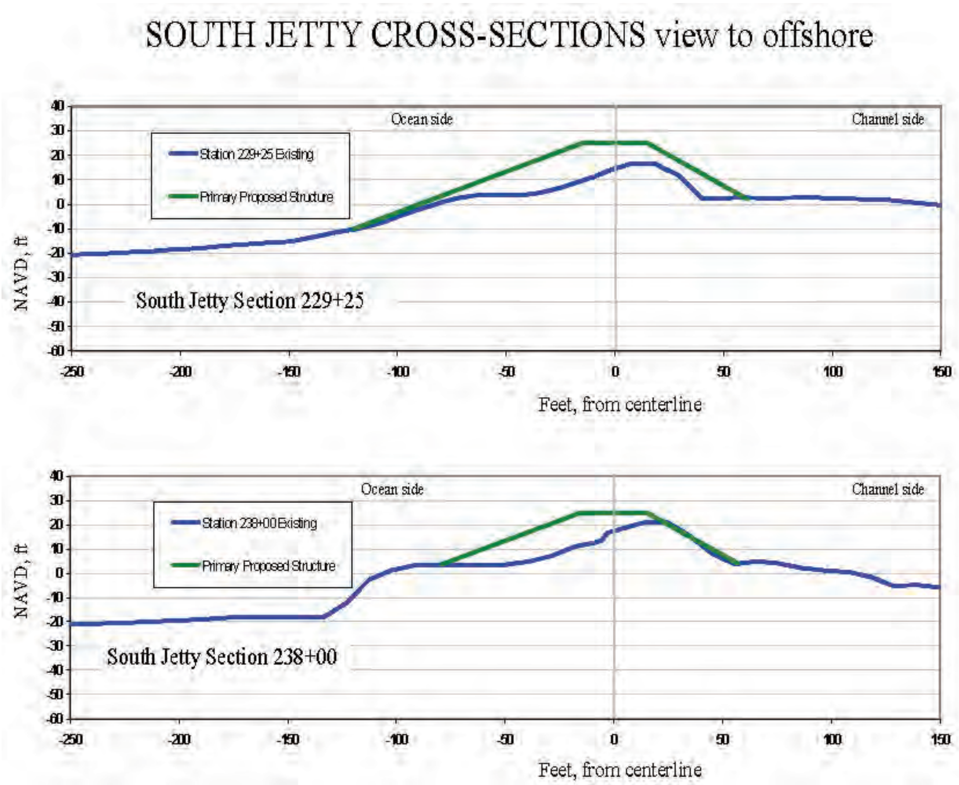

Figure 22. *Diagram of sections of the southern jetty on Clatsop Spit from Final Environmental Assessment Repair of North and South Jetties Mouth of Columbia River (https://www.nwp.usace.army.mil/issues/jetty/docs/finalea25jan05.pdf). Blue line illustrates the cross section of the jetty in 2005. Green line is proposed jetty reconstruction cross section.*

After processing, the topographic data were viewed in *ArcMap* to make sure that the transitions along dataset edges were smooth. In some areas, the transition between the NED data and the LiDAR data formed a step ranging from 1 to 5 meters. A 75 meter data buffer was generated in the NED data to reduce the sharpness of this transition. Figure 23 shows the non-buffered and buffered cross sections in one area. Data were then converted to xyz format using *FME* for the final gridding process.

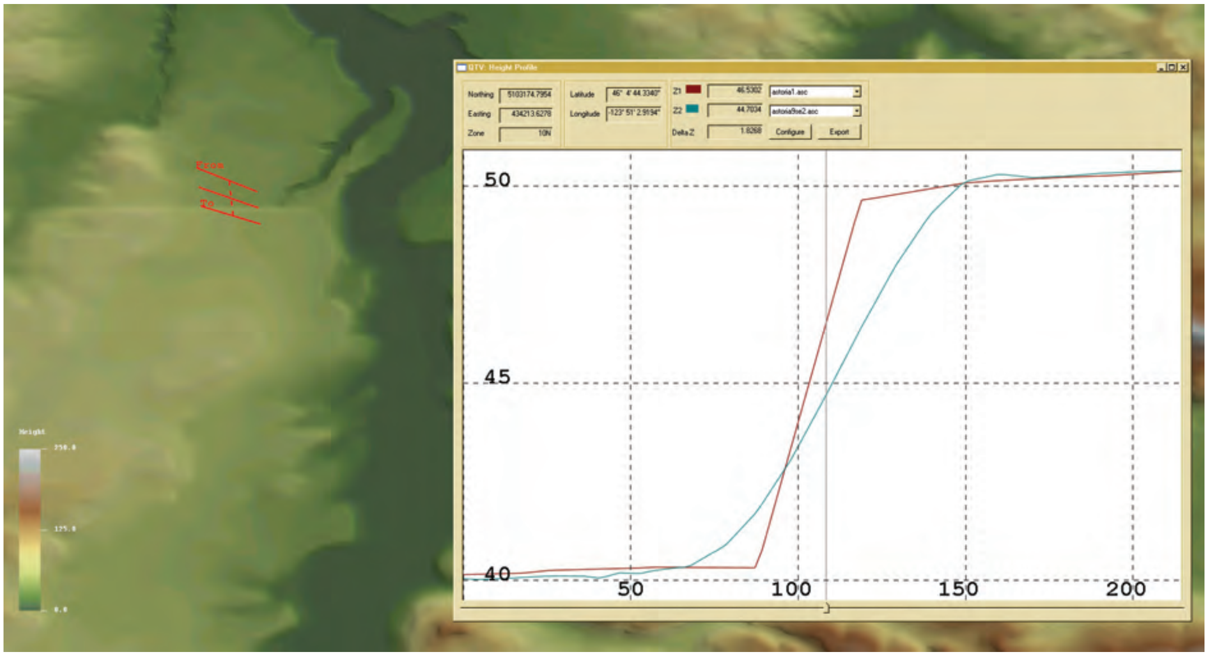

Figure 23. *QT Modeler illustration of two cross sections at dataset transition between LiDAR at the top of image and NED below. The red line in profile represents a preliminary DEM surface before using buffer in transition zone. Teal line is final DEM surface using buffer.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Astoria DEM were originally referenced to a number of vertical datums including Mean Lower Low Water (MLLW), Mean Sea Level (MSL), and NAVD88. All datasets were transformed to MHW to provide the maximum flooding for inundation modeling. Units were converted from feet to meters as appropriate.

1) **Bathymetric data**

   NGDC created two offset grids approximating the relationship between MLLW and MHW, and MSL and MHW for the west coast of Oregon and Washington. The grids were built in *ArcGIS* using the Inverse Distance Weighting (IDW) tool and the differences between the vertical datums as measured at 25 NOAA tide stations in the area (http://tidesandcurrents.noaa.gov/). The grids spanned from 40.7167° to 48.4167° N, and 124.6867° to 122.8868° W with a grid cell size of 0.1 degrees. The NOS hydrographic surveys, USGS and NGDC multibeam surveys, USACE surveys, and the nautical chart soundings were transformed from MLLW and MSL to MHW, using *FME* software, by adding the appropriate offset grid.

2) **Topographic data**

   NGDC created an offset grid approximating the relationship between NAVD88 and MHW along the Pacific Northwest coast. The grid was built in *ArcGIS* using the Inverse Distance Weighting (IDW) tool and the difference between the vertical datums as measured at 16 NOAA tide stations in the region (http://tidesandcurrents.noaa.gov/). The grids spanned from 40.7167° to 48.4167° N, and 124.6867° to 122.8868° W with a grid cell size of 0.1 degrees. The USGS NED 1/3 arc-second DEMs, the PSLC topographic LiDAR, and the CSC topographic LiDAR data were originally referenced to NAVD88. Conversion to MHW, using *FME* software, was accomplished by adding the offset grid to the survey data.

Table 9. Relationship between Mean High Water and other vertical datums at the Astoria tide station #9431647.

Vertical datum	*Difference to MHW in meters*
MSL	-2.466
NAVD88	-1.043
MLLW	-2.428

3.2.2 Horizontal datum transformations

Datasets used to compile the Astoria DEM were originally referenced to WGS 84 geographic, NAD 83 geographic, NAD 27 geographic, NAD 1913, NAD 83 Oregon State Plane North, NAD 83 State Plane Washington South, NAD 83 State Plane Washington North, and NAD 83 UTM Zone 10 North datums. The relationships and transformational equations between these horizontal datums are well established. All data were converted to a horizontal datum of NAD 83 geographic using *FME* software or *ArcGIS*.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting ESRI shape files were checked in *ArcMap* for consistency between datasets. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shape files were then converted to xyz files in preparation for gridding. Problems included:

- Suspect topographic elevations located on open-ocean in both NED and LiDAR datasets.
- Inconsistencies between the NED and LiDAR topographic data.
- Data errors in multibeam swath sonar surveys, which were expressed as anomalous spikes. Manual editing of the multibeam sonar data were necessary to minimize these artifacts.
- Topographic CSC LiDAR dataset not processed to bare earth. The dataset required filtering of elevation values on land and removal of returns from the water surface.
- Digital, measured bathymetric values from NOS surveys date back over 100 years. More recent data, such as the USACE hydrographic survey depths, differed from older NOS data by as much as 10 meters nearshore and up to 75 meters in deeper water compared to multibeam data. The older NOS survey data were excised where more recent bathymetric data exists.

3.3.2 Smoothing of bathymetric data

The NOS hydrographic surveys are generally sparse at the resolution of the 1/3 arc-second Astoria DEM: in both deep water and in some areas close to shore, the NOS survey data have point spacing up to 1900 m apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the DEM due to these low-resolution datasets, and to provide effective interpolation into the coastal zone, a 1 arc-second-spacing 'pre-surface' bathymetric grid was generated using *GMT*, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

To further reduce the interpolation errors between high resolution multibeam and the channel line USACE surveys, the USACE surveys in the Grays Harbor area were blockmeaned using *GMT* in order to "densify" the data and reduce the rippled effect (Figs. 24 and 25). This technique was also used on USACE survey 210501 at the entrance to the Columbia River.

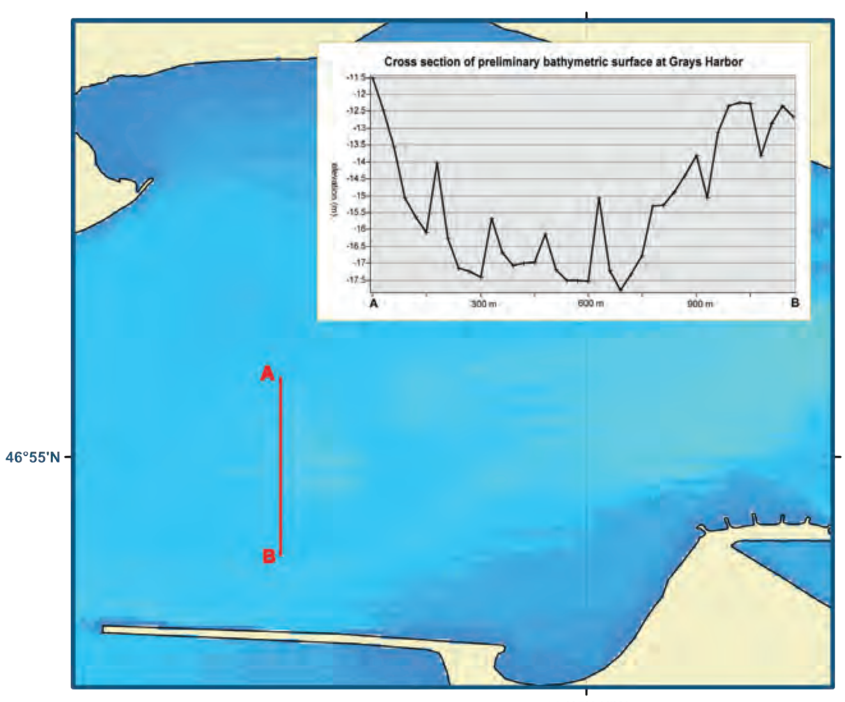

__Figure 24.__ A preliminary bathymetric surface showing cross section of area containing ridges generated from surfacing raw USACE datasets.

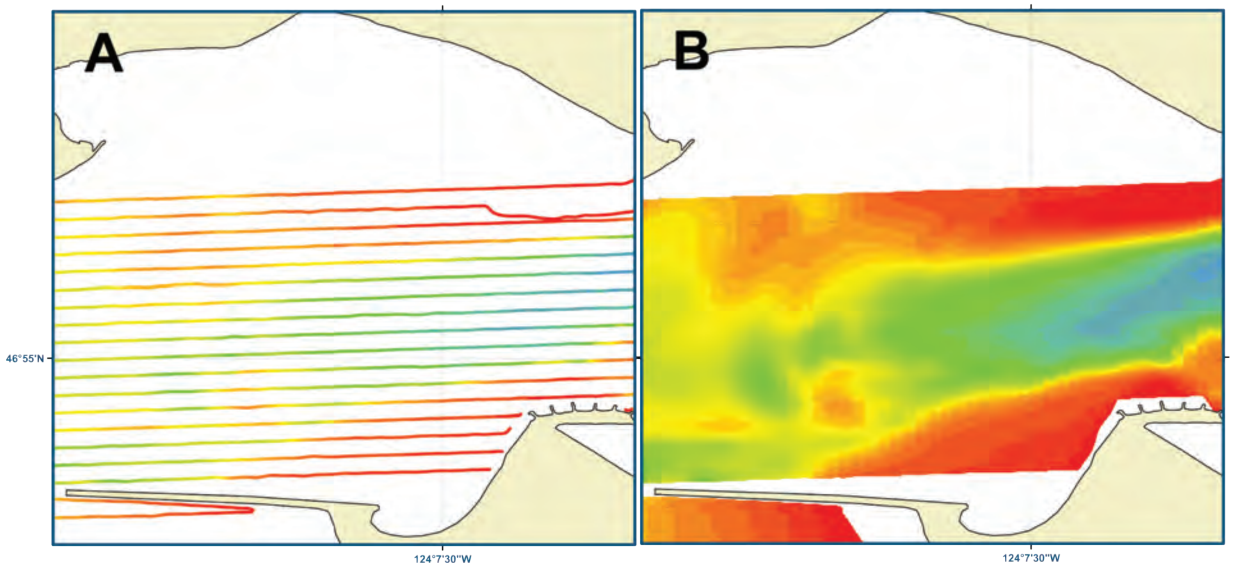

Figure 25. *USACE data in Grays Harbor before and after blockmean processing. A) Raw data points of channel line surveys colored by elevation. B) Blockmean data points of same surveys.*

The NOS hydrographic point data, in xyz format, were clipped to remove overlap with the USACE soundings, NGDC multibeam data, USGS multibeam survey data, and nautical chart sounding data and combined into a single file, along with points extracted from the combined coastline—to provide a buffer along the entire coastline. The coastline elevation value was set at -1.0 m to ensure a bathymetric surface below zero in areas where data are sparse or non-existent. The CSC Willapa Bay LiDAR data were included in creating the bathymetric surface, as the project was flown at low tide specifically to record elevation of tidal flats located within the bay.

The point data were median-averaged using the *GMT* tool ‘blockmedian’ to create a 1 arc-second grid 0.05 degrees (~5%) larger than the Astoria DEM gridding region. The *GMT* tool ‘surface’ was then used to apply a tight spline tension to interpolate elevations for cells without data values. The *GMT* grid created by ‘surface’ was converted into an ESRI Arc ASCII grid file, and clipped to the combined coastline (to eliminate data interpolation into land areas). The resulting surface was compared with original soundings to ensure grid accuracy (e.g., Fig. 26) and exported as an xyz file for use in the final gridding process (see Table 10).

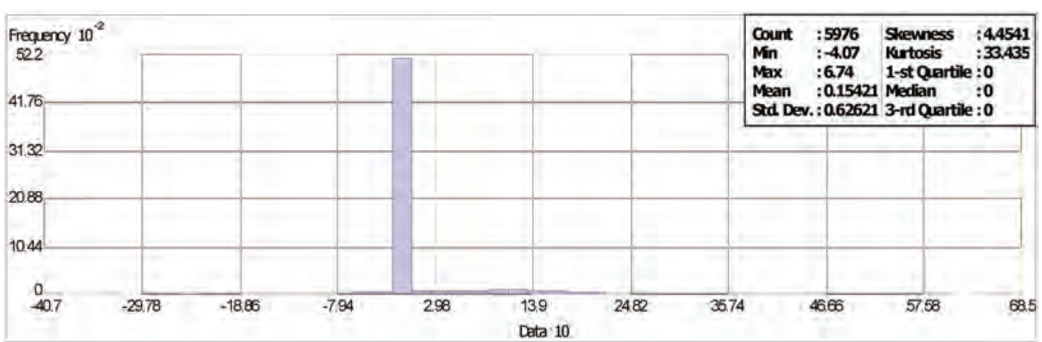

Figure 26. *Histogram of the differences between NOS hydrographic survey H08416 and the 1 arc-second pre-surfaced bathymetric grid.*

3.3.3 Gridding the data with MB-System

MB-System (http://www.ldeo.columbia.edu/res/pi/MB-System/) was used to create the 1/3 arc-second Astoria DEM. *MB-System* is an NSF-funded free software application specifically designed to manipulate submarine multibeam sonar data, though it can utilize a wide variety of data types, including generic xyz data. The *MB-System* tool 'mbgrid' was used to apply a tight spline tension to the xyz data, and interpolate values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 10. Greatest weight was given to the CSC LiDARand USACE survey data. Least weight was given to the pre-surfaced 1 arc-second bathymetric grid and Astoria coastline. Gridding was performed in quadrants, with the resulting Arc ASCII grids seamlessly merged in ArcCatalog to create the final 1/3 arc-second Astoria DEM.

Table 10. Data hierarchy used to assign gridding weight in ***MB-System*****.**

Dataset	*Relative Gridding Weight*
CSC topographic LiDAR	1,000
USGS Multibeam survey	10
NGDC Multibeam surveys	10
USACE surveys	1,000
Nautical chart soundings	10
USGS NED topographic DEM	100
PSLC LiDAR	10,000
NOS hydrographic surveys	10
NOS survey H11723	1,000
Astoria coastline	1
NGDC digitized jetty	10,000
Pre-surfaced bathymetric grid	1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Astoria DEM is dependent upon the datasets used to determine corresponding DEM cell values. Topographic features have an estimated accuracy of 10 meters: PSLC topographic LiDAR data have an accuracy of less then 1 meter, CSC topographic LiDAR data have an accuracy between 1 and 3 meters; NED topography is accurate to within about 10 meters. Bathymetric features are resolved only to within a few tens of meters in deep-water areas. Shallow, near-coastal regions, rivers, and harbor surveys have an accuracy approaching that of sub aerial topographic features. Positional accuracy is limited by: the sparseness of deep-water soundings; potentially large positional uncertainty of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys; and by manmade morphologic change (e.g., channel dredging and building of jetties).

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the Astoria DEM is also highly dependent upon the source datasets contributing to DEM cell values. Topographic areas have an estimated vertical accuracy between 0.1 to 0.3 meters for CSC LiDAR and PSLC LiDAR data, and up to 7 meters for NED topography. Bathymetric areas have an estimated accuracy of between 0.1 meters and 5% of water depth. Those values were derived from the wide range of input sounding data measurements from the early 20th century to recent, GPS-navigated sonar surveys. Gridding interpolation to determine values between sparse, poorly-located NOS soundings degrades the vertical accuracy of elevations in deep water.

3.4.3 Slope maps and 3-D perspectives

ESRI ArcCatalog was used to generate a slope grid from the Astoria DEM to allow for visual inspection and identification of artificial slopes along boundaries between datasets (e.g., Fig. 27). The DEM was transformed to UTM Zone 10 coordinates (horizontal units in meters) in ArcCatalog for derivation of the slope grid; equivalent horizontal and vertical units are required for effective slope analysis. Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEM. Three-dimensional viewing of the UTM-transformed DEM was accomplished using ESRI ArcScene. Figure 28 shows a color image of the 1/3 arc-second Astoria DEM in its final version.

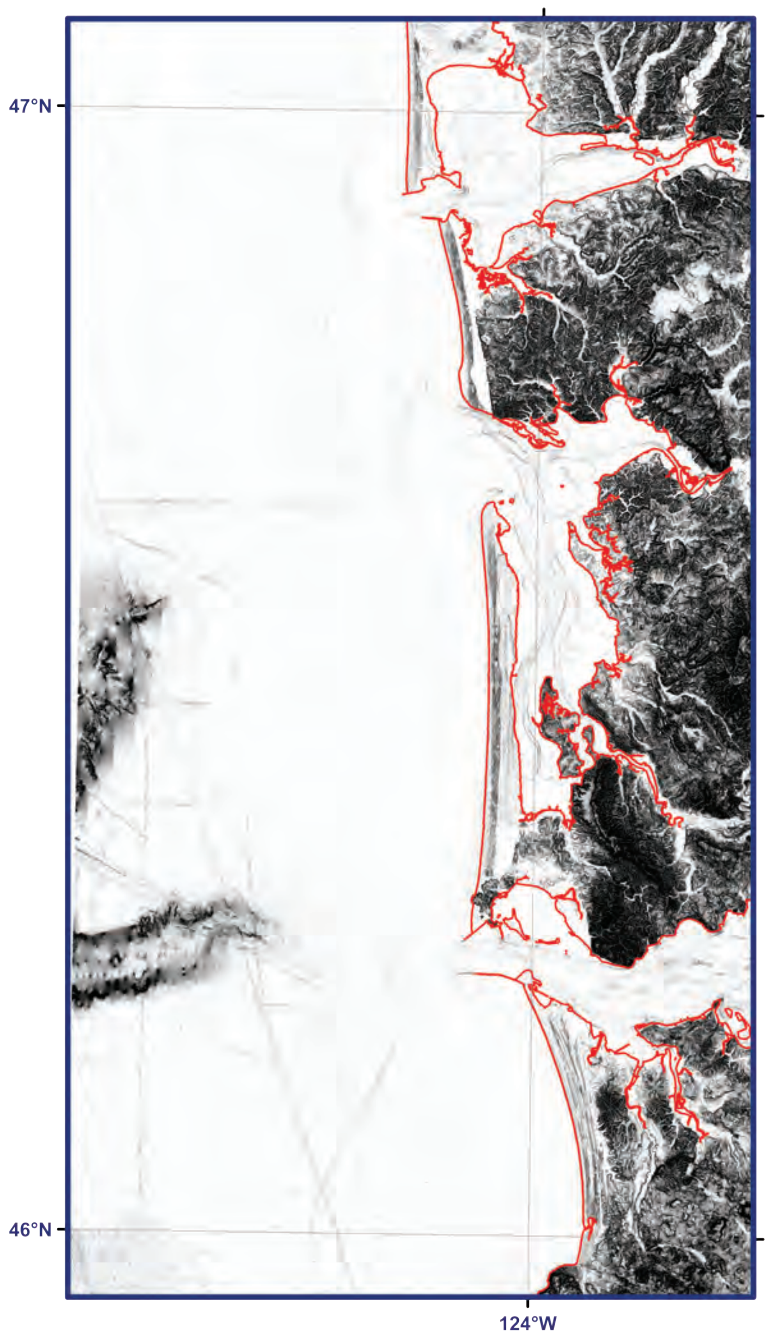

Figure 27. *Slope map of the Astoria DEM. Flat-lying slopes are white; dark shading denotes steep slopes; Astoria coastline in red.*

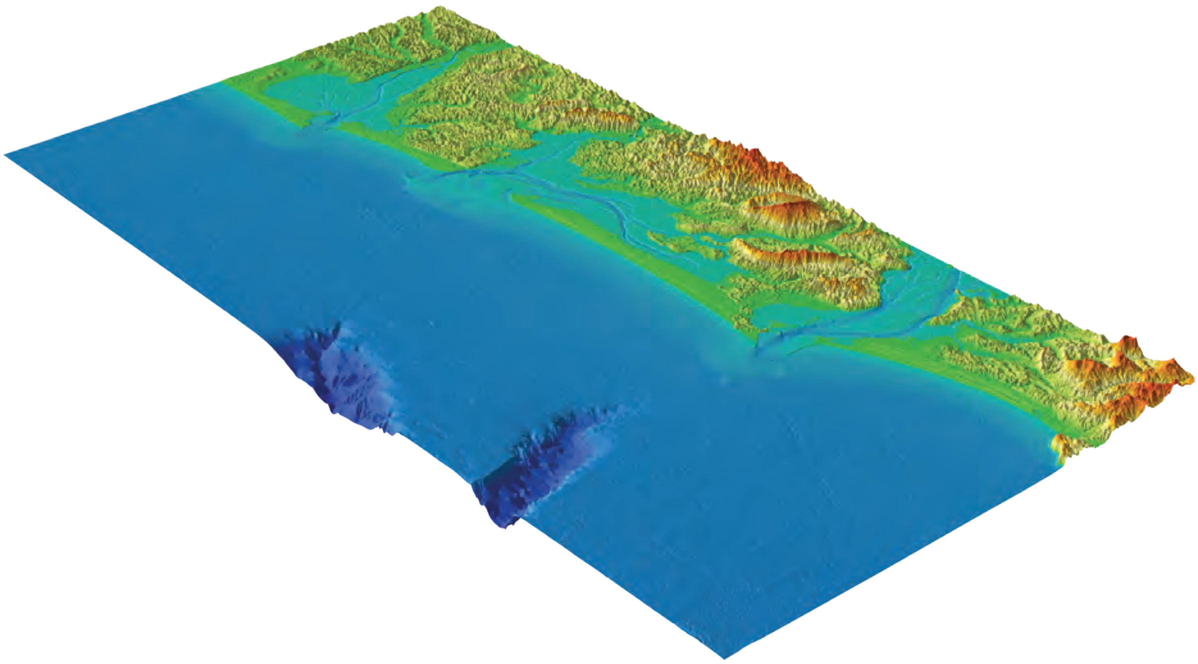

Figure 28. *Perspective view from the southwest of the Astoria DEM. 4x vertical exaggeration.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the Astoria DEM was compared to select source data files. Files were chosen on the basis of their contribution to the grid-cell values in their coverage areas (i.e., had the greatest weight and did not significantly overlap other data files with comparable weight). A histogram of the differences between a section of the non-bare earth CSC ALACE LiDAR survey file located on Cape Disappointment and the Astoria DEM is shown in Figure 29. Differences range from -36.54 to 29.3 meters. Negative values result from the elevation of the LiDAR data being higher than the DEM elevation. The area where the greatest difference occurred is on the heavily vegetated steep hillsides just north of Cape Disappointment at North Head.

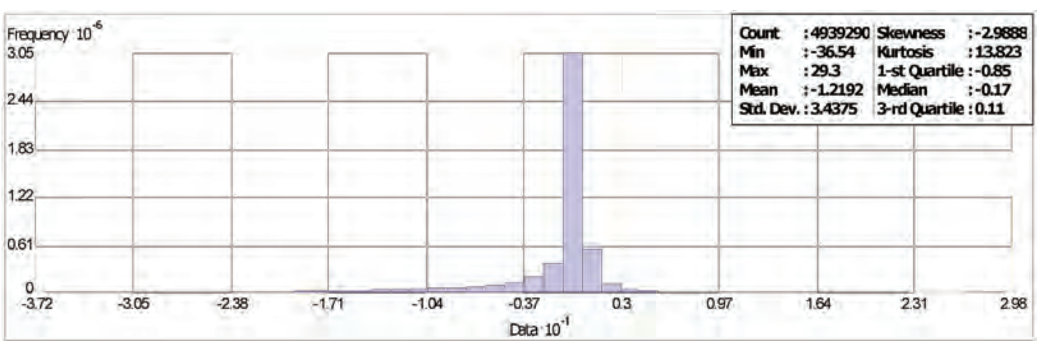

Figure 29. *Histogram of the differences between a section of the CSC ALACE LiDAR survey and the Astoria DEM.*

3.4.5 Comparison with NGS geodetic monuments

The elevations of 710 NOAA NGS geodetic monuments were extracted from online shape files of monument datasheets (http://www.ngs.noaa.gov/cgi-bin/datasheet.prl), which give monument positions in NAD 83 (typically sub-mm accuracy) and elevations in NAVD88 (in meters). Monuments installed on lighthouses or buildings were not included in assessment of the DEM.

Elevations were shifted to MHW vertical datum (see Table 10) for comparison with the Astoria DEM (see Fig. 31 for monument locations). Differences between the Astoria DEM and the NGS geodetic monument elevations range from -86.62 to 180.12 meters, with the majority of them within ± 10 meters (Fig. 30). Negative values indicate that the DEM is less than the monument elevation. Monuments located in a lighthouse, on steep embankments, on a removed church tower, and lost monuments had the greatest negative values. The monuments with the greatest positive values were located at the top of a steep hill, at the top of a lighthouse, and on top of Astoria Column. The elevation recorded for the lighthouse monument was listed as the height of the lighthouse, not the height of the lighthouse plus the elevation of the cliff where it is located. Astoria Column is 125 ft (38.1 meters) high on top of a hill above the town, yet the monument elevation is recorded as 2 meters. The horizontal accuracy of some of these monuments could be off by ± 6 arc-seconds (~180 meters).

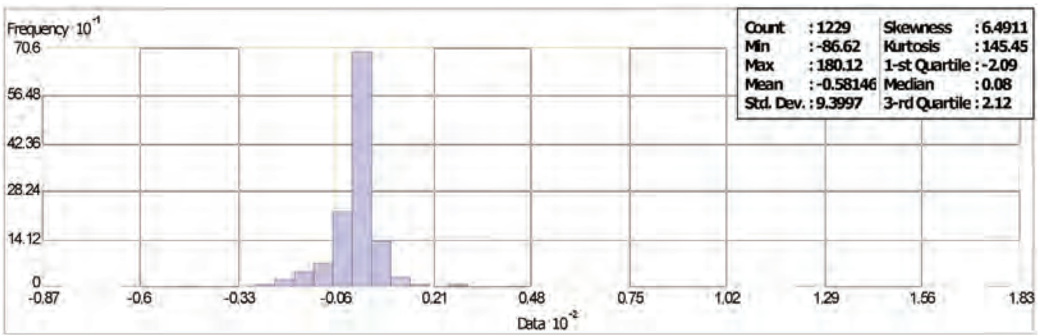

Figure 30. *Histogram of the differences between NGS geodetic monument elevations and the Astoria DEM.*

Figure 31. *Location of NGS geodetic monuments, shown as green triangles, and the NOAA tide stations, red circles. NGS monument elevations were used to evaluate the DEM.*

4. Summary and Conclusions

An integrated bathymetric–topographic digital elevation model of the Astoria, Oregon region, with cell spacing of 1/3 arc-second, was developed for the Pacific Marine Environmental Laboratory (PMEL) NOAA Center for Tsunami Research. The best available digital data from U.S. federal, state and local agencies were obtained by NGDC, shifted to common horizontal and vertical datums, and evaluated and edited before DEM generation. The data were quality checked, processed and gridded using ESRI *ArcGIS*, *FME*, *GMT*, *MB-System*, *CARIS*, and *Quick Terrain Modeler* software.

Recommendations to improve the Astoria DEM, based on NGDC's research and analysis, are listed below:

- Conduct hydrographic surveys in near-shore areas, especially in bays and river inlets.
- Complete bathymetric–topographic LiDAR surveying of entire region.
- Process CSC topographic LiDAR data to bare earth.
- Conduct hydrographic surveys to replace older, low-resolution NOS surveys in some deep water areas.
- Include deep water multibeam survey of Astoria Canyon and NOS hydrographic survey H11724, neither of which were available for use in this DEM.

5. Acknowledgments

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6. References

Nautical Chart #18500 (RNC and ENC), 29nd Edition, 2004. Columbia River to Destruction Island. Scale 1: 180,789. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18502 (ENC and RNC), 86th Edition, 2007. Greys Harbor – Westhaven Cove. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18504 (RNC), 66th Edition, 2006. Willapa Bay – Toke Point. Scale 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18520 (ENC and RNC), 26th Edition, 2005. Yaquina Head to Columbia River – Netarts Bay. Scale 1:185,238. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #18521 (ENC and RNC), 72nd Edition, 2005. Columbia River Pacific Ocean to Harrington Point – Ilwaco Harbor. Scale 1:196,948. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

U.S. Army Corps of Engineers, Portland District. 2005. Final Environmental Assessment Repair of North and South Jetties Mouth of the Columbia River Clatsop County, Oregon and Pacific County, Washington. https://www.nwp.usace.army.mil/issues/jetty/documents.asp

7. Data Processing Software

ArcGIS v. 9.2, developed and licensed by ESRI, Redlands, Oregon, http://www.esri.com/

FME 2008 GB – Feature Manipulation Engine, developed and licensed by Safe Software, Vancouver, BC, Canada, http://www.safe.com/

GEODAS v. 5 – Geophysical Data System, free software developed and maintained by Dan Metzger, NOAA National Geophysical Data Center, http://www.ngdc.noaa.gov/mgg/geodas/

GMT v. 4.1.4 – Generic Mapping Tools, free software developed and maintained by Paul Wessel and Walter Smith, funded by the National Science Foundation, http://gmt.soest.hawaii.edu/

MB-System v. 5.1.0, free software developed and maintained by David W. Caress and Dale N. Chayes, funded by the National Science Foundation, http://www.ldeo.columbia.edu/res/pi/MB-System/

Quick Terrain Modeler v. 6.0.1, LiDAR processing software developed by John Hopkins University's Applied Physics Laboratory (APL) and maintained and licensed by Applied Imagery, http://www.appliedimagery.com/

CARIS Bathy DataBASE 2.0, bathymetric data processing software developed and licensed by CARIS, Fredericton, NB, Canada, http://www.caris.com/