Canadian Technical Report of

Hydrography and Ocean Sciences 196

1998

BASIN AREAS AND VOLUMES FOR COASTAL SOUTHWEST BRITISH COLUMBIA AND NORTHWEST WASHINGTON

by

R. E. Thomson and M. G. G. Foreman

Fisheries and Oceans Canada
Institute of Ocean Sciences
9860 West Saanich Road
Sidney, British Columbia
V8L 4B2

Cat. No. Fs 97-18/196 ISSN 0711-6764

Correct citation for this publication:

Thomson, R. E., and M. G. G. Foreman. 1998. Basin areas and volumes for coastal southwest British Columbia and northwest Washington. Can. Tech. Rep. Hydrogr. Ocean Sci. 196: 17 p.

ABSTRACT

Thomson, R. E., and M. G. G. Foreman. 1998. Basin areas and volumes for coastal southwest British Columbia and northwest Washington. Can. Tech. Rep. Hydrogr. Ocean Sci. 196: 17 p.

We use gridded seafloor topography from an extended version of the finite-element numerical tidal model of Foreman et al. (1995) to estimate surface areas and water volumes for selected oceanic basins and channels on the southwest coast of British Columbia and northwest Washington State. Regions considered are: Juan de Fuca Strait, the Strait of Georgia, Puget Sound, Hood Canal, the Gulf-San Juan Islands region, Howe Sound, and Burrard Inlet. Areas and volumes are calculated from the triangular elements of the numerical model and are prescribed as functions of water depth for: (1) Depths greater than 0, 10, 50, 100, 200, and 300 m; and (2) for depth ranges of 0-10, 0-50, 0-100, 50-100, 50-200, and 100-300 m. Low water has been used as the reference depth in all cases.

RÉSUMÉ

Thomson, R. E., and M. G. G. Foreman 1998. Basin areas and volumes for coastal southwest British Columbia and northwest Washington. Can. Tech. Rep. Hydrogr. Ocean Sci. 196: 17 p.

Nous utilisons la topographie de fond de mer cadrillé tirée d'une interprétation étendue du modèle élément-fini numérique de marée de Foreman et al. (1995) pour évaluer les aires à la surface et les volumes d'eau pour bassins et canaux océaniques sélectionnés sur la côte sud-ouest de la Colombie-Britannique et le nord-ouest de l'État de Washington. Les régions considérées sont: le détroit de Juan de Fuca, le détroit de Georgia, Puget Sound, Howe Sound, Hood Canal, et le bras de mer Burrard. Les aires et volumes sont calculés à partir des facteurs triangulaires du modèle numérique et sont prescrits en fonction de la profondeur d'eau pour: (1) profondeurs au plus de 0, 10, 50, 100, 200, et 300 m; et (2) profondeurs d'étendue de 0-10, 0-50, 0-100, 50-100, 50-200, et 100-300 m. La marée basse a été utilisée comme profondeur de référence dans tous les cas.

INTRODUCTION

Estimates of the surface areas and volumes of oceanic basins are often required for specific marine applications. Applications might include calculation of the tidal prism for the basin, estimation of the basin-scale dilution of water-borne pollutants, and calculation of the surface area occupied by near-shore benthic regions. Although some of these estimates exist within the literature, many are difficult to locate and few have accompanying documentation that specify the boundaries and sources used in the estimate.

The advent of high-speed computers and sophisticated numerical modeling methods has lead to the widespread incorporation of high quality, high resolution, bathymetric data into finite-difference and finite-element numerical simulation models. These bathymetric data are readily ameanable to numerical manipulation and, in most cases, have been carefully edited to eliminate erroneous depths that might adversely affect the estimation of water elevations, currents, and other simulated quantities.

In this report, we use the triangularly shaped depth elements from the extended version of the finite-element numerical tidal model of Foreman et al. (1995) to estimate the oceanic areas and volumes encompassed by the major oceanic regions of the Georgia Basin of southwestern British Columbia and northwestern Washington State (Figure 1). Areas and volumes are presented for mean water depths exceeding 0, 10, 50, 100, 200, and 300 m and for depth ranges of 0-10, 0-50, 0-100, 50-100, 50-200, and 100-300 m. In all cases, low water is used as the reference level for the depth estimates.

METHODS

The regional boundaries for the various basins presented in this report (Figure 1) are based on Canadian hydrographic charts, Sailing Directions (1987), and on the observed water properties and regional oceanic dynamics of the various basins (e.g. Waldichuck, 1957; Ebbesmeyer and Barnes, 1980; LeBlond, 1983; Thomson, 1994). The specific regions considered are: Juan de Fuca Strait, the Strait of Georgia, Puget Sound, Hood Canal, the Gulf-San Juan Islands region, Howe Sound, and Burrard Inlet (Figures 2a-g).

For each basin, the area and volume estimates are calculated from the triangular elements used in an extended version of the calibrated and verified finite-element tidal model of Foreman et al. (1995). The finite-element numerical grid and depths associated with this grid are presented in Figures 3 and 4, respectively. Each triangle is defined by three nodes for which physical oceanographic parameters such as temperature, current velocity, and pressure are determined. Because the area of each element is directly proportional to the water depth, the number of elements increases linearly with decreasing water depth. As a consequence, the accuracy of the area and volume estimates are greatest for shallow waters, as one would like.

Aside from the algorithm used to define the grid elements from the initial topography, the most complex part of our analysis occurs when the three corners of an element have different water depths (Figure 5). In such cases, the water depths, z_k ($k = 1,2,3$), at each node need to be

considered when estimating the surface area for a particular grid. Here, we are seeking the surface area of the basin for specified depths, z_k, greater than or equal to H (i.e. for $z_k \geq H$). Values apply to low water conditions and will change slightly with changes in water level due to the tides and other factors. There are four possible cases to consider: (1) All three nodes have depths, z_k, greater than or equal to H (Figure 5a); (2) No nodes have depths greater than or equal to H (Figure 5b); (3) One of the nodes (say, z_1) has depth $z_1 \geq H$ but the other two nodes have depth less than H (Figure 5c); and (4) Two of the nodes (say, nodes z_1 and z_2) have depths z_1, $z_2 \geq H$ but the other node has depth less than H (Figure 5d). For case 1, the area and volume are found directly from the area and height of the particular grid while for case 2, the area is set equal to zero. For case 3, we interpolate along the sides of the triangle to the locations where the depths are equal to H (the "x" locations in Figure 5c) and then include only the area for triangle T^+ in the region for which $z \geq H$. A slightly different procedure is followed for case 4. Here, we interpolate as before until we find the locations for depth H (the "x"s in Figure 5d) but then subtract the area of triangle T from the area of the original triangular grid.

RESULTS

The surface areas and water volumes calculated for the seven specified basins within the Strait of Georgia-Puget Sound-Juan de Fuca Strait system are presented in Tables 1 and 2. Estimates apply to water depths greater than the specified low water depth. For example, the surface areas listed under the heading "0" metres in Table 1 give the basin surface areas for depths greater than the lower water depth of 0 m, which corresponds to the total surface area of the basin (Figure 2). Similarily, the volumes listed under the heading "0" metres in Table 2 give the total water volumes contained within each basin. Values listed under the heading "10" metres in Tables 1 and 2 give the surface areas and volumes for water depths greater than 10 m, and so on. Except for the Strait of Georgia and the Gulf/San Juan Islands region, none of the basins have water depths greater than 300 m.

The surface areas for the different depth levels listed in Table 1 can be subtracted to give estimates of the basin surface areas for specified depth ranges. Results for selected depth ranges are presented in Table 3. Similarly, the water volumes for different depth levels listed in Table 2 can be subtracted to give estimates of the basin volumes for specified depth ranges (Table 4).

DISCUSSION AND SUMMARY

The accuracies of the area and volume estimates are limited by the resolution of the bathymetric charts, the digitization process used to produce the gridded seafloor topography, and the length scales of the triangular elements relative to the spatial variability of the bottom contours. Aside from the fact that nautical charts tend to be biased toward shallow depths, there are no other obvious sources of systematic errors in our estimates. We therefore assume our calculations are correct to within a few percent but have not attempted to verify this estimate. However, these errors will be small compared to changes in surface area and water volume associated with the tides. Daily excursions of several metres occur in most regions as a result of diurnal and

semidiurnal tidal fluctuations. Considerably smaller changes in surface area and volume are associated with fortnightly, monthly and seasonal variations in water level. Higher tidal levels increase the areas and volumes for specified water depths while lower water levels decrease the areas and volumes. Because the extended model of Foreman et al. (1995) does not allow for wetting and drying coastal regions, we cannot use the model to estimate the effective changes in area or volume associated with time-varying water levels. However, such models are under development and will soon enable us to make areal and volumetric estimates for different stages of the tide.

ACKNOWLEDGEMENTS

We thank Dr. Roy Walters of the United States Geological Survey for the Puget Sound and Hood Canal bathymetric data, Mike Tarbotton of Triton Consultants for the Burrard Inlet and Indian Arm portion of the grid and bathymetry, and Patricia Kimber for drafting the figures. The French translation was expertly provided by Moneca Bracken.

Table 1. Basin surface areas (in square kilometers; km^2) for water depths, z, greater than or equal to the specified water depth, H, at low water (i.e. for depths $z \geq H$).

Water depth, H (metres)	0	10	50	100	200	300
Juan de Fuca Strait	4068	3913	3158	1957	215	0
Puget Sound	2132	1631	968	545	58	0
Hood Canal	378	321	197	89	0	0
Gulf/San Juan Islands	2127	1842	839	357	109	4.4
Strait of Georgia	6515	6284	5341	4374	2171	852
Burrard Inlet	59	48	15	6.5	0.4	0
Howe Sound	274	268	220	143	20.8	0

Table 2. Basin water volumes (in millions of cubic meters; $\times 10^9$ m^3) for water depths, z, greater than or equal to the specified water depth, H, at low water (i.e. for depths $z \geq H$).

Water depth, H (metres)	0	10	50	100	200	300
Juan de Fuca Strait	4.171	3.819	2.403	1.114	0.033	0
Puget Sound	1.361	1.147	0.688	0.320	0.014	0
Hood Canal	0.237	0.191	0.102	0.035	0.0	0
Gulf/San Juan Islands	1.242	1.062	0.551	0.279	0.057	0.0014
Strait of Georgia	10.481	9.887	7.621	5.245	1.945	0.408
Burrard Inlet	0.024	0.014	0.0066	0.0029	0.00006	0
Howe Sound	0.298	0.271	0.162	0.080	0.014	0

Table 3. Basin surface areas (in square kilometers; km^2) for specified depth ranges, $H_1 \leq z \leq H_2$, in metres.

Depth range (metres)	0-10	0-50	0-100	50-100	50-200	100-300
Juan de Fuca Strait	155	910	2111	1201	2943	1957
Puget Sound	501	1164	1587	423	910	545
Hood Canal	57	181	289	108	197	89
Gulf/San Juan Islands	285	1288	1770	482	730	353
Strait of Georgia	231	1174	2141	967	3171	3522
Burrard Inlet	11	44	52.5	8.5	14.6	6.5
Howe Sound	6	54	136	77	199	143

Table 4. Basin water volumes (in millions of cubic meters; $\times 10^9$ m^3) for specified depth ranges, $H_1 \leq z \leq H_2$, in metres.

Depth range (metres)	0-10	0-50	0-100	50-100	50-200	100-300
Juan de Fuca Strait	0.352	1.768	3.057	1.289	2.370	1.114
Puget Sound	0.214	0.673	1.041	0.368	0.674	0.320
Hood Canal	0.046	0.135	0.202	0.067	0.102	0.035
Gulf/San Juan Islands	0.180	0.691	0.963	0.272	0.494	0.278
Strait of Georgia	0.594	2.860	5.236	2.376	5.676	4.837
Burrard Inlet	0.010	0.017	0.021	0.004	0.007	0.003
Howe Sound	0.027	0.136	0.218	0.082	0.148	0.080

References

Ebbesmeyer, C.C., and C.A. Barnes. 1980. Control of a fjord basin's dynamics by tidal mixing in embracing sill zones. *Estuarine Coastal and Marine Science*, 11: 311-330.

Foreman, M.G.G., R.A. Walters, R.F. Henry, C.P. Keller, and A.G. Dolling. 1995. A tidal model for eastern Juan de Fuca Strait and the southern Strait of Georgia. *Journal of Geophysical Research*, C1, 100: 721-740.

LeBlond, P.H. 1983. The Strait of Georgia: functional anatomy of a coastal sea. *Canadian Journal of Fisheries and Aquatic Sciences*, 40: 1033-1063.

Thomson, R.E. 1994. Physical oceanography of the Strait of Georgia-Puget Sound-Juan de Fuca Strait system. *In*: R.H. Wilson, R.J. Beamish, F. Aitkens and J. Bell (eds). Review of the marine environment and biota of Strait of Georgia Puget Sound and Juan de Fuca Strait. Proceedings of the BC/Washington Symposium on the Marine Environment, January 13 & 14, 1994, 36-100.

Waldichuck, M. 1957. Physical oceanography of the Strait of Georgia, British Columbia. *Journal of the Fisheries Research Board of Canada*, 14: 321-486.

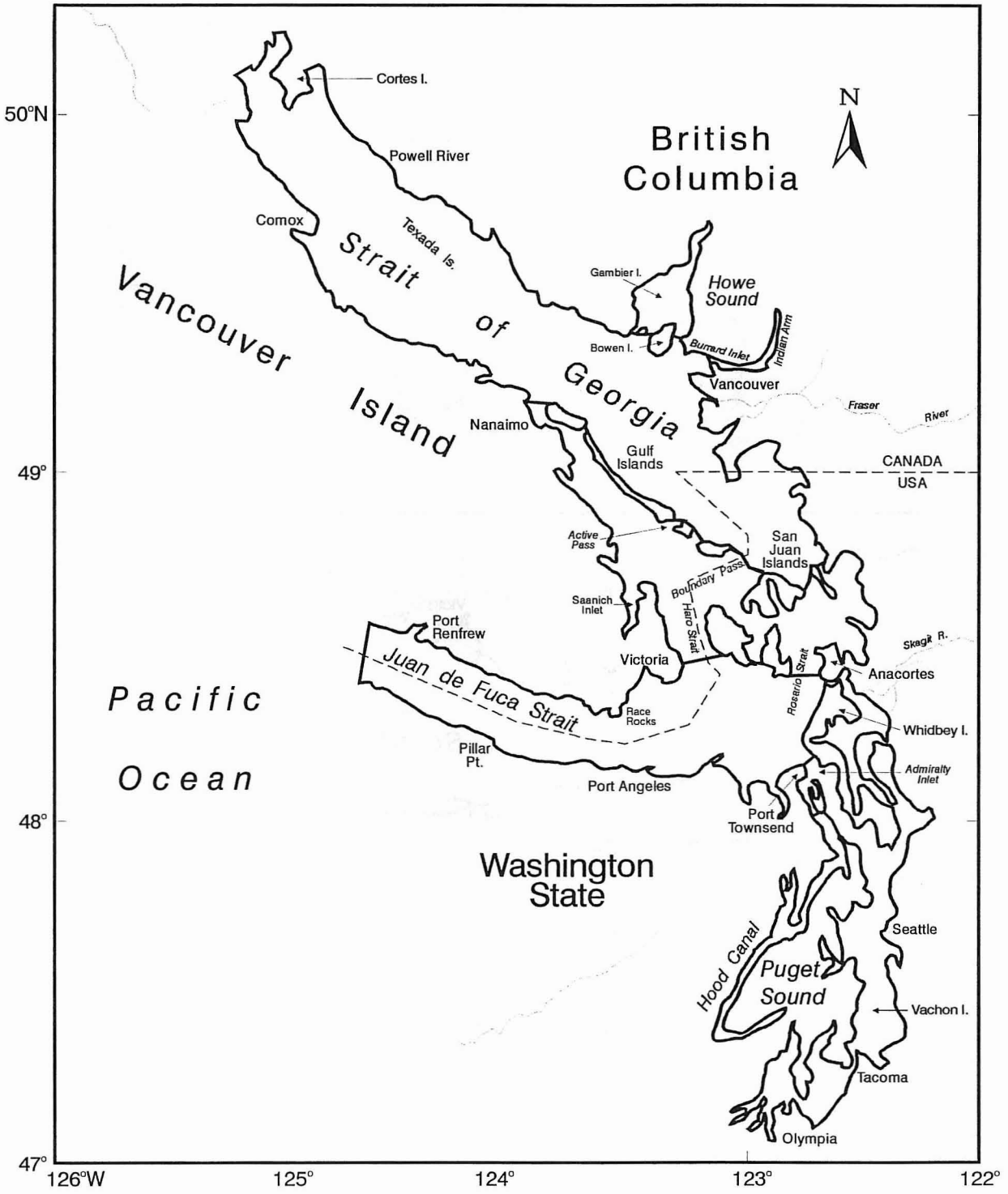

Figure 1. Map of the coastal waters of British Columbia and Washington State showing major geographical place names. The thick solid lines denote the boundaries of the basins considered in this report.

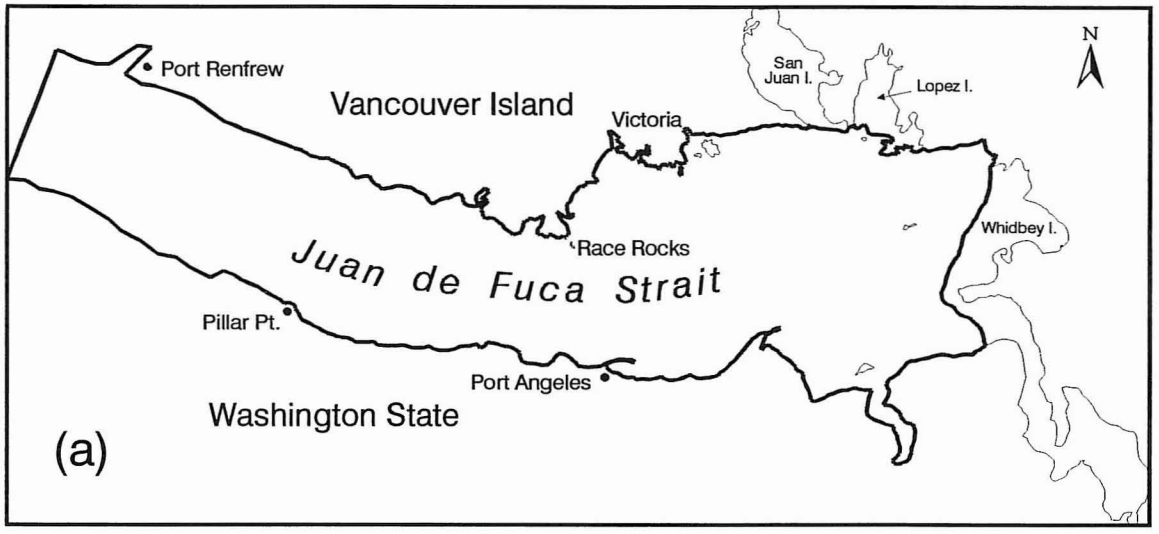

Figure 2(a). Detailed coastal boundary for Juan de Fuca Strait. The islands within the bounded regions are excluded from the aerial estimates.

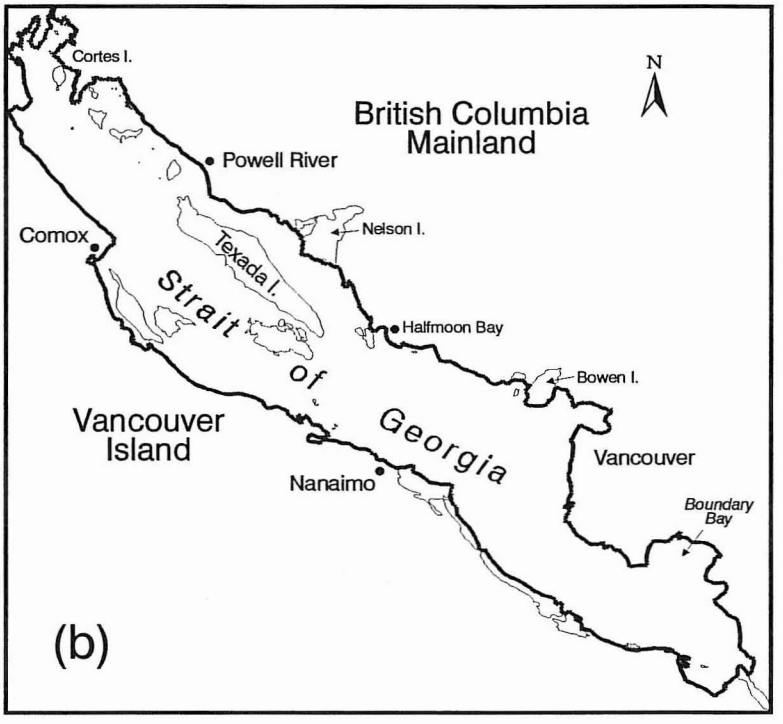

Figure 2(b). Detailed coastal boundary for the Strait of Georgia.

Figure 2(c). Detailed coastal boundary for Puget Sound.

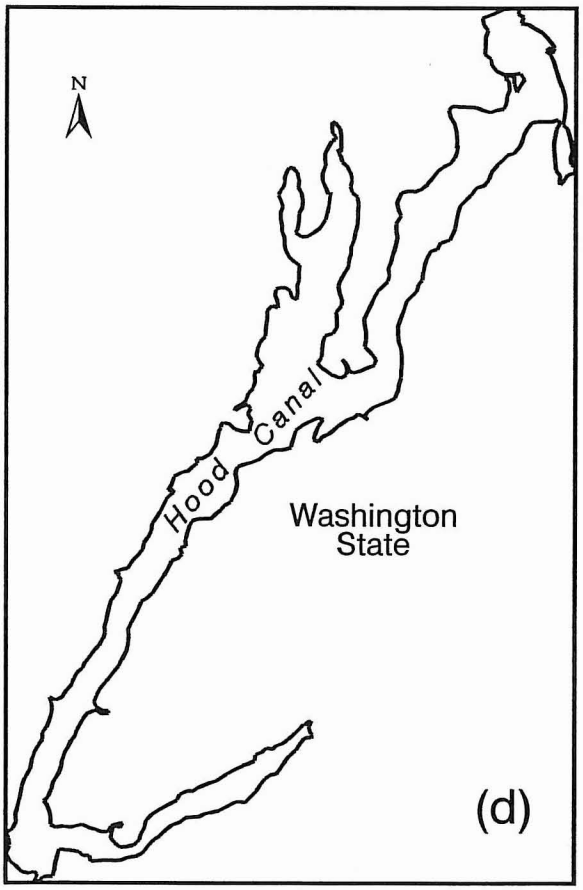

Figure 2(d). Detailed coastal boundary for Hood Canal.

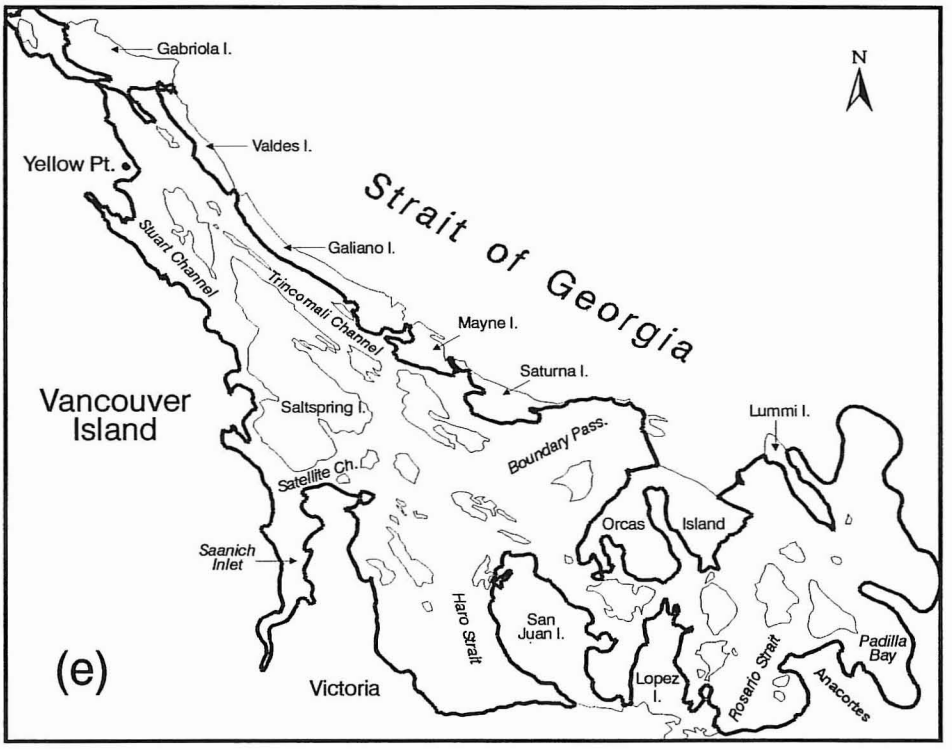

Figure 2(e). Detailed coastal boundary for the Gulf-San Juan Islands region.

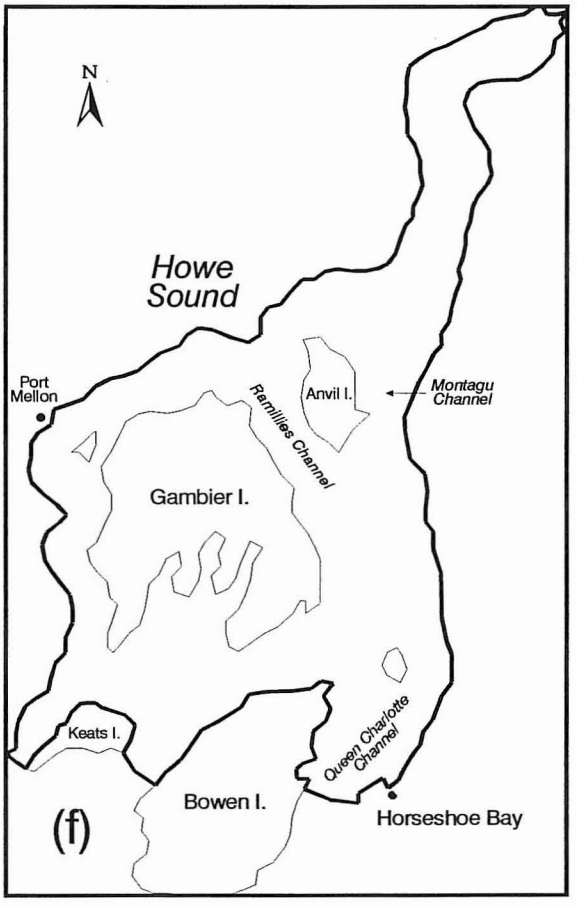

Figure 2(f). Detailed coastal boundary for Howe Sound.

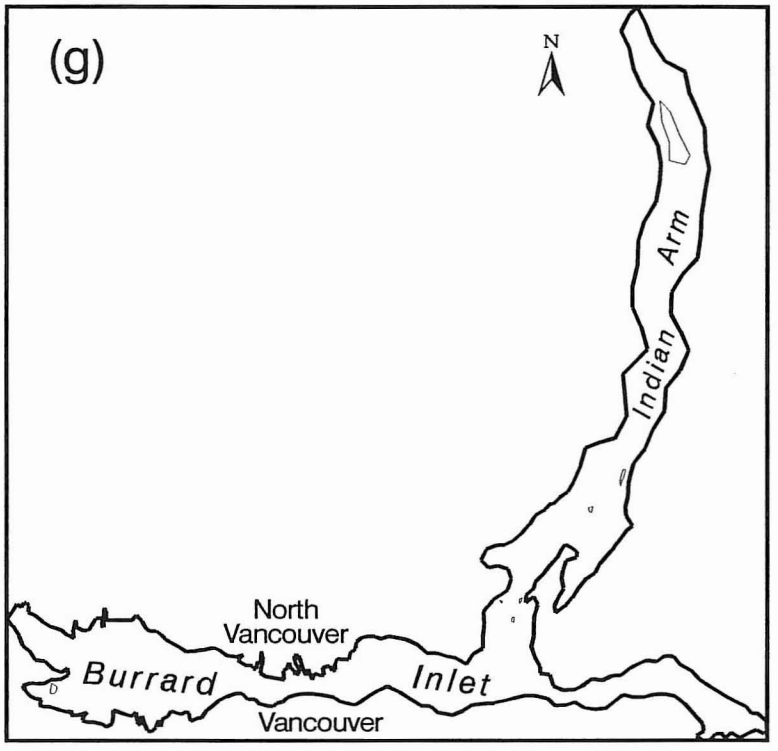

Figure 2(g). Detailed coastal boundary for Burrard Inlet, Indian Arm area.

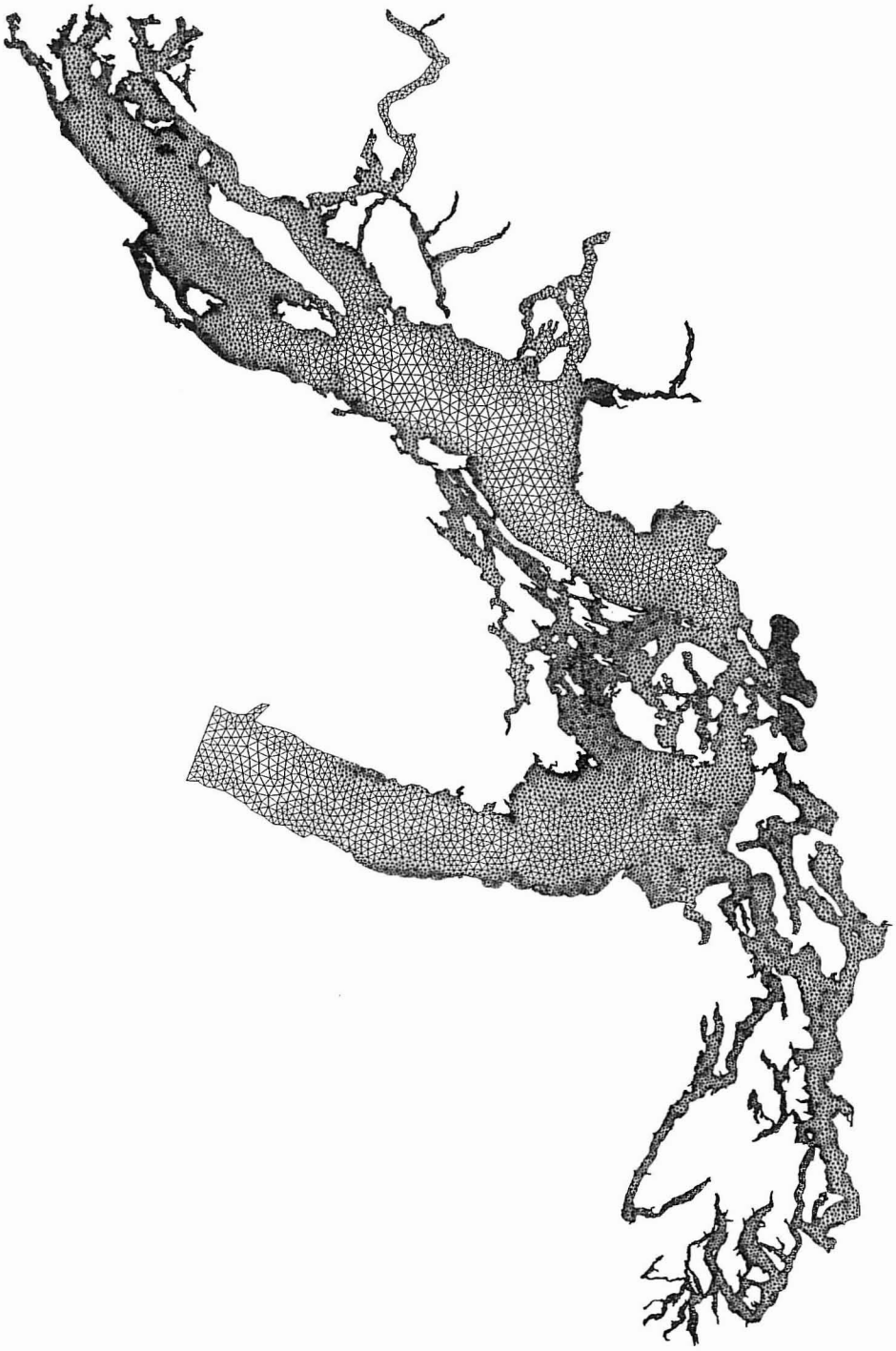

Figure 3. The finite-element grid covering the coastal waters of southern British Columbia and northern Washington State. The grid array for Puget Sound and Hood Canal was provided by Dr. Roy Walters of the United States Geological Survey. The grid array for the remaining portion of the region is from an extended version of the grid used by Foreman et al. (1995).

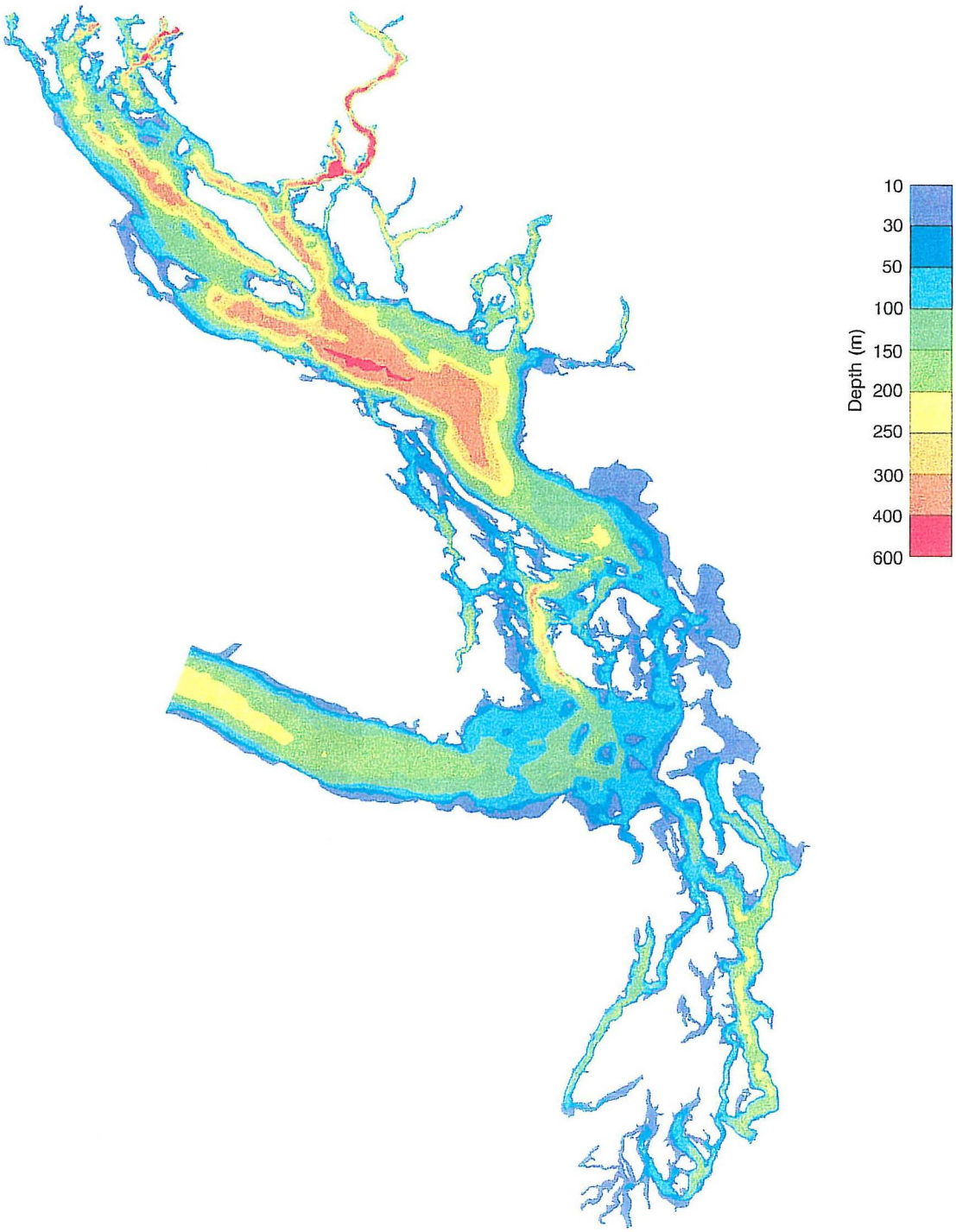

Figure 4. Map of the low water depths derived from the finite-element grid in Figure 3.

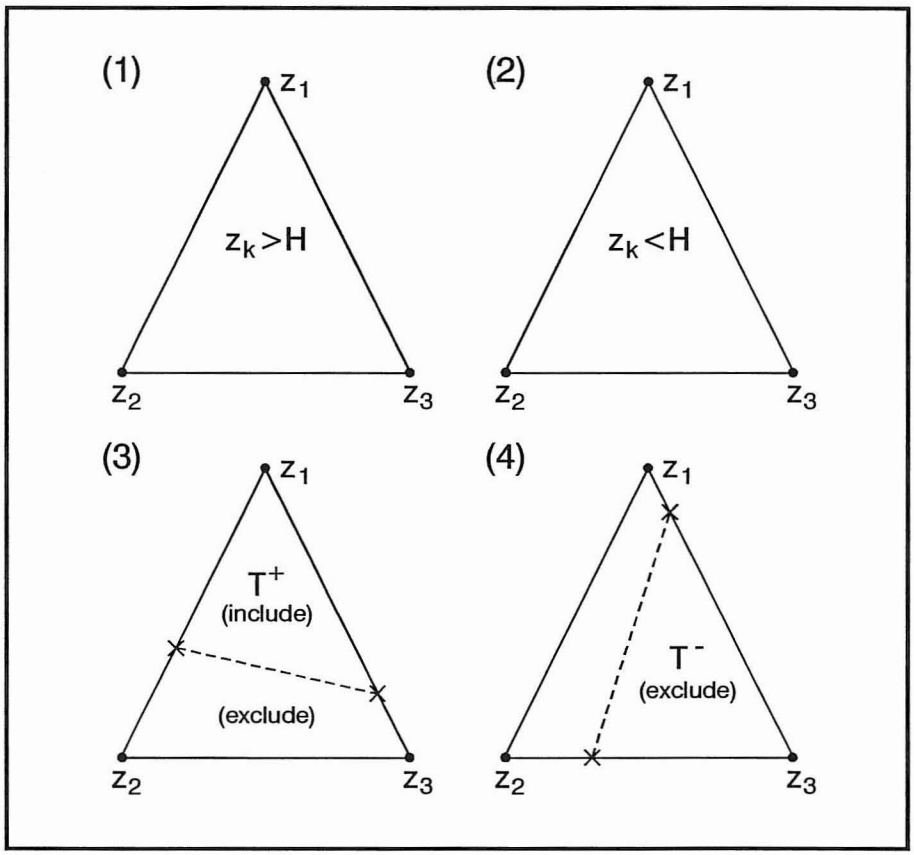

Figure 5. Surface area determination for depth, H, for the four possible configurations of the triangular grid elements: (1) All three nodes have depths $z_k \geq H$; $k = 1,2,3$; (2) no nodes have depths $z_k \geq H$; (3) one of the nodes (z_1) has depth $z_1 \geq H$ while the other two nodes have depths less than H; and (4) two of the nodes, z_1, z_2, have depths z_1, $z_2 \geq H$ but the other node has depth less than H. The "x"s denote locations along the sides of the triangles where the interpolated depths are equal to H. T^+ denotes the triangle to be included in the depth integration for case 3 while T^- denotes the triangle to be excluded from the depth integration for case 4.