Appendix B: NOAA Technical Memorandum OAR PMEL-129, "A digital elevation model for Seaside, Oregon: Procedures, data sources, and analyses" by A.J. Venturato.

NOAA Technical Memorandum OAR PMEL-129

A DIGITAL ELEVATION MODEL FOR SEASIDE, OREGON: PROCEDURES, DATA SOURCES, AND ANALYSES

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A Digital Elevation Model for Seaside, Oregon: Procedures, Data Sources, and Analyses

Angie J. Venturato[1]

1. Introduction

As part of a probabilistic tsunami hazard assessment pilot study to modernize Flood Insurance Rate Maps for the Federal Emergency Management Agency (González *et al.*, 2004), the NOAA Center for Tsunami Inundation Mapping Efforts (TIME) developed a digital elevation model (DEM) for the purpose of modeling tsunami inundation for Seaside, Oregon. The finite-difference inundation model requires a series of nested computational elevation grids to simulate tsunami generation, propagation, and inundation in the region of interest (Fig. 1). To properly simulate the non-linear wave dynamics of inundation, a high-resolution DEM merging land and seafloor elevations is required (González *et al.*, 2005). A merged DEM with a resolution of 1/3 arc-seconds (approximately 10 meters) was developed for the Seaside, Oregon area. This technical memorandum provides a summary of the data sources and methodology used.

2. Study Area

The study area covers the coastal communities of Seaside and Gearhart in Clatsop County, Oregon. The Seaside-Gearhart area has a population of 6900 based on 2000 U.S. Census data, with a projected growth rate of 13% within the next decade (Clatsop County, 2005). The area's economy is primarily based on tourism with tens of thousands of visitors during the peak summer season (Oregon Coast Visitors Association, personal communication). Several tourist accommodations line the promenade, a 2-mile concrete boardwalk along the ocean beachfront.

Seaside is part of the Clatsop Plains, which is a low-lying coastal area from the Columbia River to Tillamook Head abutted on the east side by the hills of the Oregon Coast Range (Fig. 1b). Soils consist primarily of sand dune ridges and silt loam (USDA Natural Resources Conservation Service, 1994). The sand ridges run parallel to the ocean shore due to littoral accretion from the Columbia River (Fiedorowicz, 1997). Beachgrass and shrubs along sand ridges and Sitka spruce inland are the main vegetation types outside of urban areas (Oregon Natural Heritage Program, 1999).

The Necanicum River flows through the center of Seaside where it joins the Neawanna and Neacoxie Creeks, forming an estuary bay before draining into the Pacific Ocean (Fig. 1c). The Necanicum River bar-built estuary has a low water volume with a watershed of approximately 225 square kilometers (Oregon Ocean-Coastal Management Program, 2000).

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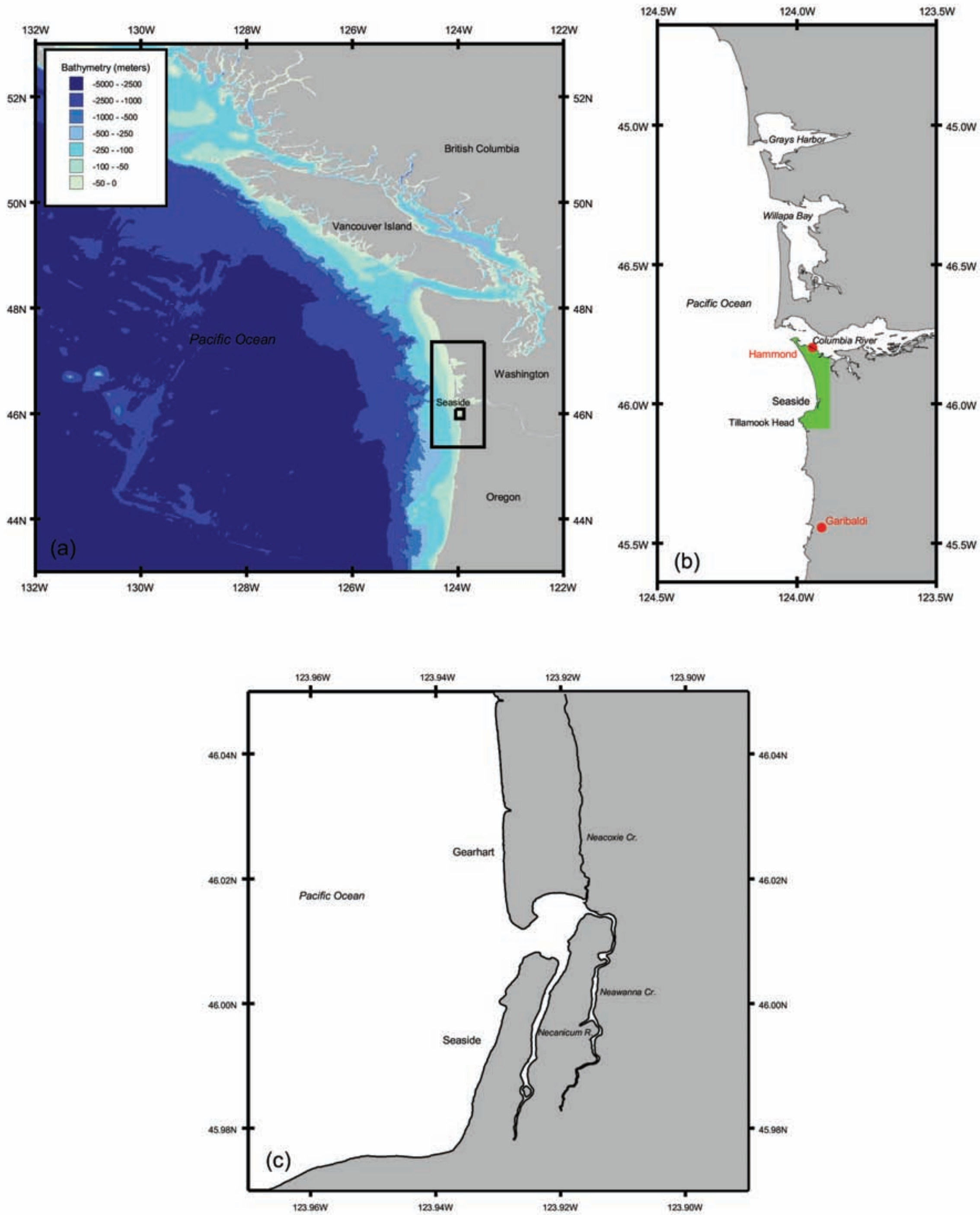

Figure 1: Study area of the FEMA FIRM project for Seaside, Oregon. (a) The nested grids used by the model. (b) Display of the Columbia River littoral cell with associated NOS water-level stations. (c) Details of the study region.

3. Methodology

The modeler set parameters for the grid based on input requirements for the inundation model (Table 1). Other criteria, such as obtaining the best available data, were also established in the planning process using recommended practices from prior inundation modeling efforts (González *et al.*, 2005). Data processing, grid assembly, and quality assurance are described in the following subsections.

3.1 Data Sources and Processing

Bathymetric, topographic, shoreline, control, and orthophotographic data were obtained from various government agencies. The primary data sources were obtained from the U.S. Geological Survey (USGS), NOAA National Ocean Service (NOS), and the Oregon Geospatial Data Clearinghouse (OGDC). Datasets were converted into formats compatible with ESRI ArcView GIS© 3.3.

Data sets were corrected to the common data framework established by modeler parameters. The ArcView Projection Utility was used to convert projected horizontal coordinates and datums to geographic coordinates and NAD83. Vertical datum transformation was applied based on the methodology described in Mofjeld *et al.* (2004). A vertical datum surface was developed using linearly interpolated values from official NOS datums at Hammond and Garibaldi, Oregon and a historical tertiary NOS water-level station in the Necanicum River estuary (Fig. 2).

3.1.1 Shoreline

Vector data representing the Mean High Water line were collected from the NOAA Shoreline Data Explorer and OGDC (Table 2). Significant discrepancies were found when comparing datasets (Fig. 3a). Orthorectified photographs conducted in 2000 by the National Aerial Photography Program (NAPP) were obtained from OGDC to perform a visual analysis (Table 2). A

Table 1: Parameters set by the modeler for the high-resolution DEM.

Pilot study site	Seaside, Oregon
Coverage area	West boundary: −124.04
	East boundary: −123.89
	North boundary: 46.08
	South boundary: 45.90
Coordinate system	Geographic decimal degrees
Horizontal datum	North American Datum of 1983 (NAD83)
Vertical datum	Mean High Water
Vertical units	Meters
Grid resolution	1/3 arc-seconds
Grid format	ASCII raster grid

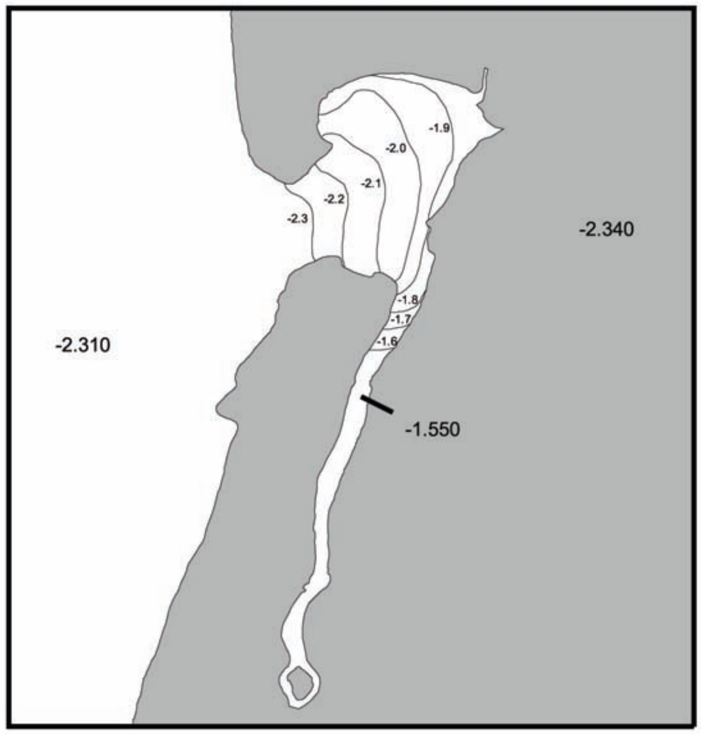

Figure 2: Estimated contours used to correct vertical datums to Mean High Water. Values are based on Mofjeld *et al.* (2004).

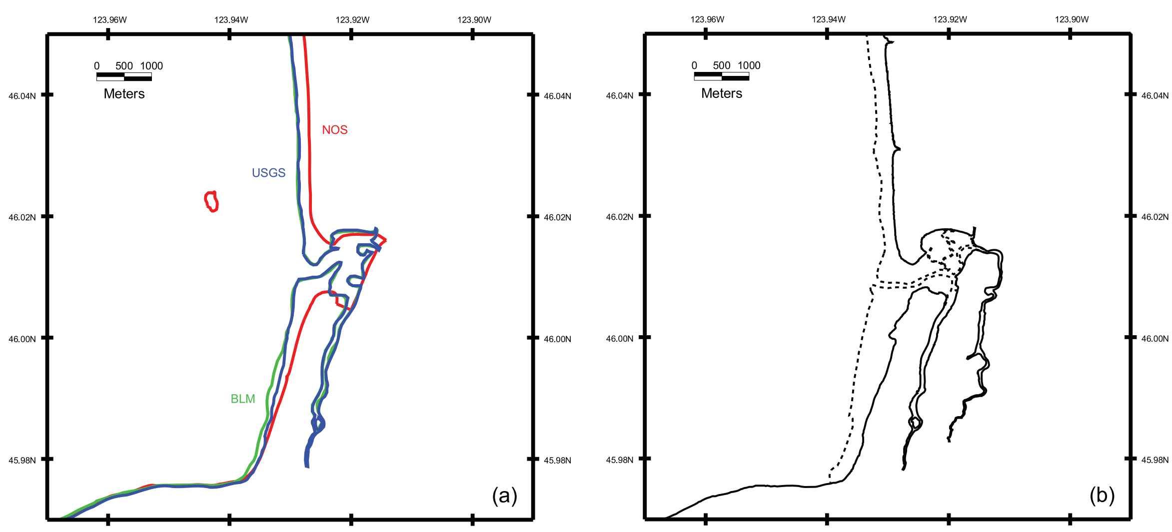

Figure 3: Shoreline vector analysis. (a) Shoreline vectors from the Bureau of Land Management (BLM) in green, National Ocean Service (NOS) in red, and U.S. Geological Survey (USGS) in blue. (b) Corrected shoreline vectors used in DEM development. The dashed line represents apparent Mean Lower Low Water based on recent orthophotos. The solid line represents Mean High Water.

Table 2: Shoreline data sources.

Source	Survey(s)	Year	Scale
NOAA Shoreline Data Explorer	OR43C04	1926	1:20,000
USGS Hydrographic Vectors	45123h8 46123a8	1973	1:24,000
Bureau of Land Management	Various	1999	1:24,000
National Aerial Photography Program	45123h8 46123a8	2000	1:24,000

Table 3: Bathymetric data sources from the National Ocean Service. No survey data were available for the Necanicum River region.

Source	Survey	Year	Scale	Spatial Resolution
NOSHDB	H04611	1926	1:20,000	50–200 m
NOSHDB	H04612	1926	1:20,000	50–200 m
NOSHDB	H04635	1926	1:40,000	50–200 m
NOSHDB	H08417	1958	1:20,000	50–200 m
LDART	Spring 1998	1998	N/A	5 m

resulting shoreline file with vectors representing both Mean High Water and Mean Lower Low Water was created using the Bureau of Land Management (BLM) vectors with revisions made based on photography (Fig. 3b). Polygonal files representing water and land were derived from data corresponding to the Mean High Water line.

3.1.2 Bathymetry

Bathymetric datasets consisted of four hydrographic surveys obtained from the NOS Hydrographic Database (NOSHDB) and LIDAR data from the NOS Coastal Services Center (CSC) (Table 3). Various Federal, State, and local agencies were contacted for recorded depth information on the Necanicum River estuary, yielding no results. Tom Horning of Horning Geosciences provided an estimated depth based on field observations (personal communication). This estimation was combined with limited LIDAR data within the intertidal zone to develop an estimated depth surface for the estuary (Fig. 4).

NOSHDB surveys were conducted using a single-beam digital echo sounder or lead line sounding method. The database processing system converted sounding depths to NAD83 and corrected meters using the National Geodetic Survey (NGS) NADCON software and Carter's tables (Carter, 1980), respectively. The accuracy of these surveys is difficult to determine. Accuracy standards were not established until 1965, and the values were digitized from hand-drawn maps. The surveys within the immediate vicinity of Seaside were based on the North American Datum of 1913, which required an

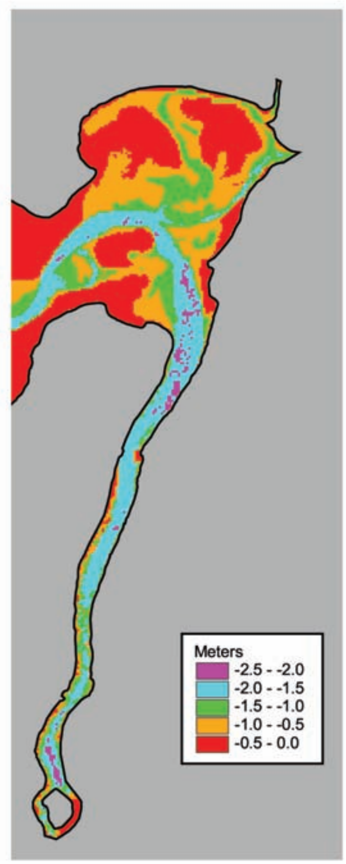

Figure 4: Estimated depth surface of the Necanicum River estuarine region.

additional transformation based on a single pair of datum shift values before applying NADCON (National Geophysical Data Center, 2004).

LIDAR data were obtained using the CSC LIDAR Data Retrieval Tool (LDART) to cover the intertidal zone. The Topography section provides details on these data.

Approximately 75,000 bathymetric points were selected from the surveys and surface model with recent data superseding older data in overlapping areas. Four anomalous points were removed from the selection. Spatial polygons were created to display selected coverage areas (Fig. 5) within the area of interest. 95% of the project area was covered by NOS survey soundings of variable density.

3.1.3 Topography

LIDAR data from LDART, a 10-meter DEM from the USGS National Elevation Dataset (NED), and a 10-meter DEM used in prior tsunami hazard modeling (Priest *et al.*, 1998) were obtained as topographic datasets. Fifteen

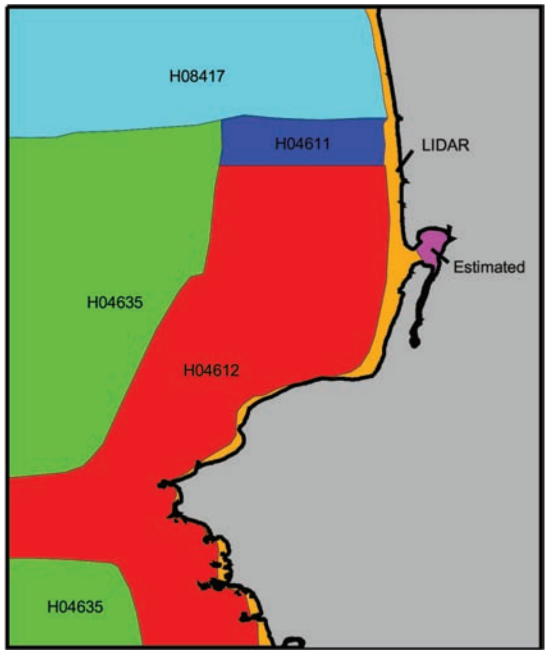

Figure 5: Coverage areas of bathymetric data sources used in the DEM. The Necanicum River region was estimated from limited LIDAR data and estimates from Horning (see Fig. 4). The coverage areas were clipped to the study area boundaries for display purposes; however, the selected data sources extend beyond the boundary to avoid interpolation edge errors during grid development.

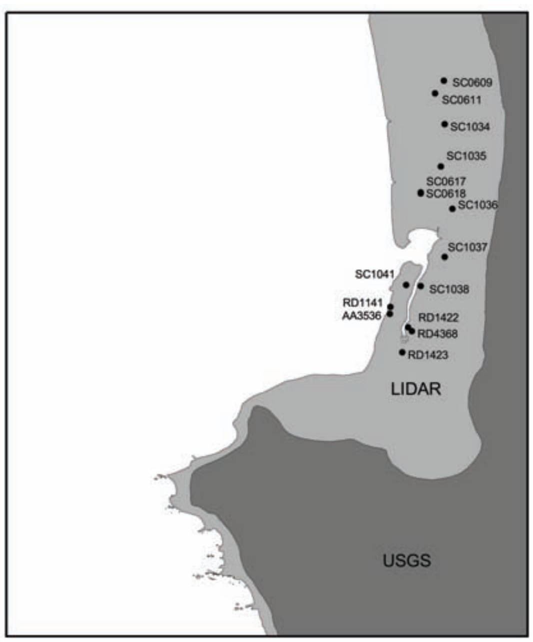

Figure 6: Coverage area of topographic data sources used in DEM development (clipped to boundary for display). Vertical control points are depicted by identification number.

Table 4: Topographic data sources. The associated root mean square (RMS) error is based on source metadata and NGS control point comparison.

Source	Survey	Year	Spatial Resolution	Horizontal RMS Error based on metadata	Vertical RMS Error based on metadata	Vertical RMS Error based on comparison
LDART	Spring 1998	1998	5 m	0.80 m	0.15 m	0.21 m
LDART	Fall 1997	1997	5 m	0.80 m	0.15 m	0.37 m
David C. Smith & Associates, Inc.	1996	1996	10 m	N/A	N/A	0.77 m
USGS NED	45123h8 46123a8	1973	10 m	15 m	15 m	1.24 m

vertical survey control datasheets were collected from NGS for comparison with each dataset (Fig. 6). Table 4 provides information on each dataset.

The LIDAR surveys were conducted as part of the Airborne Topographic Mapper Mission to cover coastal areas. The data were collected at low tide using a pulsed laser with a wavelength of 550 nanometers. Quality assessment of the survey data is limited to internal consistency checks with filtering to remove outliers of first returns. A detailed analysis of the LIDAR data was made to remove vegetation by selecting points with the highest likelihood of being on the surface. This analysis was conducted using Spatial Analyst and 3D Analyst (Fig. 7b). Rectified orthophotos were used to remove points representing apparent vegetation or structures (Fig. 7c) to create a corrected LIDAR dataset.

The USGS NED DEM was developed in 1999. The dataset was derived using bilinear interpolation of hypsography and hydrography contours based on surveys conducted in 1973. The majority of the Seaside area is below the hypsography contour interval of 25 feet (7.6 m). A comparative analysis of the USGS data with the corrected LIDAR survey data revealed significant differences in these low-lying areas. The USGS DEM was edited to select only those values above the 250-foot contour and outside of the boundary of the available LIDAR data. Further edits were made to contours derived from the USGS DEM to remove boundary discrepancies (Fig. 7d).

David C. Smith and Associates, Inc., developed the 10-meter DEM used in prior tsunami hazard modeling. It was based on 1996 orthorectified aerial photography. DEM values did not compare well with LIDAR or USGS data (Fig. 7e). Comparison with control data along the coast also showed an average error of 3 m. Since little information was available on the development procedure for this dataset, it was not considered a viable input option.

The corrected 1998 LIDAR survey and USGS NED DEM data were selected as final input for the DEM (Fig. 6). LIDAR covered approximately 45% of the project area.

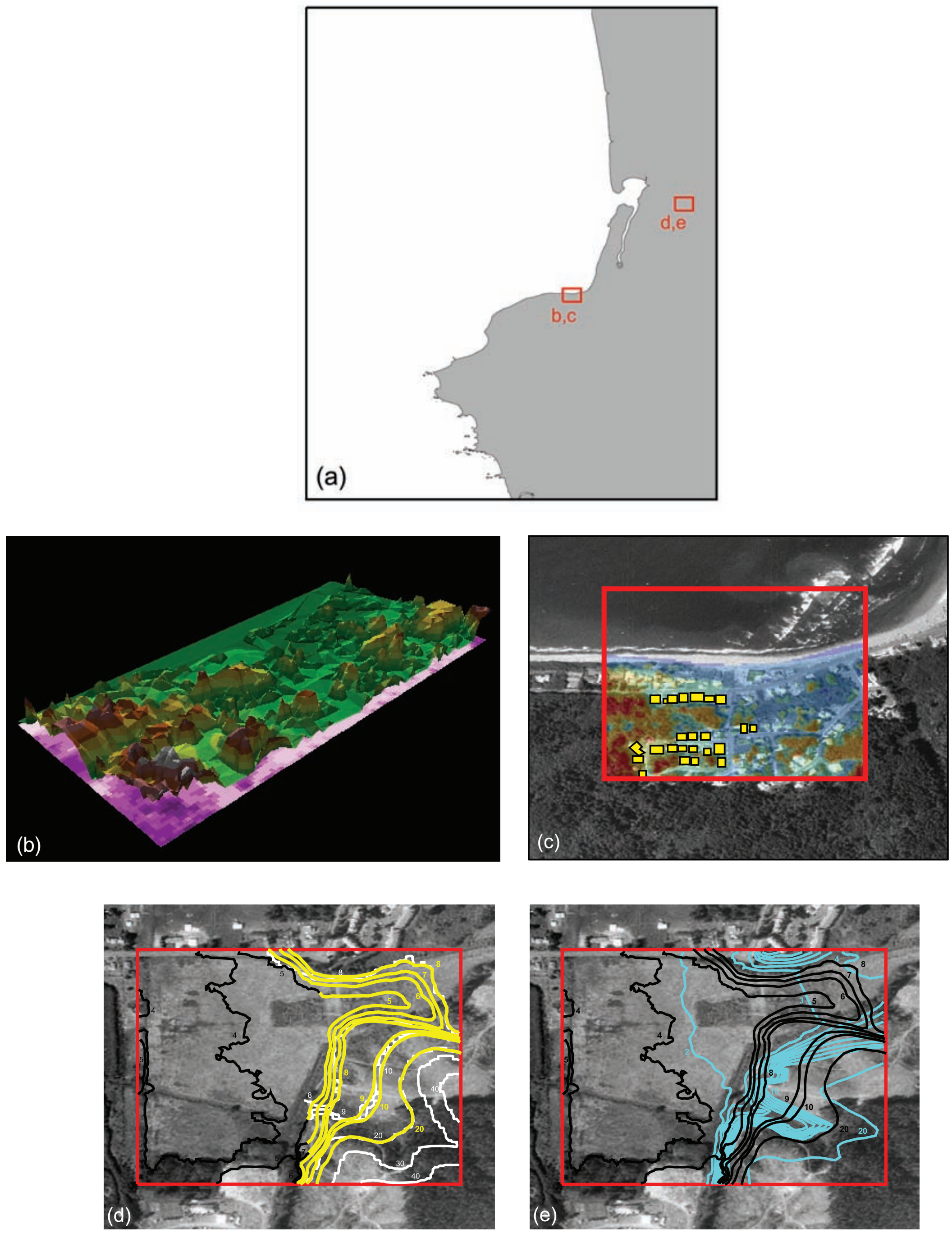

Figure 7: Topographic data analyses. (a) Red boxes depict sample areas as detailed in associated panels. (b) Analysis of LIDAR data using 3D Analyst with 2 m vertical exaggeration. Peaks suggest possible vegetation or infrastructure. (c) LIDAR data is corrected to remove vegetation and infrastructure using orthophotography as a reference. Polygons (yellow boxes) representing buildings are drawn to select and remove data values that do not represent the “bald earth.” (d) Contour comparison of LIDAR (black) and USGS NED (white) data along the boundary of the LIDAR survey. A vector file (yellow) is created to correct disparities between datasets with reference to orthophotography. (e) Contour comparison of corrected data (black) with DEM used in prior tsunami hazard modeling efforts (blue).

3.2 DEM Development

A simple method of Delauney triangulation and natural neighbor interpolation was used to build the DEM. Delauney triangulation, also known as the triangular irregular network (TIN) method, constructs a surface of continuous non-overlapping triangles based on mass points and breaklines. A TIN maintains data values within the range of vertices and will not extend beyond boundaries. Its main disadvantage is the creation of triangular plateaus due to all vertices having the same elevation value. This usually occurs when using contours as an input. The inputs for this study consisted primarily of mass points.

Natural neighbor interpolation helps create a smoother raster grid by using an areal weighting scheme on the nearest TIN vertices to the output raster cell. Other methods such as spline interpolation with tension or inverse distance weighting are also viable options, but were not investigated.

DEM development consisted of three steps: building the bathymetric grid, building the topographic grid, and then merging the two grids into the final DEM (Fig. 8). This process was chosen based on modeler requirements to ensure a definitive distinction between land (positive) and water (negative) values. Zero or near-zero values cause anomalies in the inundation model. Consequently, all land values were restricted to $\geq$0.01 m and all water values to ≤ -0.01 m.

The bathymetric grid was built using selected bathymetric data and the land polygon (with a value of -0.01 m) as input for the interpolation. The resulting grid was clipped to the water polygon. The topographic grid used selected topographic data sources and the water polygon (with a value of 0.01 m) as input and then clipped to the land polygon in the same manner. Spatial analysis was used to find problem areas, which were corrected by re-interpolating after removing anomalous points or adding supplementary points and contours.

The topographic and bathymetric grids were merged into a final DEM and analyzed for consistency. Any null values were set to 0.01 m. The DEM was exported to an ASCII raster grid and distributed to the modeler.

3.3 Quality Assurance

The quality of the DEM is difficult to determine. A number of different factors contribute to cumulative DEM error, including inherent error within the various selected data sources, conversion error, error due to interpolation of spatially varying data sources, and error due to subjective interpretation. An attempt to quantify some of these factors is provided below.

Inherent errors in the data sources are provided in the Data Sources and Processing section. The spatial density of selected bathymetry and topography data show high-density in low-lying and intertidal areas with sparse data offshore (Fig. 9). Offshore values of the DEM are based on interpolation of distant data points, whereas near-shore values are based on data points that support the requested 1/3 arc-second resolution.

Horizontal datum conversions were primarily made using NADCON trans-

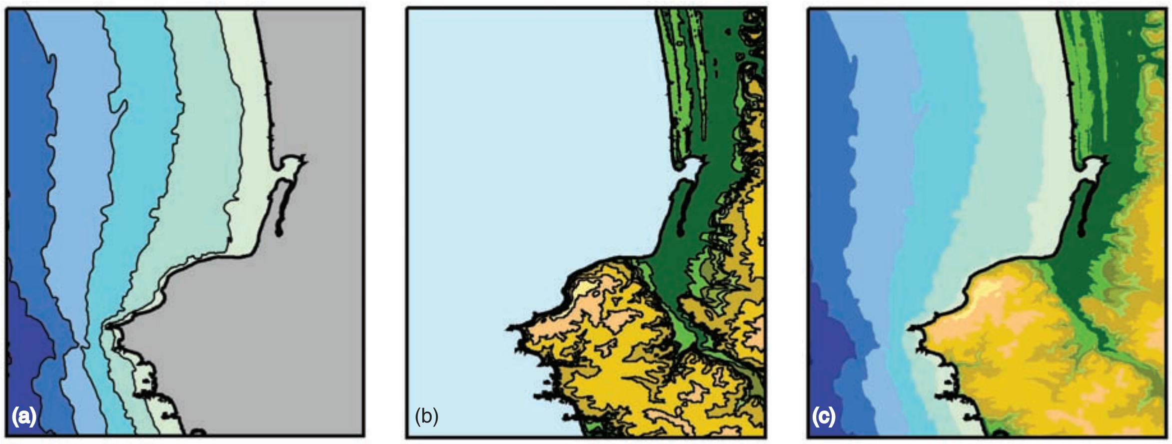

Figure 8: Steps of DEM development: (a) bathymetric grid, (b) topographic grid, and (c) merged grid.

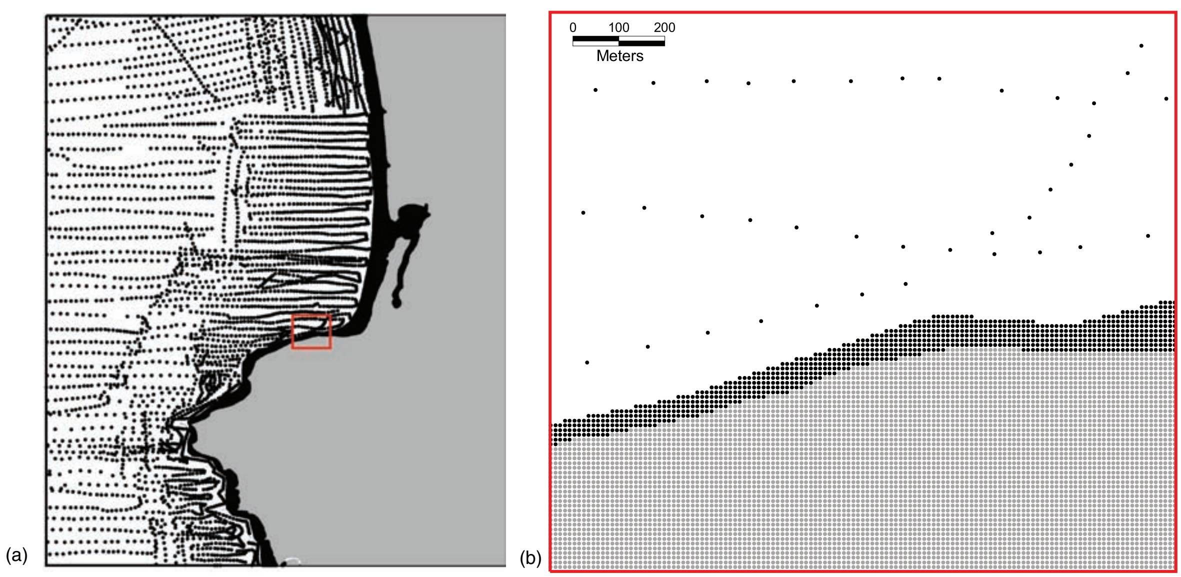

Figure 9: Spatial density distribution. (a) Spatial density of selected bathymetric (black) and topographic (gray) data sources. Red box depicts (b) detailed display of distribution. The topographic data had a much higher density (ranging from 5–10 m) than the bathymetric data (ranging from 5–200 m).

formation, which is based on a minimum-curvature model (Dewhurst, 1990). The conversion from NAD27 to NAD83 introduces uncertainty of 0.15 m at a 67% confidence level. Converting from older North American datums to NAD83 leads to a conversion error of 0.20 m (National Geodetic Survey, 2004).

Converting from a map projection to geographic coordinates also introduces error. A few data sources were in Oregon Lambert Projection or Oregon State Plane Projection. The conversion error for both of these projections is 0.10 m (Snyder, 1987).

Vertical datum conversion based on the interpolation of tidal and geodetic datums obtained from NOS tidal benchmarks produced an error of 0.05 m (Mofjeld *et al.*, 2004). Additional vertical control error was created based on estimating the interaction between the open coast and the Necanicum River estuary. The estuarine region is not well defined (see Bathymetry section 3.1.2); thus, the vertical datum surface (Fig. 2) does not account for the possibility of a deltaic sill affecting tidal circulation. This may add a vertical error of up to 0.35 m within the estuary.

Assessing the quality of the DEM was based on comparison with vertical control and source data. Vertical control data existed only for land elevation values, yielding a RMS error of 0.135 m (Fig. 6, Table 5). A direct difference between bathymetric source data and the DEM yielded a RMS error of 0.01 m.

Subjective interpretation may also introduce error. The construction of shoreline and contours based on disparate sources are two of the primary components that could affect DEM quality. Descriptions of these data provided in the methodology section provide some guidance on the quality of the interpretation.

Table 5: Comparison of NGS vertical control points with the DEM. Average error was 0.404 m with a RMS error of 0.135 m. See Fig. 6 for a spatial display of the control points.

Control Point	Latitude	Longitude	Control Elevation (m)	DEM Elevation (m)	Absolute Difference (m)
AA3536	−123.929722	45.993056	8.210	7.715	0.495
RD1141	−123.929551	45.995082	7.297	6.990	0.307
RD1422	−123.924444	45.989167	5.490	5.374	0.116
RD1423	−123.926111	45.981944	6.074	5.992	0.082
RD4368	−123.923333	45.988056	5.640	5.232	0.408
SC0609	−123.914167	46.060278	8.152	8.923	0.771
SC0611	−123.916698	46.056681	20.911	20.494	0.417
SC0617	−123.920805	46.028119	11.834	11.754	0.080
SC0618	−123.920833	46.027778	9.562	9.881	0.319
SC1034	−123.913889	46.047778	6.190	6.764	0.574
SC1035	−123.915000	46.035556	6.964	8.292	1.328
SC1036	−123.911667	46.023333	7.095	7.043	0.052
SC1037	−123.913889	46.009444	4.164	4.185	0.021
SC1038	−123.920833	46.001111	6.103	5.683	0.420
SC1041	−123.925000	46.001389	5.362	4.697	0.665

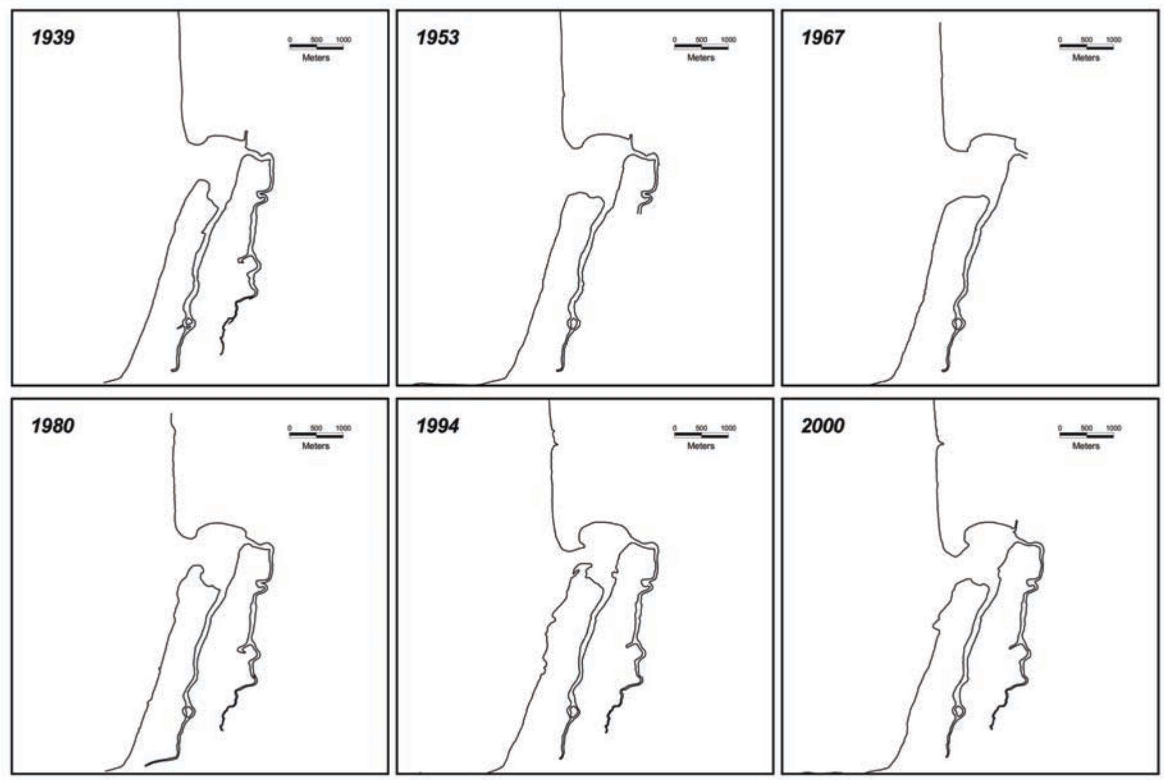

Figure 10: Historical shoreline depicting the apparent Mean High Water line based on orthophotography obtained from the University of Oregon. The northern outer coast has an accretion rate of approximately 45 meters every 14 years. The southern outer coast varies little over the same period.

3.4 Historical shoreline analysis

The discovery of significant shoreline differences with source data and recent aerial photography from 1996 and 2000 led to an analysis of historical shoreline for the Seaside area. Past aerial photographs were obtained from the University of Oregon. Apparent mean high water and mean lower low water were digitized and georeferenced in ArcGIS©.

The resulting files show a very dynamic shoreline pattern likely due to the Seaside area residing within the Columbia River littoral cell. A general trend of accretion averaging 3.2 m/y on the outer coast north of the Necanicum River mouth is apparent (Fig. 10). These values nearly match the historical accretion rates of the Clatsop Plains sub-cell, which averages 3.3 m/y (Woxell, 1998).

There is also a cyclic pattern seen within the Necanicum River mouth (Fig. 11). The northern extent of the mouth shows an accretion rate of approximately 7 m/y since 1939. The southern extent varies between accretion and erosion over an estimated 15-year cycle. Over 55 years, the mouth span ranged from 300–800 m width.

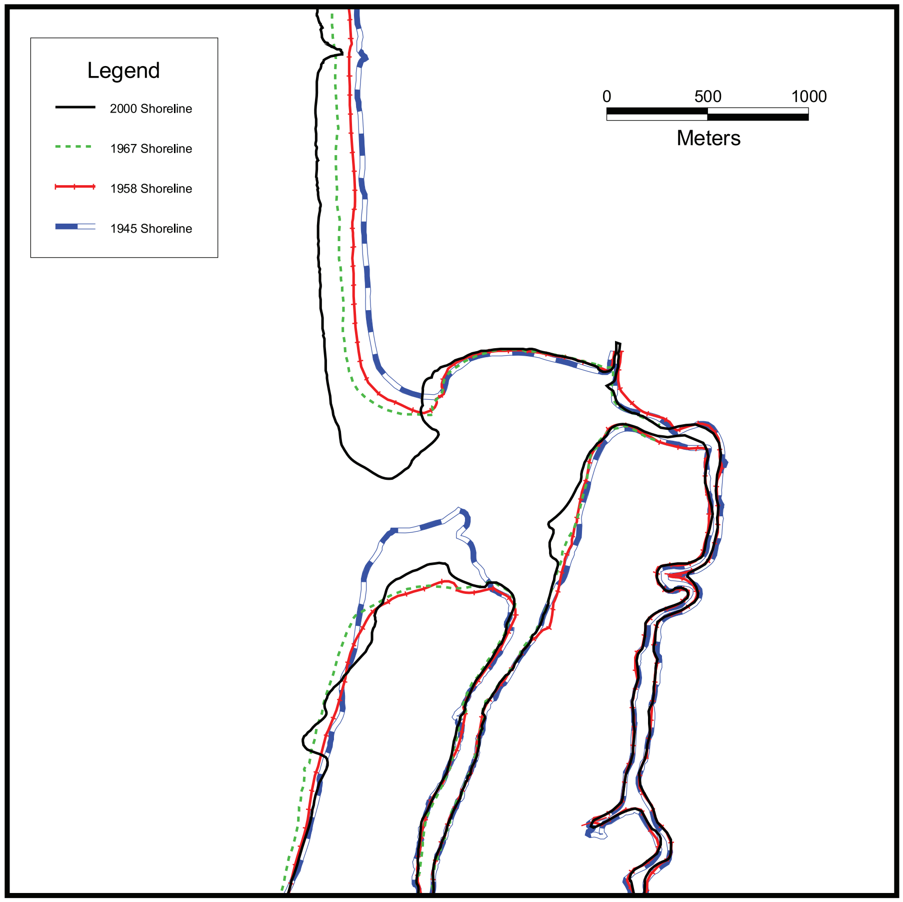

Figure 11: Accretion and erosion trends of the Necanicum River mouth over a 55-year period.

4. Summary and Conclusions

A digital elevation model consisting of merged bathymetry and topography and covering the Seaside, Oregon region was built for use in a tsunami inundation model as part of a FEMA FIRM Pilot Study. The DEM consisted of disparate data sources from various Federal, State, and local agencies. Data were collected and processed according to requested parameters. Best available data were selected as input for the grid. A simple interpolation method based on Delauney triangulation and a natural neighborhood filter was used to build the DEM.

The DEM was analyzed for quality by making comparisons with input data sources and vertical control points. Total DEM error is difficult to quantify due to subjective factors in development; however, an estimated total error range is provided in Table 6. The methodology described in this report helps provide a qualitative assessment of the DEM.

The DEM provides a snapshot of a dynamic region. Varying shoreline

Table 6: Estimate of total DEM error. These estimates are based on a quantitative assessment of the DEM. The total error is sum of the quantitative values. Subjective interpretation adds unknown error to the DEM.

Error Type	Horizontal Error Range (meters)	Vertical Error Range (meters)
Projection/Datum conversion	0.35–0.45	0.05–0.40
Comparison with vertical control		0.14–1.33
Comparison with original data sources	0.80–10	0.01–1.24
Total known quantitative error	1.15–10.45	0.20–2.97

patterns may affect maximum credible tsunami inundation. Further analysis and subsequent updates are necessary to ensure accurate tsunami hazard assessments.

The inherent uncertainty based on disparate data sources and the dynamic nature of the shoreline led to a set of recommendations to improve the DEM. These recommendations are listed below in no particular order:

- New bathymetric multibeam surveys should be conducted for the Necanicum River and the offshore region of northern Oregon. This could significantly reduce error in the DEM by providing greater spatial density and better information on the current state of the seafloor.

- Recent 2002 LIDAR surveys should be used to update the topography and intertidal zone. Given the dynamic nature of the shoreline, these data could also be used to further analyze Columbia River littoral exchange patterns. Ideally, data with vegetation already removed would be available to reduce processing time.

- A high-resolution tidal model to explore the tidal relationship between the Necanicum River estuary and open ocean should be developed. Tertiary tide gages should be installed to provide a recent observational record of current tidal trends, thereby reducing vertical datum conversion errors.

- The latest orthophotos and high-resolution vectors representing Mean High Water to more accurately depict the shoreline should be obtained. New false-color orthoimagery is being collected by the State of Oregon (Oregon Geospatial Enterprise Office, 2005).

- Different interpolation schemes should be tested to assess the best method for the inundation model.

5. Data Credit

David C. Smith and Associates, Inc. (1996): 10-meter DEM. Portland, Oregon.

NOAA Coastal Services Center (2004): Aircraft Laser/GPS Mapping of Coastal Topography, LDART. Charleston, South Carolina. `http://www.csc.noaa.gov/lidar/`

NOAA National Geodetic Survey (2004): Vertical Geodetic Control Data. Silver Spring, Maryland. `http://www.ngs.noaa.gov/`

NOAA National Geodetic Survey (2004): OR43C04 1926 Shoreline, Shoreline Data Explorer. Silver Spring, Maryland. `http://www.ngs.noaa.gov/newsys_ims/shoreline/`

NOAA National Geophysical Data Center (2002): NOS Hydrographic Database, GEODAS Version 4.1.18. Boulder, Colorado. `http://ngdc.noaa.gov/`

NOAA National Ocean Service (2004): Regional Water-Level Station Benchmarks. Silver Spring, Maryland. `http://tidesandcurrents.noaa.gov/benchmarks/`

Oregon Bureau of Land Management (2001): Oregon Watershed Boundaries. Portland, Oregon. Data obtained through the Oregon Geospatial Data Clearinghouse. `http://www.gis.state.or.us/`

USGS EROS Data Center (1973): Hydrographic Vectors. Sioux Falls, South Dakota. Data obtained through the Oregon Geospatial Data Clearinghouse. `http://www.gis.state.or.us/`

USGS EROS Data Center (1999): National Elevation Dataset. Sioux Falls, South Dakota. `http://gisdata.usgs.net/ned/`

USGS National Aerial Photography Program (2002): 2000 Digital Orthophoto Quads. Reston, Virginia. Data obtained through the Oregon Geospatial Data Clearinghouse. `http://www.gis.state.or.us/`

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References

Carter, D.J.T. (1980): Echo-Sounding Correction Tables, third edition. Hydrographic Department, Ministry of Defence, Taunton Somerset.

Clatsop County (2005): Clatsop County Community Profile. Clatsop County Community Development, Astoria, Oregon.

Dewhurst, W.T. (1990): NADCON—The application of minimum-curvature-derived surfaces in the transformation of positional data from North American Datum of 1927 to the North American Datum of 1983. NOAA Tech. Memo. NOS NGS-50, National Ocean Survey, 30 pp.

Fiedorowicz, B.K. (1997): Geologic evidence of historic and prehistoric tsunami inundation at Seaside, Oregon. M.S. thesis, Portland State University.

González, F.I., E. Geist, C. Synolakis, and V.V. Titov (2004): Probabilistic tsunami hazard assessment: the Seaside, Oregon pilot study. In *2004 Fall AGU Conference Proceedings*, OS22B-04.

González, F.I., V.V. Titov, H.O. Mofjeld, A.J. Venturato, R.S. Simmons, R. Hansen, R. Combellick, R.K. Eisner, D.F. Hoirup, B.S. Yanagi, S. Yong, M. Darienzo, G.R. Priest, G.L. Crawford, and T.J. Walsh (2005): Progress in NTHMP hazard assessment. *Nat. Hazards*, *35*(1), 89–110.

Mofjeld, H.O., A.J. Venturato, F.I. González, and V.V. Titov (2004): Background tides and sea level variations at Seaside, Oregon. NOAA Tech. Memo. OAR PMEL-126, NOAA/Pacific Marine Environmental Laboratory, 15 pp.

National Geodetic Survey (2004): NADCON Version 2.10 Documentation. Boulder, CO.

National Geophysical Data Center (2004): *GEODAS Help Manual*. National Geophysical Data Center, Marine Geology and Geophysics Department, Boulder, CO.

Oregon Geospatial Enterprise Office (2005): 2005 Orthoimagery Update. `http://www.oregon.gov/DAS/IRMD/GEO/`.

Oregon Natural Heritage Program (1999): Oregon GAP analysis project—A geographic approach to planning for biological diversity. Oregon Department of Fish and Wildlife, Portland, OR, 168 pp.

Oregon Ocean-Coastal Management Program (2000): Oregon Coastal Atlas. `http://www.coastalatlas.net/`.

Priest, G.R., E. Myers, A. Baptista, R.A. Kamphaus, B.K. Fiedorowicz, C.D. Peterson, and T.S. Horning (1998): Tsunami Hazard Map of the Seaside-Gearhart Area, Clatsop County, Oregon. IMS-3, Scale 1:12,000, Oregon Department of Geology and Mineral Industries, Portland, OR.

Snyder, J.P. (1987): Map Projections—A working manual. USGS Professional Paper 1395, 383 pp.

USDA Natural Resources Conservation Service (1994): Soil survey of Clatsop County, Oregon, OR007. U.S. Department of Agriculture, Portland, OR, 189 pp.

Woxell, L.K. (1998): Prehistoric beach accretion rates and long-term response to sediment depletion in the Columbia River Littoral System, USA. M.S. thesis, Portland State University, Portland, OR, 113 pp.