PREDICTED CHANGES IN TIDAL CIRCULATION DUE TO CONSTRUCTION OF CONTAINMENT ISLANDS IN THE LOWER BAY OF NEW YORK HARBOR

Mário E.C. Vieira
September 1986

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Approved for Distribution

D.W. Pritchard
D.W. Pritchard, Acting Director

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ABSTRACT

The effects of constructing 500 acre islands at three predetermined sites within the Lower Bay of New York Harbor were evaluated with a vertically integrated, non-linear, finite difference numerical model. The simulations were carried out for islands of circular and elliptical shape, and the tidal circulation patterns and surface water elevation changes compared with presently existing conditions. Results suggest that the differences in tidal elevation and tidal currents will be very small, mostly limited to the immediate vicinity of those islands, and negligible in relation to the non-tidal fluctuations induced by meteorological and density forcing.

INTRODUCTION

The disposal of dredged sediment in containment facilities in shallow protected areas is a method that may be contemplated in special cases (Conner et al., 1979). Among the alternatives, the feasibility of containment islands was discussed in the final environmental impact statement "Disposal of Dredged Material from the Port of New York and New Jersey" (U.S. Army Corps of Engineers, 1983). In their discussion, the authors of this statement point out that one of the adverse environmental effects could be changes in water circulation patterns, and stress the importance of adequate site selection as a factor in the minimization of such effects.

Subsequently, three sites were identified in the Lower Bay of New York Harbor (Fig. 1) as the most likely for the construction of large containment islands (Bokuniewicz and Cerrato, 1985). In this report which identified and addressed several critical obstacles to the construction of such facilities, the authors suggested 500 acres as a reasonable size for these islands.

Clearly, for an assessment of the environmental impacts resulting from the construction of these suggested islands it is critical to determine the changes in tidal circulation and tidal elevation in the Lower Bay which would be produced by these radical changes in bathymetry. The purpose of this study is to evaluate the perturbation suffered by the tidal patterns due to the construction of these suggested containment islands.

METHODS

A numerical model was utilized to simulate the tidal circulation patterns and elevations in the Bay, first for the existing bathymetric conditions, and then for the altered configurations corresponding to different shapes of containment islands. The model used is a vertically integrated, two-dimensional, non-linear, semi-implicit finite difference numerical scheme based on the algorithms of Leendertse (1967). This hydrodynamic model was initially developed at the Ocean Engineering Department of the University of Rhode Island. It has been tested in a number of semi-enclosed waterways and found to be efficient and accurate in the prediction of shallow water tides, as exemplified by the work of Hess and White (1974), Bowman et al. (1980) and Chiswell (1983).

The model is based on the vertically integrated continuity and momentum equations which are adequate for simulations of tidal circulation in the shallow waters of the Lower Bay. This model is fully non-linear; the advection terms are included and the bottom stress is formulated as a quadratic function of the current velocity using a Chezy friction coefficient that is dependent on depth.

In the semi-implicit scheme, the time step is divided in two half-steps. In the first, both the water surface elevation and the x-component of the current velocity, U, are computed along columns of a Cartesian grid applied to the area. The y-component of the current velocity, V, is calculated explicitly at this time from U and the elevation fields. In the second half-time step, the elevation and V are computed implicitly and then U calculated again explicitly.

A rectangular grid was established, with a grid size of 200 m. This fine mesh was judged necessary to allow for flexibility in the configuration of the containment islands; as a result the model had to deal with 7290 active grid elements. Basic information which must be supplied to run the model includes a representative mean low water depth for each grid element and the time variation in water surface elevation along all the open boundaries. The geometrical and bathymetric data was extracted from the National Ocean Survey (NOS) navigation chart no. 12327, 80th edition, Dec. 1984.

The open boundary conditions were updated before each half-time step. In this application of the model the open boundaries were at Manhattan Beach (eastern end of Coney Island), the transect between Fort Hamilton and Fort Wadsworth (The Narrows), the transect between Rockaway Point and Sandy Hook, at the mouth of Arthur Kill (Tottenville) and at the mouth of the Raritan River from Perth Amboy to South Amboy. The mean tidal amplitude and phase information at these boundaries was taken from the predicted regional tides published by NOS (1985) and are presented in Table I. These conditions are interpolated for each grid element along each open boundary. For simplicity, and given its preponderance, these conditions were assumed pertaining only to the semi-diurnal lunar M2 tidal harmonic component.

Table I

Amplitude and phase of the tide specified at the open boundaries.

Boundary	Amplitude (m)	Phase (Degrees Relative to Rockaway Point)
Manhattan Beach	0.747	2.416
Fort Hamilton	0.716	7.730
Fort Wadsworth	0.655	9.179
Rockaway Point	0.701	0.000
Sandy Hook	0.716	5.314
Tottenville	0.808	9.662
Perth Amboy	0.793	13.527
South Amboy	0.762	10.628

A time step of 62.1 seconds (one M2 lunar minute) was chosen for the computations, following the Courant-Friedrichs-Lewy stability criterion. Since the objective of this study concerns the tidal circulation, no surface wind stress was applied to the model. It must be emphasized that changes in water surface elevation occur which are not forced by the astronomical tides. These non-tidal fluctuations are superimposed on the tides and are caused by variations in density distribution in the water body, by atmospheric pressure gradients and by wind. These latter meteorologically induced oscillations in both the water surface elevations and current velocities can represent a significant fraction of the variance of the total signal, as shown for the Chesapeake Bay by Vieira (1985); for the East River, fluctuations of this kind were reported (Wilson et al., 1985) with a period on the order of 7 days and a range of about 15 cm. In Long Island Sound non-tidal water level oscillations of 50 and 75 cm tend to recur about every 3 and 8 months respectively, as noted by Bokuniewicz and Gordon (1980).

This report deals only with the deterministic (astronomical) part of the tidal signals in the Lower Bay of New York Harbor; hence no effort was made to account for the possible effects of the non-tidal forcing agents.

The model was first run for several tidal cycles for the existing bathymetry; this allowed for a proper spin-up from the initial conditions and yielded steady-state tidal elevations and tidal currents at the end of this series of runs. The model was next exercised for different bathymetric configurations representing the containment islands, and the results compared to those from the first run with the undisturbed field.

The islands were assumed to have an area of 500 acres. Two configurations were considered: circular and elliptical. The placement of these islands in the 3 previously identified areas was determined by the following criteria: 1) fit as much as possible within the area, 2) have one side adjacent to a channel or located in water at least 6 m deep, 3) be in deeper water to maximize volume. As a result, the islands were located as shown in Figures 2 and 3.

RESULTS

1. Existing bathymetry

The tidal current field throughout the Lower Bay is depicted in Figures 4-9 at different stages of the tide, referred to High Water at Sandy Hook. The maximum tidal current isotachs during a tidal cycle are shown in Fig. 10; the currents only reach above 25 cm/s in the initial sections of the Ambrose and Sandy Hook channels; in the containment areas they never reach 15 cm/s.

The residual (average over the tidal cycle) tidal currents show the presence of some eddies of small proportions (Fig. 11), but the magnitude of these residual flows is overall quite small, only reaching 30 mm/s at the entrance to the Sandy Hook channel (Fig. 12). The maximum and minimum tidal elevations (Figs. 13 and 14), referred to mean sea level, do not vary more than 5 cm throughout the Lower Bay.

2. Circular containment islands

The simulated tidal conditions after the construction of circular containment islands are shown in Figures 15-25.

The changes in the maximum tidal current speeds which arise with the construction of the circular containment islands are concentrated in a pattern around the islands (Fig. 26); the largest values, however, are less than 10 cm/s and throughout most of the Lower Bay the changes are kept below 1 cm/s. The residual tidal current speeds do not show changes above 3 mm/s and are circumscribed to the immediate vicinity of the islands (Fig. 27). The maximum tidal elevations at high tide will increase by no more than 8 mm (Fig. 28), while the level of the low tide will not dip by more than 5 mm (Fig. 29).

3. Elliptical containment islands

Tidal conditions were simulated for the existence of elliptical containment islands; the results are depicted in Figures 30-40.

The changes in maximum tidal current speeds are again distributed around the islands (Fig. 41); they do not exceed 9 cm/s and throughout most of the Bay are kept below 1 cm/s. The pattern is very similar to that of the circular islands.

Residual tidal current changes in speed do not go above 4 mm/s, are limited to the vicinity of the islands and are otherwise negligible throughout the Bay (Fig. 42).

The maximum tidal elevations will increase by at most 6 mm on the west coast of the middle island (Fig. 43). The minimum tidal elevations at low tide show an extreme value of -4 mm on the east coast of the northern island (Fig. 44).

4. Independence of results at each site

The numerical model was exercised considering the simulated construction of the 3 islands simultaneously. This was done to avoid running the model independently for each individual island, a costly proposition which is quite unnecessary. In fact, the distance between the individual islands is large enough that the propagation of the tidal wave past one island is not affected by shadow effects of diffraction or refraction at another. Indeed, as clearly demonstrated by Figures 26-29 for the circular islands, and Figures 41-44 for the elliptical islands, the changes between the simulated conditions and the presently existing bathymetric situation are basically circumscribed to the vicinity of each island and do not exhibit any complex pattern of interpenetration. In other words, one can consider the results corresponding to the construction of one only island as being equivalent to those of removing in Figs. 26-29 and 41-44 the other 2 islands and their respectively associated fields of change.

CONCLUSIONS

It is clear that some small changes in the tidal conditions throughout the Lower Bay of New York Harbor would result from the construction of containment islands. These changes are, however, very small; tidal elevations would differ by a few millimeters, which is a negligible amount when compared to the spring-neap fortnightly oscillations on the order of 30 cm experienced in the area, non-tidal surface level fluctuations of 15 cm or more and a rising trend in mean sea level of 3 mm/yr (Hicks, 1973). Likewise the maximum changes in tidal currents of about 9 cm/s are circumscribed to the neighborhood of the islands and are one order of magnitude lower than the values of the flows themselves. Furthermore, they are not significant when compared with the variations that the winds, run-off conditions and density differences can impose upon the tidal currents.

ACKNOWLEDGMENTS

This work was supported by the New York District of the U.S. Army Corps of Engineers. I would like to thank Dr. Malcolm Bowman for making the numerical model available to me and Mr. Andre Visser for his precious cooperation and guidance through the intricacies of the numerical code.

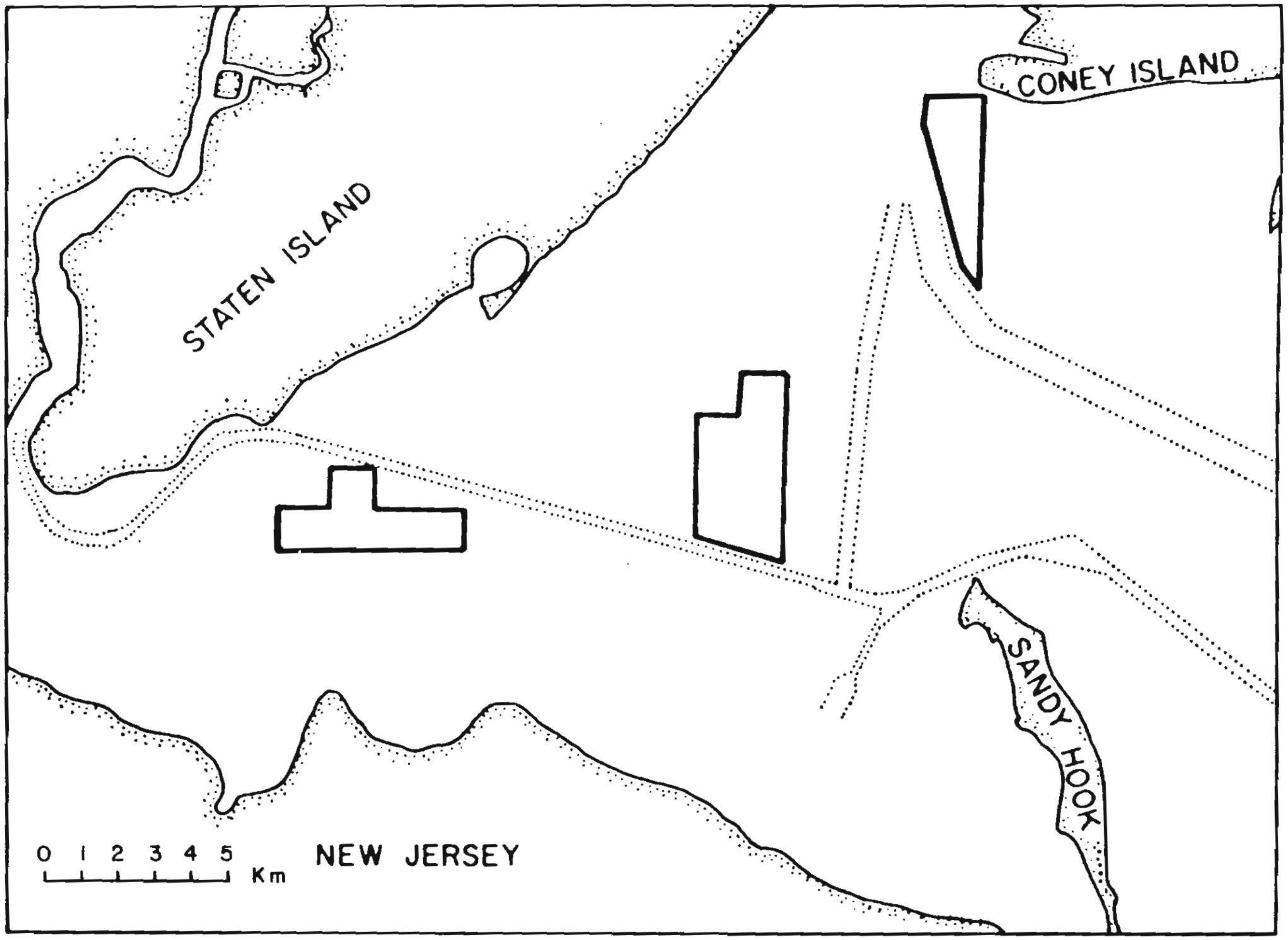

Figure 1. Potential containment area sites in the Lower Bay of New York Harbor (from Bokuniewicz and Cerrato, 1985).

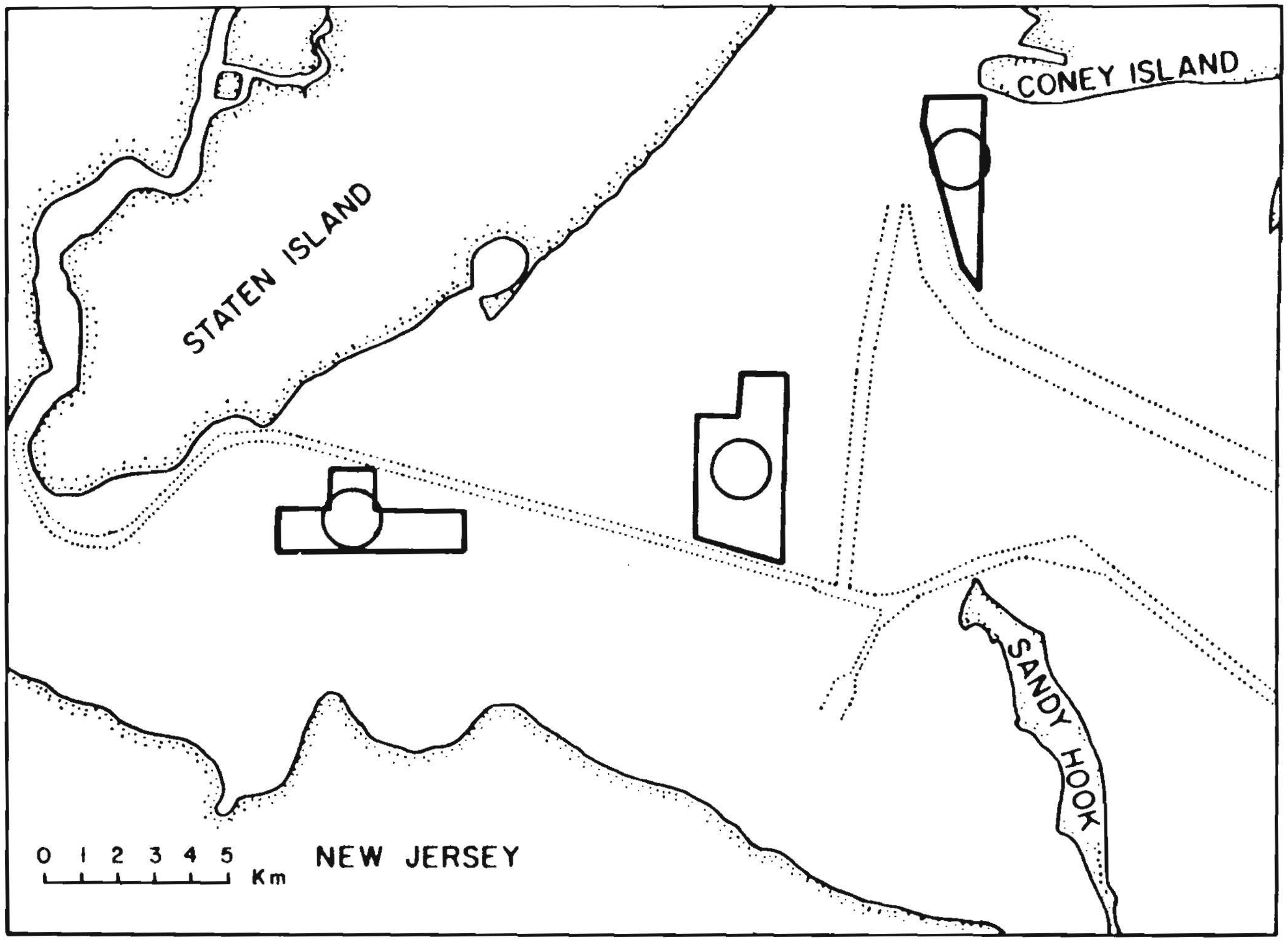

Figure 2. Placement of the circular containment islands.

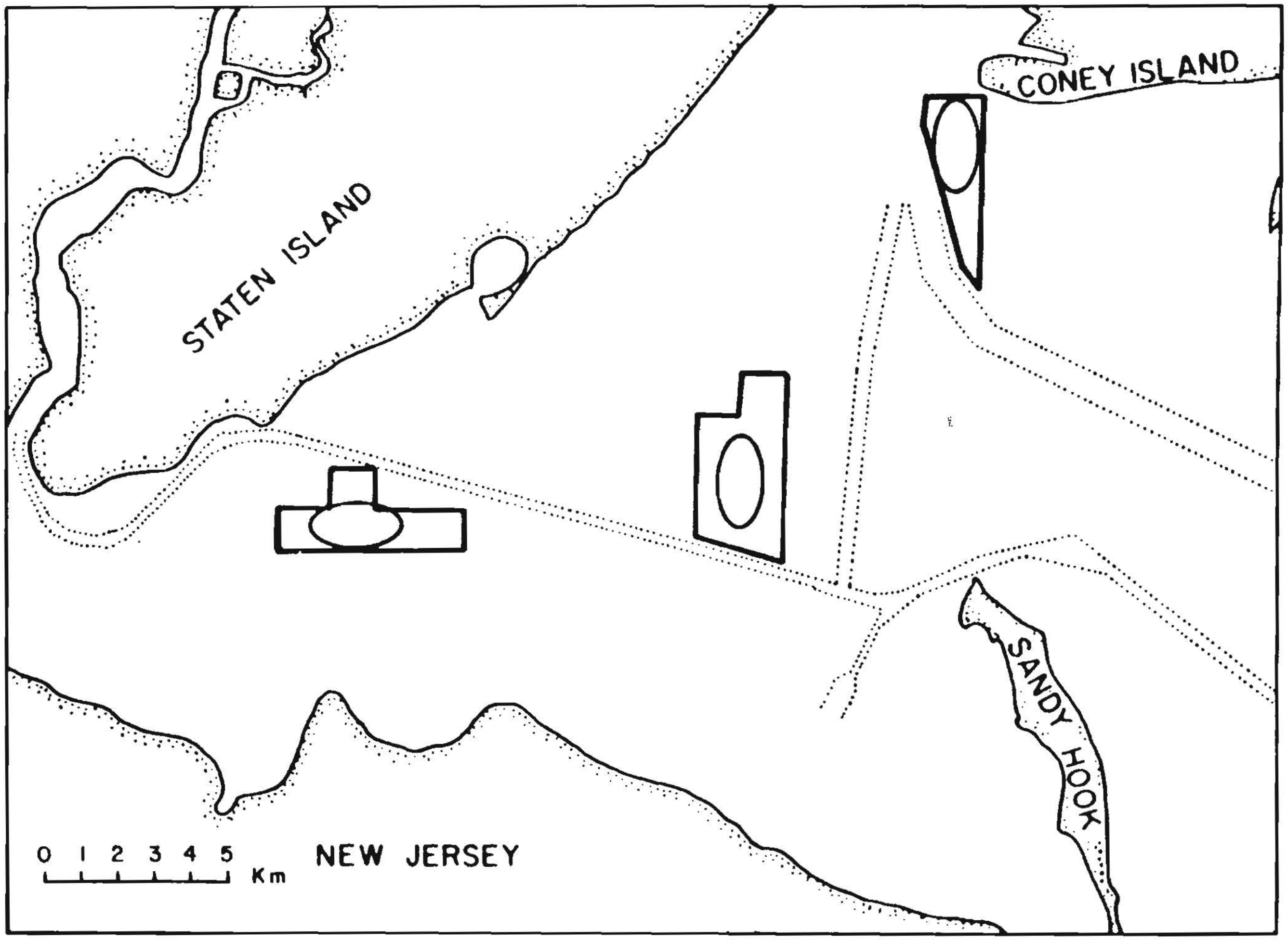

Figure 3. Placement of the elliptical containment islands.

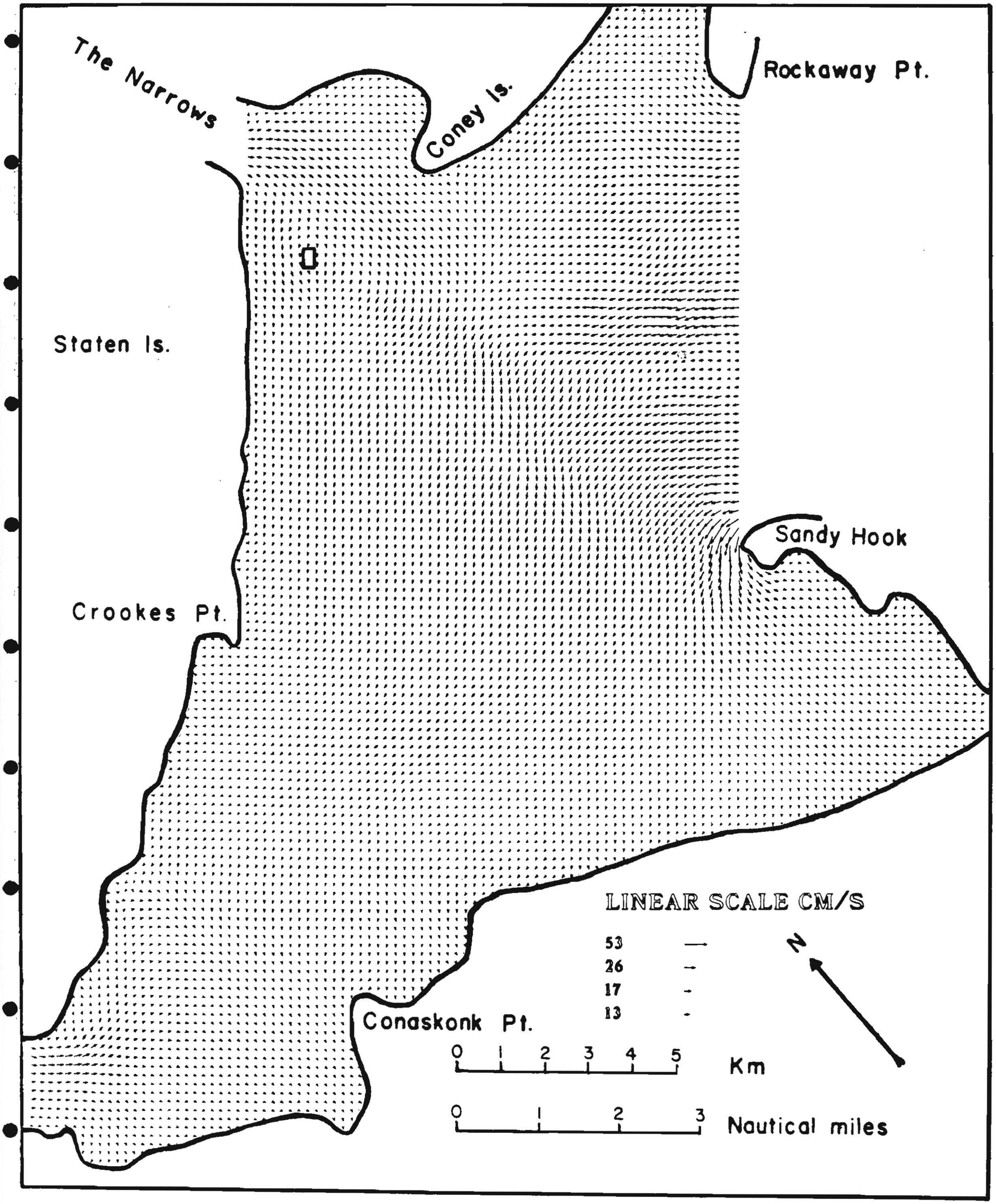

Figure 4. Tidal current vectors for existing bathymetry 3.93 hours before High Water at Sandy Hook.

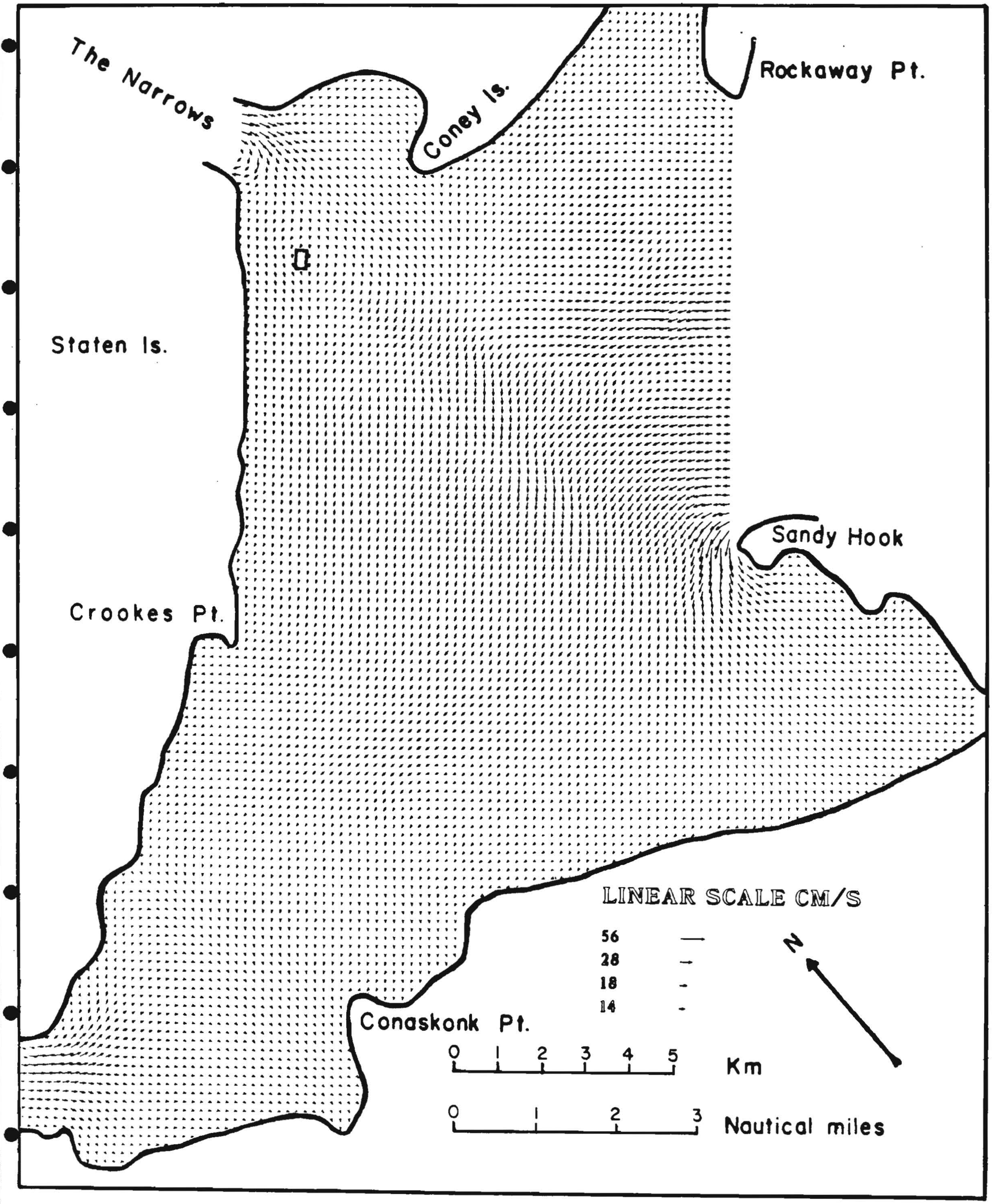

Figure 5. Tidal current vectors for existing bathymetry 1.86 hours before High Water at Sandy Hook.

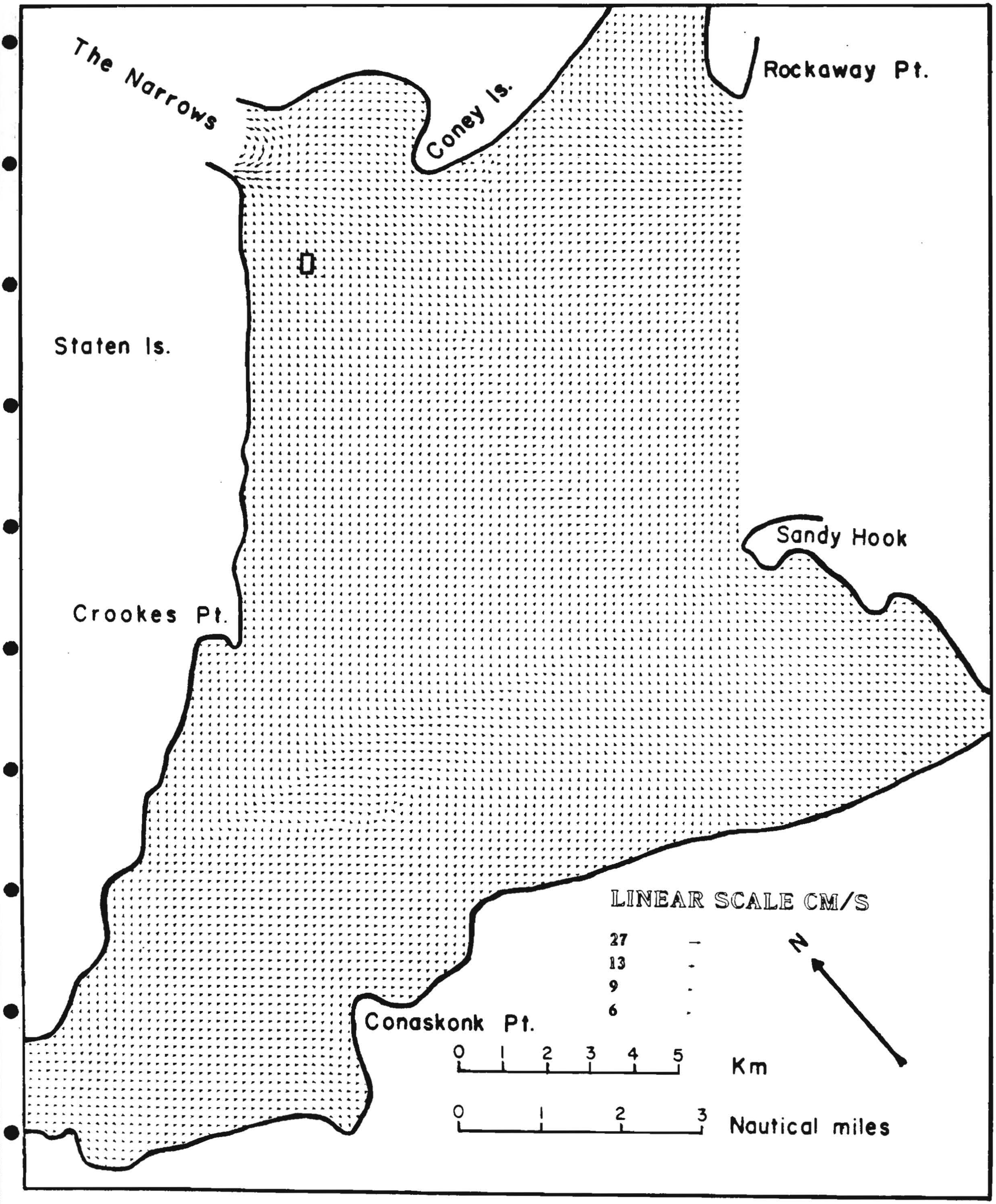

Figure 6. Tidal current vectors for existing bathymetry 0.21 hours after High Water at Sandy Hook.

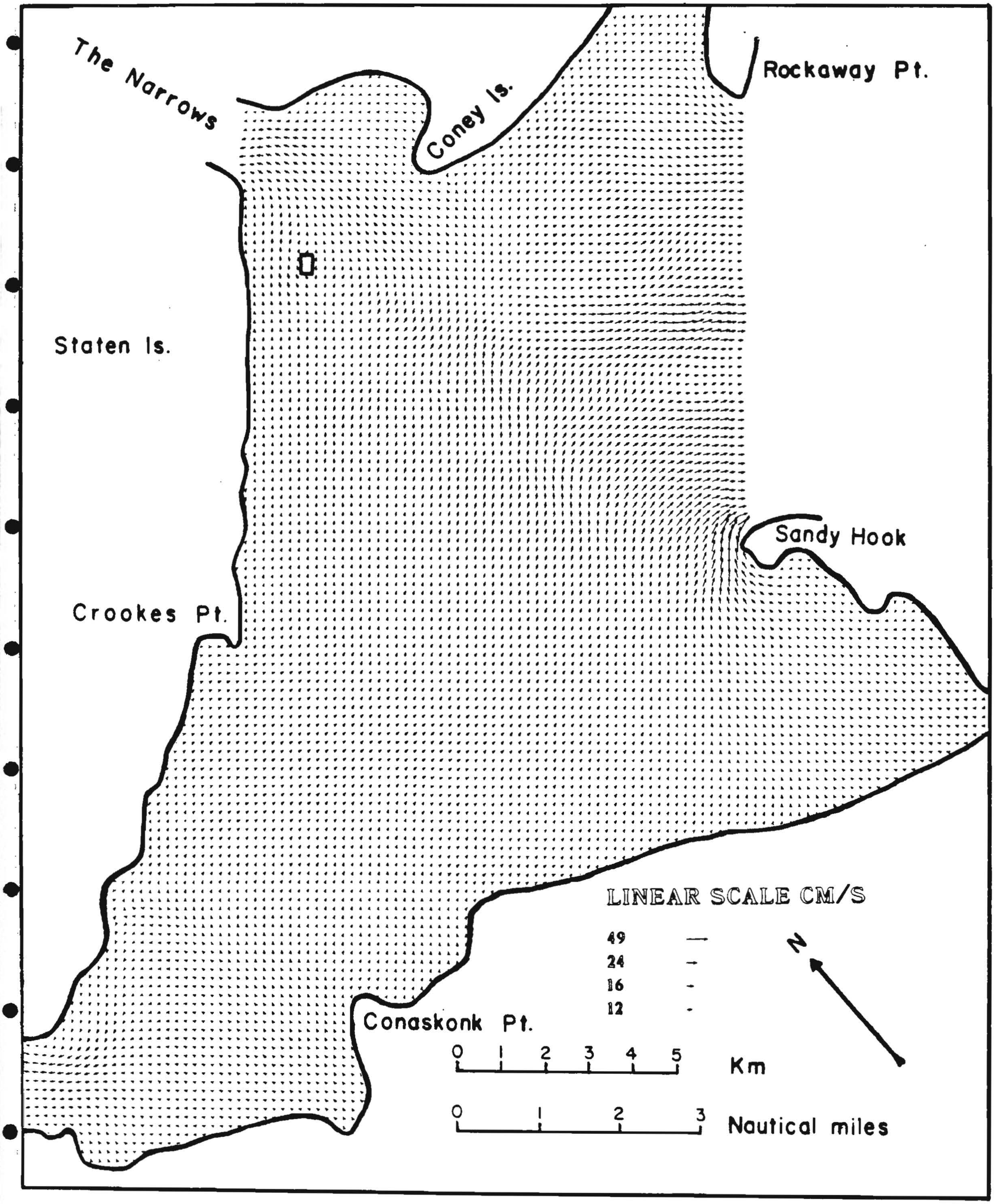

Figure 7. Tidal current vectors for existing bathymetry 2.28 hours after High Water at Sandy Hook.

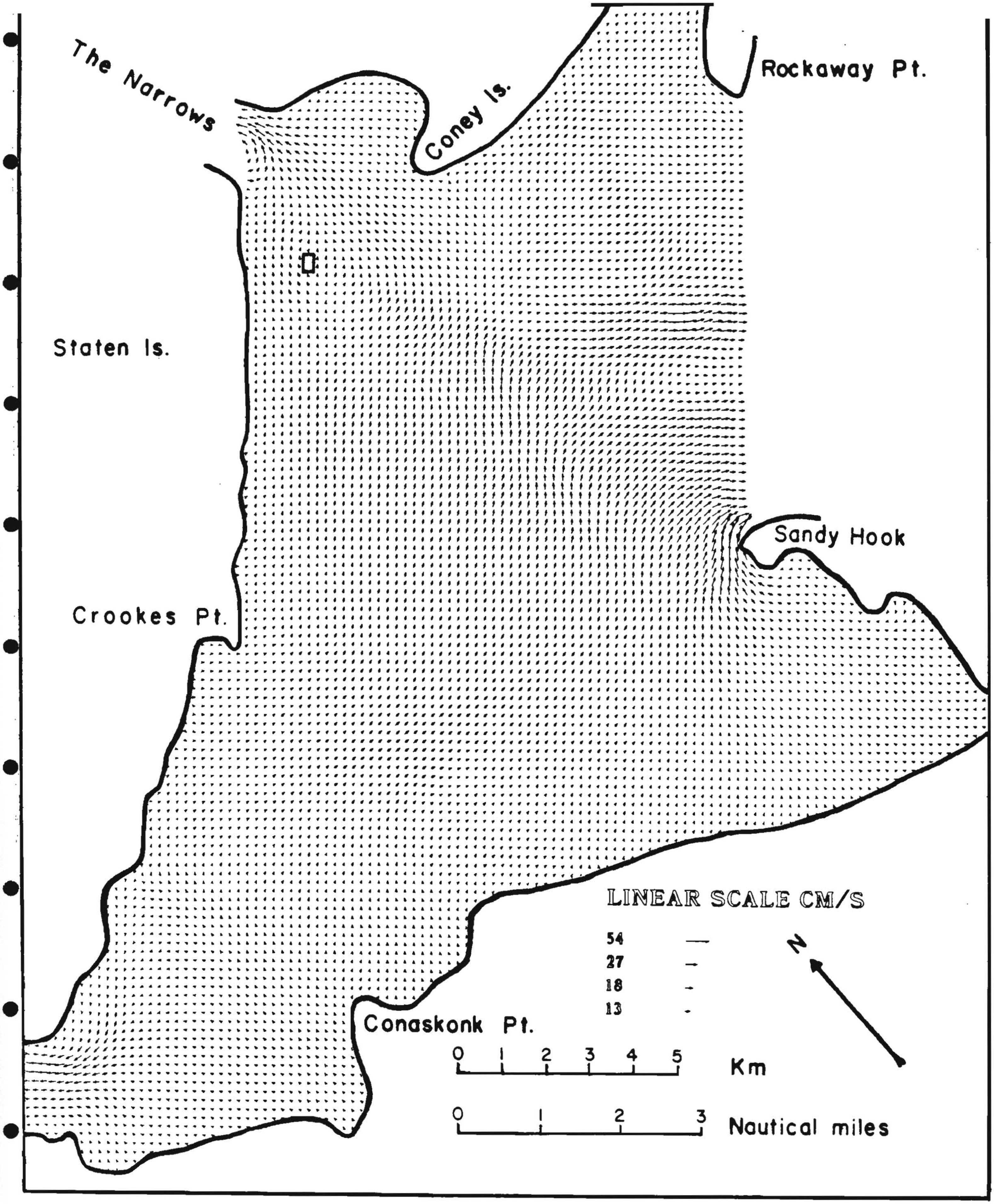

Figure 8. Tidal current vectors for existing bathymetry 4.35 hours after High Water at Sandy Hook.

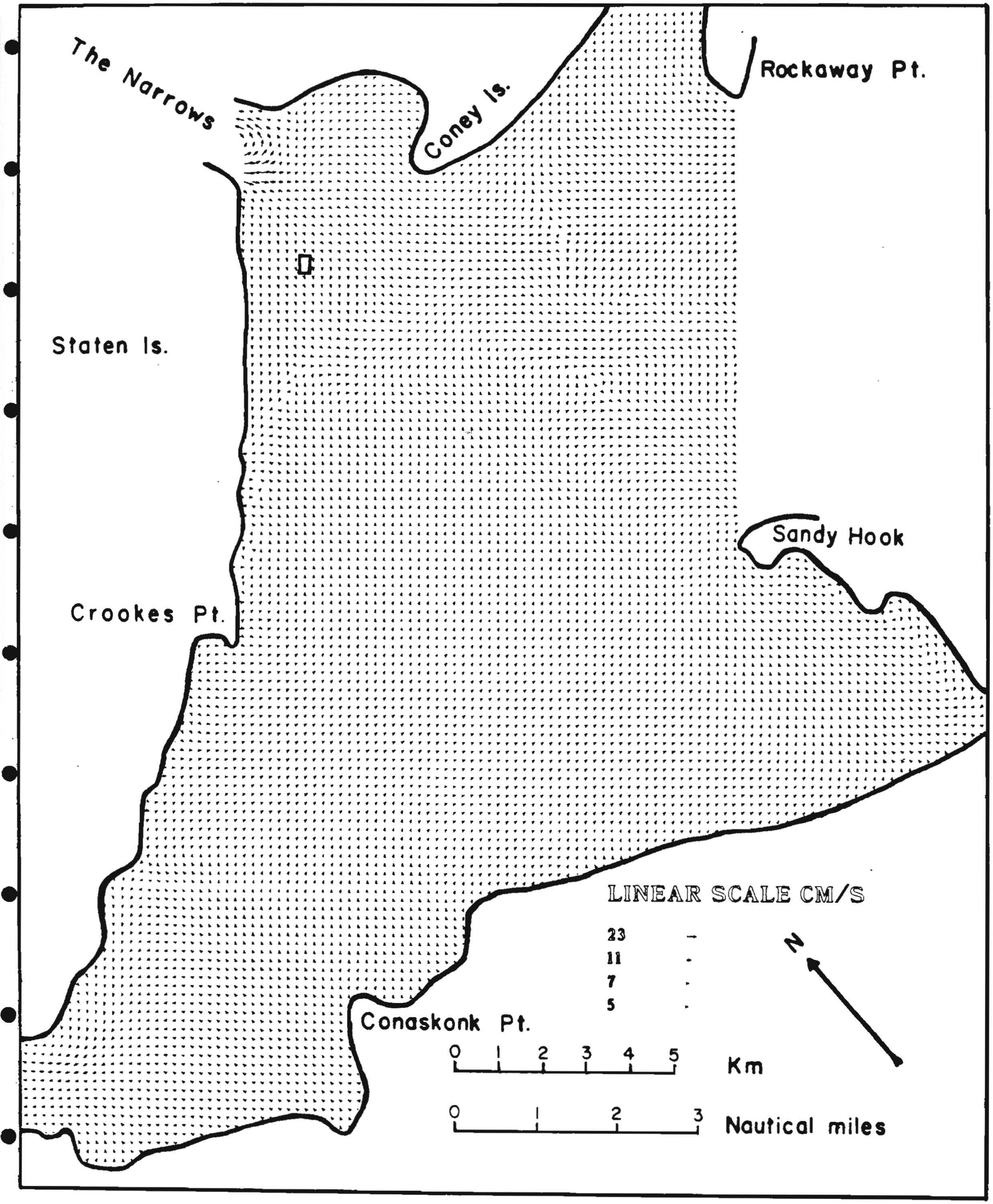

Figure 9. Tidal current vectors for existing bathymetry 6.42 hours after High Water at Sandy Hook.

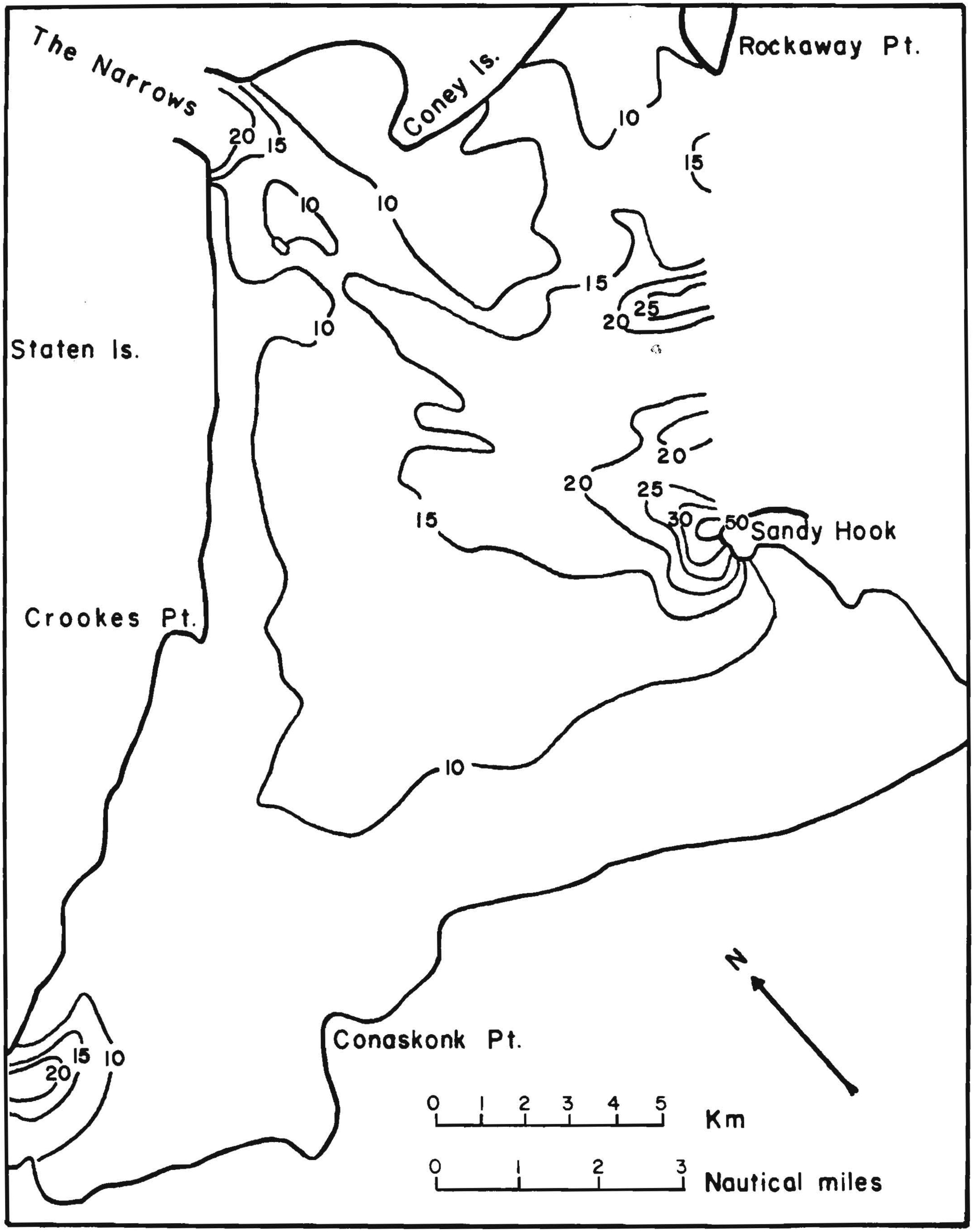

Figure 10. Maximum tidal current isotachs, in cm/s, for existing bathymetry.

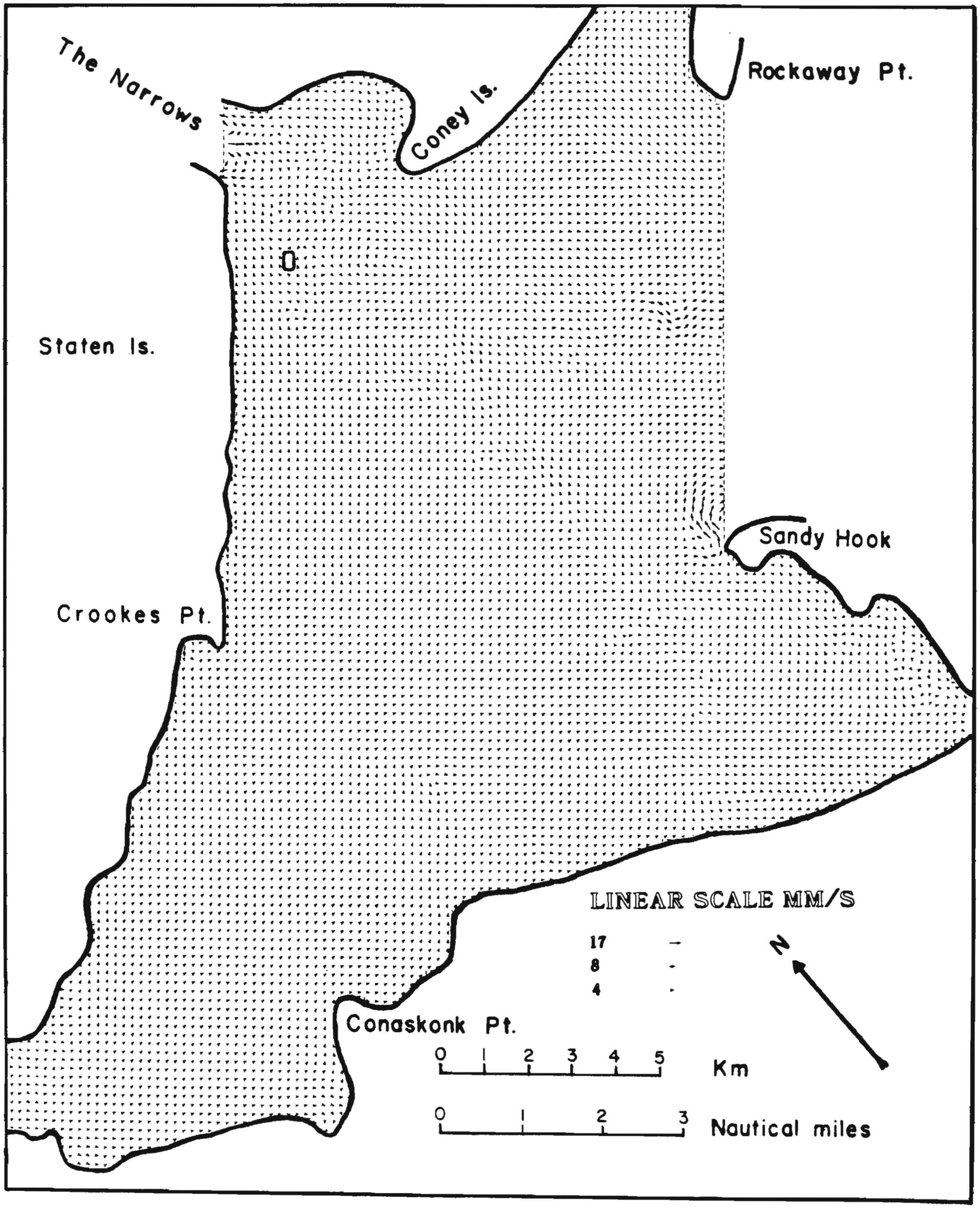

Figure 11. Residual tidal current vectors for existing bathymetry.

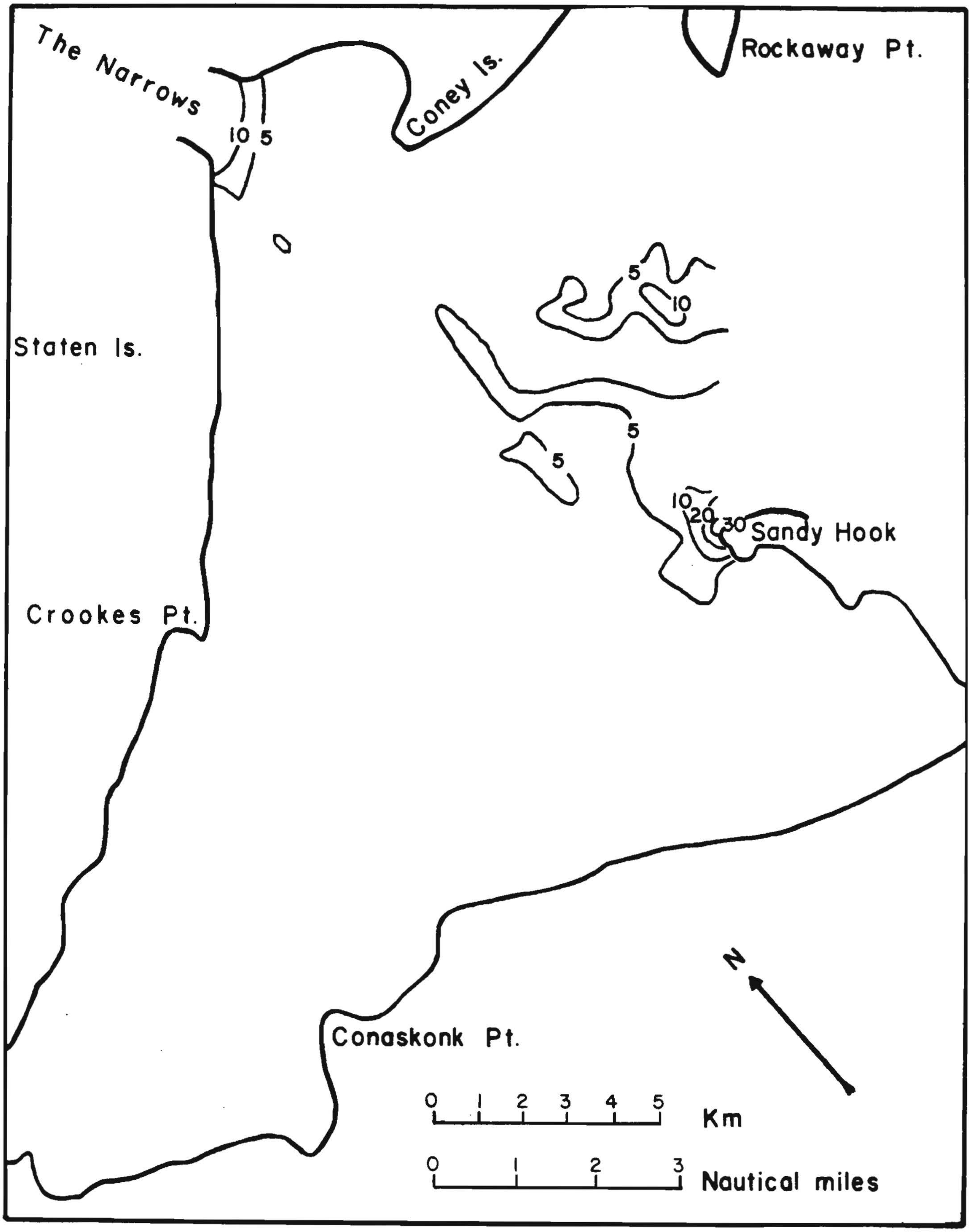

Figure 12. Residual tidal current isotachs, in mm/s, for existing bathymetry.

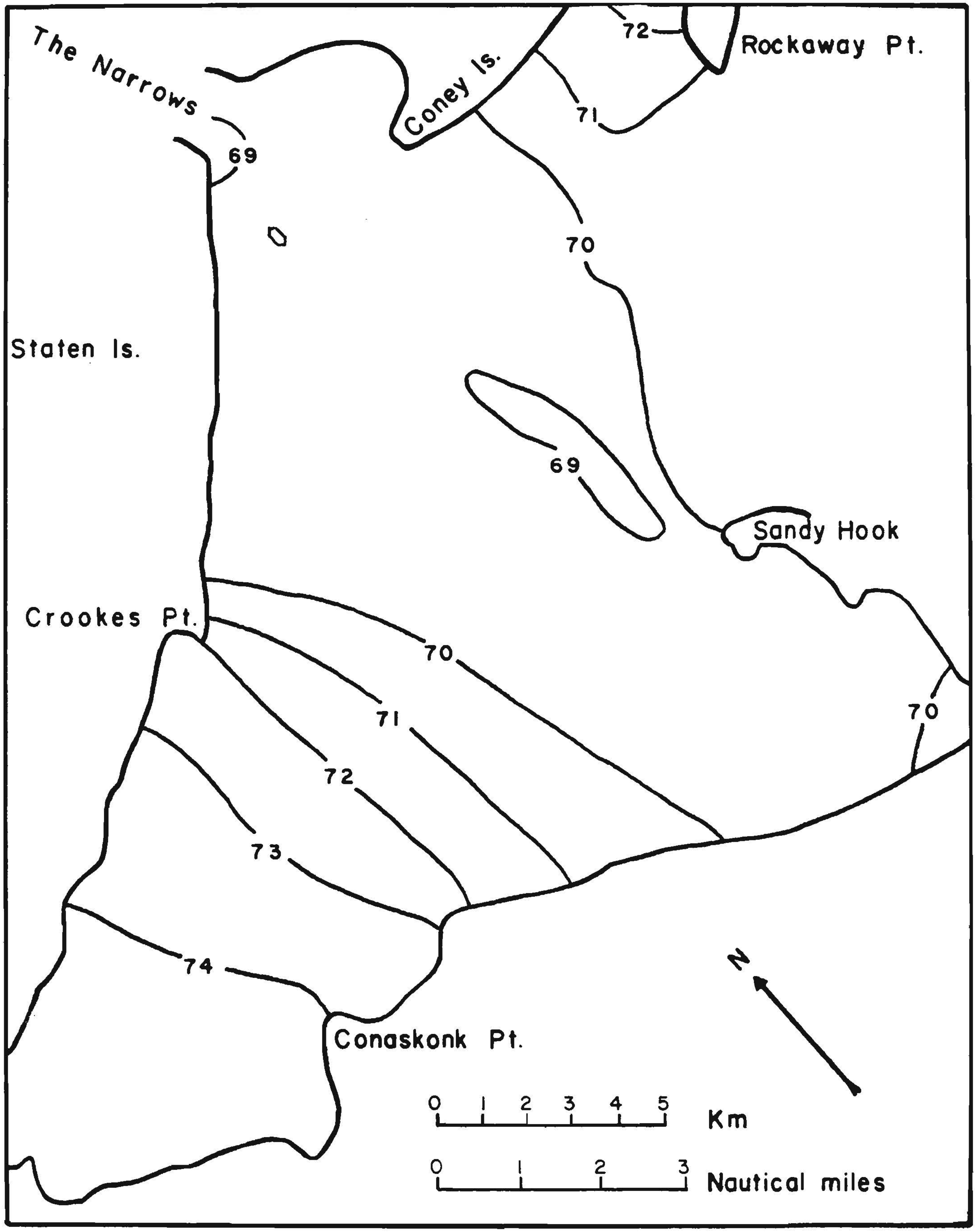

Figure 13. Maximum tidal elevations above mean sea level, in cm, for existing bathymetry.

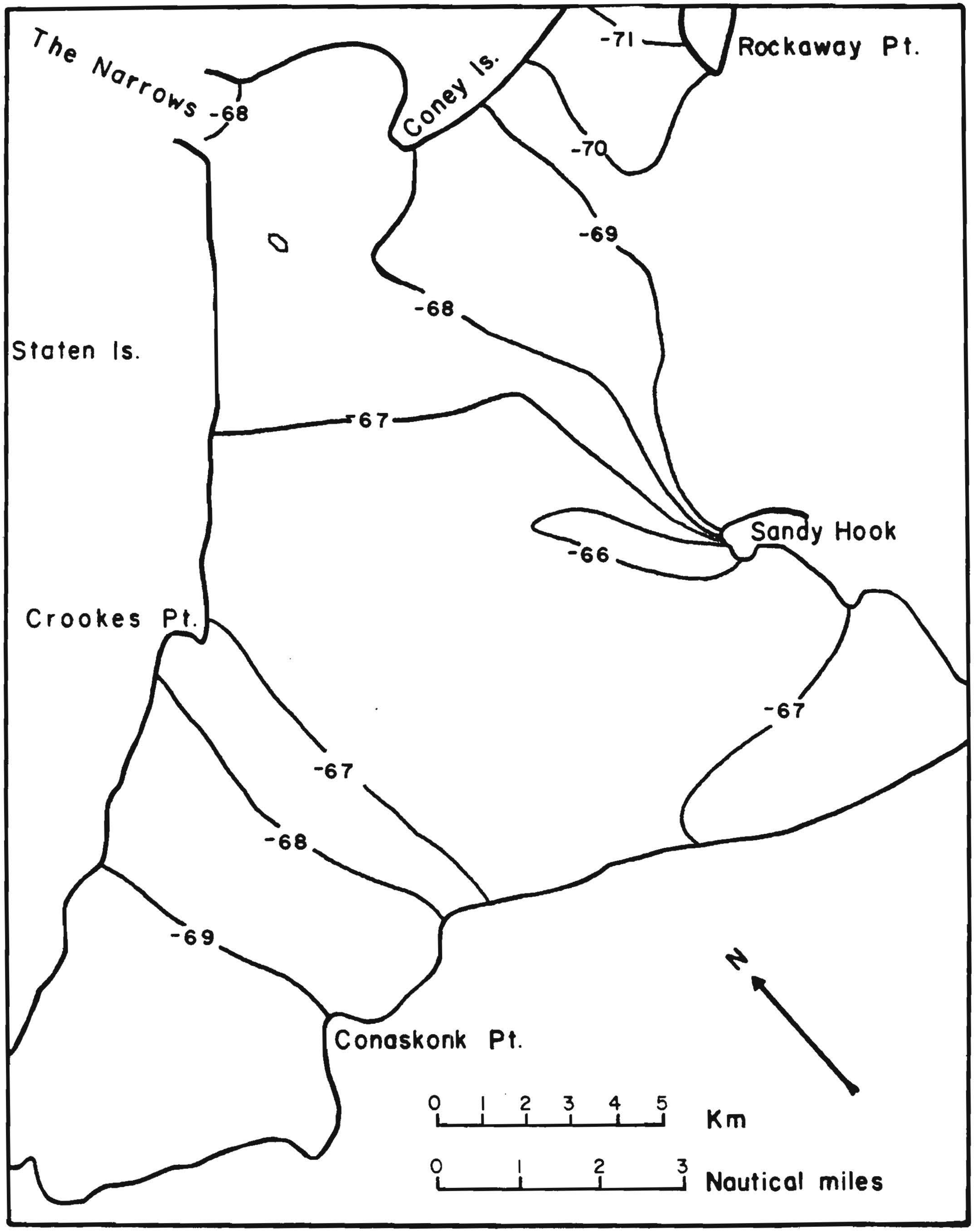

Figure 14. Minimum tidal elevations below mean sea level, in cm, for existing bathymetry.

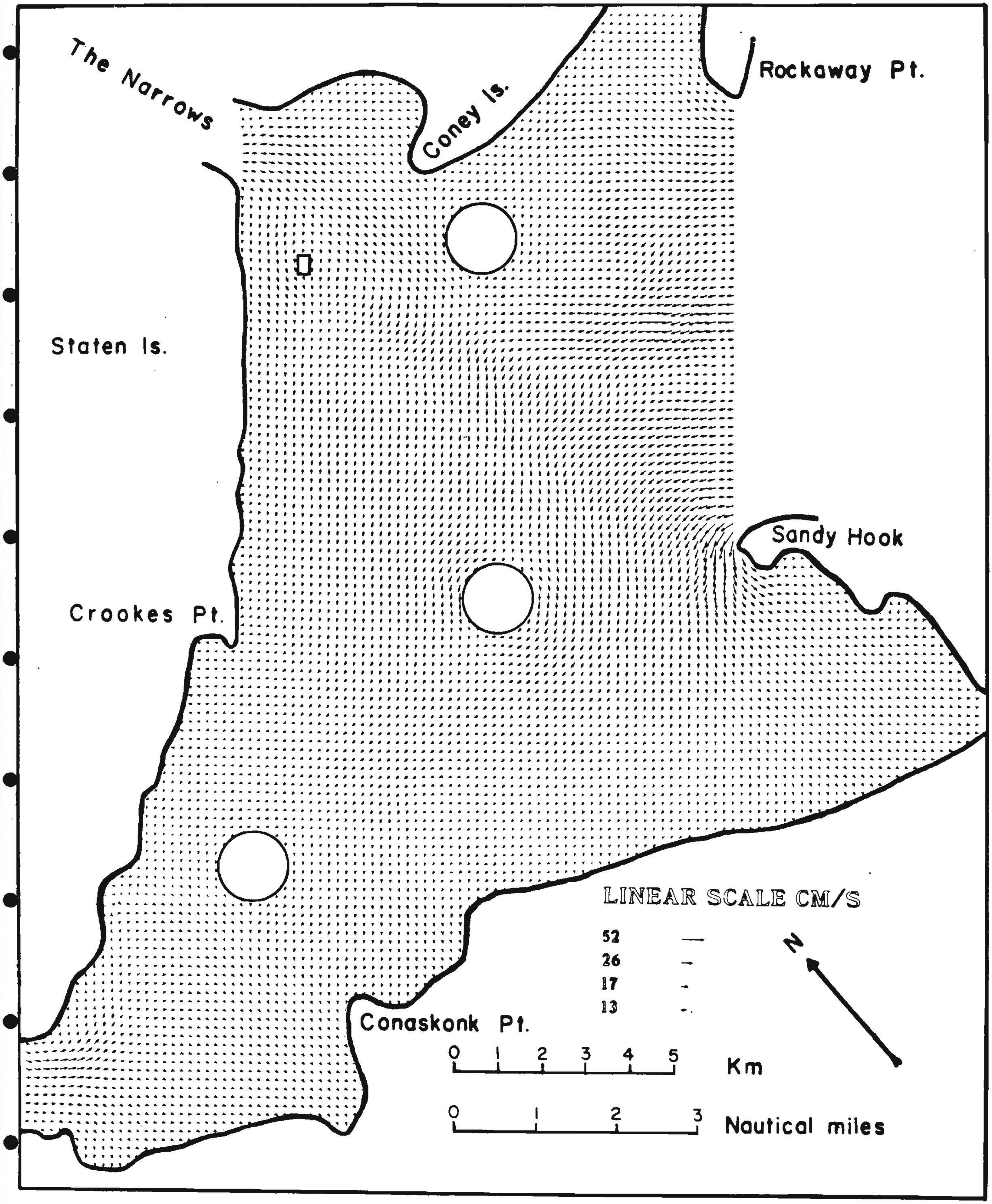

Figure 15. Tidal current vectors, after construction of circular containment islands, 3.93 hours before High Water at Sandy Hook.

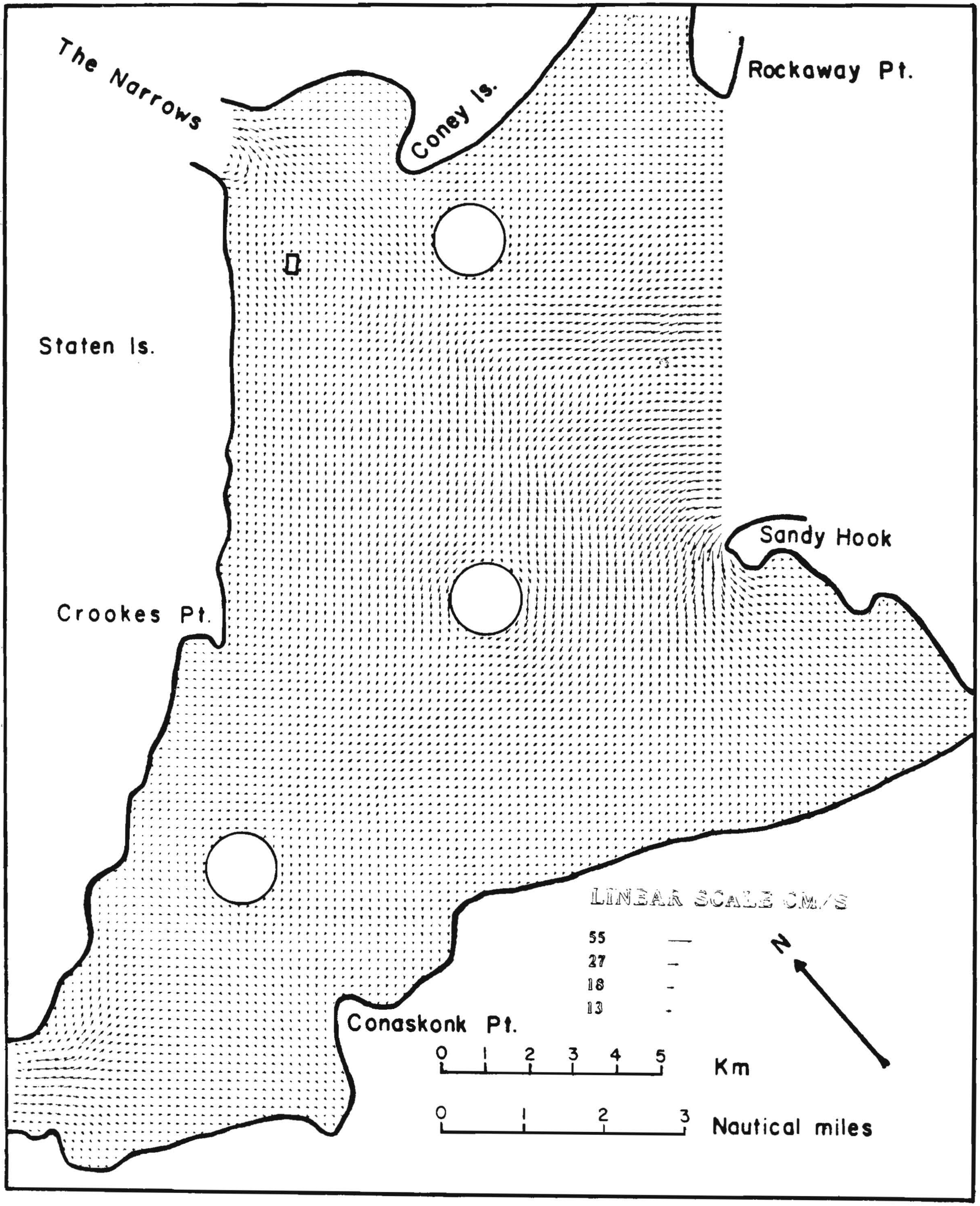

Figure 16. Tidal current vectors, after construction of circular containment islands, 1.86 hours before High Water at Sandy Hook.

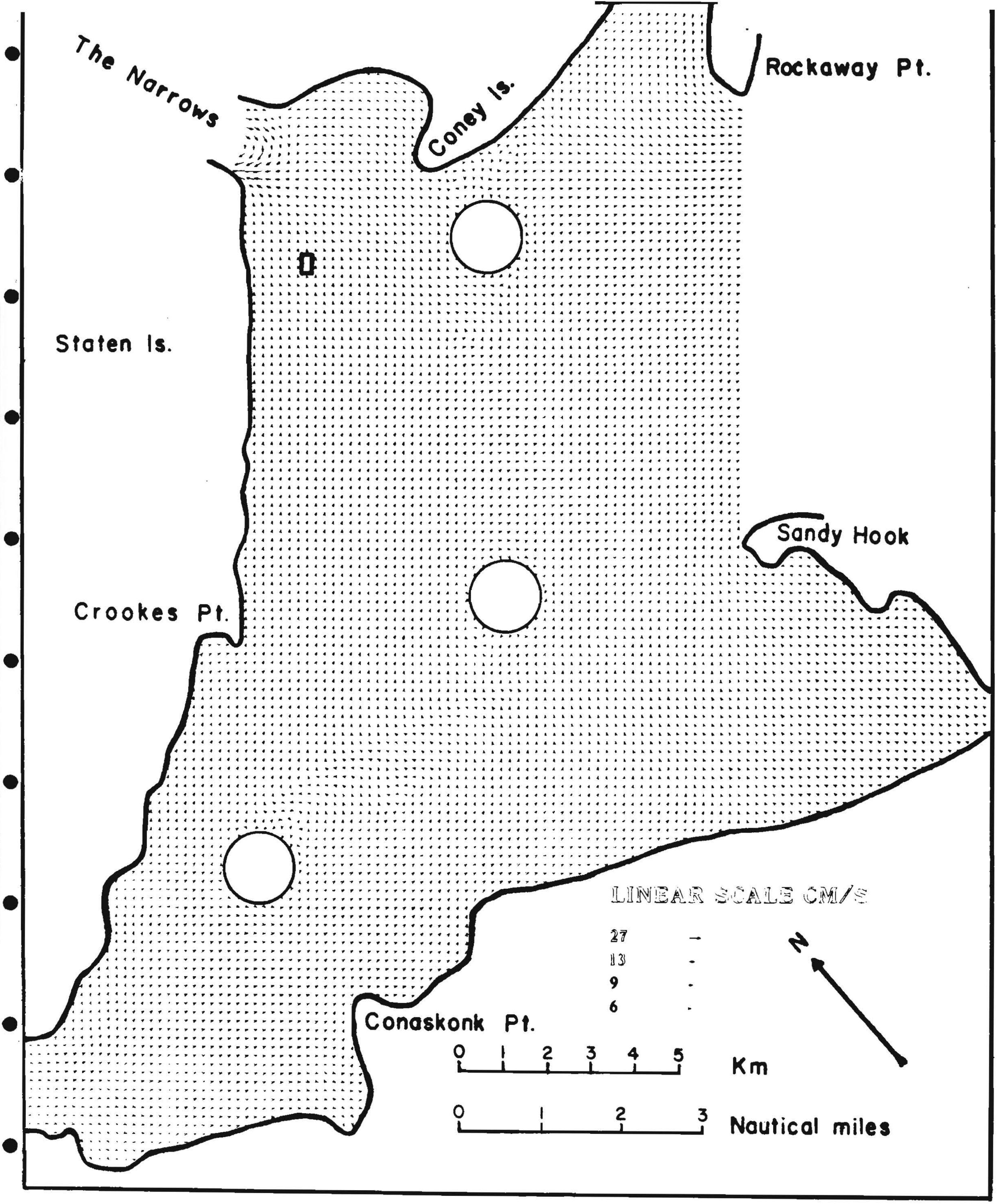

Figure 17. Tidal current vectors, after construction of circular containment islands, 0.21 hours after High Water at Sandy Hook.

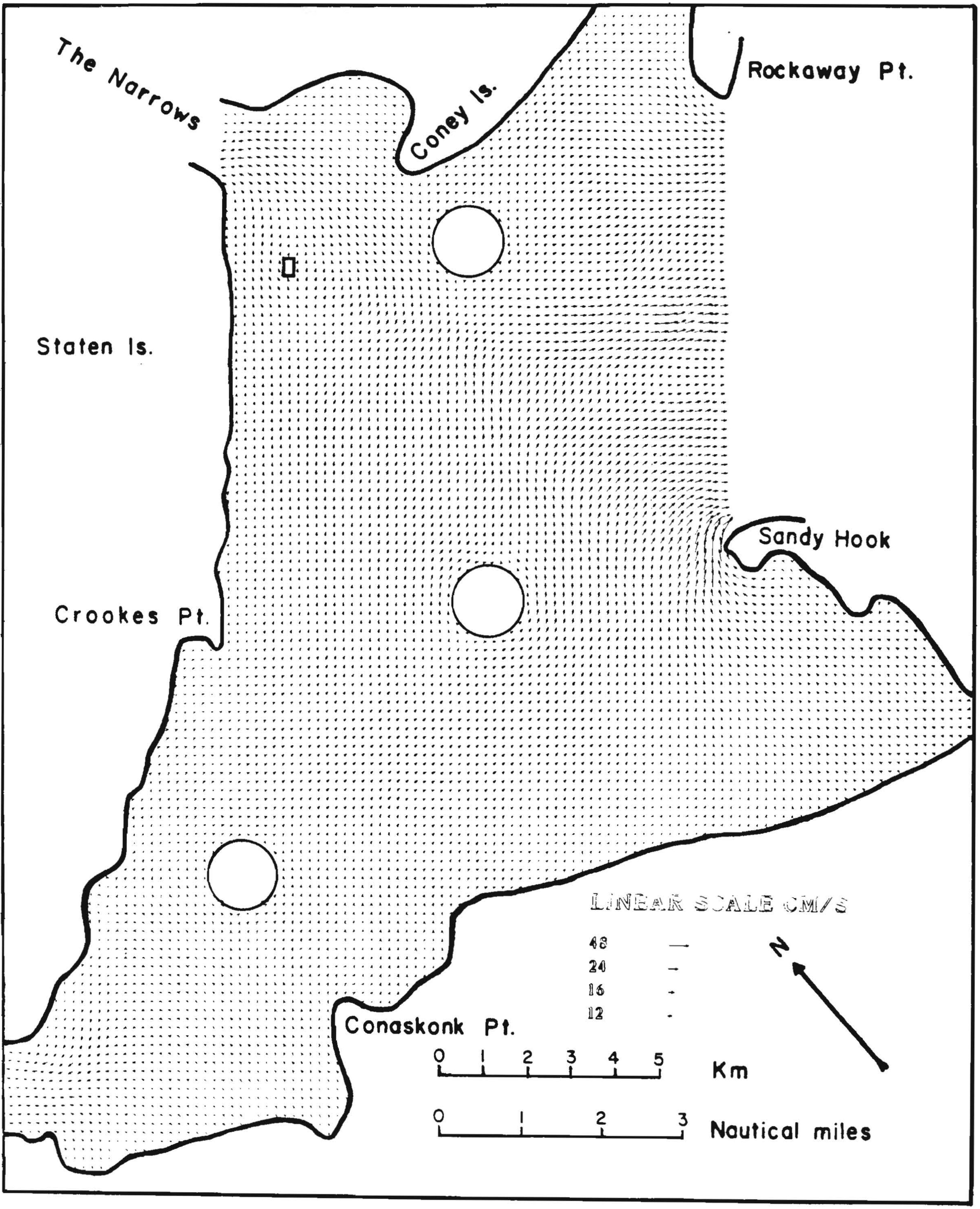

Figure 18. Tidal current vectors, after construction of circular containment islands, 2.28 hours after High Water at Sandy Hook.

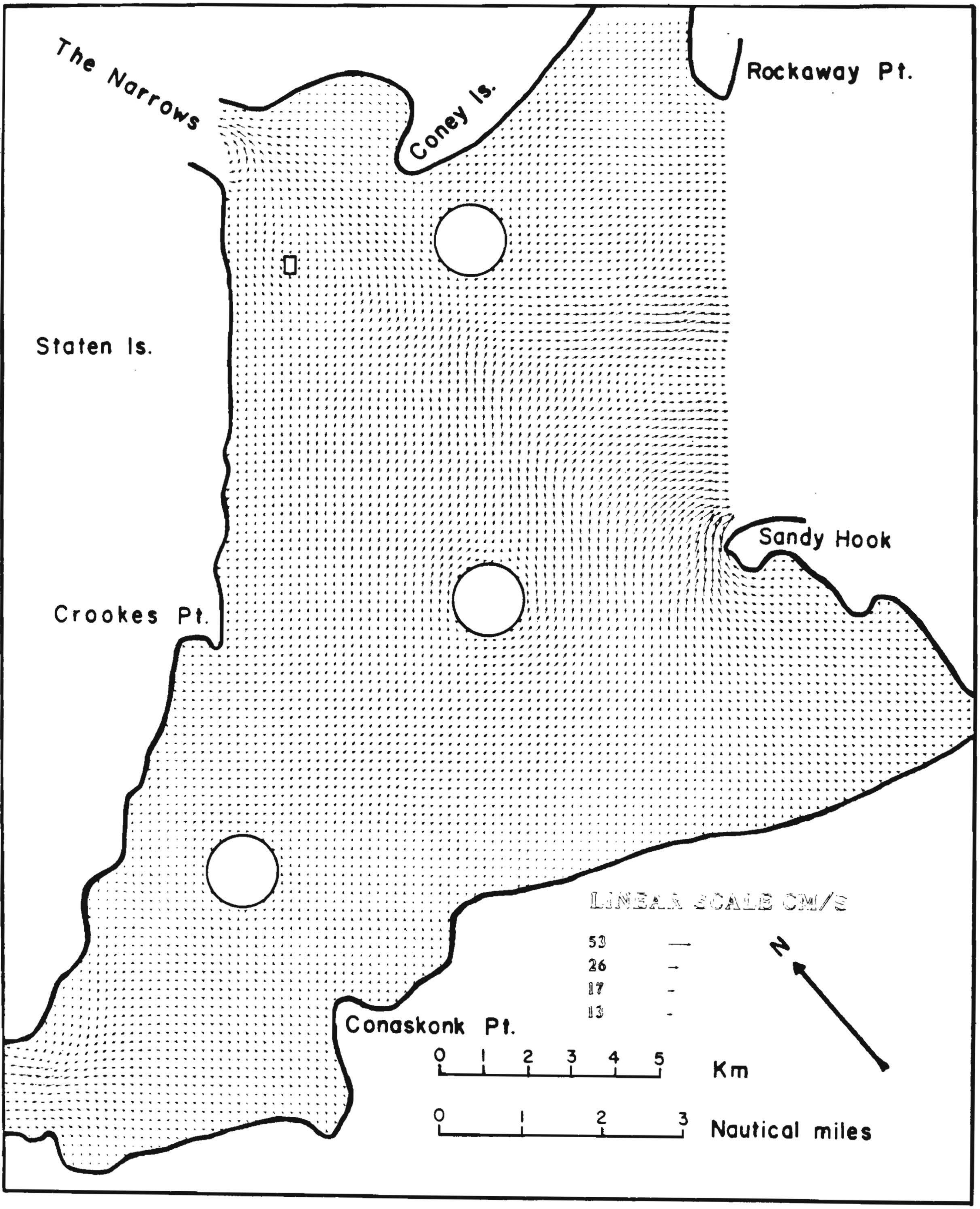

Figure 19. Tidal current vectors, after construction of circular containment islands, 4.35 hours after High Water at Sandy Hook.

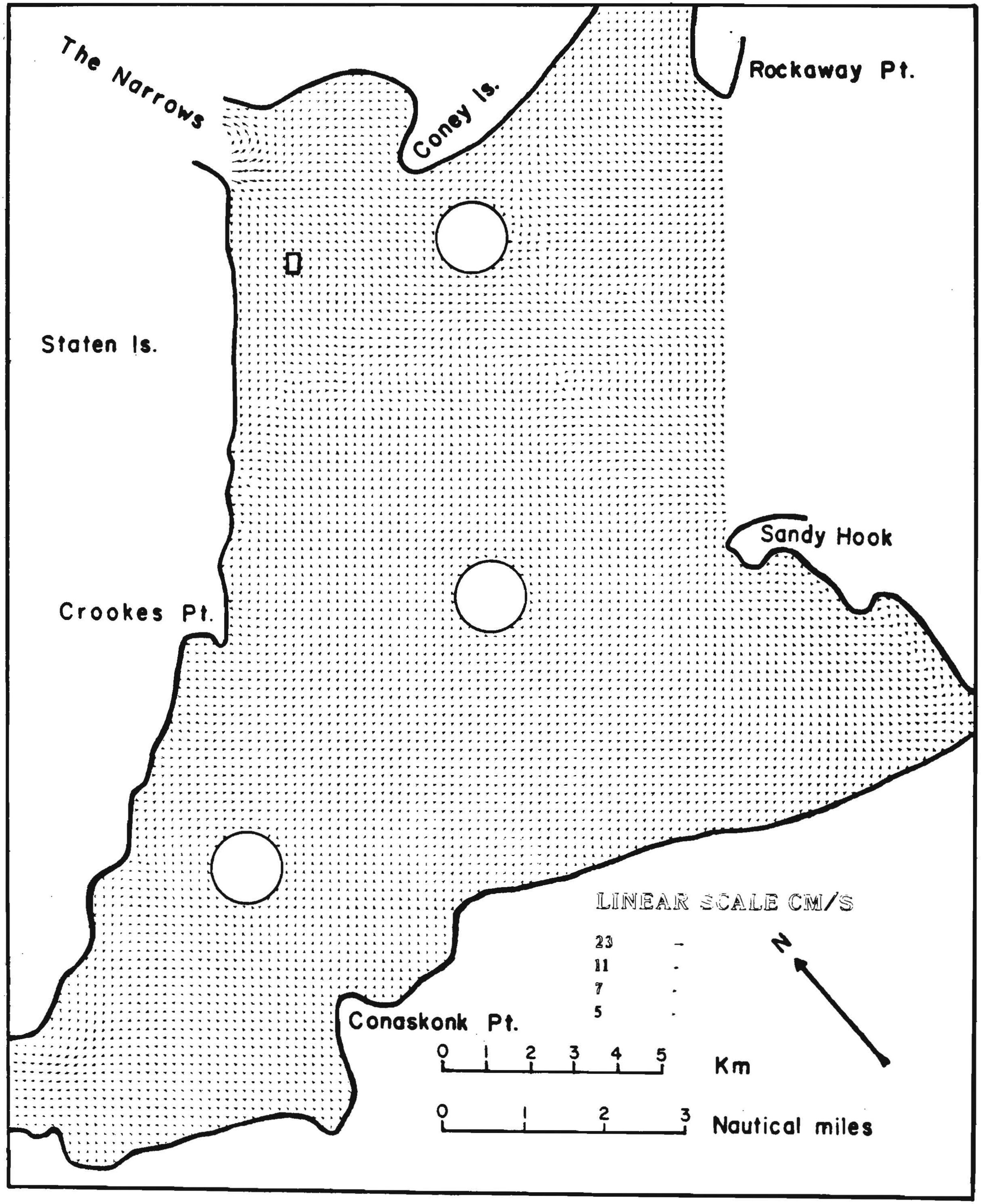

Figure 20. Tidal current vectors, after construction of circular containment islands, 6.42 hours after High Water at Sandy Hook.

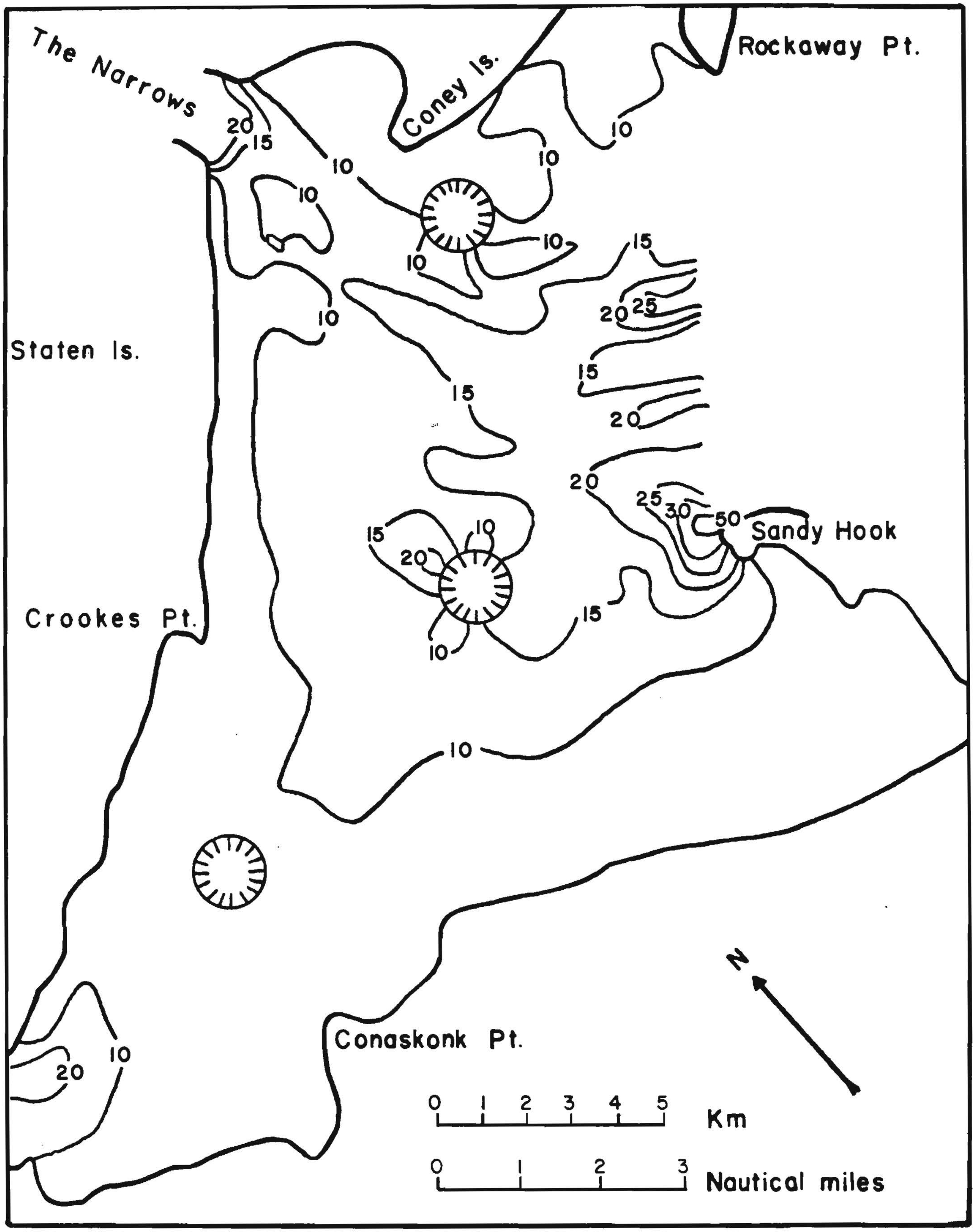

Figure 21. Maximum tidal current isotachs, in cm/s, after construction of circular containment islands.

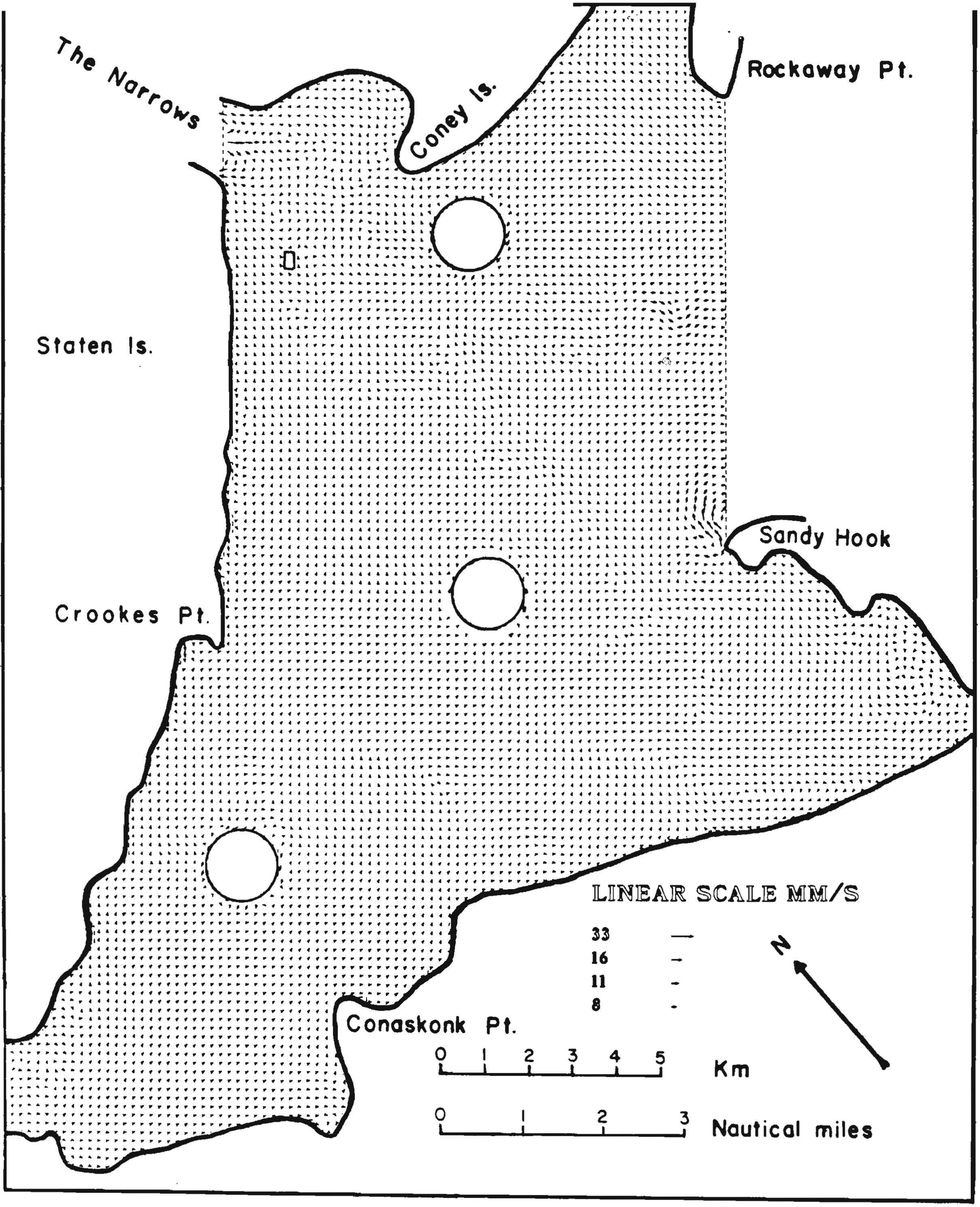

Figure 22. Residual tidal current vectors after construction of circular containment islands.

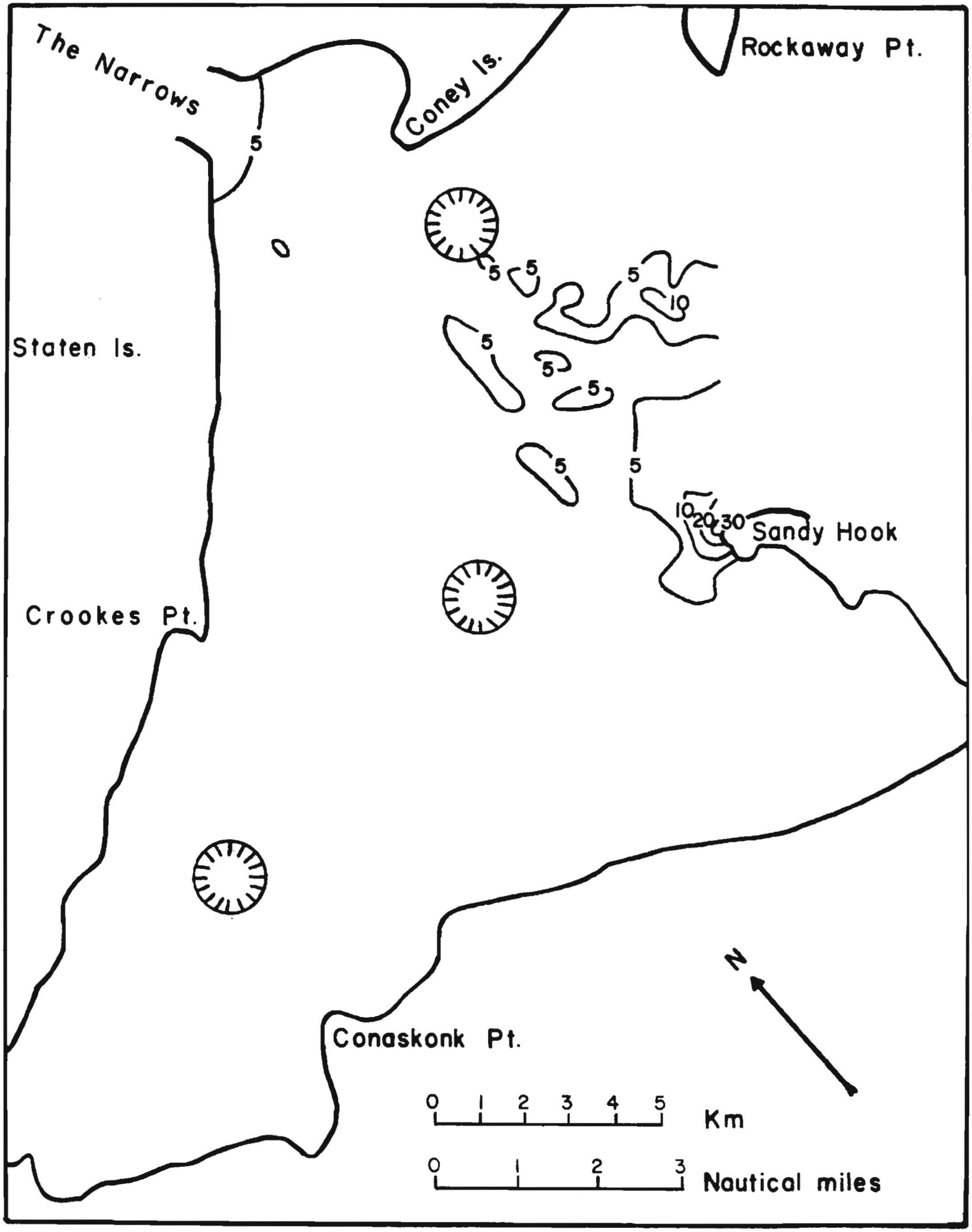

Figure 23. Residual tidal current isotachs, in mm/s, after construction of circular containment islands.

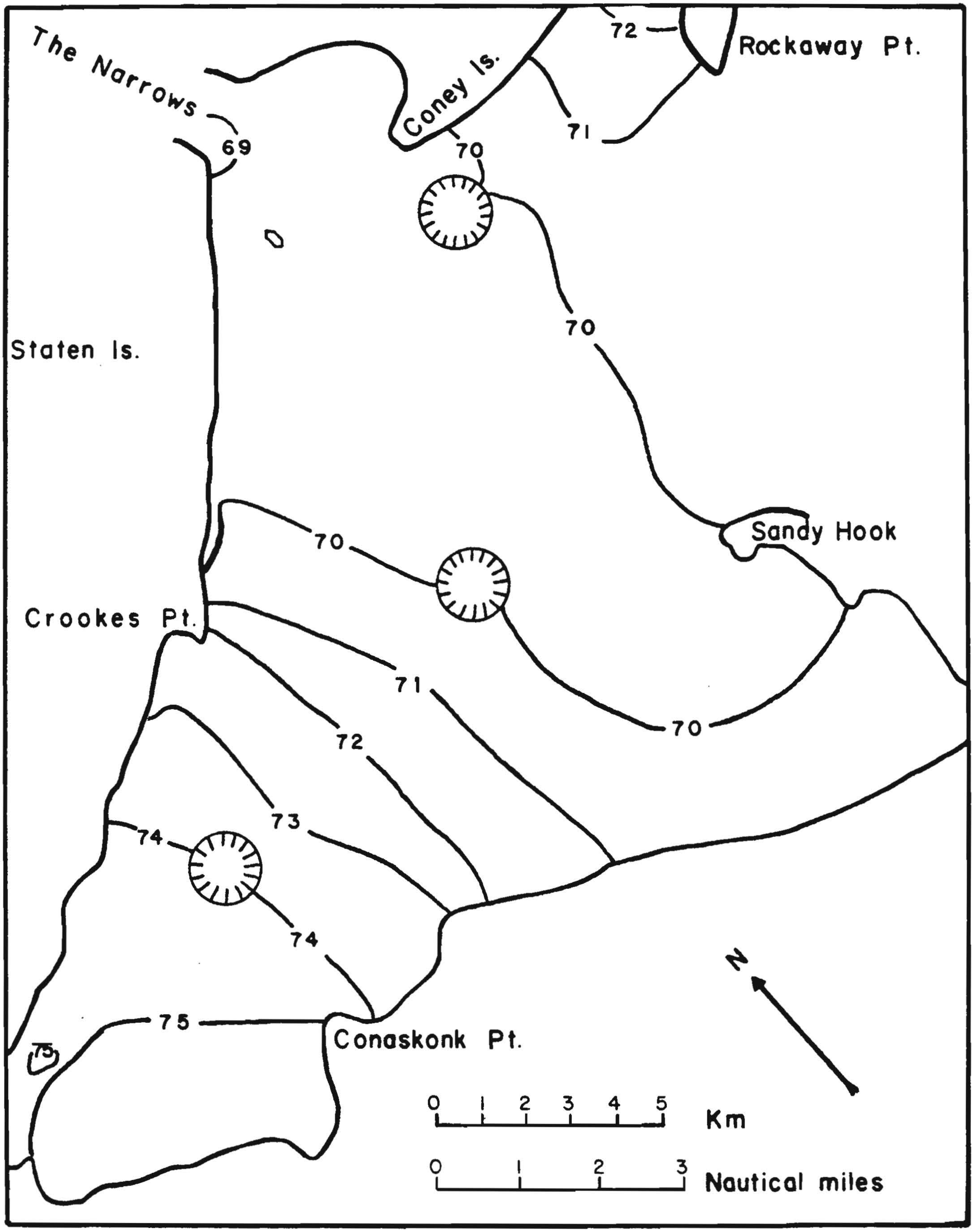

Figure 24. Maximum tidal elevations above mean sea level, in cm, after construction of circular containment islands.

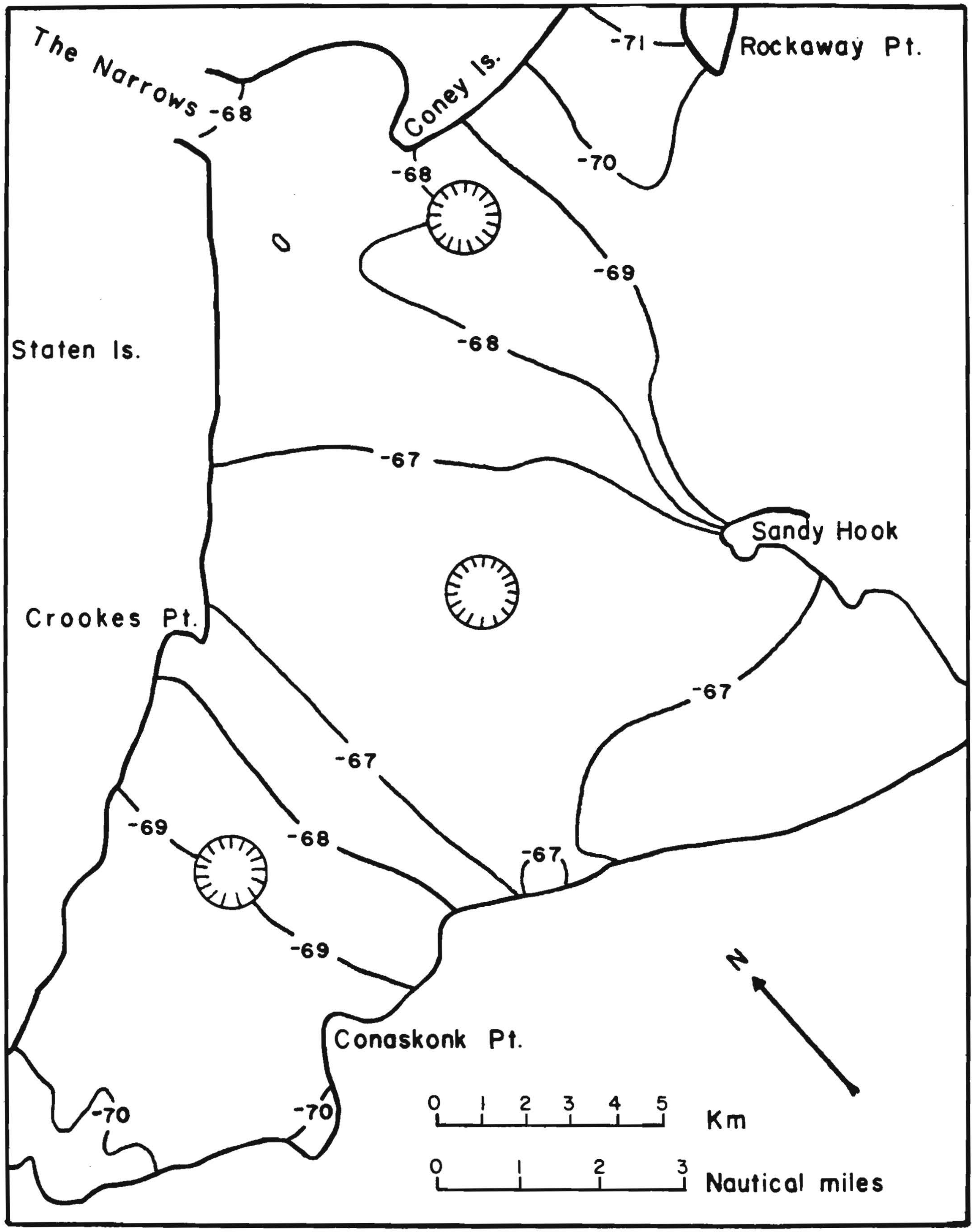

Figure 25. Minimum tidal elevations below mean sea level, in cm, after construction of circular containment islands.

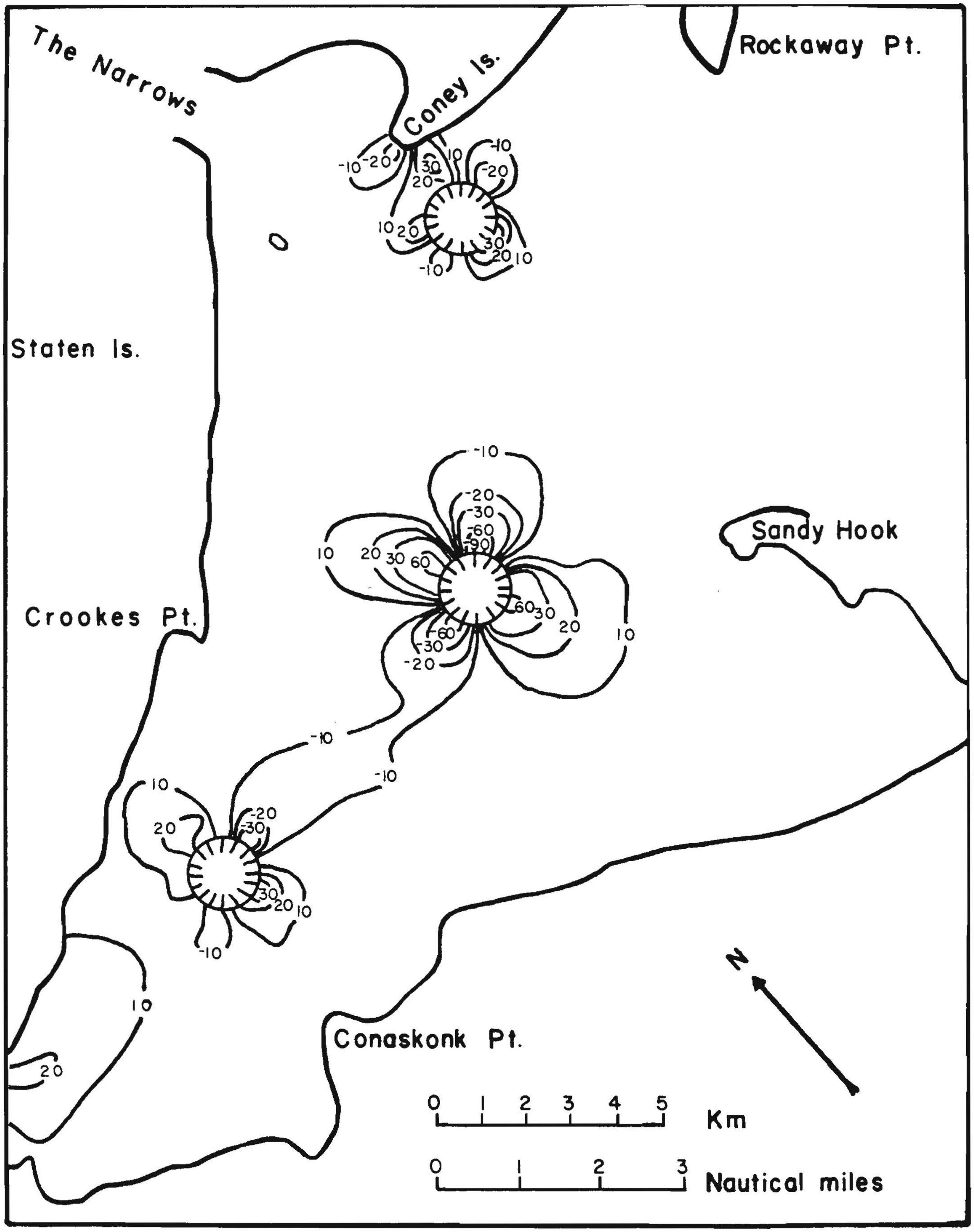

Figure 26. Changes in maximum tidal current speed, in mm/s, after construction of circular containment islands. Positive values denote an increase in speed.

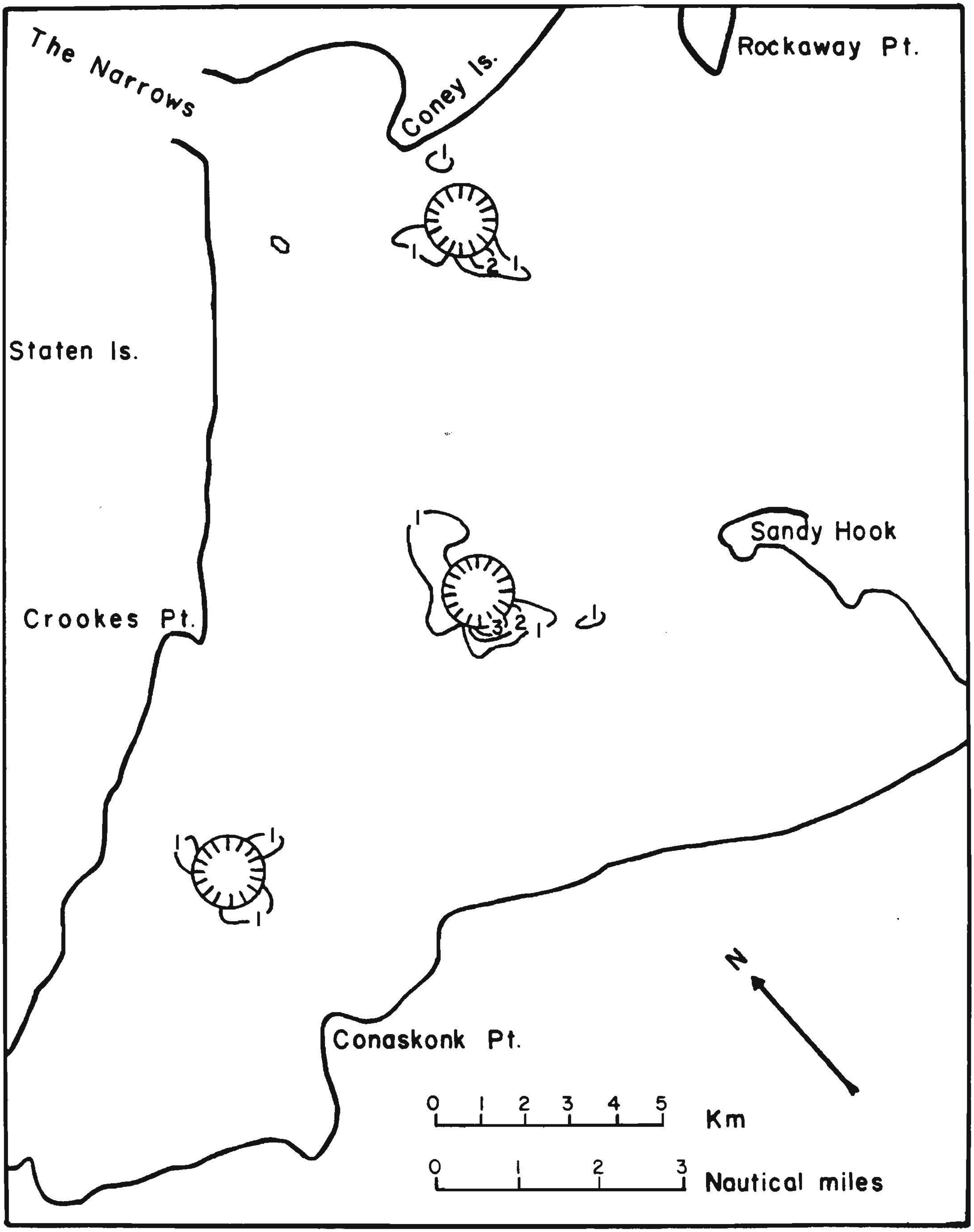

Figure 27. Changes in residual tidal current speed, in mm/s, after construction of circular containment islands. Positive values denote an increase in speed.

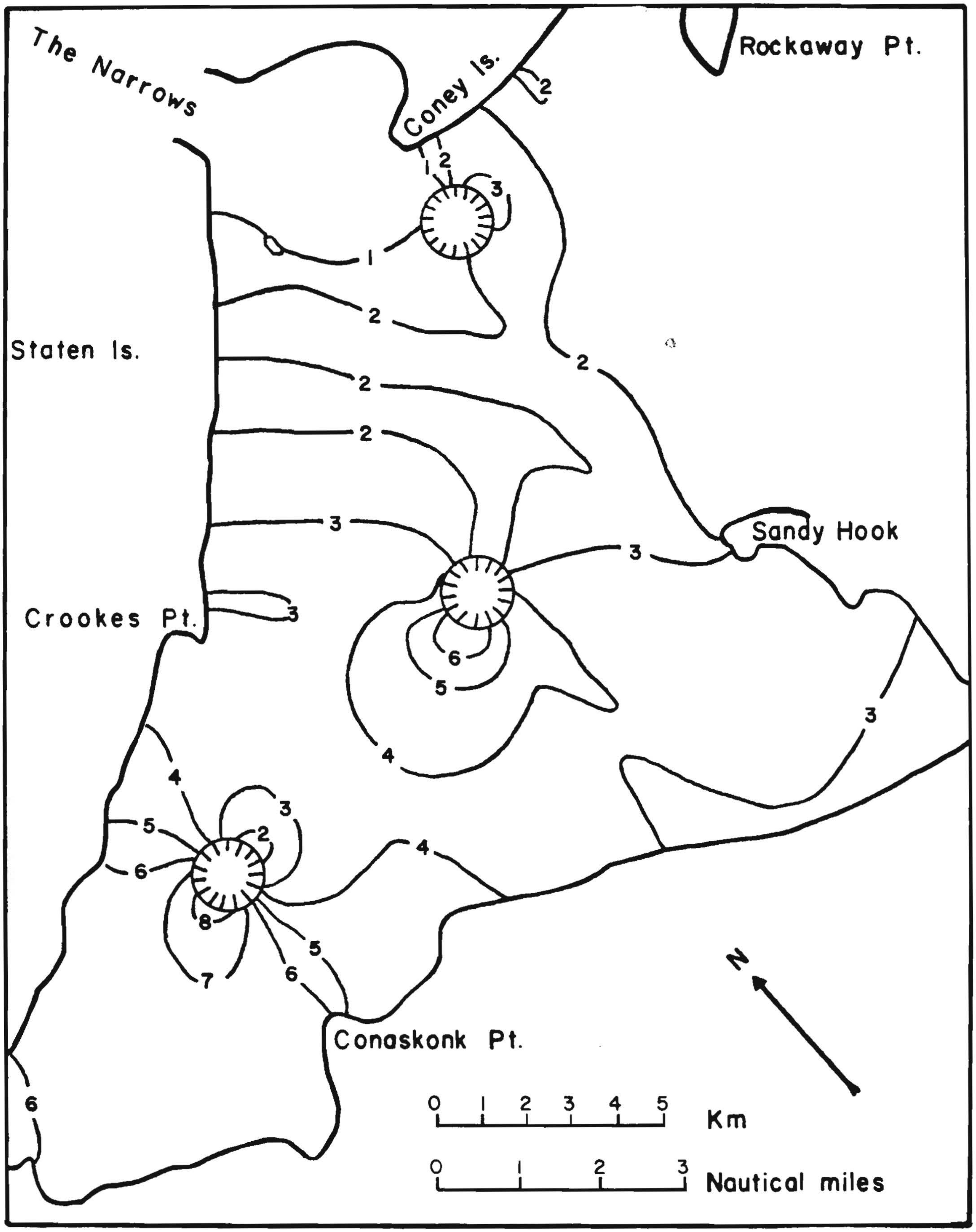

Figure 28. Changes in maximum tidal elevation (in mm) above mean sea level, after construction of circular containment islands.

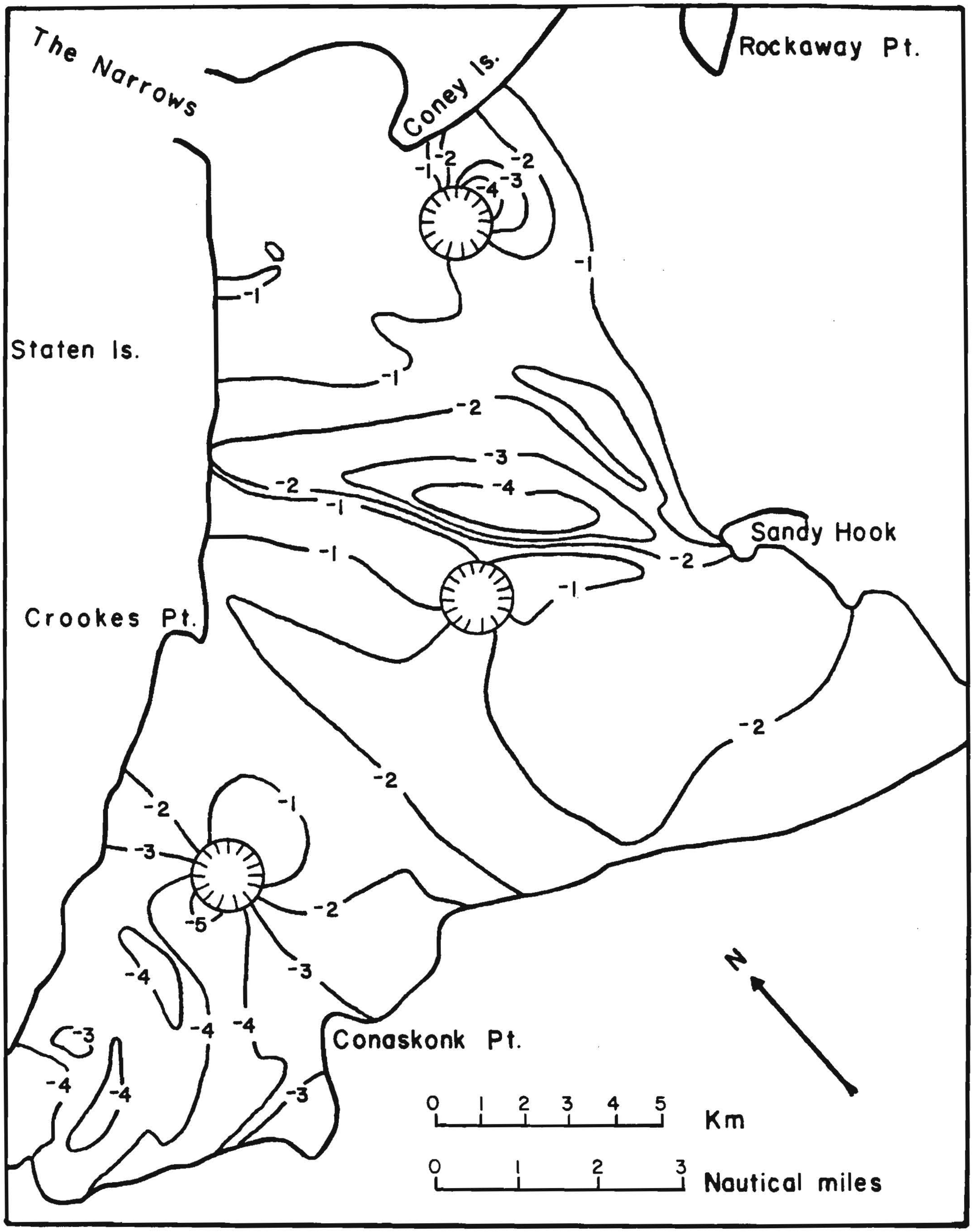

Figure 29. Changes in minimum tidal elevation (in mm) below mean sea level, after construction of circular containment islands.

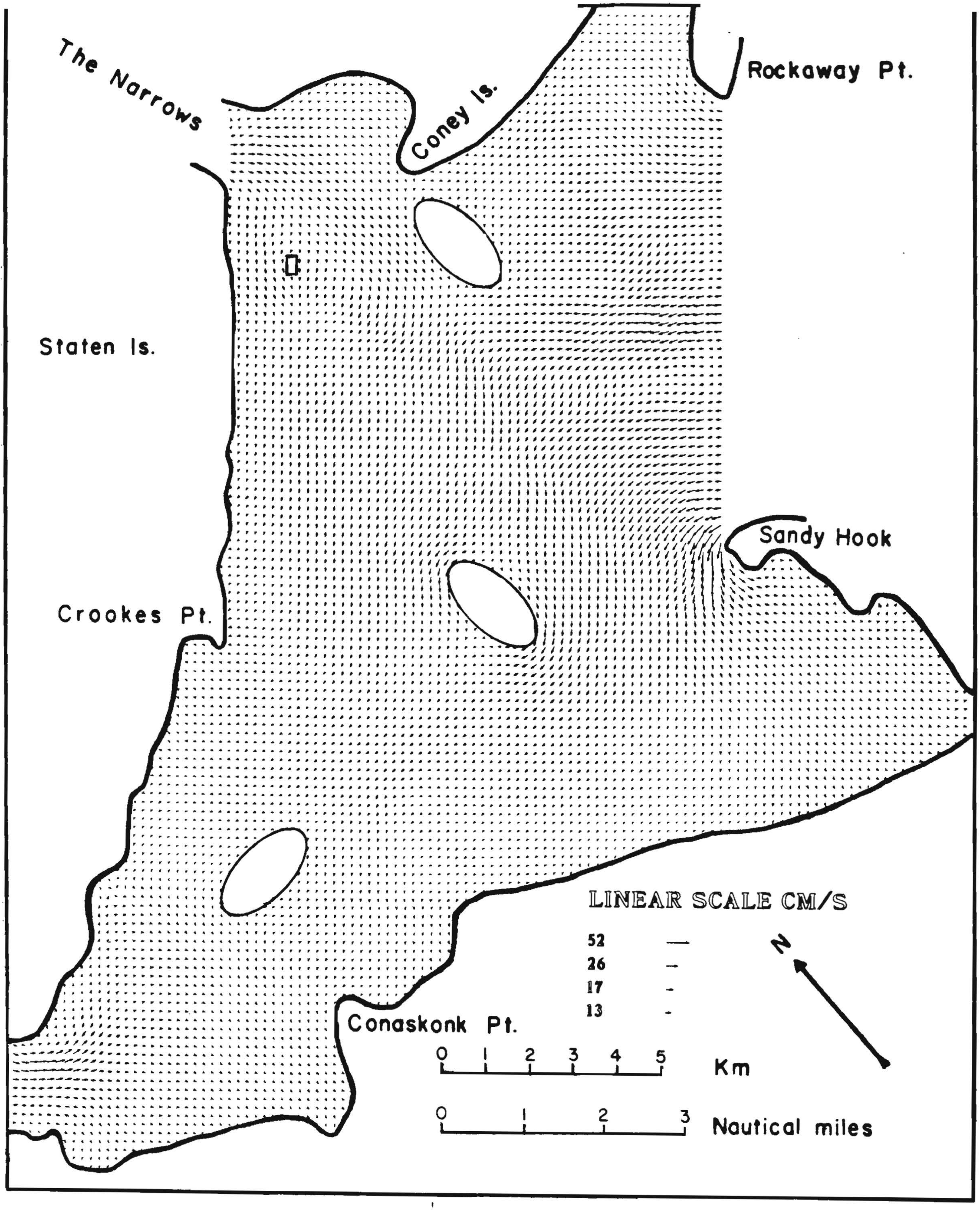

Figure 30. Tidal current vectors, after construction of elliptical containment islands, 3.93 hours before High Water at Sandy Hook.

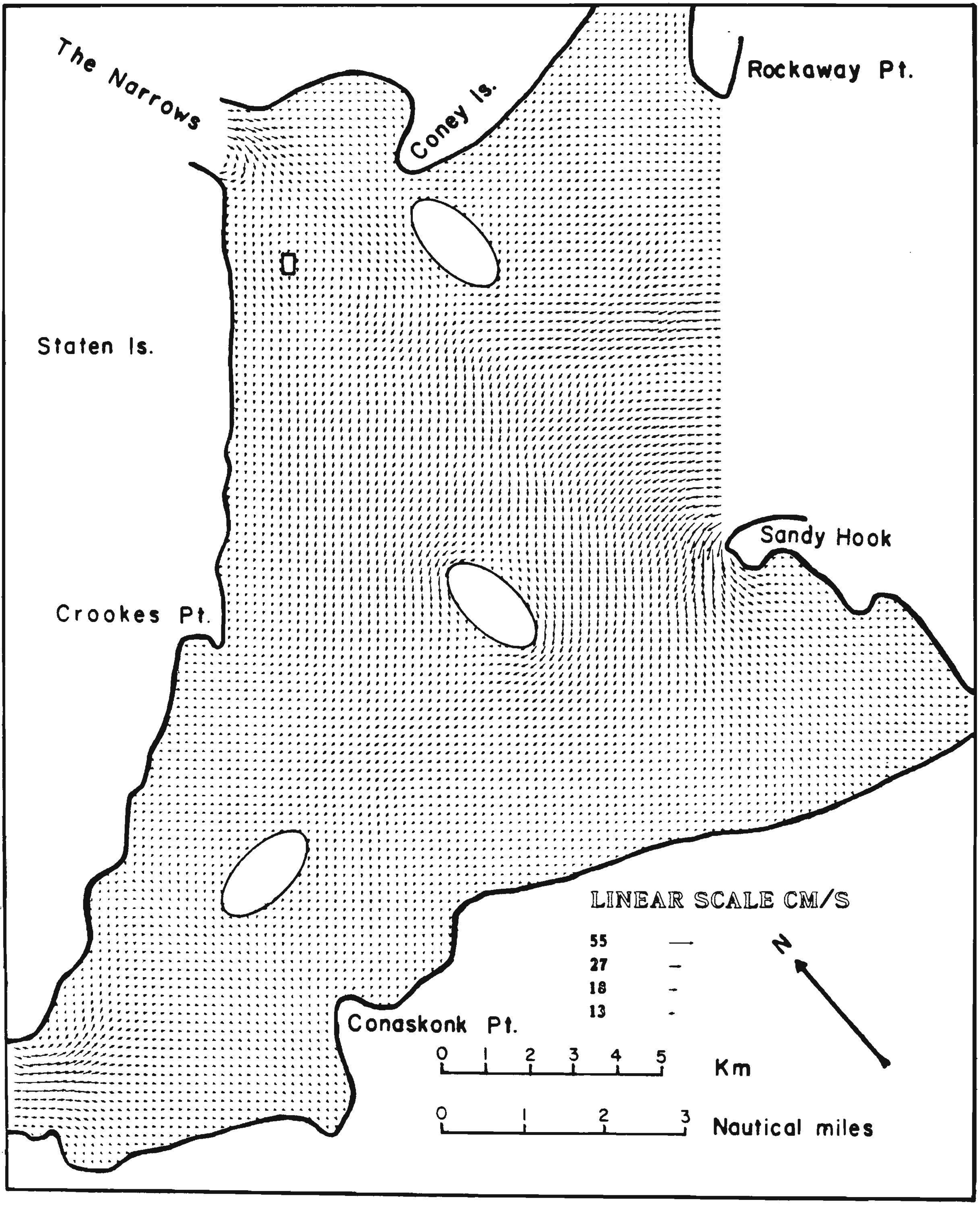

Figure 31. Tidal current vectors, after construction of elliptical containment islands, 1.86 hours before High Water at Sandy Hook.

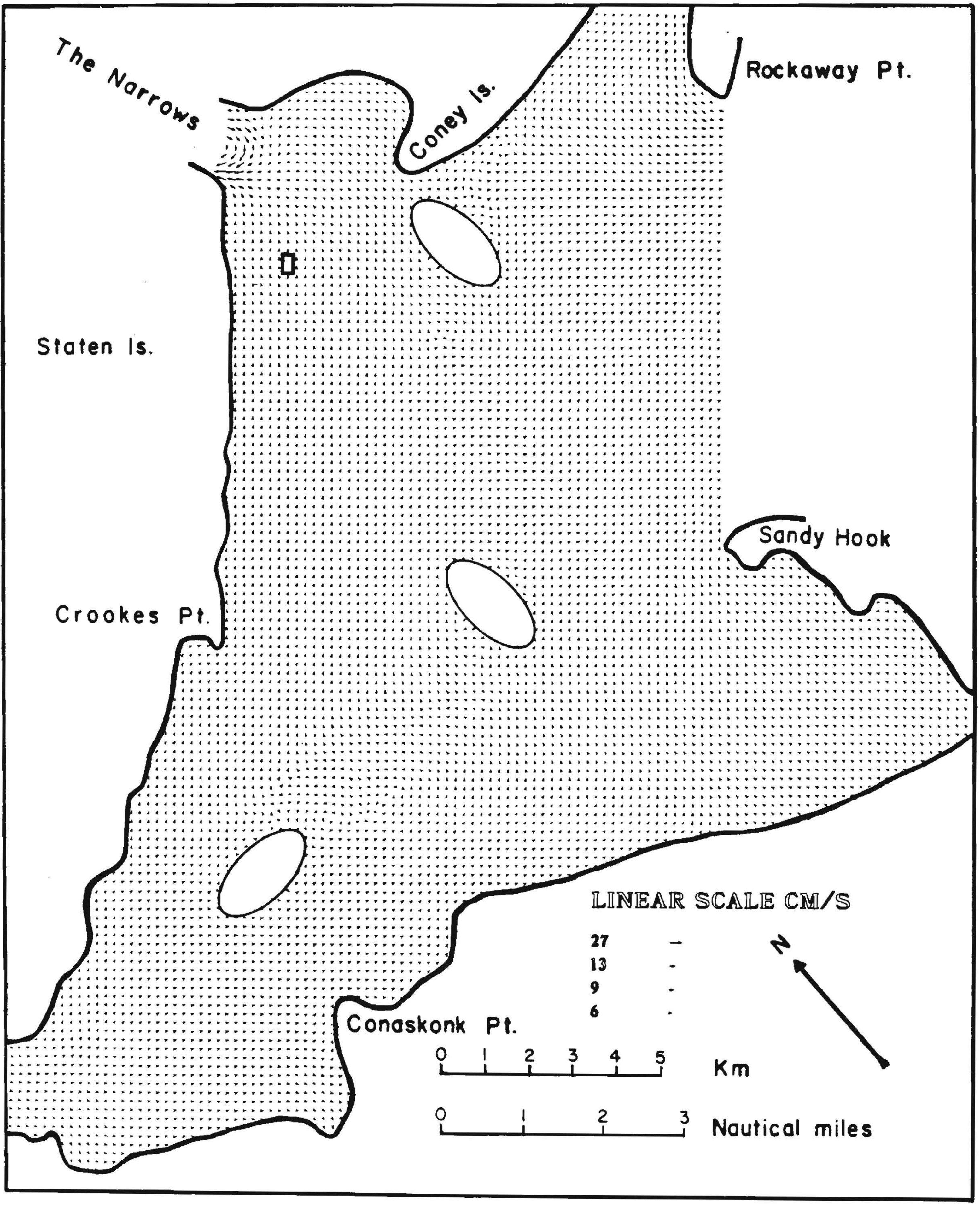

Figure 32. Tidal current vectors, after construction of elliptical containment islands, 0.21 hours after High Water at Sandy Hook.

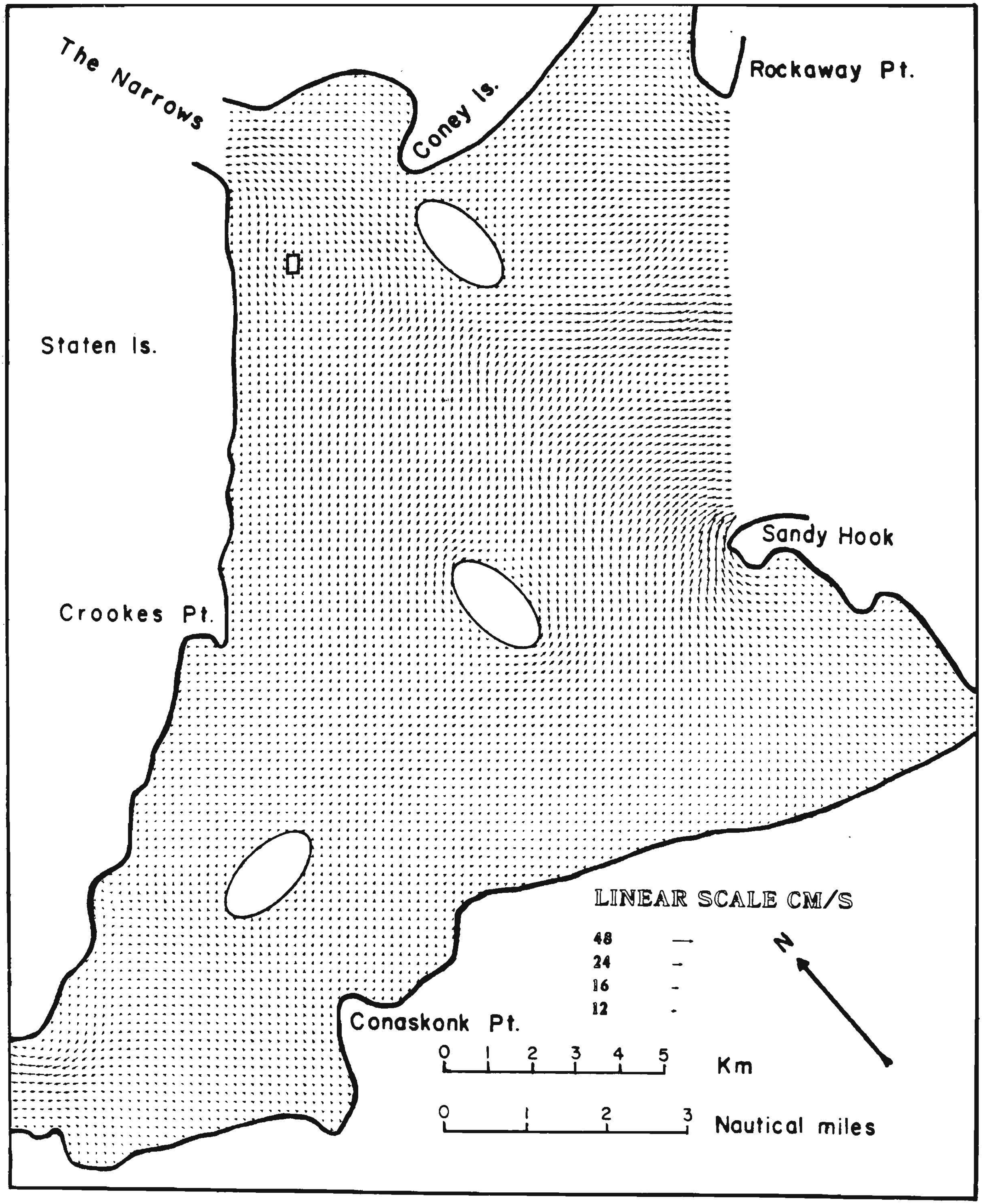

Figure 33. Tidal current vectors, after construction of elliptical containment islands, 2.28 hours after High Water at Sandy Hook.

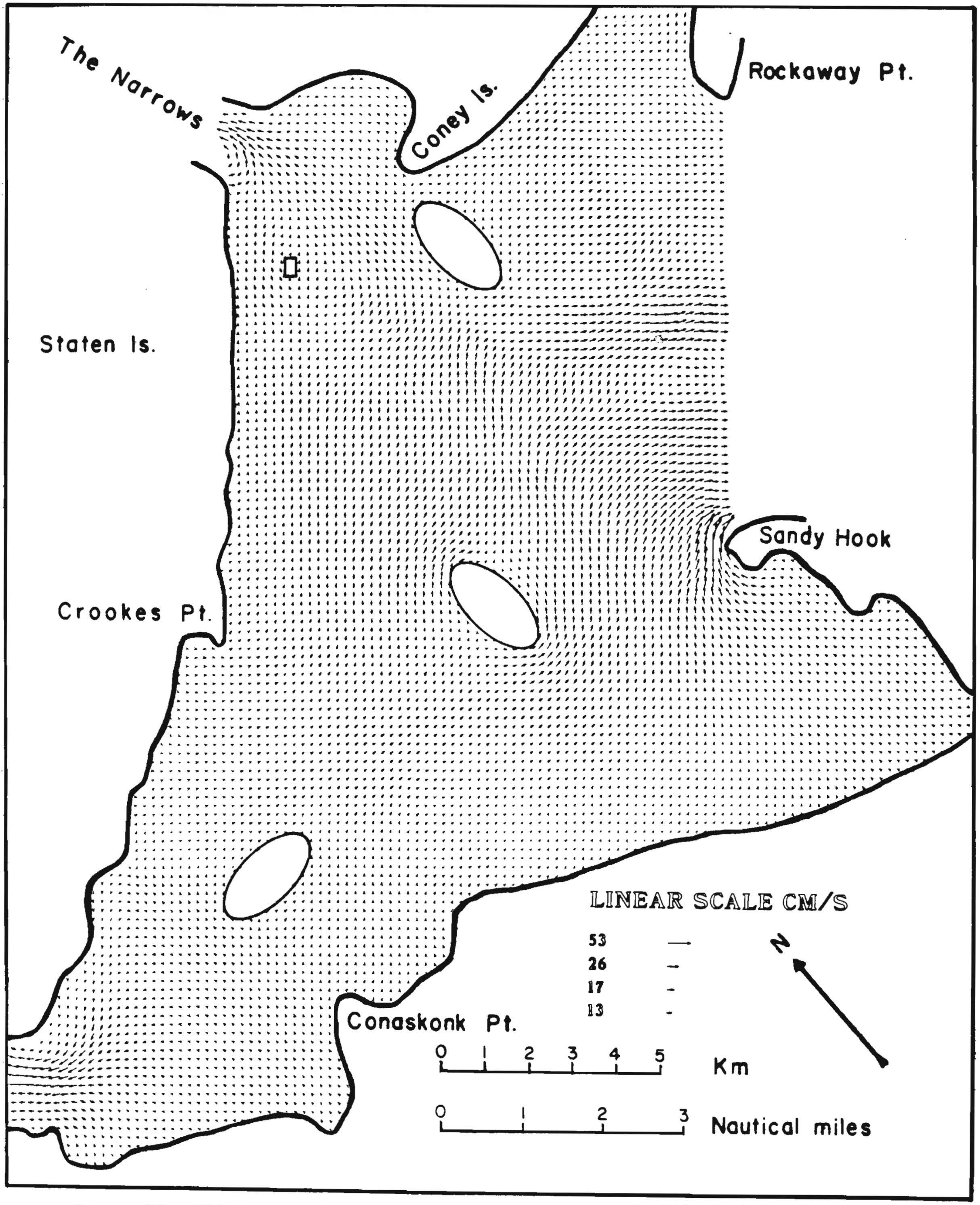

Figure 34. Tidal current vectors, after construction of elliptical containment islands, 4.35 hours after High Water at Sandy Hook.

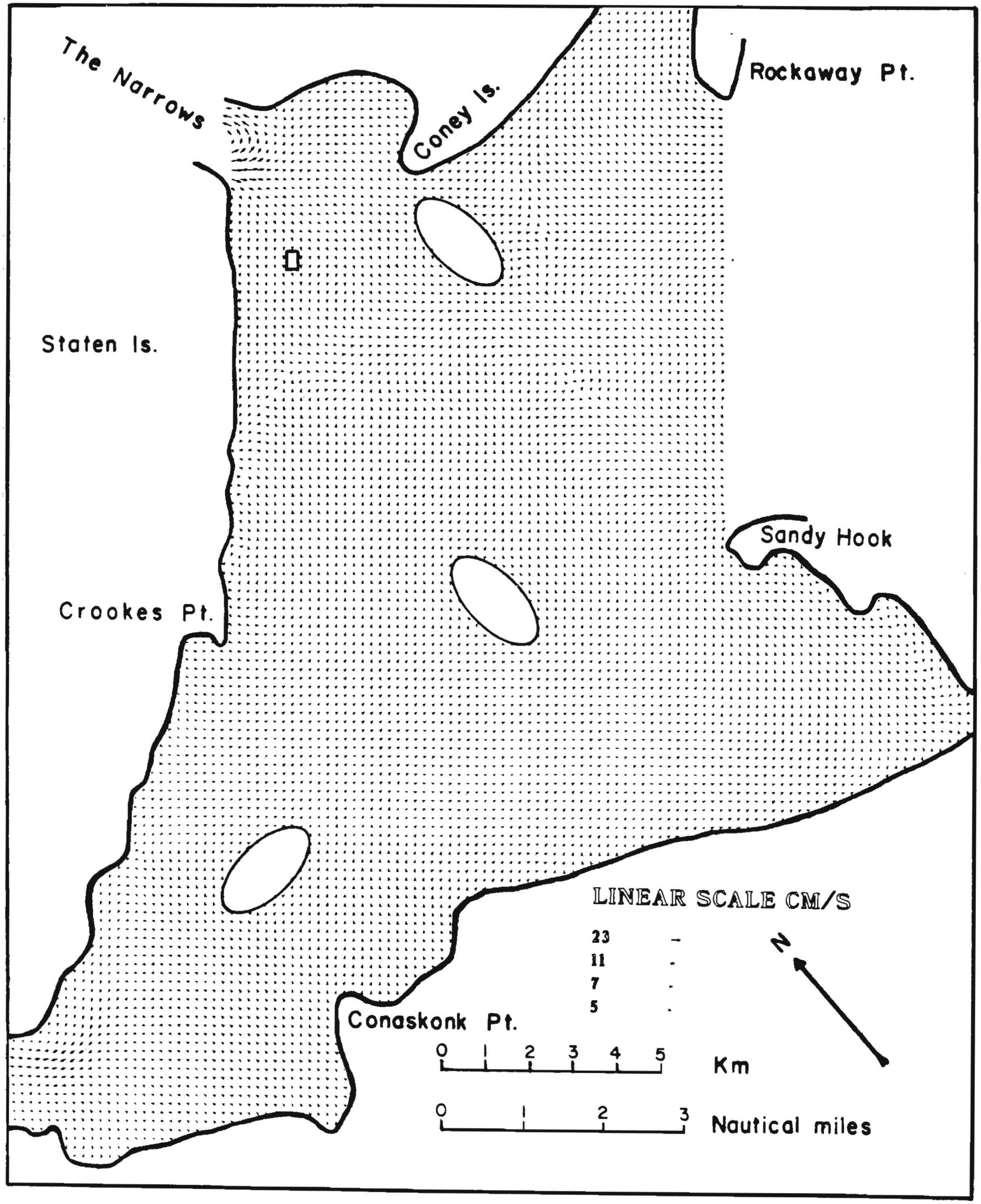

Figure 35. Tidal current vectors, after construction of elliptical containment islands, 6.42 hours after High Water at Sandy Hook.

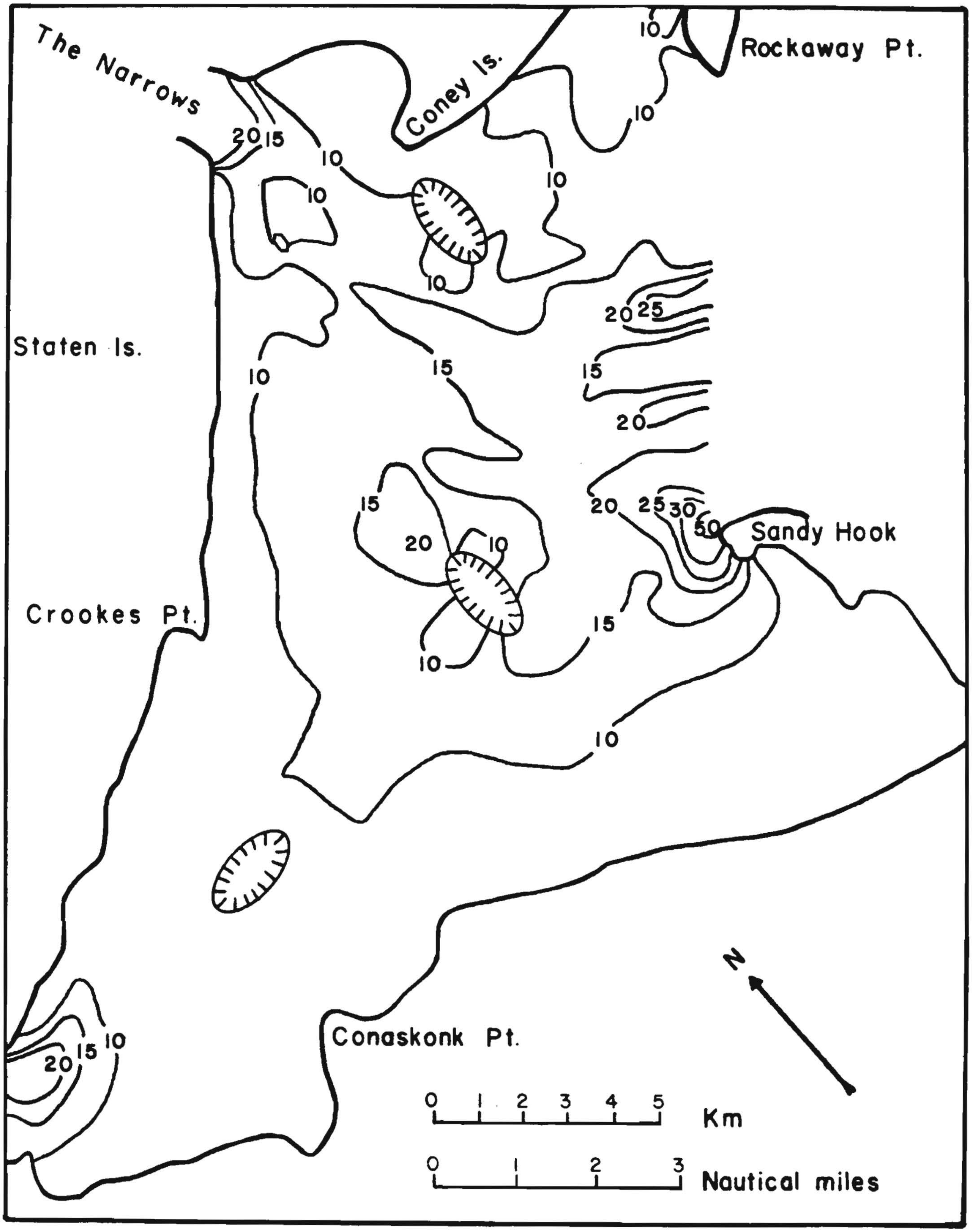

Figure 36. Maximum tidal current isotachs, in cm/s, after construction of elliptical containment islands.

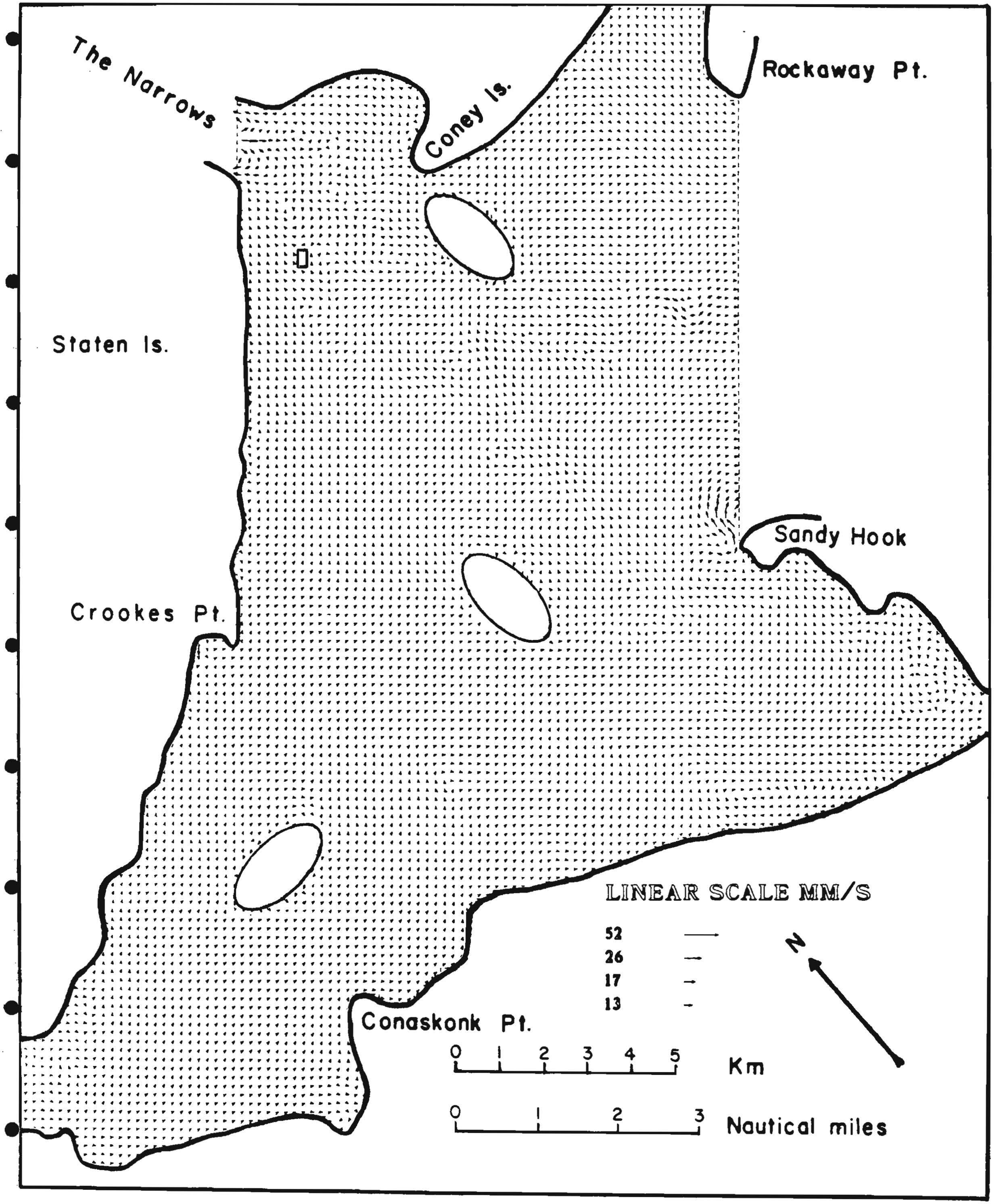

Figure 37. Residual tidal current vectors after construction of elliptical containment islands.

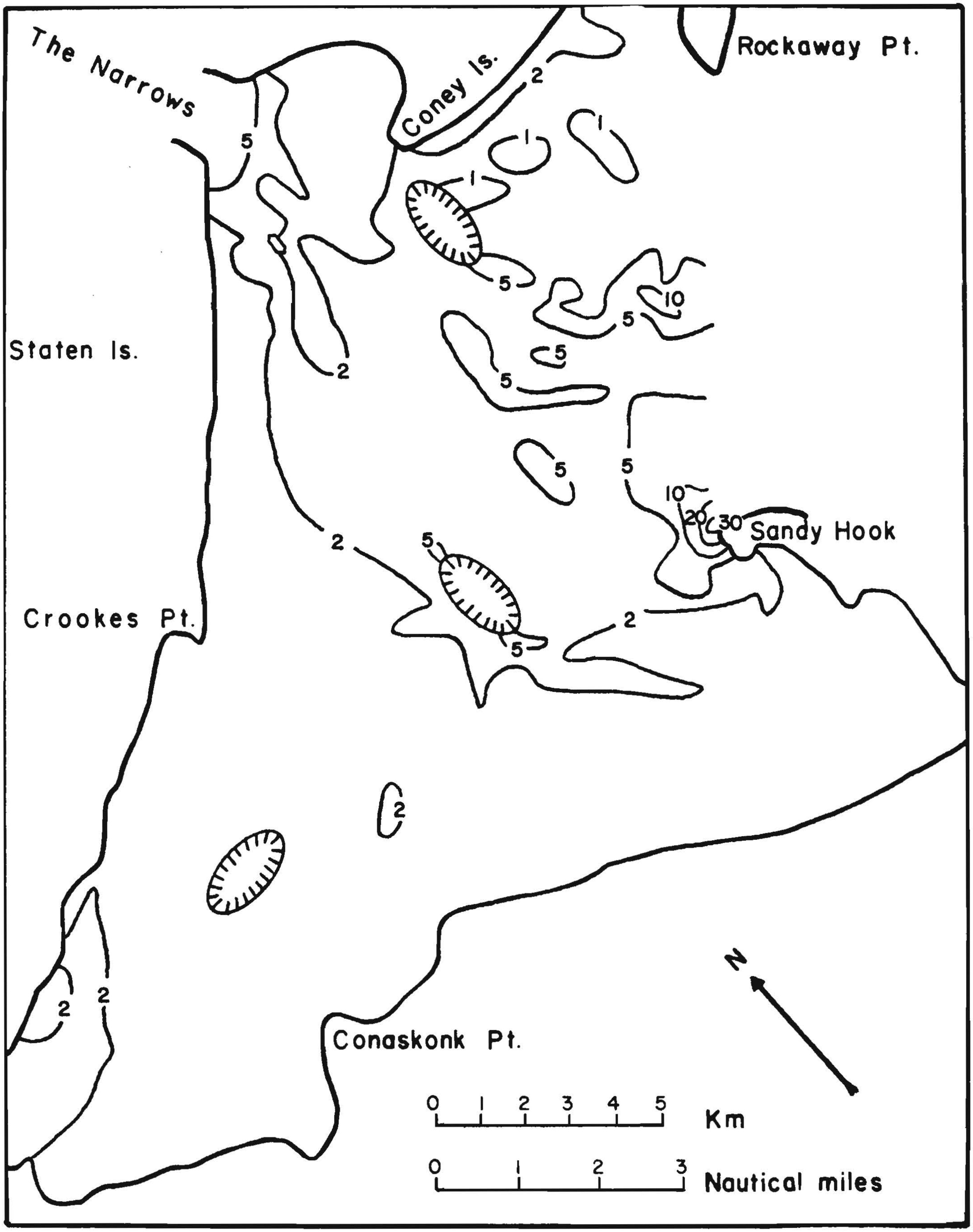

Figure 38. Residual tidal current isotachs, in mm/s, after construction of elliptical containment islands.

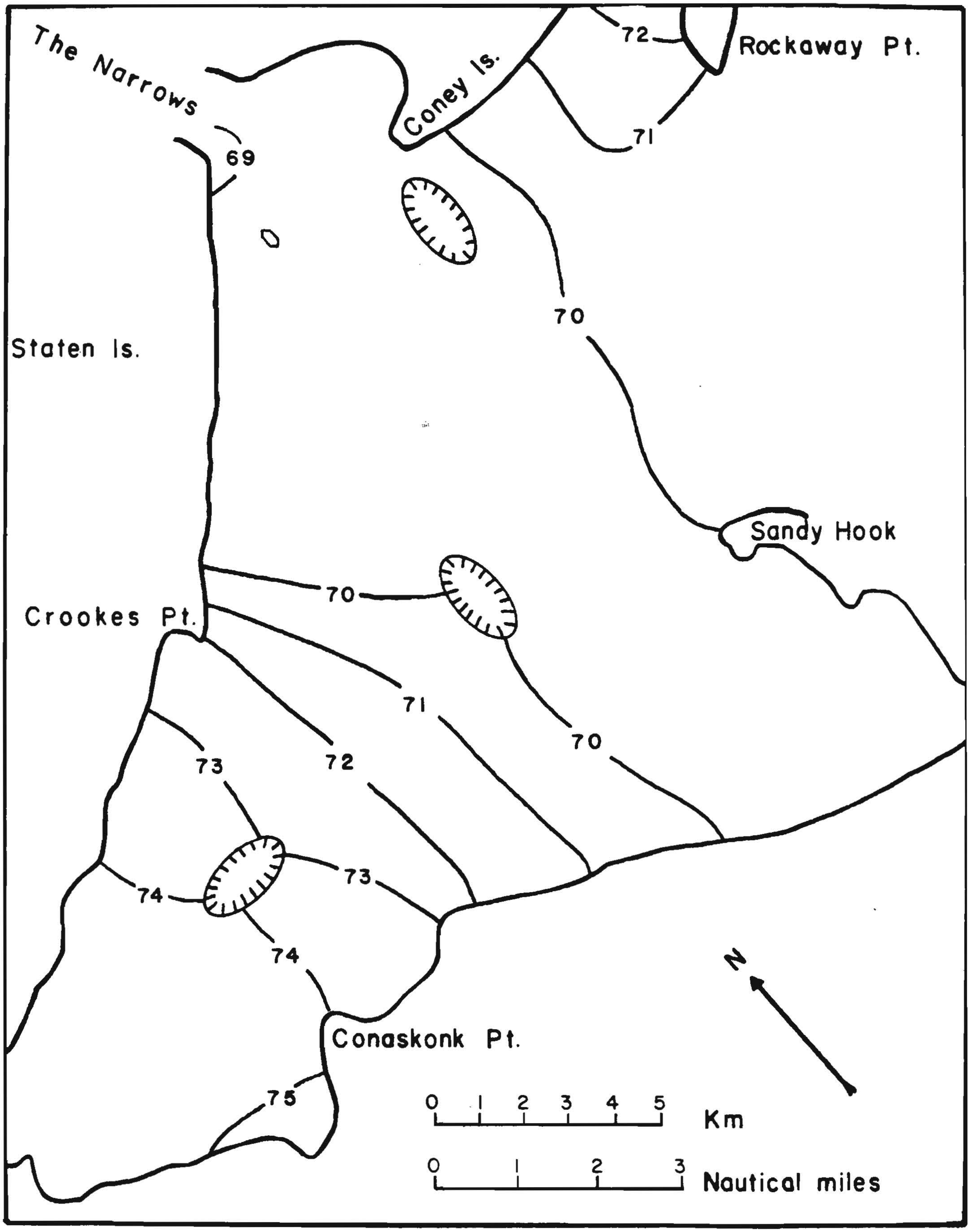

Figure 39. Maximum tidal elevations above mean sea level, in cm, after construction of elliptical containment islands.

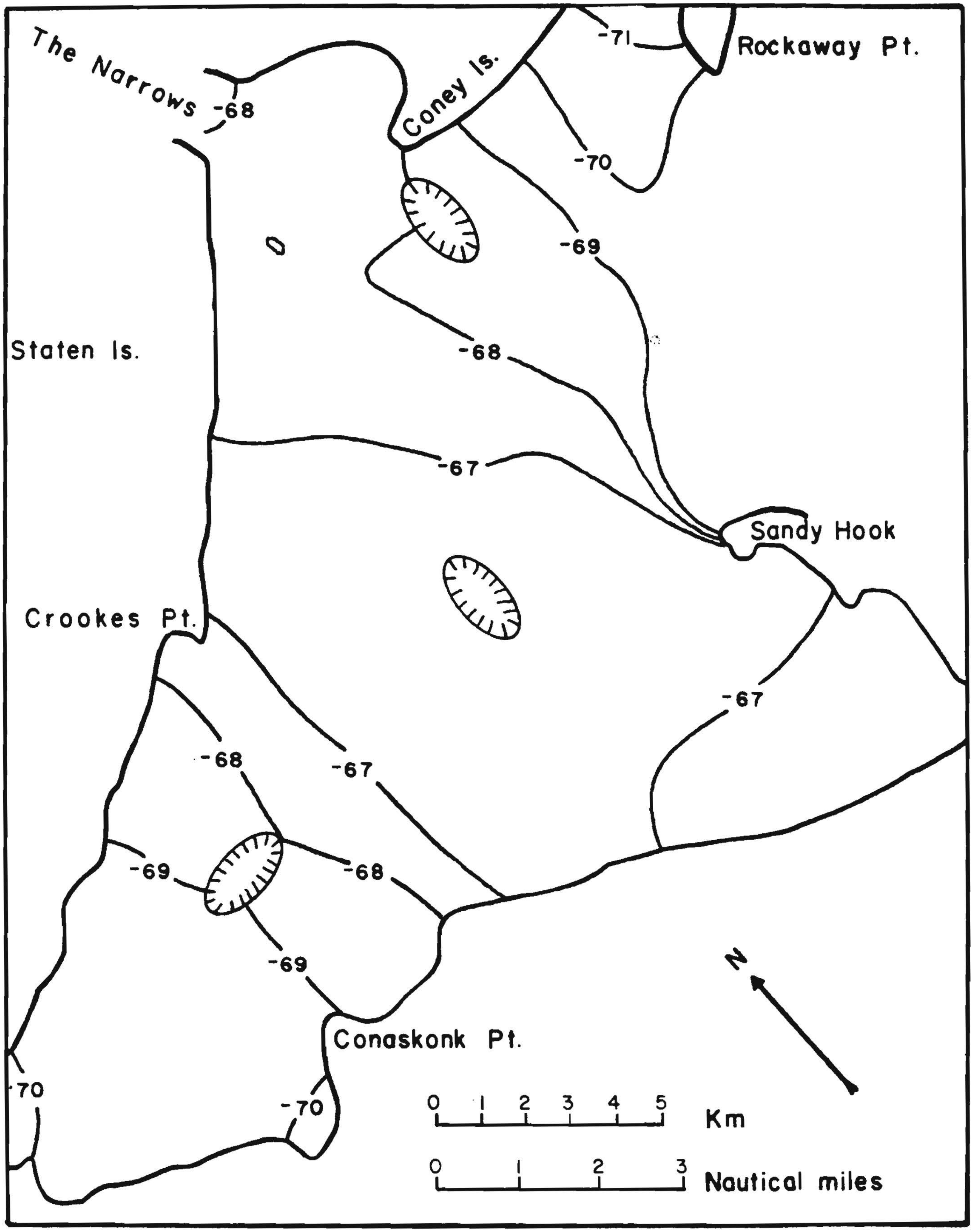

Figure 40. Minimum tidal elevations below mean sea level, in cm, after construction of elliptical containment islands.

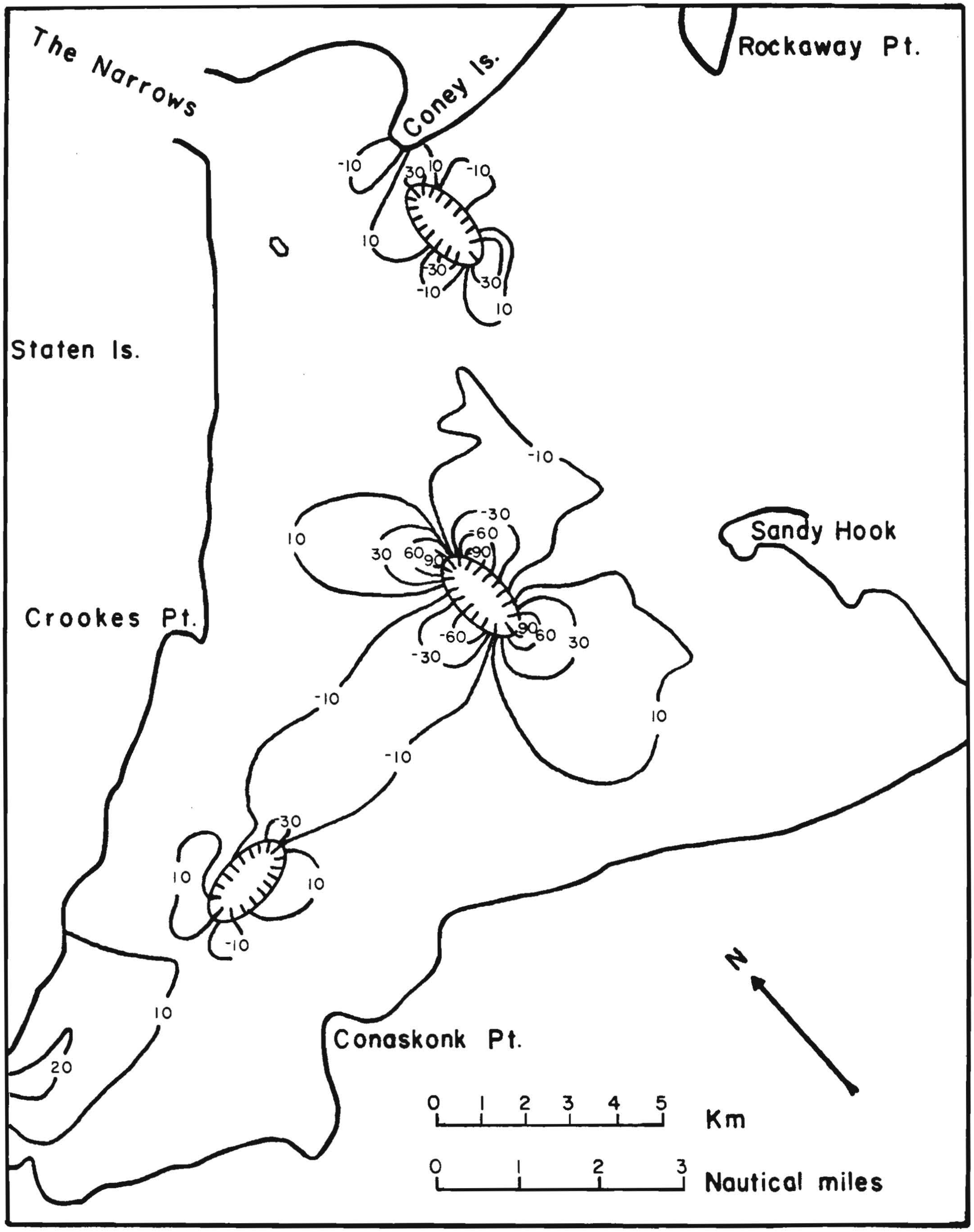

Figure 41. Changes in maximum tidal current speed in mm/s, after construction of elliptical containment islands.

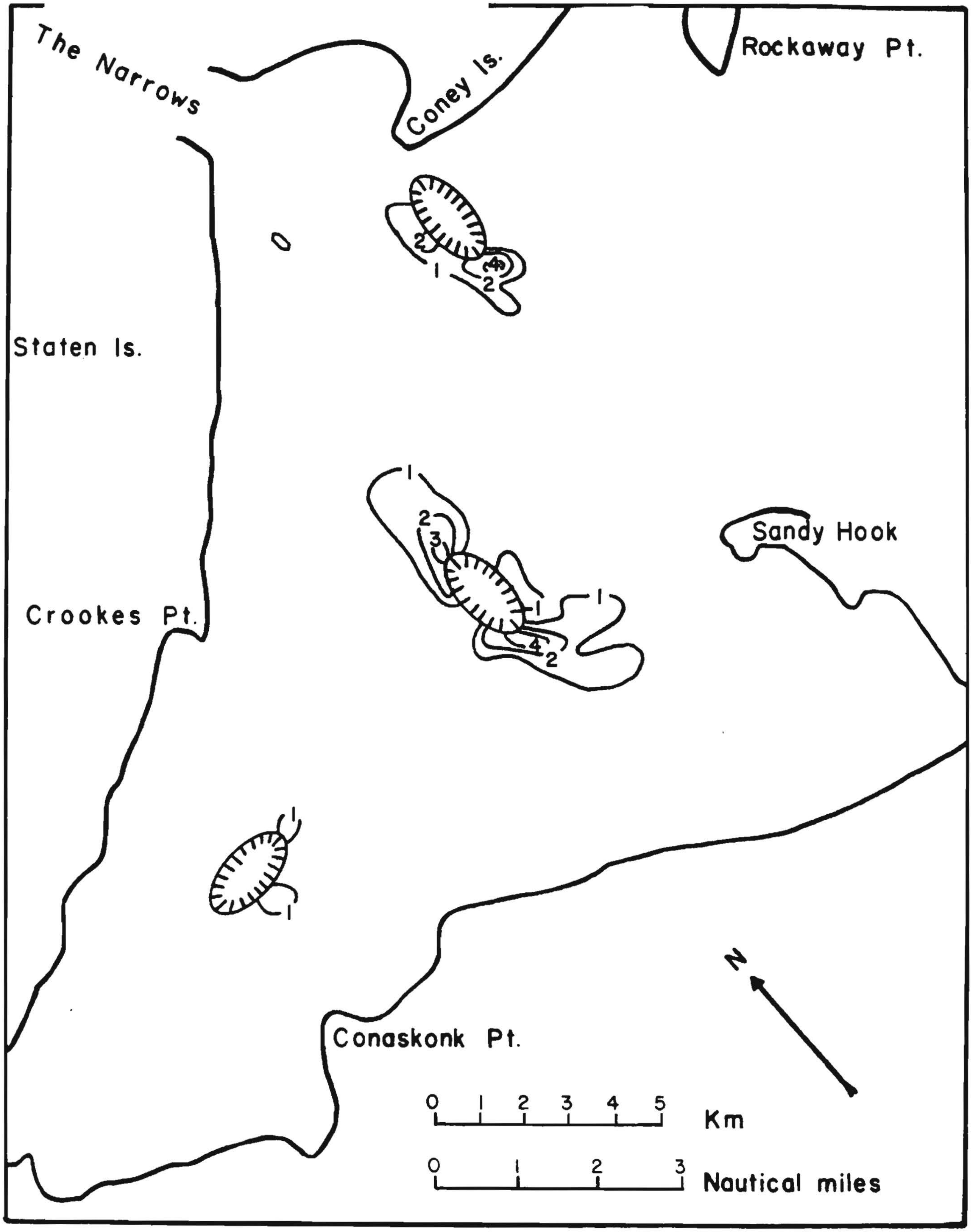

Figure 42. Changes in residual tidal current speed in mm/s, after construction of elliptical containment islands. Positive values denote an increase in speed.

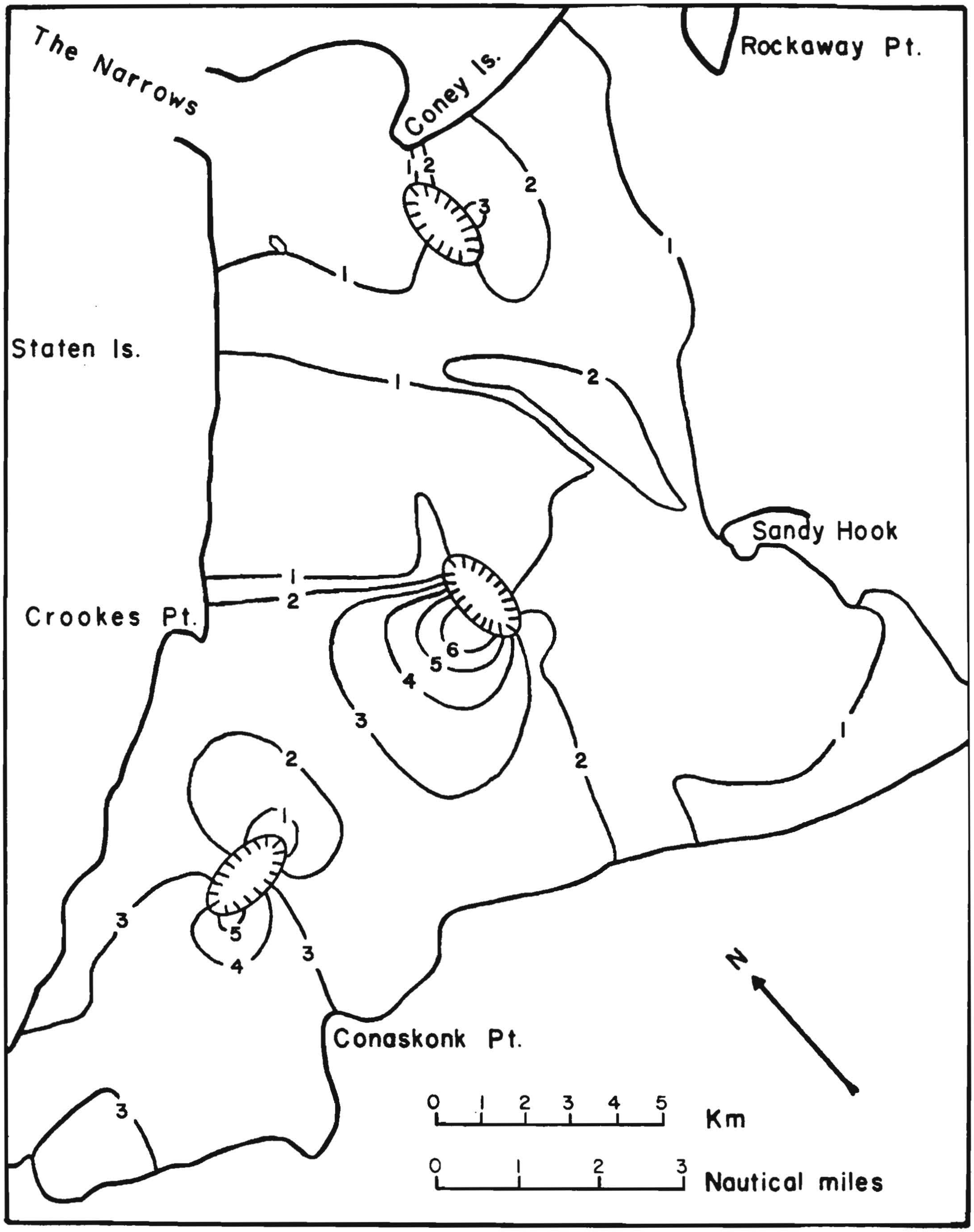

Figure 43. Changes in maximum tidal elevation (in mm) above mean sea level, after construction of elliptical containment islands.

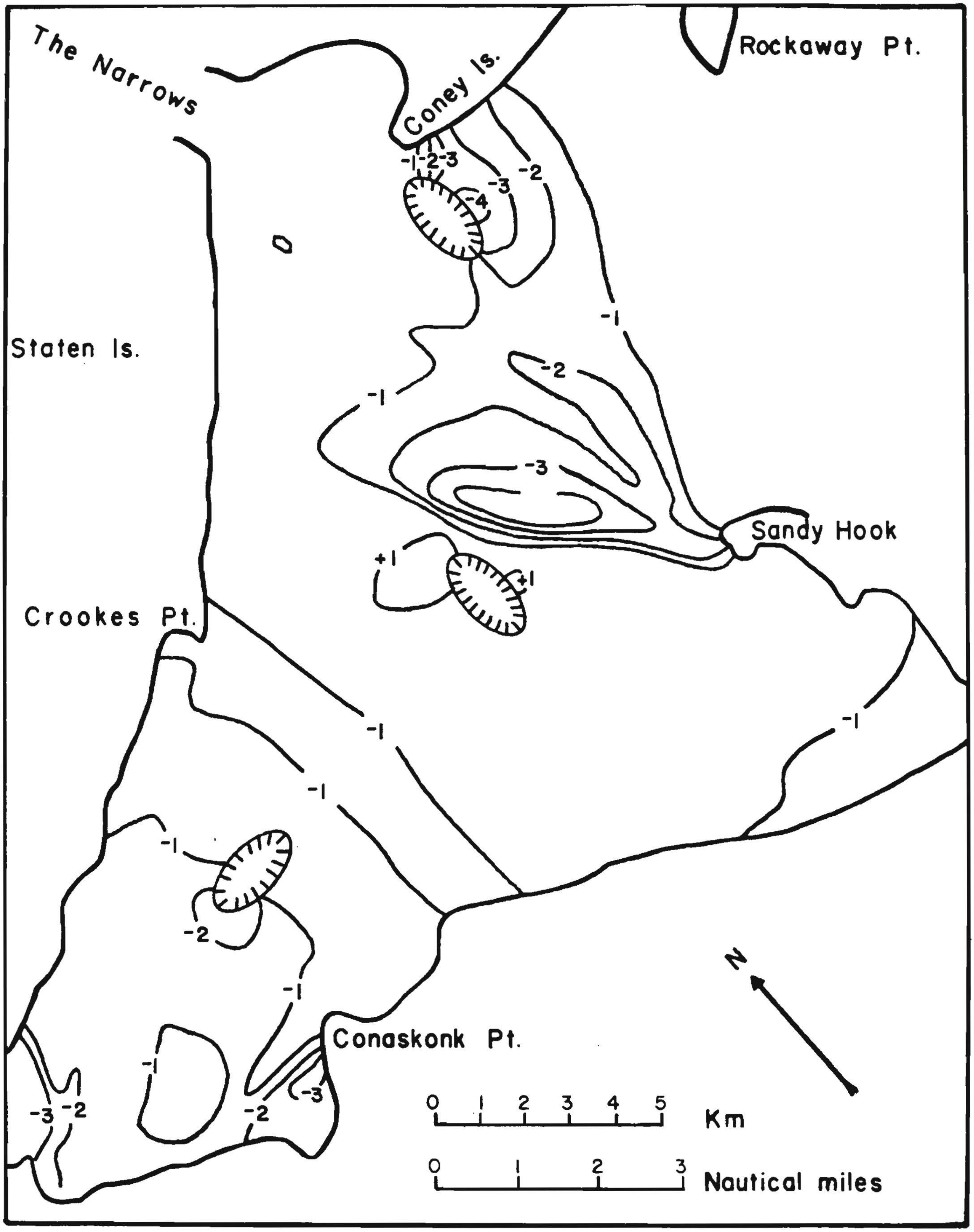

Figure 44. Changes in minimum tidal elevation (in mm) below mean sea level, after construction of elliptical containment islands.

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