NOAA Technical Memorandum NOS CS 4

VDATUM FOR PUGET SOUND: GENERATION OF THE GRID AND POPULATION WITH TIDAL DATUMS AND SEA SURFACE TOPOGRAPHY

Silver Spring, Maryland
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noaa National Oceanic and Atmospheric Administration

U.S. DEPARTMENT OF COMMERCE
National Ocean Service
Coast Survey Development Laboratory

Office of Coast Survey
National Ocean Service
National Oceanic and Atmospheric Administration
U.S. Department of Commerce

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VDATUM FOR PUGET SOUND: GENERATION OF THE GRID AND POPULATION WITH TIDAL DATUMS AND SEA SURFACE TOPOGRAPHY

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ABSTRACT

The generation and population of the VDatum tidal grid for Puget Sound, Washington, is discussed. The VDatum grid has a spacing of approximately 0.1 nautical miles. Points in the grid are first determined to be either land or water, depending on their location relative to a digitized coastline. Land points are given null values. For water points, the tidal datum fields are searched to provide a value. The tidal datum fields were generated by spatial interpolation, taking land-water boundaries into account, of datum values at 69 historical stations. The sea surface topography, or difference between local mean sea level and the NAVD 88 geopotential surface, is generated by a minimum curvature algorithm using data at 11 tide stations.

Key Words: tides, tidal datums, Puget Sound, North American Vertical Datum of 1988, mean sea level, spatial interpolation, coast line.

1. INTRODUCTION

The National Ocean Service (NOS) is developing a vertical datum transformation tool called VDatum (Milbert, 2002; Parker, 2002). For previous VDatum grids (Hess, 2001), a tide model was used to determine which VDatum points represented water and which represented land. If a Vdatum point was within a specified distance from a tidal data point, the point was considered to be water, and the datum values for that point were taken from the tide model. However, points in water areas where there were no tidal values were left unfilled. A new approach for the generation and population of the VDatum grid is described herein and applied to Puget Sound. In the new approach, the VDatum grid points are first determined to be land or water, based on their relationship to the digitized coastline, and then the tidal data are searched for a value.

2. TIDAL DATUM FIELDS

Tidal datum fields for Puget Sound, Washington, were generated on a 0.125 nautical miles (nmi) tidal grid using TCARI (Hess, 2002; 2003). The grid was generated using NOAA's National Geophysical Data Center's (NGDC's) digitized, high-resolution shoreline. The method for generation of the datum fields is discussed in Hess and Gill (2003) (see Appendix A), but the final tidal datum fields described here were re-generated using tidal values updated by NOS' Center for Operational Oceanographic Products and Services (CO-OPS) to the most recent National Tidal Datum Epoch, 1983-2001 (see Appendix B).

3. DIGITIZED SHORELINE

Initially, the NGDC shoreline was used (as it was for the tidal datum fields) to create the VDatum grid. However, a more recent digitized shoreline is available from CSDL's Extracted Vector Shoreline (EVS) project. The new shoreline differs from the older shoreline (Figure 1) due to physical changes in the coast and because newer charts have been updated using geographical positions revised using GPS. Both sets of data use the NAD 83 horizontal datum.

The EVS shoreline for Mean High Water (MHW) from NOS Chart 18440 ('Puget Sound'), valid for 2002, was reformatted (using rd_evs.f), and subject to the concatenation process (using concat.f) to connect short line segments. This shoreline is shown in Figure 2. In the EVS data file, geographic positions are in decimal degrees, with six places to the right of the decimal point, and line segments are separated by records containing two zeros. Notice that chart borders were included as 'coastline' in the EVS for this chart, as were some bridges. A digitized Mean Lower Low Water (MLLW) shoreline is also available.

Since the original shoreline data contained numerous small lakes, which were not needed for the project, they were manually removed to create a new digitized shoreline. That shoreline is shown in Figure 3.

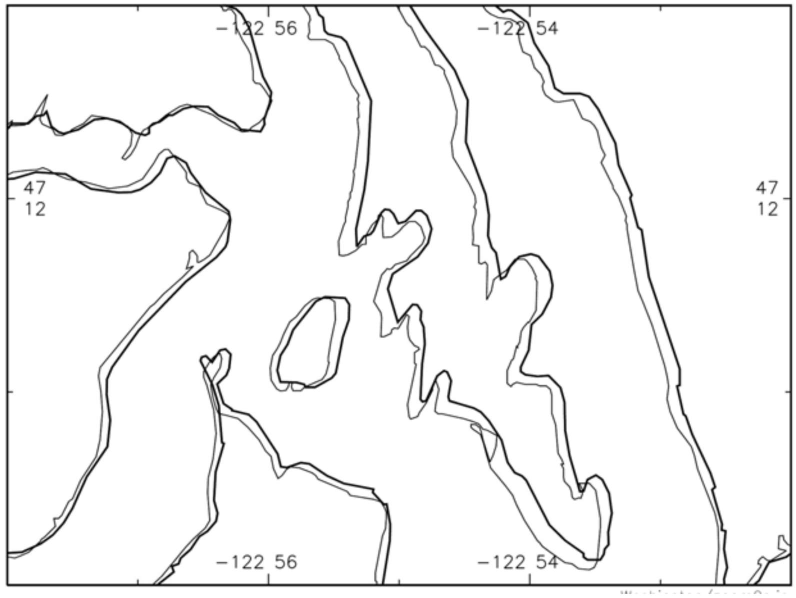

Figure 1. Sample coastline in Puget Sound showing the NGDC shoreline (thin line) and the newer, EVS shoreline (thick line). In this figure, the maximum difference in position is approximately 0.1 nmi.

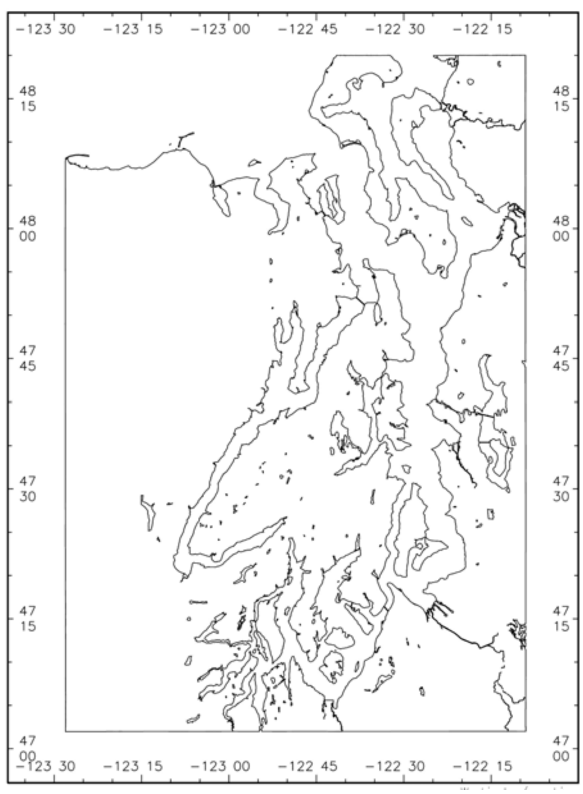

Figure 2. Initial Puget Sound EVS shoreline for MHW as extracted from NOS Chart No. 18440. Note the presence of numerous small lakes; the next figure shores the revised EVS shoreline with the lakes removed.

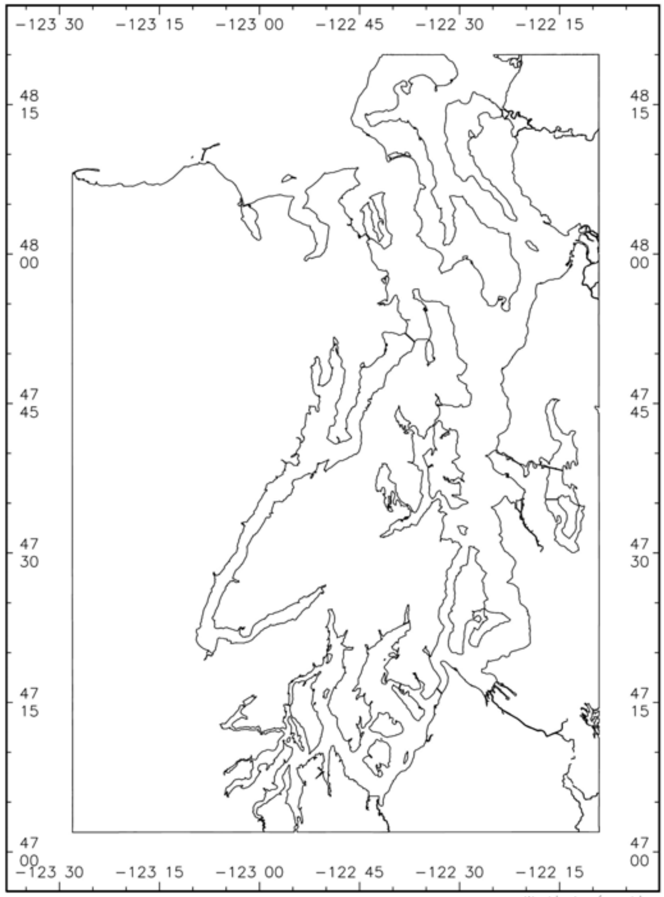

Figure 3. Digitized shoreline for Puget Sound from NOS Chart No. 18440, revised to exclude lakes.

The next step was to create the 'mainland' polygon, a single, continuous, closed (i.e., with matching end points) line segment that encloses all the land area in the chart except for islands. The mainland polygon (Figure 4) is used as a reference landmass when determining whether other closed line segments are islands or lakes. The polygon was created in several steps. The first step was to manually remove the bridges in the EVS that created a discontinuous body of water for the Sound. The bridges were in the Hood Canal at Port Gamble, in the lower Sound at Tacoma, and at Bremerton. The removal was accomplished by inserting new segment end points, removing the points representing the bridges, and re-concatenating the resulting segments. Several other bridges were allowed to remain since they connected small islands with the mainland and did not cut off embayments from the Sound proper.

Following the removal of bridges, the next step was to move the southern chart boundary line further south and the eastern chart boundary line further east. The main problem with these boundaries was that some rivers, which themselves are part of the shoreline, intersected the boundaries (Figure 5), thereby creating a discontinuity along a border. The segments of these rivers closest to the boundaries were removed, and then the borders were moved down and to the right. The resulting mainland polygon is shown in Figure 4.

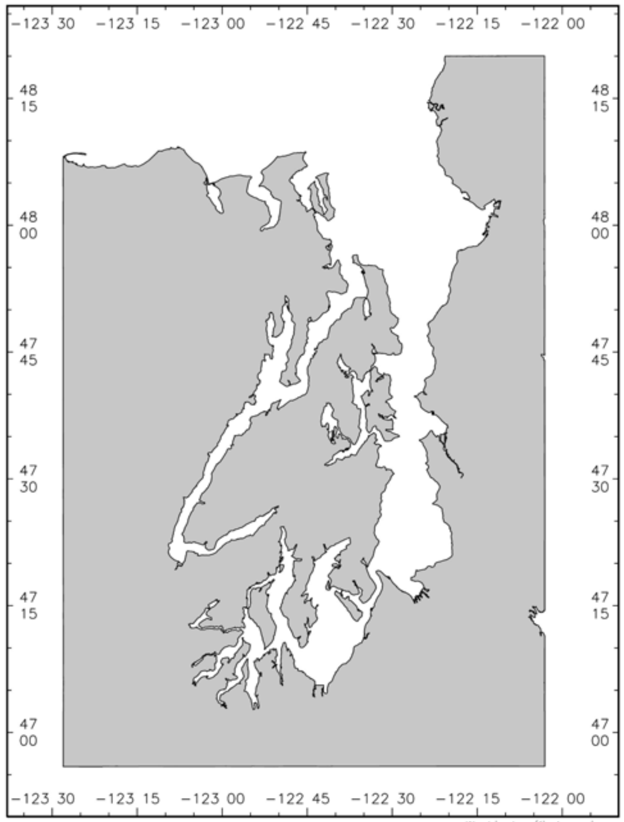

Figure 4. The mainland polygon as formed by a closed boundary segment.

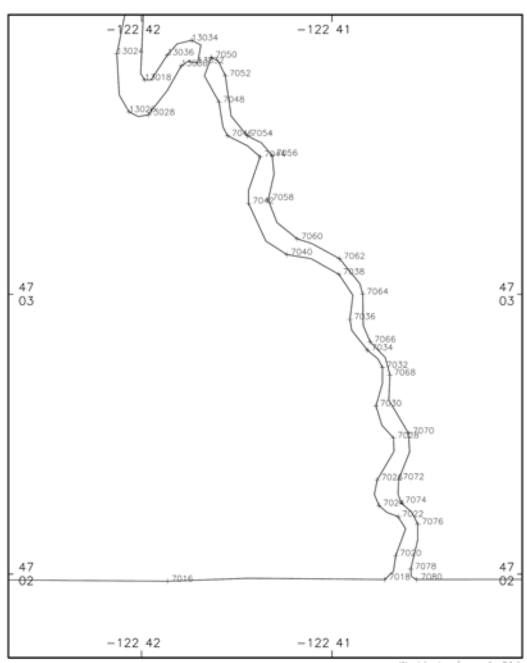

Figure 5. Line segment with numbered points that defines a river intersecting the chart border.

The final step was to search the coastline file to identify islands and any remaining lakes using the mainland polygon. The points defining the mainland polygon were renumbered so that the points appear in counterclockwise (CCW) order (using program landolakes.f). Each remaining closed line segment was analyzed as follows. For the latitude of a point in the segment, the closest point at the same latitude in the mainland polygon was found. Since the mainland polygon's points are numbered CCW, the orientation of the mainland polygon indicates whether the segment is inside or outside the mainland polygon. If the line segment is inside the mainland polygon, it must enclose water (i.e., be a lake); if outside, the line segment must enclose land (i.e., be an island).

4. THE BOUNDING POLYGON

Points in the VDatum grid were further constrained by allowing water, or non-null, tidal values only within a bounding polygon. The bounding polygon can be used, for example, to exclude tidal areas that may be within the coastline rectangle but for which no tidal data are available. The bounding polygon created for the Puget Sound region is shown in Figure 6.

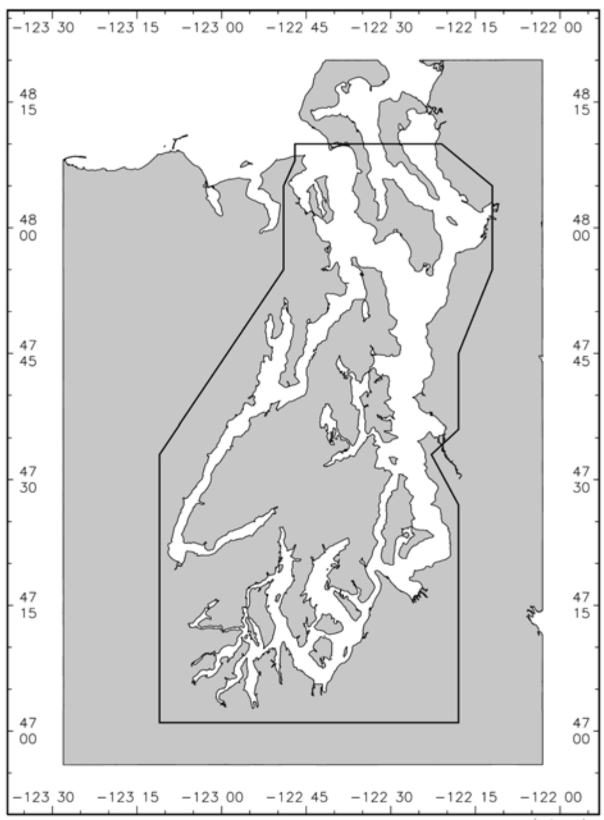

Figure 6. Bounding polygon (solid line) and mainland polygon (gray area) for Puget Sound.

5. VDATUM GRID POINTS

The VDatum grid for the Puget Sound area was generated by a new program, vgridder.f, which is a modification of the TCARI grid program pa.f. Here, the grid origin is at $latitude_0$ and $longitude_0$, and extends to $latitude_1$ and $longitude_1$. The longitudinal spacing between points is *delx*, and the latitudinal spacing is *dely*. The VDatum grid consists of points as defined by

$$longitude_i = longitude_0 + (i - 1)*delx$$

$$latitude_j = latitude_0 + (j - 1)*dely$$

where the index *i* denotes longitude and index *j* denotes latitude. The range of *i* is 1 to *imax* and the range of *j* is 1 to *jmax*, where

$$imax = (longitude_1 - longitude_0)/delx$$

$$jmax = (latitude_1 - latitude_0)/dely$$

For Puget Sound, the grid origin is at $latitude_0$ = 47.0167 (47° 1' N), $longitude_0$ = -123.1833 (123° 11' W). The upper right corner is at $latitude_1$ = 48.1833 (48° 11' N), $longitude_1$ = -122.1667 (122° 10' W). The spacing between points is *delx* = 0.0025 deg, *dely* = 0.0018 deg. This results in a distance between points of approximately 200 m (0.1 nmi).

Each point in the VDatum grid is designated as being either a null point (i.e., having no valid tidal datum transfer values) or a non-null point. Several steps were required to make that determination. Note that for the following discussion, an 'A cell' is defined as the rectangular area, centered on a VDatum grid point, whose corners are the centers of the four surrounding 'B cells' (Figure 7). A B cell is defined as the rectangular area whose corners are VDatum points.

In the first step in identifying null and non-null points, each point is checked to determine whether it lies within the bounding polygon. Then, if it does, the A cell in the VDatum grid is checked for the possibility of containing shoreline. Specifically, if any point along the border of the A cell lies within the water area, the VDatum point is designated as water, or non-null. This means that a VDatum point can lie a distance as much as *½delx* or *½dely* on the land side of the shoreline and still be considered to in the water.

Next, all B cells are checked to determine whether at least one corner is an non-null point; if so, then the B cell is considered to be water. Then, if a VDatum point is surrounded by four water B cells, that point is made non-null. Finally, one or more layers of water cells can be added to the B cells, and non-null VDatum points subsequently added if they are surrounded by water B cells.
A sample of the VDatum grid with no added layers is shown in Figure 8, and the final grid for the entire Puget Sound area is shown in Figure 9.

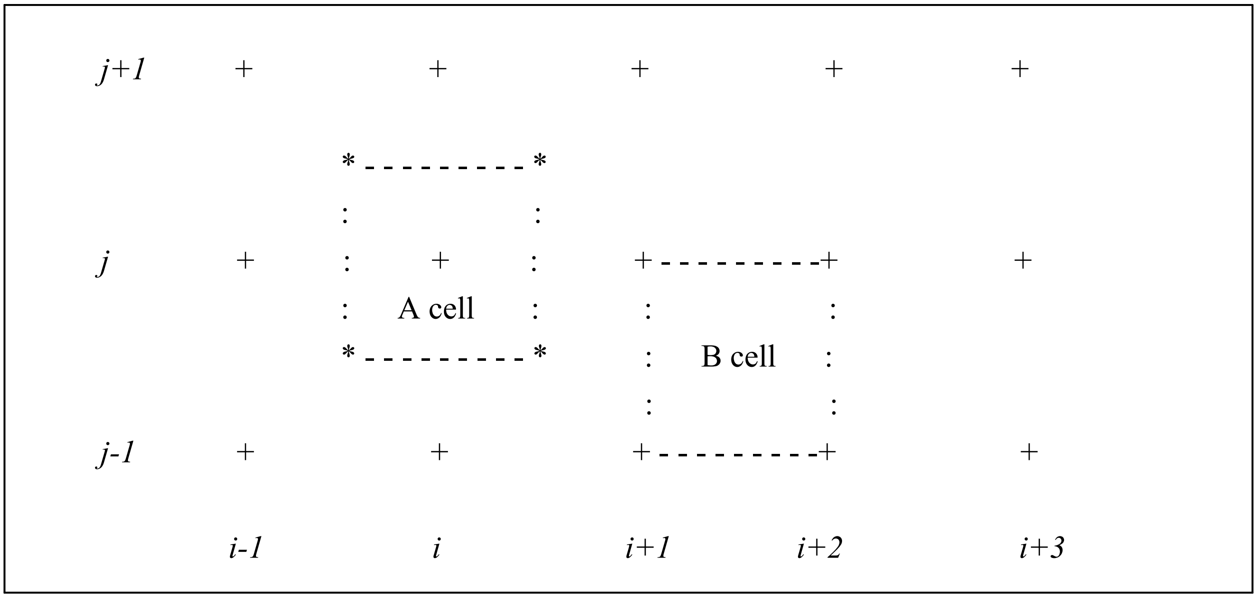

Figure 7. Schematic showing the VDatum grid points (+ symbols), an 'A cell' and a 'B cell'. The A cell is centered on the VDatum grid point, while the corners of the B cell are the VDatum points. The symbol * denotes a corner of an A cell, *i* is the longitude index, and *j* is the latitude index.

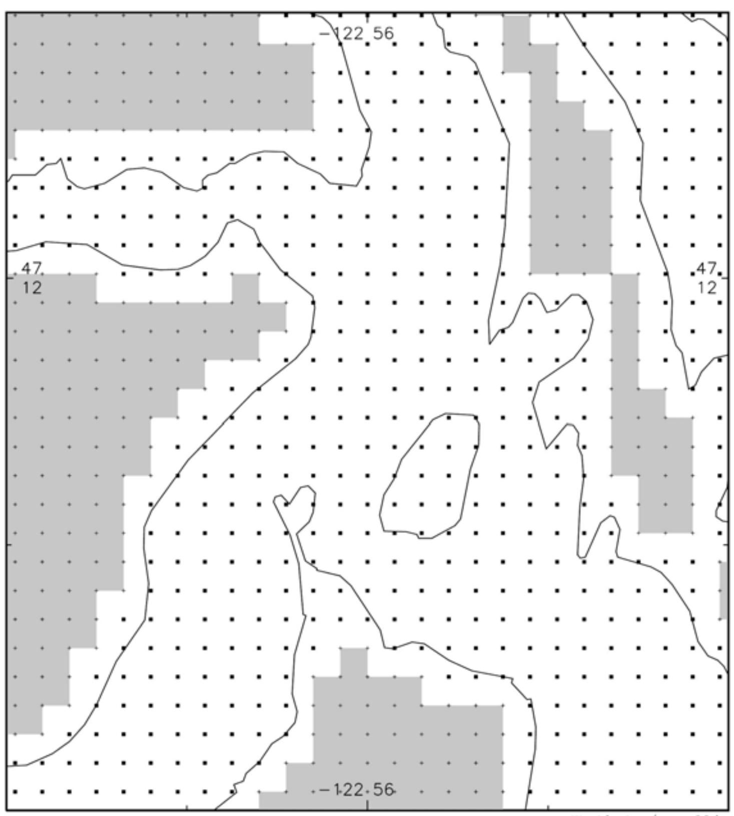

Figure 8. Portion of the VDatum grid for Puget Sound. The small dark squares show locations of non-null values and the '+' symbols show locations of null values. The curved line shows the MHW coastline, white areas show water (i.e., locations where a non-null tidal datum value will be found), and gray areas are land.

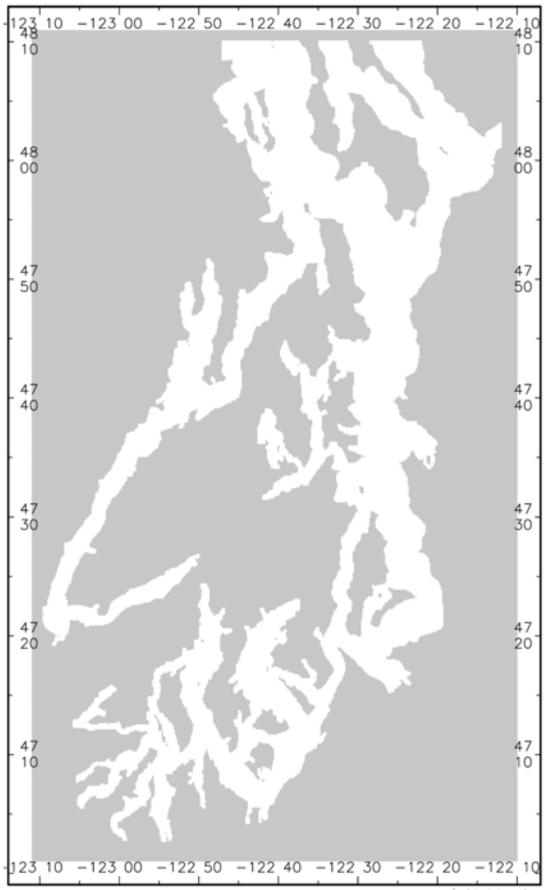

Figure 9. VDatum grid points for Puget Sound. The areas with null values are shown in gray, and the areas covered by non-null tidal datum values are shown as white within the gray area.

6. POPULATION OF THE VDATUM GRID WITH TIDAL DATUMS

The VDatum grid was populated (using the program vpop.f) with tidal datums using the fields previously generated using TCARI. For each non-null point in the VDatum grid, the tidal datum values within a circle of user-specified radius (here 0.02 deg) are selected and a weighted mean (using the inverse distance squared) is computed. After the non-null points are filled in the above manner, a search is made for unfilled points. For these locations, the datums from an adjacent, filled non-null point are used.

The input tidal datums are referenced to mean sea level (MSL). The output files, which are also referenced to MSL, are for the datums of mean higher high water (MHHW), MHW, mean low water (MLW), MLLW, mean tide level (MTL) and diurnal tide level (DTL).

7. COMPARISON OF VDATUM GRIDDED VALUES WITH OBSERVED DATUMS

Comparisons were made (using the program cp.f) of the tidal datum values for MHHW, MHW, MLW, and MLLW obtained from the VDatum gridded files and the datum values at both the water level stations and at the benchmarks. Both a root mean squared error (RMSE) and a standard deviation (SD) were computed for the four values at each location.

For the water level stations, the datums from the TideSheet052 file (Hess and Wilson, in prep.) that were available for generating the tidal datum fields were used (Appendix B). The comparison at 68 stations show a mean RMSE of 0.2 cm and a mean SD of 0.2 cm (Appendix C). The maximum RMSE, 2.9 cm, and maximum SD, 2.7 cm, occurred at the same location: station 9445293 at Pleasant Harbor on Hood Canal. Pleasant Harbor was too small a feature to be included in the tidal datum grid, so tidal datum values there were taken from adjacent VDatum points.

For the datums at the benchmarks, data from NGS were used. Note that the new method of generating the VDatum grid locations allows for non-null VDatum points to occur on land that is within a small distance (about equal to the grid point spacing) of the shoreline. The comparison at 67 locations show a mean RMSE of 0.6 cm and a mean SD of 0.6 cm (Appendix D). The maximum RMSE, 6.6 cm, and maximum SD, 2.6 cm, occurred at the same location: station 9444900 (or PID of TR0559) at Port Townsend. These errors apparently are due to the presence of older tidal data in the NGS database.

8. SUMMARY OF THE VDATUM GRID GENERATION PROCESS

The following table summarized the process of generating the grid and populating the grid with tidal datum values.

Table 1. Summary of steps in production of the VDatum grid.

Step	Action	Computer Program
1	Obtain digitized shoreline (preferably EVS)	rd_evs.f
2	Concatenate shoreline	concat.f
3	Clean up segments	clean.f
4	Remove bridges	-
5	Make closed, long segment	-
6	Make CCW, Remove Lakes	landolakes.f
7	Create bounding polygon	-
8	Create grid points	vgridder.f
9	Fill points with tidal datum values	vpop.f
10	Compare with CO-OPS and NGS data	cp.f

9. GENERATION OF THE GRIDDED TOPOGRAPHY OF THE SEA SURFACE

VDatum uses a gridded Topography of the Sea Surface (TSS), which is the elevation of the North American Vertical Datum 1988 (NAVD 88) relative to local mean sea level (LMSL). The TSS required orthometric height relationships for the NOAA tide stations where elevation information has been compiled. The tide stations and associated elevation information used in the computation of the TSS are presented in Table 2. The average NAVD 88-to-MSL offset was -1.291 m, and the maximum difference in the offset values 0.17 m. All data are based on the most recent National Tidal Datum Epoch (1983-2001). A positive value means that the NAVD 88 reference value is further from the center of the Earth than the local mean sea-level surface. The values in the table show that the southern Sound (Tacoma, 9446484), MSL sits above NAVD 88 by 1.356 m, and in the northern Sound (Port Townsend, 9444900), MSL sits above NAVD 88 by 1.185 m. This difference probably reflects the fact that the southern Sound contains fresher, and therefore, less dense water, and so must have a higher sea surface to maintain a horizontal pressure balance.

Table 2. Location and elevation information for NOAA tide stations.

Station Number	Latitude	Longitude	LMSL	NAVD 88	NAVD 88 -LMSL
9446969	47.0600	-122.9033	2.546	1.227	-1.319
9445958	47.5617	-122.6233	2.080	0.769	-1.311
9447110	47.5850	-122.3617	2.028	0.727	-1.301
9447130	47.6050	-122.3383	2.023	0.715	-1.308
9445133	47.7483	-122.7267	1.978	0.728	-1.250
9447427	47.8133	-122.3833	1.959	0.637	-1.322
9444900	48.1117	-122.7583	1.522	0.337	-1.185
9446484	47.2667	-122.4133	2.094	0.758	-1.336
9447659	47.9800	-122.2233	1.976	0.620	-1.356
9449424	48.8633	-122.7583	1.610	0.293	-1.317
9444122	48.1400	-123.4133	1.282	0.097	-1.185

A continuous surface (Figure 10) was produced by the minimum curvature interpolation method (Smith and Wessel, 1990), using data at the 11 tide stations in Table 2. This method creates a surface that honors the data as closely as possible. The grid point locations are the same as those used for the tidal datums. The maximum residuals value used was 0.00005 meters, and to control the amount of bowing on the interior and at the edges of the grid, internal and boundary tensions of 0.3 were utilized. The mean difference between the derived TSS grid and values at the tidal benchmarks where known relationships exist was 0.001 meters. It should be noted that tide stations leveled in NAVD 88 were not available in Hood Canal. Therefore, caution should be taken in using the TSS field in this area.

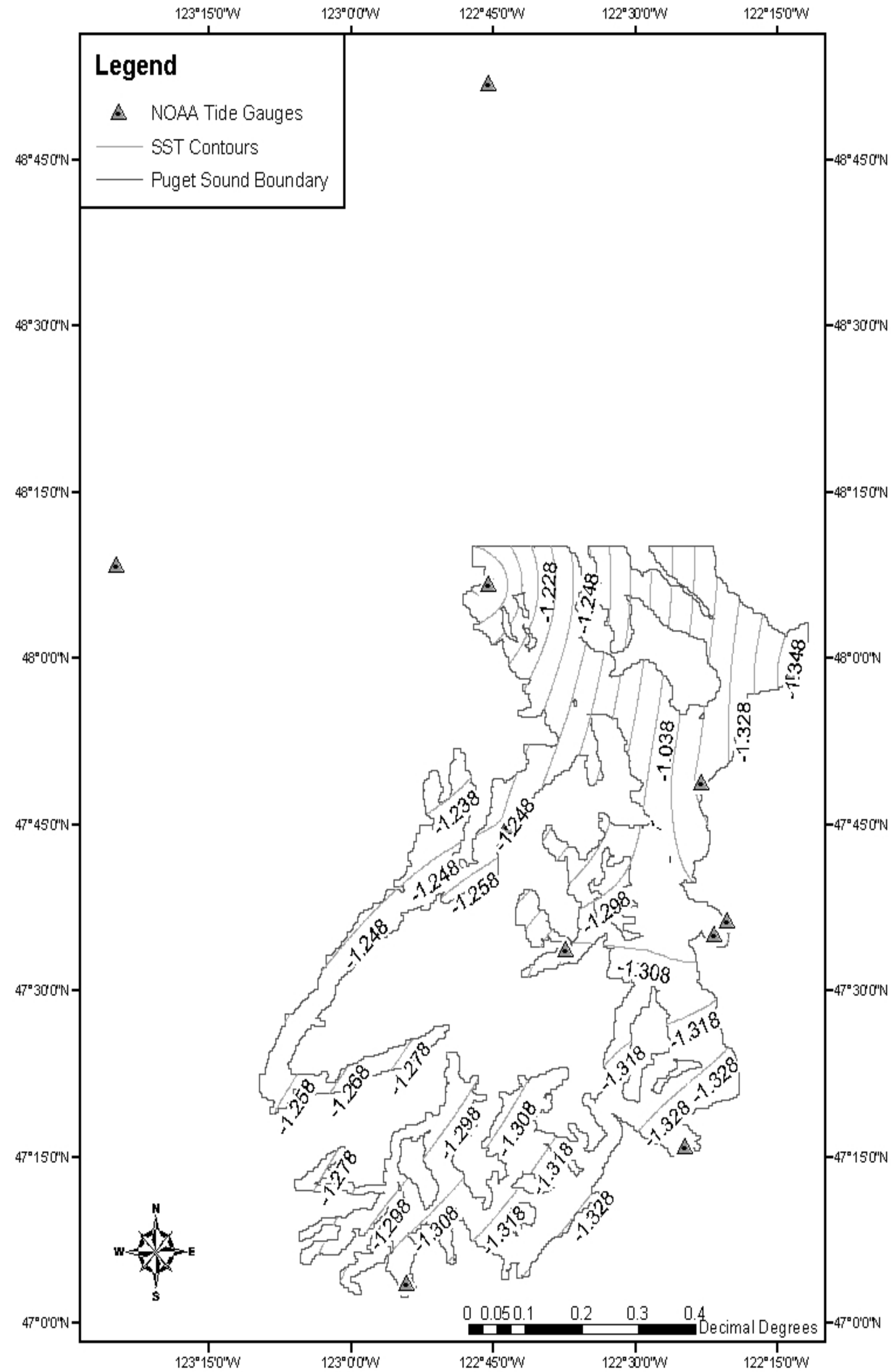

Figure 10. The TSS field (m) for Puget Sound and the locations of the tide stations (denoted by filled triangles) used to generate the field of values.

ACKNOWLEDGEMENTS

Digital coastline was provided by CSDL's Annie Raymond, working in the Extracted Vector Shoreline project begun by CSDL's Roger Johnson. Dennis Milbert of NOS' National Geodetic Survey (NGS) provided insights into generating, populating, and testing the VDatum grid, and provided NGS benchmark data.

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APPENDIX A. COPY OF AMS PAPER

6.1 PUGET SOUND TIDAL DATUMS BY SPATIAL INTERPOLATION

Kurt W. Hess* and Stephen K. Gill, National Ocean Service, NOAA

1. INTRODUCTION

The National Ocean Service (NOS) of the National Oceanic and Atmospheric Administration (NOAA) requires tidal datum information such as mean high water (MHW) and mean lower low water (MLLW) to support nautical charting, navigational safety, shoreline photogrammetry, and marine boundary determination. In addition, tidal datum information is needed for referencing NOS' bathymetric data (which is referenced to MLLW) to any one of the other vertical elevation reference systems. A software tool under development at NOS called VDatum (Milbert, 2002) is designed to transform among approximately 30 vertical reference datums. To be applicable over coastal waters, VDatum requires tidal datum fields, where the field describes the two dimensional, horizontal variability of the datum elevation. Tidal datum fields for VDatum have been produced by NOS for Tampa Bay and coastal southern Louisiana, the New York Bight, central coastal California, and Delaware Bay (Hess, 2001). Once VDatum has been established for a region, data can be incorporated into integrated bathymetric-topographic Digital Elevation Models for use in coastal GIS applications (Parker et al., 2001; Gesch and Wilson, 2002). VDatum will also be needed for carrying out the kinematic-GPS hydrographic surveying that NOS is planning to implement.

NOS routinely collects water level observations at shore-based stations along U.S. coasts and analyzes them to produce tidal datums. As described above, there is an important need to obtain two-dimensional tidal datum fields that cover the coastal waters between the water level stations. This paper discusses a method for obtaining tidal datum fields in Puget Sound, Washington, by the method of spatial interpolation of tidal data.

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2. TIDES AND DATUMS

Tidal datums at water level stations are elevation values that are determined from a time series of observations. For stations located along the coasts of the U.S. (except for the Great Lakes), the analysis starts with the identification of all the tidal extrema (highs and lows) in the record, and continues with the selection (within a 25-hour time period) of the higher of the two highs and the lower of the two lows. If only one high water is present in the time period, it is categorized as a higher high. Thus, for high water (for example), each day has either a high and a higher high, or a single higher high. The average of all the highs and the higher highs is called the Mean High Water (MHW), and the average of just the higher highs is called the Mean Higher High Water (MHHW). The process for producing Mean Low Water (MLW) and MLLW from the low waters is similar. The average of the MHW and the MLW is called the Mean Tide Level (MTL) and the average of the MHHW and the MLLW is called the Diurnal Tidal Level (DTL). Mean Sea Level (MSL) is the average of the hourly water levels. Where MSL is not computed, the MTL or DTL can be used as approximations. For further information on tidal datums, see Gill and Schultz (2001).

Observations made in a limited time period are adjusted to represent equivalent values for a 19-year National Tidal Datum Epoch (NTDE). The present NTDE of 1983-2001 was just implemented in April 2003 and replaced the previous 1960-1978 NTDE period. This recent epoch will give more accurate datums for locations where apparent sea levels are changing rapidly due to local land subsidence caused by mineral and ground water extraction, isostatic rebound following the last ice age, or tectonic motion.

Tidal datum values at NOS water level stations are routinely computed and are available to the public in the form of the station benchmark sheets. Within the Puget Sound, Washington, study area (between latitudes 47° 3' N and 48° 11' N, and longitudes 123° 11' W and 122° 10' W) there are 69 stations with historical tidal datum values. Those used in this study are shown in Figure 1. In this area, the value of the elevation of MHHW above MSL varies from 0.8 m at the northern end to 2.0 m at the southern end, and the MLLW varies from -1.6 m at the northern end to -2.5 m at the southern end. These changes are generally correlated with changes in the range of tide.

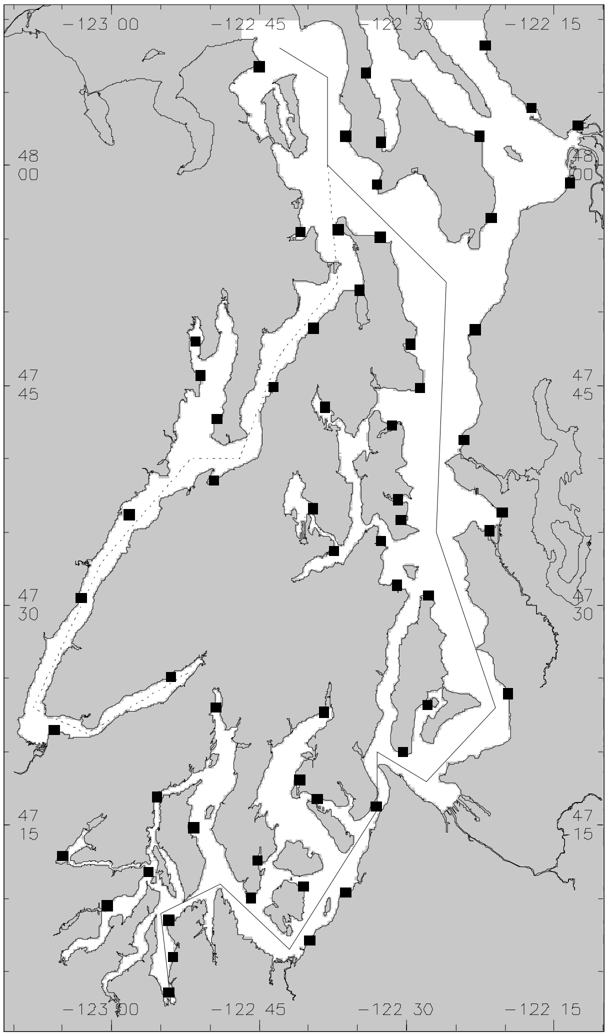

Figure 11. The Puget Sound study area with historical tide stations (squares), water cells in the computational grid (white area), the main axis of the Sound (solid line, with several straight segments, in white area), and the main axis of Hood Canal (dashed line).

3. SPATIAL INTERPOLATION

Spatial interpolation is used to generate the tidal datum fields. The interpolation method requires the datum field, *f,* to satisfy Laplace's Equation (LE),

$$\nabla^2 f = 0 \qquad (1)$$

and the solution is found numerically on a grid. No water depth data are used. The solution field matches the input data at the water level stations and takes into account land forms by the use of a specialized land-water boundary condition:

$$\frac{\partial f}{\partial n} = a\overline{\frac{\partial f}{\partial n}} \qquad (2)$$

where *n* is the normal direction, α is a constant, and the overbar signifies a local average. The interpolation method was shown to give useful digital representations of amplitude and phase distributions as produced by numerical models of tidally dominated bays, as well as datum planes, such as the ellipsoidally-referenced MSL or the MSL-to-MLLW difference (Hess, 2003; Hess, 2002).

The first step in the application of the interpolation method to Puget Sound, Washington, was to create a regular grid of square cells. A cell size of 231 m (0.125 nautical miles) was chosen to resolve many of the narrow passages in the Sound. This yields an undifferentiated grid with 329 cells in the eastward direction and 560 cells in the northward direction. A digitized coastline, obtained from the web site of NOAA's National Geophysical Data Center, was used to define the land-water boundary. A small number of natural passages were too narrow to be resolved automatically, and so were added by manual editing of 70 cells. The resulting grid (Fig. 1) has 37,280 water cells.

The next step was to apply the LE interpolation to the required datum levels. Tidal datums for stations were used for boundary values if the station was adjacent to water; of those available (69), 60 were used (Fig.1). The solution method for the LE, successive over-relaxation, required approximately 1,700 iterations to reach convergence for each of the datum fields (MHHW, MHW, MLW, and MLLW). Convergence was defined as when the maximum change between iterations in the numerical solution at any cell was less than 2.5 x 10^{-5} times the difference between the maximum and minimum input datum values. The spatially-interpolated tidal datums for MHHW, MHW, MLW, and MLLW for Puget Sound are shown in Figures 2 to 5, respectively.

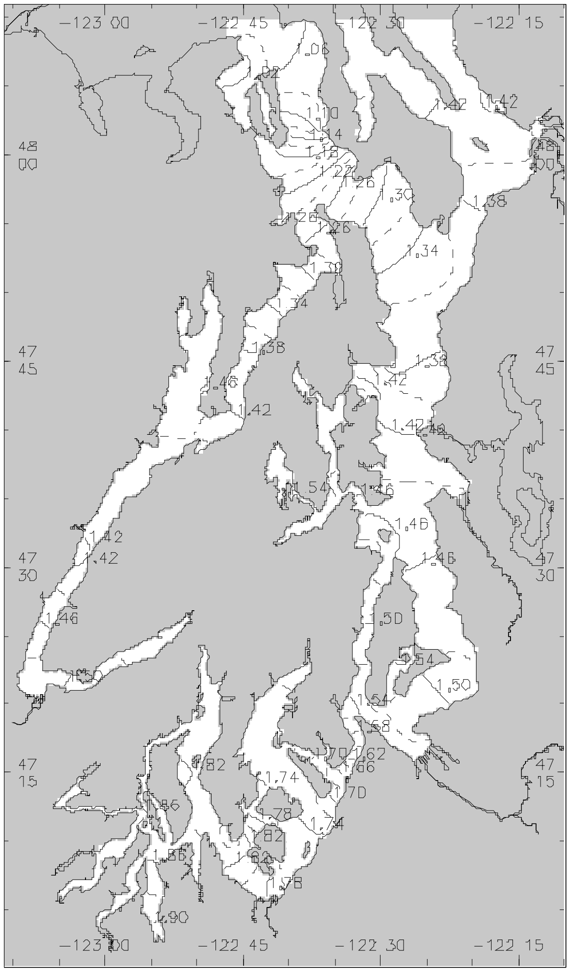

Figure 2. Contours of the interpolated MHHW tidal datum field (m).

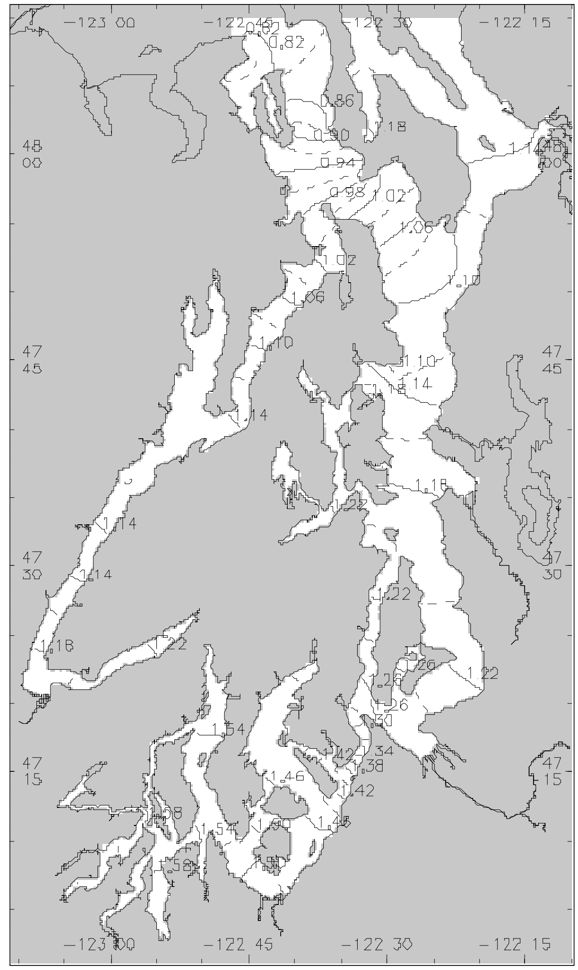

Figure 3. Contours of the interpolated MHW tidal datum field (m).

4. DISCUSSION

The accuracy of the computations is, in general, difficult to assess since there are few published datum fields based solely on observations. However, the accuracy was estimated in the following manner. For the MHHW datum, 60 additional approximations of the datum field were generated. To generate each new field, one of the 60 stations was removed as input, a different station for each new field. Then the value from each new field at the cell where the datum input was removed was compared to the value at the same cell in the original field, where the datum input was used. The root mean square (RMS), average, and maximum differences (original value minus new value) are 3.4 cm, -0.3 cm, and 16.4 cm, respectively. The maximum difference, at Bush Point on the west side of Whidbey Island (at 48° 2.0' N and 122° 36.2' W), occurs in a region with a relatively large horizontal datum gradient (appx. 3 cm per km).

Another useful, but non-rigorous, assessment of accuracy was made by plotting the interpolated tidal datums along the axes of the main channels (shown in Figure 1) and the datums at the nearby tide stations (Figure 6). The results show that the interpolated solution varies little from the input data values.

A third approach to assessing accuracy is to compare interpolated fields with the datums from tidal hydrodynamic models. For example, a tidal model for Puget Sound has been applied to the task of computing tidal datum fields (Mofjeld et al., 2002). In a comparison of the spatially interpolated solution and the modeled datum at 471 locations, the RMS difference for all datums was 5.2 cm. Statistics on the differences between the two models are shown in Table 1.

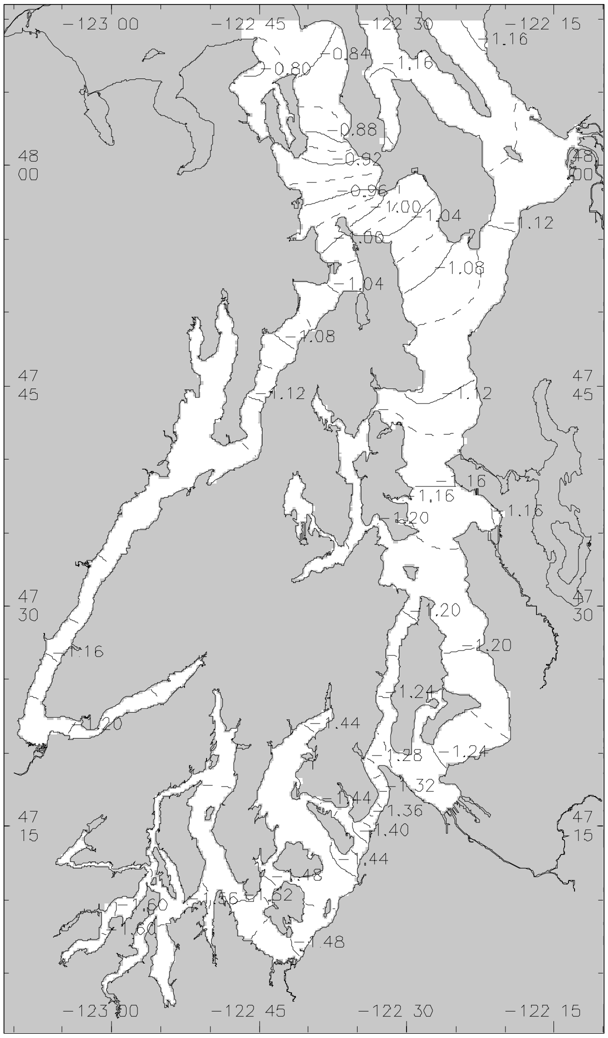

Figure 4. Contours of the interpolated MLW tidal datum field (m).

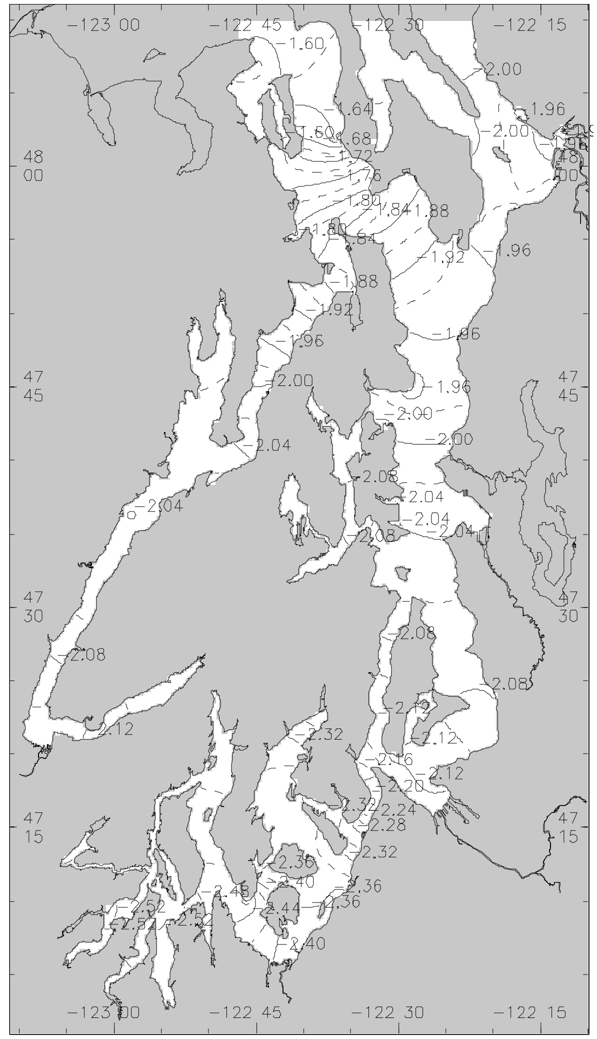

Figure 5. Contours of the interpolated MLLW tidal datum field (m).

TABLE 1

Differences in tidal datum fields (interpolated minus hydrodynamic model-based values).

Tidal Datum	Avg. Diff. (cm)	RMS Diff. (cm)	Max. Abs. Diff. (cm)
MHHW	-5.8	6.4	11.8
MHW	-2.6	3.3	7.5
MLW	-1.3	2.9	10.9
MLLW	-5.9	7.0	18.4

Since hydrodynamic models incorporate the physics of water flow, they can produce datum fields that more accurately represent bathymetric influences. However, these models typically require long periods of time (months to years) to calibrate and, because of the complexity of the flow field, usually do not exactly match the data at the tide stations. By contrast, spatial interpolation matches the data at the tide stations but involves no tidal physics. NOS is exploring the approach of taking the results from hydrodynamic models, where they exist, and then spatially-interpolating the errors to produce final, corrected datum fields.

Finally, since datum values at locations other than water level stations are difficult to obtain, especially offshore, NOS has plans to develop rapidly-deployable buoys with GPS positioning capability, but these would not be ready for a few years.

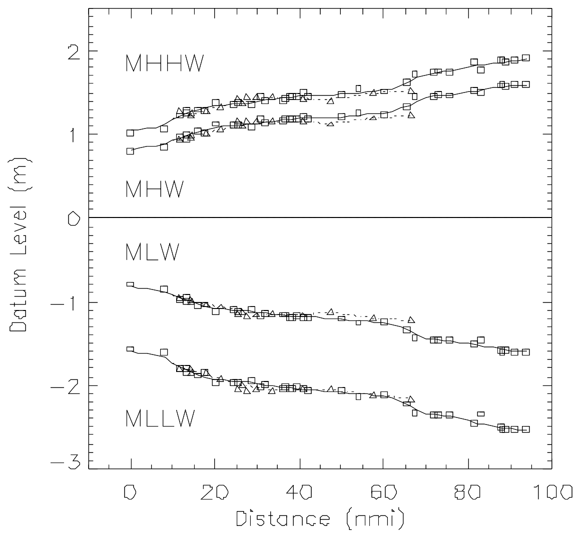

Figure 6. For four tidal datums, the interpolated elevations are shown along the main channel (solid line) and data from nearby tide stations (squares), and along Hood Canal (dashed line) and nearby stations (triangles). The main axis and Hood Canal axis are shown in Fig.1.

5. SUMMARY AND CONCLUSIONS

The spatial interpolation of tidal datums is a fast and relatively accurate method of producing tidal datum fields. For Puget Sound, the MHHW field ranges from 0.8 m at the northern end to 2.0 m at the southern end, and the MLLW ranges from -1.6 m at the northern end to -2.5 m at the southern end. The relative accuracy of the MHHW field was estimated to be 3.4 cm. In coastal regions where a tidal hydrodynamic model has been calibrated, the modeled datum field can be corrected by interpolating the errors at the tide stations to produce a more accurate field. These datum fields will facilitate the development of the VDatum tool for the Puget Sound region.

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APPENDIX B. TIDE STATIONS AND TIDAL DATUMS

Table B.1. Tide stations and datums relative to MSL. Number is the 7-digit NOS station number. In the column with heading NB, the letter ‘a’ denotes stations not used in generating the tidal datum fields.

N	Number	Latitude	Longitude	MHHW	MHW	MLW	MLLW	MTL	DTL	NB
1	9444705	48.0583	-122.9167	0.945	0.732	-0.731	-1.463	-9.999	0.000	a
2	9444900	48.1117	-122.7500	1.074	0.867	-0.762	-1.522	0.000	0.053	a
3	9445016	47.9267	-122.6167	1.253	0.997	-0.997	-1.844	-9.999	0.000	
4	9445017	47.9250	-122.6800	1.220	0.976	-0.975	-1.798	-9.999	0.000	
5	9445059	47.8583	-122.5800	1.280	1.006	-1.036	-1.859	-9.999	0.000	
6	9445088	47.8150	-122.6583	1.332	1.061	-1.060	-1.932	-9.999	0.000	
7	9445133	47.7483	-122.7267	1.396	1.125	-1.101	-1.978	0.000	0.012	
8	9445246	47.7617	-122.8500	1.447	1.155	-1.159	-2.073	-9.999	0.000	
9	9445269	47.7117	-122.8217	1.463	1.158	-1.158	-2.042	-9.999	0.000	
10	9445272	47.8000	-122.8583	1.414	1.156	-1.158	-2.054	0.000	-0.001	
11	9445293	47.6650	-122.9117	1.463	1.158	-1.189	-2.073	-9.999	0.000	a
12	9445296	47.6417	-122.8267	1.444	1.155	-1.156	-2.070	-9.999	0.000	
13	9445326	47.6033	-122.9700	1.430	1.161	-1.158	-2.039	-9.999	0.000	
14	9445388	47.5083	-123.0517	1.415	1.125	-1.124	-2.051	-9.999	0.000	
15	9445441	47.4183	-122.9000	1.533	1.225	-1.225	-2.158	-9.999	0.000	
16	9445478	47.3583	-123.0983	1.497	1.198	-1.198	-2.112	-9.999	0.000	
17	9445526	47.9183	-122.5450	1.295	1.039	-1.043	-1.887	-9.999	0.000	
18	9445639	47.7967	-122.4933	1.375	1.116	-1.115	-1.975	-9.999	0.000	
19	9445683	47.7467	-122.4767	1.359	1.097	-1.098	-1.942	-9.999	0.000	
20	9445717	47.7250	-122.6383	1.487	1.219	-1.219	-2.091	-9.999	0.000	
21	9445719	47.7250	-122.6383	1.487	1.219	-1.219	-2.091	-9.999	0.000	
22	9445753	47.7050	-122.5250	1.463	1.188	-1.159	-2.012	-9.999	0.000	
23	9445832	47.6433	-122.6150	1.491	1.226	-1.225	-2.112	-9.999	0.000	a
24	9445882	47.6200	-122.5150	1.402	1.158	-1.158	-2.042	-9.999	0.000	
25	9445901	47.6100	-122.6600	1.555	1.280	-1.280	-2.103	-9.999	0.000	
26	9445913	47.5967	-122.5100	1.463	1.189	-1.189	-2.042	-9.999	0.000	
27	9445938	47.5733	-122.5433	1.448	1.186	-1.185	-2.045	-9.999	0.000	
28	9445958	47.5617	-122.6233	1.498	1.230	-1.212	-2.080	0.000	0.009	
29	9445993	47.5233	-122.5167	1.494	1.219	-1.189	-2.042	-9.999	0.000	
30	9446025	47.5117	-122.4633	1.454	1.189	-1.188	-2.060	-9.999	0.000	
31	9446248	47.4000	-122.3283	1.475	1.204	-1.207	-2.079	-9.999	0.000	
32	9446273	47.3867	-122.4650	1.542	1.264	-1.253	-2.131	0.000	0.006	
33	9446281	47.3833	-122.8233	1.838	1.555	-1.554	-2.478	-9.999	0.000	
34	9446291	47.3783	-122.6400	1.707	1.433	-1.433	-2.286	-9.999	0.000	
35	9446366	47.3417	-122.7750	1.829	1.554	-1.555	-2.469	-9.999	0.000	a
36	9446369	47.3400	-122.5883	1.494	1.250	-1.250	-2.103	-9.999	0.000	
37	9446375	47.3333	-122.5067	1.512	1.244	-1.240	-2.112	-9.999	0.000	
38	9446451	47.3017	-122.6817	1.744	1.460	-1.460	-2.365	-9.999	0.000	
39	9446484	47.2667	-122.4133	1.511	1.246	-1.224	-2.093	0.000	0.011	a
40	9446486	47.2717	-122.5517	1.612	1.338	-1.341	-2.225	-9.999	0.000	
41	9446489	47.2817	-122.9233	1.838	1.554	-1.555	-2.475	-9.999	0.000	
42	9446491	47.2800	-122.6517	1.719	1.442	-1.442	-2.338	-9.999	0.000	
43	9446545	47.2550	-122.4317	1.503	1.235	-1.234	-2.106	-9.999	0.000	a
44	9446583	47.2467	-122.8617	1.814	1.524	-1.524	-2.441	-9.999	0.000	
45	9446628	47.2150	-123.0833	1.996	1.691	-1.540	-2.332	0.000	0.076	
46	9446638	47.2100	-122.7533	1.768	1.493	-1.463	-2.347	-9.999	0.000	
47	9446666	47.1967	-122.9383	1.890	1.585	-1.585	-2.499	-9.999	0.000	

Table B.1. (Continued).

N	Number	Latitude	Longitude	MHHW	MHW	MLW	MLLW	MTL	DTL	NB
48	9446671	47.1667	-122.7633	1.856	1.521	-1.521	-2.466	-9.999	0.000	
49	9446705	47.1800	-122.6750	1.757	1.475	-1.454	-2.351	0.000	0.011	
50	9446714	47.1733	-122.6033	1.741	1.463	-1.460	-2.368	-9.999	0.000	
51	9446742	47.1583	-123.0083	1.899	1.603	-1.607	-2.527	0.000	-0.002	
52	9446800	47.1417	-122.9033	1.859	1.576	-1.579	-2.521	-9.999	0.000	
53	9446807	47.1000	-122.8967	1.879	1.591	-1.598	-2.535	0.000	-0.004	
54	9446828	47.1183	-122.6650	1.750	1.466	-1.469	-2.368	-9.999	0.000	
55	9446969	47.0600	-122.9033	1.908	1.597	-1.597	-2.530	-9.999	0.000	
56	9447029	47.5350	-122.3217	1.417	1.143	-1.143	-1.966	-9.999	0.000	a
57	9447110	47.5850	-122.3600	1.442	1.179	-1.161	-2.027	0.000	0.009	
58	9447111	47.5850	-122.3600	1.442	1.179	-1.161	-2.027	0.000	0.009	a
59	9447130	47.6050	-122.3383	1.439	1.175	-1.159	-2.023	0.000	0.008	
60	9447131	47.6033	-122.3383	1.438	1.176	-1.158	-2.021	0.000	0.009	a
61	9447265	47.6883	-122.4033	1.405	1.143	-1.147	-2.003	-9.999	0.000	
62	9447427	47.8133	-122.3833	1.365	1.106	-1.107	-1.960	-9.999	0.000	
63	9447659	47.9800	-122.2233	1.404	1.138	-1.122	-1.976	0.000	0.008	
64	9447725	48.0450	-122.2100	1.396	1.137	-1.140	-1.905	-9.999	0.000	
65	9447773	48.0650	-122.2883	1.432	1.158	-1.128	-1.951	-9.999	0.000	
66	9447814	47.9400	-122.3567	1.378	1.125	-1.125	-1.981	-9.999	0.000	
67	9447827	47.9783	-122.5500	1.280	0.951	-0.948	-1.792	-9.999	0.000	
68	9447854	48.0333	-122.6033	1.067	0.854	-0.853	-1.615	-9.999	0.000	
69	9447855	48.0267	-122.5433	1.454	1.183	-1.183	-2.033	-9.999	0.000	
70	9447856	48.0333	-122.3767	1.417	1.152	-1.152	-2.012	-9.999	0.000	
71	9447883	48.1050	-122.5700	1.432	1.158	-1.159	-2.012	-9.999	0.000	
72	9448094	48.1367	-122.3667	1.411	1.143	-1.162	-2.015	0.000	-0.009	

APPENDIX C. NOS TIDE STATION NUMBERS AND NAMES.

Table C.1. NOS station numbers and names in the Puget Sound region.

N	NOS Station Number	Name
1	9444705	GARDINER LNDG PORST DISCOVERY WA
2	9444900	PORT TOWNSEND ADMIRALTY INLET WA
3	9445016	FOULWEATHER BLUFF TWIN SPITS WA
4	9445017	PORT LUDLOW ADMIRALY INLET WA
5	9445059	PORT GAMBLE HOOD CANAL WA
6	9445088	LOFALL WA
7	9445133	BANGOR WA
8	9445246	WHITNEY POINT WA
9	9445269	ZELATCHED POINT DABOB BAY WA
10	9445272	QUILCENE DABOB BAY HOOD CANAL WA
11	9445293	PLEASANT HARBOR HOOD CANAL WA
12	9445296	SEABECK HOOD CANAL WA
13	9445326	TRITON HEAD WA
14	9445388	AYOCK POINT WA
15	9445441	LYNCH COVE DOCK WA
16	9445478	UNION HOOD CANAL WA
17	9445526	HANSVILLE WA
18	9445639	KINGSTON APPLE TREE COVE WA
19	9445683	POINT JEFFERSON PUGET SOUND WA
20	9445717	POULSBO WA
21	9445719	POULSBO WA
22	9445753	PORT MADISON BAINBRIDGE ISLAND WA
23	9445832	BROWNSVILLE WA
24	9445882	EAGLE HARBOR BAINBRIDGE ISLAND WA
25	9445901	TRACYTON DYES INLET PUGET SND WA
26	9445913	PORT BLAKELY PUGET SOUND WA
27	9445938	CLAM BAY WA
28	9445958	BREMERTON WA
29	9445993	SOUTH COLBY-HARPER YUKON HBR WA
30	9446025	POINT VASHON WA
31	9446248	DES MOINES WA
32	9446273	BURTON QUARTERMASTER HBR VASHON WA
33	9446281	ALLYN WA
34	9446291	WAUNA CARR INLET PUGET SOUND WA
35	9446366	VAUGHN CASE INELT PUGET SOUND WA
36	9446369	GIG HARBOR PUGET SOUND WA
37	9446375	NEILL POINT WA
38	9446451	GREEN POINT WA
39	9446484	TACOMA COMMENCEMENT BAY WA
40	9446486	TACOMA NARROWS BRIDGE WA
41	9446489	WALKERS LANDING WA
42	9446491	ARLET WA
43	9446545	TACOMA WA
44	9446583	BALLOW WA
45	9446628	SHELTON OAKLAND BAY WA

Table C.1. (Continued)

N	NOS Station Number	Name
46	9446638	LONGBRACH FILUCE B PUGET SND WA
47	9446666	ARCADIA TOTTEN INLET WA
48	9446671	DEVIL'S HEAD WA
49	9446705	YOMAN POINT ANDERSON ISLAND WA
50	9446714	STEILACOOM WA
51	9446742	BARRON POINT LITTLE SKOOKUM INLET ENT WA
52	9446800	DOFFLEMEYER POINT WA
53	9446807	BUDD INLET SOUTH OF GULL HARBOR WA
54	9446828	DUPONT NISQUALLY REACH WA
55	9446969	OLYMPIA WA
56	9447029	DUWAMISH RIVER (8TH AVE SOUTH) WA
57	9447110	LOCKHEED SHIPYARD TEST CONTROL WA
58	9447111	LOCKHEED SHIPYARD TEST SITE WA
59	9447130	SEATTLE PUGET SOUND WA
60	9447131	SEATTLE PUGET SOUND (BACKUP) WA
61	9447265	MEADOW POINT WA
62	9447427	EDMONDS WA
63	9447659	EVERETT WA
64	9447725	EBEY SLOUGH POSSESSION SOUND WA
65	9447773	TULALIP TULALIP BAY WA
66	9447814	GLENDALE POSSESSION SOUND WA
67	9447827	DOUBLE BLUFF ADMIRALTY INLET WA
68	9447854	BUSH POINT WHIDBEY ISLAND WA
69	9447855	HOLLY HARBOR FARMS WA
70	9447856	SANDY POINT SARATOGA PASSAGE WA
71	9447883	GREENBANK WHIDBEY ISLAND WA
72	9448094	KAYAK PT PORT SUSAN WA

APPENDIX D. SUMMARY OF COMPARISONS WITH CO-OPS STATION DATA.

Table D.1. For each station, the RMS error (RMSE) and standard deviation (SD) between the observed values of MHHW, MHW, MLW, and MLLW and the corresponding values obtained from the VDatum gridded files. Under 'Status', an entry of 'null' means that no VDatum values were found.

n	Number	Latitude	Longitude	RMSE(m)	SD(m)	Status
1	9444705	48.05833	-122.91666	0.00000	0.00000	null
2	9444900	48.11167	-122.75000	0.00361	0.00330	
3	9445016	47.92667	-122.61667	0.00218	0.00206	
4	9445017	47.92500	-122.68000	0.00179	0.00167	
5	9445059	47.85833	-122.58000	0.00062	0.00059	
6	9445088	47.81500	-122.65833	0.00086	0.00083	
7	9445133	47.74833	-122.72667	0.00113	0.00095	
8	9445246	47.76167	-122.85000	0.00079	0.00070	
9	9445269	47.71167	-122.82166	0.00147	0.00110	
10	9445272	47.80000	-122.85833	0.00057	0.00056	
11	9445293	47.66500	-122.91167	0.02884	0.02680	
12	9445296	47.64167	-122.82667	0.00085	0.00077	
13	9445326	47.60333	-122.97000	0.00128	0.00124	
14	9445388	47.50834	-123.05167	0.00157	0.00155	
15	9445441	47.41833	-122.90000	0.00049	0.00049	
16	9445478	47.35833	-123.09834	0.00062	0.00062	
17	9445526	47.91833	-122.54500	0.00227	0.00215	
18	9445639	47.79667	-122.49333	0.00086	0.00085	
19	9445683	47.74667	-122.47667	0.00532	0.00531	
20	9445717	47.72500	-122.63834	0.00015	0.00013	
21	9445719	47.72500	-122.63834	0.00015	0.00013	
22	9445753	47.70500	-122.52500	0.00308	0.00297	
23	9445832	47.64333	-122.61500	0.00000	0.00000	null
24	9445882	47.62000	-122.51500	0.00105	0.00085	
25	9445901	47.61000	-122.66000	0.00033	0.00032	
26	9445913	47.59667	-122.51000	0.00037	0.00036	
27	9445938	47.57333	-122.54333	0.00140	0.00126	
28	9445958	47.56167	-122.62334	0.00031	0.00030	
29	9445993	47.52333	-122.51667	0.00293	0.00189	
30	9446025	47.51167	-122.46333	0.00158	0.00101	
31	9446248	47.40000	-122.32833	0.00033	0.00032	
32	9446273	47.38667	-122.46500	0.00065	0.00064	
33	9446281	47.38334	-122.82333	0.00013	0.00013	
34	9446291	47.37833	-122.64000	0.00063	0.00061	
35	9446366	47.34167	-122.77500	0.00695	0.00678	
36	9446369	47.34000	-122.58833	0.00017	0.00017	
37	9446375	47.33333	-122.50667	0.00133	0.00133	
38	9446451	47.30167	-122.68166	0.00125	0.00123	
39	9446484	47.26667	-122.41333	0.01680	0.01327	
40	9446486	47.27167	-122.55167	0.00069	0.00069	
41	9446489	47.28167	-122.92333	0.00000	0.00000	
42	9446491	47.28000	-122.65166	0.00026	0.00025	
43	9446545	47.25500	-122.43166	0.01237	0.01224	
44	9446583	47.24667	-122.86166	0.00057	0.00057	

Table D.1. (Continued).

n	Number	Latitude	Longitude	RMSE	SD	Status
45	9446628	47.21500	-123.08334	0.00113	0.00041	
46	9446638	47.21000	-122.75333	0.00052	0.00040	
47	9446666	47.19667	-122.93833	0.00146	0.00136	
48	9446671	47.16667	-122.76334	0.00656	0.00656	
49	9446705	47.18000	-122.67500	0.00111	0.00029	
50	9446714	47.17333	-122.60333	0.00089	0.00086	
51	9446742	47.15833	-123.00833	0.00044	0.00043	
52	9446800	47.14167	-122.90334	0.00107	0.00098	
53	9446807	47.10000	-122.89667	0.00070	0.00058	
54	9446828	47.11833	-122.66500	0.00145	0.00144	
55	9446969	47.06000	-122.90334	0.00007	0.00006	
56	9447029	47.53500	-122.32166	0.00000	0.00000	null
57	9447110	47.58500	-122.36000	0.00020	0.00017	
58	9447111	47.58500	-122.36000	0.00020	0.00017	
59	9447130	47.60500	-122.33833	0.00022	0.00021	
60	9447131	47.60333	-122.33833	0.00170	0.00141	
61	9447265	47.68833	-122.40334	0.00052	0.00044	
62	9447427	47.81333	-122.38333	0.00034	0.00033	
63	9447659	47.98000	-122.22334	0.00034	0.00034	
64	9447725	48.04500	-122.21000	0.00030	0.00029	
65	9447773	48.06500	-122.28833	0.00147	0.00056	
66	9447814	47.94000	-122.35667	0.00108	0.00095	
67	9447827	47.97833	-122.55000	0.00173	0.00155	
68	9447854	48.03333	-122.60333	0.00452	0.00448	
69	9447855	48.02667	-122.54333	0.00000	0.00000	null
70	9447856	48.03333	-122.37666	0.00056	0.00049	
71	9447883	48.10500	-122.57000	0.00025	0.00025	
72	9448094	48.13667	-122.36667	0.00073	0.00038	

```
error summary
    number    =       68
    avg. rmse =  0.00203
    avg. std  =  0.00183
    max. rmse =  0.02884 at i=  11
    max. std  =  0.02680 at i=  11
```

APPENDIX E. SUMMARY OF COMPARISONS WITH NGS BENCHMARK DATA.

Table E.1. For each station, the RMS error (RMSE) and standard deviation (SD) between the observed values of MHHW, MHW, MLW, and MLLW and the corresponding values obtained from the VDatum gridded files. The PID is the NGS's identification number. Under 'Status', an entry of 'null' means that no VDatum values were found.

n	PID	Number	Latitude	Longitude	RMSE(m)	SD(m)	Status
1	SY0225	9447814	47.93916	-122.35666	0.00081	0.00062	
2	SY0227	9447814	47.93916	-122.35666	0.00081	0.00062	
3	TR0186	9447725	48.05138	-122.17916	0.00000	0.00000	null
4	TR0184	9447725	48.05361	-122.17555	0.00000	0.00000	null
5	TR0185	9447725	48.05277	-122.17722	0.00000	0.00000	null
6	SY0003	9447659	47.97944	-122.21555	0.00000	0.00000	null
7	SY0004	9447659	47.97944	-122.21583	0.00000	0.00000	null
8	SY0004	9447659	47.97944	-122.21583	0.00000	0.00000	null
9	SY0002	9447659	47.98055	-122.21527	0.00000	0.00000	null
10	SY0128	9447427	47.81138	-122.38250	0.00056	0.00021	
11	SY0126	9447427	47.81305	-122.38027	0.00060	0.00025	
12	SY0282	9447130	47.60194	-122.33250	0.00000	0.00000	null
13	SY0328	9447130	47.59944	-122.32861	0.00000	0.00000	null
14	SY0288	9447130	47.60416	-122.33361	0.00928	0.00138	
15	SY0283	9447130	47.60194	-122.33388	0.00930	0.00137	
16	SY0284	9447130	47.60166	-122.33500	0.00931	0.00137	
17	SY0286	9447130	47.60305	-122.33444	0.00929	0.00137	
18	SY0290	9447130	47.60388	-122.33750	0.00926	0.00141	
19	SY0289	9447130	47.60444	-122.33500	0.00928	0.00138	
20	SY0287	9447130	47.60305	-122.33583	0.00928	0.00138	
21	SY0865	9446969	47.05166	-122.90250	0.00068	0.00059	
22	SY0866	9446969	47.05194	-122.90388	0.00071	0.00062	
23	SY0869	9446969	47.04583	-122.90055	0.00000	0.00000	null
24	SY0868	9446969	47.05000	-122.90138	0.00073	0.00063	
25	SY0867	9446969	47.04972	-122.90083	0.00000	0.00000	null
26	SY0743	9446828	47.11888	-122.66305	0.00205	0.00164	
27	SY0741	9446828	47.11888	-122.66305	0.00205	0.00164	
28	SY0738	9446828	47.11694	-122.66500	0.00261	0.00234	
29	SY0740	9446828	47.11694	-122.66444	0.00267	0.00240	
30	SY0739	9446828	47.11750	-122.66500	0.00239	0.00207	
31	SY0757	9446714	47.17250	-122.60166	0.00220	0.00048	
32	SY0756	9446714	47.17111	-122.60111	0.00236	0.00061	
33	SY0755	9446714	47.17388	-122.59694	0.00526	0.00441	
34	SY0754	9446714	47.17250	-122.60111	0.00216	0.00046	
35	SY0536	9446545	47.26416	-122.41194	0.01254	0.01236	
36	SY0535	9446545	47.25888	-122.41916	0.00000	0.00000	null
37	SY0534	9446545	47.25416	-122.42916	0.00000	0.00000	null
38	SY0532	9446545	47.25500	-122.43361	0.01270	0.01253	
39	SY0533	9446545	47.24916	-122.43444	0.00000	0.00000	null
40	SY0541	9446545	47.24583	-122.43444	0.00000	0.00000	null
41	SY2987	9446491	47.28277	-122.65805	0.00186	0.00180	
42	SY0536	9446484	47.26416	-122.41194	0.01436	0.01420	
43	SY0535	9446484	47.25888	-122.41916	0.00000	0.00000	null
44	SY0534	9446484	47.25416	-122.42916	0.00000	0.00000	null
45	SY0840	9446375	47.33222	-122.50555	0.00245	0.00179	
46	SY0808	9446281	47.38972	-122.82361	0.00057	0.00049	

Table E.1 (Continued).

n	PID	Number	Latitude	Longitude	RMSE(m)	SD(m)	Status
47	SY0807	9446281	47.38972	-122.82361	0.00057	0.00049	
48	SY0805	9446281	47.38361	-122.82527	0.00052	0.00044	
49	SY0806	9446281	47.38500	-122.82666	0.00054	0.00045	
50	SY0804	9446281	47.38444	-122.82750	0.00053	0.00043	
51	SY0645	9446254	47.38722	-122.46166	0.00624	0.00076	
52	SY0646	9446254	47.38638	-122.45722	0.00618	0.00163	
53	SY0647	9446254	47.38638	-122.45611	0.00620	0.00179	
54	SY2364	9446248	47.40277	-122.32833	0.00206	0.00062	
55	SY0917	9445958	47.56361	-122.62916	0.00000	0.00000	null
56	SY0922	9445958	47.56305	-122.62416	0.01042	0.00164	
57	SY0920	9445958	47.56305	-122.62527	0.01043	0.00165	
58	SY0919	9445958	47.56361	-122.62694	0.01044	0.00165	
59	SY0915	9445958	47.56277	-122.63055	0.00000	0.00000	null
60	SY0902	9445938	47.57111	-122.55111	0.00288	0.00262	
61	SY0902	9445938	47.57111	-122.55111	0.00288	0.00262	
62	SY0900	9445938	47.57138	-122.55166	0.00343	0.00316	
63	SY0901	9445938	47.57583	-122.54833	0.00486	0.00464	
64	SY4915	9445683	47.75583	-122.47000	0.01276	0.01269	
65	SY1272	9445478	47.35694	-123.10305	0.00159	0.00159	
66	SY1275	9445478	47.35722	-123.09944	0.00066	0.00063	
67	SY1274	9445478	47.35694	-123.10083	0.00081	0.00079	
68	SY1271	9445478	47.35722	-123.10305	0.00159	0.00159	
69	SY1236	9445388	47.50750	-123.05750	0.00135	0.00113	
70	SY1238	9445388	47.49972	-123.06055	0.00877	0.00865	
71	SY5514	9445326	47.60305	-122.98222	0.00390	0.00379	
72	SY1163	9445246	47.76138	-122.85000	0.00237	0.00072	
73	SY1162	9445246	47.76194	-122.85000	0.00237	0.00082	
74	SY1164	9445246	47.76138	-122.85000	0.00237	0.00072	
75	SY0959	9445133	47.74666	-122.72638	0.01622	0.00789	
76	TR2726	9444900	48.11138	-122.76166	0.06637	0.02576	
77	TR0559	9444900	48.11583	-122.75194	0.06569	0.02565	
78	TR2693	0	48.07916	-123.04416	0.00000	0.00000	null
79	TR0852	0	48.08027	-123.04527	0.00000	0.00000	null
80	TR0851	0	48.08027	-123.04527	0.00000	0.00000	null
81	TR0850	0	48.08000	-123.04527	0.00000	0.00000	null
82	TR0186	0	48.05138	-122.17916	0.00000	0.00000	null
83	TR0184	0	48.05361	-122.17555	0.00000	0.00000	null
84	SY0783	0	47.28250	-122.92250	0.00000	0.02565	
85	SY0782	0	47.28333	-122.92305	0.00000	0.02565	
86	SY0274	0	47.58416	-122.36138	0.00000	0.02565	
87	SY0273	0	47.58416	-122.36250	0.00000	0.02565	
88	SY0272	0	47.58194	-122.36277	0.00000	0.02565	
89	SY0271	0	47.57833	-122.36277	0.00000	0.02565	
90	SY0270	0	47.57444	-122.36277	0.00000	0.02565	
91	SY0269	0	47.57916	-122.35388	0.00000	0.00000	null
92	SY0268	0	47.57500	-122.35416	0.00000	0.02565	

Table E.1 (Continued).

93	SY0267	0	47.57888	-122.35444	0.00000	0.00000	null
94	SY0266	0	47.57694	-122.35500	0.00000	0.00000	null
95	SY0265	0	47.57111	-122.34472	0.00000	0.02565	

```
error summary
     number    =       67
     avg. rmse =  0.00587
     avg. std  =  0.00627
     max. rmse =  0.06637 at i=  76
     max. std  =  0.02576 at i=  76
```