NOAA Technical Memorandum NESDIS NGDC-40

DIGITAL ELEVATION MODELS OF PRINCE WILLIAM SOUND, ALASKA: PROCEDURES, DATA SOURCES AND ANALYSIS

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1. Introduction

In April of 2009, the National Geophysical Data Center (NGDC), an office of the National Oceanic and Atmospheric Administration (NOAA), developed a set of integrated bathymetric–topographic digital elevation models (DEMs) covering the Prince William Sound, Alaska region (Fig. 1) for the Geophysical Institute at the University of Alaska at Fairbanks (UAF). These DEMs are nested at 8 arc-second[1], 8/3 arc-second and 8/15 arc-second, with the highest- resolution grids centered on the harbors at Whittier and Cordova. The coastal DEMs will be used as input for the university-developed modeling system to simulate tsunami generation, propagation, and inundation (http://www.aeic.alaska.edu/tsunami/). The DEMs were generated from diverse digital datasets in the region (grid sources shown in Figure 4) and were designed to represent modern morphology. They will be used for tsunami inundation modeling by the Alaska Earthquake Information Center in support of the National Tsunami Hazard Mitigation Program (http://nthmp.tsunami.gov/). This report provides a description of the data sources and methodology used to develop the Prince William Sound DEMs.

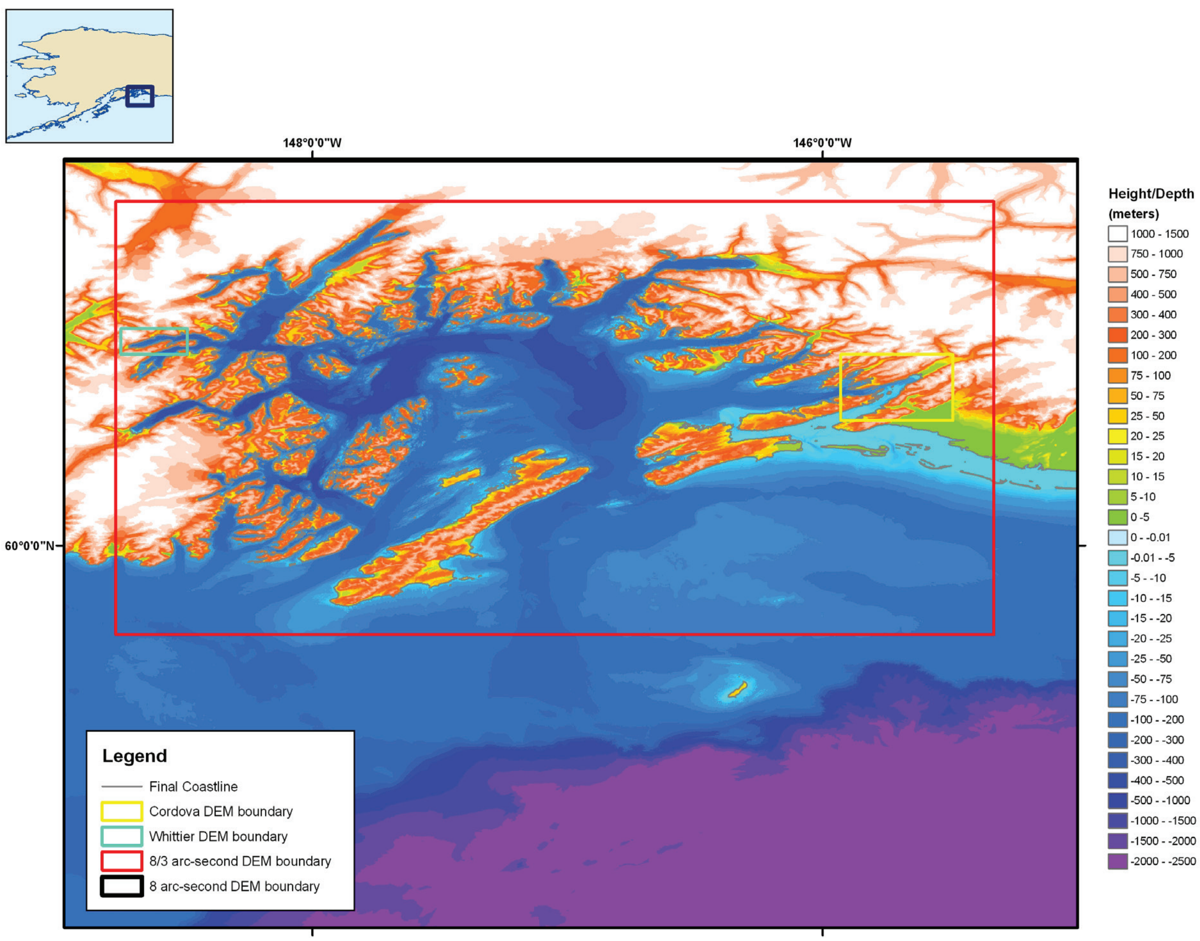

Figure 1. *Boundaries of the Prince William Sound, Alaska nested DEMs. Inset (upper left) shows position of the 8 arc-second DEM boundary relative to the Alaskan coastline. Color image of the 8 arc-second DEM is in the background.*

1. In polar latitudes, longitude lines are spaced significantly closer together than latitude lines, approaching zero at the poles. While the DEMs are built upon grids of square cells in geographic coordinates, they are not square cells when converted to meters. At the latitude of Cordova, Alaska (60º32'34.1"N, 145º45'36.59"W) 1 arc-second of latitude is equal to 31.01 meters; 1 arc-second of longitude is 15.23 meters.

2. Study Area

Prince William Sound is surrounded by the Chugach Mountains to the east, west, and north. Fifty-mile long Montague Island and several smaller islands form natural breakwaters between the Sound and the Gulf of Alaska to the south (Fig. 2). Between the barrier islands stretch underwater sills separating the Sound's deep waters from the much shallower coastal waters of the Gulf of Alaska. Millions of years of glaciation have gradually carved away a coastal plateau (see Fig. 1), creating a sound with many tributary fjords and passageways, islands, and rocky shores. Approximately 10,000 people live in the three towns of Whittier, Valdez, and Cordova along the shores of the Sound.

Figure 2. *Map of the region surrounding Prince William Sound, Alaska. Major geographical features identified. (http://www.alaska101.com/exploreAlaska/maps/princeWilliamSound.gif)*

The effects of climate change on glaciation are exemplified by Columbia Glacier (Fig. 3a). From 1982 to 2000, the Columbia Glacier retreated 12 kilometers and lost over 400 meters of thickness (Fig 3b; Krimmel 2001). The escarpments at the glacial toe create significant vertical gradients from the topographic cliffs at the glacial edge to the oceanic troughs of nearly 400 meters.

Prince William Sound is in an earthquake prone region, making the area highly vulnerable to tsunamis. The second most powerful earthquake in the twentieth century occurred on March 27, 1964. Its epicenter was located approximately 90 miles west of Valdez near College Fjord (see Fig. 2). Measuring 9.2 on the Richter scale, the earthquake caused major vertical displacements in and around Prince William Sound, with uplift reported up to 15 meters and maximum subsidence of 2.3 meters relative to sea level (http://www.drgeorgepc.com/Earthquake1964Alaska.html). These semi-permanent, vertical displacements of the seafloor have reduced the accuracy and reliability of pre-1965 hydrographic surveys.

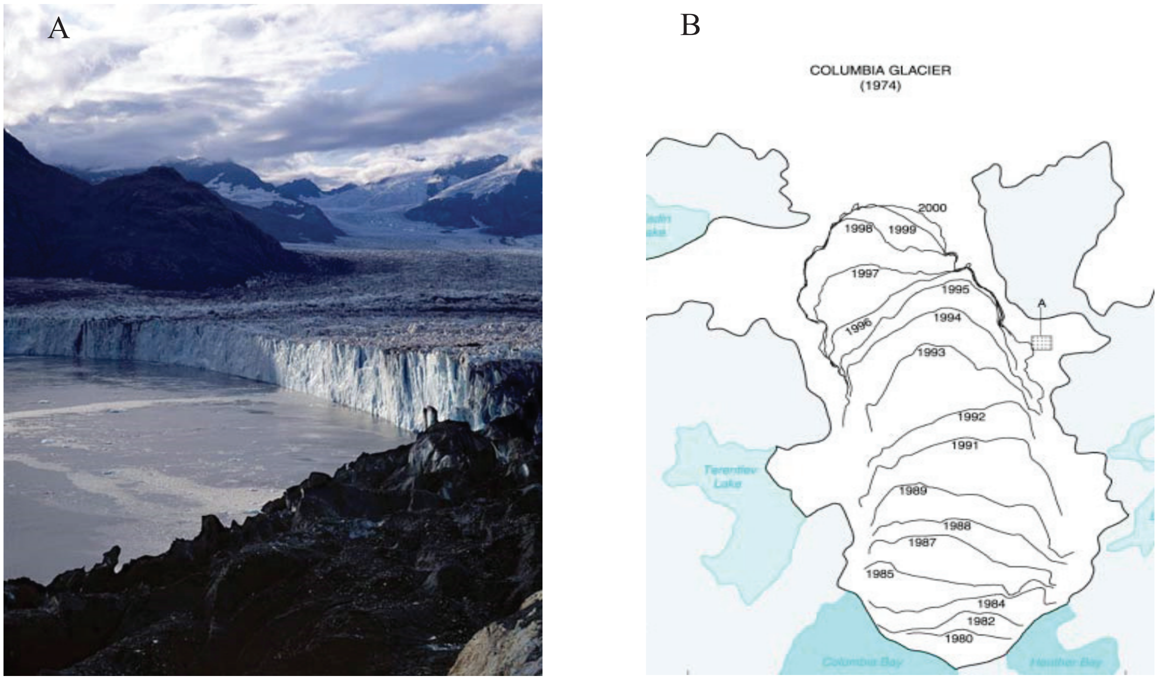

Figure 3. *Columbia Glacier. A) 2008 photograph of Columbia Glacier from http://www.livescience.com/imageoftheday/siod_051208.html. B) Diagram from USGS Report 01-4089 showing the rapid retreat of Columbia Glacier from 1974-2000 (Krimmel 2001).*

3. Methodology

The Prince William Sound DEMs were developed to meet the specifications in Table 1, which have slightly larger extents (~5 percent) than that required by UAF's tsunami modeling requirements. The best available digital data were obtained by NGDC and shifted to common horizontal and vertical datums: World Geodetic System 1984 (WGS 84) geographic[2] and Mean Higher High Water (MHHW), for modeling of maximum flooding, respectively. Data processing and evaluation, and DEM assembly and assessment are described in the following subsections.

Table 1a: Specifications for the 8 arc-second Prince William Sound, Alaska DEM.

Grid Area	Prince William Sound, Alaska
Coverage Area	149.01º to 144.99º W; 58.49º to 61.51º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8 arc-seconds
Grid Format	netCDF

Table 1b: Specifications for the 8/3 arc-second Prince William Sound, Alaska DEM.

Grid Area	Prince William Sound, Alaska
Coverage Area	148.77º to 145.33º W; 59.65º to 61.35º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8/3 arc-second
Grid Format	netCDF

Table 1c: Specifications for the 8/15 arc-second Cordova, Alaska DEM.

Grid Area	Cordova, Alaska
Coverage Area	145.93º to 145.49º W; 60.49º to 60.75º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8/15 arc-second
Grid Format	netCDF

Table 1d: Specifications for the 8/15 arc-second Whittier, Alaska DEM.

Grid Area	Whittier, Alaska
Coverage Area	148.75º to 148.91º W; 60.75º to 60.85º N
Coordinate System	Geographic decimal degrees
Horizontal Datum	World Geodetic System 1984 (WGS 84)
Vertical Datum	Mean Higher High Water (MHHW)
Vertical Units	Meters
Cell Size	8/15 arc-second
Grid Format	netCDF

2. The horizontal difference between the North American Datum of 1983 (NAD 83) and World Geodetic System of 1984 (WGS 84) horizontal datums is approximately one meter across the contiguous U.S., which is significantly less than the cell size of the DEMs. 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 the 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, for their DEMs so that they can model the wave's passage across ocean basins. These DEMs are identified as having a WGS 84 horizontal datum even though the underlying elevation data were typically transformed to NAD 83. At the scale of the DEMs, WGS 84 and NAD 83 are identical and may be used interchangeably.

3.1 Data Sources and Processing

Shoreline, bathymetric, and topographic digital datasets (Fig. 4) were obtained from several U.S. federal and academic agencies, including: NOAA's National Ocean Service (NOS), Office of Coast Survey (OCS), and NGDC; the U.S. Fish and Wildlife Service (FWS); the U.S. Geological Survey (USGS); and the U.S. Army Corps of Engineers (USACE). 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 into ESRI (http://www.esri.com/) *ArcGIS* shapefiles[3]. The shapefiles were then displayed with *ArcGIS* to assess data quality and manually edit datasets. The methodology used for vertical datum adjustments is described in Section 3.2.1.

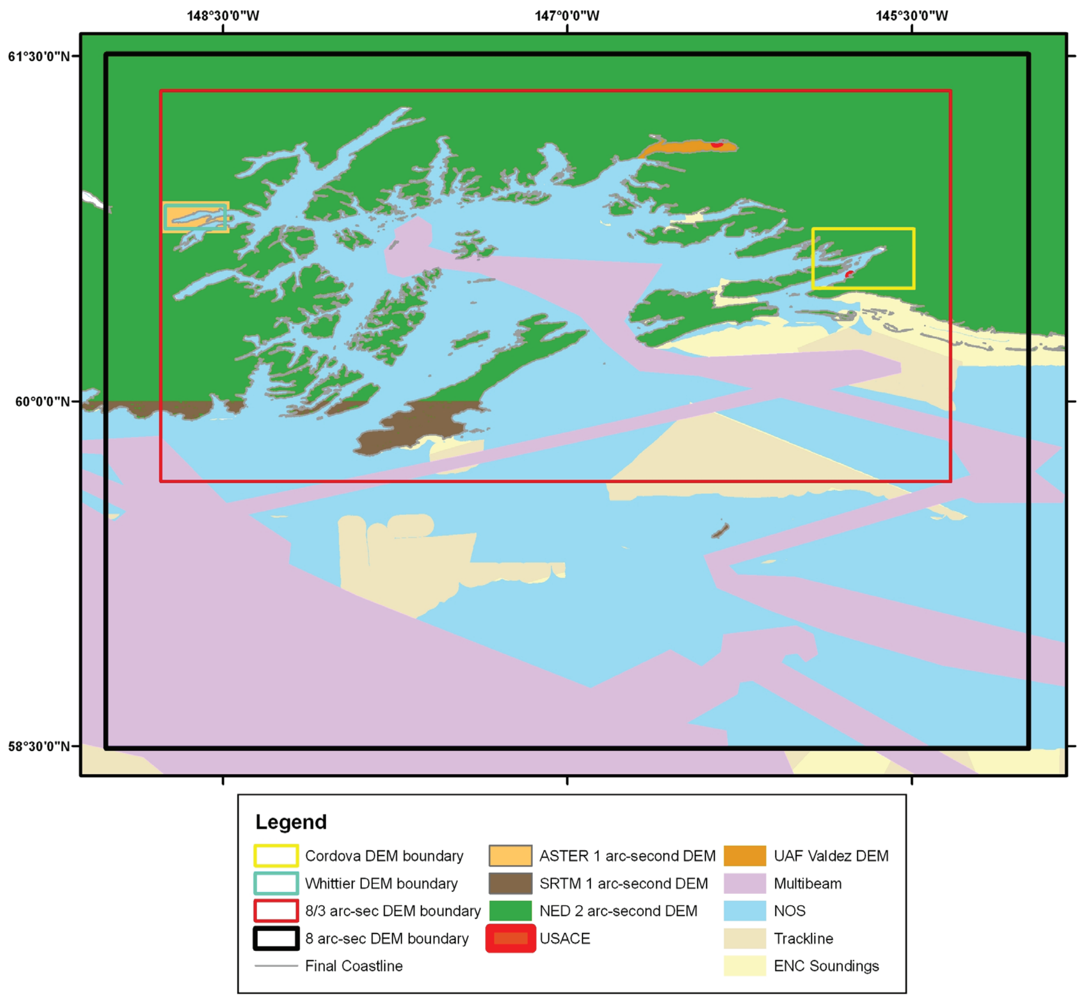

Figure 4. *Principal source dataset contributions to the Prince William Sound, Alaska DEMs.*

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

Two digital coastline datasets of the Prince William Sound region were analyzed for inclusion in the Prince William Sound DEMs: NOAA ENCs (see Table 3) and U.S. Fish and Wildlife Service (FWS) statewide Alaska digital coastline (Table 2; Fig. 5). Comparisons between the two coastline datasets, NOS hydrographic surveys, and the NED and SRTM topographic DEMs showed that the FWS coastline (Figs. 6 and 7) best fit the topographic and bathymetric data overall and was merged with large-scale ENC coastlines to create a 'final coastline' of the Prince William Sound region.

Table 2. Shoreline datasets used in compiling the Prince William Sound, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*
FWS	2006	Compiled coastline	Various	WGS 84 geographic	Undefined
NOAA nautical charts	1997-1998	Inferred MHHW coastline	Digitized from 1:10000,1:30000 and 1:80000 scale charts	WGS 84 geographic	Inferred MHHW

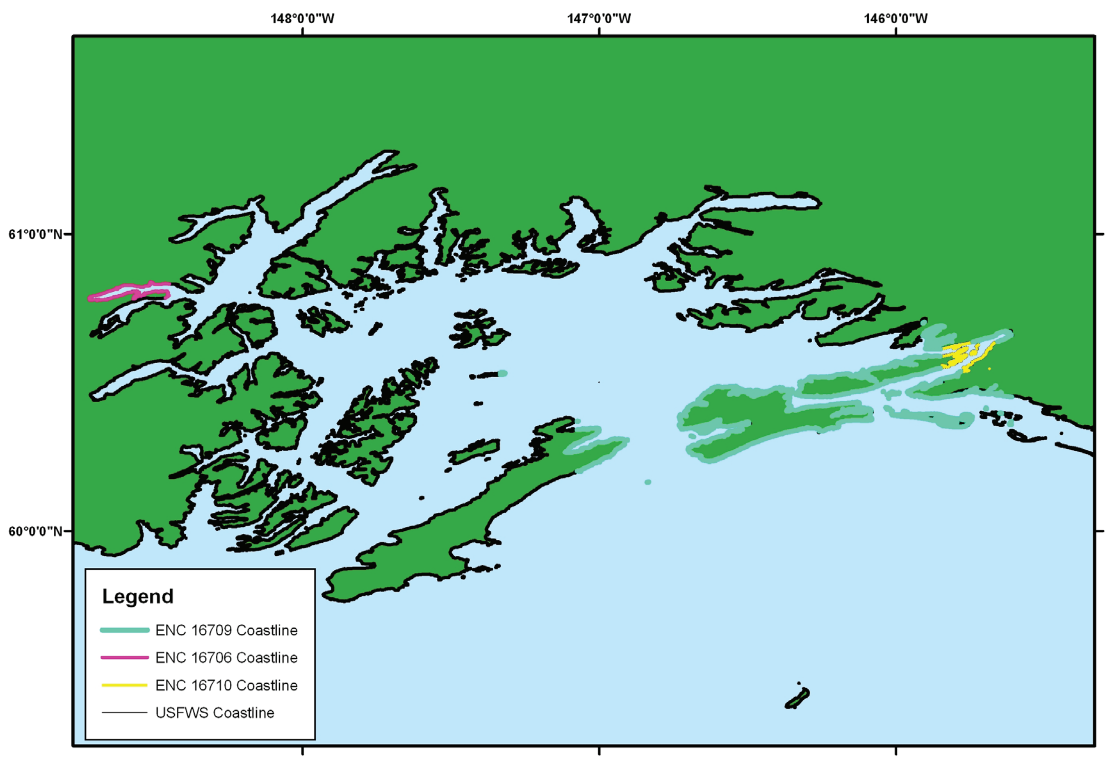

Figure 5. *Digital coastline datasets used to compile the 'final coastline' of the Prince William Sound region.*

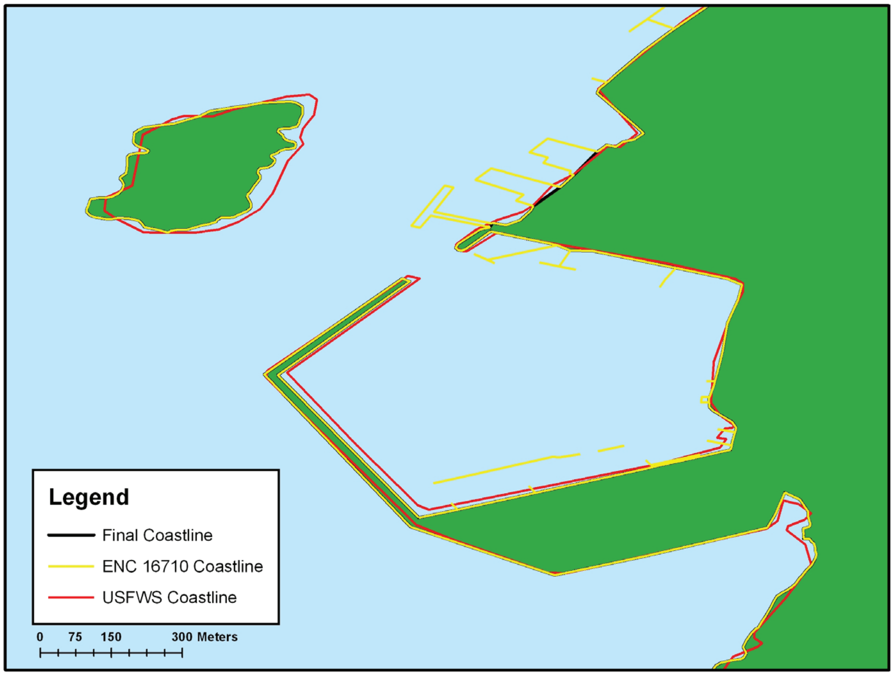

Figure 6. *Digital coastline datasets surrounding Cordova Harbor. The ENC coastline was edited to remove piers and docks and incorporated into the final coastline. The final coastline (shaded in green) was then used in developing the Prince William Sound DEMs.*

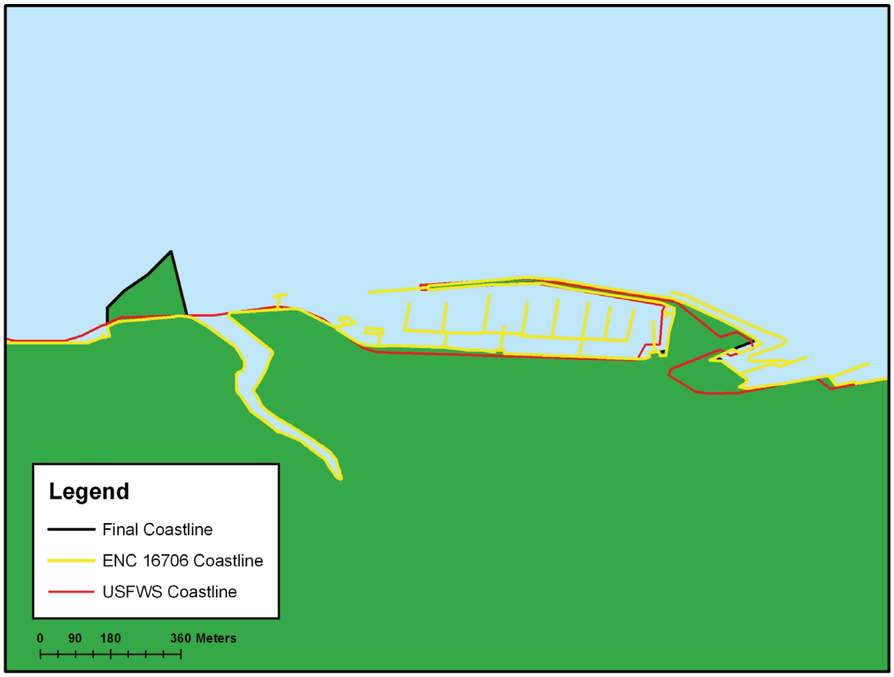

Figure 7. *Digital coastline datasets surrounding Whittier Harbor.*

1) U.S. Fish and Wildlife Service

The U.S. Fish and Wildlife Service (FWS) has compiled a seamless digital coastline of the State of Alaska from a variety of sources, including: the National Hydrography Dataset, NOAA nautical charts, U.S. Fish and Wildlife Service, National Geographic Topo Software, U.S. Army Corps of Engineers, and Alaska Department of Natural Resources. This dataset was graciously provided to NGDC by Bret Christensen, U.S. Fish and Wildlife Service. Though efforts were made to obtain the highest resolution coastlines available, vertical datums were apparently not determined nor controlled in any way in compiling the FWS coastline; the horizontal datum of the compiled FWS coastline is WGS 84. The FWS coastline provides complete coverage of the Prince William Sound region.

2) NOAA nautical charts

Seventeen NOAA nautical charts were available for the Prince William Sound area (Table 3), and were downloaded from NOAA's Office of Coast Survey web site (http://www.nauticalcharts.noaa.gov/mcd/enc/index.htm). All charts are available as georeferenced Raster Nautical Charts (RNCs; digital images of the charts), which were used to assess the quality of bathymetric datasets. The charts were also available as Electronic Navigational Charts (ENCs) that represent chart features as individual digital objects. The ENCs are in S-57 format and include coastline data files referenced to Mean High Water (MHW). The ENC coastlines were assumed to be essentially the same at MHHW once adjusted to fit the bathymetric datasets. The average vertical offset from MHW to MHHW based on regional tide stations (see Table 8) is approximately 0.3 meters.

ENCs #16709 and #16710 provided detailed coastlines covering the area surrounding Cordova, Alaska. ENC #16706 provided detailed coastline data for the region around Whittier Harbor. Each of the ENC coastline datasets contained many piers and other man made structures that had to be removed when building the final coastline (e.g., Figs. 6 and 7). Satellite imagery from Google Earth (http://www.google.com/earth/index.html) and photographs of Whittier and Cordova, Alaska, were referenced while manually adjusting the coastlines in the immediate vicinity of the harbors (e.g., Figs. 8 and 9).

Table 3. NOAA nautical charts in the Prince William Sound region.

Chart	*Title*	*Edition*	*Edition Date*	*Format*	*Scale*
531	Gulf of Alaska, Strait of Juan de Fuca to Kodiak Island	13th	2008	ENC and RNC	1:2,100,000
16013	Cape St. Elias to Shumagin Islands	30th	2008	RNC	1:969,761 with 1:400,000 inset
16680	Point Elrington to East Chugach Island	5th	2007	ENC and RNC	1:200,000
16683	Point Elrington to Cape Resurrection	6th	2008	ENC and RNC	1:81,436
16700	Prince William Sound	2nd	2008	ENC and RNC	1:200,000
16701	Prince William Sound, Western Entrance	9th	2007	ENC and RNC	1:81,436
16702	Latouche Passage to Whale Bay	7th	2008	ENC and RNC	1:40,000
16704	Drier Bay	3rd	2007	ENC and RNC	1:20,000
16705	Prince William Sound, Western Part	5th	2007	ENC and RNC	1:80,000
16706	Passage Canal including Port of Whittier	3rd	2008	ENC and RNC	1:20,000 with 1:10,000 inset
16707	Prince William Sound, Valdez Arm, and Port Valdez	17th	2008	ENC and RNC	1:40,000 with 1:20,000 and 1:10,000 insets
16708	Prince William Sound, Port Fidalgo and Valdez Arm	15th	2008	ENC and RNC	1:79,291 with 1:40,000 inset
16709	Prince William Sound, Eastern Entrance	11th	2008	ENC and RNC	1:80,000
16710	Orca Bay and Inlet Channel Islands to Cordova	6th	2008	ENC and RNC	1:30,000
16711	Port Wells, College Fiord	2nd	2007	ENC and RNC	1:50,000
16712	Unakwik Inlet to Esther Passage and College Fiord	3rd	2007	ENC and RNC	1:50,000
16713	Naked Island to Columbia Bay	9th	2008	ENC and RNC	1:50,000

To obtain the best digital MHHW coastline of the Prince William Sound region, NGDC merged the FWS coastline and large-scale ENCs into a 'final coastline' (see Fig. 5). The final coastline was edited to be consistent with the NOS hydrographic survey data and two recent USACE harbor surveys at Valdez and Cordova. For example, the coastline was manually edited using NOS hydrographic survey H11494 in the region of Columbia Glacier due to the rapid recession of the glacier in the past two decades. Piers and docks were also manually removed from the final coastline.

The final coastline was sub-sampled to 10-meter spacing using NGDC's *GEODAS* software and converted to point data for use as a coastal buffer for the bathymetric pre-surfacing algorithm (see Section 3.3.2) to ensure that interpolated bathymetric values reached "zero" at the coast. The final coastline was used to clip the SRTM and NED topographic DEMs, which contained elevation values, typically zero, over the open ocean (see Section 3.1.3).

Figure 8. *An oblique photograph of Cordova Harbor. Picture downloaded from travel.webshots.com by member krusejm. Taken October 3, 2005. Source: http://travel.webshots.com/photo/1468070354079299222SgXegr*

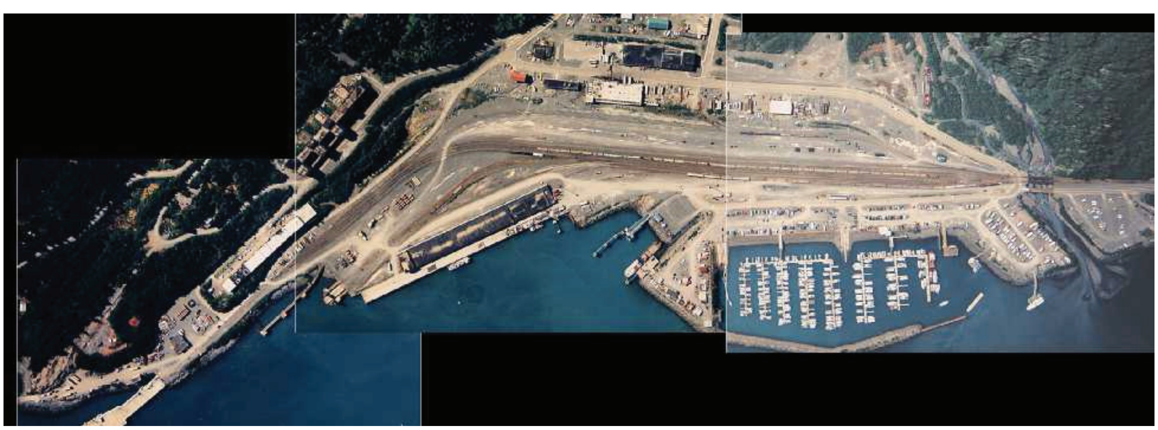

Figure 9. *A composite aerial photograph of Whittier Harbor. Picture downloaded from alaskarails.org. Source: http://www.alaskarails.org/route-map/cities/whittier/overhead.jpg*

3.1.2 Bathymetry

Bathymetric datasets used in the compilation of the Prince William Sound DEMs included NOS hydrographic surveys, two recent USACE harbor surveys, NOAA ENC chart soundings, multibeam swath sonar surveys, and NGDC trackline surveys (Table 4).

Table 4. Bathymetric datasets used in compiling the Prince William Sound, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
NOS	1902-2006	Hydrographic survey soundings	Ranges from 10 meters to 1.5 kilometers (varies with scale of survey, depth, traffic and probability of obstructions)	NAD 27, NAD 83, Early Alaskan Datum, Valdez Datum, Undetermined Datum	MLLW (meters)	http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html
USACE	2006	Harbor surveys	~2 to 10 meters	Alaska State Plane, Zone 3, NAD 83 feet	MLLW (meters)	http://www.poa.usace.army.mil/en/hydro/
NOAA ENCs	2008	NOAA digitized nautical chart soundings	~500 to 1200 meters	WGS 84 geographic	MLLW (meters)	http://www.nauticalcharts.noaa.gov/mcd/enc/index.htm
NGDC/BSH	1996-2004	Multibeam swath sonar	Raw MB files gridded to 8 arc-second	WGS 84 geographic	Assumed MSL	http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html
NGDC	1970-1999	Trackline	Raw MB files gridded to 8 arc-second	WGS 84 geographic	Assumed MSL	http://www.ngdc.noaa.gov/mgg/geodas/trackline.html
NGDC	2009	Digitized soundings	~10 to 100 meters	WGS 84 geographic	Inferred MHHW	

1) NOS hydrographic survey data

A total of 263 NOS hydrographic surveys conducted between 1902 and 2006 were used in Prince William Sound DEM development (Appendix A; Fig. 10). The hydrographic survey data were originally vertically referenced to Mean Lower Low Water (MLLW) and horizontally referenced to NAD 27 or NAD 83 geographic, Early Alaska, Valdez, or "undetermined" datums.

Data point spacing for the surveys ranged from approximately 10 to 60 meters in shallow water up to 1.5 kilometers in deep water. All surveys were extracted from NGDC's online database (http://www.ngdc.noaa.gov/mgg/bathymetry/hydro.html) in their original datums (see Appendix A). The data were then converted to NAD 83 geographic using *FME* software, an integrated collection of spatial extract, transform, and load tools for data transformation (http://www.safe.com/). NOS surveys in Early Alaska, Valdez, or undetermined datums were manually shifted in *ArcGIS* to fit the final coastline. The surveys were subsequently clipped to a polygon 0.05 degrees (~5%) larger than the 8 arc-second gridding area to support data interpolation across DEM boundaries.

After converting all NOS survey data to MHHW (see Section 3.2.1), the data were displayed in ESRI *ArcMap* and reviewed for digitizing errors against scanned original survey smooth sheets and compared to the NED and SRTM topographic data and the final coastline.

Older NOS surveys conducted prior to 1965 were clipped to the newer surveys to minimize the influence of soundings taken prior to the 1964 earthquake.

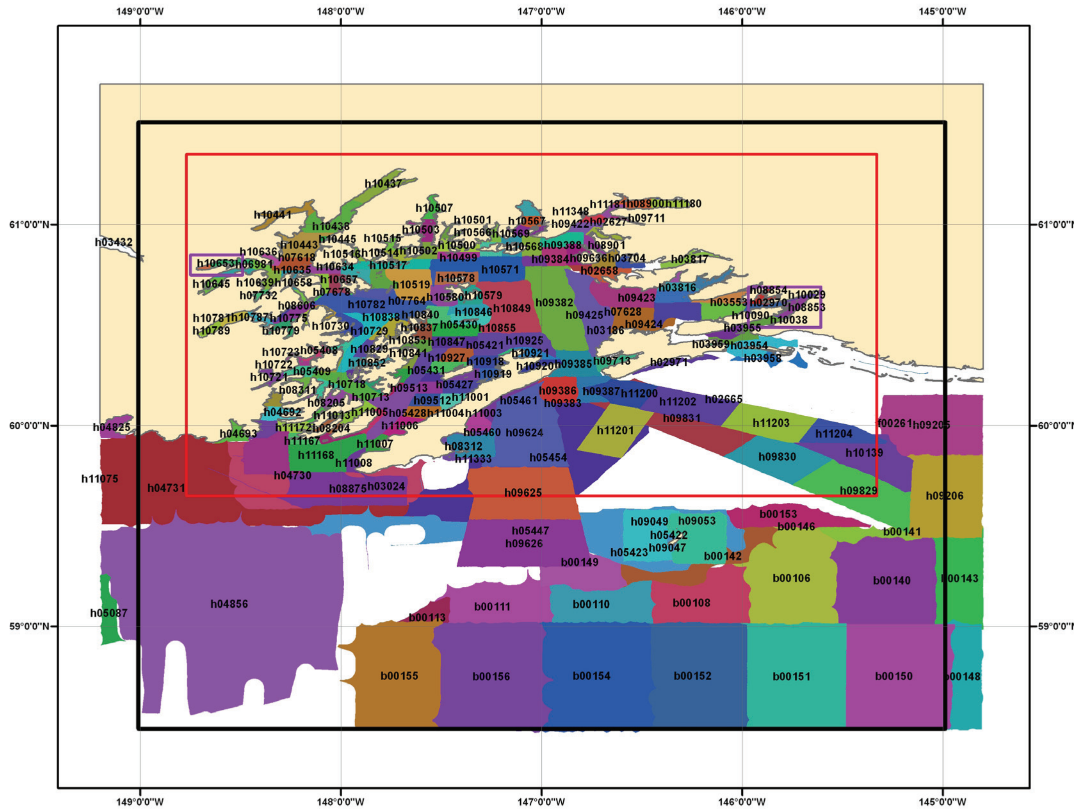

Figure 10. *Digital NOS hydrographic survey coverage in the Prince William Sound region. Black denotes boundary of the 8 arc-second DEM. Red denotes boundary of the 8/3 arc-second DEM; purple denotes boundary of the 8/15 arc-second DEMs; coastline in grey. Water areas without digital NOS soundings depicted as white.*

2) USACE harbor surveys

USACE conducted high-resolution hydrographic harbor surveys of Valdez and Cordova Harbors in 2006 (http://www.poa.usace.army.mil/en/hydro/). The surveys were originally referenced to NAD 83 Alaska State Plane coordinates (feet) and MLLW vertical datum (feet). The horizontal spacing of the surveys ranges from ~2 to 10 meters with depths ranging from -0.03 to -94.2 meters at MHHW.

3) NOAA Electronic Navigational Chart soundings

Nautical charts #531, #16680, #16700, #16701, and #16709 were available from NOAA's Office of Coast Survey in ENC chart format and, as no bathymetric survey data were available for these areas, sounding data were extracted from these charts using *FME*. The point spacing and vertical resolution of the ENCs vary by the scale of the charts (see Table 3).

4) Multibeam swath sonar files

Six multibeam swath sonar surveys (Table 5, Fig. 4) were available from the NGDC multibeam sonar bathymetry database (http://www.ngdc.noaa.gov/mgg/bathymetry/multibeam.html) and from the Bathymetric Data Center at the Bundesamt für Seeschiffarhrt und Hydrographie (BSH; http://www.bsh.de/en/Marine_data/Hydrographic_surveys_and_wreck_search/Bathymetry/index.jsp) for use in building the Prince William Sound DEMs. The NGDC and BSH databases are comprised of the original swath sonar files of surveys conducted mostly by U.S. and German fleets, respectively. Most of the NGDC multibeam swath sonar surveys were transits rather than dedicated seafloor surveys. All surveys have a horizontal datum of WGS 84 geographic and undefined vertical datum, assumed to be equivalent to mean sea level (MSL). The Sonne survey data were generously provided by Volkmar Leimer of BSH.

The downloaded data were gridded at 8 arc-seconds using the 'mbgrid' tool in *MB-System* to apply a tight spline tension. *MB-System* is an NSF-funded free software application specifically designed to manipulate multibeam swath sonar data (http://www.ldeo.columbia.edu/res/pi/MB-System/). The gridded data were converted to shapefiles and transformed to MHHW using *FME*.

Table 5. Multibeam swath sonar surveys used in compiling the Prince William Sound, Alaska DEMs.

Survey ID	*Ship*	*Year*	*Original Vertical Datum*	*Original Horizontal Datum*	*Institution*
EW0205	Ewing	2002	Assumed Mean Sea Level	WGS 84 geographic	Columbia University
EW0408	Ewing	2004	Assumed Mean Sea Level	WGS 84 geographic	Columbia University
EW0409	Ewing	2004	Assumed Mean Sea Level	WGS 84 geographic	Columbia University
AT03L37	Atlantis	1999	Assumed Mean Sea Level	WGS 84 geographic	Woods Hole Oceanographic Institute
SO96-2	Sonne	1996	Assumed Mean Sea Level	WGS 84 geographic	Bundesamt für Seeschiffarhrt und Hydrographie, Germany
SO97-1	Sonne	1997	Assumed Mean Sea Level	WGS 84 geographic	Bundesamt für Seeschiffarhrt und Hydrographie, Germany

5) Trackline data files

Sixteen trackline surveys (Table 6, Fig. 4) were available from the NGDC trackline survey database (http://www.ngdc.noaa.gov/mgg/geodas/trackline.html) for use in building the Prince William Sound DEMs. The Marine Trackline Geophysics database contains bathymetry, magnetics, gravity and seismic navigation data collected during marine cruises from 1953 to the present. All surveys have a horizontal datum of WGS 84 geographic and undefined vertical datum assumed to be mean sea level (MSL). The downloaded data in xyz format were then converted to shapefiles and transformed to MHHW using *FME* software.

Table 6. Trackline surveys used in compiling the Prince William Sound, Alaska DEMs.

Survey ID	*Institution*	*Year*
rc1407	Lamont-Doherty Earth Observatory	1971
pol7103	NOAA	1971
pol7001	NOAA	1970
conmalas	NOAA NOS	1972
yaq704	Oregon State University	1970
yaq703	Oregon State University	1970
farn0689	UK National Environmental Research Council	1989
s877eg	USGS	1977
l677eg	USGS	1977
g175eg	USGS	1975
s678eg	USGS	1978
s376wg	USGS	1976
l781wg	USGS	1981
l476wg	USGS	1976
l378eg	USGS	1978
f186ga	USGS	1986

6) NGDC Digitized Features

In regions of poor data coverage, NGDC digitized points using nearby NOS hydrographic soundings or ENC/RNC soundings to approximate depths. Generally, the values ranged from -0.5 to -100 meters. Most of these digitized soundings were added in the Copper River delta region, approximately 50 miles southeast of Cordova where soundings are very sparse (e.g., Fig. 11).

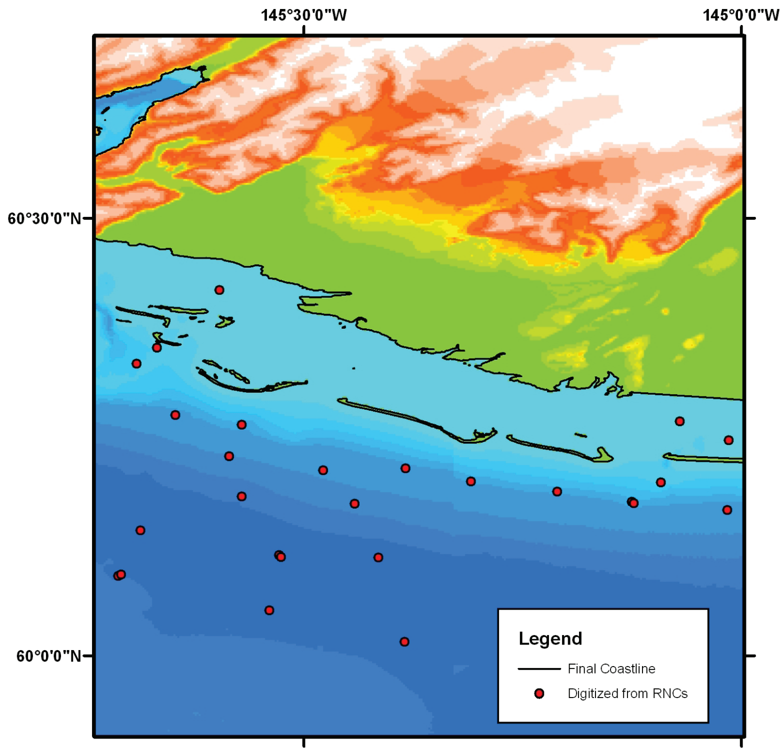

Figure 11. *NGDC-digitized points from raster nautical charts (RNCs) in the Copper River delta region. A color image of the 8 arc-second Prince William Sound DEM is in the background.*

3.1.3 Topography

Topographic datasets of the Prince William Sound region were obtained from the U.S. Geological Survey and National Aeronautics and Space Administration (NASA; Fig. 12 and Table 7). NGDC also digitized breakwaters not resolved in either topographic dataset.

Table 7. Topographic datasets used in compiling the Prince William Sound, Alaska DEMs.

Source	*Year*	*Data Type*	*Spatial Resolution*	*Original Horizontal Datum/Coordinate System*	*Original Vertical Datum*	*URL*
USGS NED	2006	Topographic DEM	2 arc-second grid	NAD 27 geographic	NGVD 29 (meters)	http://ned.usgs.gov/
NASA SRTM	2000	Topographic DEM	1 arc-second grid	WGS 84 geographic	WGS 84/EGM 96 Geoid (meters)	http://srtm.usgs.gov/
ASTER	2009	Topographic DEM	1 arc-second grid	WGS 84 geographic	WGS 84/EGM 96 Geoid (meters)	http://asterweb.jpl.nasa.gov/gdem.asp
NGDC	2009	Digiized harbor features	Variable	WGS 84 geographic	MHHW	

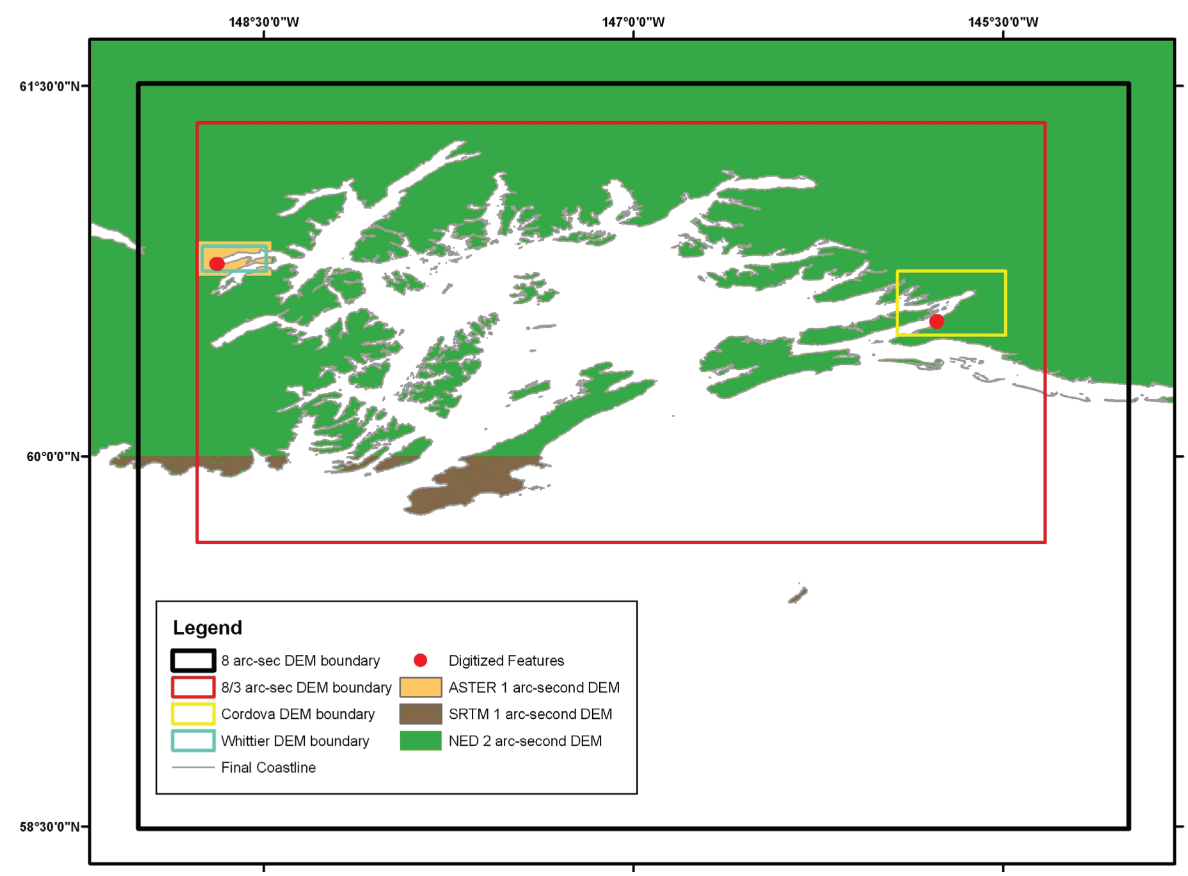

Figure 12. *Principal topographic dataset contributions to the Prince William Sound DEMs.*

1) USGS NED topography

The U.S. Geological Survey's (USGS) National Elevation Dataset (NED; http://ned.usgs.gov/) provides complete 2 arc-second coverage of Alaska[4]. Data are in NAD 27 geographic coordinates and NGVD 29 vertical datum (meters), and are available for download as raster DEMs. The extracted 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 quad maps and aerial photos based on surveys conducted in the 1970s and 1980s. The NED DEM contains values over the open ocean, which were deleted by clipping to the final coastline.

Evaluation of the NED data indicated three issues that required quality control. First, the NED data had values over the open ocean that were deleted by clipping to the coastline. Second, the NED data for the Prince William Sound region were misaligned with other datasets by approximately one grid cell (2 arc-seconds) to the south. This resulted in a preponderance of steep slopes on south facing shores (e.g., Fig. 13a). To rectify the issue, the data were shifted northward by 2 arc-seconds prior to using the data in DEM development (e.g., Fig. 13b). Last, for the high-resolution grids at 8/15 arc-seconds, the coarse resolution of the NED data led to unrepresentative slopes at the coast. NGDC smoothed the 2 arc-second NED data to 8/15 arc-second using a Kriging interpolation method (see Section 3.3.3).

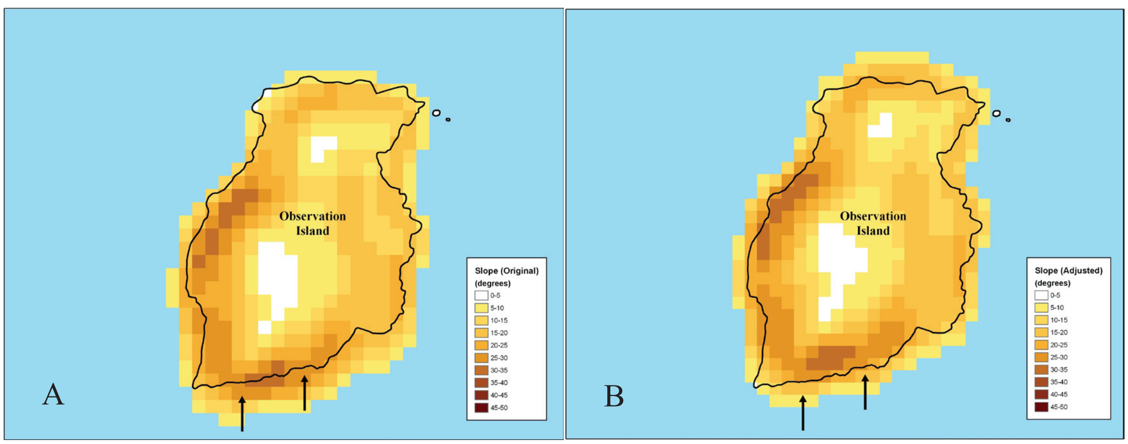

Figure 13. *NED data shift. A) Slope map of the original NED data for Observation Island. B) Slope map of the adjusted NED data for Observation Island after shifting northward 2 arc-seconds. Final coastline in black. Note the better correlation of steep slopes with respect to the final coastline (black arrows), particularly on south facing shorelines.*

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 Alaska. The dataset provides seamless coverage of the United States, Hawai'i, Alaska, 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 Alaska, which is NAD 27. The vertical datum is NAVD 88, except for Alaska, which is NGVD 29. 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 web site]

2) NASA space shuttle radar topography

The NASA Shuttle Radar Topography Mission (SRTM) obtained elevation data on a near-global scale (60° S to 60° N) to generate the most complete high-resolution digital topographic database of Earth[5]. The SRTM consisted of a specially modified radar system that flew onboard the Space Shuttle Endeavour during an 11-day mission in February of 2000. Data from this mission have been processed into 1 degree × 1 degree tiles that have been edited to define the coastline, and are available from the USGS Seamless web site (http://seamless.usgs.gov/) as raster DEMs. The data have not been processed to bare earth, but meet the absolute horizontal and vertical accuracies of 20 and 16 meters, respectively.

For the Prince William Sound region, the data have 1 arc-second spacing and are referenced to the WGS 84/EGM 96 Geoid. The SRTM provides only limited coverage of Prince William Sound and exhibits numerous small areas with "no data" values (e.g., Fig. 14) necessitating the use of the lower-resolution NED topographic data in these areas. The SRTM DEM also contains values over the open ocean, which were deleted by clipping to the final coastline.

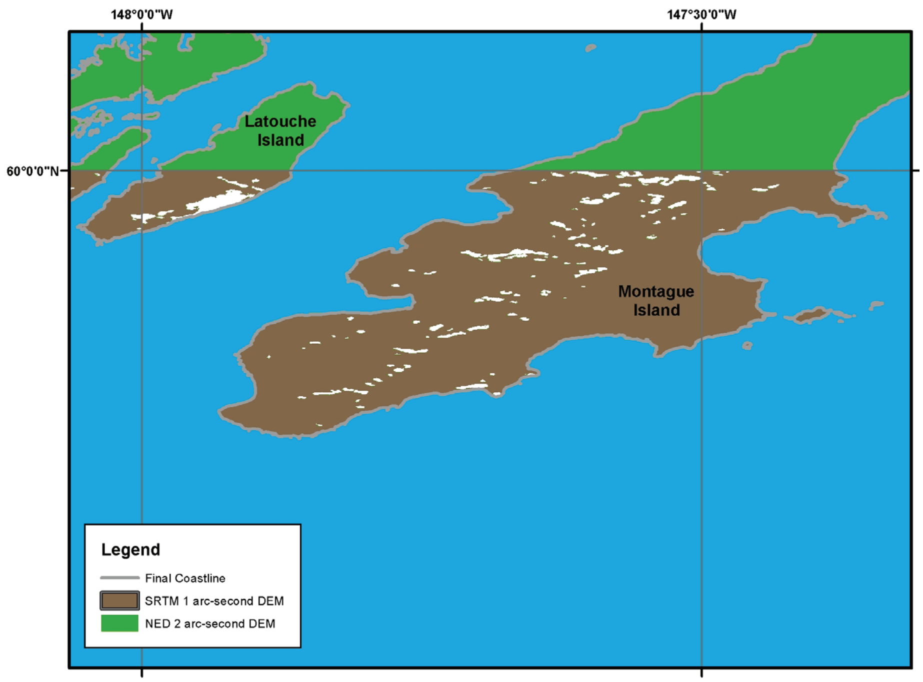

Figure 14. *Example of gaps (white area) in the SRTM data coverage on Montague and Latouche Islands. Gaps were filled with topographic data from the NED DEM. Final coastline in gray. Blue represents zero values over the open ocean. NED data north of 60° N in green.*

5. The SRTM data sets result from a collaborative effort by the National Aeronautics and Space Administration (NASA) and the National Geospatial-Intelligence Agency (NGA – previously known as the National Imagery and Mapping Agency, or NIMA), as well as the participation of the German and Italian space agencies, to generate a near-global digital elevation model (DEM) of the Earth using radar interferometry. The SRTM instrument consisted of the Spaceborne Imaging Radar-C (SIR-C) hardware set modified with a Space Station-derived mast and additional antennae to form an interferometer with a 60 meter long baseline. A description of the SRTM mission can be found in Farr and Kobrick (2000). Synthetic aperture radars are side-looking instruments and acquire data along continuous swaths. The SRTM swaths extended from about 30 degrees off-nadir to about 58 degrees off-nadir from an altitude of 233 km, and thus were about 225 km wide. During the data flight the instrument was operated at all times the orbiter was over land and about 1000 individual swaths were acquired over the ten days of mapping operations. Length of the acquired swaths range from a few hundred to several thousand km. Each individual data acquisition is referred to as a "data take." SRTM was the primary (and pretty much only) payload on the STS-99 mission of the Space Shuttle Endeavour, which launched February 11, 2000 and flew for 11 days. Following several hours for instrument deployment, activation and checkout, systematic interferometric data were collected for 222.4 consecutive hours. The instrument operated almost flawlessly and imaged 99.96% of the targeted landmass at least one time, 94.59% at least twice and about 50% at least three or more times. The goal was to image each terrain segment at least twice from different angles (on ascending, or north-going, and descending orbit passes) to fill in areas shadowed from the radar beam by terrain. This 'targeted landmass' consisted of all land between 56 degrees south and 60 degrees north latitude, which comprises almost exactly 80% of Earth's total landmass. [Extracted from SRTM online documentation]

3) METI/NASA ASTER topography

Japan's Ministry of Economy, Trade and Industry (METI) and NASA announced the release of the Advanced Spaceborne Thermal Emission and Reflection Radiometer (ASTER) Global Digital Elevation Model (GDEM) on June 29, 2009. The GDEM was created by stereo-correlating the 1.3 million scene ASTER visible and near infrared (VNIR) archive, covering the Earth's land surface between 83N and 83S latitudes. The GDEM is produced with 30 meter postings, and is formatted in 1 x 1 degree tiles as GeoTIFF files. For the Prince William Sound region, the data are referenced to the WGS 84/EGM 96 Geoid.

The University of Alaska at Fairbanks visited the Whittier region and collected scattered GPS elevations for the region. Based on these data, the USGS NED did not properly represent the morphology along the road connecting the cruise ship docks with the airport. Although the GDEM data have not been processed to bare earth, the GDEM provided improved representation of the morphology surrounding Whittier Harbor and the elevations of glaciers at higher elevations. Therefore, the ASTER GDEM was used in place of the USGS NED (Fig. 15) for the Whittier DEM.

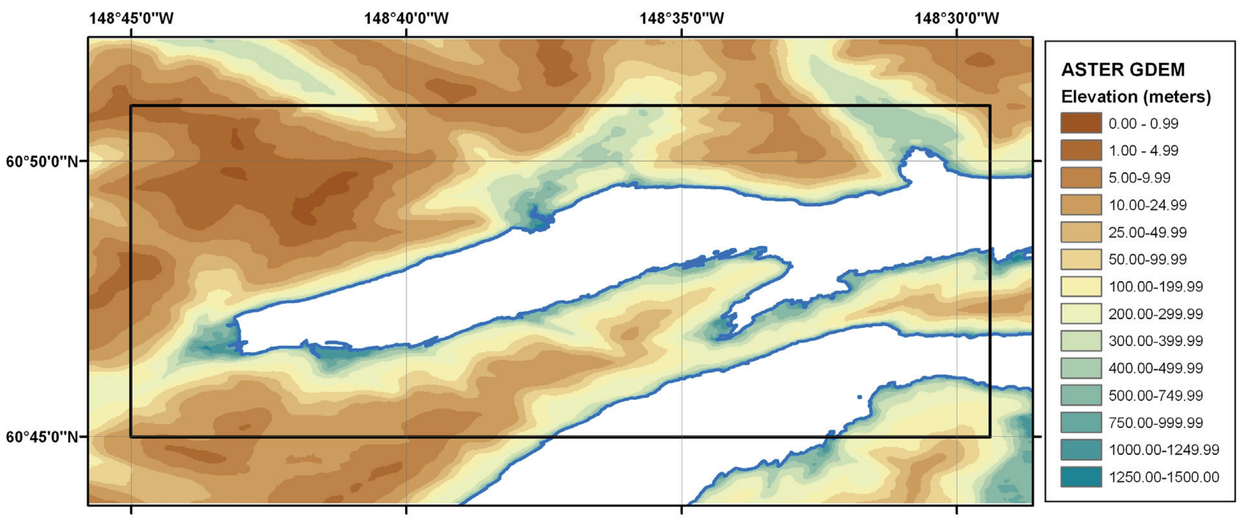

Figure 15. *ASTER GDEM coverage and elevations for the region surrounding Whittier, Alaska. Whittier 1 arc-second extents shown in black. Final coastline in blue. White areas denote elevations below zero that were clipped to the coastline.*

4) NGDC digitized features

Using the USACE project drawing of Cordova Harbor (http://www.poa.usace.army.mil/en/hydro/Cordova/2006/) as a reference, NGDC digitized the main harbor features at Cordova (Fig. 16). Similar features at Whittier Harbor were digitized using aerial photographs as a guide (Fig. 17). The breakwater that forms the southeastern barrier of Cordova and the breakwater that forms the barrier to the north of the Whittier Harbor entrance were assigned elevation values of 1.5 meters above MHHW, estimated from aerial photographs (e.g., Figs. 9 and 17 inset).

In addition to digitizing the breakwaters, NGDC also digitized the road extending from the Whittier cruise ship dock to the airport to improve representation in the high-resolution Whittier DEM (Fig. 18).

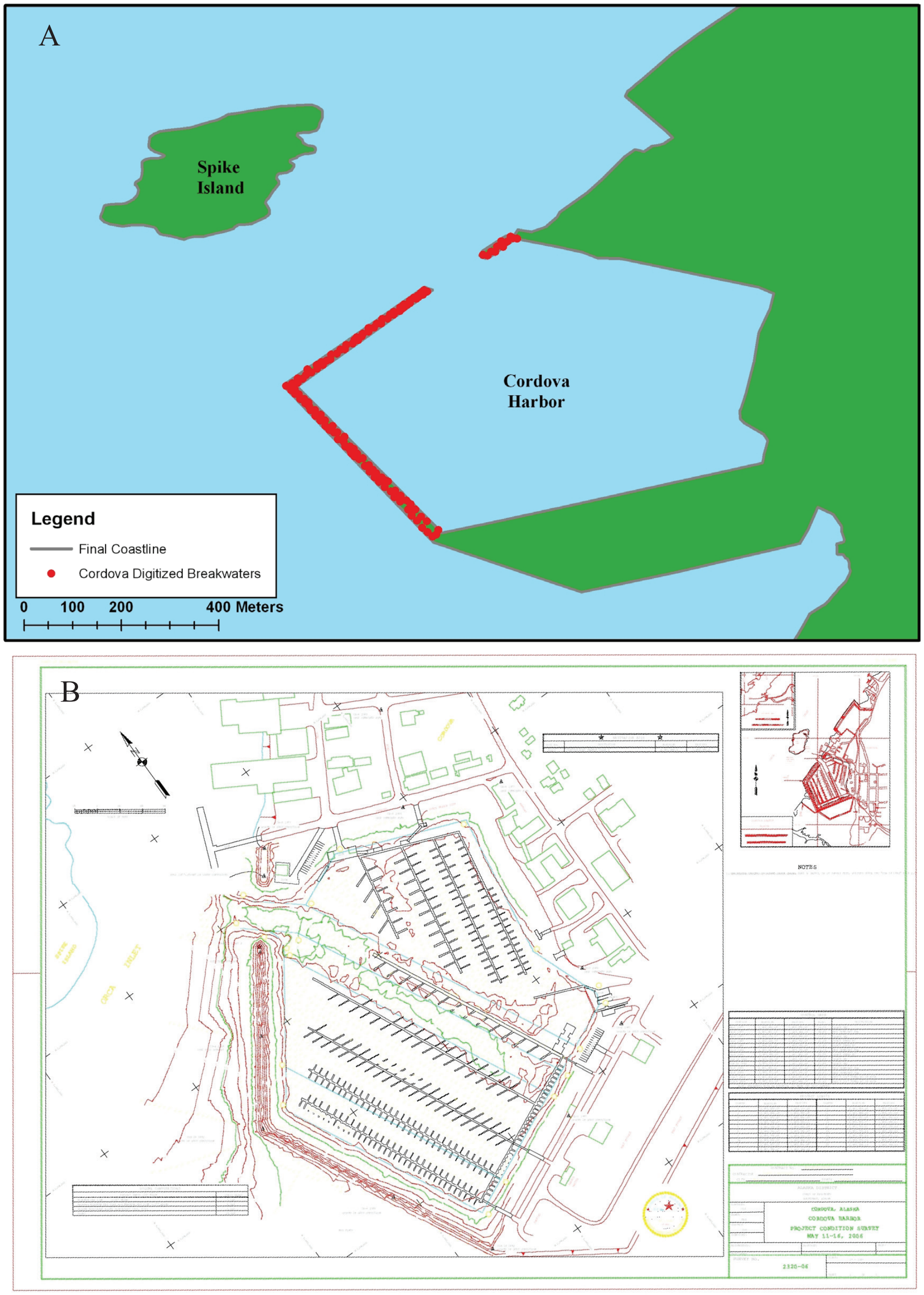

Figure 16. *Cordova Harbor. A) Detail of Cordova Harbor with digitized breakwaters shown in red. B) 2006 USACE project drawing for Cordova Harbor.*

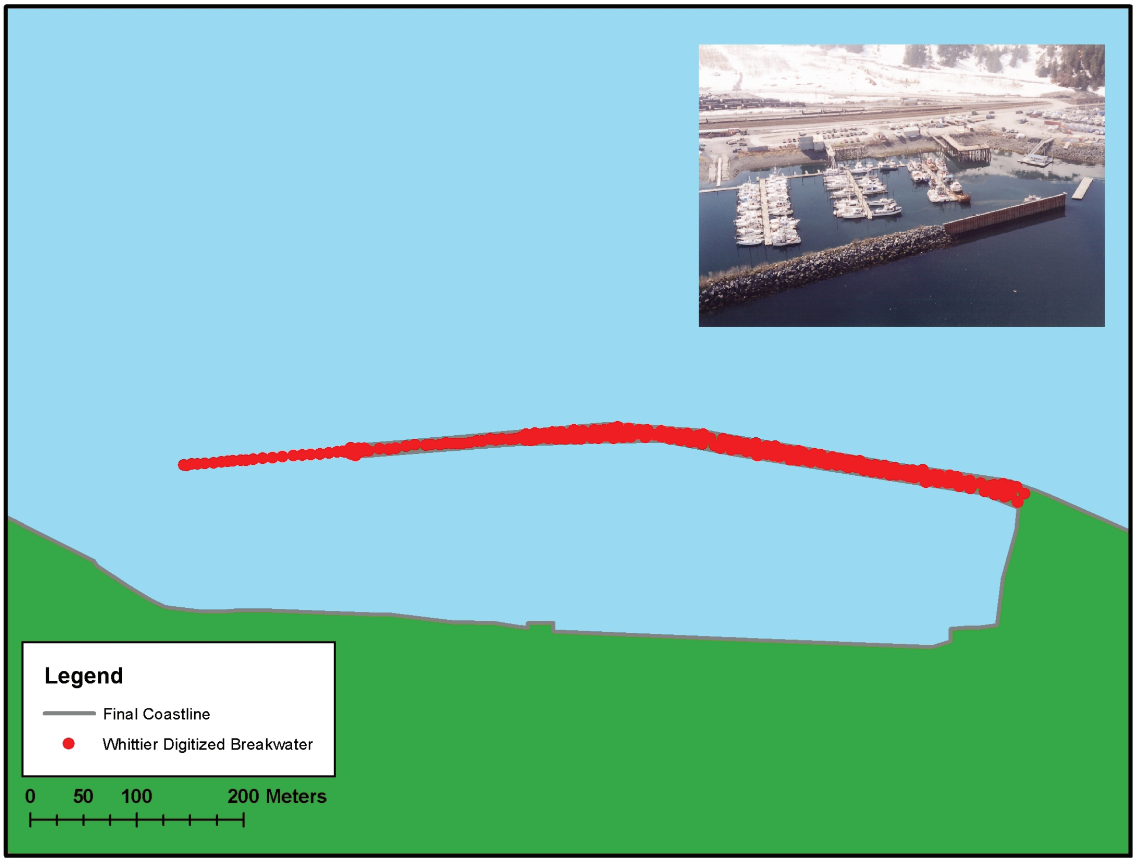

Figure 17. *Detail of Whittier Harbor with digitized breakwater shown in red. Inset photograph of the breakwater at Whittier Harbor (http://www.asgdc.state.ak.us/maps/cplans/pws/esi/photos/sensarea/SENS11.JPG).*

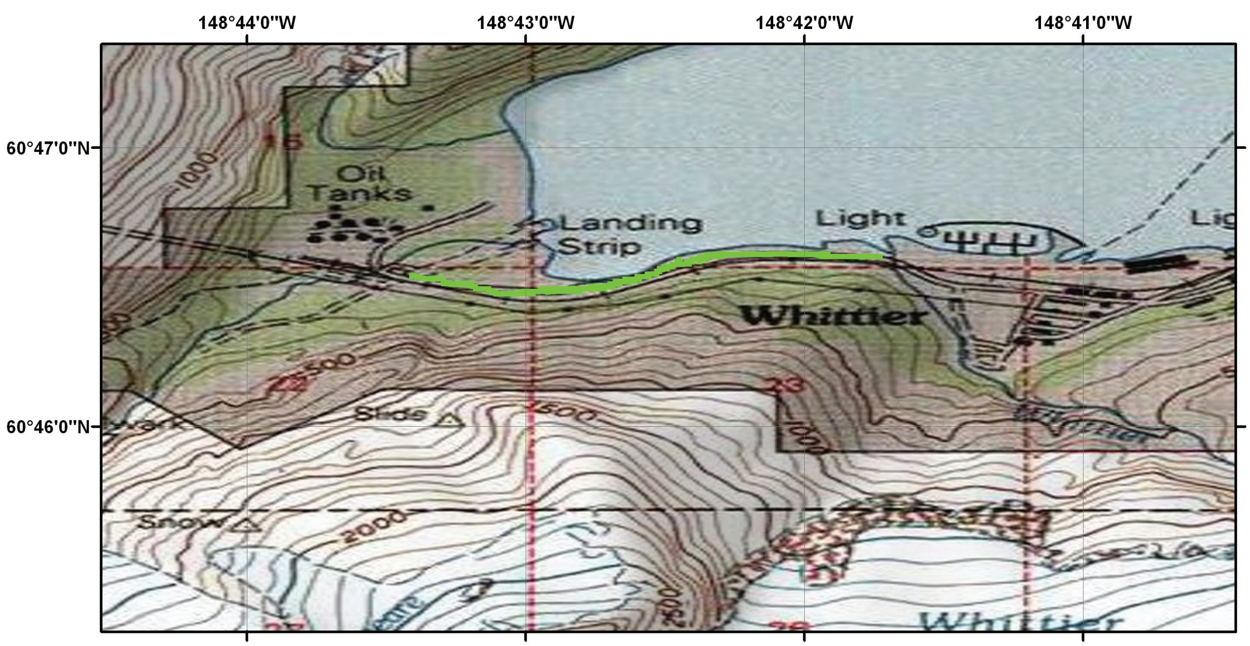

Figure 18. *Digitized road from near Whittier Harbor to the airport (green). ESRI US Topo Map layer is in the background.*

3.1.4 Bathymetry-Topography

The development of the 8/3 arc-second Prince William Sound DEM included a high-resolution, bathymetric-topographic DEM of Valdez, Alaska, provided by UAF. The Valdez DEM has a grid-size of 15 meters and covers the region from 60.05° to 61.15° N and from 146.25° to 146.72° W (Figs. 4 and 19). The Valdez, Alaska DEM was originally referenced to a vertical datum of MHW and horizontal datum of UTM Zone 6N (meters)/NAD 83. The primary datasets used to compile the Valdez DEM included LiDAR flown for the City of Valdez, multibeam bathymetric data, and tidal flat images near the city at different tidal cycles.

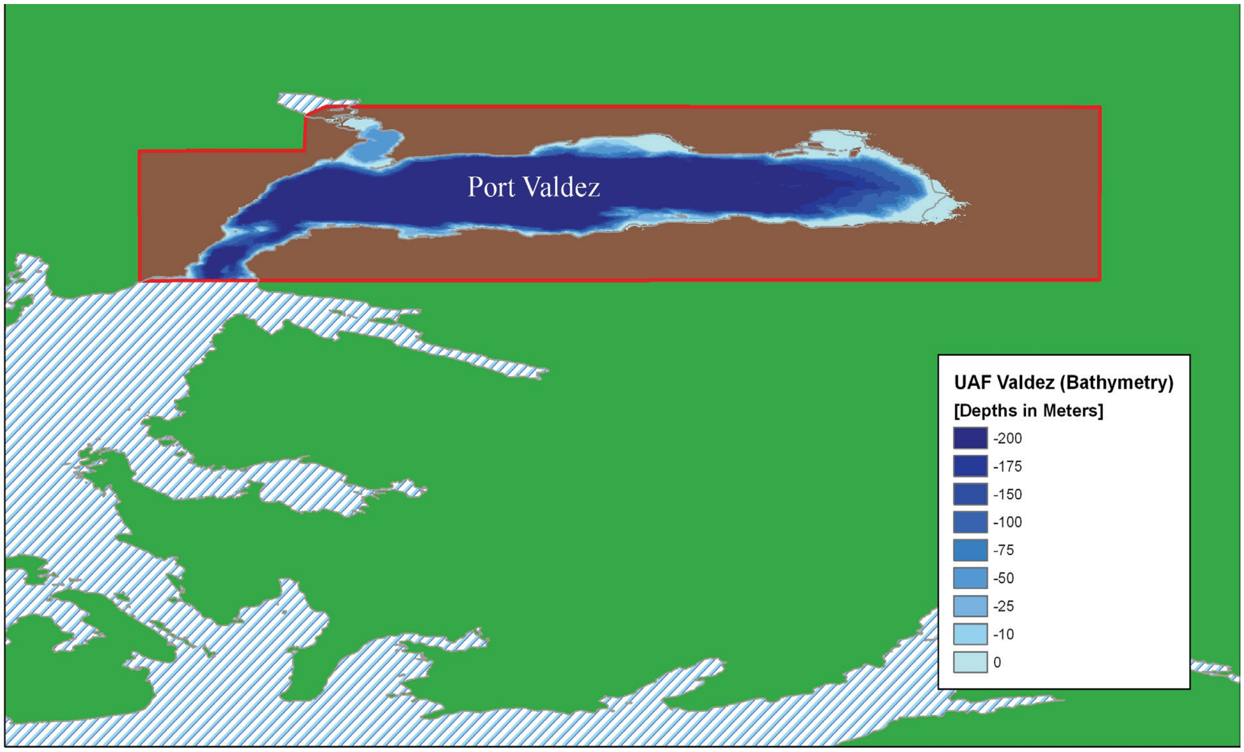

Figure 19. *Spatial coverage of the UAF Valdez DEM. Bathymetry is shown as blue shading with topography in brown. UAF Valdez DEM boundary shown in red, remaining water as hashed blue lines, and final coastline in grey. Green represents the NED topography north of 60° N.*

3.2 Establishing Common Datums

3.2.1 Vertical datum transformations

Datasets used in the compilation and evaluation of the Prince William Sound DEM were originally referenced to a number of vertical datums including: Mean Lower Low Water (MLLW), Mean Sea Level (MSL), Mean High Water (MHW), WGS 84/EGM 96 Geoid, and North American Vertical Datum of 1929 (NGVD 29). All datasets were transformed to MHHW for modeling of maximum flooding. Vertical datum transformations to MHHW were accomplished using *FME* and *ArcGIS*, based upon data from NOAA tide stations in the region.

NGDC created two offset grids approximating the relationship between MHHW and MLLW, and MHHW and MSL for the Prince William Sound Region. The grids were built in *ArcGIS* using the 'Kriging' tool and the differences, in meters, between the vertical datums as measured at 12 NOAA tide stations (http://tidesandcurrents.noaa.gov/), 10 tide prediction sites (http://co-ops.nos.noaa.gov/tides05/tab2wc2b.html), and two deep-ocean DART buoys (http://www.ndbc.noaa.gov/dart.shtml) (Table 8; Fig. 20). The grids span from 150.0º W to 143.5º W and 55.0º N to 62.0º N with a grid cell size of 0.02 degrees. All vertical transformations were performed using these offset grids developed by NGDC (e.g., Fig. 20).

1) Bathymetric data

The NOS hydrographic surveys, the multibeam swath sonar surveys, the trackline surveys, the USACE survey data, and the nautical chart soundings were transformed from either MSL or MLLW to MHHW (e.g., Fig. 20), using *FME* software, by subtracting the corresponding offset grid value.

2) Topographic data

The NED and SRTM DEMs were originally referenced to NGVD 29 and WGS 84/EGM96 Geoid vertical datums, respectively. There are no survey markers in the vicinity of Prince William Sound that relate these two geodetic datums to the local tidal datums. Therefore, it was assumed that both datums are essentially equivalent to MSL in this area (Table 8). Conversion to MHHW, using *FME* software, was accomplished by subtracting the MSL to MHHW offset grid.

Table 8. Relationship between Mean Higher High Water and other vertical datums in the Prince William Sound region.

NAME	*Station ID*	*Longitude*	*Latitude*	*MHHW*	*MHW*	*MSL*	*MLLW*
Busby	9454373	-146.781667	60.898333	3.632	3.359	1.938	0
Columbia Glacier	9454460	-147.085000	61.023333	3.659	3.384	1.961	0
Cordova	9454050	-145.753333	60.558333	3.838	3.558	2.056	0
Montague Island	9454616	-147.591667	60.025000	3.506	3.227	1.853	0
Perch Point	9454561	-147.400000	60.125000	3.571	3.270	1.876	0
Port Chalmers	9454511	-147.248333	60.241667	3.630	3.349	1.929	0
Snug Harbor	9454662	-147.716667	60.250000	3.515	3.244	1.876	0
Valdez	9454240	-146.361667	61.125000	3.702	3.416	1.979	0
Whittier	9454949	-148.665000	60.778333	3.715	3.434	1.988	0
Cape St Elias	9453849	-144.591667	59.795000	2.932	-	1.591	0
Camp Cove	9455151	-149.748000	59.693000	3.250	-	1.700	0
Agnes Cove	9455120	-149.588000	59.773000	3.257	-	1.703	0
Middleton Island	TPS	-143.313497	59.459435	3.139	-	1.676	0
Patton Bay	TPS	-147.433000	59.900000	3.109	-	1.645	0
Day Harbor	TPS	-149.050000	60.016667	3.200	-	1.706	0
Hogg Bay	TPS	-149.200000	60.066667	3.231	-	1.706	0
Port Etches	TPS	-146.550000	60.333333	3.414	-	1.798	0
Eyak River	TPS	-145.666670	60.466670	3.292	-	1.767	0
Shag Rock	TPS	-145.983330	60.466667	3.475	-	1.859	0
Gravel Point	TPS	-145.966670	60.466667	3.749	-	2.011	0
Copper River Delta	TPS	-145.400000	60.383300	3.048	-	1.645	0
Culross Bay	TPS	-148.183333	60.733330	3.688	-	1.960	0
DART II Buoy 46410	Buoy	-143.804000	57.634000	2.950	-	1.554	0
DART II Buoy 46409	Buoy	-148.500000	55.300000	2.491	-	1.409	0

TPS = Tide Prediction Site

3) Bathymetric-topographic data

The Valdez, Alaska DEM was originally referenced to a vertical datum of MHW. The average offset from MHW to MHHW based on regional tide stations (see Table 8) is approximately 0.3 meters. Therefore, the Valdez, Alaska DEMs were assumed to be essentially equivalent to MHHW.

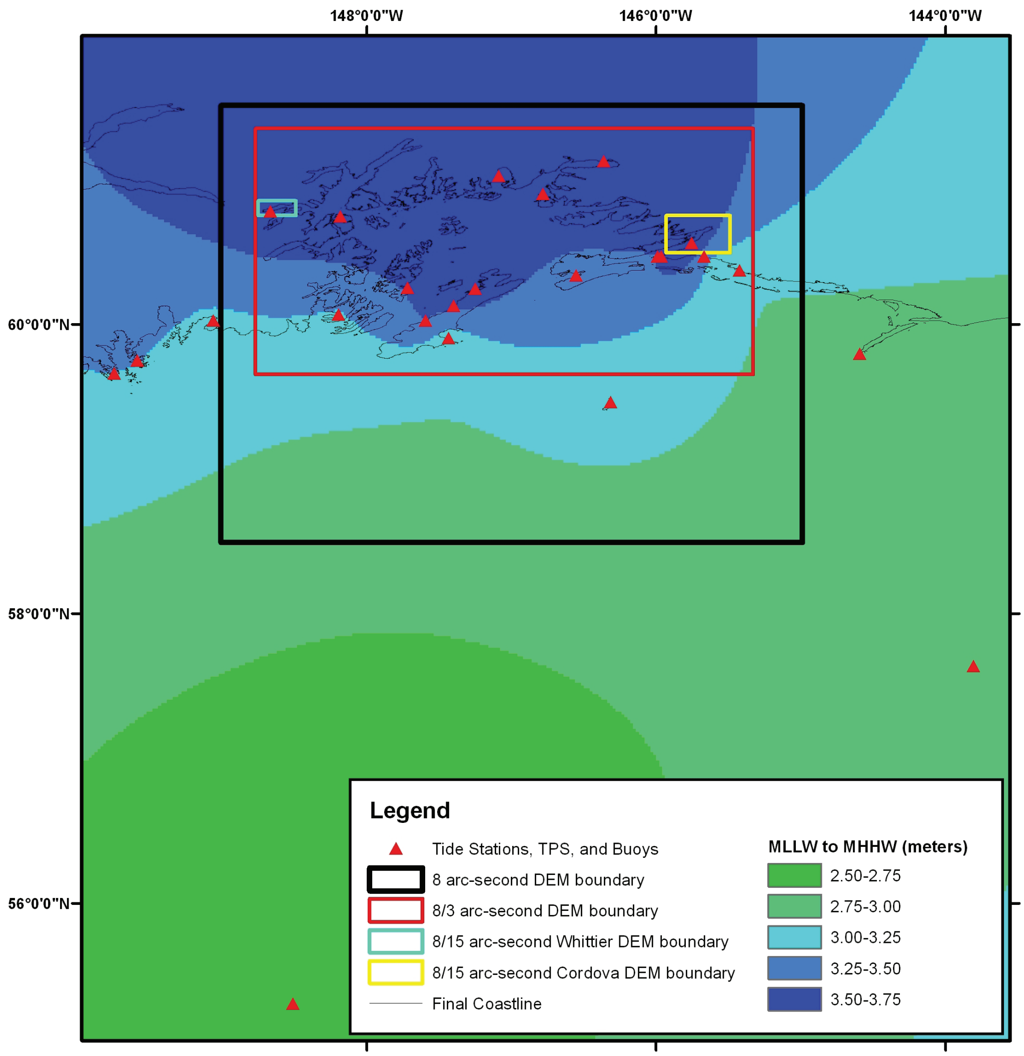

Figure 20. *Image of the MLLW to MHHW offset grid of the Prince William Sound region. Tide stations and buoys used in developing the offset grid are shown in red. Differences between MLLW and MHHW range from 2.50 to 3.75 meters.*

3.2.2 Horizontal datum transformations

Datasets used to compile the Prince William Sound DEMs were originally referenced to Early Alaska, Valdez, "undetermined", NAD 83 Alaska State Plane (feet), UTM Zone 6N (meters)/NAD 83, and NAD 27, NAD 83, and WGS 84 geographic horizontal datums. The relationships and transformational equations between the Alaska State Plane, UTM, and geographic horizontal datums are well established. All of these data were converted to a horizontal datum of NAD 83/WGS 84 geographic using *FME* software. The NOS surveys referenced to Early Alaska, Valdez and "undetermined" horizontal datums were manually shifted in *ArcGIS* to fit the final coastline.

3.3 Digital Elevation Model Development

3.3.1 Verifying consistency between datasets

After horizontal and vertical transformations were applied, the resulting ESRI shapefiles were checked in ESRI *ArcMap* and *Quick Terrain Modeler* for inter-dataset consistency. Problems and errors were identified and resolved before proceeding with subsequent gridding steps. The evaluated and edited ESRI shapefiles were then converted to xyz files in preparation for gridding. Problems included:

- Data values over the open ocean in the NED and SRTM topographic DEMs. Each dataset required automated clipping to the final coastline.
- NED data were misaligned approximately one cell (2 arc-seconds) southward and required shifting to the north.
- Lack of good bathymetric data near the Copper River delta.
- Lack of good bathymetric data in the Whittier 8/15 arc-second grid region.
- Lack of good bathymetric data near the coastline, particularly in and near retreating glaciers.
- Misaligned NOS surveys with Early Alaska, Valdez, or "undetermined" horizontal datums.
- Piers and docks in the coastline datasets that had to be removed

3.3.2 Smoothing of bathymetric data

The NOS hydrographic surveys are generally sparse at the resolution of the Prince William Sound DEMs. In both deep water and near shore, the NOS survey data have point spacing up to 1.5 kilometers apart. In order to reduce the effect of artifacts in the form of lines of "pimples" in the DEMs due to this low resolution dataset, and to provide effective interpolation into the coastal zone, bathymetric 'pre-surfaces' or grids were generated using *GMT*, an NSF-funded share-ware software application designed to manipulate data for mapping purposes (http://gmt.soest.hawaii.edu/).

A Cordova 8/15 arc-second, 'pre-surface' grid was compiled from NOS hydrographic point data, USACE surveys, ENC soundings, trackline surveys, and NGDC multibeam swath sonar bathymetry data by converting the files to xyz format. These xyz files were combined into a single file, along with points extracted every 10 meters from the final coastline. To provide a slightly negative buffer along the entire coastline, the extracted points were assigned values of -1 meter to make sure that the offshore elevations remained negative; this was necessary due to the sparseness of the bathymetric data near the coast. These point data were then smoothed using the *GMT* tool 'blockmedian' onto a 8/15 arc-second grid. The *GMT* tool 'surface' was then applied to interpolate values for cells without data values. The netcdf grid created by 'surface' was converted into an ESRI Arc ASCII grid file using the *MB-System* tool 'mbm_grd2arc'. Conversion of this Arc ASCII grid file into an Arc raster permitted clipping of the grid with the final coastline (to eliminate data interpolation into land areas).

For the Whittier 8/15 arc-second 'pre-surface', the data from NOS hydrographic surveys was more limited; and, the north-south linearity of the soundings resulted in lineations in the bathymetric 'pre-surface' grid. To alleviate the impact of the spline tension interpolation in regions of sparse data, the NOS survey point data were interpolated using the 'triangulation' tool in *GMT* to create a triangular irregular network (TIN) surface. The resultant TIN grid was used as a 'pre-pre-surface' grid and served as an additional input dataset using the methodology described above for Cordova.

The 'pre-surfaces' were compared with the original soundings to ensure grid accuracy, converted to a shapefile, and then exported as an xyz file for use in the final gridding process (Table 9). The statistical analysis of the differences between the 8/15 arc-second bathymetric surfaces at Cordova and Whittier and NOS surveys H11496 and H10655, respectively, show that the majority of the NOS soundings are in good agreement (Figs. 21 and 22) with the bathymetric surfaces. The few exceptions where the differences reached up to 39.05 meters are attributed to rugged bathymetry where two or more closely positioned points were averaged to obtain the elevation of one grid cell.

Pre-surface grids for the larger 8/3 and 8 arc-second grids were built following the Cordova methodology.

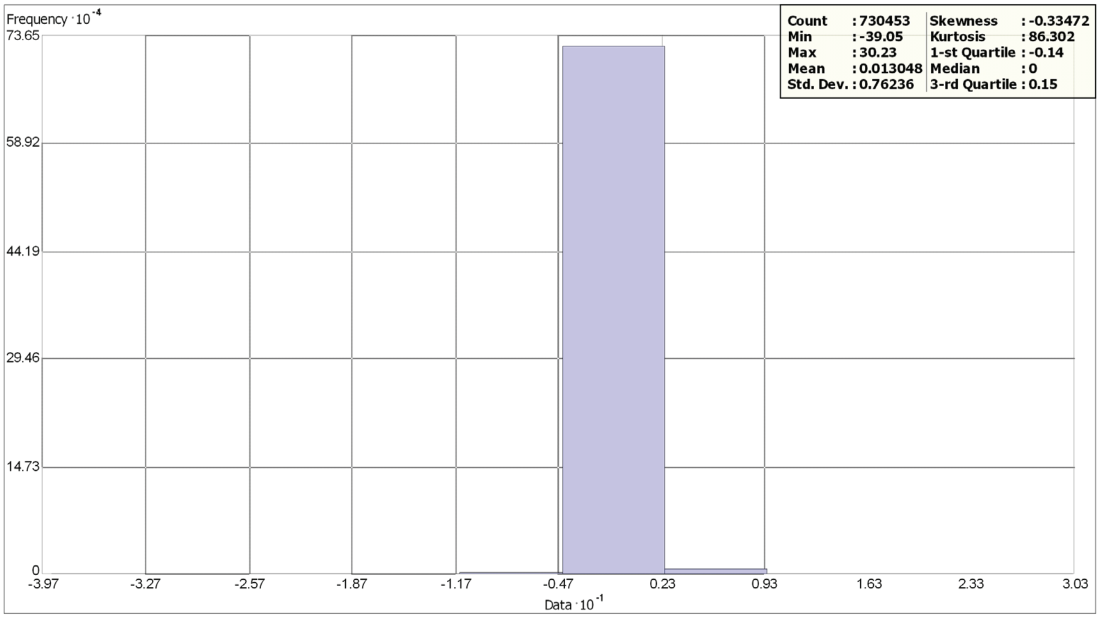

Figure 21. *Histogram of the differences between NOS hydrographic survey H11496 and the 8/15 arc-second pre-surfaced bathymetric grid of Cordova. Large differences result from averaging of multiple, closely-spaced NOS soundings in regions of steep bathymetry.*

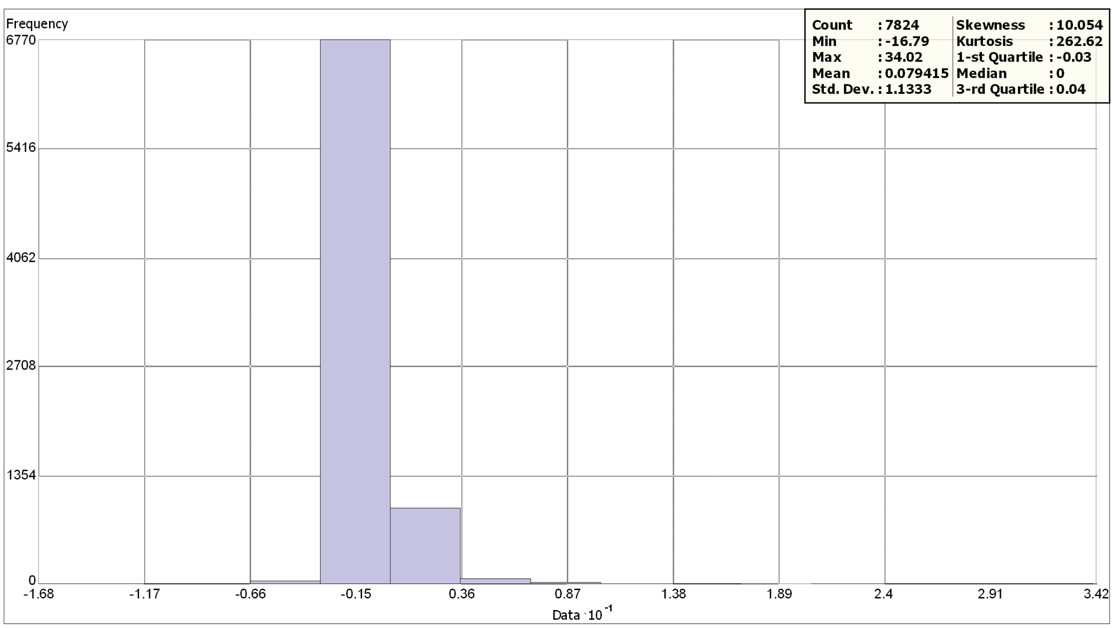

Figure 22. *Histogram of the differences between NOS hydrographic survey H10655 and the 8/15 arc-second pre-surfaced bathymetric grid of Whittier. Large differences result from averaging of multiple, closely-spaced NOS soundings in regions of steep bathymetry.*

3.3.3 *Smoothing of topographic data*

The resolution of the NED data (2 arc-seconds) was coarse compared to the 8/15 arc-second grids and led to unrepresentative slopes where zero values at the coast interpolate to the nearest NED point data. To better approximate the local topography in the high-resolution grids, a kriging interpolation was performed using two datasets: (a) the 2 arc-second NED data points clipped to the coastline and then to extents slightly larger (~ 5 percent) than the high-resolution grids and (b) points at 0 meters elevation extracted every 10 meters from the final coastline. These point data were then smoothed onto an 8/15 arc-second grid using the 'Kriging' tool in *ArcMap*. The resultant *ESRI Arc* raster was then clipped again to the final coastline to eliminate data interpolation into bathymetric regions. The surface was then compared with the original NED data to ensure grid accuracy, converted to a shapefile, and then exported as an xyz file for use in the final gridding process.

3.3.4 *Building the DEMs with MB System*

MB-System was used to create 8 and 8/3 arc-second DEMs of Prince William Sound and 8/15 arc-second DEMs of Cordova and Whittier, Alaska. The *MB-System* tool 'mbgrid' applied a tight spline tension to the xyz data, and interpolated values for cells without data. The data hierarchy used in the 'mbgrid' gridding algorithm, as relative gridding weights, is listed in Table 9. Greatest weight was given to the high-resolution datasets and digitized features. Least weight was given to the pre-surfaced bathymetric grids and trackline soundings. As noted in the hierarchy, higher resolution DEMs generated by NGDC (8/15 and 8/3 arc-second) and a high-resolution DEM for Valdez, Alaska from UAF, also served as sources for the coarser 8/3 and 8 arc-second grids.

Table 9. Data hierarchy used to assign gridding weight in MB-System

Dataset	*Relative Gridding Weight*
USACE surveys	100
USGS NED topographic DEM	100
ENC soundings	100
NGDC digitized features	100
UAF Valdez DEM	100
SRTM topographic DEM	10
NOS hydrographic surveys	10
Final coastline at 0 meters elevation	10
Higher resolution DEMs	10
NGDC hydrographic sonar multibeam	10
Pre-surfaced bathymetric grid	1
Trackline soundings	0.1

3.4 Quality Assessment of the DEM

3.4.1. Horizontal accuracy

The horizontal accuracy of topographic and bathymetric features in the Prince William Sound DEMs are dependent upon the DEM cell size and datasets used to determine corresponding DEM cell values. Topographic features have an estimated horizontal accuracy of 50 to 75 meters, based on the documented accuracy of the NED and SRTM DEMs. Bathymetric features in areas covered by early 20th-century NOS hydrographic soundings—along the margins of the DEM—are resolved only to within a few tens of meters in shallow water, and to a few hundred meters in deep-water areas; their positional accuracy is limited by the sparseness of soundings, and potentially large positional accuracy of pre-satellite navigated (e.g., GPS) NOS hydrographic surveys.

3.4.2 Vertical accuracy

Vertical accuracy of elevation values for the DEMs are also highly dependent upon the source datasets contributing to grid cell values. Topographic datasets have vertical accuracies of between 10 and 15 meters (NED: ~10 meters; SRTM: <16 meters). Bathymetric values are derived from a wide range of input data, consisting of single and multibeam sounding measurements from the early 20th century to recent GPS-navigated sonar surveys. Modern NOS standards are 0.3 m in 0 to 20 m of water, 1.0 m in 20 to 100 m of water, and 1% of the water depth in 100 m of water. Gridding interpolation to determine bathymetric values between sparse, poorly located NOS soundings degrades the vertical accuracy of elevations in deep water to about 5% of water depth.

3.4.3 Slope maps and 3-D perspectives

ESRI *ArcCatalog* was used to generate a slope grid from the 8/15 arc-second DEMs at both Cordova and Whittier to allow for visual inspection and identification of artificial slopes along boundaries between datasets (Figs. 23 and 24). The DEMs were transformed to NAD 83/UTM Zone 6 coordinates (horizontal units in meters) in *ArcCatalog* for derivation of the slope grids; equivalent horizontal and vertical units are required for effective slope analysis. Three-dimensional viewing of all the DEMs (Figs. 25 through 28) was accomplished using *POV Ray,* a shareware tool for generating three-dimensional graphics (http://www.povray.org/). Analysis of preliminary grids revealed suspect data points, which were corrected before recompiling the DEMs.

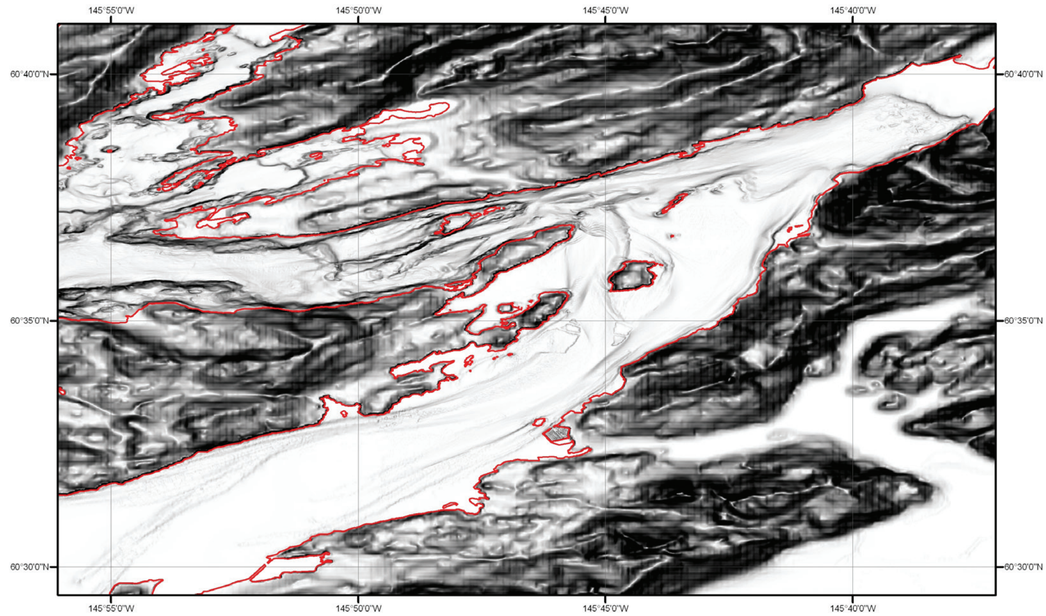

Figure 23. *Slope map of the 8/15 arc-second Cordova DEM. Flat-lying slopes are white; dark shading denotes steep slopes; final coastline in red.*

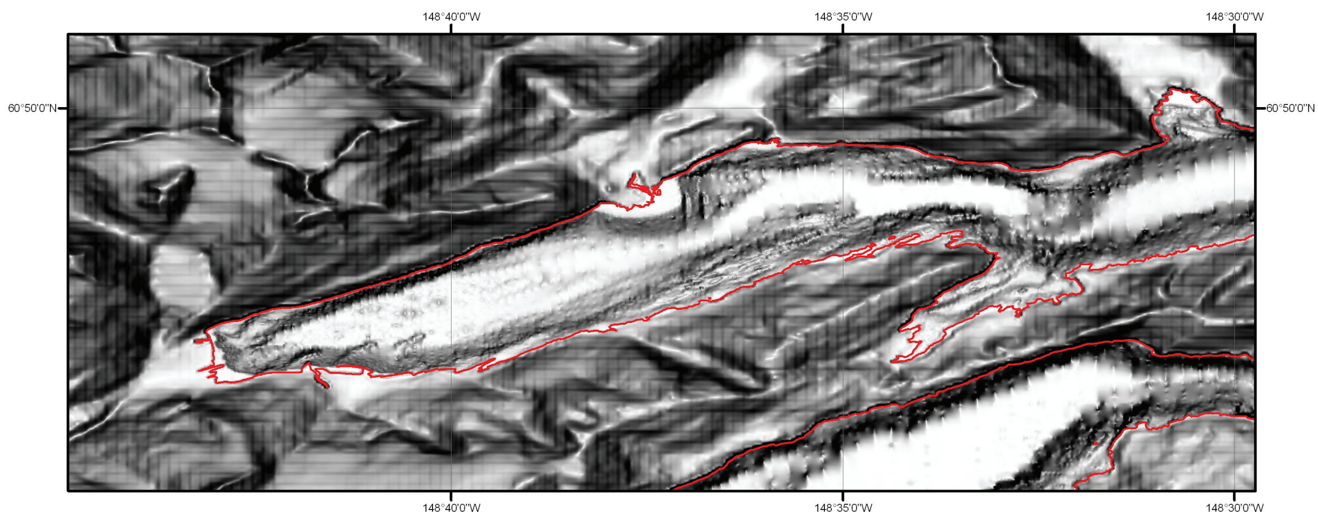

Figure 24. *Slope map of the 8/15 arc-second Whittier DEM. Flat-lying slopes are white; dark shading denotes steep slopes; final coastline in red.*

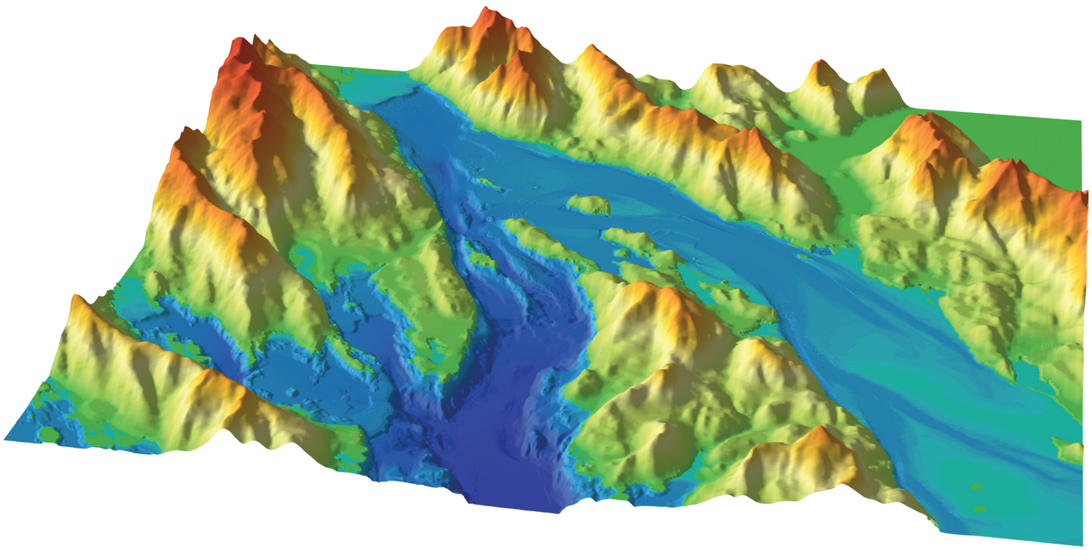

Figure 25. *Perspective view from the west of the 8/15 arc-second Cordova DEM. Vertical exaggeration–times 2.*

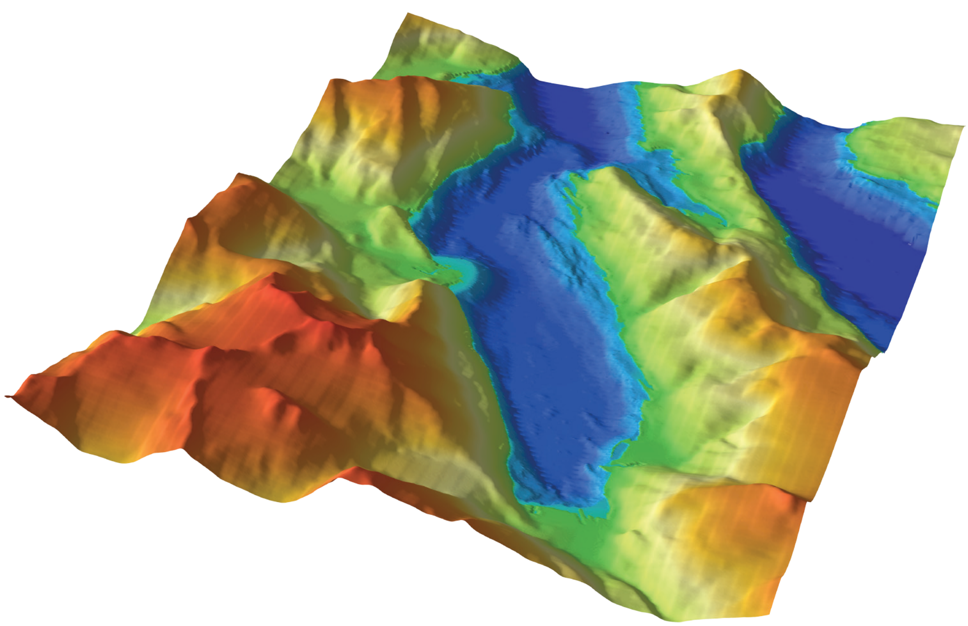

Figure 26. *Perspective view from the west of the 8/15 arc-second Whittier DEM. Vertical exaggeration–times 2.*

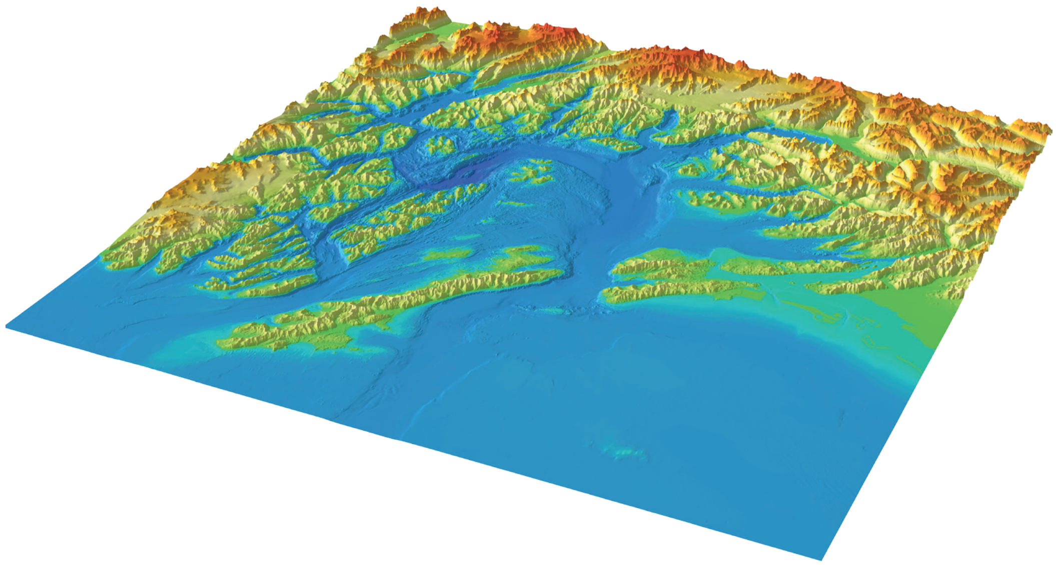

Figure 27. *Perspective view from the southeast of the 8/3 arc-second Prince William Sound DEM. Vertical exaggeration–times 2.*

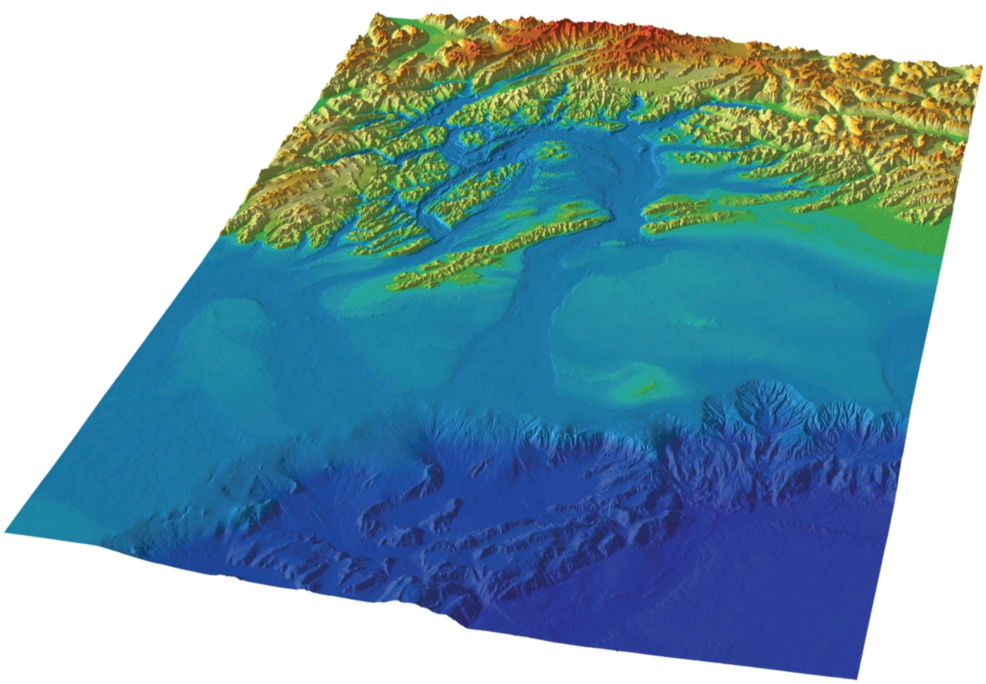

Figure 28. *Perspective view from the southeast of the 8 arc-second Prince William Sound DEM. Vertical exaggeration–times 2.*

3.4.4 Comparison with source data files

To ensure grid accuracy, the 8/3 arc-second Prince William Sound 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. A histogram of the differences between selected NED data points and the 8/3 arc-second Prince William Sound DEM is shown in Figure 29.

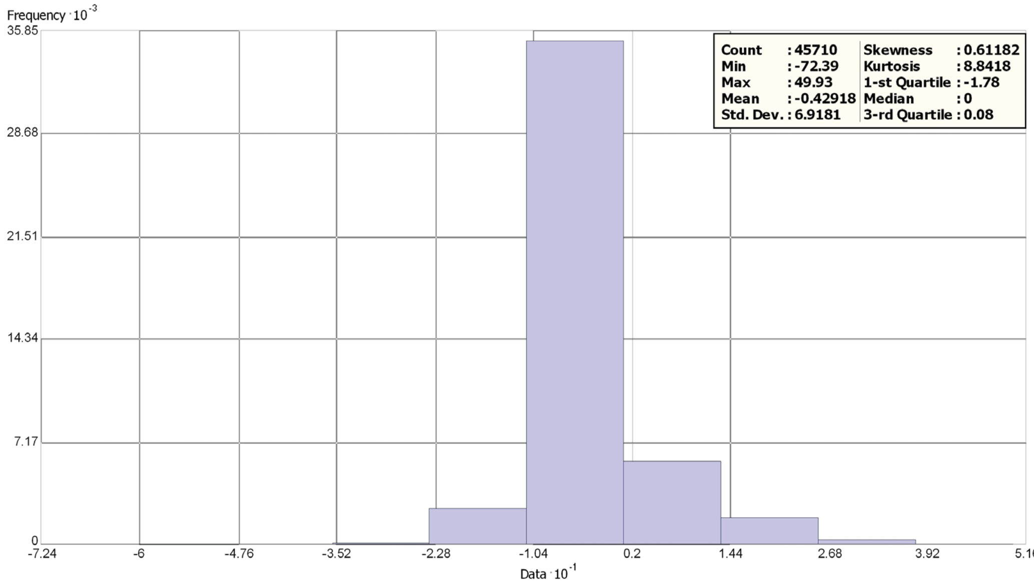

Figure 29. *Histogram of the differences between the NED topographic data and the 8/3 arc-second Prince William Sound DEM.*

3.4.5 Comparison with USGS topographic contours

USGS topographic quadrangles, Cordova C-5 SW and Seward C-5, were downloaded for the vicinity of Cordova and Whittier, Alaska, respectively (http://agdc.usgs.gov/index.html). The Cordova quadrangle gives position and elevation in NAD 83 and NGVD 29 vertical datum (in feet) and has a scale of 1:25,000 with a 20-foot contour interval. The Seward quadrangle gives position and elevation in NAD 83 and NGVD 29 vertical datum (in feet) and has a scale of 1:63,360 with a 100-foot contour interval.

To be consistent with the USGS quadrangles, the 8/15 arc-second DEMs at Cordova and Whittier were converted from meters into feet. A contour map with a 100-foot interval was created using the 8/15 arc-second DEM at Whittier Harbor, while a contour map with a 20-foot interval was created for Cordova. The contour maps were then compared against the USGS topographic quadrangle contours (Figs. 30 and 31). Although the figures show that differences exist between the 8/15 arc-second DEMs and the USGS topographic map contours, the morphology of the regions surrounding Whittier and Cordova is preserved. The exception is the existence of reduced elevations on Spike Island, northwest of Cordova, where there is no 20-foot elevation contour (Fig. 30b). With a maximum pixel value of approximately 2 meters, the NED data do not properly represent the elevations for Spike Island displayed on the USGS topographic quadrangle.

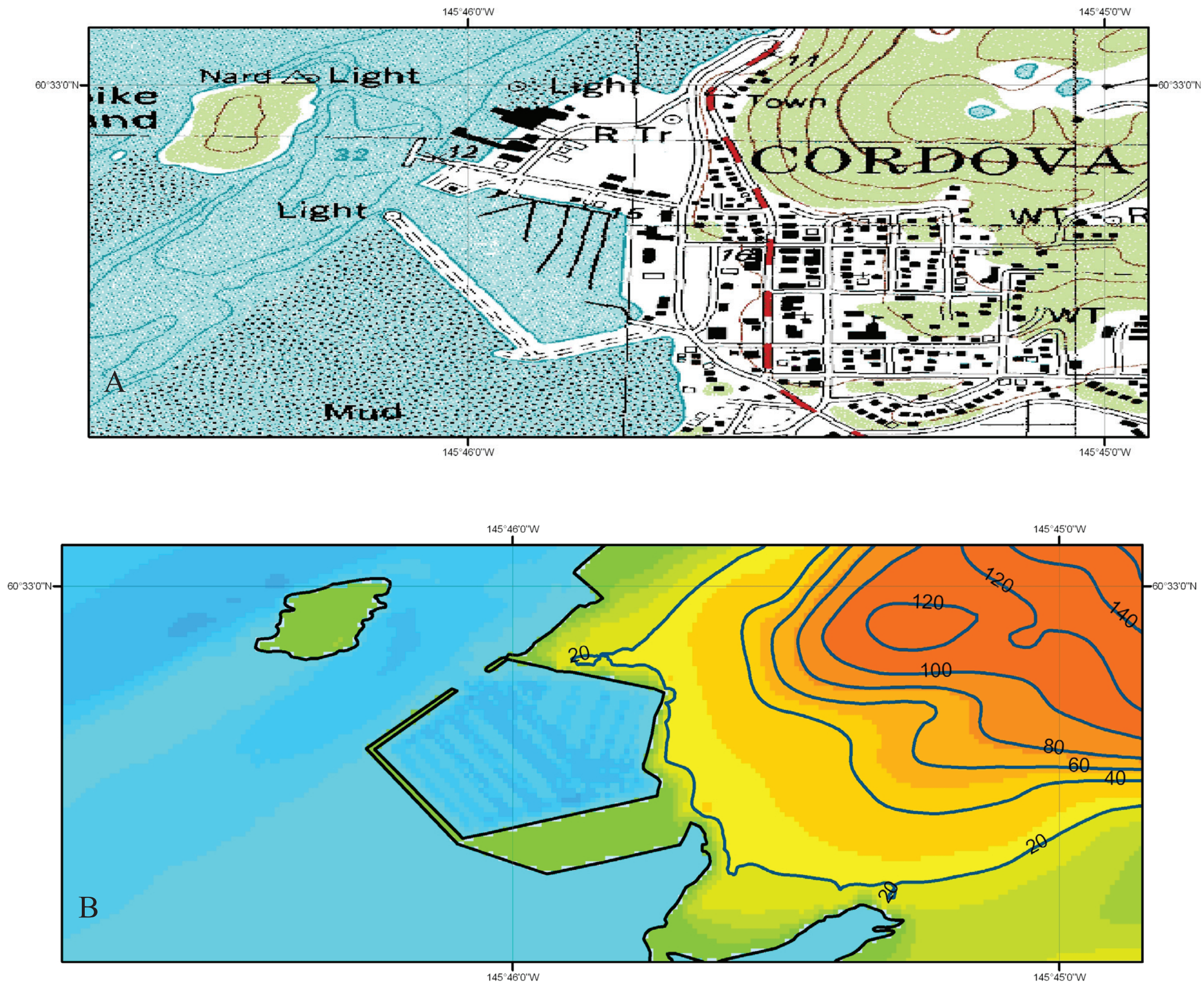

Figure 30. *Comparison between USGS topographic contours and topographic contours from the 8/15 arc-second Cordova DEM. A) Brown lines and numbers represent 20-foot contours from the USGS topographic map. B) Dark blue lines and black numbers represent 20-foot contours from the 8/15 arc-second Cordova DEM.*

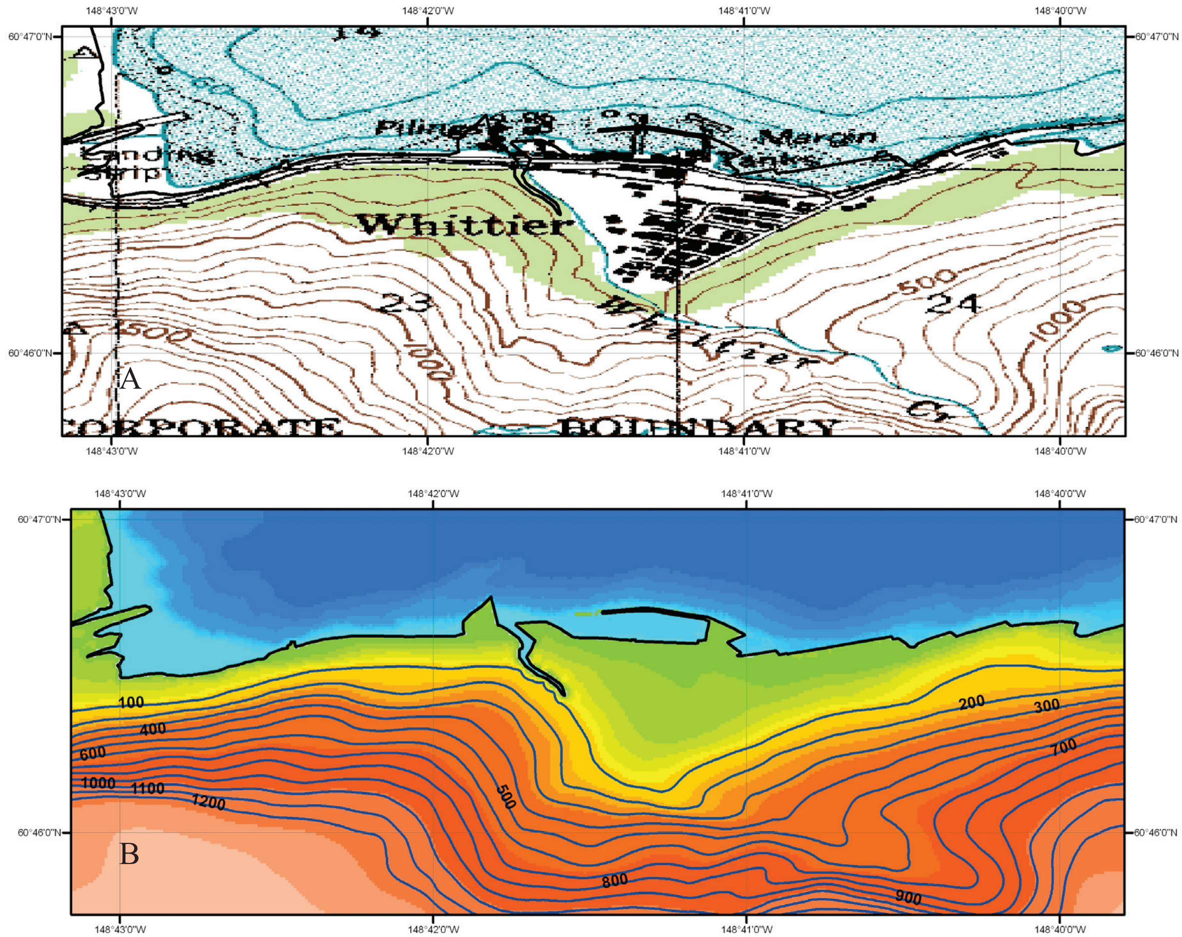

__Figure 31.__ Comparison between USGS topographic contours and topographic contours from the 8/15 arc-second Whittier DEM. A) Brown lines and numbers represent 100-foot contours from the USGS topographic map. B) Dark blue lines and black numbers represent 100-foot contours from the 8/15 arc-second Whittier DEM.

4. Summary and Conclusions

Four nested, integrated topographic–bathymetric digital elevation models of the Prince William Sound, Alaska area, with cell sizes of 8 arc-second, 8/3 arc-second, and 8/15 arc-second, were developed for the University of Alaska at Fairbanks (UAF) Geophysical Institute. The best available digital data 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*, *Quick Terrain Modeler*, *POV Ray*, and *MB-System* software.

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

- Conduct bathymetric surveys in the southwestern quarter of the 8 arc-second DEM area where digital sounding data are sparse or non-existent.
- Conduct high-resolution topographic surveys of Cordova and Whittier.
- Obtain more recent data in the area immediately around the Copper River delta.
- Establish, via survey, the relationships between tidal and geodetic datums in the Prince William Sound region.
- Determine the relationship between Early Alaska and NAD 83/WGS 84 geographic horizontal datums.

5. Acknowledgments

The creation of the DEMs was funded by the University of Alaska at Fairbanks. The authors thank Elena Suleimani, Dave West, and Dmitry Nicolsky (UAF), Bret Christensen (U.S. Fish and Wildlife Service), and Gary Nelson and Brooke McMahon (NOS Pacific Hydrographic Branch). We would also like to extend our appreciation to Volkmar Leimer (BSH) for providing access to the Sonne multibeam datasets. In addition, photographs by Ken Rice were especially helpful in the identification of structures in and surrounding Whittier Harbor.

6. References

Krimmel, Robert M., Photogrammetric Data Set (1957-2000) and Bathymetric Measurements for Columbia Glacier, Alaska, 2001. Water-Resources Investigations Report 01-4089. U.S. Geological Survey.

Nautical Chart #531 (ENC and RNC), 13th Edition, 2008. Gulf of Alaska, Strait of Juan de Fuca to Kodiak Island. 1:2,100,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16013 (RNC), 30th Edition, 2008. Cape St. Elias to Shumagin Islands. 1:969,761 with 1:400,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16680 (ENC and RNC), 5th Edition, 2007. Point Elrington to East Chugach Island. 1:200,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16683 (ENC and RNC), 6th Edition, 2008. Point Elrington to Cape Resurrection. 1:81,436. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16700 (ENC and RNC), 2nd Edition, 2008. Prince William Sound. 1:200,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16701 (ENC and RNC), 9th Edition, 2007. Prince William Sound, Western Entrance. 1:81,436. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16702 (ENC and RNC), 7th Edition, 2008. Latouche Passage to Whale Bay. 1:40,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16704 (ENC and RNC), 3rd Edition, 2007. Drier Bay. 1:20,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16705 (ENC and RNC), 5th Edition, 2007. Prince William Sound, Western Part. 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16706 (ENC and RNC), 3rd Edition, 2008. Passage Canal including Port of Whittier. 1:20,000 with 1:10,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16707 (ENC and RNC), 17th Edition, 2008. Prince William Sound, Valdez Arm, and Port Valdez. 1:40,000 with 1:20,000 and 1:10,000 insets. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16708 (ENC and RNC), 15th Edition, 2008. Prince William Sound, Port Fidalgo and Valdez Arm. 1:79,291 with 1:40,000 inset. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16709 (ENC and RNC), 11th Edition, 2008. Prince William Sound, Eastern Entrance. 1:80,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16710 (ENC and RNC), 6th Edition, 2008. Orca Bay and Inlet Channel Islands to Cordova. 1:30,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16711 (ENC and RNC), 2nd Edition, 2007. Port Wells, College Fiord. 1:50,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16712 (ENC and RNC), 3rd Edition, 2007. Unakwik Inlet to Esther Passage and College Fiord. 1:50,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

Nautical Chart #16713 (ENC and RNC), 9th Edition, 2008. Naked Island to Columbia Bay. 1:50,000. U.S. Department of Commerce, NOAA, National Ocean Service, Coast Survey.

7. Data Processing Software

ArcGIS v. 9.2, developed and licensed by ESRI, Redlands, California, 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. 4.3.0 – 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/

Persistence of Vision Pty. Ltd,. (2004), Persistence of Vision™ Raytracer. Persistence of Vision Pty. Ltd., Williamstown, Victoria, Australia, http://www.povray.org/

Quick Terrain Modeler v.6.0.1, developed by Johns Hopkins University Applied Physics Laboratory, licensed by Applied Imagery, Silver Spring, Maryland, http://www.appliedimagery.com/

Appendix A. NOS Hydrographic Surveys

Table A-1. NOS Hydrographic Surveys used in Compiling the Prince William Sound DEMs

Name	*Year*	*Scale of Survey*	*Original Horizontal Datum*	*Original Vertical Datum*
B00106	1987	50,000	NAD 83	Mean Lower Low Water
B00108	1987	50,000	NAD 83	Mean Lower Low Water
B00110	1987	50,000	NAD 83	Mean Lower Low Water
B00111	1987	50,000	NAD 83	Mean Lower Low Water
B00113	1987	50,000	NAD 83	Mean Lower Low Water
B00140	1988	50,000	NAD 83	Mean Lower Low Water
B00141	1988	50,000	NAD 83	Mean Lower Low Water
B00142	1988	50,000	NAD 83	Mean Lower Low Water
B00143	1988	50,000	NAD 83	Mean Lower Low Water
B00146	1988	50,000	NAD 83	Mean Lower Low Water
B00148	1988	50,000	NAD 83	Mean Lower Low Water
B00149	1988	50,000	NAD 83	Mean Lower Low Water
B00150	1988	50,000	NAD 83	Mean Lower Low Water
B00151	1988	50,000	NAD 83	Mean Lower Low Water
B00152	1988	50,000	NAD 83	Mean Lower Low Water
B00153	1988	50,000	NAD 83	Mean Lower Low Water
B00154	1988	50,000	NAD 83	Mean Lower Low Water
B00155	1988	50,000	NAD 83	Mean Lower Low Water
B00156	1988	50,000	NAD 83	Mean Lower Low Water
F00252	1983	2,500	Early Alaska Datum	Mean Lower Low Water
F00261	1984	10,000	Early Alaska Datum	Mean Lower Low Water
H02627	1902	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H02658	1903	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H02665	1903	600,000	Undetermined Horizontal Datum	Mean Lower Low Water
H02970	1908/1909	15,000	Valdez Datum	Mean Lower Low Water
H02971	1908	40,000	Valdez Datum	Mean Lower Low Water
H03024	1909	200,000	Valdez Datum	Mean Lower Low Water
H03186	1910	20,000	Valdez Datum	Mean Lower Low Water
H03411	1912	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H03432	1912	30,000	Undetermined Horizontal Datum	Mean Lower Low Water
H03553	1913	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H03704	1914	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H03816	1915	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H03817	1915	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H03954	1916	20,000	Valdez Datum	Mean Lower Low Water
H03955	1916	20,000	Valdez Datum	Mean Lower Low Water
H03958	1916	80,000	Valdez Datum	Mean Lower Low Water
H03959	1916	10,000	Undetermined Horizontal Datum	Mean Lower Low Water
H04692	1927	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H04693	1927	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H04730	1927/1928	60,000	Undetermined Horizontal Datum	Mean Lower Low Water
H04731	1927/1928	80,000	Undetermined Horizontal Datum	Mean Lower Low Water
H04825	1928	20,000	Undetermined Horizontal Datum	Mean Lower Low Water
H04856	1928	200,000	Undetermined Horizontal Datum	Mean Lower Low Water
H05035	1930	10,000	Early Alaska Datums	Mean Lower Low Water
H05087	1930	160,000	Early Alaska Datum	Mean Lower Low Water

H05408	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05409	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05421	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05422	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05423	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05427	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05428	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05430	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05431	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05447	1933	200,000	Early Alaska Datum	Mean Lower Low Water
H05454	1933	80,000	Early Alaska Datum	Mean Lower Low Water
H05460	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H05461	1933	20,000	Early Alaska Datum	Mean Lower Low Water
H06981	1948	10,000	Early Alaska Datum	Mean Lower Low Water
H07187	1947	10,000	Early Alaska Datum	Mean Lower Low Water
H07618	1948	20,000	Early Alaska Datum	Mean Lower Low Water
H07628	1947	40,000	Early Alaska Datum	Mean Lower Low Water
H07678	1949	20,000	Early Alaska Datum	Mean Lower Low Water
H07725	1948	10,000	Early Alaska Datum	Mean Lower Low Water
H07732	1948	40,000	Early Alaska Datum	Mean Lower Low Water
H07764	1949	20,000	Early Alaska Datum	Mean Lower Low Water
H08204	1955	10,000	NAD 27	Mean Lower Low Water
H08205	1954/1957	10,000	NAD 27	Mean Lower Low Water
H08206	1955	10,000	Early Alaska Datum	Mean Lower Low Water
H08310	1956	5,000	Early Alaska Datum	Mean Lower Low Water
H08311	1957	2,500	NAD 27	Mean Lower Low Water
H08312	1957	20,000	Early Alaska Datum	Mean Lower Low Water
H08606	1961	10,000	NAD 27	Mean Lower Low Water
H08852	1965	5,000	Early Alaska Datum	Mean Lower Low Water
H08853	1965	10,000	Early Alaska Datum	Mean Lower Low Water
H08854	1965	20,000	Early Alaska Datum	Mean Lower Low Water
H08875	1965	40,000	NAD 27	Mean Lower Low Water
H08899	1966	5,000	NAD 27	Mean Lower Low Water
H08900	1966	20,000	Early Alaska Datum	Mean Lower Low Water
H08901	1966	10,000	NAD 27	Mean Lower Low Water
H08913	1966	5,000	Early Alaska Datum	Mean Lower Low Water
H09047	1969	10,000	Early Alaska Datum	Mean Lower Low Water
H09049	1969	20,000	Early Alaska Datum	Mean Lower Low Water
H09053	1969	20,000	Early Alaska Datum	Mean Lower Low Water
H09205	1971	40,000	NAD 27	Mean Lower Low Water
H09206	1971	40,000	NAD 27	Mean Lower Low Water
H09382	1973	40,000	Early Alaska Datum	Mean Lower Low Water
H09383	1973	10,000	Early Alaska Datum	Mean Lower Low Water
H09384	1973	10,000	Early Alaska Datum	Mean Lower Low Water
H09385	1973	20,000	Early Alaska Datum	Mean Lower Low Water
H09386	1973	20,000	Early Alaska Datum	Mean Lower Low Water
H09387	1973	20,000	Early Alaska Datum	Mean Lower Low Water
H09388	1973	20,000	Early Alaska Datum	Mean Lower Low Water
H09422	1974	20,000	NAD 27	Mean Lower Low Water
H09423	1974	20,000	Early Alaska Datum	Mean Lower Low Water

H09424	1974	20,000	NAD 27	Mean Lower Low Water
H09425	1974	40,000	Early Alaska Datum	Mean Lower Low Water
H09512	1975	20,000	Early Alaska Datum	Mean Lower Low Water
H09513	1975	20,000	Early Alaska Datum	Mean Lower Low Water
H09624	1976	40,000	Early Alaska Datum	Mean Lower Low Water
H09625	1976	40,000	Early Alaska Datum	Mean Lower Low Water
H09626	1976	40,000	Early Alaska Datum	Mean Lower Low Water
H09636	1976	10,000	Early Alaska Datum	Mean Lower Low Water
H09637	1976	10,000	Early Alaska Datum	Mean Lower Low Water
H09711	1977	10,000	Early Alaska Datum	Mean Lower Low Water
H09713	1977	10,000	Early Alaska Datum	Mean Lower Low Water
H09829	1979	40,000	Early Alaska Datum	Mean Lower Low Water
H09830	1979	40,000	Early Alaska Datum	Mean Lower Low Water
H09831	1979	40,000	Early Alaska Datum	Mean Lower Low Water
H10029	1982	10,000	Early Alaska Datum	Mean Lower Low Water
H10038	1982	10,000	Early Alaska Datum	Mean Lower Low Water
H10090	1983/1984	20,000	Early Alaska Datum	Mean Lower Low Water
H10139	1984	40,000	Early Alaska Datum	Mean Lower Low Water
H10437	1992	20,000	NAD 83	Mean Lower Low Water
H10438	1992	20,000	NAD 83	Mean Lower Low Water
H10441	1992	20,000	NAD 83	Mean Lower Low Water
H10443	1992	20,000	NAD 83	Mean Lower Low Water
H10445	1992	10,000	NAD 83	Mean Lower Low Water
H10499	1993	10,000	NAD 83	Mean Lower Low Water
H10500	1993	10,000	NAD 83	Mean Lower Low Water
H10501	1993	10,000	NAD 83	Mean Lower Low Water
H10502	1993/1994	10,000	NAD 83	Mean Lower Low Water
H10503	1993	20,000	NAD 83	Mean Lower Low Water
H10507	1993	20,000	NAD 83	Mean Lower Low Water
H10514	1993	10,000	NAD 83	Mean Lower Low Water
H10515	1993	10,000	NAD 83	Mean Lower Low Water
H10516	1993	10,000	NAD 83	Mean Lower Low Water
H10517	1993	20,000	NAD 83	Mean Lower Low Water
H10519	1993/1994	20,000	NAD 83	Mean Lower Low Water
H10566	1994	10,000	NAD 83	Mean Lower Low Water
H10567	1994	10,000	NAD 83	Mean Lower Low Water
H10568	1994	10,000	NAD 83	Mean Lower Low Water
H10569	1994	10,000	NAD 83	Mean Lower Low Water
H10570	1994	10,000	NAD 83	Mean Lower Low Water
H10571	1994	20,000	NAD 83	Mean Lower Low Water
H10578	1994	10,000	NAD 83	Mean Lower Low Water
H10579	1994	10,000	NAD 83	Mean Lower Low Water
H10580	1994	10,000	NAD 83	Mean Lower Low Water
H10634	1995	10,000	NAD 83	Mean Lower Low Water
H10635	1995	10,000	NAD 83	Mean Lower Low Water
H10636	1995	10,000	NAD 83	Mean Lower Low Water
H10637	1995	10,000	NAD 83	Mean Lower Low Water
H10639	1995	10,000	NAD 83	Mean Lower Low Water
H10640	1995	10,000	NAD 83	Mean Lower Low Water
H10644	1995	10,000	NAD 83	Mean Lower Low Water

H10645	1995	10,000	NAD 83	Mean Lower Low Water
H10650	1995	10,000	NAD 83	Mean Lower Low Water
H10653	1995	10,000	NAD 83	Mean Lower Low Water
H10655	1995	5,000	NAD 83	Mean Lower Low Water
H10657	1995	10,000	NAD 83	Mean Lower Low Water
H10658	1995	10,000	NAD 83	Mean Lower Low Water
H10712	1996	10,000	NAD 83	Mean Lower Low Water
H10713	1996	10,000	NAD 83	Mean Lower Low Water
H10715	1996	10,000	NAD 83	Mean Lower Low Water
H10716	1996	10,000	NAD 83	Mean Lower Low Water
H10717	1996	10,000	NAD 83	Mean Lower Low Water
H10718	1996	40,000	NAD 83	Mean Lower Low Water
H10719	1996	10,000	NAD 83	Mean Lower Low Water
H10721	1996	10,000	NAD 83	Mean Lower Low Water
H10722	1996	10,000	NAD 83	Mean Lower Low Water
H10723	1996	10,000	NAD 83	Mean Lower Low Water
H10725	1996	10,000	NAD 83	Mean Lower Low Water
H10726	1996	10,000	NAD 83	Mean Lower Low Water
H10729	1996	40,000	NAD 83	Mean Lower Low Water
H10730	1996	10,000	NAD 83	Mean Lower Low Water
H10773	1997	10,000	NAD 83	Mean Lower Low Water
H10774	1997	10,000	NAD 83	Mean Lower Low Water
H10775	1997	40,000	NAD 83	Mean Lower Low Water
H10776	1997	10,000	NAD 83	Mean Lower Low Water
H10777	1997/1998	10,000	NAD 83	Mean Lower Low Water
H10778	1997	10,000	NAD 83	Mean Lower Low Water
H10779	1997	10,000	NAD 83	Mean Lower Low Water
H10781	1997	10,000	NAD 83	Mean Lower Low Water
H10782	1997	40,000	NAD 83	Mean Lower Low Water
H10785	1997	10,000	NAD 83	Mean Lower Low Water
H10786	1997	10,000	NAD 83	Mean Lower Low Water
H10787	1997	10,000	NAD 83	Mean Lower Low Water
H10789	1997	10,000	NAD 83	Mean Lower Low Water
H10791	1997	10,000	NAD 83	Mean Lower Low Water
H10829	1998	10,000	NAD 83	Mean Lower Low Water
H10837	1998	10,000	NAD 83	Mean Lower Low Water
H10838	1998	10,000	NAD 83	Mean Lower Low Water
H10840	1998	10,000	NAD 83	Mean Lower Low Water
H10841	1998	10,000	NAD 83	Mean Lower Low Water
H10843	1998	10,000	NAD 83	Mean Lower Low Water
H10846	1998	10,000	NAD 83	Mean Lower Low Water
H10847	1998	10,000	NAD 83	Mean Lower Low Water
H10849	1998	40,000	NAD 83	Mean Lower Low Water
H10852	1998	10,000	NAD 83	Mean Lower Low Water
H10853	1998	10,000	NAD 83	Mean Lower Low Water
H10855	1998	10,000	NAD 83	Mean Lower Low Water
H10918	1999	10,000	NAD 83	Mean Lower Low Water
H10919	1999	10,000	NAD 83	Mean Lower Low Water
H10920	1999	10,000	NAD 83	Mean Lower Low Water
H10921	1999	10,000	NAD 83	Mean Lower Low Water

H10922	1999	10,000	NAD 83	Mean Lower Low Water
H10923	1999	10,000	NAD 83	Mean Lower Low Water
H10925	1999	40,000	NAD 83	Mean Lower Low Water
H10927	1999	10,000	NAD 83	Mean Lower Low Water
H10928	1999	10,000	NAD 83	Mean Lower Low Water
H10929	1999	10,000	NAD 83	Mean Lower Low Water
H10932	1999	10,000	NAD 83	Mean Lower Low Water
H10933	1999	10,000	NAD 83	Mean Lower Low Water
H10940	1999	10,000	NAD 83	Mean Lower Low Water
H11000	2000	10,000	NAD 83	Mean Lower Low Water
H11001	2000	40,000	NAD 83	Mean Lower Low Water
H11003	2000	10,000	NAD 83	Mean Lower Low Water
H11004	2000	10,000	NAD 83	Mean Lower Low Water
H11005	2000	10,000	NAD 83	Mean Lower Low Water
H11006	2000	10,000	NAD 83	Mean Lower Low Water
H11008	2002	10,000	NAD 83	Mean Lower Low Water
H11012	2000	10,000	NAD 83	Mean Lower Low Water
H11013	2000	10,000	NAD 83	Mean Lower Low Water
H11075	2001	20,000	NAD 83	Mean Lower Low Water
H11167	2002	10,000	NAD 83	Mean Lower Low Water
H11171	2002	10,000	NAD 83	Mean Lower Low Water
H11172	2002	10,000	NAD 83	Mean Lower Low Water
H11180	2002	10,000	NAD 83	Mean Lower Low Water
H11181	2003	10,000	NAD 83	Mean Lower Low Water
H11182	2002	10,000	NAD 83	Mean Lower Low Water
H11200	2003	20,000	NAD 83	Mean Lower Low Water
H11201	2003	20,000	NAD 83	Mean Lower Low Water
H11202	2003	20,000	NAD 83	Mean Lower Low Water
H11203	2003	20,000	NAD 83	Mean Lower Low Water
H11204	2003	20,000	NAD 83	Mean Lower Low Water
H11267	2003	10,000	NAD 83	Mean Lower Low Water
H11348	2004	10,000	NAD 83	Mean Lower Low Water
H11002 [a]	2000	10,000	UTM06 NAD 83	Mean Lower Low Water
H11007 [a]	2000	10,000	UTM06 NAD 83	Mean Lower Low Water
H11017 [a]	2000/2002	10,000	UTM06 NAD 83	Mean Lower Low Water
H11166 [a]	2002	10,000	UTM06 NAD 83	Mean Lower Low Water
H11168 [a]	2002	20,000	UTM06 NAD 83	Mean Lower Low Water
H11333 [b]	2004	20,000	UTM06 NAD 83	Mean Lower Low Water
H11349 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11350 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11351 [b]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11366 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11368 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11387 [b]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11388 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11389 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11390 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11391 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11392 [c]	2004	10,000	UTM06 NAD 83	Mean Lower Low Water
H11393 [c]	2004	20,000	UTM06 NAD 83	Mean Lower Low Water

H11490 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11491 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11492 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11493 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11494 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11496 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11497 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11498 [b]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11499 [c]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11500 [b]	2005	10,000	UTM06 NAD 83	Mean Lower Low Water
H11516 [c]	2005	10,000	UTM06 WGS 84	Mean Lower Low Water
H11608 [c]	2006	10,000	UTM06 WGS 84	Mean Lower Low Water
H11609 [c]	2006	10,000	UTM06 NAD 83	Mean Lower Low Water
H11610_Central [b]	2006	10,000	UTM06 NAD 83	Mean Lower Low Water
H11610_North [b]	2006	10,000	UTM06 NAD 83	Mean Lower Low Water
H11610_South [b]	2006	10,000	UTM06 NAD 83	Mean Lower Low Water
H11611 [c]	2006	10,000	UTM06 NAD 83	Mean Lower Low Water

[a] indicates NOS shallow-water multibeam sonar survey
[b] indicates xyz data provided by the NOS Pacific Hydrographic Branch
[c] indicates bathymetric attributed grids

Note: Some earlier surveys were referenced to horizontal datums with no known conversions to NAD 83 geographic. These surveys were manually adjusted in ArcGIS to fit the final coastline.