MARINE SCIENCES RESEARCH CENTER
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PREDICTED CHANGES IN TIDAL CIRCULATION IN THE LOWER BAY OF NEW YORK HARBOR RESULTING FROM DEEPENING A SECTION OF AMBROSE CHANNEL

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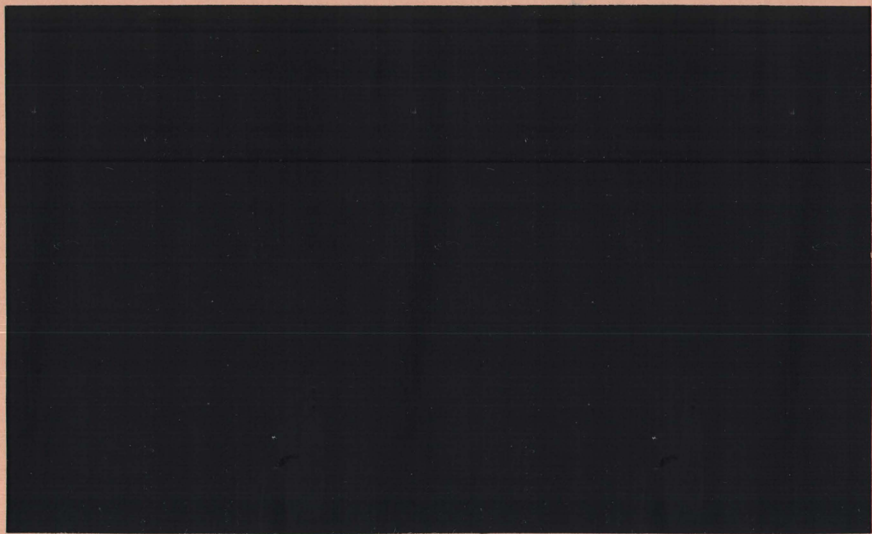

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ABSTRACT

The possible consequences of deepening to 70 feet a section of the Ambrose Channel which gives access to the Lower Bay of New York Harbor were assessed.

A vertically integrated, non-linear, finite difference numerical model was utilized. The simulated tidal amplitudes and maximum currents were compared with presently existing conditions. The results indicate a reduction in the area of least tidal amplitude (close to Sandy Hook) and a very small increase on the order of 1 or 2 mm throughout the study area, attaining a maximum of 3 mm close to the south shore of Staten Island. The pattern of maximum tidal currents did not change appreciably, although there is a tendency for slight increases on the order of a few cm/s in the immediate vicinity of the Ambrose Channel deepening.

INTRODUCTION

Mining of sand and gravel in New York Harbor is an important economic activity whose impacts on the environment are a matter of concern.

The effects of changes in the bathymetry resulting from simulated sand and gravel mining in areas of potential interest within the Lower Bay have been assessed by Wong and Wilson (1979). Their study utilized a finite element numerical model; the results suggested an increase in tidal range along Staten Island and current perturbations in the area of the borrow pits.

In a study of changes in tidal circulation due to the construction of containment islands in the Lower Bay (Vieira, 1986), the simulations from another numerical model indicated very small changes (on the order of a few millimeters) in tidal elevation throughout the study area. The changes in maximum tidal currents were concentrated in a pattern around the islands.

The purpose of the study here described is to evaluate the perturbations suffered by the tidal regime of Lower New York Harbor due to deepening the Ambrose Channel, through the transect from Sandy Hook to Breezy Point, by mining operations.

METHODS

A numerical model was used to simulate the tidal conditions in the Bay, first for the existing bathymetry and then for a deepened Ambrose Channel. The model is a vertically integrated, two-dimensional, non-linear, semi-implicit finite difference numerical algorithm based on the Leendertse (1967) scheme. This hydrodynamic model has been utilized in several estuaries and shallow ocean areas and found to be efficient and accurate in its results, as illustrated by the work of Hess and White (1974), Bowman et al. (1980), Chiswell (1983) and Vieira (1986).

The model uses the vertically integrated continuity and momentum equations, is fully non-linear, includes advective terms and parameterizes the bottom stress through a Chezy coefficient.

A grid with a mesh of 200 meters was applied to the study area (Figure 1). Such a fine mesh was necessary to accommodate the configuration of the deepened region within Ambrose Channel. The model has to be supplied with mean low water depths for each grid element, as well as with sea level elevation on all open boundaries. The geometric and bathymetric data was taken from the National Ocean Survey Chart No. 12327, 80th Edition, December 1984.

The open boundaries were at the entrance to Rockaway Inlet, the transect between Sandy Hook and Breezy Point, the mouth of Arthur

Kill at Tottenville, the mouth of the Raritan River (Perth Amboy to South Amboy) and the transect between Fort Wadsworth and Fort Hamilton at the Narrows. Mean tidal amplitudes and phases at these boundaries were extracted from the predicted tidal information supplied by NOS (1988).

Given the preponderance of the semi-diurnal M2 component in the tides of this area, the model was forced at the boundaries with this harmonic, with a time step of 62.1 seconds (one M2 lunar minute). The Courant-Friedrichs-Lewy stability criterion was followed in this choice.

No wind stress forcing was applied, since this study deals only with the tidally forced circulation. This report deals solely with the astronomically determined tidal signals in the Lower Bay of New York Harbor; no effort was made to include non-tidally driven forcing, such as gravitationally or wind induced effects.

The model was spun-up with the existing bathymetry for several tidal cycles until steady-state conditions were observed. This procedure was repeated for a deepened Ambrose Channel configuration; the results were then compared.

In this simulation, the Ambrose Channel was deepened from its existing depth of 45 feet to 70 feet between the ocean boundary of the model (i.e., the transect between Sandy Hook and Breezy Point) and a line connecting chanel buoys 7 and 6.

RESULTS

The tidal amplitude is defined as one half of the tidal range, which is the difference in elevation between High Water and Low Water during one tidal cycle (12.42 hours).

a) Existing bathymetry: The tidal amplitude (Figure 2), referred to mean sea level, does not vary by more than 6 cm throughout the system. The maximum tidal current isotachs during one tidal cycle are shown in Figure 3; the currents only reach above 25 cm/s in the initial part of the Ambrose and Sandy Hook channels. In fact, the currents are below 15 cm/s throughout most of the area.

b) Deepened Ambrose Channel: The tidal amplitude (Figure 4) spatial gradient is the same as before. However, there is a sizable reduction of the area inside the 69-cm isoline (i.e., amplitudes between 68 and 69 cm) which became restricted to the vicinity of Sandy Hook. The increases in tidal amplitude at individual locations are primarily between 1 and 2 mm; they attain a maximum of 3 mm only in the region of the south shore of Staten Island.

The pattern of maximum tidal currents does not appear to have changed substantially anywhere in the Bay (Figure 5) except in the immediate vicinity of the Ambrose Channel deepening. Here the pattern was very slightly displaced to the south, while the 20-cm/s isotach now extends further into the Bay than before. Otherwise, throughout the system site specific increases or decreases in current magnitude average about 0.5 cm/s.

These results are consistent with the increased conveyance at the Breezy Point-Sandy Hook transect offered by a deepened Ambrose Channel. An enlarged tidal prism results in slightly higher amplitudes throughout, whereas the current magnitude may be affected in different ways at different locations. These results must also be judged in relation to the oscillations resulting from the fortnightly lunar cycle (on the order of 30 cm), non-tidally driven fluctuations (15 cm or more) and a rising trend in mean sea level of 3 mm/year.

The tidal elevation referred to mean sea level and the two orthogonal components of the tidal current are also computed by the model at each grid element. Figures 6 to 11 allow a comparison of the parameters before and after the hypothetical deepening of Ambrose Channel at the three locations indicated in Figure 1. The differences are very small.

CONCLUSIONS

It appears from the simulations that some minor changes in the tidal regime throughout the Lower Bay of New York Harbor might result from the deepening of the Ambrose Channel through the transect. Tidal amplitudes would increase by no more than 3 mm (south Staten Island), which is negligible compared to spring-neap fortnightly oscillations, non-tidally forced fluctuations and a rising trend in mean sea level. Similarly, the increases in tidal current magnitude are one order of magnitude smaller than the tidal streams themselves; they only produce a different configuration of the isotachs in the vicinity of the Ambrose Channel deepened location.

ACKNOWLEDGMENTS

We thank Dr. Malcolm Bowman and Dr. Andre Visser for making the numerical model available to us.

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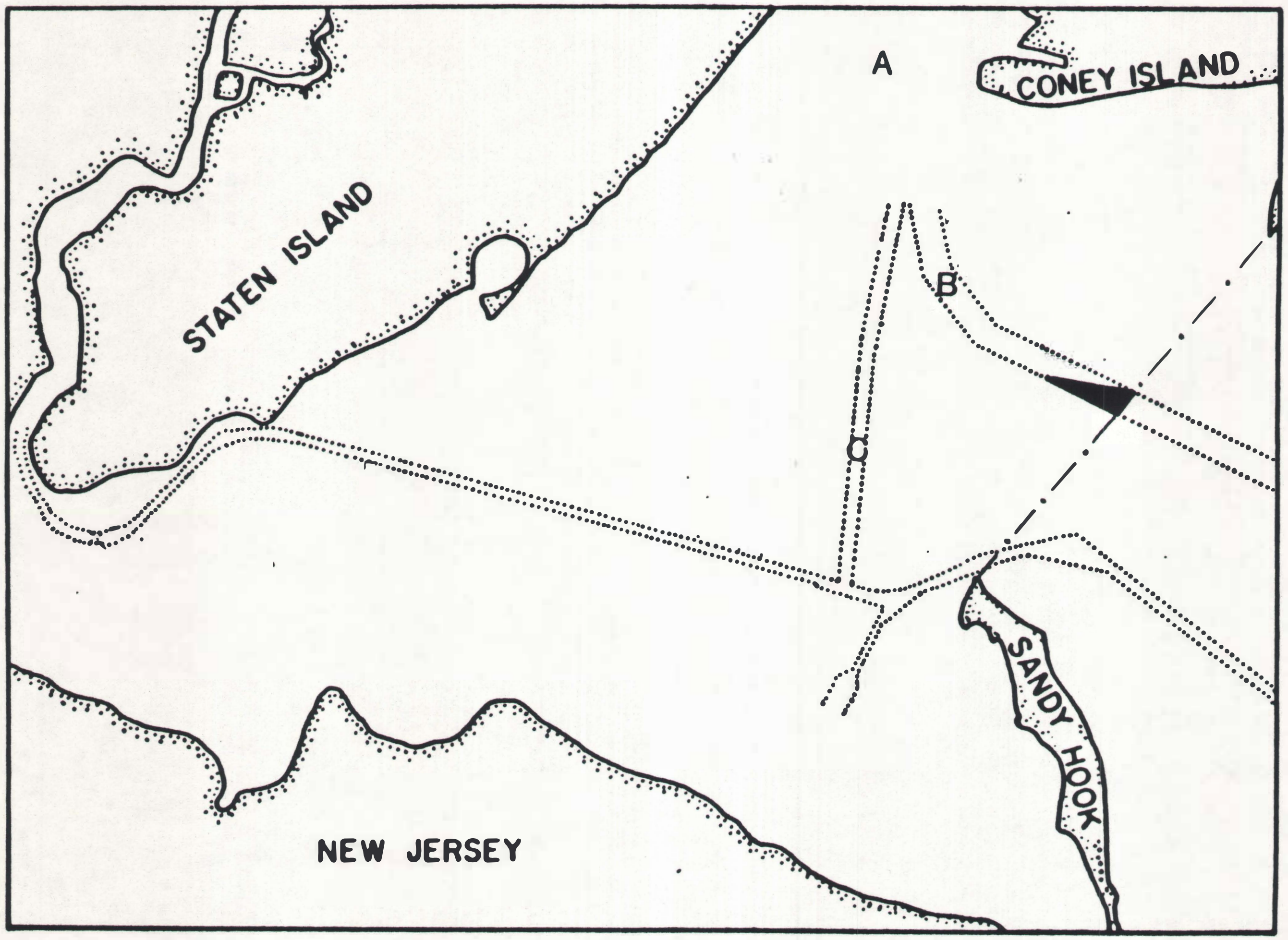

Figure 1. The study area. The black triangle denotes the Ambrose Channel deepened to 70 ft. The letters A, B and C indicate the location of the elements referred to in Fig. 6-11. The -·-·- is the ocean boundary of the model.

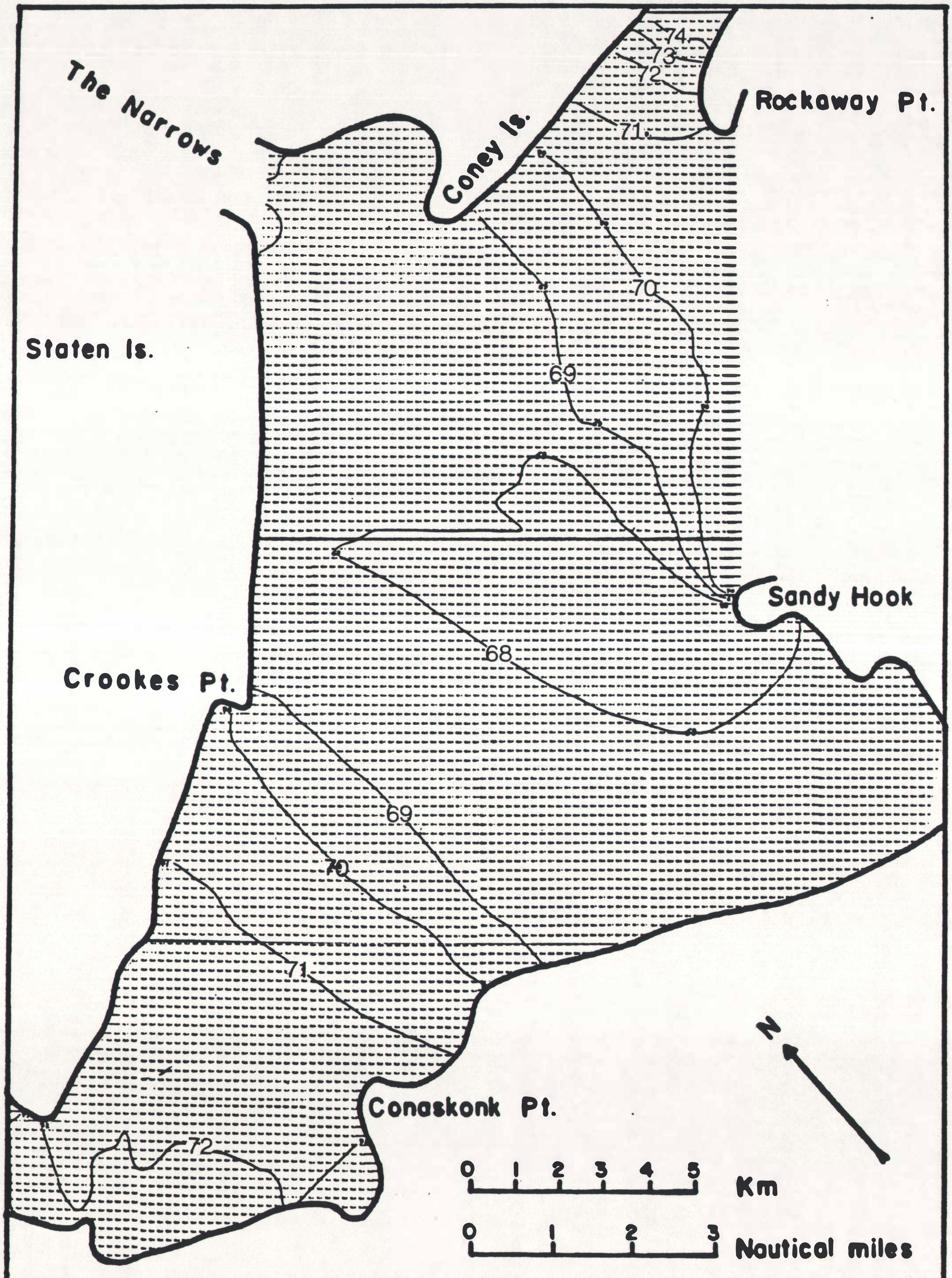

Figure 2. Present bathymetry. Tidal amplitude referred to MSL (cm).

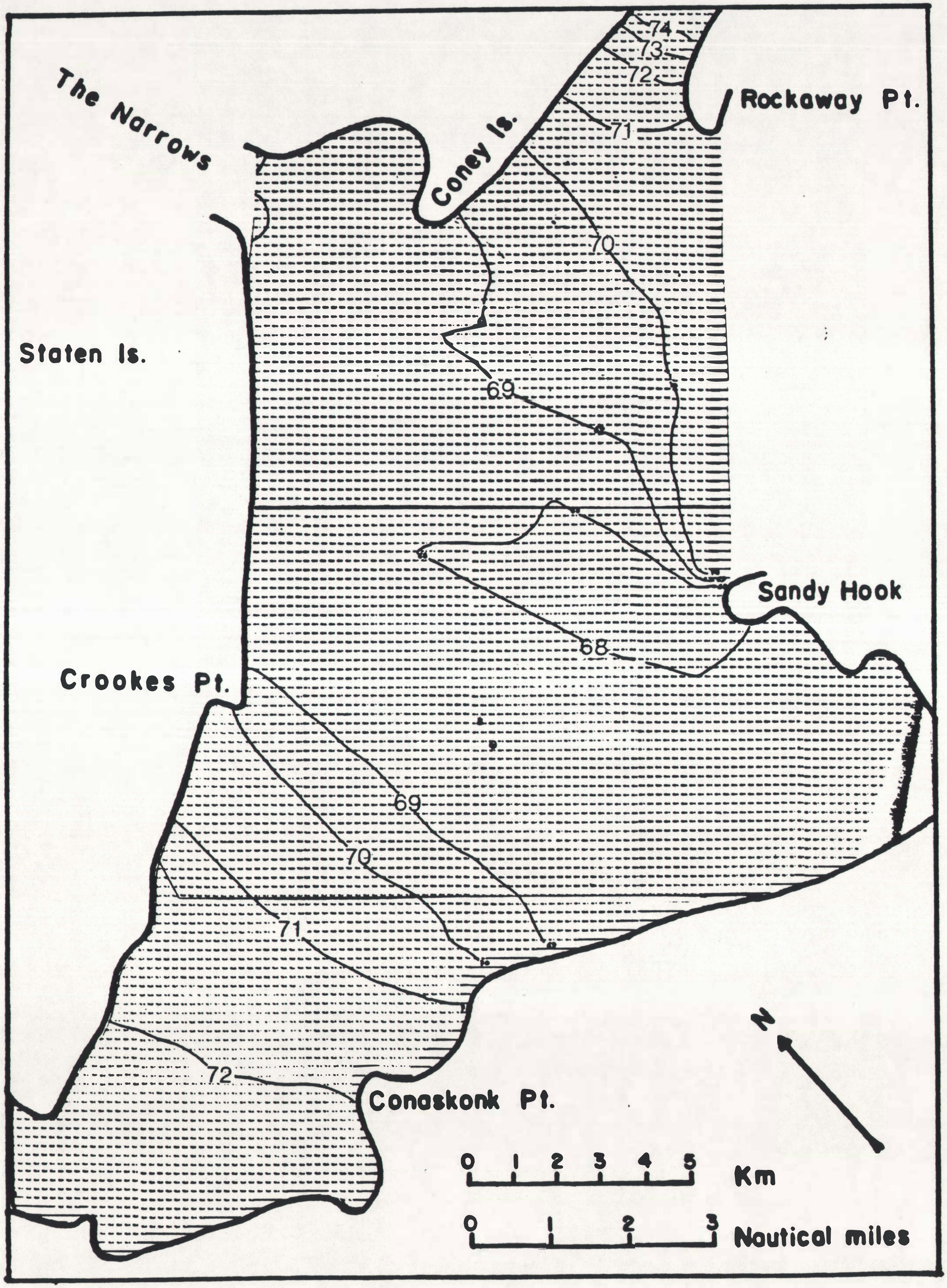

Figure 3. Ambrose Channel deepened. Tidal amplitude referred to MSL (cm).

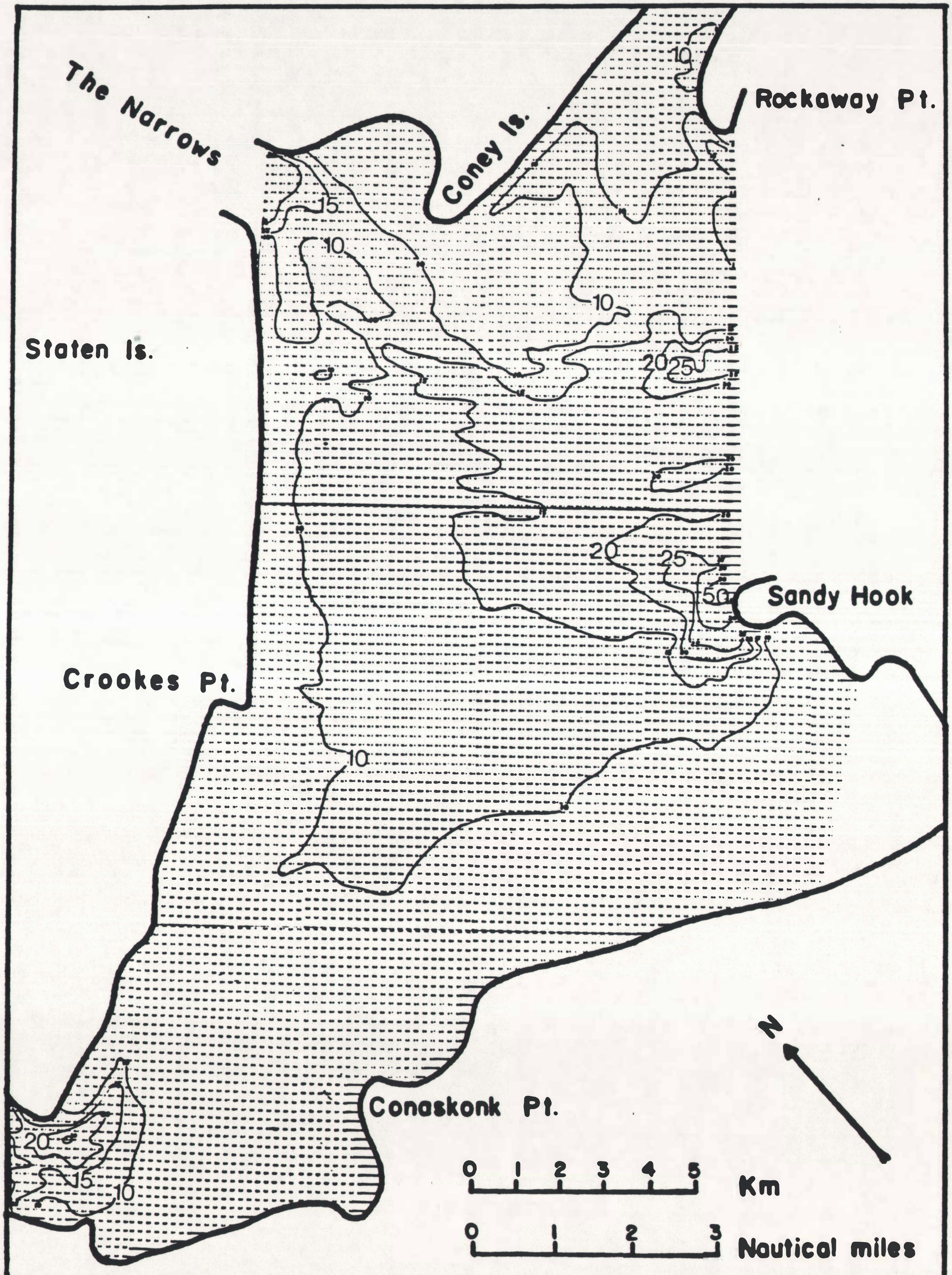

Figure 4. Present bathymetry. Maximum tidal currents (cm/s).

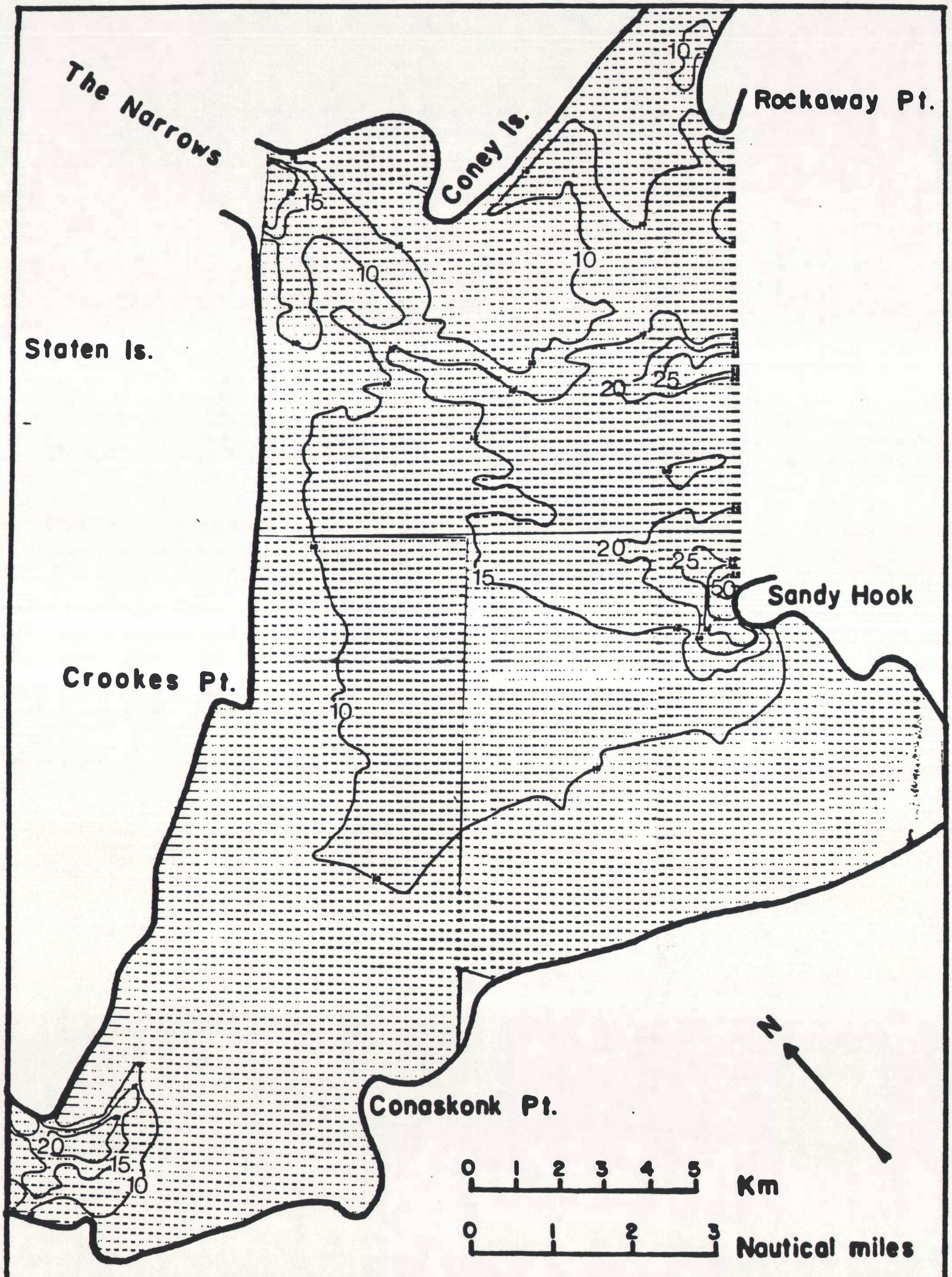

Figure 5. Ambrose Channel deepened. Maximumtidal currents (cm/s).

TIME	SE	V	U	VORTICITY
49.68	-0.120	0.077	0.087	-69.123
49.89	-0.051	0.080	0.090	-79.025
50.09	0.021	0.082	0.092	-87.851
50.30	0.091	0.083	0.093	-95.130
50.51	0.161	0.084	0.093	-100.839
50.72	0.230	0.083	0.093	-105.094
50.92	0.296	0.082	0.092	-108.059
51.13	0.359	0.080	0.090	-109.811
51.34	0.419	0.077	0.087	-110.434
51.54	0.474	0.074	0.083	-110.009
51.75	0.524	0.069	0.079	-108.644
51.96	0.569	0.064	0.073	-106.453
52.16	0.607	0.058	0.067	-103.597
52.37	0.639	0.052	0.060	-100.281
52.58	0.664	0.044	0.052	-96.757
52.78	0.681	0.037	0.043	-93.388
52.99	0.691	0.028	0.034	-90.695
53.20	0.694	0.020	0.023	-89.372
53.41	0.688	0.012	0.012	-90.031
53.61	0.675	0.005	-0.001	-91.852
53.82	0.654	-0.003	-0.014	-91.172
54.03	0.626	-0.014	-0.028	-84.488
54.23	0.588	-0.024	-0.038	-71.873
54.44	0.545	-0.031	-0.045	-56.139
54.65	0.497	-0.037	-0.051	-40.086
54.85	0.444	-0.043	-0.057	-24.555
55.06	0.386	-0.050	-0.064	-9.468
55.27	0.325	-0.056	-0.069	5.195
55.48	0.259	-0.062	-0.075	19.244
55.68	0.192	-0.068	-0.080	32.474
55.89	0.122	-0.073	-0.084	44.764
56.10	0.052	-0.077	-0.088	55.988
56.30	-0.018	-0.080	-0.091	66.002
56.51	-0.088	-0.083	-0.093	74.667
56.72	-0.157	-0.084	-0.094	81.908
56.92	-0.224	-0.085	-0.094	87.766
57.13	-0.289	-0.085	-0.093	92.328
57.34	-0.350	-0.084	-0.092	95.667
57.55	-0.408	-0.082	-0.089	97.840
57.75	-0.462	-0.079	-0.086	98.894
57.96	-0.511	-0.075	-0.082	98.894
58.17	-0.555	-0.071	-0.076	97.911
58.37	-0.592	-0.065	-0.070	96.055
58.58	-0.624	-0.058	-0.063	93.492
58.79	-0.648	-0.050	-0.055	90.477
58.99	-0.666	-0.042	-0.046	87.379
59.20	-0.676	-0.032	-0.036	84.791
59.41	-0.678	-0.023	-0.025	83.740
59.62	-0.673	-0.013	-0.014	85.390
59.82	-0.661	-0.003	-0.001	88.698
60.03	-0.641	0.006	0.012	88.779
60.24	-0.614	0.017	0.026	81.461
60.44	-0.580	0.029	0.039	67.217
60.65	-0.538	0.039	0.049	47.823
60.86	-0.491	0.046	0.057	26.669
61.06	-0.439	0.053	0.063	6.428
61.27	-0.382	0.058	0.069	-11.966
61.48	-0.322	0.064	0.074	-28.478
61.69	-0.257	0.069	0.079	-43.365
61.89	-0.190	0.073	0.083	-56.753
62.10	-0.121	0.077	0.087	-68.655

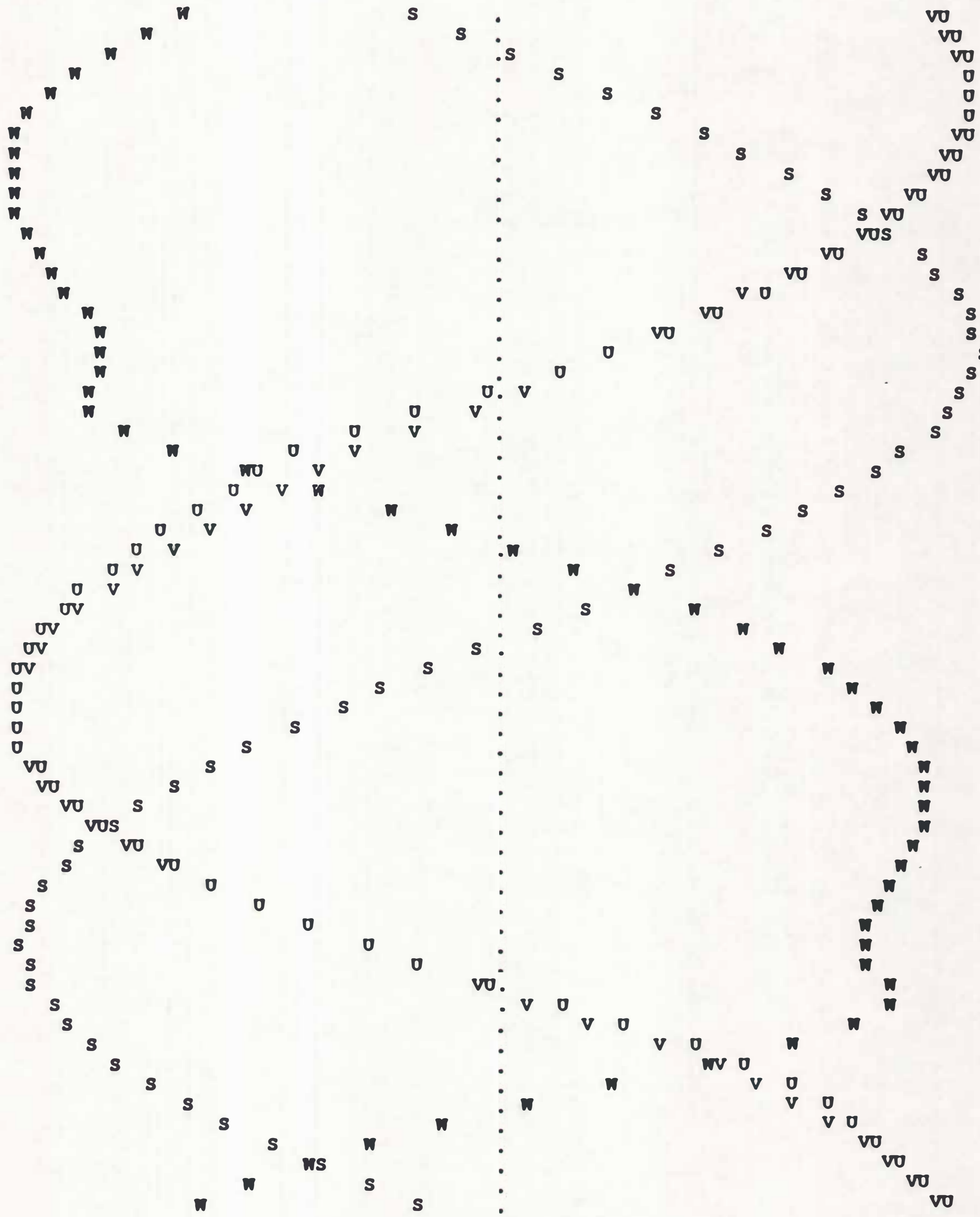

Figure 6. Present bathymetry. Tidal elevation referred to MSL (S) and tidal current components towards NE (U) and SE (V) at grid element A, during one tidal cycle (12.42 hours). Units: m and m/s.

TIME	SE	V	U	VORTICITY
49.68	-0.136	-0.114	0.029	6.438
49.89	-0.067	-0.117	0.031	5.753
50.09	0.004	-0.120	0.033	5.683
50.30	0.075	-0.122	0.034	6.063
50.51	0.145	-0.123	0.036	6.710
50.72	0.214	-0.123	0.037	7.460
50.92	0.281	-0.123	0.037	8.210
51.13	0.345	-0.122	0.038	8.903
51.34	0.406	-0.120	0.038	9.491
51.54	0.463	-0.117	0.037	9.934
51.75	0.515	-0.113	0.037	10.200
51.96	0.561	-0.108	0.035	10.272
52.16	0.602	-0.103	0.033	10.139
52.37	0.635	-0.096	0.031	9.777
52.58	0.662	-0.088	0.028	9.184
52.78	0.682	-0.079	0.024	8.348
52.99	0.693	-0.069	0.020	7.236
53.20	0.696	-0.056	0.014	5.830
53.41	0.691	-0.042	0.007	4.105
53.61	0.678	-0.024	-0.001	2.231
53.82	0.658	-0.002	-0.012	0.815
54.03	0.630	0.027	-0.019	-3.356
54.23	0.593	0.052	-0.021	-11.264
54.44	0.550	0.068	-0.021	-18.967
54.65	0.503	0.079	-0.022	-24.019
54.85	0.452	0.088	-0.023	-26.823
55.06	0.396	0.094	-0.024	-28.194
55.27	0.335	0.099	-0.026	-28.838
55.48	0.272	0.104	-0.027	-29.166
55.68	0.206	0.107	-0.029	-29.454
55.89	0.138	0.110	-0.030	-29.837
56.10	0.069	0.112	-0.031	-30.363
56.30	0.000	0.114	-0.032	-31.015
56.51	-0.070	0.116	-0.033	-31.726
56.72	-0.138	0.117	-0.033	-32.403
56.92	-0.205	0.118	-0.034	-32.960
57.13	-0.270	0.118	-0.034	-33.335
57.34	-0.333	0.117	-0.033	-33.485
57.55	-0.392	0.116	-0.033	-33.374
57.75	-0.447	0.114	-0.032	-32.972
57.96	-0.498	0.111	-0.031	-32.258
58.17	-0.544	0.108	-0.030	-31.208
58.37	-0.584	0.103	-0.028	-29.803
58.58	-0.618	0.098	-0.026	-28.026
58.79	-0.645	0.092	-0.024	-25.859
58.99	-0.665	0.085	-0.021	-23.281
59.20	-0.678	0.077	-0.018	-20.271
59.41	-0.682	0.067	-0.014	-16.800
59.62	-0.678	0.057	-0.009	-12.860
59.82	-0.666	0.043	-0.003	-8.443
60.03	-0.646	0.027	0.004	-3.769
60.24	-0.620	0.007	0.013	0.581
60.44	-0.587	-0.022	0.019	8.425
60.65	-0.546	-0.048	0.021	18.427
60.86	-0.500	-0.067	0.020	23.289
61.06	-0.449	-0.081	0.020	22.373
61.27	-0.394	-0.090	0.021	18.586
61.48	-0.334	-0.098	0.023	14.327
61.69	-0.272	-0.104	0.025	10.702
61.89	-0.206	-0.110	0.027	8.085
62.10	-0.137	-0.114	0.029	6.480

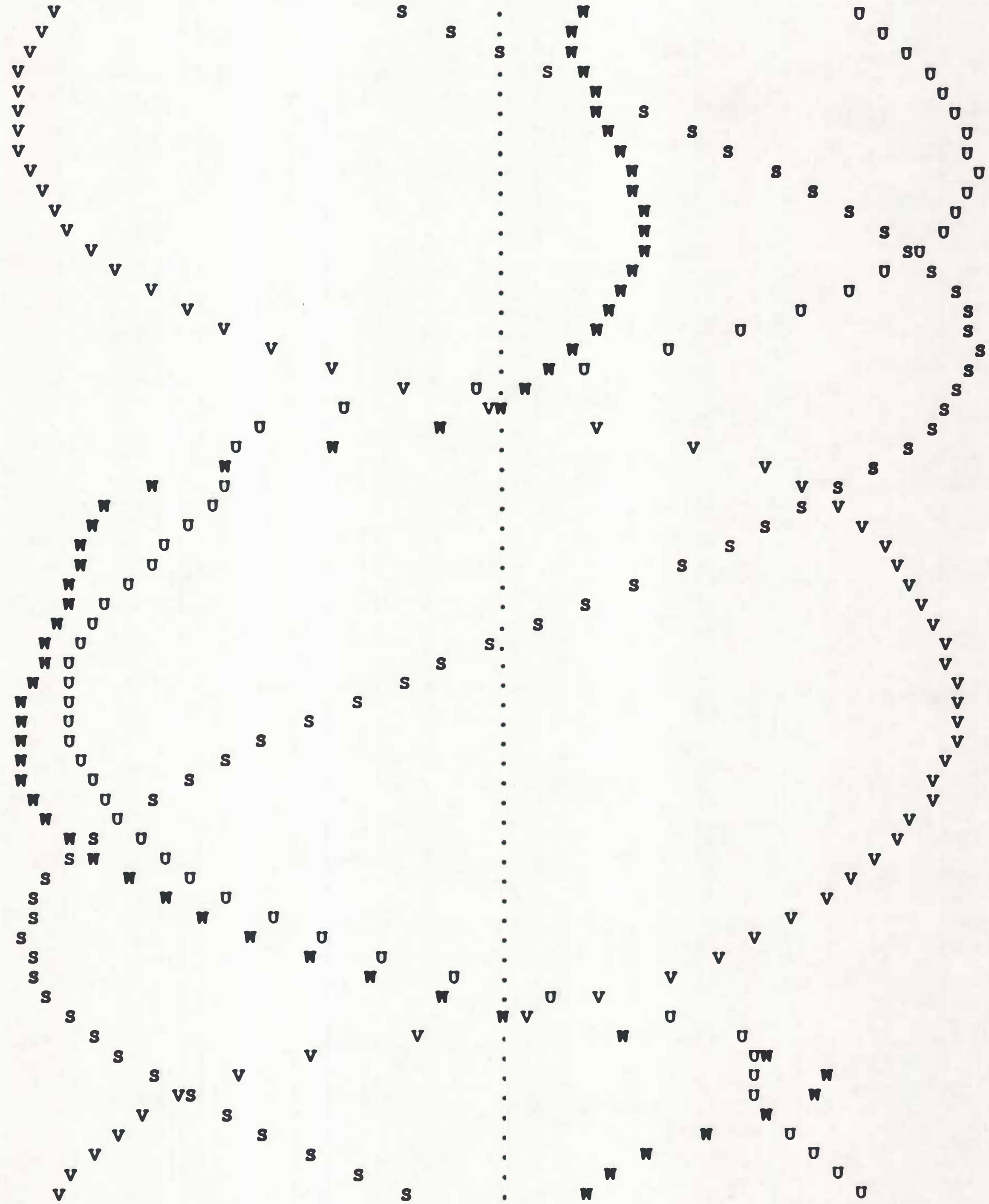

Figure 7. Present bathymetry. Tidal elevation referred to MSL (S) and tidal current components towards NE (U) and SE (V) at grid element B, during one tidal cycle (12.42 hours). Units: m and m/s.

TIME	SE	V	U	VORTICITY
49.68	-0.255	-0.003	0.137	35.512
49.89	-0.194	-0.003	0.143	37.075
50.09	-0.129	-0.003	0.148	38.559
50.30	-0.063	-0.003	0.153	39.865
50.51	0.004	-0.003	0.157	40.966
50.72	0.071	-0.003	0.160	41.818
50.92	0.138	-0.003	0.162	42.374
51.13	0.205	-0.003	0.163	42.599
51.34	0.270	-0.003	0.162	42.471
51.54	0.334	-0.002	0.160	41.975
51.75	0.394	-0.002	0.157	41.086
51.96	0.451	-0.002	0.152	39.797
52.16	0.504	-0.001	0.146	38.088
52.37	0.552	-0.001	0.138	35.939
52.58	0.594	0.000	0.127	33.332
52.78	0.630	0.001	0.115	30.242
52.99	0.659	0.002	0.100	26.627
53.20	0.680	0.004	0.082	22.436
53.41	0.691	0.006	0.061	17.563
53.61	0.691	0.011	0.034	11.836
53.82	0.679	0.021	-0.001	4.373
54.03	0.661	0.026	-0.033	-6.797
54.23	0.632	0.022	-0.056	-15.867
54.44	0.596	0.015	-0.074	-19.333
54.65	0.556	0.010	-0.087	-18.862
54.85	0.513	0.007	-0.097	-16.653
55.06	0.465	0.006	-0.105	-14.051
55.27	0.413	0.005	-0.112	-11.623
55.48	0.358	0.004	-0.118	-9.607
55.68	0.301	0.004	-0.124	-8.036
55.89	0.242	0.003	-0.129	-6.853
56.10	0.181	0.002	-0.134	-5.966
56.30	0.119	0.001	-0.138	-5.296
56.51	0.056	0.001	-0.142	-4.779
56.72	-0.007	0.000	-0.145	-4.365
56.92	-0.069	-0.001	-0.147	-4.017
57.13	-0.131	-0.002	-0.148	-3.705
57.34	-0.192	-0.003	-0.149	-3.408
57.55	-0.251	-0.004	-0.149	-3.110
57.75	-0.309	-0.005	-0.148	-2.799
57.96	-0.364	-0.006	-0.146	-2.463
58.17	-0.416	-0.007	-0.144	-2.085
58.37	-0.465	-0.007	-0.140	-1.660
58.58	-0.509	-0.008	-0.135	-1.167
58.79	-0.550	-0.009	-0.128	-0.587
58.99	-0.585	-0.009	-0.120	0.103
59.20	-0.615	-0.010	-0.110	0.947
59.41	-0.638	-0.010	-0.098	1.991
59.62	-0.654	-0.010	-0.083	3.326
59.82	-0.661	-0.010	-0.064	5.080
60.03	-0.658	-0.012	-0.040	7.417
60.24	-0.641	-0.018	-0.007	9.835
60.44	-0.621	-0.022	0.027	10.898
60.65	-0.593	-0.017	0.053	12.591
60.86	-0.557	-0.011	0.073	16.405
61.06	-0.517	-0.007	0.089	21.151
61.27	-0.473	-0.005	0.102	25.449
61.48	-0.424	-0.003	0.113	28.824
61.69	-0.372	-0.003	0.122	31.443
61.89	-0.315	-0.003	0.129	33.579
62.10	-0.256	-0.003	0.136	35.427

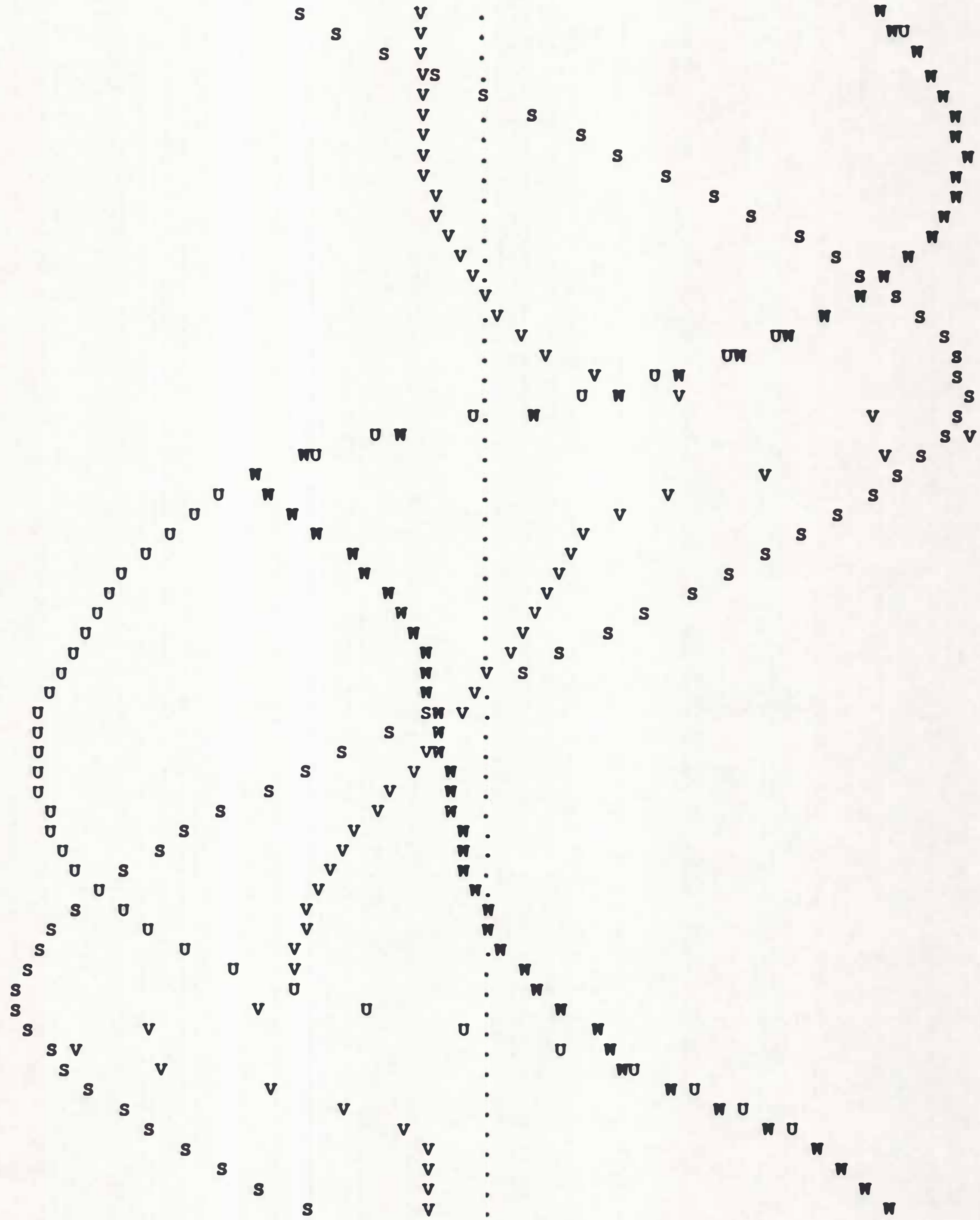

Figure 8. Present bathymetry. Tidal elevation referred to MSL (S) and tidal current components towards NE (U) and SE (V) at grid element C, during one tidal cycle (12.42 hours). Units: m and m/s.

TIME	SE	V	U	VORTICITY
49.68	-0.105	0.065	0.075	-58.030
49.89	-0.048	0.063	0.073	-64.597
50.09	0.024	0.068	0.079	-71.118
50.30	0.094	0.071	0.081	-77.454
50.51	0.165	0.072	0.083	-83.041
50.72	0.233	0.072	0.083	-87.919
50.92	0.299	0.072	0.083	-91.635
51.13	0.362	0.070	0.081	-94.305
51.34	0.421	0.068	0.079	-95.847
51.54	0.476	0.065	0.076	-96.299
51.75	0.526	0.061	0.071	-95.838
51.96	0.571	0.056	0.066	-94.544
52.16	0.609	0.051	0.060	-92.565
52.37	0.640	0.044	0.054	-90.139
52.58	0.665	0.037	0.046	-87.544
52.78	0.682	0.030	0.038	-85.161
52.99	0.692	0.022	0.029	-83.532
53.20	0.694	0.015	0.019	-83.281
53.41	0.689	0.008	0.008	-84.588
53.61	0.675	0.000	-0.005	-85.915
53.82	0.654	-0.008	-0.019	-83.412
54.03	0.625	-0.018	-0.031	-74.939
54.23	0.587	-0.027	-0.040	-61.502
54.44	0.544	-0.032	-0.046	-46.238
54.65	0.496	-0.037	-0.051	-31.579
54.85	0.443	-0.042	-0.056	-17.877
55.06	0.385	-0.048	-0.061	-4.704
55.27	0.324	-0.053	-0.067	8.121
55.48	0.258	-0.059	-0.072	20.499
55.68	0.191	-0.064	-0.076	32.298
55.89	0.121	-0.069	-0.081	43.413
56.10	0.051	-0.073	-0.084	53.704
56.30	-0.020	-0.076	-0.087	62.993
56.51	-0.090	-0.078	-0.088	71.092
56.72	-0.158	-0.079	-0.089	77.890
56.92	-0.225	-0.080	-0.089	83.401
57.13	-0.290	-0.079	-0.088	87.689
57.34	-0.352	-0.078	-0.087	90.820
57.55	-0.410	-0.077	-0.084	92.851
57.75	-0.464	-0.074	-0.081	93.830
57.96	-0.513	-0.070	-0.077	93.816
58.17	-0.556	-0.065	-0.071	92.899
58.37	-0.594	-0.060	-0.065	91.200
58.58	-0.625	-0.053	-0.058	88.891
58.79	-0.649	-0.045	-0.050	86.238
58.99	-0.666	-0.037	-0.042	83.649
59.20	-0.676	-0.028	-0.032	81.765
59.41	-0.679	-0.019	-0.022	81.638
59.62	-0.674	-0.009	-0.011	84.017
59.82	-0.661	0.000	0.002	87.018
60.03	-0.641	0.009	0.015	85.623
60.24	-0.614	0.019	0.028	77.076
60.44	-0.580	0.030	0.040	62.197
60.65	-0.538	0.040	0.050	42.841
60.86	-0.490	0.046	0.057	22.448
61.06	-0.438	0.051	0.062	3.530
61.27	-0.381	0.056	0.067	-13.284
61.48	-0.320	0.061	0.071	-28.229
61.69	-0.256	0.065	0.076	-41.703
61.89	-0.189	0.069	0.080	-53.886
62.10	-0.120	0.073	0.083	-64.807

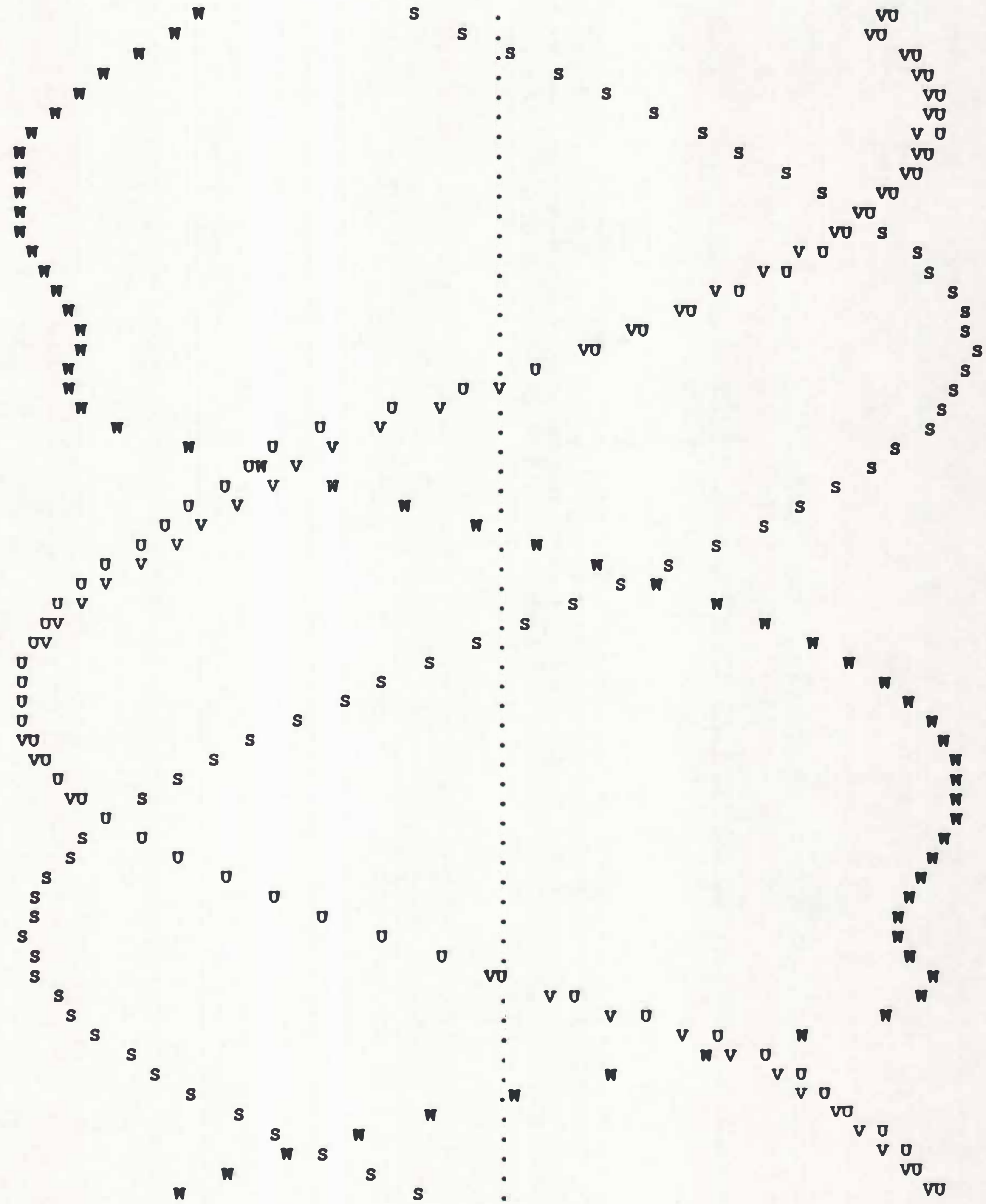

Figure 9. Ambrose Channel deepened. Tidal elevation referred to MSL (S) and tidal current components towards NE (U) and SE (V) at grid element A, during one tidal cycle (12.42 hours). Units: m and m/s.

TIME	SE	V	U	VORTICITY
49.68	-0.115	-0.114	0.025	4.653
49.89	-0.054	-0.117	0.026	3.535
50.09	0.012	-0.126	0.026	3.929
50.30	0.083	-0.129	0.029	4.012
50.51	0.153	-0.130	0.030	4.285
50.72	0.222	-0.131	0.032	5.162
50.92	0.289	-0.130	0.033	6.208
51.13	0.353	-0.129	0.034	7.215
51.34	0.413	-0.127	0.034	8.119
51.54	0.469	-0.124	0.034	8.857
51.75	0.520	-0.119	0.033	9.390
51.96	0.566	-0.114	0.032	9.689
52.16	0.606	-0.108	0.030	9.747
52.37	0.639	-0.101	0.028	9.553
52.58	0.665	-0.093	0.025	9.092
52.78	0.684	-0.083	0.021	8.373
52.99	0.695	-0.072	0.017	7.369
53.20	0.697	-0.059	0.012	6.067
53.41	0.692	-0.044	0.005	4.471
53.61	0.678	-0.025	-0.004	2.844
53.82	0.658	-0.002	-0.014	1.627
54.03	0.629	0.027	-0.020	-2.899
54.23	0.591	0.053	-0.021	-11.454
54.44	0.548	0.071	-0.021	-19.572
54.65	0.501	0.083	-0.021	-24.679
54.85	0.449	0.092	-0.022	-27.214
55.06	0.393	0.100	-0.023	-28.097
55.27	0.332	0.106	-0.024	-28.153
55.48	0.268	0.110	-0.026	-27.907
55.68	0.202	0.114	-0.027	-27.681
55.89	0.134	0.118	-0.028	-27.638
56.10	0.064	0.120	-0.029	-27.836
56.30	-0.005	0.123	-0.030	-28.245
56.51	-0.075	0.125	-0.031	-28.778
56.72	-0.144	0.126	-0.031	-29.314
56.92	-0.211	0.127	-0.031	-29.742
57.13	-0.276	0.127	-0.031	-29.992
57.34	-0.338	0.127	-0.030	-30.011
57.55	-0.397	0.125	-0.030	-29.767
57.75	-0.452	0.123	-0.029	-29.232
57.96	-0.503	0.120	-0.028	-28.387
58.17	-0.548	0.116	-0.027	-27.216
58.37	-0.588	0.111	-0.025	-25.709
58.58	-0.622	0.106	-0.023	-23.846
58.79	-0.648	0.099	-0.021	-21.607
58.99	-0.668	0.091	-0.018	-18.975
59.20	-0.680	0.083	-0.015	-15.920
59.41	-0.683	0.073	-0.011	-12.415
59.62	-0.679	0.061	-0.007	-8.433
59.82	-0.666	0.047	-0.001	-3.978
60.03	-0.646	0.030	0.006	0.733
60.24	-0.620	0.008	0.015	5.193
60.44	-0.586	-0.021	0.020	13.134
60.65	-0.545	-0.050	0.021	23.035
60.86	-0.498	-0.071	0.020	27.047
61.06	-0.446	-0.086	0.019	24.648
61.27	-0.390	-0.096	0.020	19.329
61.48	-0.331	-0.105	0.021	13.845
61.69	-0.268	-0.112	0.023	9.410
61.89	-0.201	-0.117	0.025	6.368
62.10	-0.133	-0.122	0.027	4.646

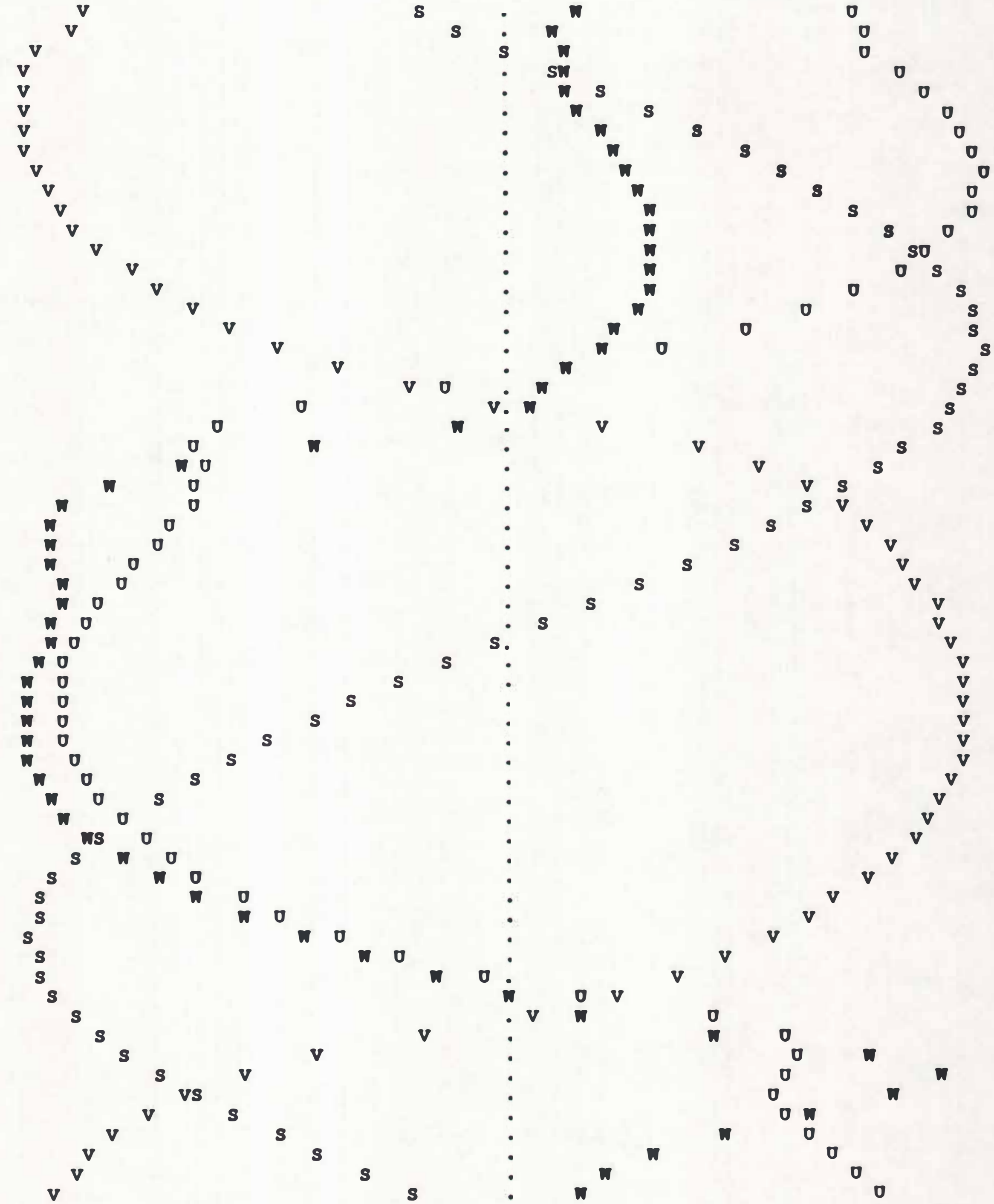

Figure 10. Ambrose Channel deepened. Tidal elevation referred to MSL (S) and tidal current components towards NE (U) and SE (V) at grid element B, during one tidal cycle (12.42 hours). Units: m and m/s.

TIME	SE	V	U	VORTICITY
49.68	-0.219	-0.002	0.128	33.142
49.89	-0.164	-0.002	0.134	34.241
50.09	-0.104	-0.004	0.138	36.189
50.30	-0.041	-0.004	0.144	38.163
50.51	0.024	-0.004	0.149	39.548
50.72	0.089	-0.004	0.153	40.518
50.92	0.155	-0.003	0.156	41.154
51.13	0.220	-0.003	0.157	41.467
51.34	0.284	-0.003	0.157	41.422
51.54	0.346	-0.003	0.156	40.989
51.75	0.406	-0.002	0.153	40.159
51.96	0.461	-0.002	0.148	38.917
52.16	0.513	-0.001	0.142	37.251
52.37	0.560	-0.001	0.134	35.147
52.58	0.601	0.000	0.123	32.577
52.78	0.636	0.001	0.111	29.521
52.99	0.664	0.002	0.096	25.945
53.20	0.684	0.004	0.078	21.783
53.41	0.694	0.006	0.056	16.955
53.61	0.693	0.011	0.029	11.276
53.82	0.680	0.022	-0.005	3.575
54.03	0.661	0.025	-0.036	-7.683
54.23	0.631	0.020	-0.059	-16.141
54.44	0.595	0.014	-0.075	-19.096
54.65	0.555	0.009	-0.089	-18.396
54.85	0.511	0.006	-0.098	-16.171
55.06	0.463	0.005	-0.106	-13.638
55.27	0.411	0.005	-0.113	-11.309
55.48	0.357	0.004	-0.119	-9.394
55.68	0.299	0.003	-0.125	-7.905
55.89	0.240	0.002	-0.130	-6.779
56.10	0.179	0.002	-0.135	-5.932
56.30	0.116	0.001	-0.139	-5.289
56.51	0.054	0.000	-0.143	-4.790
56.72	-0.009	-0.001	-0.146	-4.387
56.92	-0.072	-0.002	-0.148	-4.046
57.13	-0.134	-0.003	-0.149	-3.738
57.34	-0.195	-0.004	-0.150	-3.444
57.55	-0.254	-0.004	-0.150	-3.148
57.75	-0.312	-0.005	-0.149	-2.834
57.96	-0.367	-0.006	-0.147	-2.496
58.17	-0.419	-0.007	-0.144	-2.119
58.37	-0.467	-0.008	-0.140	-1.689
58.58	-0.512	-0.009	-0.135	-1.190
58.79	-0.552	-0.009	-0.129	-0.604
58.99	-0.587	-0.010	-0.120	0.095
59.20	-0.617	-0.010	-0.110	0.942
59.41	-0.640	-0.010	-0.098	1.997
59.62	-0.655	-0.010	-0.083	3.340
59.82	-0.662	-0.010	-0.064	5.109
60.03	-0.658	-0.012	-0.039	7.456
60.24	-0.642	-0.018	-0.006	9.856
60.44	-0.621	-0.021	0.027	10.923
60.65	-0.593	-0.017	0.054	12.700
60.86	-0.556	-0.011	0.074	16.571
61.06	-0.516	-0.007	0.090	21.327
61.27	-0.472	-0.004	0.103	25.577
61.48	-0.423	-0.003	0.114	28.891
61.69	-0.370	-0.002	0.123	31.469
61.89	-0.314	-0.002	0.131	33.585
62.10	-0.254	-0.002	0.138	35.419

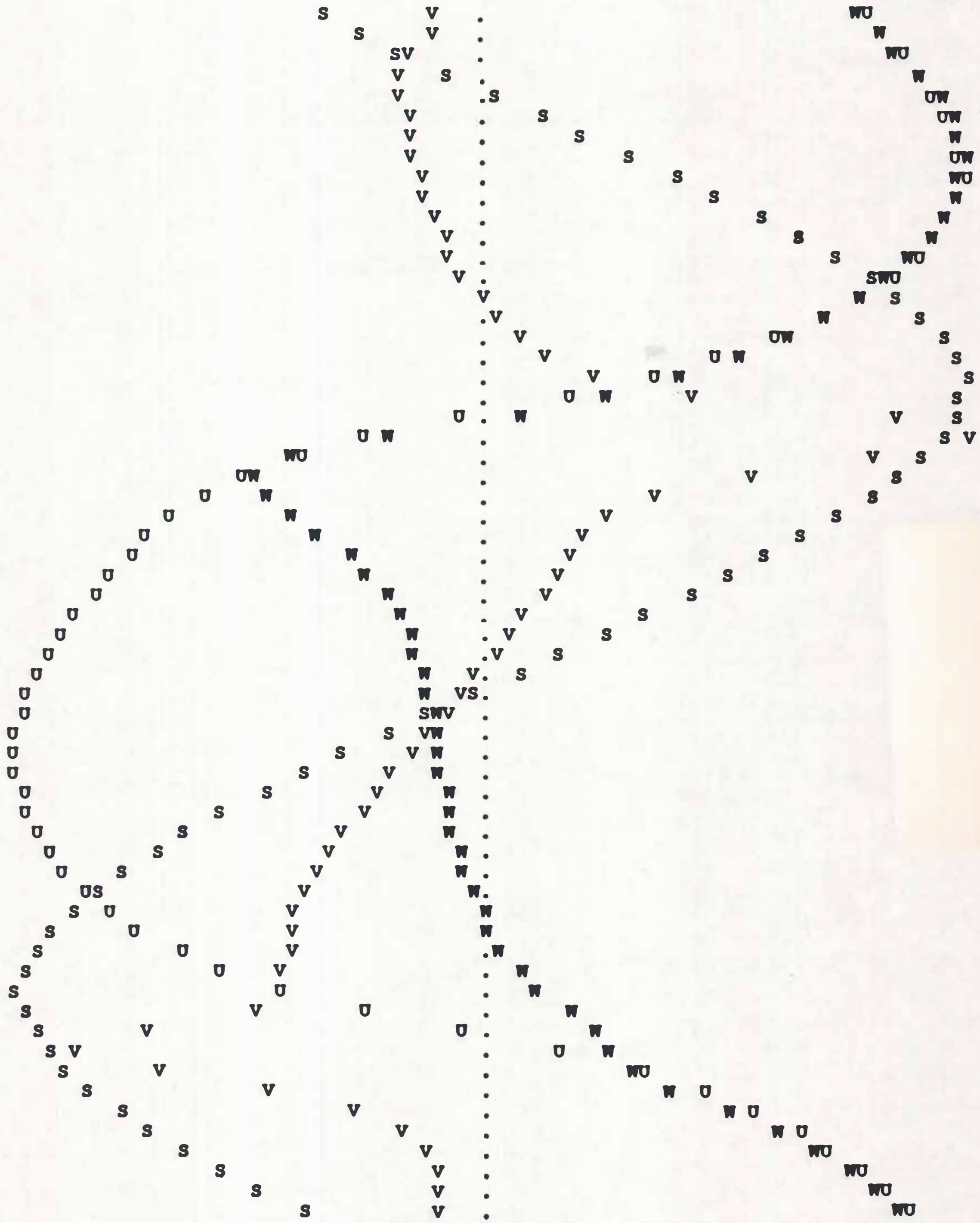

Figure 11. Ambrose Channel deepened. Tidal elevation referred to MSL (S) and tidal current components towards NE (U) and SE (V) at grid element C, during one tidal cycle (12.42 hours). Units: m and m/s.

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