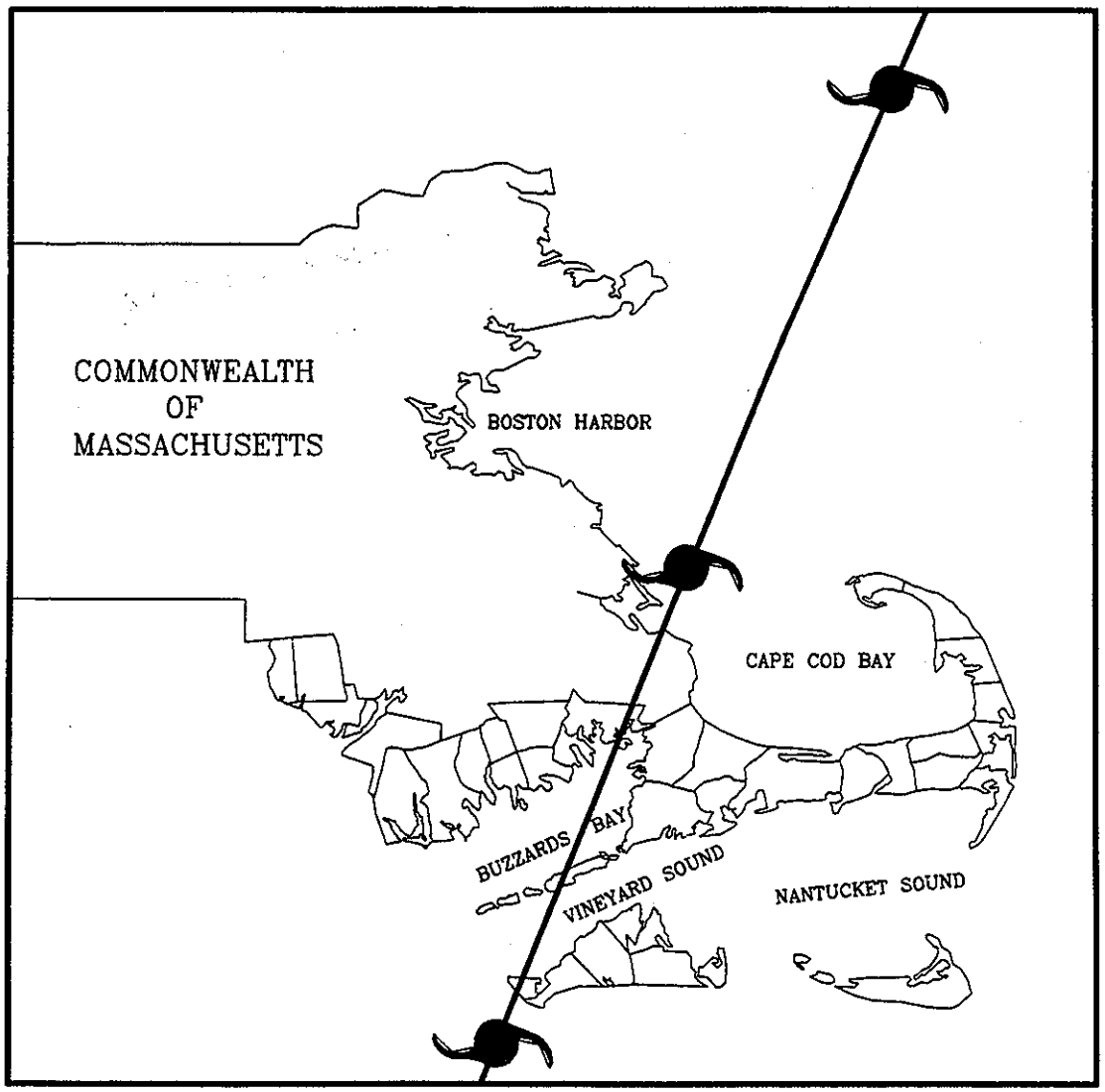
April 1997

Southern Massachusetts Hurricane Evacuation Study Appendices



US Army Corps
of Engineers
New England Division

REPORT DOCUMENTATION PAGE

Form Approved
OMB No. 0704-0188

Public reporting burden for this collection of information is estimated to average 1 hour per response, including the time for reviewing instructions, searching existing data sources, gathering and maintaining the data needed, and completing and reviewing the collection of information. Send comments regarding this burden estimate or any other aspect of this collection of information, including suggestions for reducing this burden, to Washington Headquarters Services, Directorate for Information Operations and Reports, 1215 Jefferson Davis Highway, Suite 1204, Arlington, VA 22202-4302, and to the Office of Management and Budget, Paperwork Reduction Project (0704-0188), Washington, DC 20503.

1. AGENCY USE ONLY *(Leave blank)*

2. REPORT DATE
April 1997

3. REPORT TYPE AND DATES COVERED
PL 93-288, PL 86-645 1997

4. TITLE AND SUBTITLE
Southern Massachusetts Hurricane Evacuation Study
Appendices

5. FUNDING NUMBERS

6. AUTHOR(S)
Department of the Army
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7. PERFORMING ORGANIZATION NAME(S) AND ADDRESS(ES)
US Army Corps of Engineers
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8. PERFORMING ORGANIZATION REPORT NUMBER

9. SPONSORING/MONITORING AGENCY NAME(S) AND ADDRESS(ES)
Federal Emergency Management Agency, Region I
Room 462, J.W. McCormack
Post Office and Court House
Boston, MA 02109

10. SPONSORING/MONITORING AGENCY REPORT NUMBER

11. SUPPLEMENTARY NOTES
Support documentation to the Southern Massachusetts Hurricane Evacuation Study, scheduled to be completed in May 1997

12a. DISTRIBUTION AVAILABILITY STATEMENT
Approved for public release; distribution unlimited

12b. DISTRIBUTION CODE

13. ABSTRACT *(Maximum 200 words)*

This report contains the support documentation to the main report entitled the Southern Massachusetts Hurricane Evacuation Study Technical Data Report, scheduled to be completed in May 1997. The purpose of the study is to provide the Massachusetts Emergency Management Agency and coastal communities in Southern Massachusetts with realistic data quantifying the major factors involved in hurricane evacuation decision-making. To accomplish this, the study provides information on the extent and severity of potential flooding from hurricanes, the associated vulnerable population, capacities of existing public shelters and estimated sheltering requirements, and evacuation roadway clearance times. The report also provides guidance on how this information can be used with National Hurricane Center advisories for hurricane evacuation decision-making.

14. SUBJECT TERMS
Massachusetts, Emergency Management, Hurricanes

15. NUMBER OF PAGES
382

16. PRICE CODE

17. SECURITY CLASSIFICATION OF REPORT	18. SECURITY CLASSIFICATION OF THIS PAGE	19. SECURITY CLASSIFICATION OF ABSTRACT	20. LIMITATION OF ABSTRACT
unclassified	unclassified	unclassified	

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APPENDIX A

Storm Surge Atlas for the Narragansett Bay, Rhode Island and Buzzards Bay, Massachusetts Area

A STORM SURGE ATLAS FOR THE NARRAGANSETT BAY, RHODE ISLAND AND BUZZARDS BAY, MASSACHUSETTS AREA

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1. INTRODUCTION

Storm surge is the abnormal rise in water level caused by wind and pressure forces of a hurricane. Storm surge produces most of the flood damage and drownings associated with tropical storms that make landfall or that closely approach a coastline (Anthes, 1982).

A numerical storm surge model developed by Jelesnianski (1967, 1972), Jelesnianski and Taylor (1973) and Jelesnianski et al. (1984) has been applied to the Narragansett Bay, RI and Buzzards Bay, MA region. The model, which calculates sea, lake and overland surges from hurricanes, and has the acronym "SLOSH," is a pairing of a model of a hurricane coupled to a model for storm surge. Crawford (1979) discussed some preliminary results using this model in the southeast Louisiana region.

The purpose of this atlas is to provide maps of SLOSH-modeled heights of storm surge and extent of flood inundation, for various combinations of hurricane strength, forward speed of storm and direction of storm motion. Strength is modeled by use of the central pressure and storm eye size using four of the five categories of storm intensity (Table 1), developed by Saffir and Simpson (Simpson and Riehl, 1981). Six storm-track headings were selected as being representative of storm behavior in this region on the basis of observations by forecasters at NOAA's National Hurricane Center.

The maps in this atlas summarize surge calculations made using the SLOSH model, when initialized with observed values (depths of water and heights of terrain and barriers) in the region centered on Narragansett Bay, RI and Buzzards Bay, MA.

2. THE GRID FOR THE SLOSH MODEL OF THE NARRAGANSETT AND BUZZARDS BAYS AREAS

Figure 1 illustrates the area covered by the grid for the Narragansett and Buzzards Bays SLOSH model. The area covered by the grid is called a

Table 1. Saffir/Simpson hurricane intensity categories.

	Central Pressure		Wind Speed		
Category	Millibars	Inches (Hg)	Miles per Hr.	Knots	Damage
1	≥ 980	≥ 28.9	74 - 95	64 - 83	Minimal
2	965 - 979	28.5 - 28.9	96 - 110	84 - 96	Moderate
3	945 - 964	27.9 - 28.5	111 - 130	97 - 113	Extensive
4	920 - 944	27.2 - 27.9	131 - 155	114 - 135	Extreme
5	< 920	< 27.2	> 155	> 135	Catastrophic

"basin"--the "Narragansett and Buzzards Bays Basin." The grid is a telescoping polar coordinate system with 80 arc lengths ($1 \leq I \leq 80$) and 82 radials ($1 \leq J \leq 82$). Unlike a true polar coordinate grid, which would have radial increment (ΔR) that was invariant with radius, this grid uses a ΔR that *increases with increasing distance from the grid's pole. The result is that* in each grid of the mesh, the increment of arc length (ΔS) of the side of a grid "square" is approximately equal to the radial increment of the "square," or $\Delta S \simeq \Delta R$.

The telescoping grid is a compromise between conflicting needs. What is desired is that the model domain include a large geographical area, but also that small, detailed topography be included in the model. In a Cartesian coordinate system, this combination of big area, but spatially-small grid increment, requires that a computational mesh with many grid squares be used. A large mesh requires a computer with a large central processing unit (CPU) as well as more time to perform calculations in the more numerous grid squares. The telescoping grid, by comparison, permits a resolution of these conflicting needs: it has an acceptably small spatial resolution of 1 to 10 mi^2 per grid square over land, which is the area of greatest interest. Thus, topographic details, such as highway and railroad embankments, and dikes in harbors of cities are included in the model. However, the range increment contained in each grid square becomes progressively larger with increasing distance from the pole. As a result, a large geographic area is included in the model, so that the effects of the model's boundaries on the dynamics of the storm are diminished and the storm's physics are better emulated.

The grid is tangent to the earth at the basin center, Quicksand Point on the Rhode Island-Massachusetts border at 41°27'N and 71°24'W. There, the grid increment is 1.25 statute miles. The pole (or origin) of the grid is located at 42°N and 71°01'W.

The telescoping grid has some disadvantages. Primarily, these stem from the distortion that occurs when the basin is remapped onto a display that has constant-sized increments in the vertical and horizontal, as happens when the basin is printed out by a conventional (computer) line printer. This distortion from remapping produces some difficulties in "reading" the results by the uninitiated. For example, neither latitude nor longitude lines remain uncurved and "parallels" become non-parallel. However, the projection is conformal. The projection scheme results in each grid square at I = 1, closest to the pole, representing an area of about 0.35 square mile. By contrast, at maximum distance from the pole, at I = 80, each grid square contains about 33.5 square miles. Thus, the distortions require that aids be provided to "read" and interpret the results.

3. SLOSH MODEL

A. Hurricane Model and Input

The hurricane model which drives the storm surge model was developed by Jelesnianski and Taylor (1973). It is a trajectory model of a stationary vortex and it balances the forces from pressure gradient, centrifugal, Coriolis and surface frictional effects. Adjustments are made to the computed vector wind to incorporate the hurricane's forward motion. The model's input includes the radius of maximum wind (RMW) and the difference (ΔP) in sea-level pressure between the ambient value and the minimum value in the storm's center. Directly measured wind vectors are not used. The model also requires input of the coordinates of the storm's center. Thus, input data include thirteen sets of latitude, longitude, ΔP and RMW, at six hour increments, beginning 48 hours before storm landfall and ending 24 hours after landfall. These 13 sets are then linearly interpolated into values/positions at hourly (or smaller) time increments. The model then generates the meteorological

forces--surface stress and the gradient of atmospheric pressure-that drive the underlying ocean.

B. Storm Surge Model

Storm surge is the response by the ocean to meteorological forces. The model's governing equations are those given by Jelesnianski (1967), except now for the inclusion of the finite amplitude effect. Coefficients for surface drag, eddy viscosity and bottom slip are the same as those used in an earlier model (Jelesnianski, 1972). There is no calibration or tuning to force agreement between observed and computed surges; coefficients are fixed, and do not vary from one geographical region to another.

Special techniques are incorporated to model two-dimensional inland inundation, routing of surges inland when barriers are overtopped, the effect of trees, the movement of the surge up rivers, and flow through channels, cuts and over submerged sills. Besides surge, other processes affect water height (section 4B), but are not incorporated in the model.

Not surprisingly, the accuracy of modeled surge values increases as the accuracy of the input terrain and storm data improves.

4. OUTPUT AND INTERPRETATION OF THE MODEL RESULTS

A. Output from the SLOSH Model

The output for the Narragansett and Buzzards Bays "SLOSH" model consists of maps of water heights. At each grid point, the water height is the maximum value that was computed at that point during the 72 (maximum) hours of model time. Thus, the map displays the highest water levels and does not display events at any particular instant in time. The analyzed envelopes of high water show shaded areas that represent dry land which has been inundated and contours of high water relative to mean sea level (MSL). Height of water

above terrain was not calculated because terrain height varies within a grid square. For example, the altitude of a grid square may be assigned a value of 6-ft MSL, but this value represents an average of land heights that may include values ranging from 3 ft to 9 ft MSL. Thus, a surge value of 8 ft in this square, implying 2 ft average depth of water over the grid's terrain, would include some terrain without inundation and other parts with as much as 5 ft of overlying water. Therefore, the depth of surge flooding above terrain at a specific site in the grid square is deduced by subtracting the actual terrain height from the model-generated storm surge height in that square. Also supplied are printout lists of values of surge height, wind speed and wind direction for each of 80 sites. The values are ten-minute averages, every 30 minutes. These are useful for determining the time of onset of gale force winds and surge heights, for evacuation planning.

B. Interpretation of Results

Even if the model is supplied accurate data on storm positions, intensities and sizes, the computed surges may contain errors of +/- 20% of observed water levels. These primarily stem from:

1) Maps that are outdated: The maps which supplied heights of terrain and depths of water sometimes did not include changes, often man-made, that had been made to the heights and positions of barriers (e.g., highway and railway embankments) and depths and locations of channels. Inaccuracies of topography or bathymetry will contribute directly to errors in the modeling of all storm surges.

2) Anomalous water heights: Sea level can be at an altitude different from "mean sea level," days or even weeks before a storm is actually affecting a basin. The value of the actual, local sea level -- the "local datums" for pre-storm anomaly in the Atlantic Ocean -- must be supplied to the model, before calculations are initiated.

3) Local processes, such as waves, astronomical tides, rainfall and flooding from overflowing rivers: These processes are usually included in "observations" of storm surge height, but are not surge and are not calculated by the SLOSH model.

Factors such as the foregoing must be considered when comparisons are made between modeled and observed values of storm surge.

5. HURRICANE CLIMATOLOGY

A. Tracks

Between 1886 and 1987, 21 tropical cyclones of hurricane intensity passed within 105 statute miles of Quicksand Point, RI/MA (Neumann et al., 1985), for an average of one hurricane within the 105-mile circle every 4.8 years (see Table 2).

Figures 2-4 show the tracks of these 21 storms with hurricane force winds. Figure 2 depicts the tracks for northwestbound and northbound storms, Figure 3 shows tracks for storms heading north-northeastward, and Figure 4 displays the tracks of storms heading northeastward or east-northeastward. In Figures 2-4, the tracks are labeled at 6-h intervals with month/day/hour (GMT).

The tracks represent "best estimates" and are based on a variety of data sources. Historically, storm strength, location and motion were only inferred, from analyses of wind, pressure and cloud observations made at ships and land stations being influenced by the storm. In 1943, aircraft reconnaissance of hurricanes began. Not until 1959 were there land-based weather radars, as now at Atlantic City, New York City and Chatham, Massachusetts which could be used to observe and record structure, development and motion of precipitation fields, and help infer center location and radius of maximum winds. The 1960's saw the advent of photography of tropical storms from weather satellites. Observations by aircraft, radar and satellite have shown

Table 2. Hurricanes passing within 105 statute mile circle of Quicksand Point, RI/MA (41.45°N, 71.4°W), during 1886-1987.

>>> At Closest Point of Approach: (@CPA) <<<									
Index (1)	Date (@CPA) (2)	Storm Name (3)	Range/Bearing (miles/degrees) (to CPA) (4)	/	(5)	Wind (in circle) (mph) (6)	Storm Motion (@CPA) (dir / mph) (7)	/	(8)
1	1888 Nov 27	Unnamed	91	/	120	98	NNE	/	11
2	1891 Oct 14	Unnamed	77	/	132	98	NE	/	15
3	1896 Sep 20	Unnamed	89	/	087	108	N	/	10
4	1904 Sep 15	Unnamed	1	/	036	75	NE	/	53
5	1916 Jul 21	Unnamed	20	/	124	91	NNE	/	18
6	1924 Aug 26	Unnamed	73	/	112	106	NE	/	43
7	1927 Aug 24	Unnamed	75	/	130	105	NE	/	48
8	1933 Sep 17	Unnamed	99	/	136	81	NE	/	29
9	1936 Sep 19	Unnamed	40	/	140	92	ENE	/	32
10	1938 Sep 21	Unnamed	102	/	259	90	N	/	51
11	1940 Sep 2	Unnamed	98	/	123	81	NE	/	26
12	1944 Sep 15	Unnamed	40	/	296	83	NE	/	29
13	1953 Aug 15	Barbara	84	/	154	86	ENE	/	23
14	1954 Aug 31	Carol	64	/	279	96	NNE	/	35
15	1954 Sep 11	Edna	26	/	143	96	NNE	/	46
16	1958 Aug 29	Daisy	98	/	144	119	NE	/	28
17	1960 Sep 12	Donna	54	/	274	98	NNE	/	39
18	1961 Sep 21	Esther	46	/	160	127	NE	/	6
19	1962 Aug 29	Alma	90	/	127	98	NE	/	13
20	1969 Sep 9	Gerda	105	/	122	124	NNE	/	48
21	1985 Sep 27	Gloria	92	/	288	86	NNE	/	45

Notes:

(1) Storm number for this list.

(2) Year, month and date that storm had maximum winds exceeding 74 mph and was closest to Quicksand Point, RI/MA.

(3) Storms were not formally named before 1950.

(4)-(5) Distance (statute miles) and direction (degrees) from Quicksand Point to storm when it passed abeam.

(6) Maximum sustained wind speed near storm center while center was within 105 statute miles of Quicksand Point. This is not necessarily the wind recorded at a given site.

(7)-(8) Storm heading and forward speed (mph) at hour of closest point of approach.

that the tracks of centers of hurricanes contain wobbles, gyrations and cycloidal motions (Lawrence and Mayfield, 1977) and that there often are rapid developments in size and intensity of rain bands, contractions of eyewall diameters and formation of concentric ("double") eyewalls. These factors, *poorly documented even today, indicate asymmetries in the storm's dynamical* structure and can affect the storm's surge. But they usually are smoothed out of analyses, as in Figures 2-4.

B. Intensities

Hurricane intensity is usually defined by measurements at sea level of the maximum sustained wind speed and/or by minimum barometric pressure. Neither of these is easily obtained. Accurate estimates of these parameters at sea level were acquired only when a ship or land station was traversed by the storm's "eye." Minimum central pressure was gotten only when a barometer was in the precise path of the storm's center. Because the area covered by the strongest winds is much larger than that covered by the pressure minimum, strength of many older storms was deduced from measurements of wind speed. However, with the advent of aircraft reconnaissance, measurements made at flight level of meteorological parameters allow the calculation of barometric pressure at sea level. By comparison, winds at sea level are not so readily deduced from flight level data. For all the storm tracks in Figures 2-4, an estimate was made of the maximum wind speed at intervals of 6 hours. For some, only very indirect evidence exists of actual speeds. From the hourly values of the maximum wind speed inside the 105 mile circle, the largest value was selected. This maximum sustained wind speed for the hurricane is listed in Table 2 under the heading of "wind (in circle)." Storm heading and forward speed at hour of closest point of approach are listed in the last two columns.

The values listed in column 6 sometimes are poor estimates of the maximum wind speed; the following must be considered:

1) Actual wind speeds and directions exhibit gustiness.
2) The "average wind speed" has been calculated with a variety of time intervals over the years; thus, one can find historical wind records that have used time periods such as 1 hour, or 10 or 5 minutes or 1 minute as the "standard" period of measurement. Given the same record from a recording anemometer, the use of each of these measurement periods would likely yield a different average wind speed, with shorter periods probably giving higher average speeds.
3) The platforms for measuring maximum surface wind speed have changed over the years; data from ship and land stations now are supplemented by remotely-sensed data from aircraft, satellites and radar. However, the remote platforms, especially the last two, observe the motions of clouds or precipitation echoes, and these motions are not wind speed, nor are they at sea level.

Because of these limitations in determination of maximum wind speed, the SLOSH model uses storm-center sea-level pressure as a measure of storm intensity in modeling the Narragansett and Buzzards Bays basin.

6. MAPS OF MAXIMUM ENVELOPE OF WATER ("MEOW") FROM SLOSH RUNS USING DATA FOR HYPOTHETICAL HURRICANES

A. Hypothetical Storm Tracks and Populations

The skill of the SLOSH model was evaluated by Jarvinen and Lawrence (1985), who compared modeled and observed surges at 523 sites during 10 hurricanes. They found that the mean absolute error in surge height calculated by SLOSH was 1.4 ft. Although the error range was from -7.1 ft to

+8.8 ft, the standard deviation was only 2.0 ft and 79% of the errors lay within one standard deviation of the mean error, -0.3 ft. (On the average, modeled values were slightly less than those observed.)

Because of this skill in calculating storm surge, the SLOSH model was used to create maps of surge flooding in the Narragansett and Buzzards Bays basin for use in evacuation planning. The model was supplied with data from hypothetical storms and the resulting surge calculations were composited to produce maps of the maximum envelope of water. This section details why these calculations were made and how the compositing was done.

Storm surge height partly depends on distance between the location of a particular site and the storm's center. For a single storm, the model would produce a map of surge height for the modeled period of time (usually 72 hours), with values valid for only that particular storm track. If there were two storms, identical in every respect except that one followed a track parallel to, but separated from the other by 50 miles,[1] and if the model was run with first one and then the other set of storm parameters, and a comparison made of surge values, then very likely there would be geographical sites with surge values from one storm that differed markedly from those modeled for the other storm. This dependency of surge height on storm track can be troublesome, when preparing plans for emergency evacuation. Maps are needed for basin-wide surge flooding potential—maps showing surge height for only one intensity (using the categories defined by Saffir and Simpson), one

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[1]A difference ("error") of 50 miles in storm track is not very large when compared to the vagaries of tracks of real hurricanes. The average error of 12-hour forecast landfall position, for U.S. Atlantic coast tropical cyclones, during 1970-1979, was about 59 statute miles, while for 24-hour forecasts, landfall position error was about 125 statute miles (Neumann and Pelissier, 1981). Thus, if a storm were forecast to make (eye) landfall at Quicksand Point, in 24 hours, and if, in fact, it made landfall anywhere between Rockaway Beach, Long Island and Rye Beach, New Hampshire, the error in forecast landfall position would be no worse than average.

storm speed and direction. We created such maps for this basin by making surge calculations for each of an ensemble of 3 to 12 storms all having the same intensity and speed and on parallel headings, separated by 15 miles. Then, at each grid square, the maximum surge value that was calculated from any storm in the ensemble was extracted and saved. After this procedure was performed for all grid squares, the result was a basin map depicting the "maximum envelope of water," or MEOW, for the specified storm category, direction and speed. For the Narragansett and Buzzards Bays basin, the hypothetical storms were specified to move in one of six directions, at one of three constant speeds, as summarized in Table 3. There were 8 tracks for the west-northwestward (WNW) moving storms (Figure 5), 10 tracks for the northwest-bound (NW) storms (Figure 6), 12 tracks for the north-northwest (NNW) storm headings (Figure 7), 12 tracks for the northward (N) moving storms (Figure 8), 11 tracks for the north-northeastward (NNE) storm headings (Figure 9), and up to 7 tracks for storms heading northeastward (NE), in Figure 10. In total, 536 hypothetical storms were run, using the SLOSH model, to create the results to be presented below. The selection of directions and speeds was based on advice of hurricane specialists at NOAA's National Hurricane Center.

B. Intensities and Radii of Maximum Winds of Hypothetical Storms

Most hurricanes weaken after making landfall because the central pressure increases (the storm "fills") and the RMW tends to increase. Table 4 summarizes pressure filling and RMW increases with time for the hypothetical storm runs. These rates of change were based partly on the work of Schwerdt *et al*. (1979). Storms heading northeastward were modeled to not undergo filling or to change RMW.

Table 3. Narragansett/Buzzards Bays Basin's hypothetical storms: Directions, speeds, (Saffir/Simpson) intensities, number of tracks and the number of runs.

Direction	Speed (mph)	Intensities	Tracks	Runs
WNW	20	1 through 4	8	32
NW	20	1 through 4	10	40
NNW	20, 40, 60	1 through 4	12	144
N	20, 40, 60	1 through 4	12	144
NNE	20, 40, 60	1 through 4	11	132
NE*	20, 40	1, 2, 3, 4	7, 7, 5, 3	44
			Total =	536

*Several NE moving hurricanes near or over land cannot maintain all intensity levels.

Table 4. Time change of pressure difference and radius of maximum wind for hypothetical hurricanes having headings towards the west-northwest, northwest, north-northwest, north or north-northeast in Narragansett and Buzzards Bays Basin.

Values of pressure difference (ΔP, millibars) and radius of maximum wind (RMW, statute miles), beginning at time of landfall (LF) of center of storm and every six hours after LF.

	Landfall		LF + 6		LF + 12		LF + 18		LF + 24	
Category	ΔP	RMW	ΔP	RMW	ΔP	RMW	ΔP	RMW	ΔP	RMW
1	20	30	14	30	10	30	10	35	10	40
2	40	30	31	30	22	30	13	35	10	40
3	60	30	48	30	36	30	24	35	12	40
4	80	30	65	30	50	30	35	35	20	40

C. Initial Water Height

Based on observations from tide gages in the area of this basin, tidal anomalies of about +1 ft MSL before arrival of a hurricane are not uncommon. Thus, all SLOSH runs of hypothetical hurricanes were supplied with initial datums of +1 ft MSL. In an actual hurricane, if tide gage data in this basin indicate that there is no tide anomaly, then subtract 1 ft from the modeled values found in the maps (below).

D. The "MEOW" Figures

There are 52 MEOWS and they use the distorted geography mentioned in Section 2. They are presented in the Appendix. The MEOW figures are grouped by direction: MEOWS for west-northwestbound storms are in Figures A1-A4, northwestbound storms' MEOWS are in Figures A5-A8, MEOWS for north-northwestbound storms are in Figures A9-A20, northbound storms' MEOWS are in Figures A21-A32, north-northeastbound storms' MEOWS are in Figures A33-A44, and northeast-moving storms' MEOWS are in Figures A45-A52. In the figures, the contours represent the height of water above mean sea level, in 1-ft increments, while the shaded areas indicate land areas that were modeled to have been inundated.

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8. APPENDIX: MAXIMUM ENVELOPES OF WATER (MEOW) SERIES "A"

Figure	MEOW
A- 1	West-northwestbound, 20 mph, category 1 hurricane.
A- 2	West-northwestbound, 20 mph, category 2 hurricane.
A- 3	West-northwestbound, 20 mph, category 3 hurricane.
A- 4	West-northwestbound, 20 mph, category 4 hurricane.
A- 5	Northwestbound, 20 mph, category 1 hurricane.
A- 6	Northwestbound, 20 mph, category 2 hurricane.
A- 7	Northwestbound, 20 mph, category 3 hurricane.
A- 8	Northwestbound, 20 mph, category 4 hurricane.
A- 9	North-northwestbound, 20 mph, category 1 hurricane.
A-10	North-northwestbound, 20 mph, category 2 hurricane.
A-11	North-northwestbound, 20 mph, category 3 hurricane.
A-12	North-northwestbound, 20 mph, category 4 hurricane.
A-13	North-northwestbound, 40 mph, category 1 hurricane.
A-14	North-northwestbound, 40 mph, category 2 hurricane.
A-15	North-northwestbound, 40 mph, category 3 hurricane.
A-16	North-northwestbound, 40 mph, category 4 hurricane.
A-17	North-northwestbound, 60 mph, category 1 hurricane.
A-18	North-northwestbound, 60 mph, category 2 hurricane.
A-19	North-northwestbound, 60 mph, category 3 hurricane.
A-20	North-northwestbound, 60 mph, category 4 hurricane.
A-21	Northbound, 20 mph, category 1 hurricane.
A-22	Northbound, 20 mph, category 2 hurricane.
A-23	Northbound, 20 mph, category 3 hurricane.
A-24	Northbound, 20 mph, category 4 hurricane.

A-25 Northbound, 40 mph, category 1 hurricane.

A-26 Northbound, 40 mph, category 2 hurricane.

A-27 Northbound, 40 mph, category 3 hurricane.

A-28 Northbound, 40 mph, category 4 hurricane.

A-29 Northbound, 60 mph, category 1 hurricane.

A-30 Northbound, 60 mph, category 2 hurricane.

A-31 Northbound, 60 mph, category 3 hurricane.

A-32 Northbound, 60 mph, category 4 hurricane.

A-33 North-northeastbound, 20 mph, category 1 hurricane.

A-34 North-northeastbound, 20 mph, category 2 hurricane.

A-35 North-northeastbound, 20 mph, category 3 hurricane.

A-36 North-northeastbound, 20 mph, category 4 hurricane.

A-37 North-northeastbound, 40 mph, category 1 hurricane.

A-38 North-northeastbound, 40 mph, category 2 hurricane.

A-39 North-northeastbound, 40 mph, category 3 hurricane.

A-40 North-northeastbound, 40 mph, category 4 hurricane.

A-41 North-northeastbound, 60 mph, category 1 hurricane.

A-42 North-northeastbound, 60 mph, category 2 hurricane.

A-43 North-northeastbound, 60 mph, category 3 hurricane.

A-44 North-northeastbound, 60 mph, category 4 hurricane.

A-45 Northeastbound, 20 mph, category 1 hurricane.

A-46 Northeastbound, 20 mph, category 2 hurricane.

A-47 Northeastbound, 20 mph, category 3 hurricane.

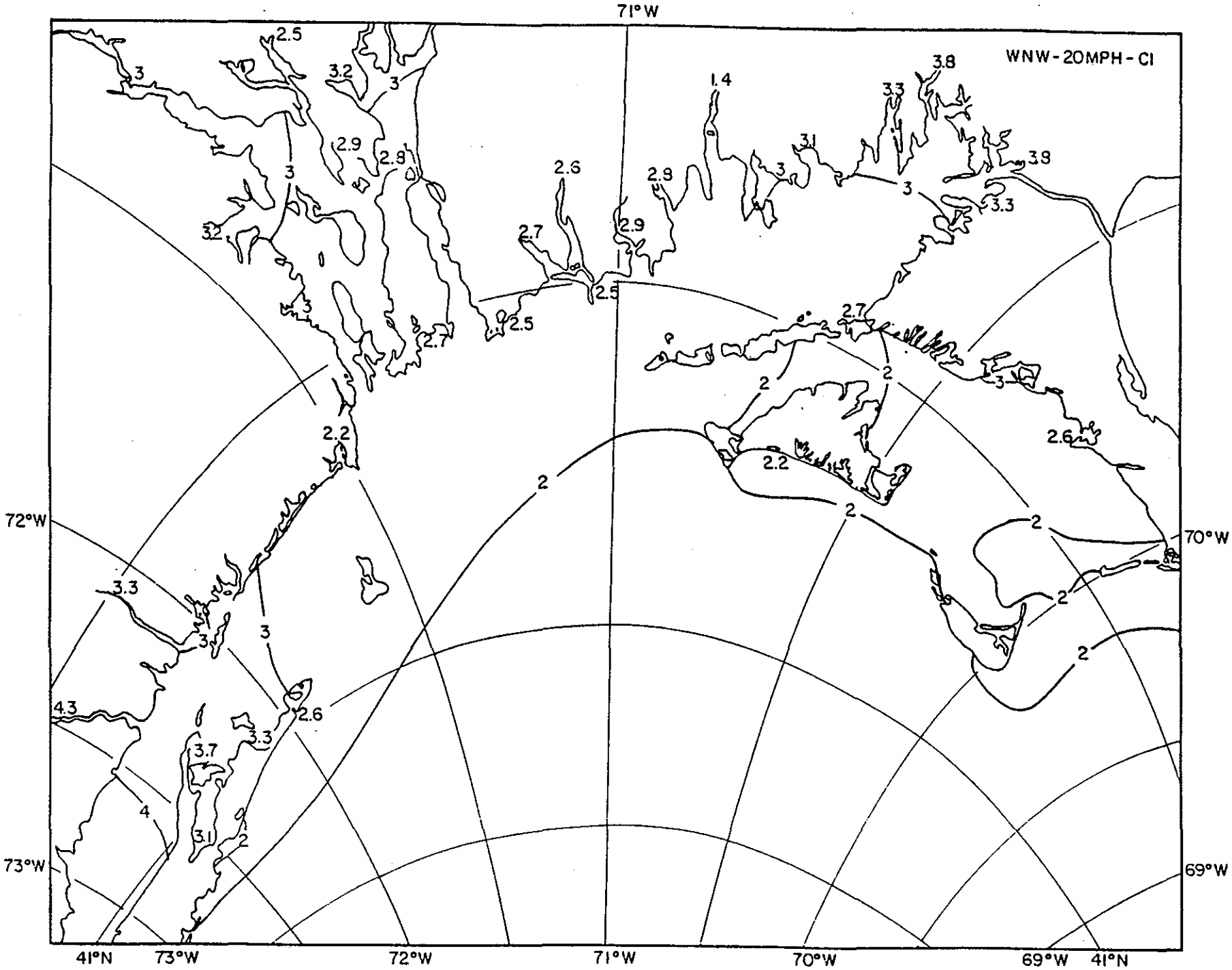
A-48 Northeastbound, 20 mph, category 4 hurricane.

A-49 Northeastbound, 40 mph, category 1 hurricane.

A-50 Northeastbound, 40 mph, category 2 hurricane.

A-51 Northeastbound, 40 mph, category 3 hurricane.

A-52 Northeastbound, 40 mph, category 4 hurricane.


WNW-20MPH-CI
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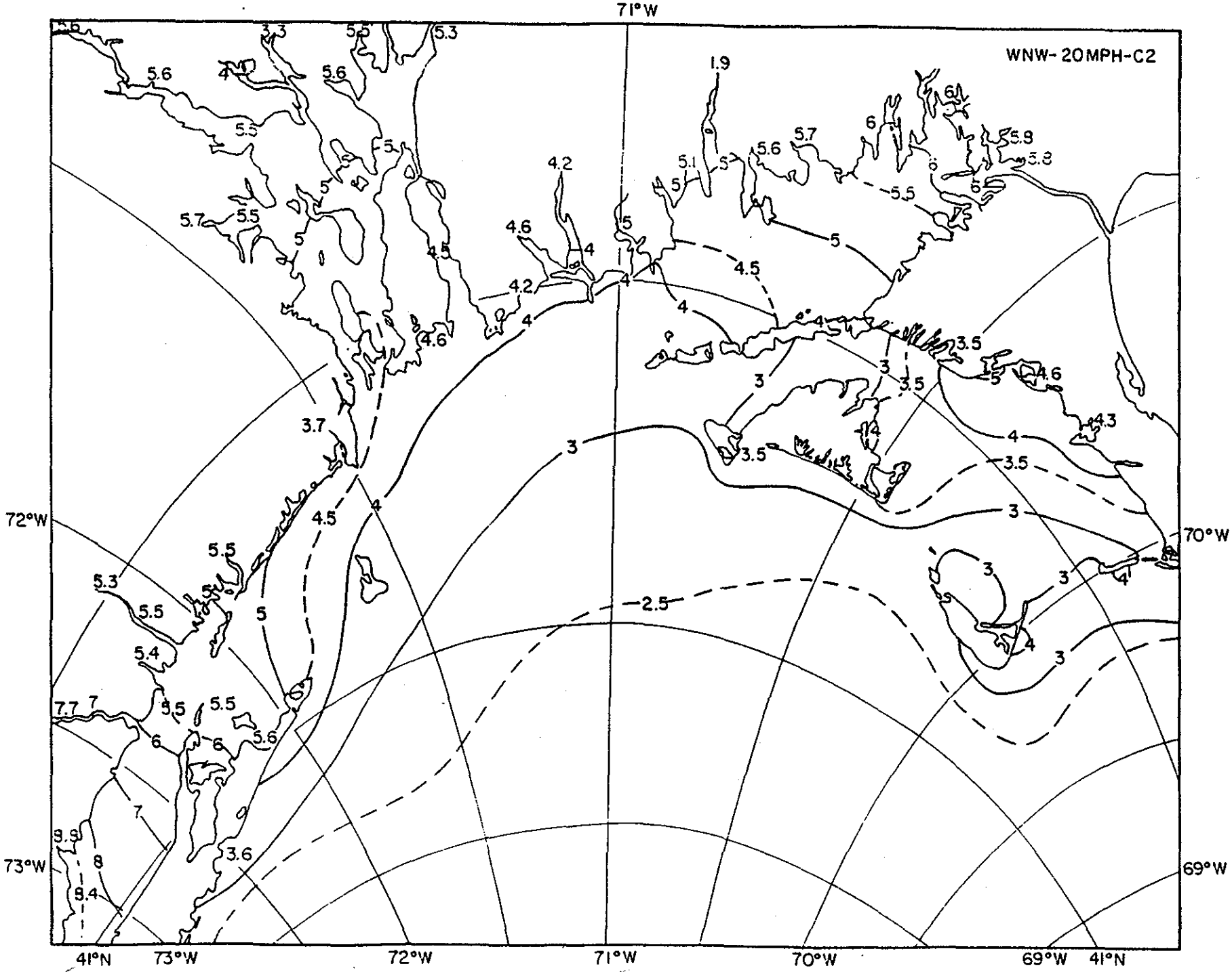
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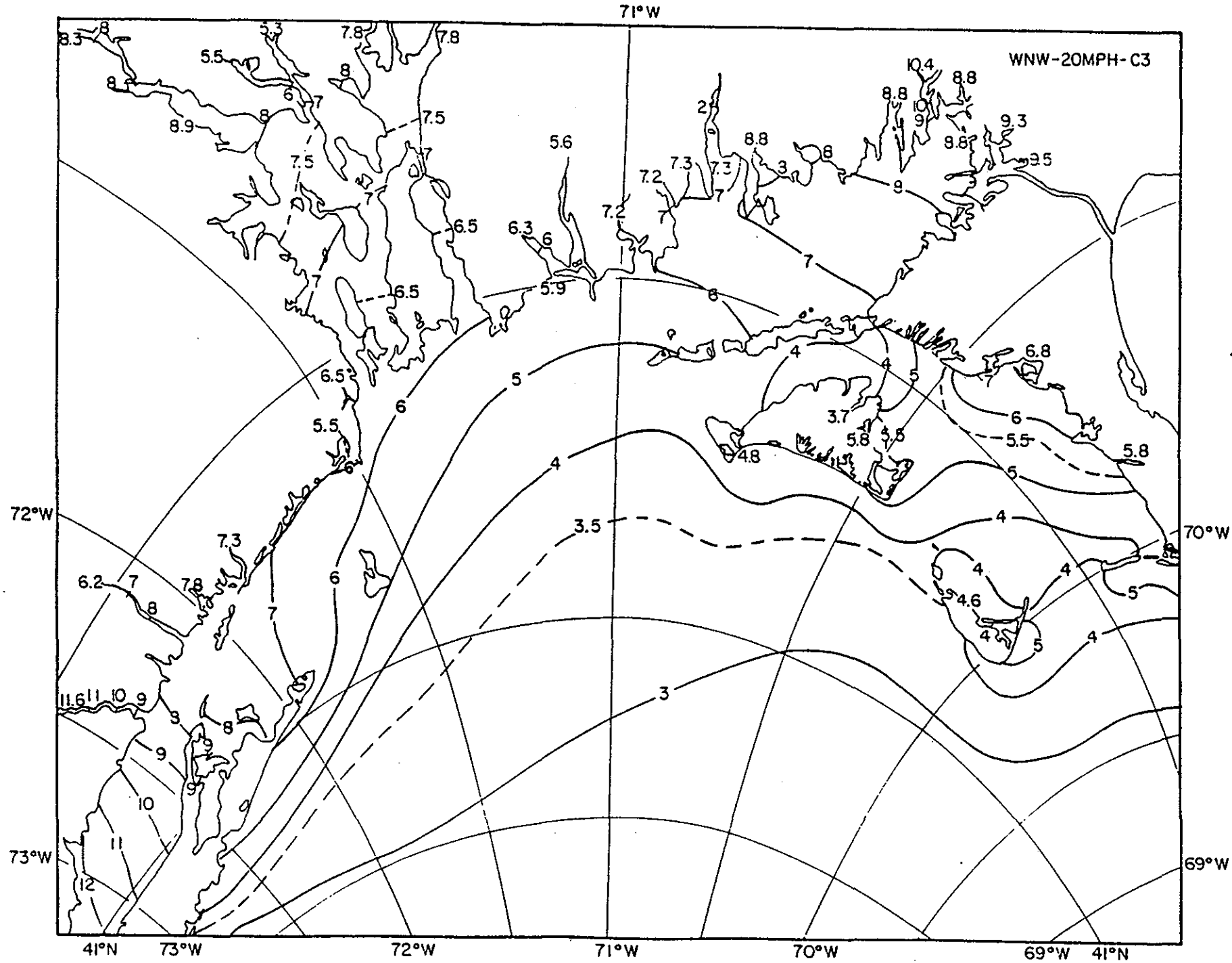
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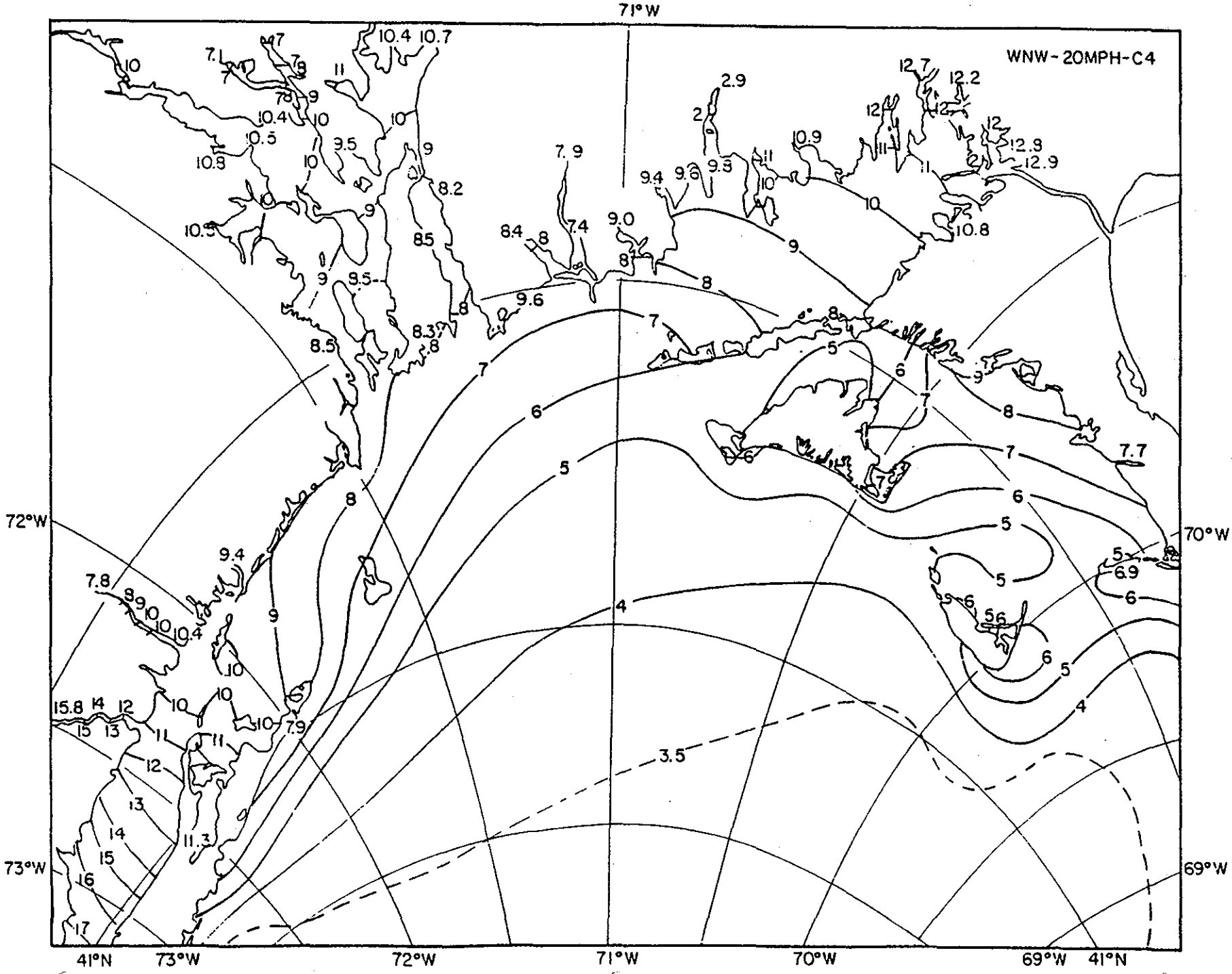
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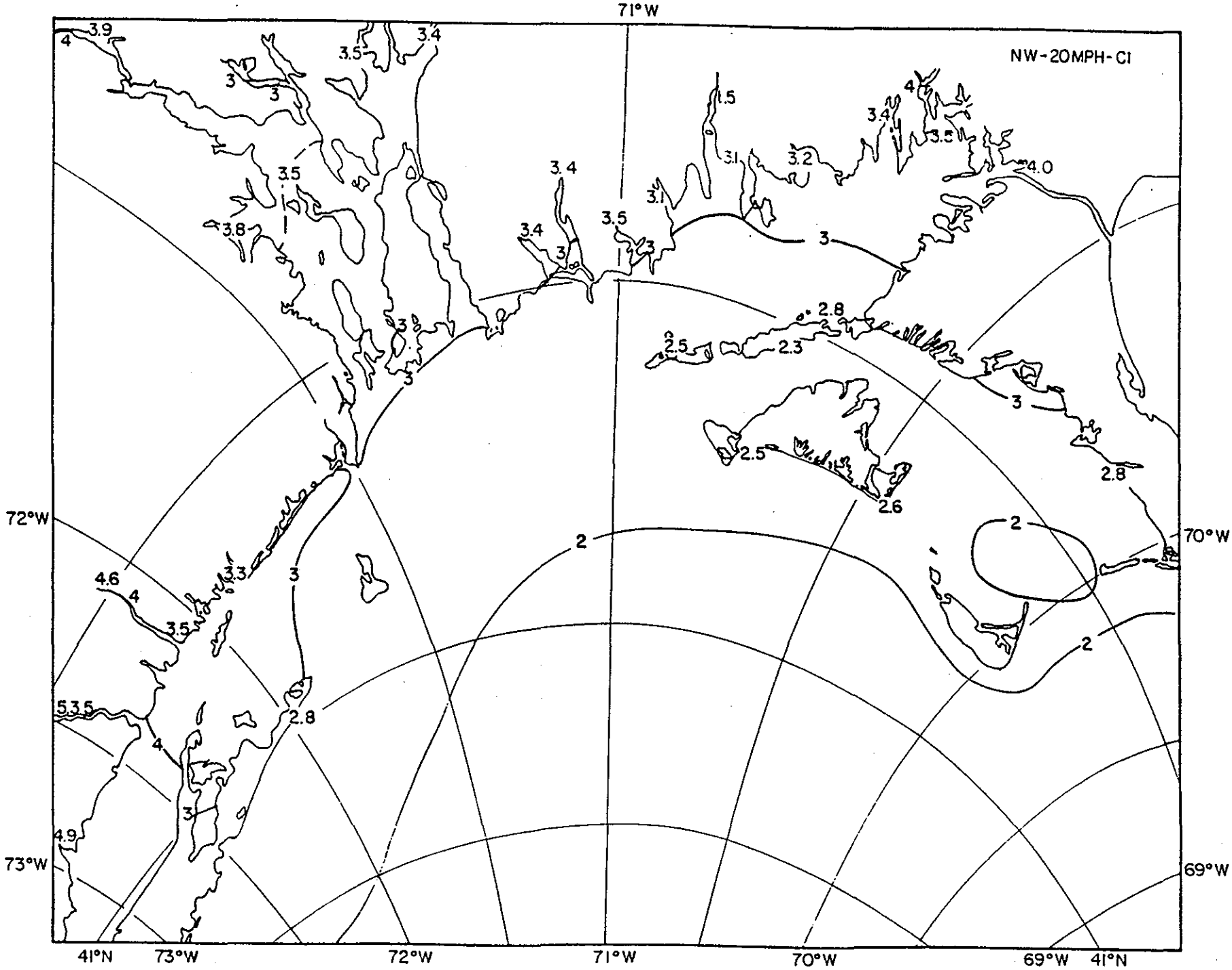
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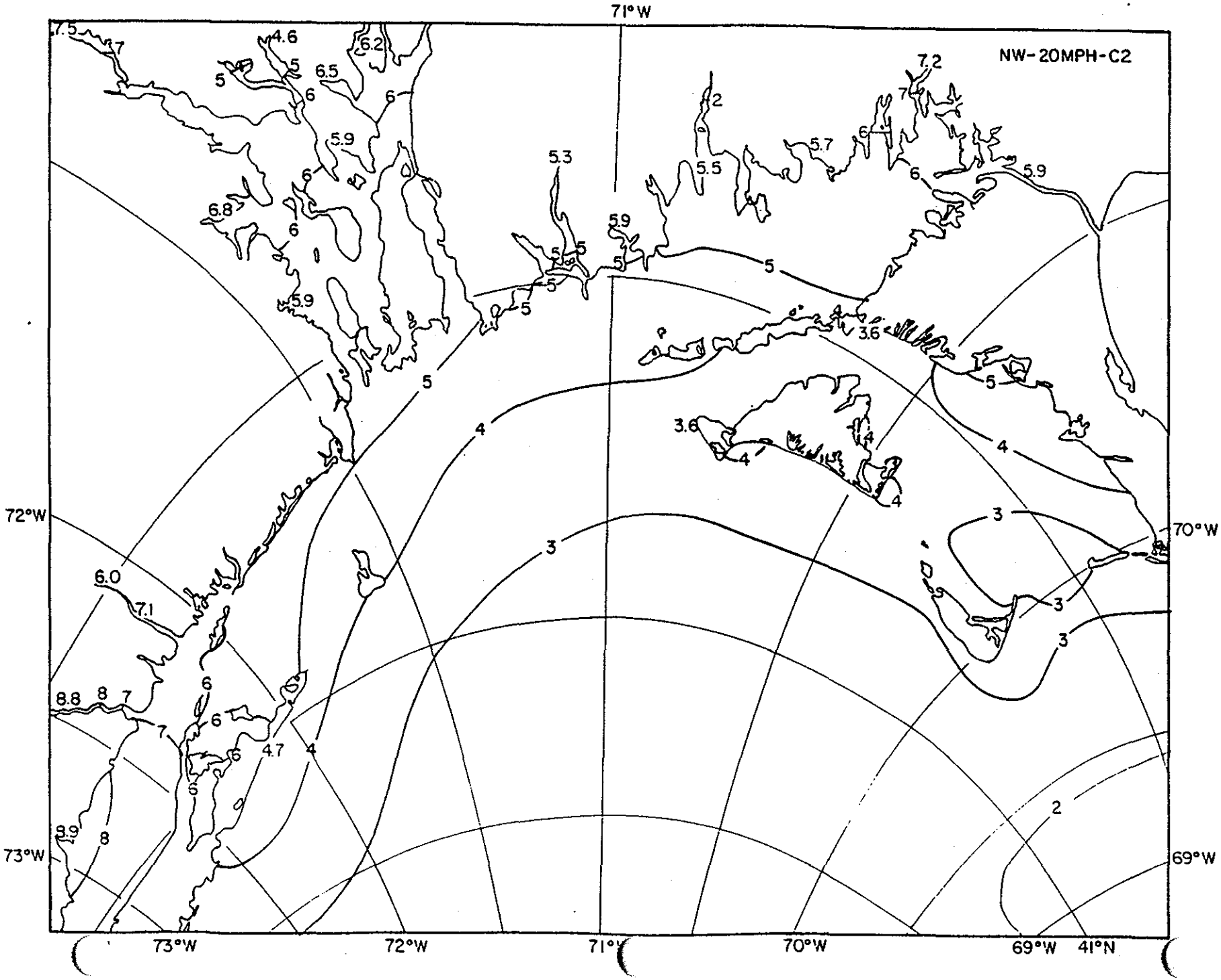
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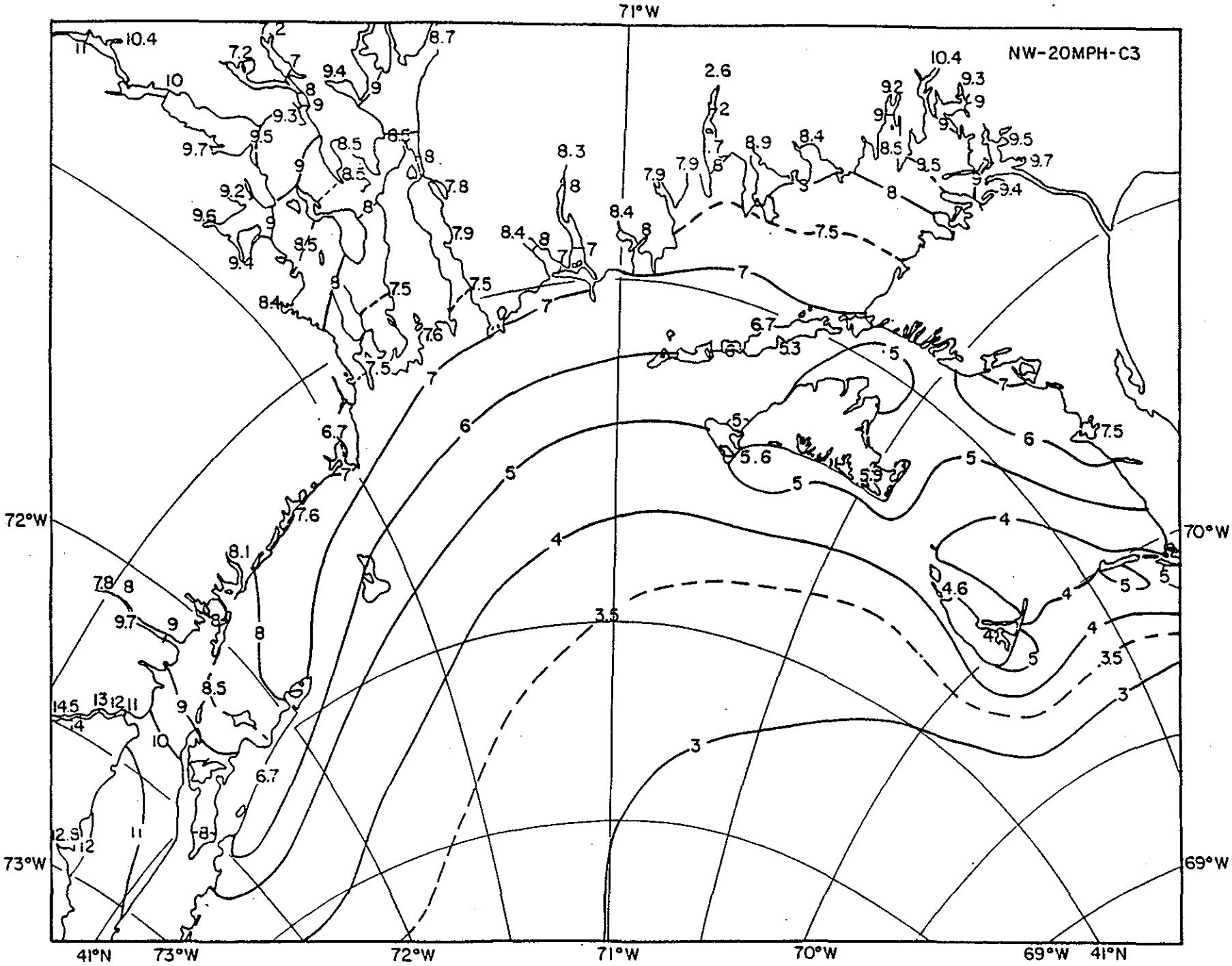
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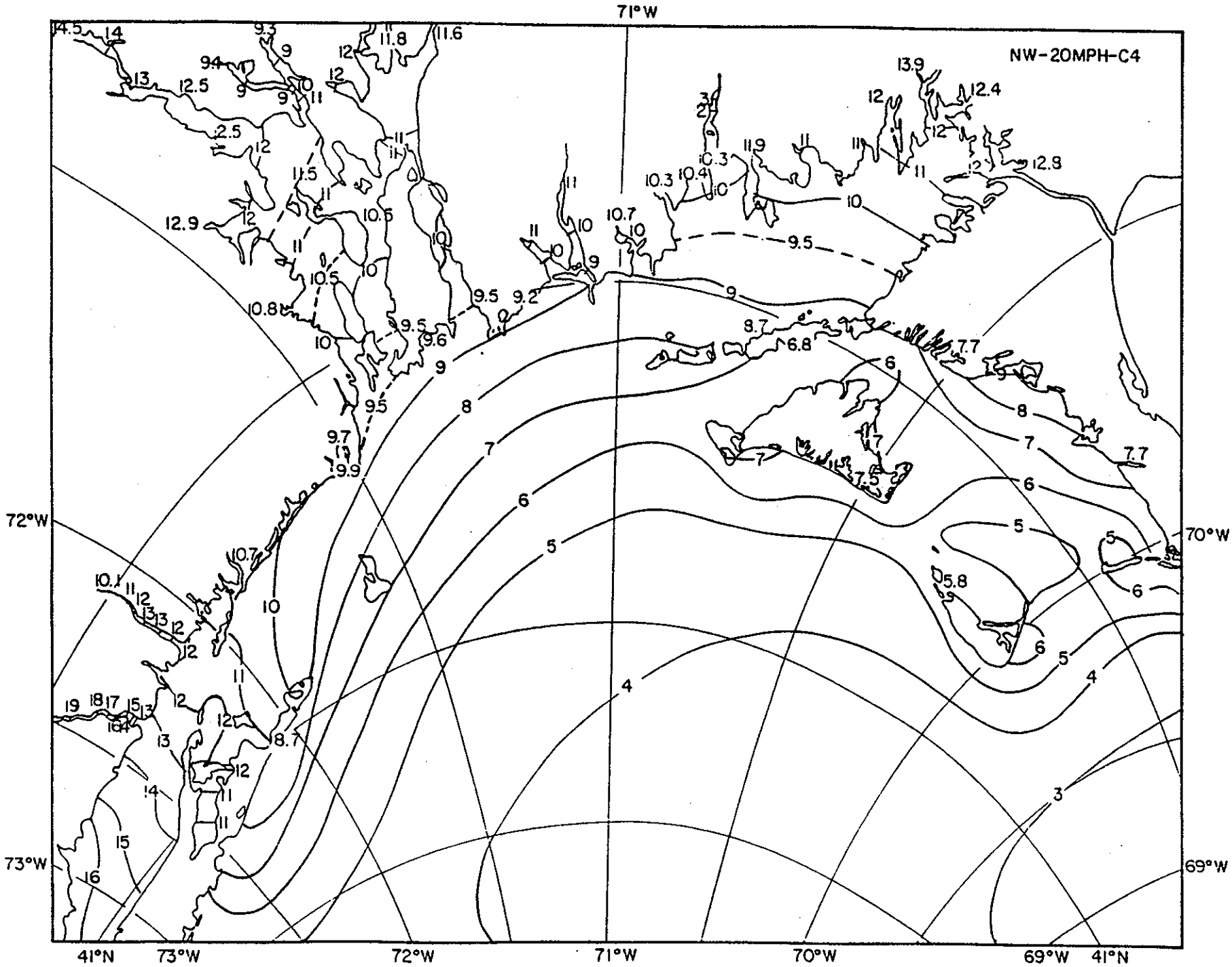
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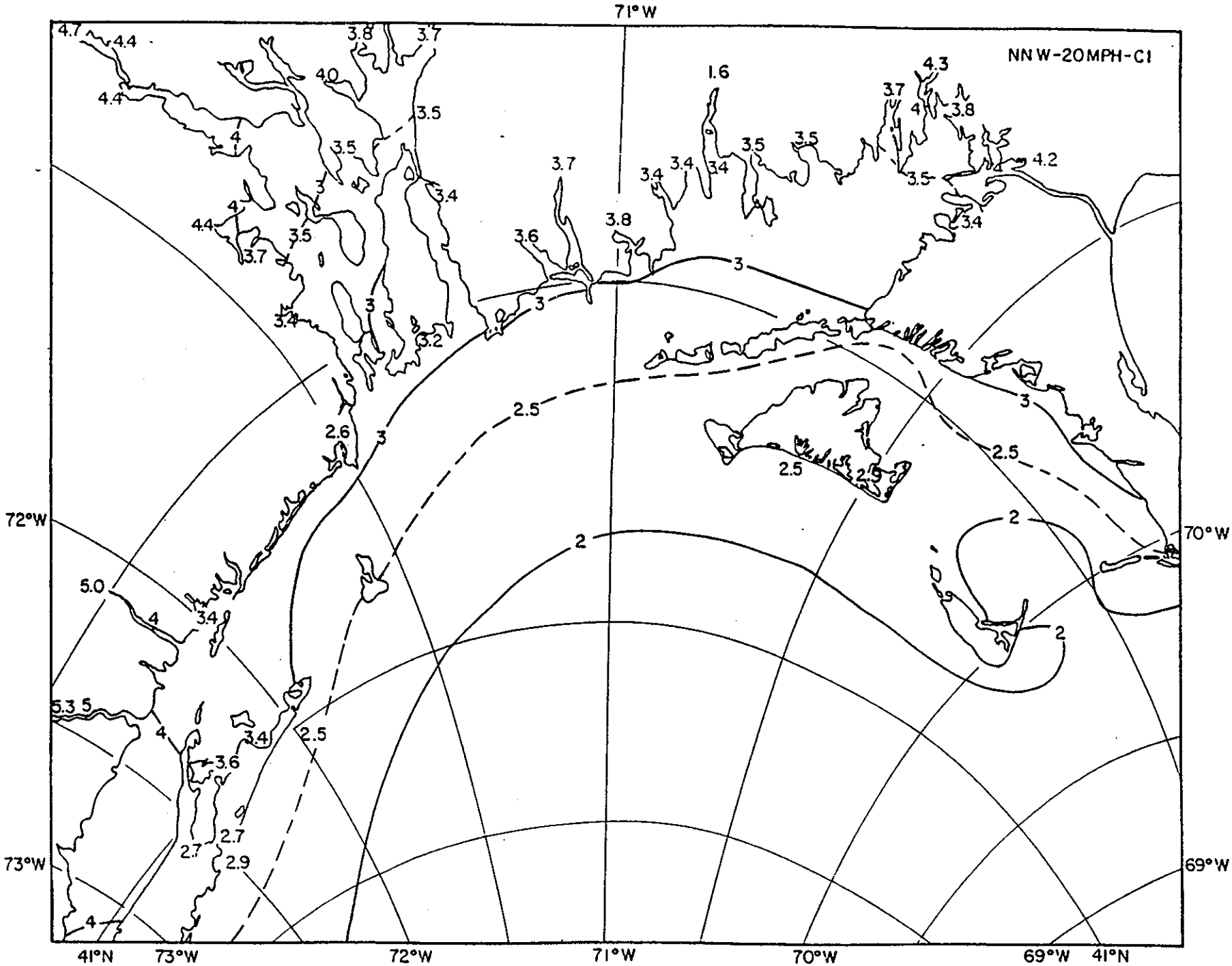
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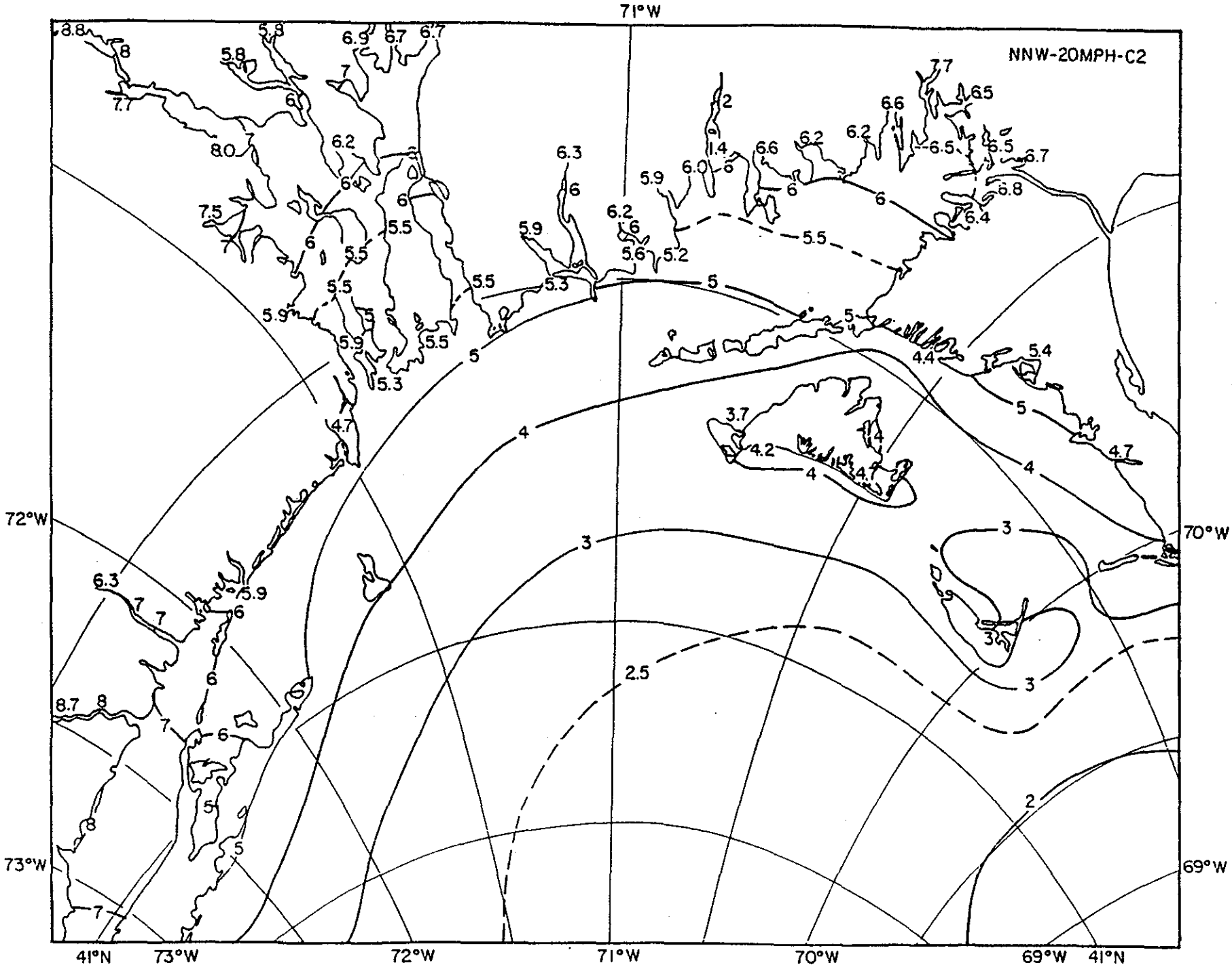
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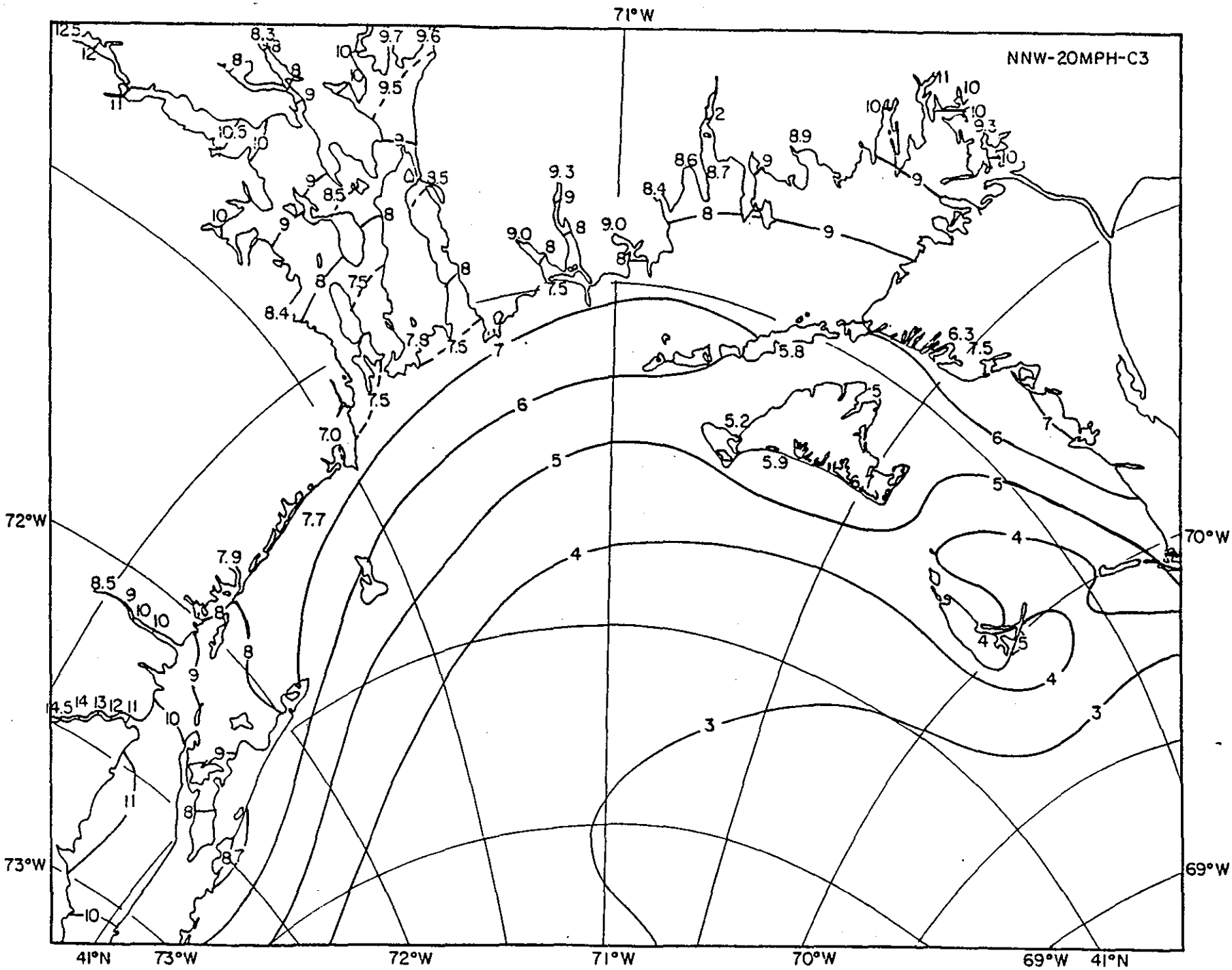
69°W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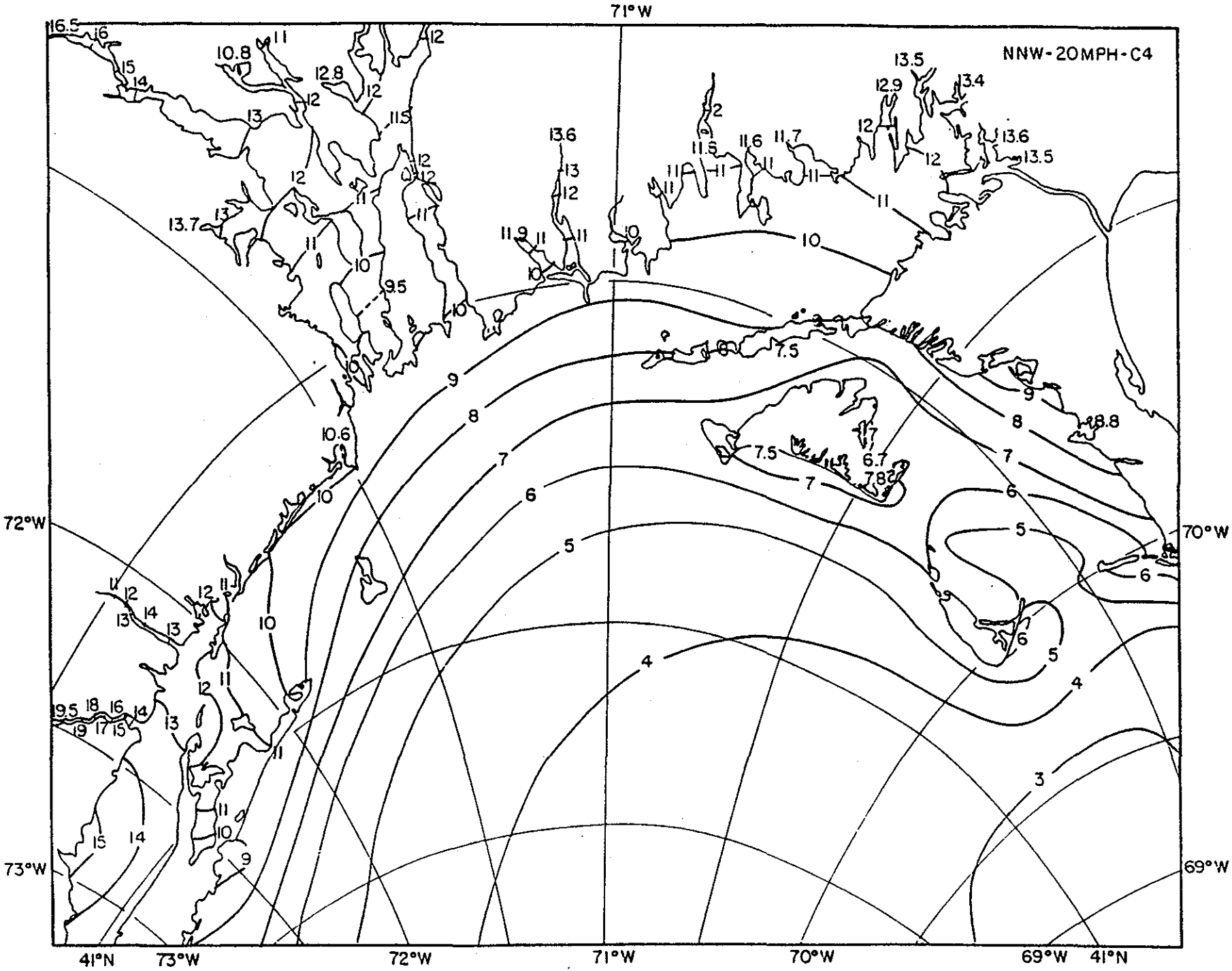
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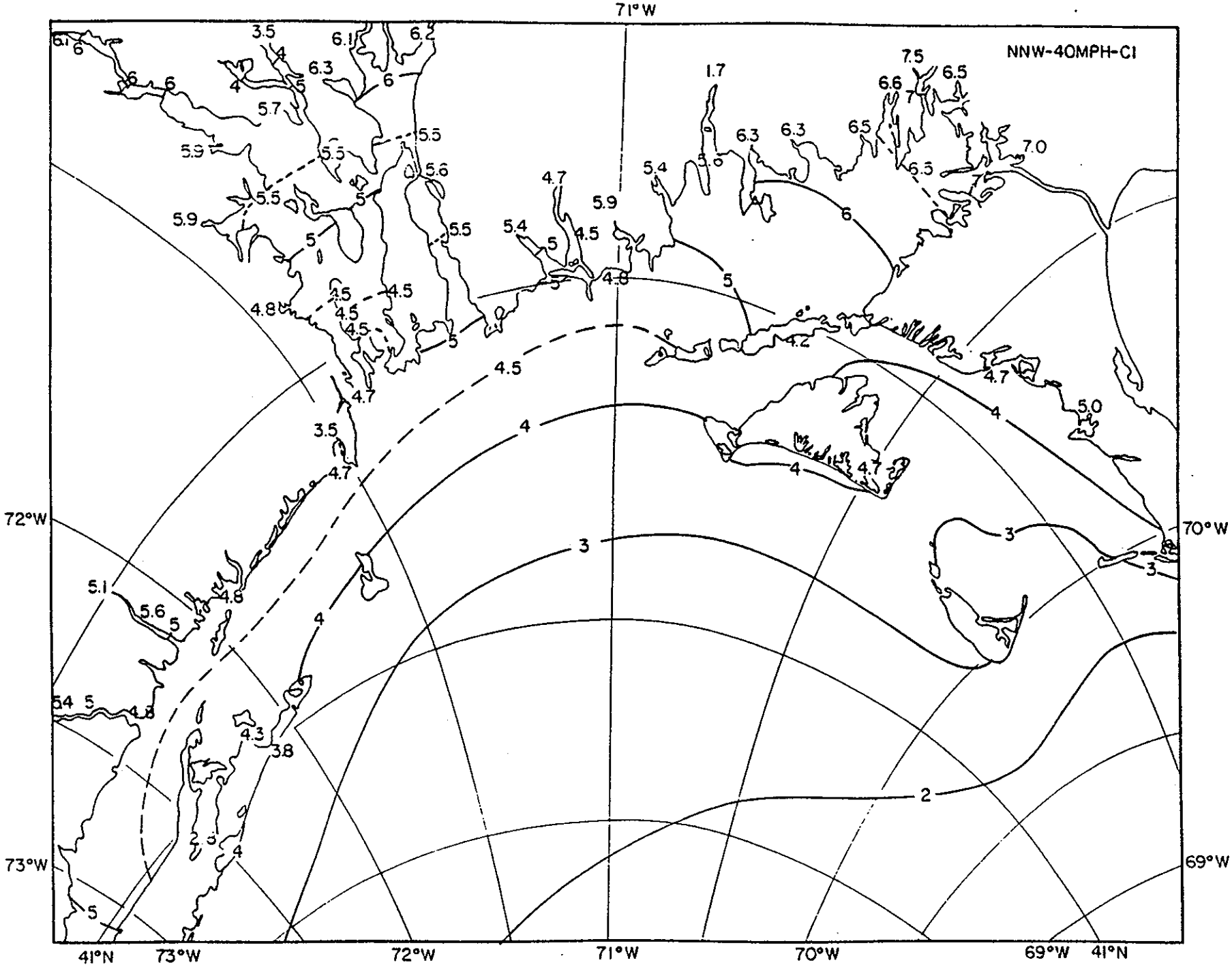
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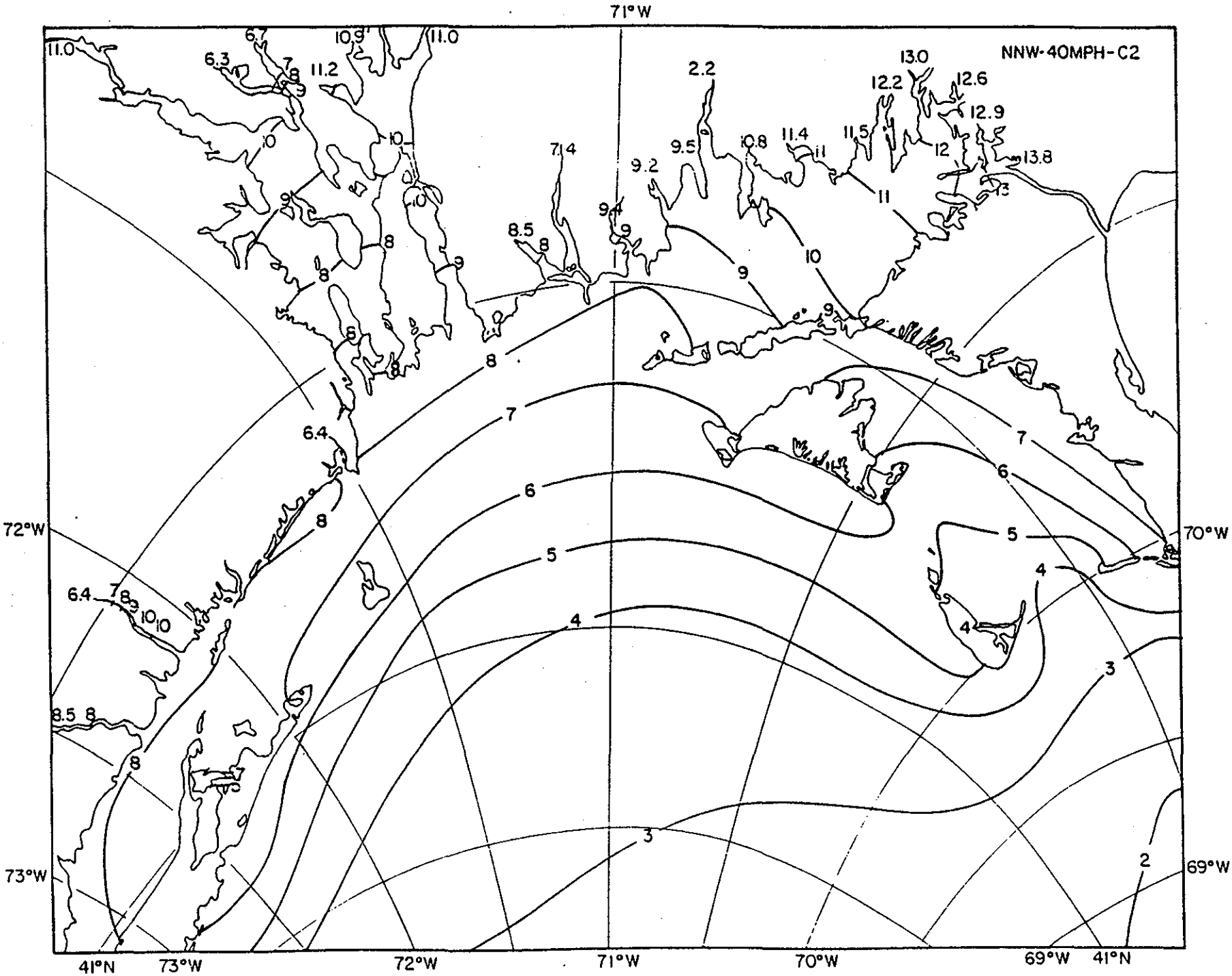
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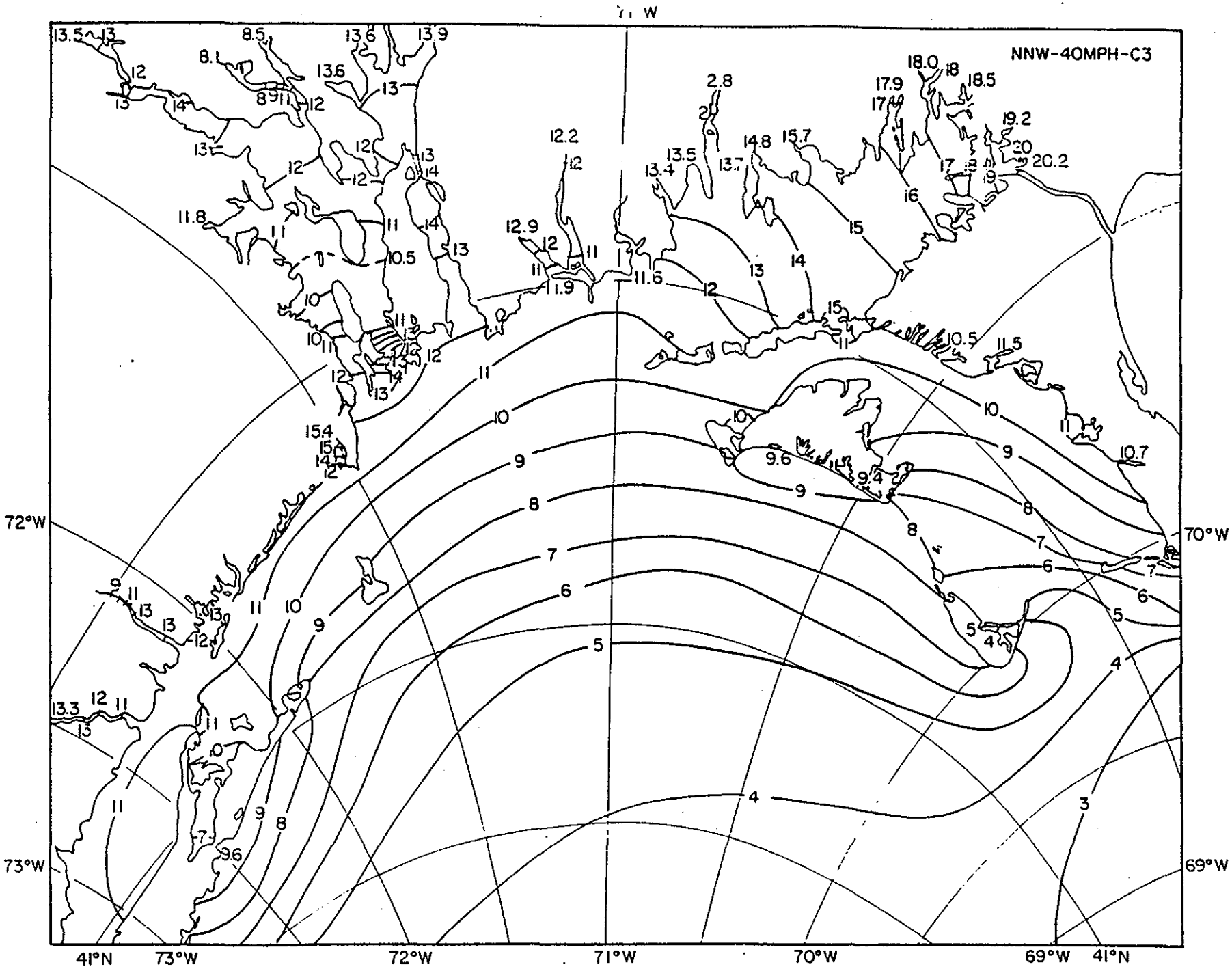
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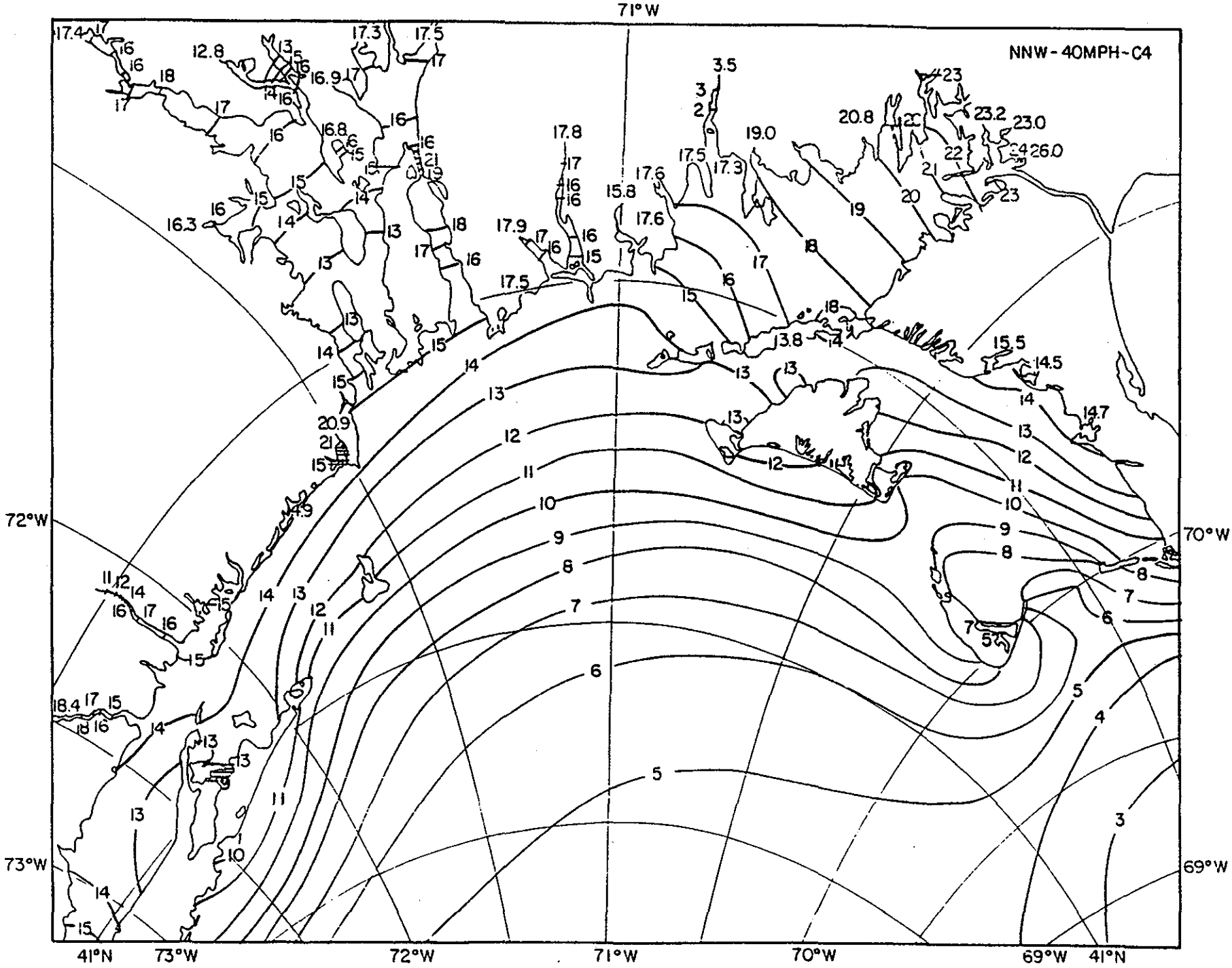
41°N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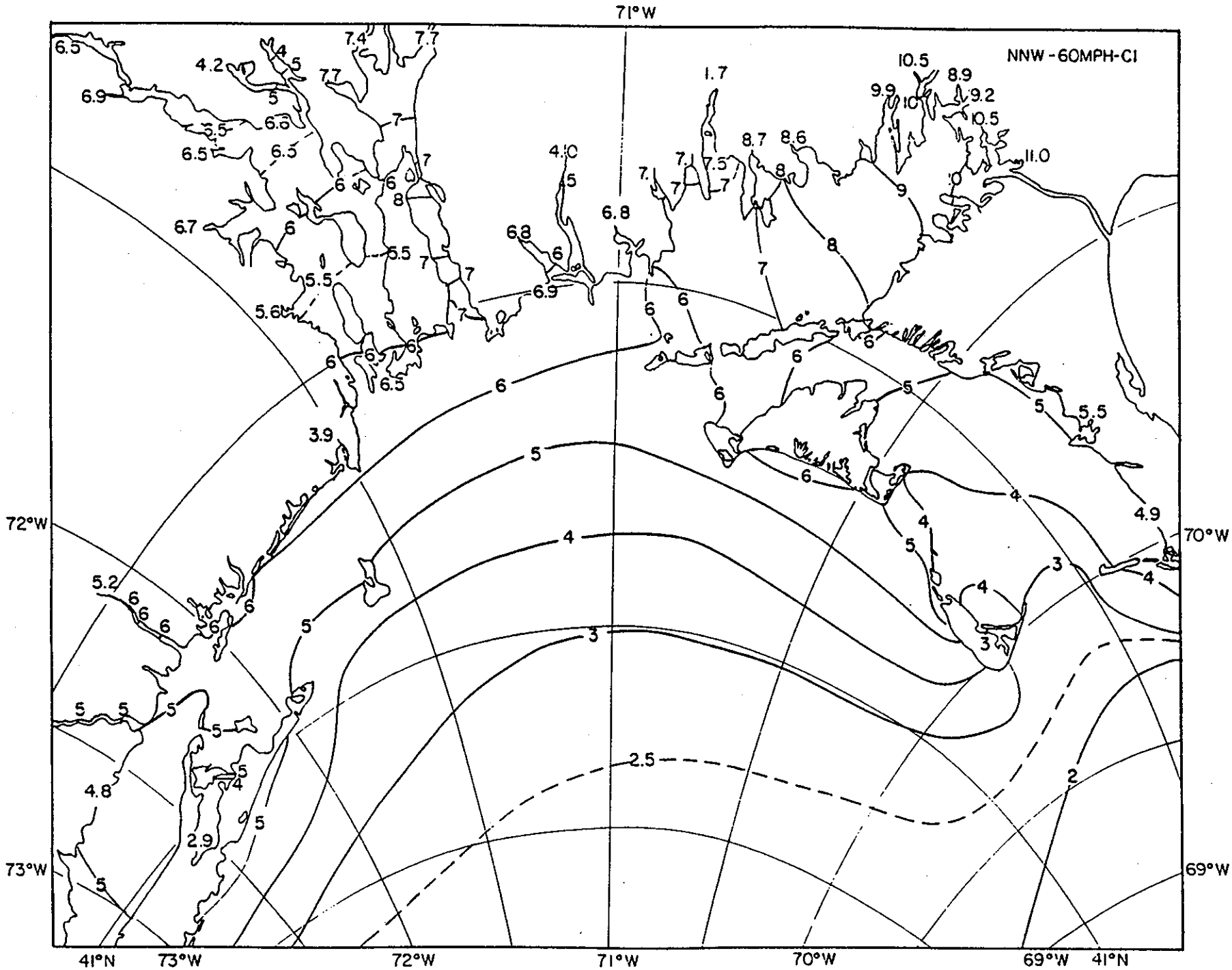
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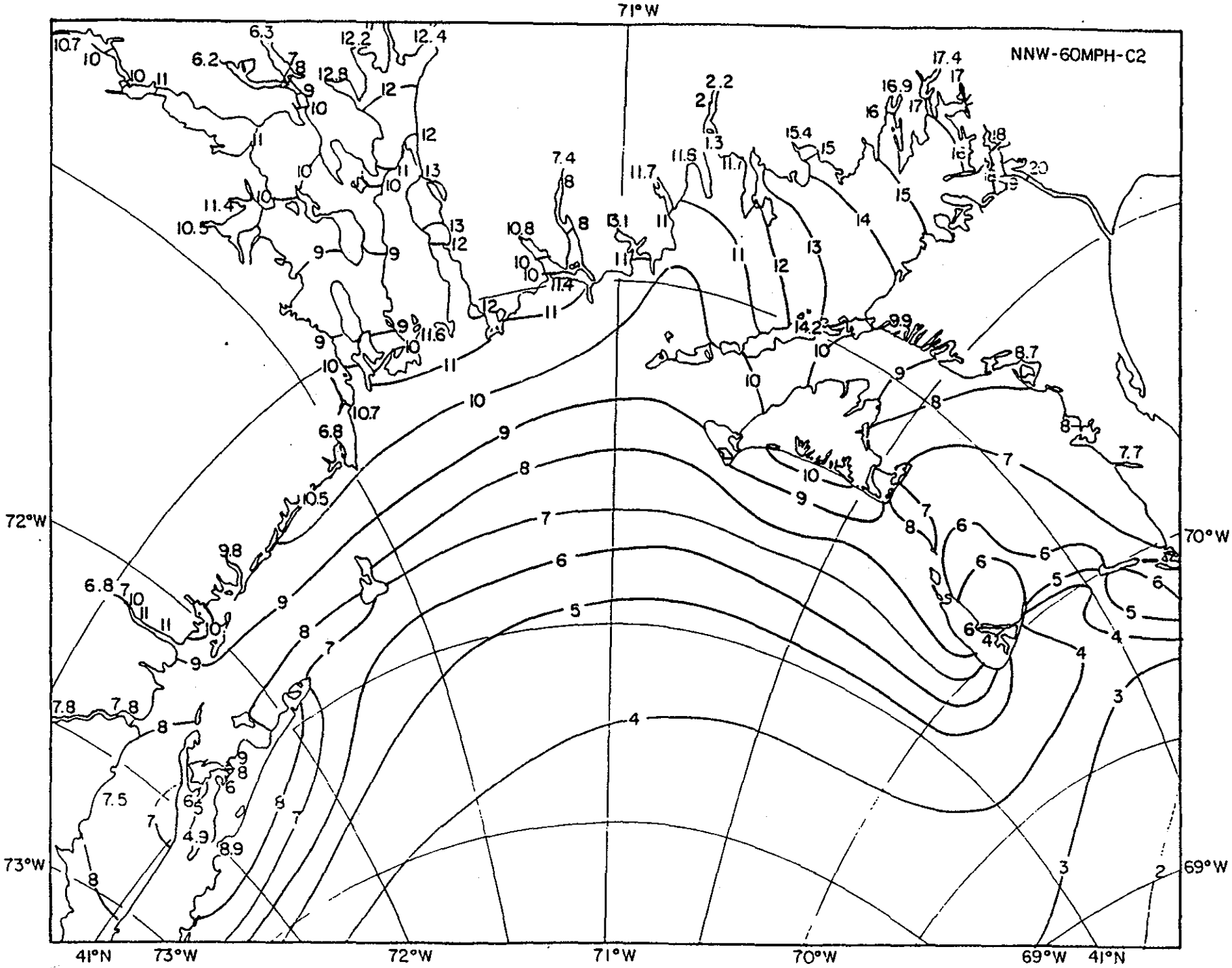
69°W



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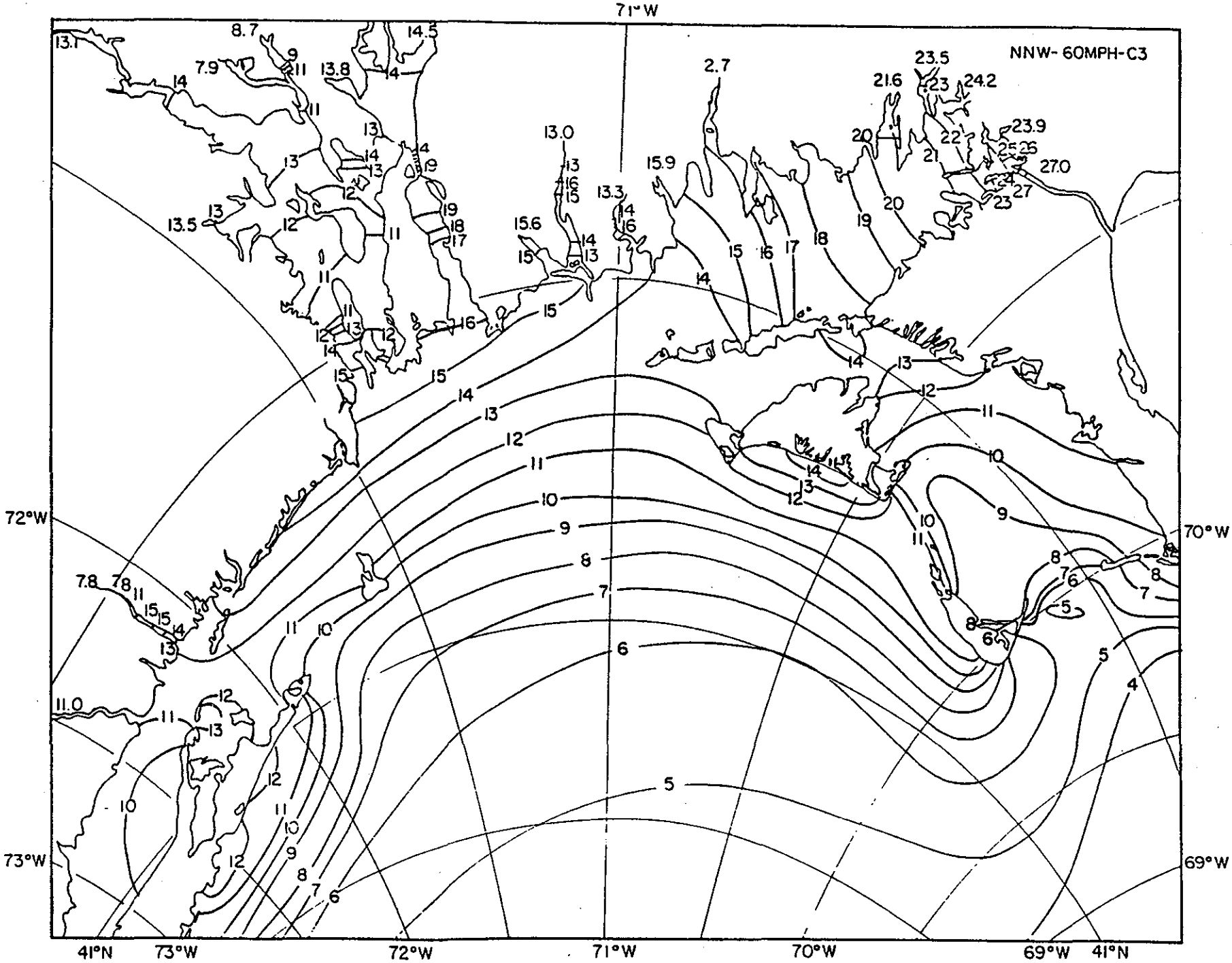
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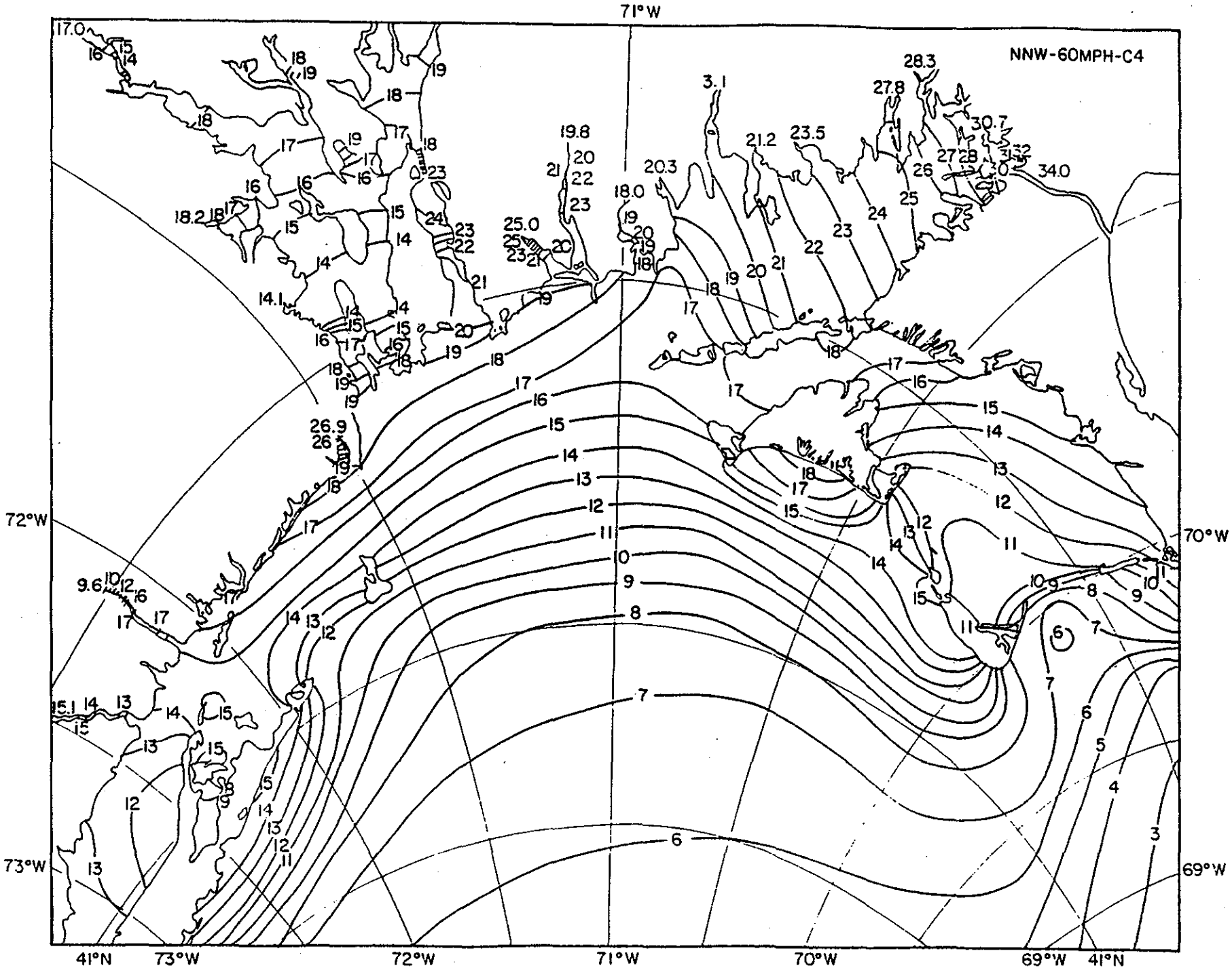
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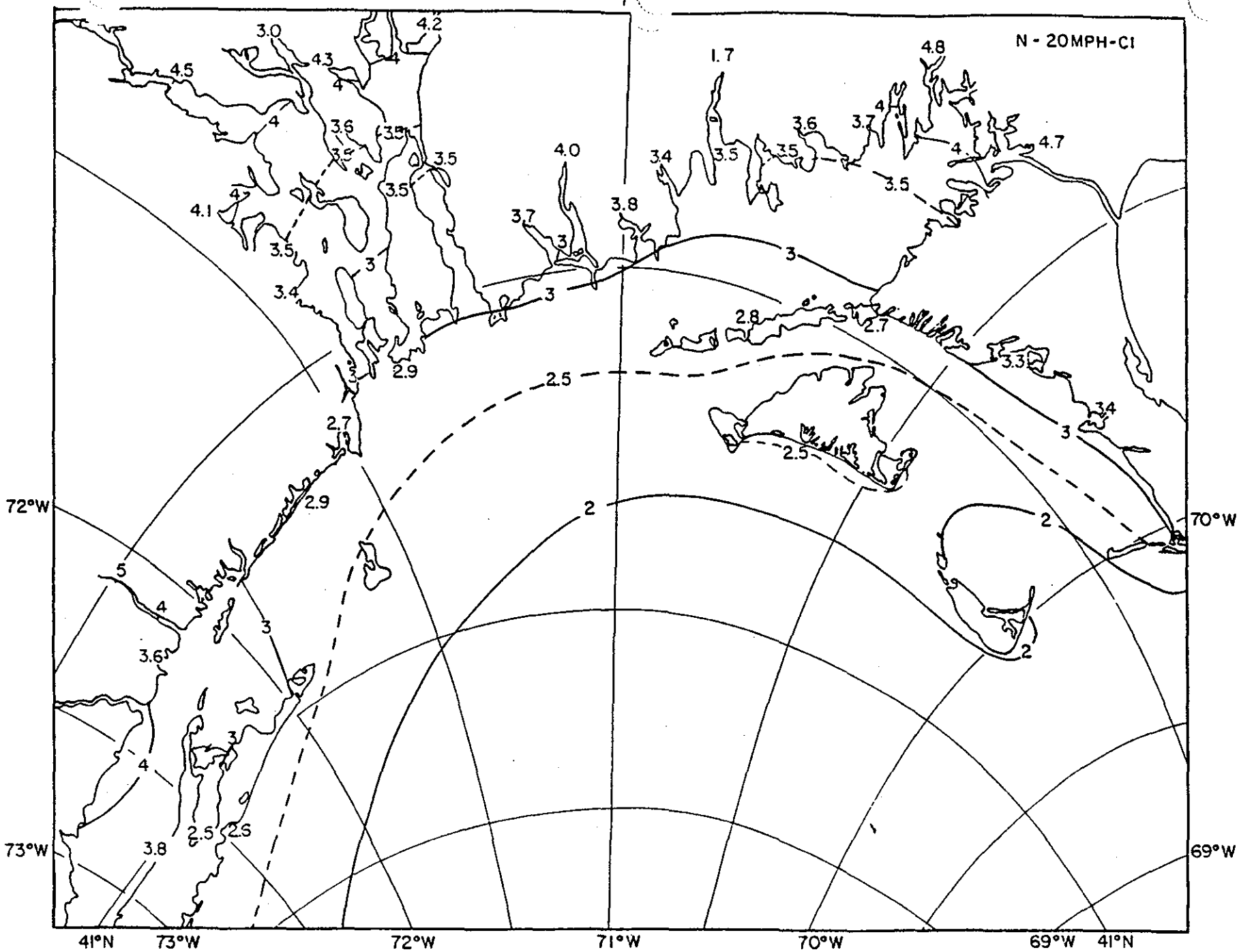
N - 20MPH-CI
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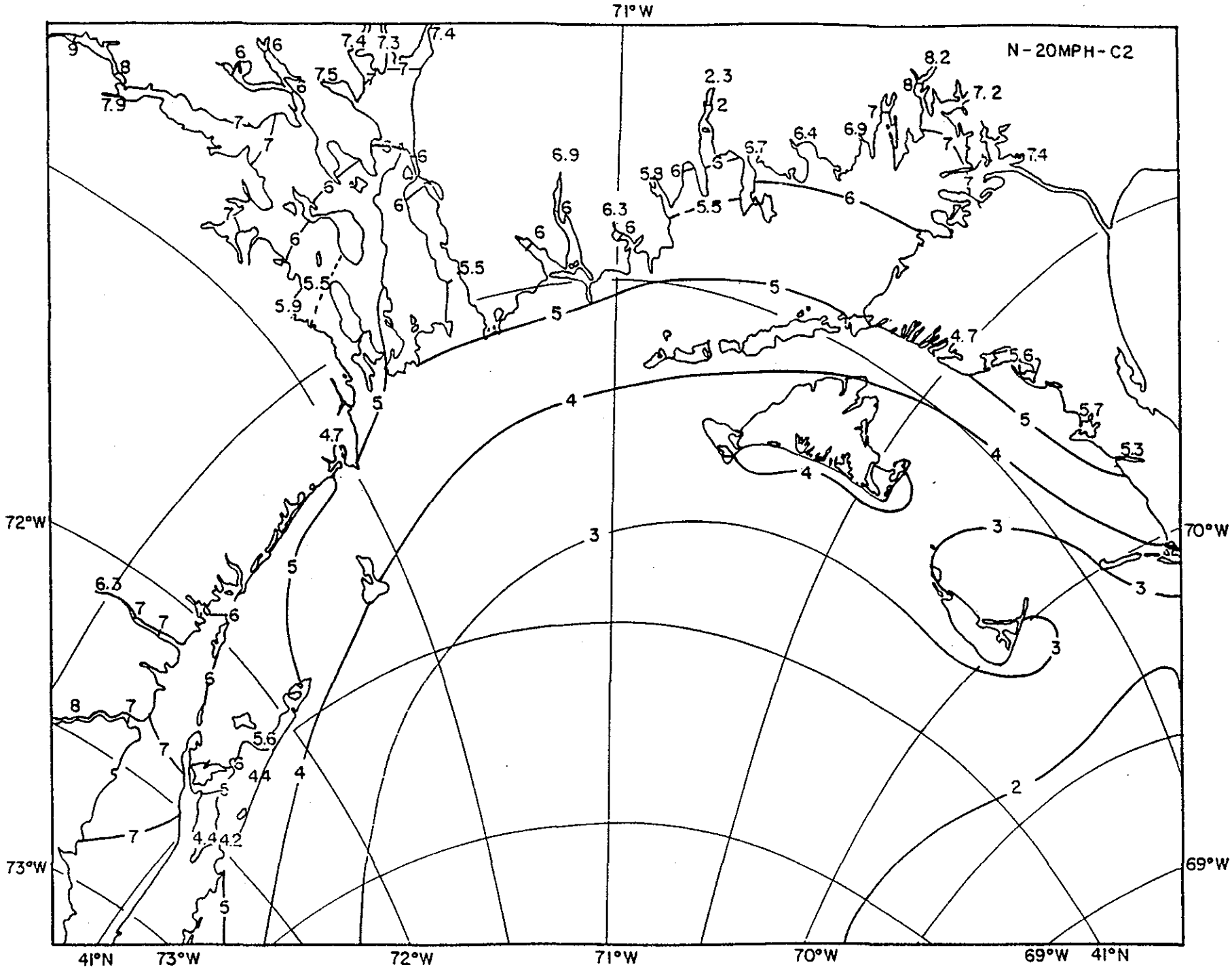
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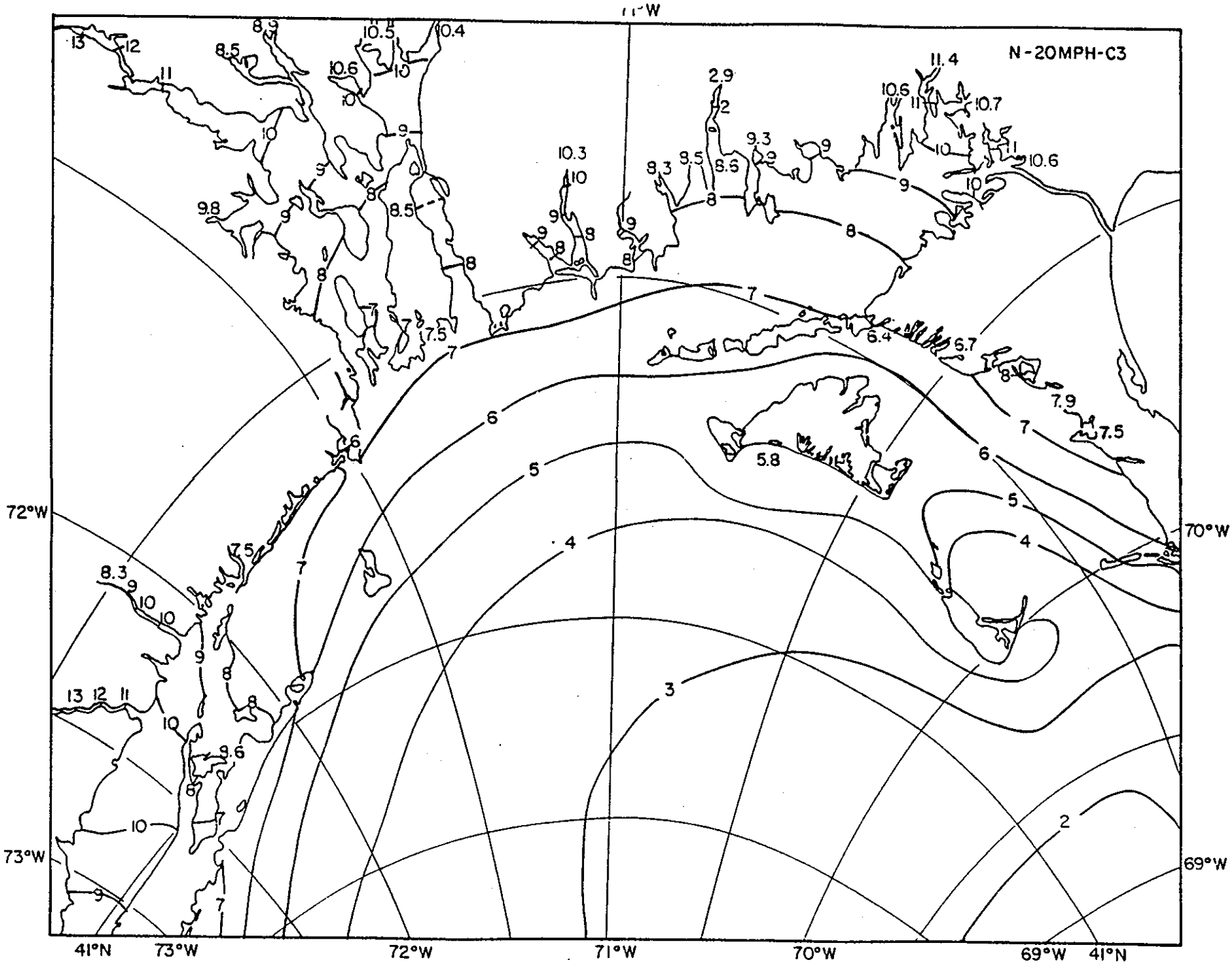
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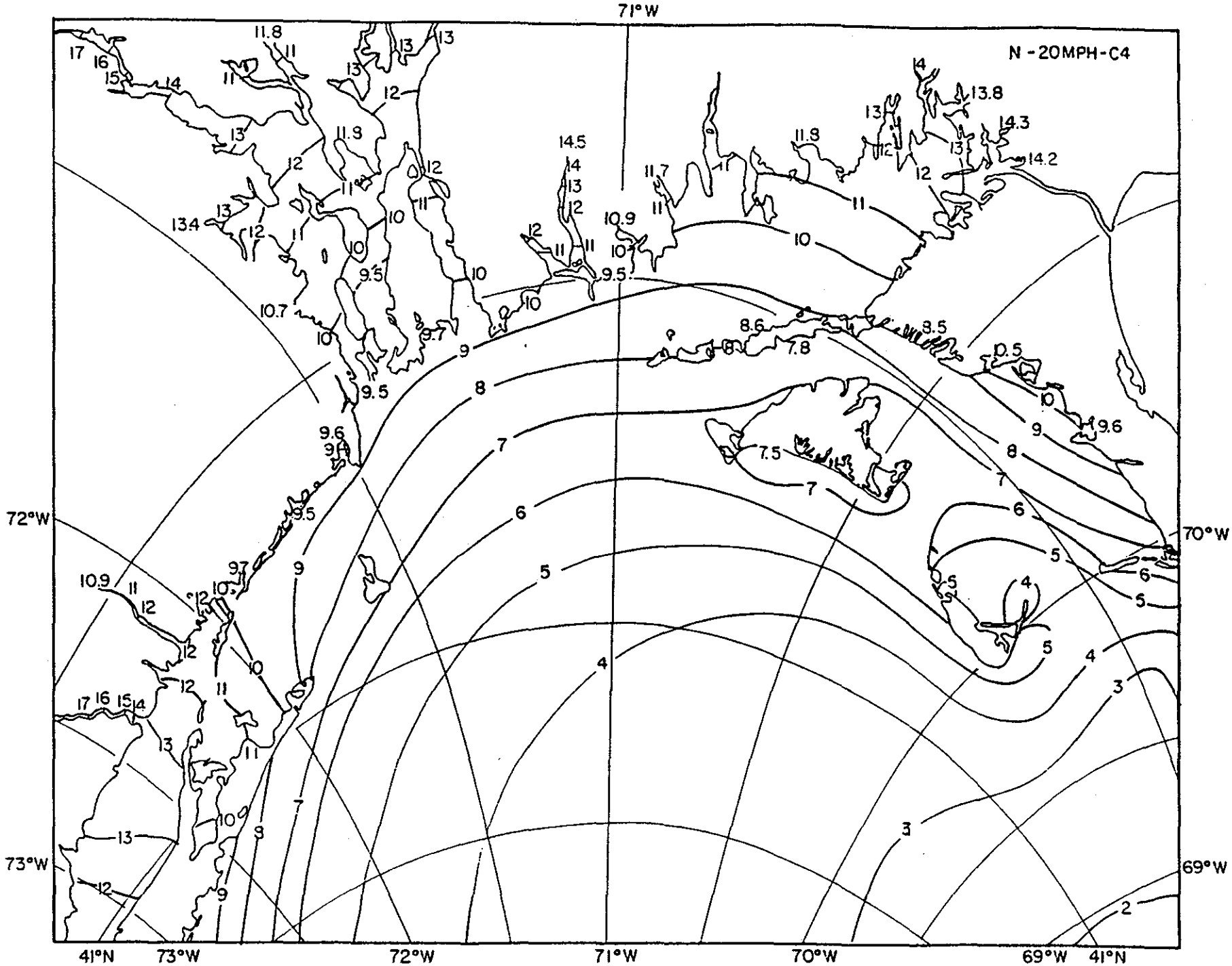
69°W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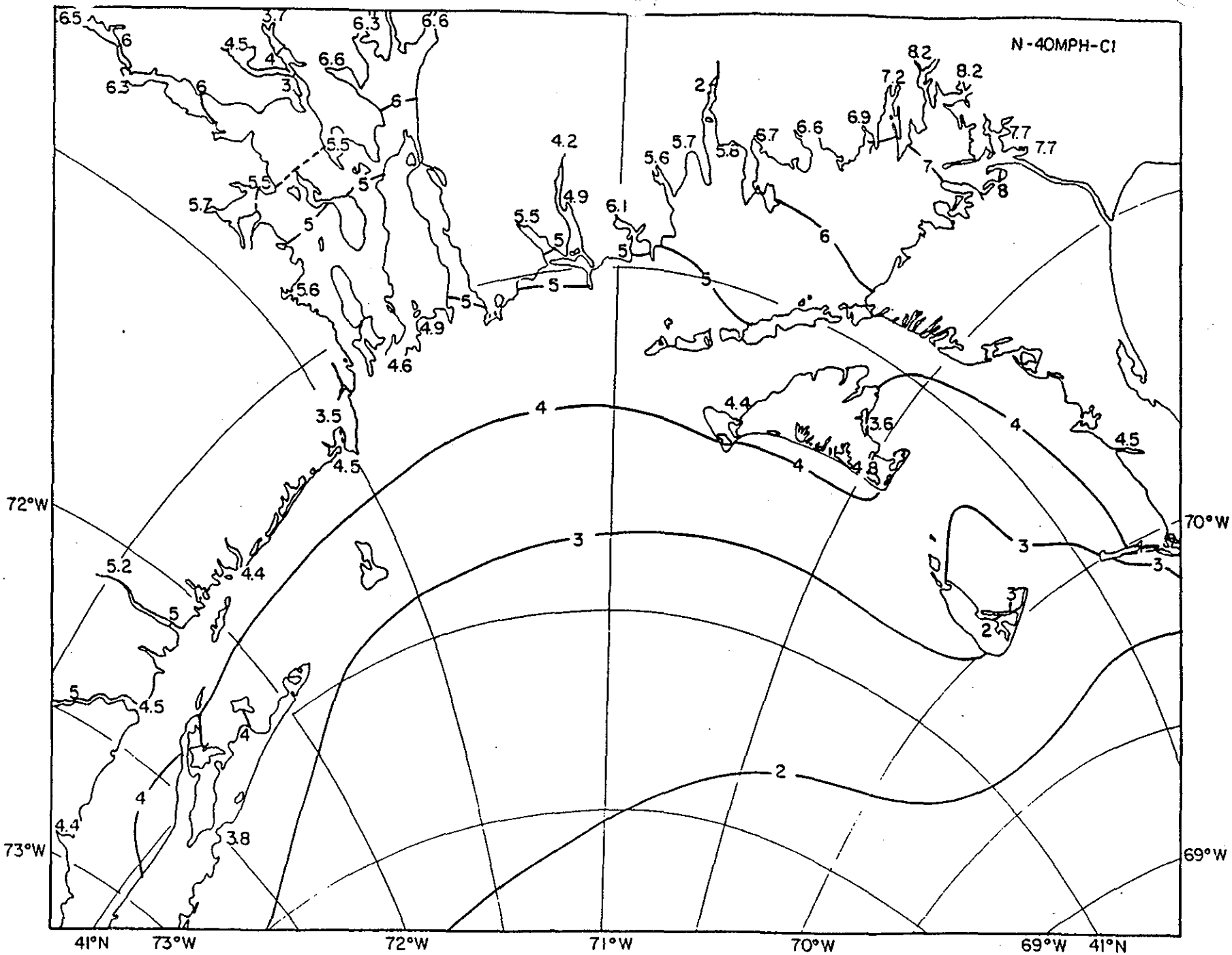
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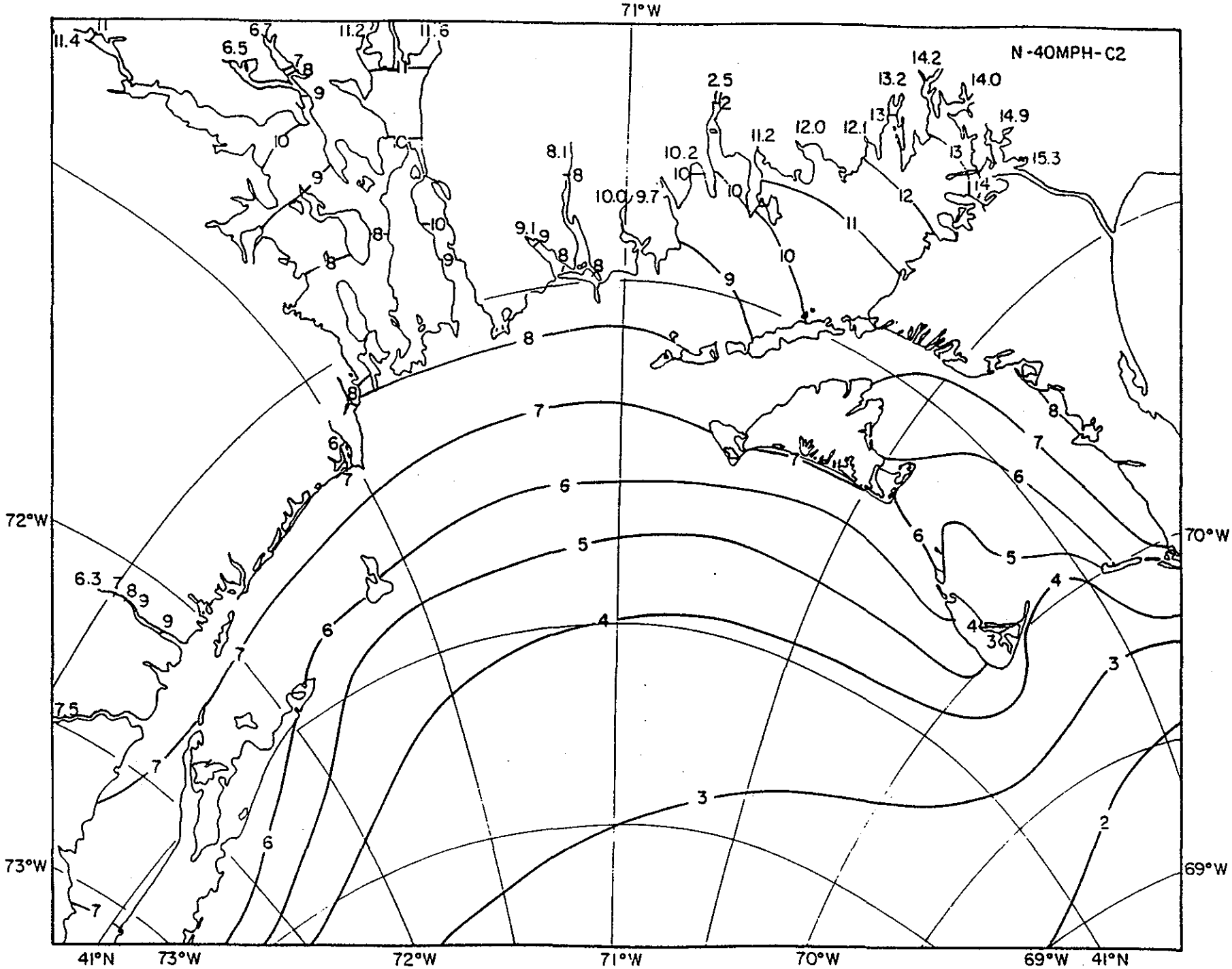
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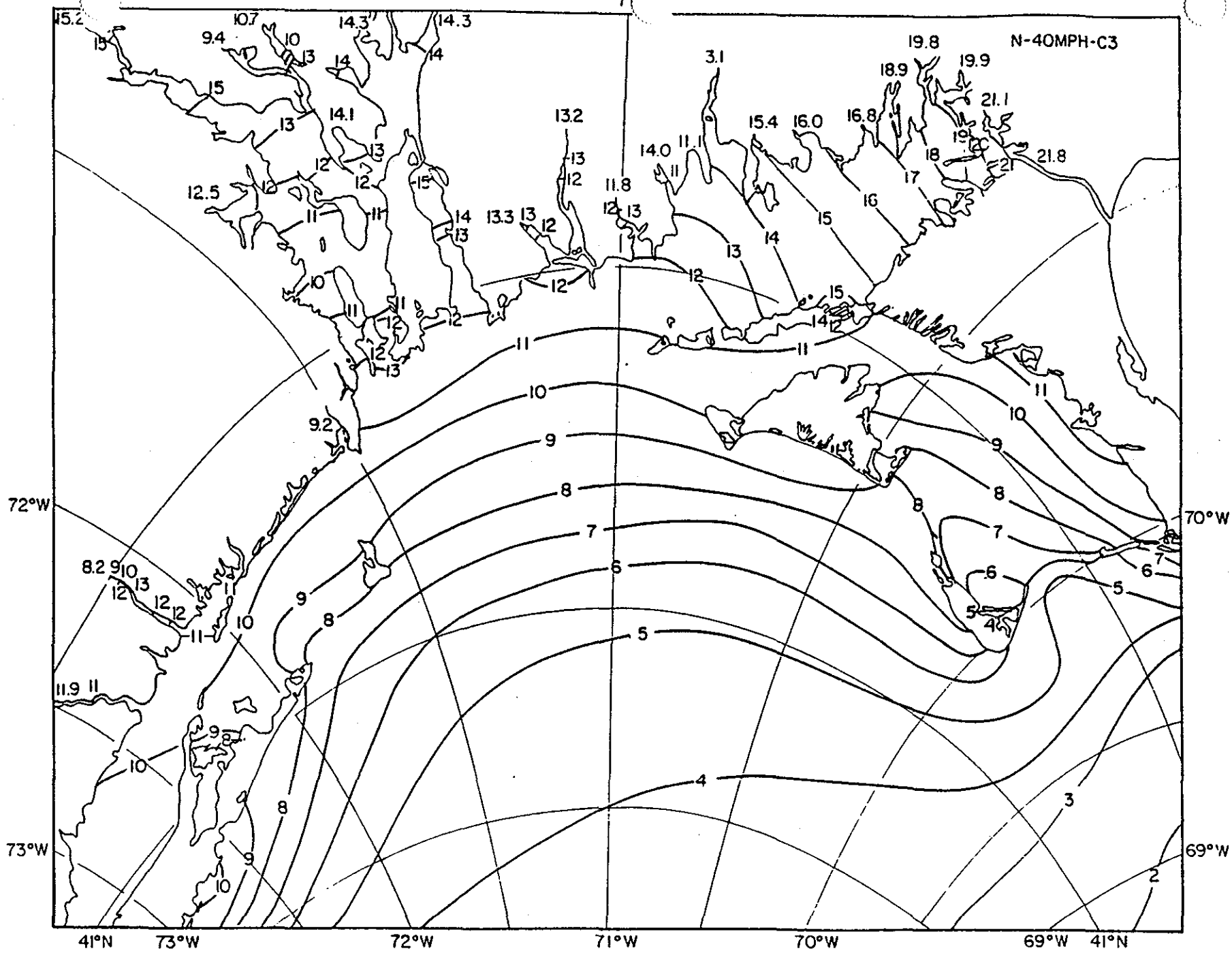
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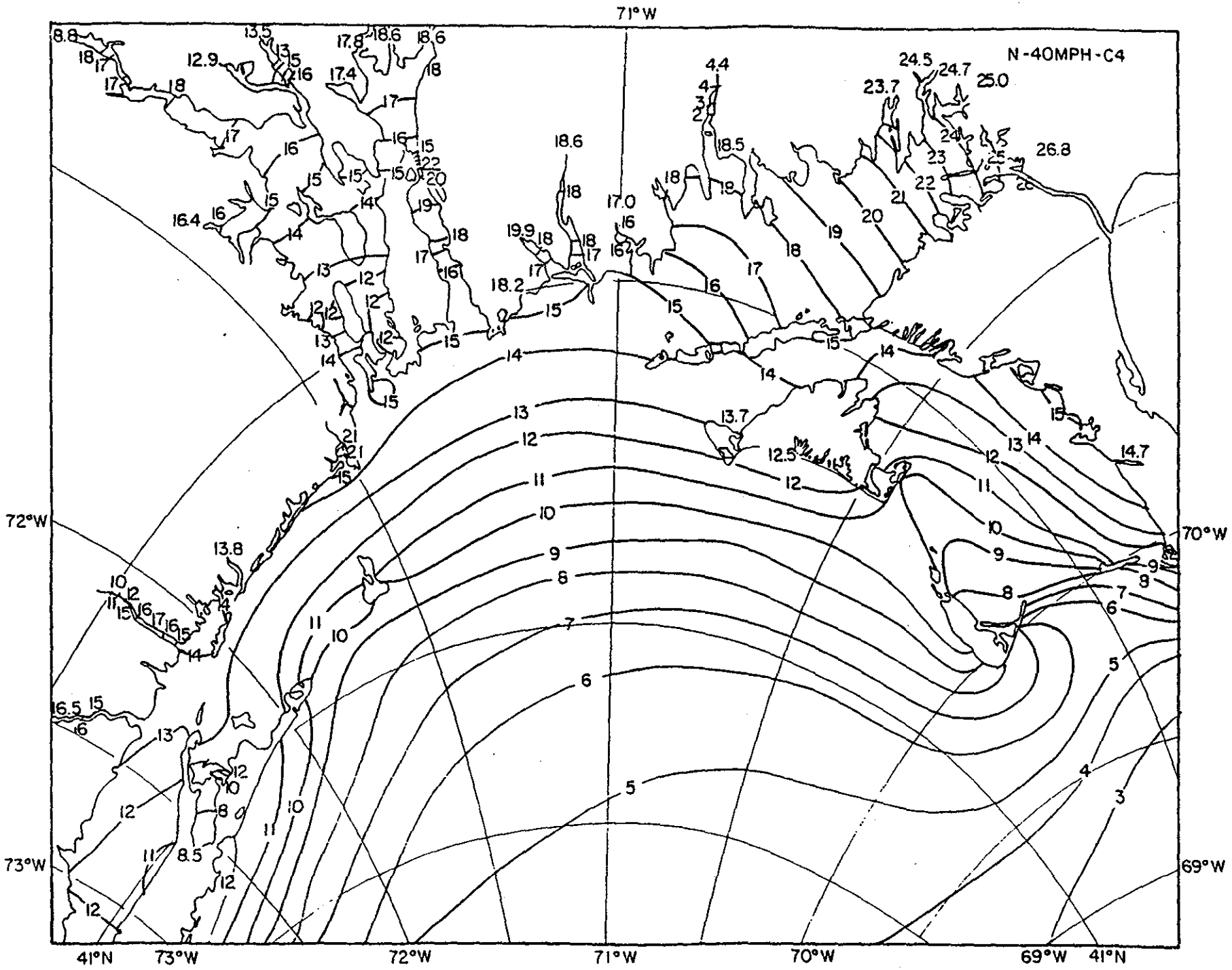
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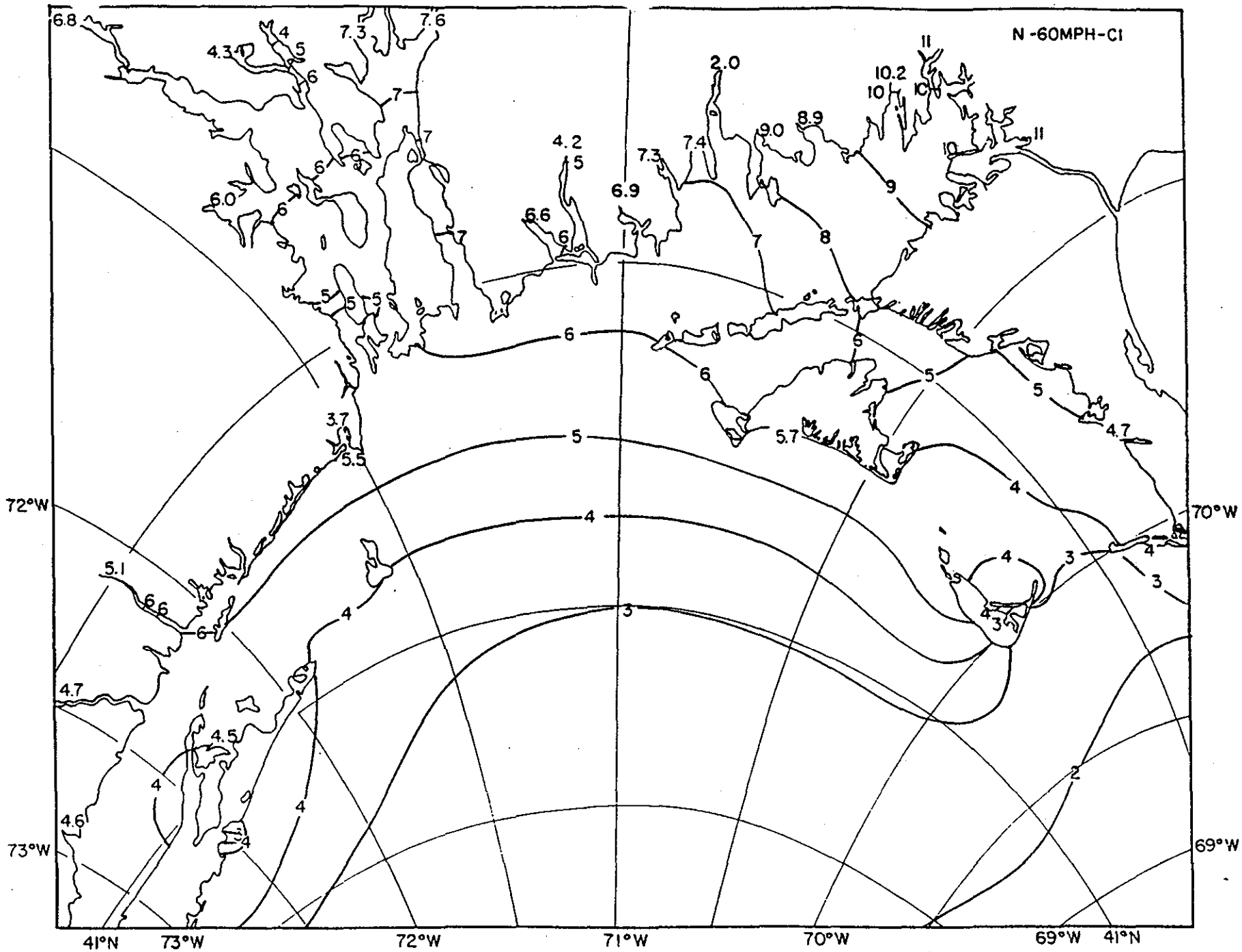
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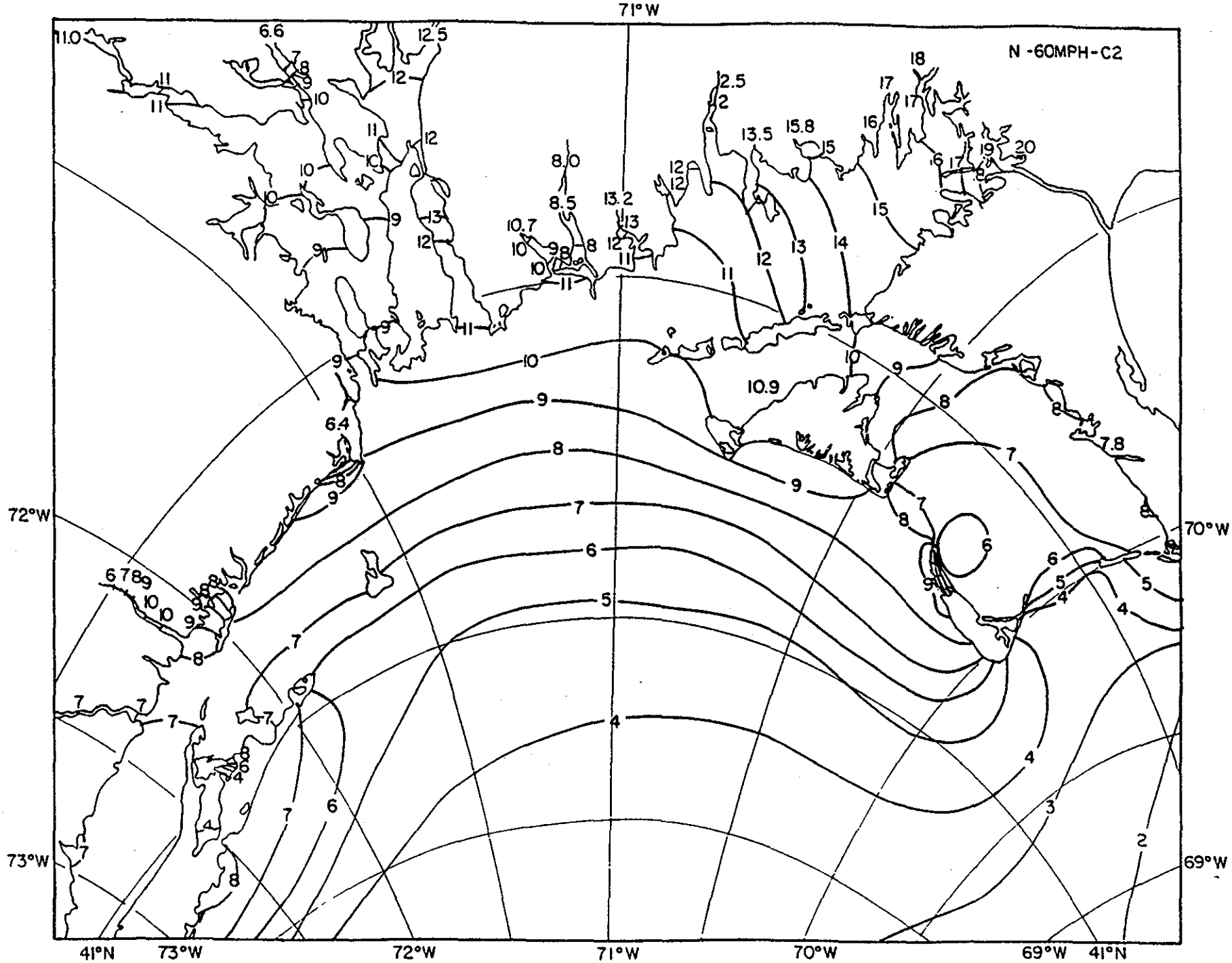
41°N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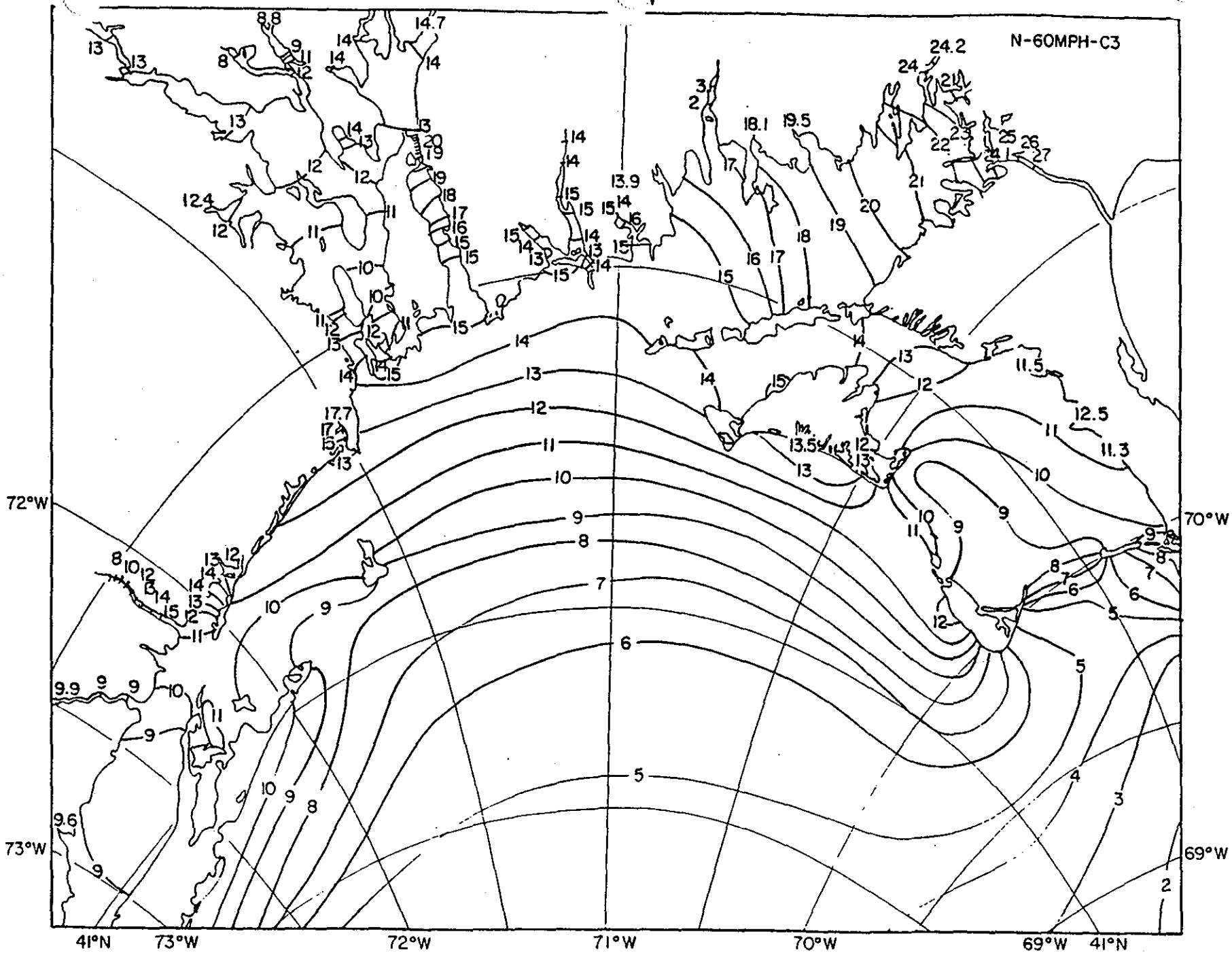
41°N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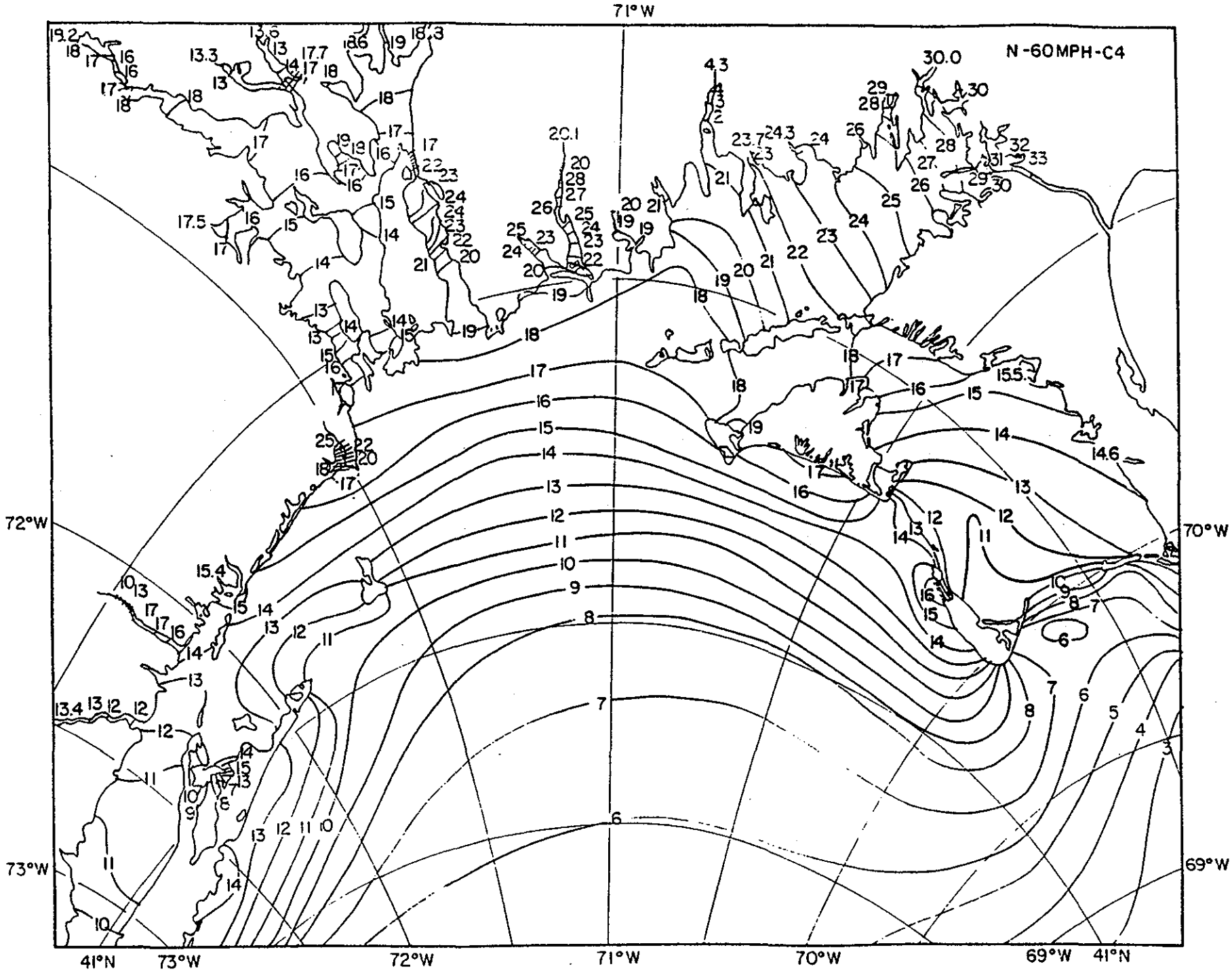
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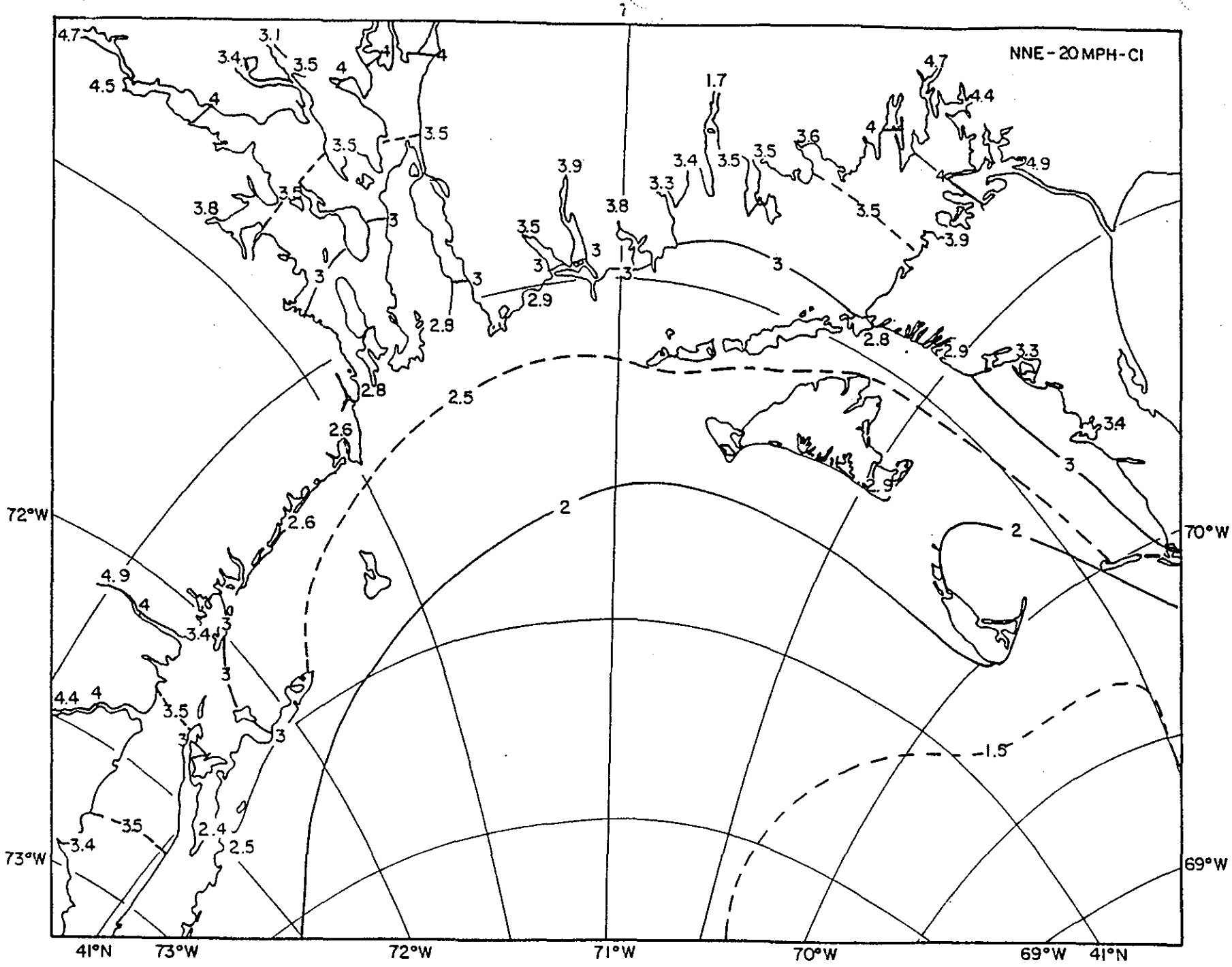
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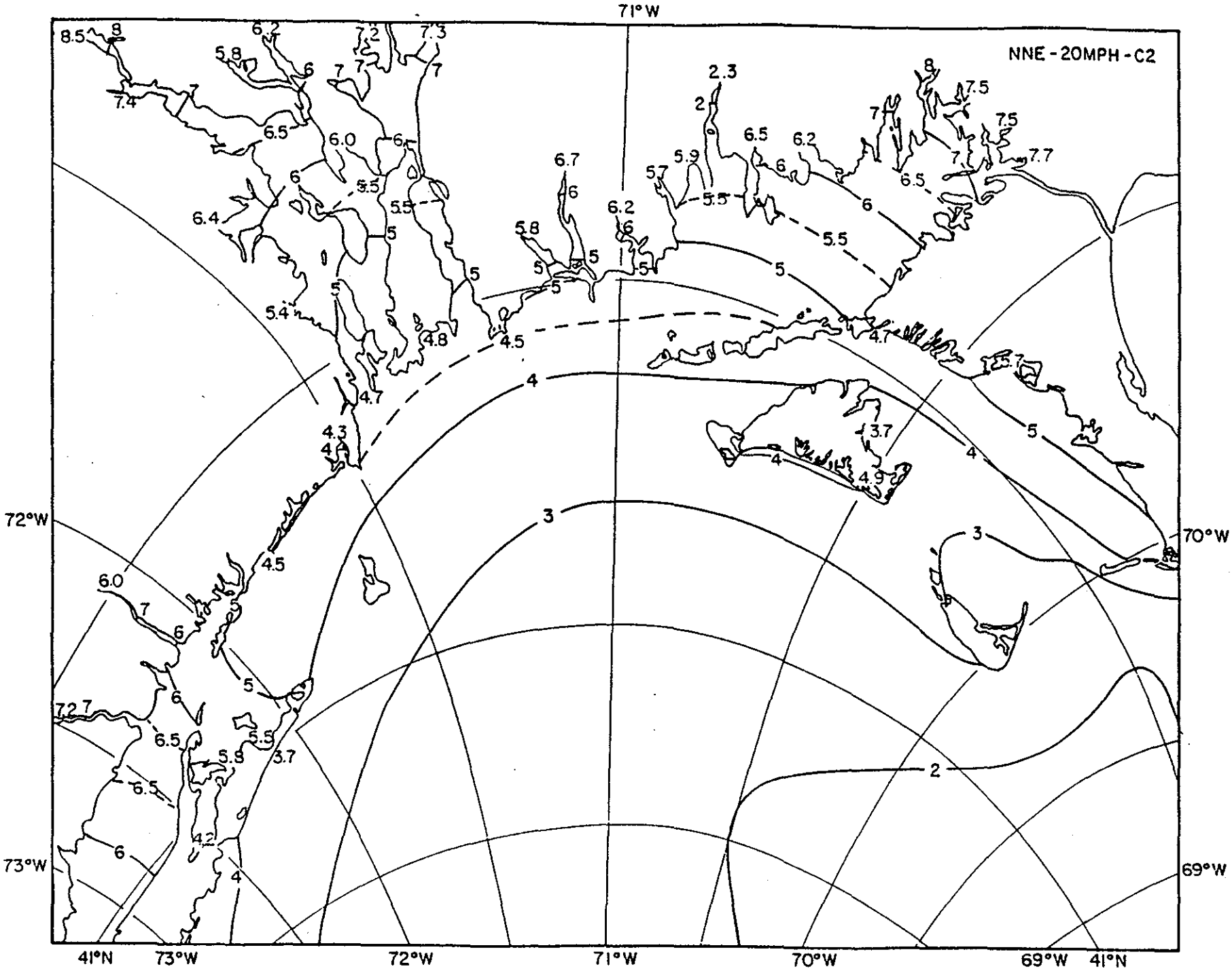
69°W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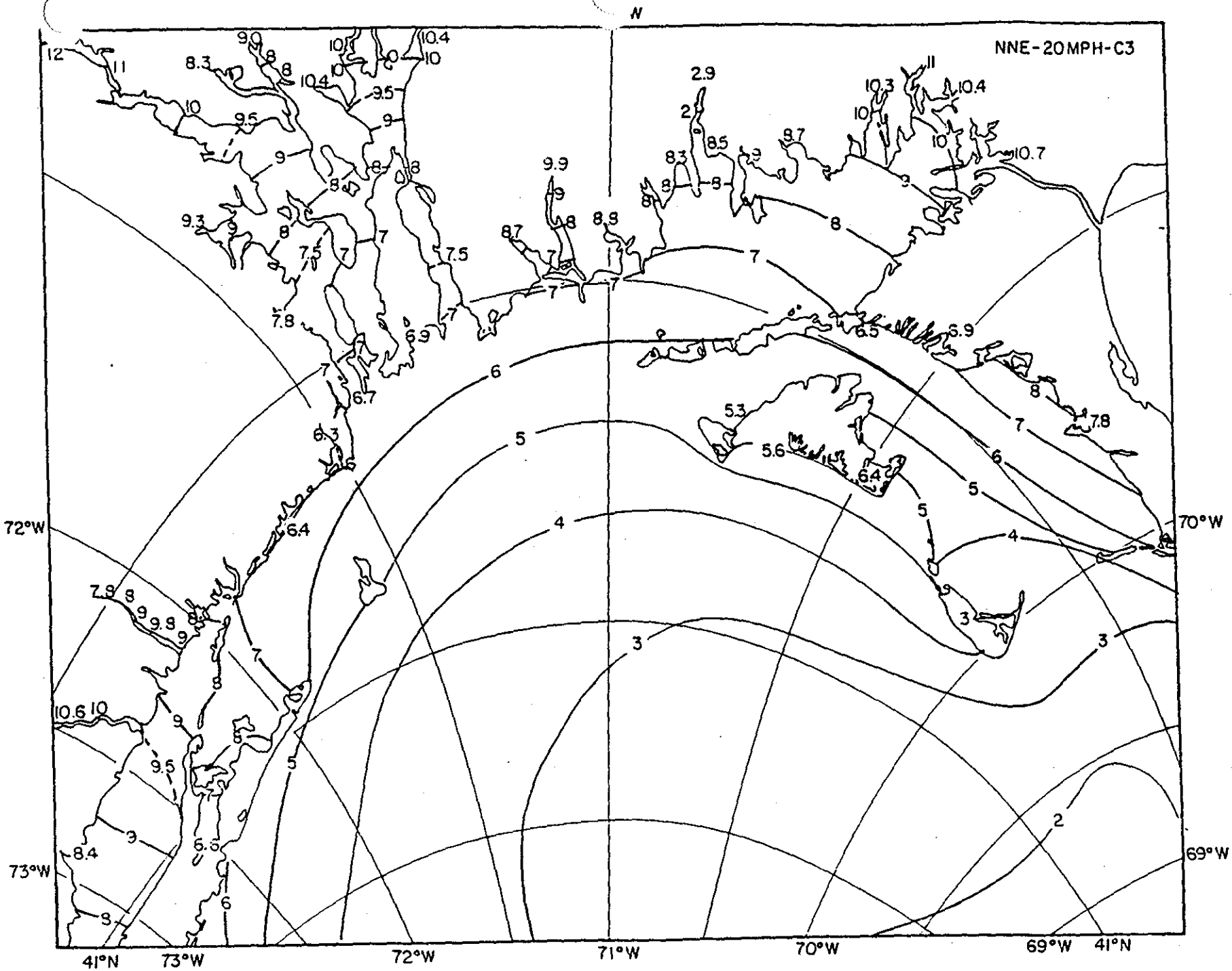
41°N
41°N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NNE-20MPH-C3
72°W
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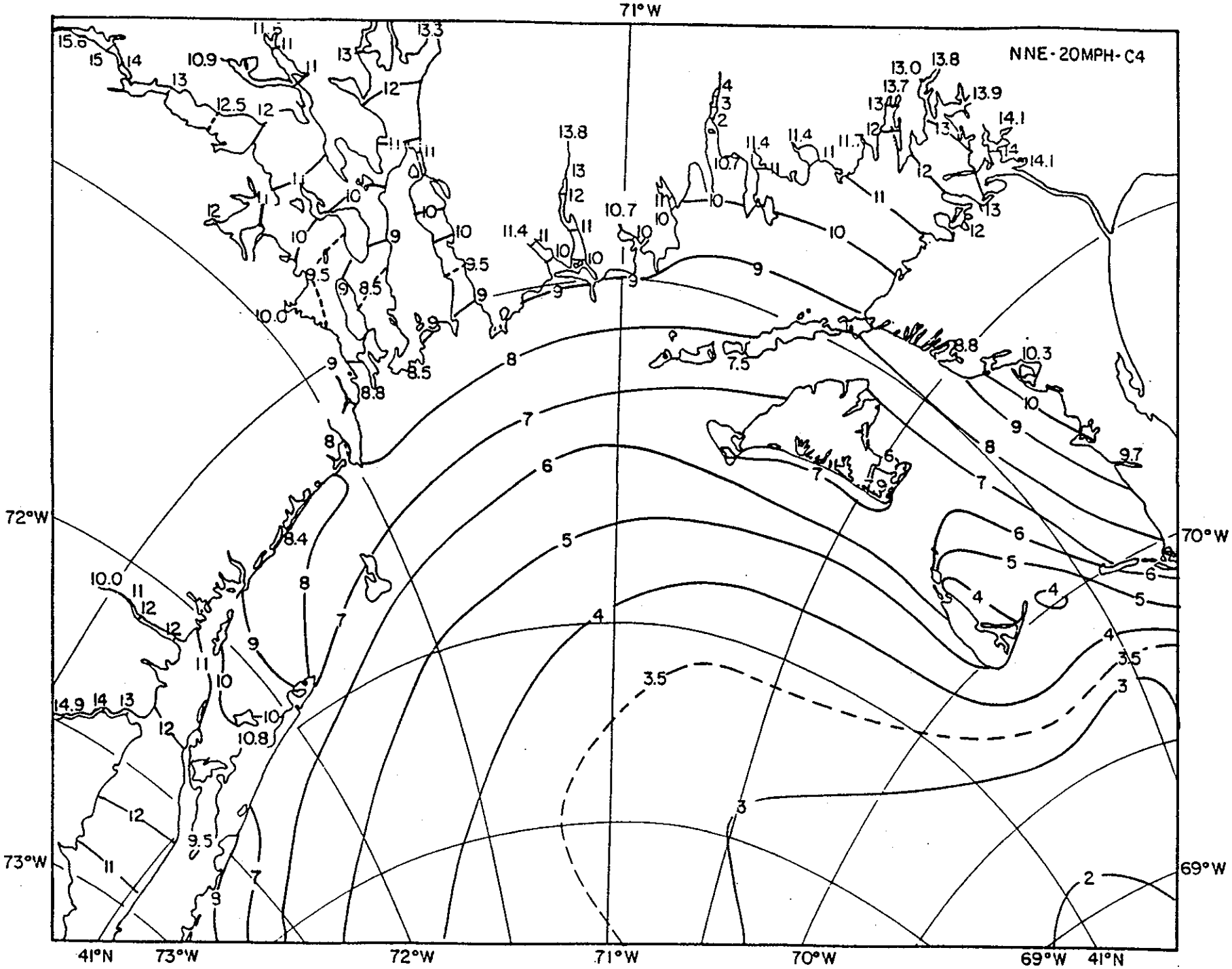
71°W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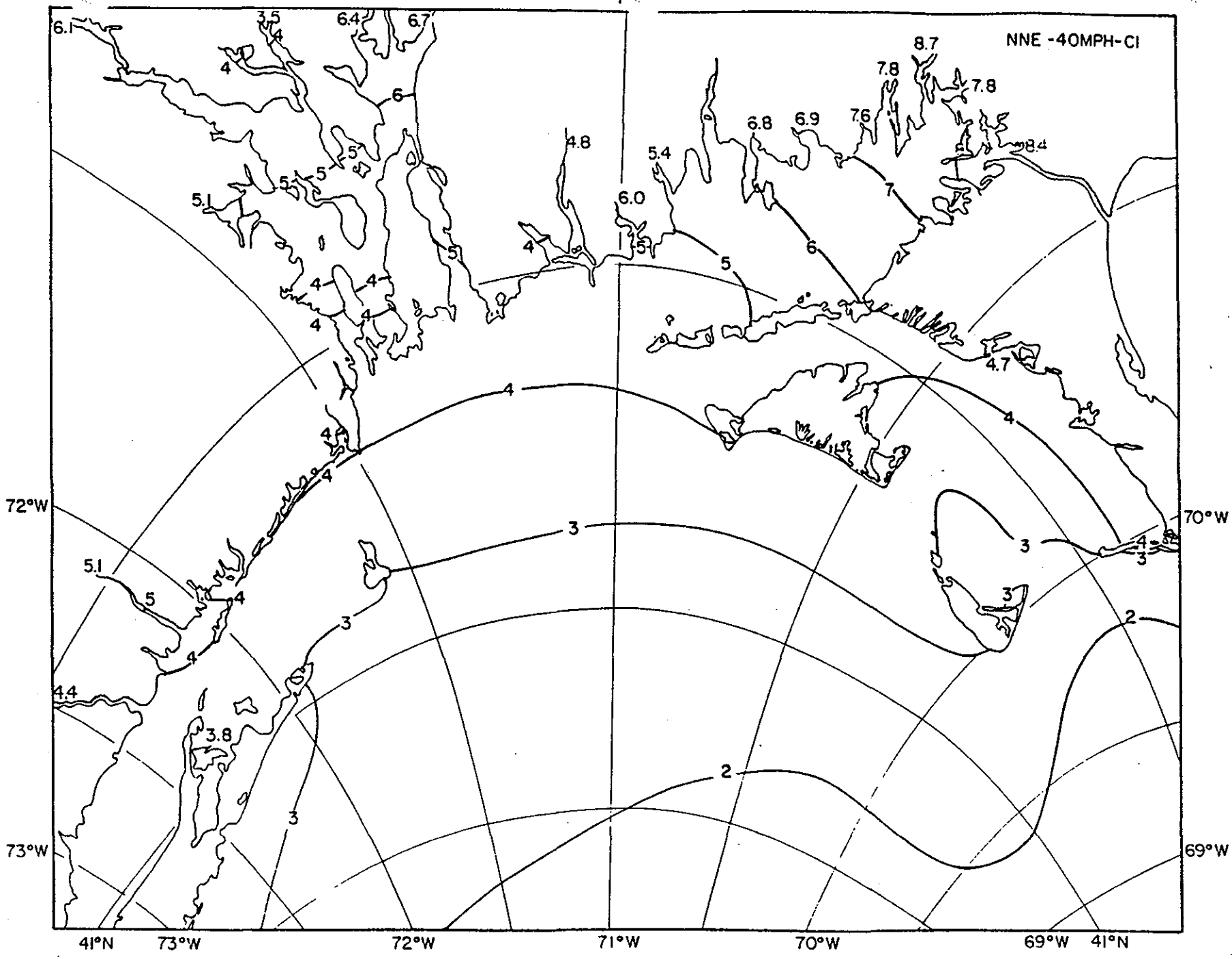
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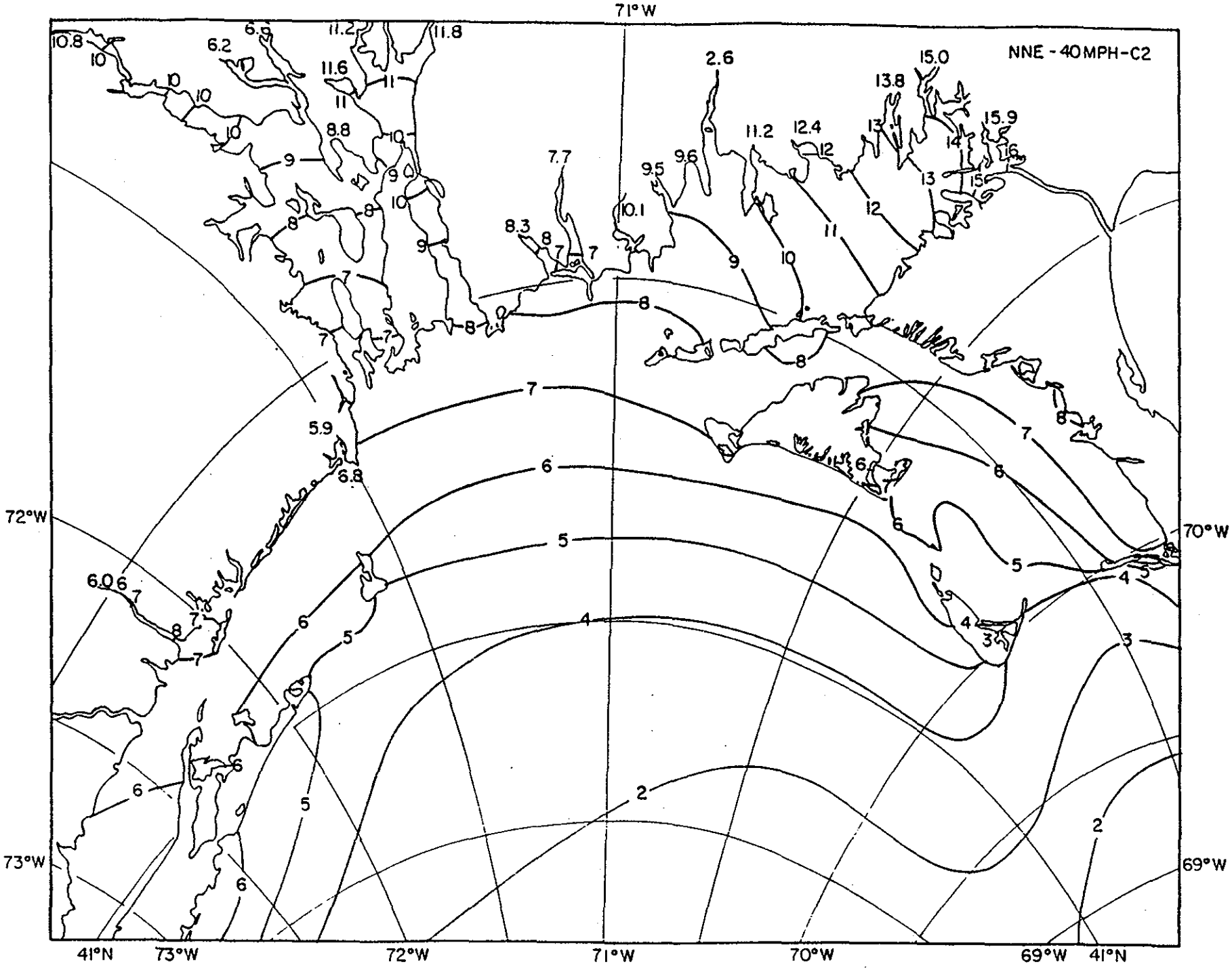
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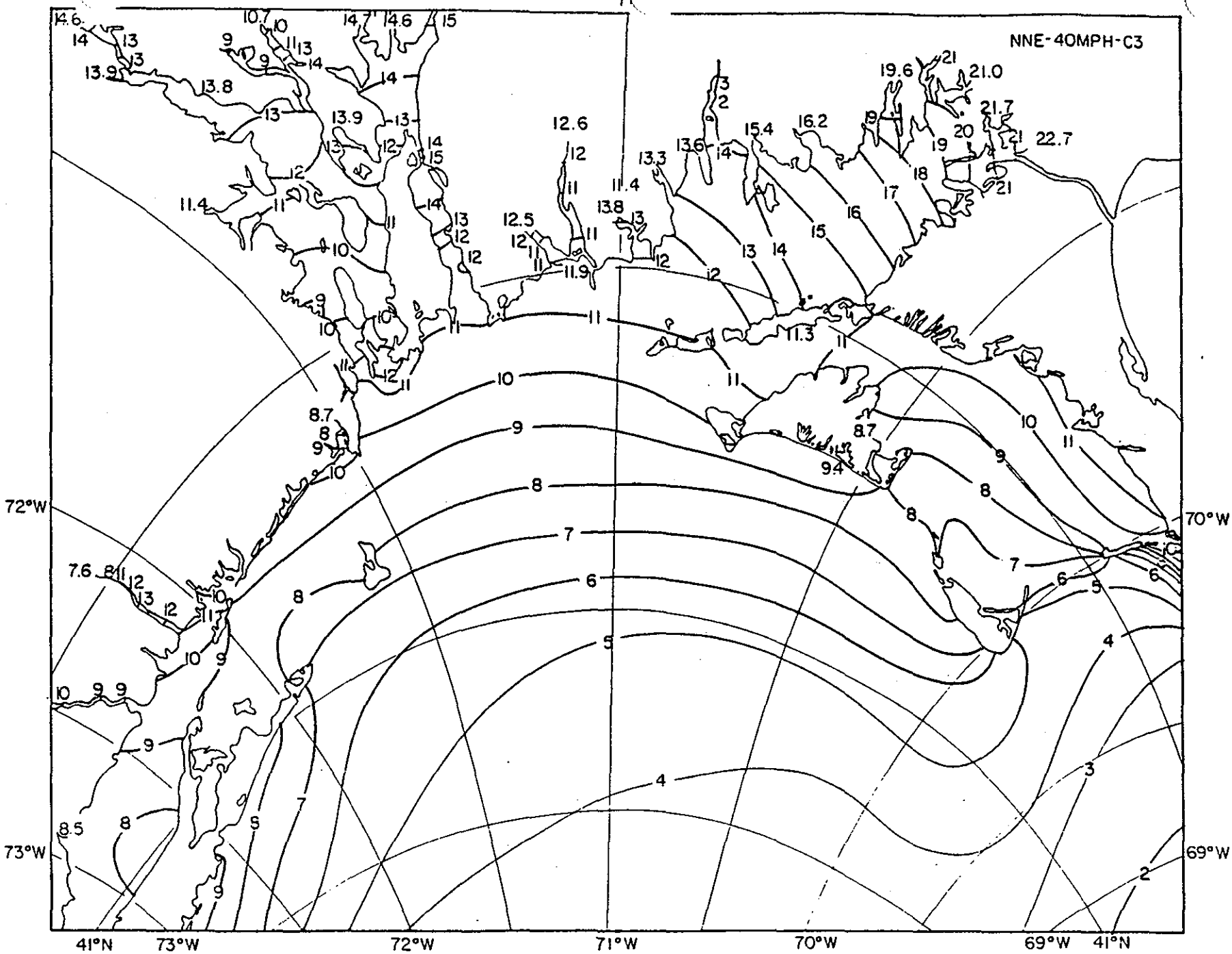
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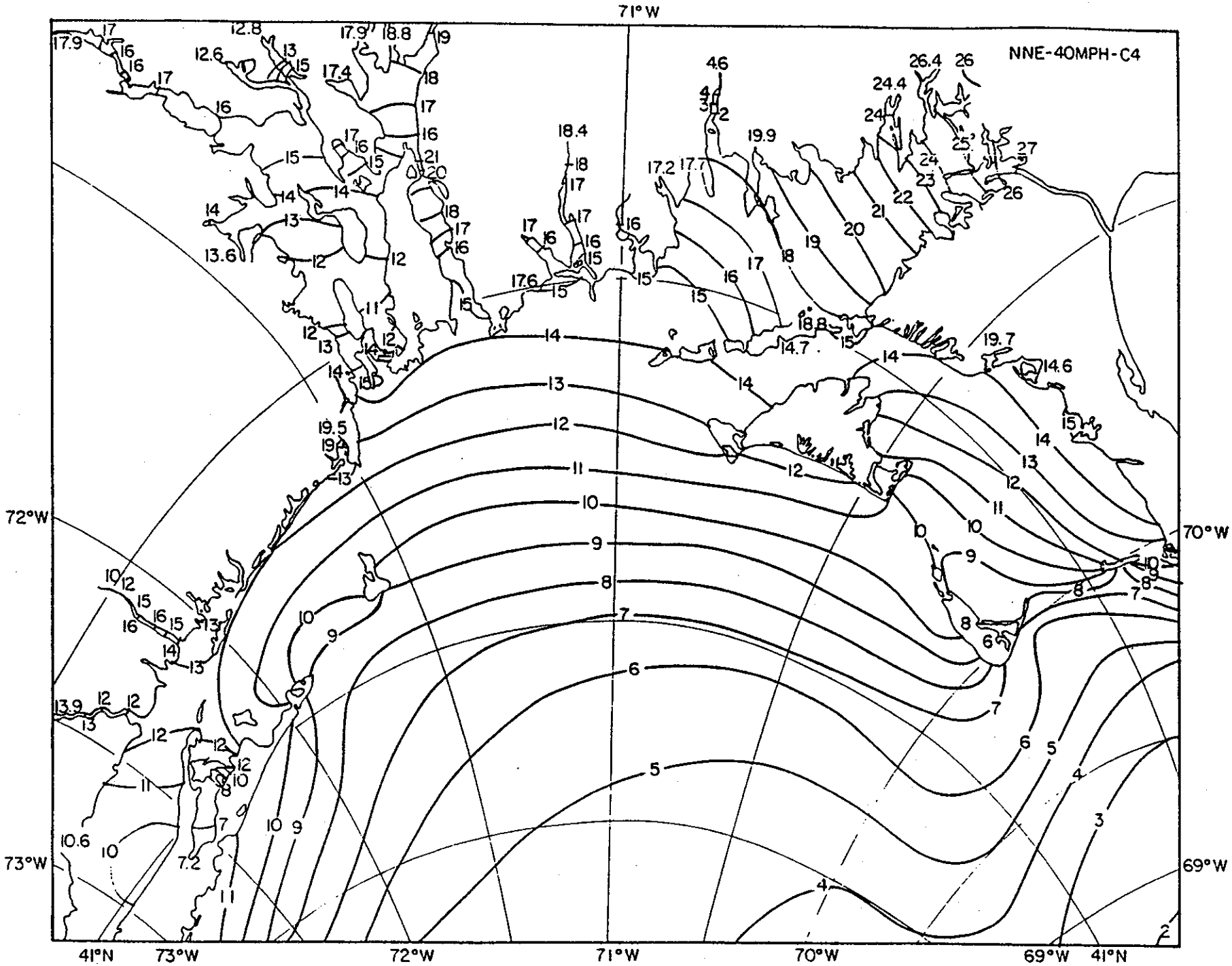
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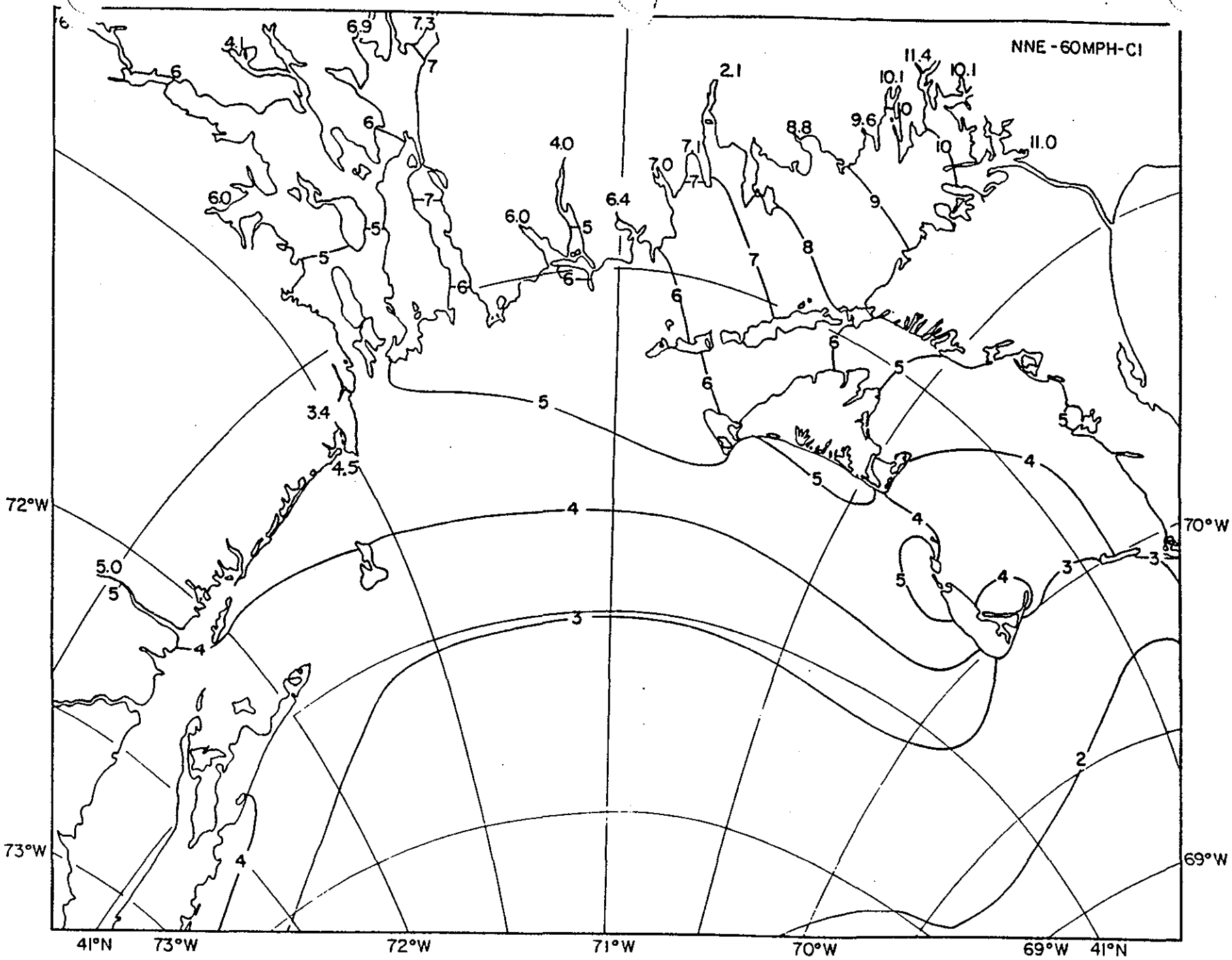
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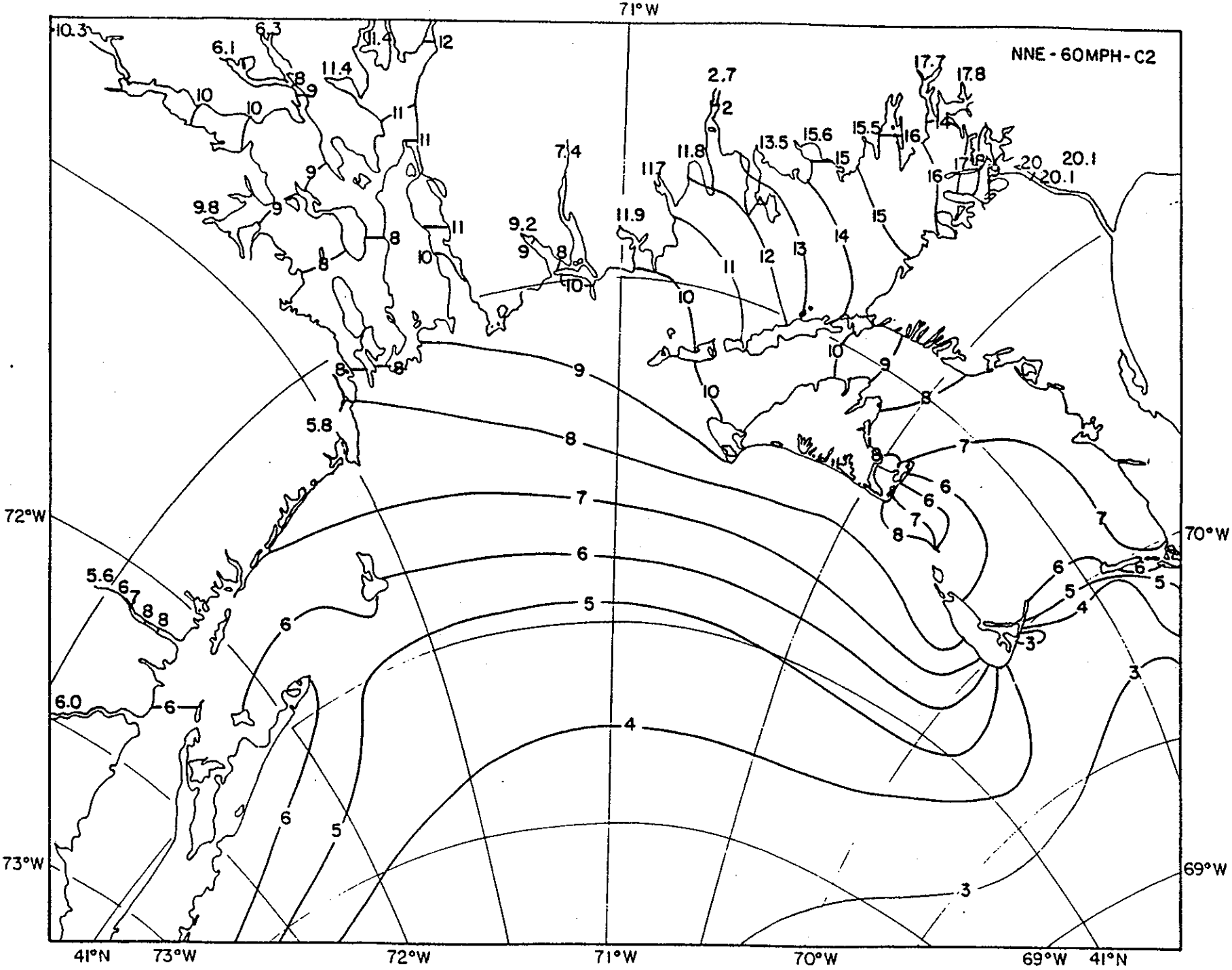
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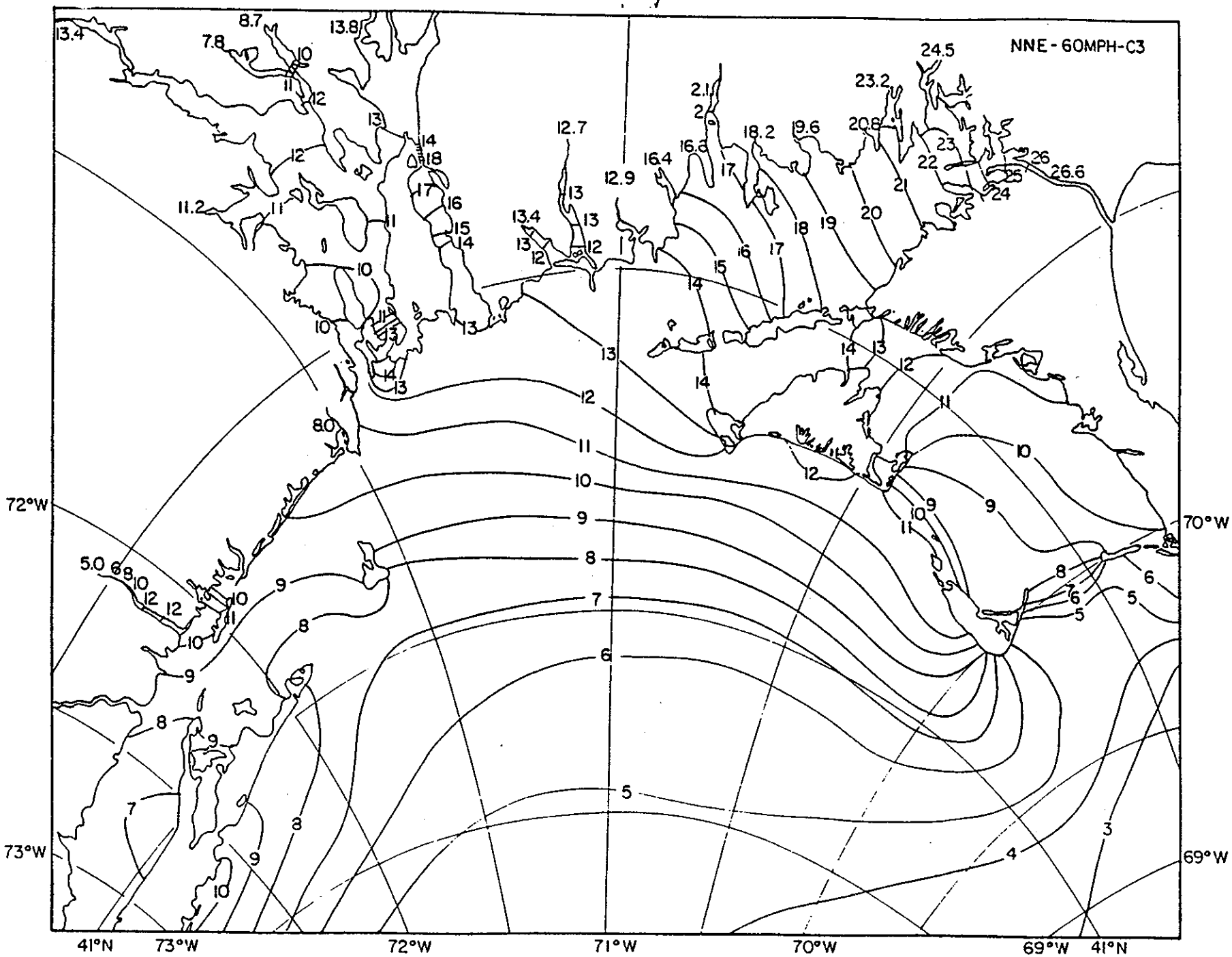
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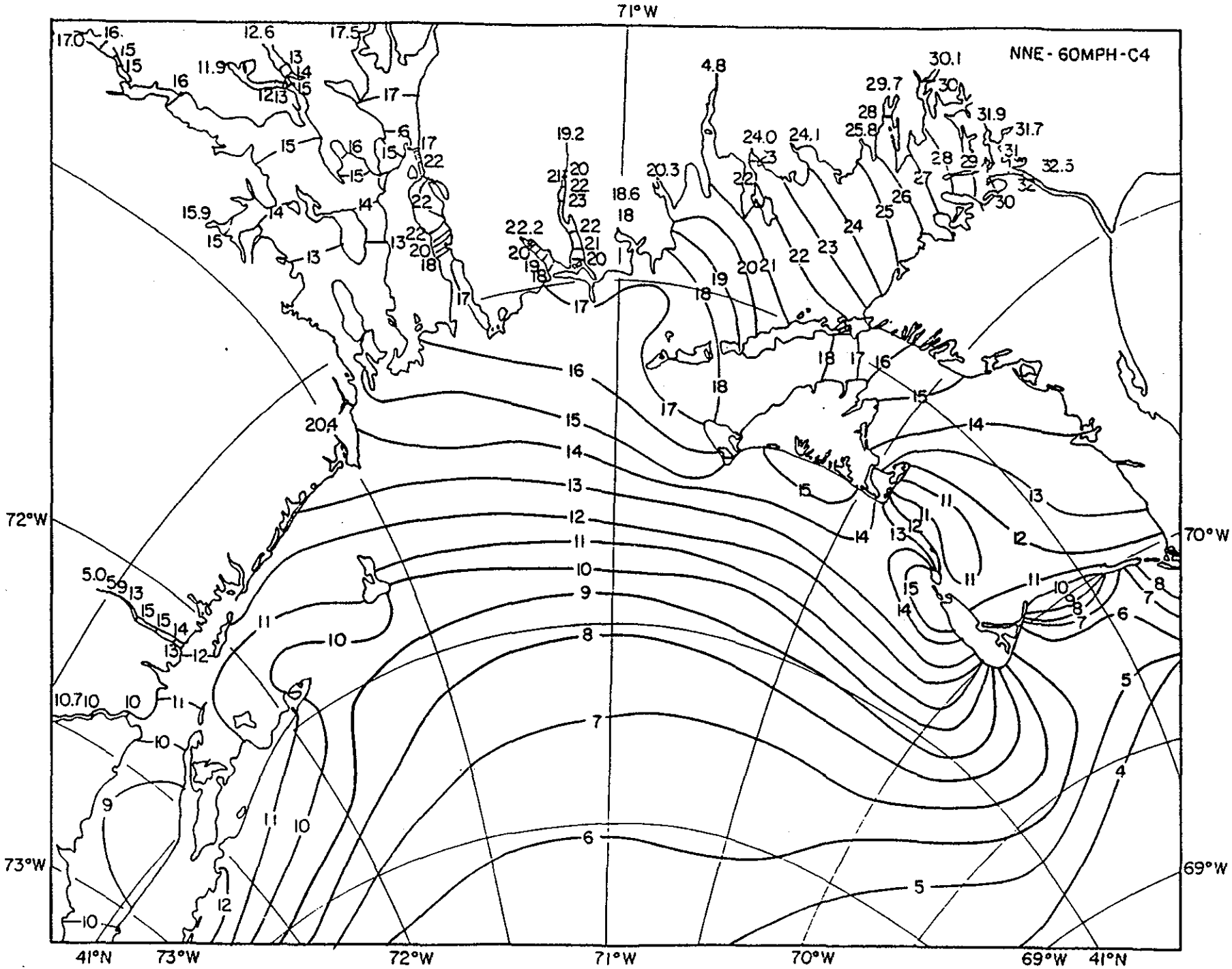
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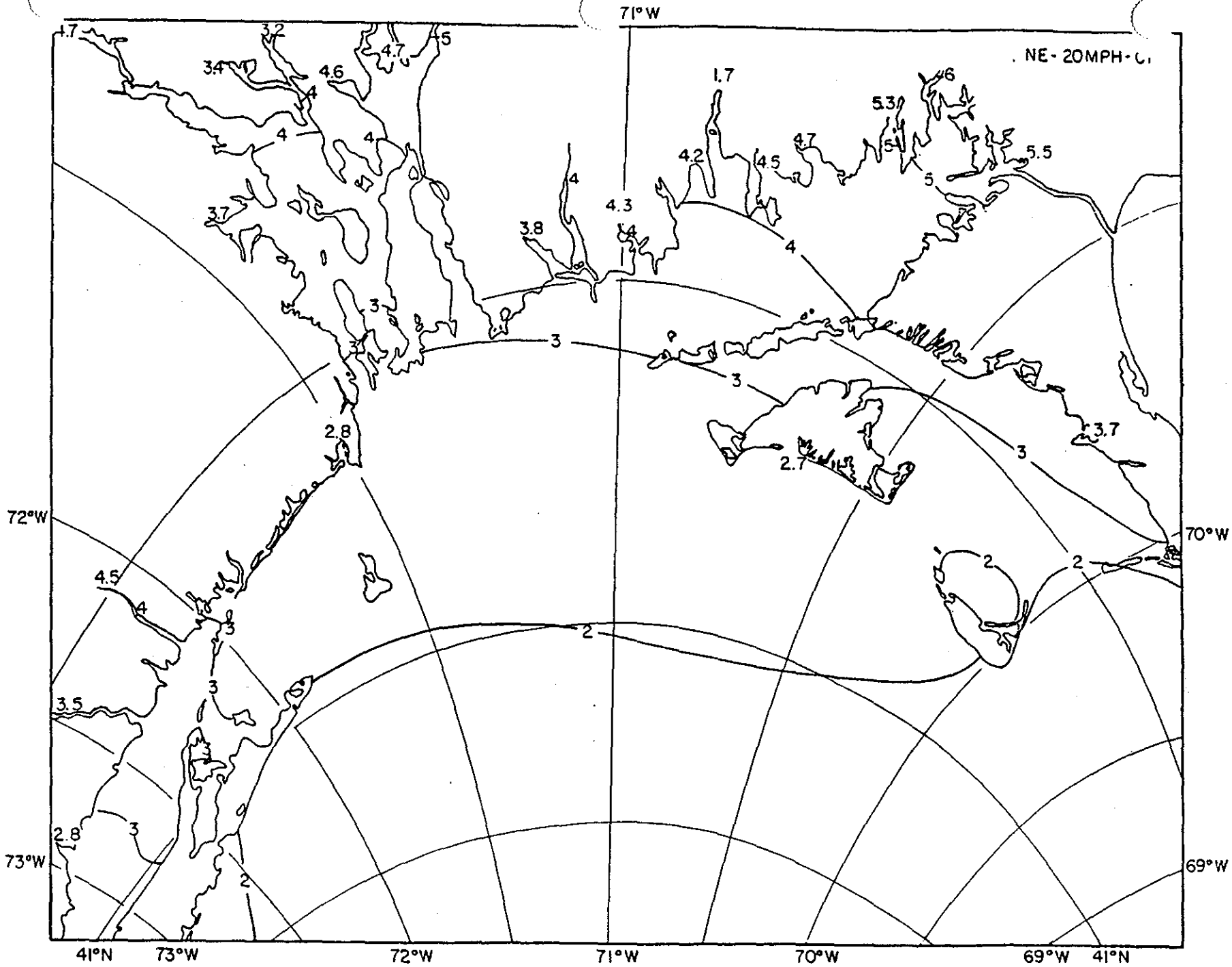
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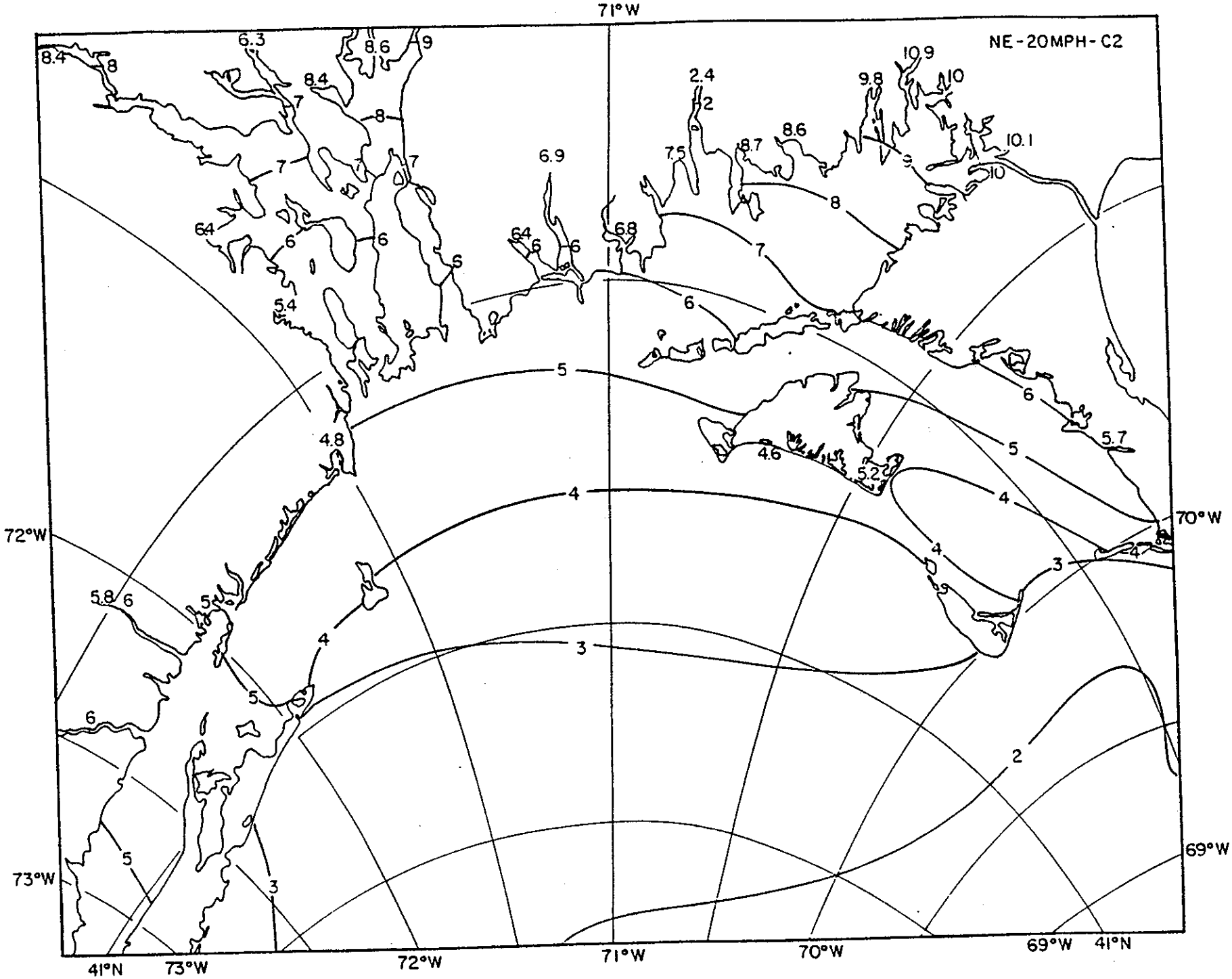
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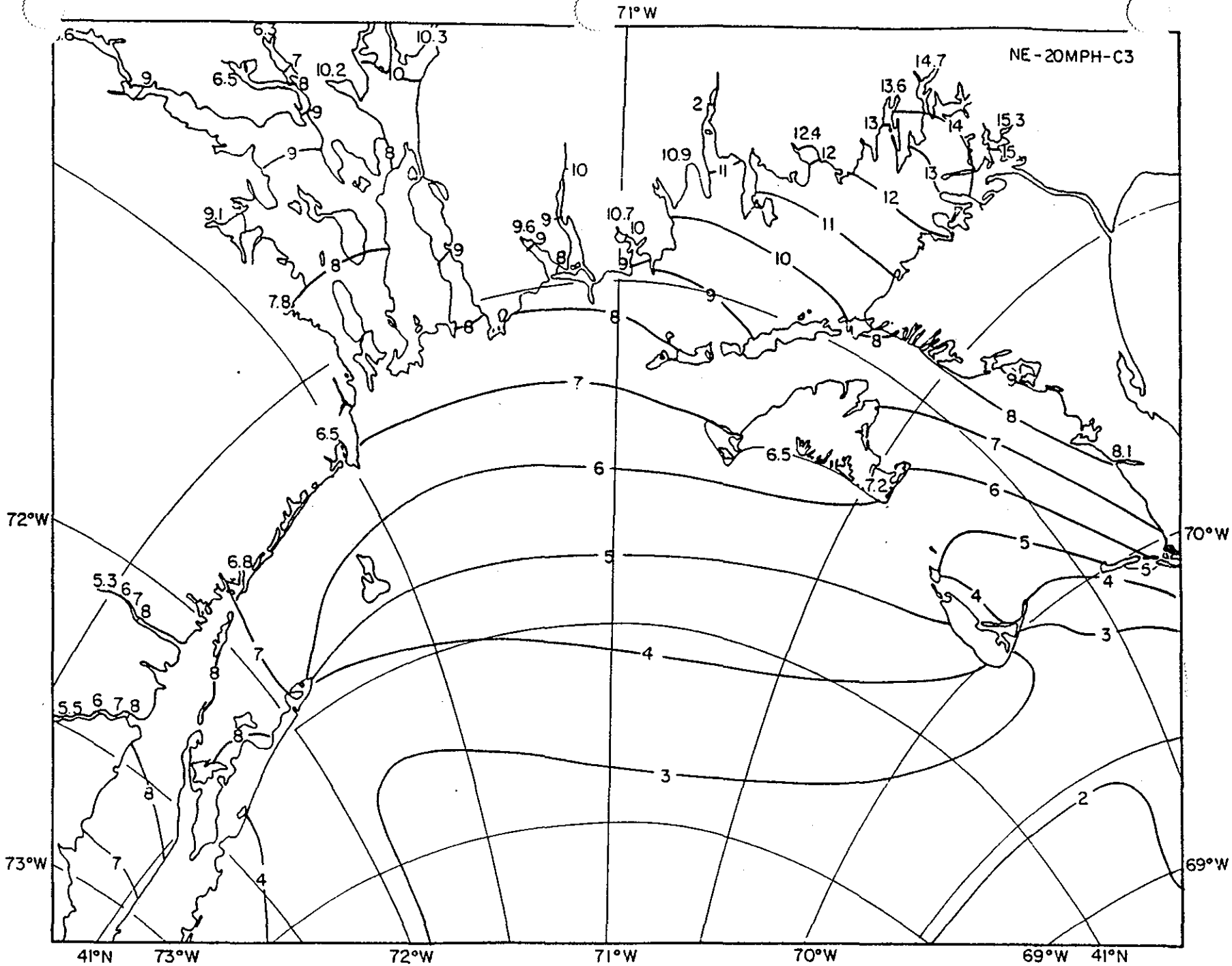
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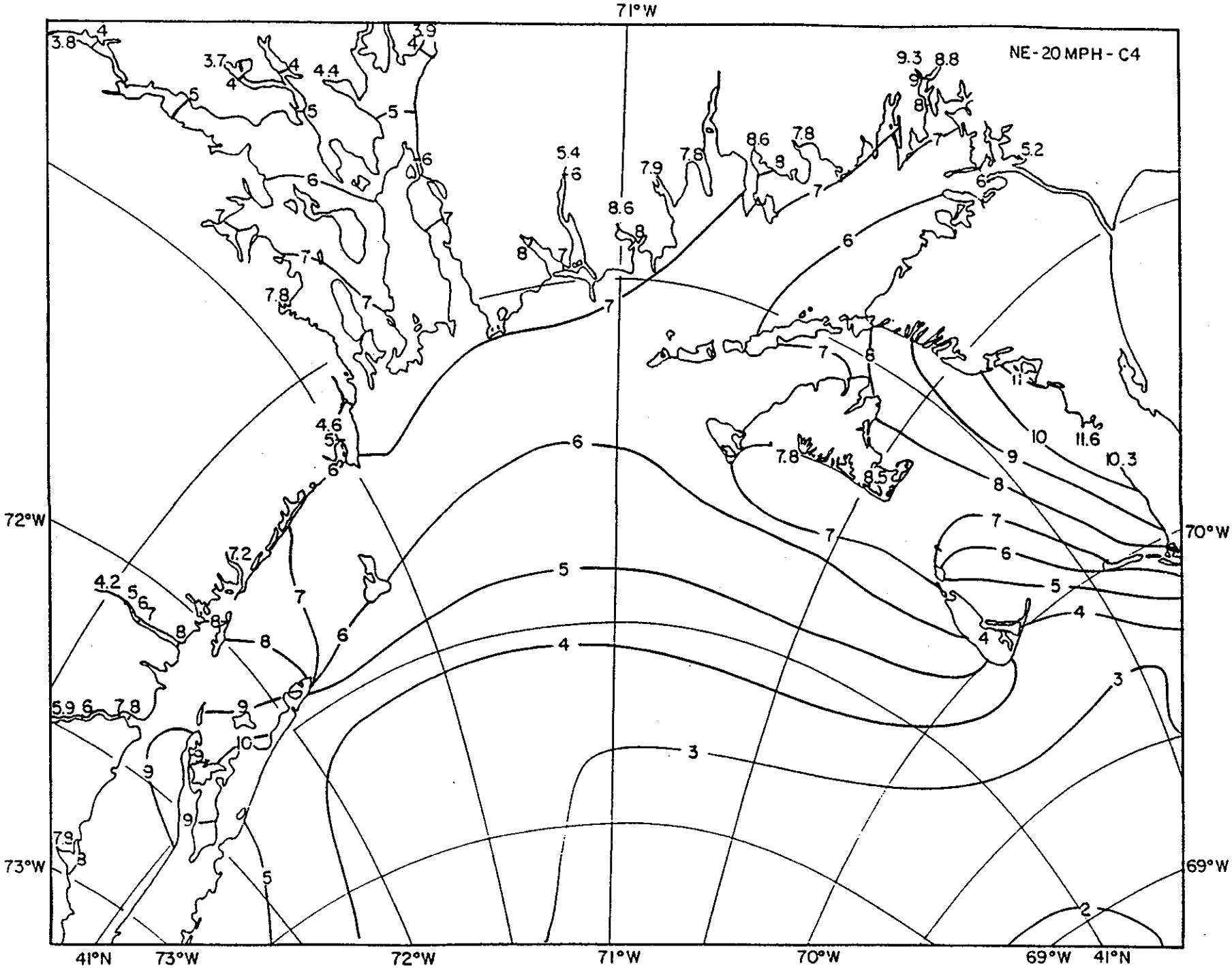
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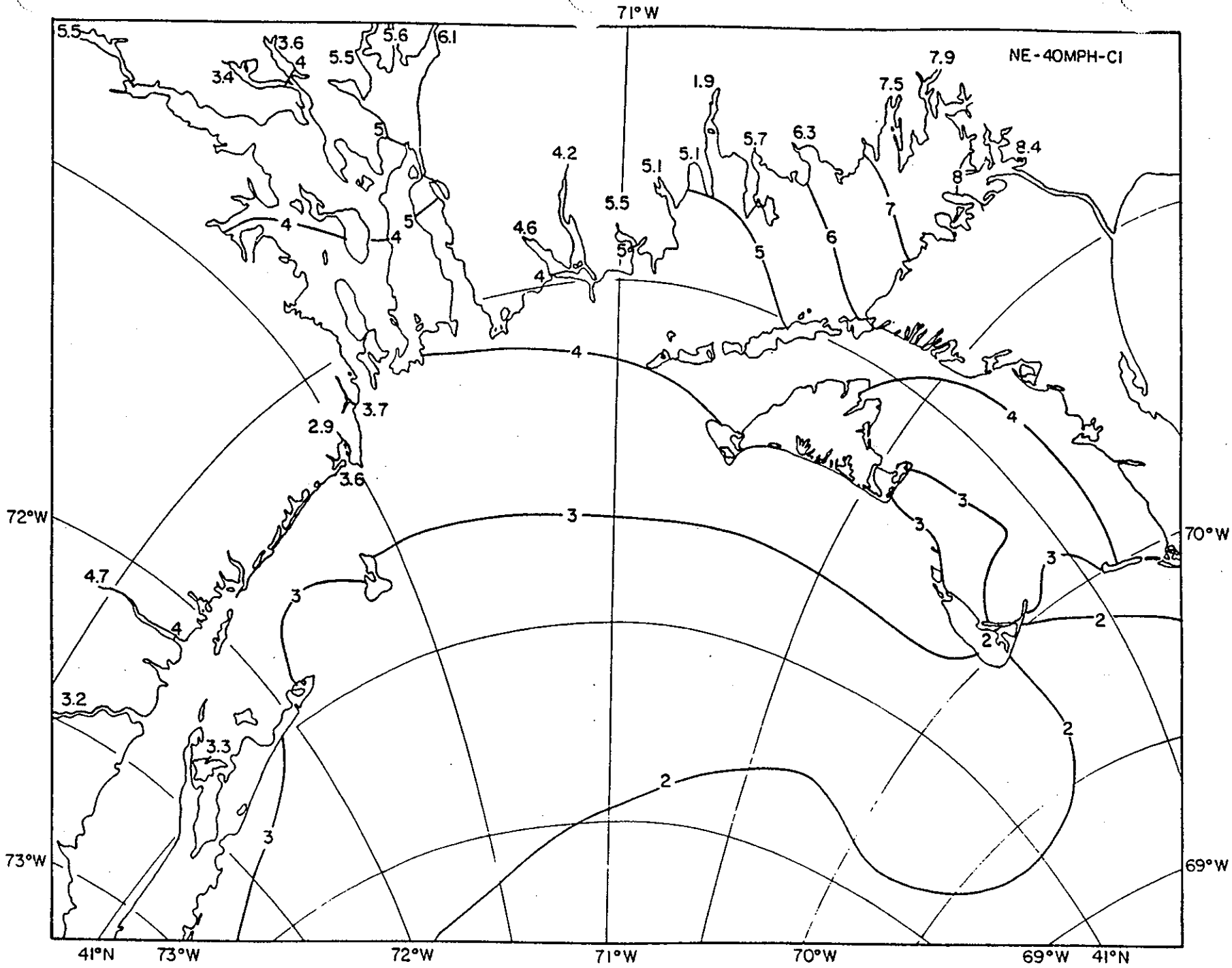
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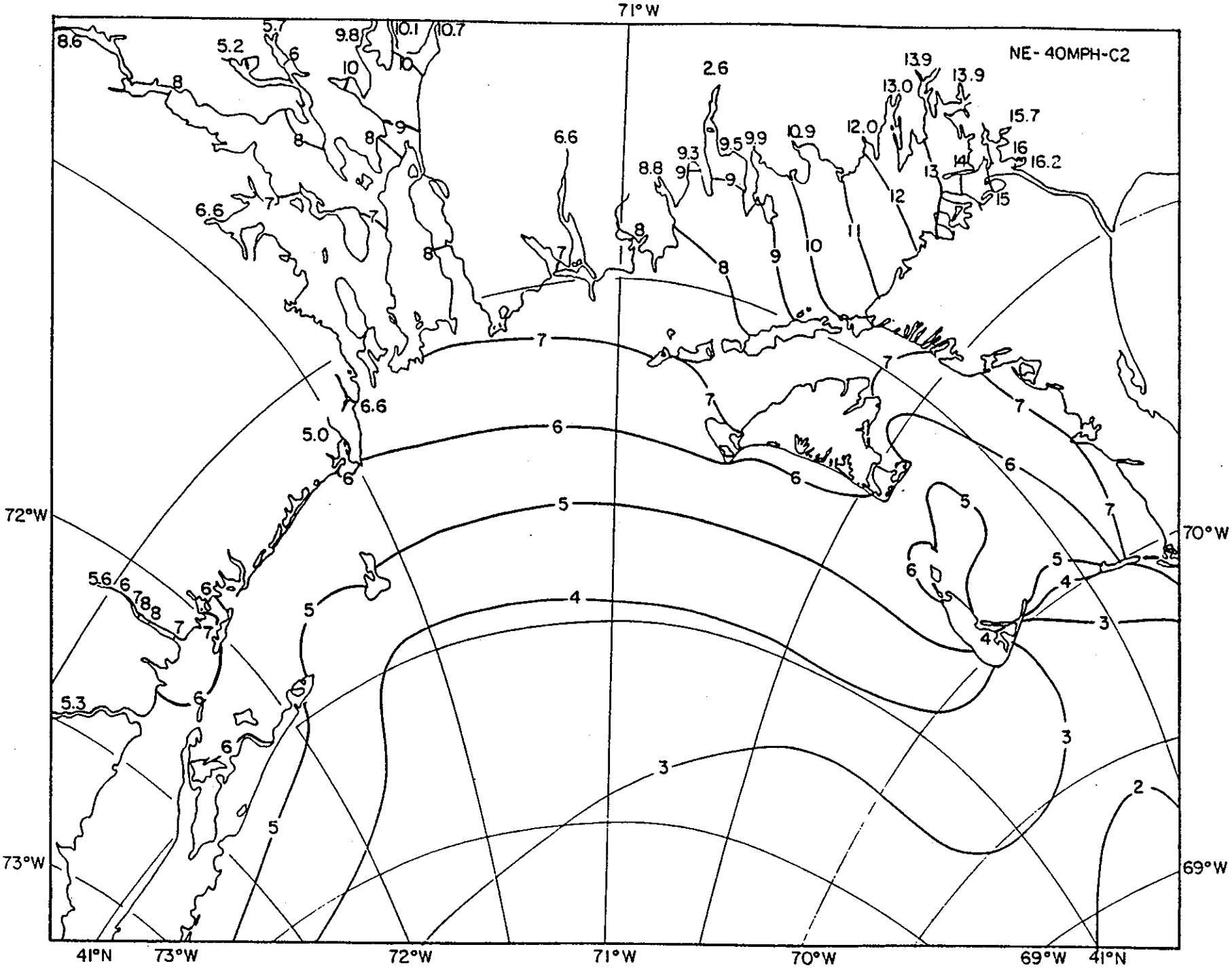
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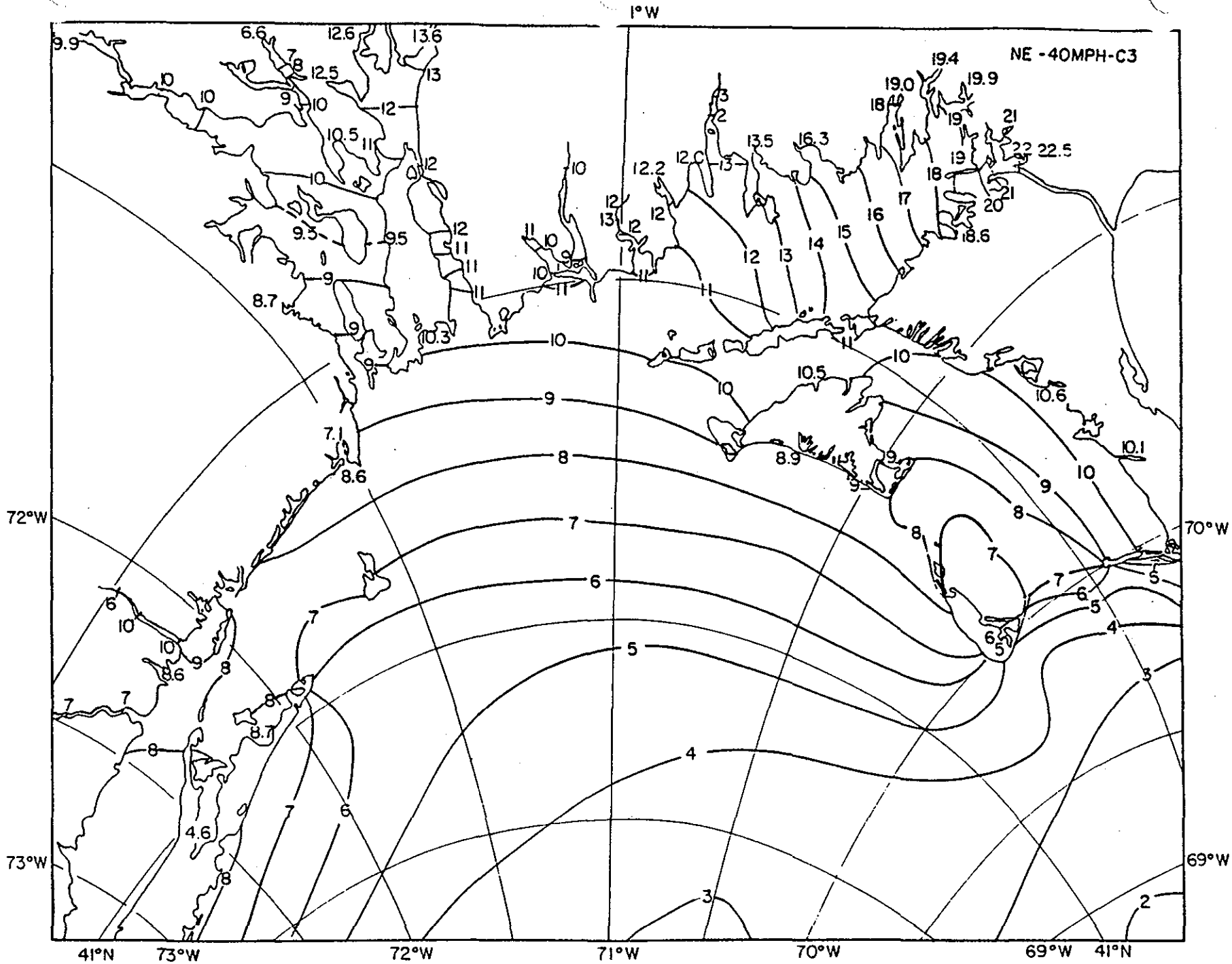
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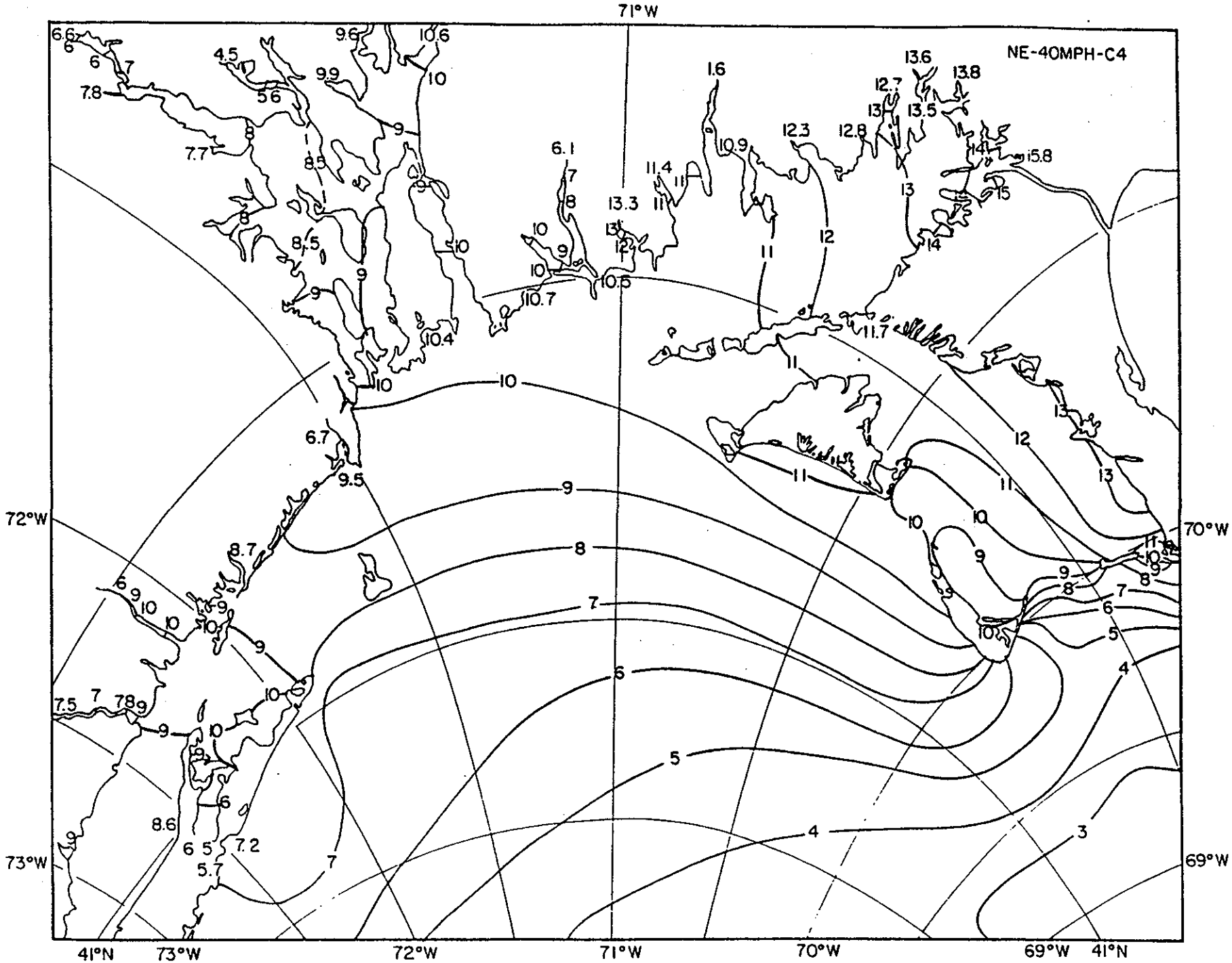
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9. FIGURE CAPTIONS

Figure 1. Grid mesh for SLOSH model for Narragansett/Buzzards Bays basin.

Figure 2. Tracks of hurricanes (1886-1986) passing within 105 miles of Quicksand Point, Rhode Island/Massachusetts: northbound storms only.

Figure 3. Same as Figure 2, but only storms heading north-northeastward.

Figure 4. Same as Figure 2, but only northeastward and east-northeastward moving storms.

Figure 5. Tracks of the hypothetical hurricanes that were used for calculating the maximum envelope of water (MEOW). Hurricane symbol is at point of landfall of eye of storm, and dots are eye positions at 6 hour increments (20 mph). Tracks are identified by the distance in miles of their landfall point to the left side (LS) or right side (RS) of Quicksand Point, Rhode Island/Massachusetts. Storms heading west-northwestward (WNW) only.

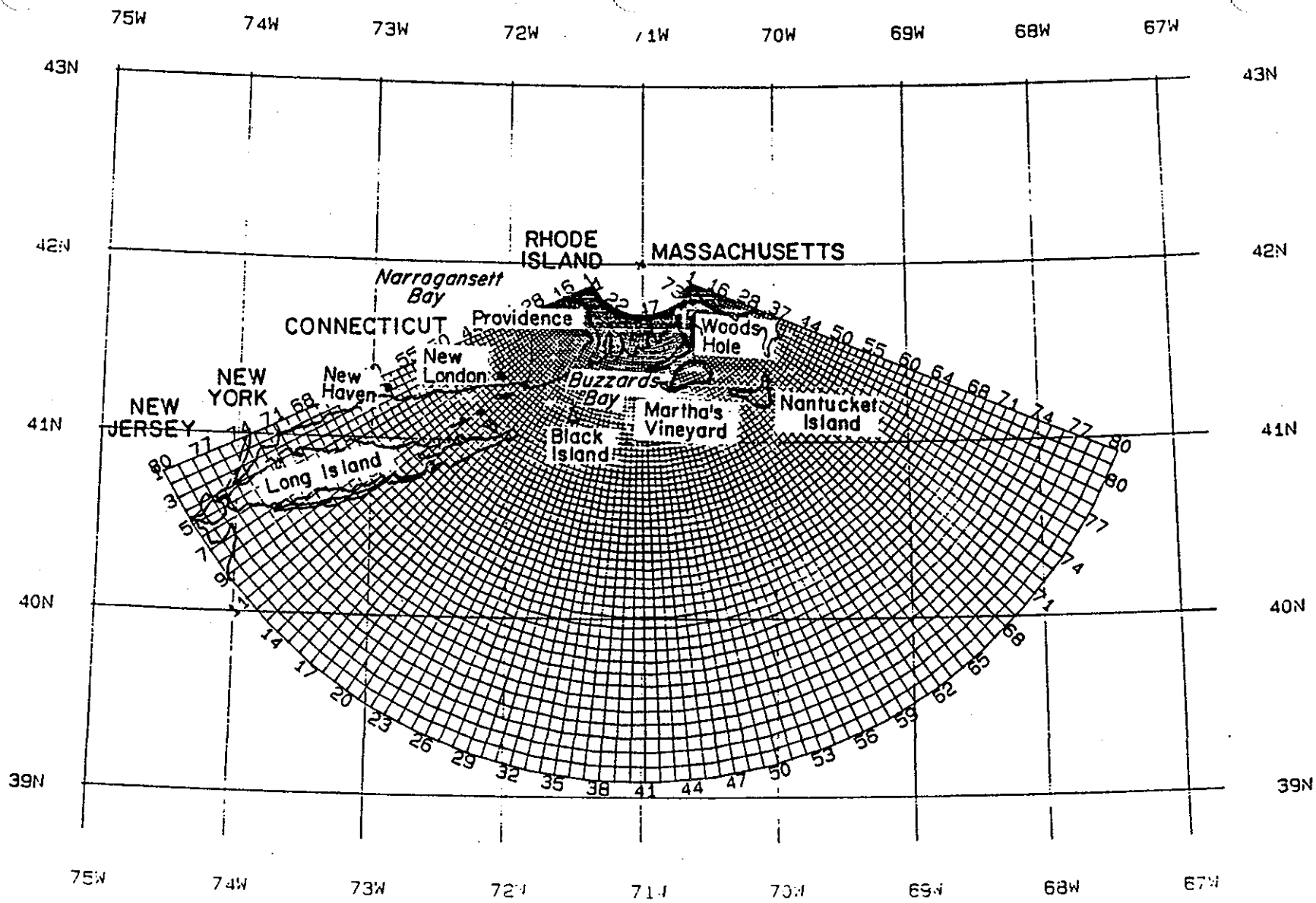
Figure 6. Same as Figure 5, but only for northwestbound (NW) storms.

Figure 7. Same as Figure 5, but only for north-northwestbound (NNW) storms.

Figure 8. Same as Figure 5, except for northbound (N) storms only.

Figure 9. Same as Figure 5, except for north-northeastward (NNE) moving storms only.

Figure 10. Same as Figure 5, except for northeastbound (NE) storms only. "Landfall points" lie on a perpendicular through Quicksand Point.



TRANSVERSE MERCATOR PROJECTION
SCALE 1: 3,400,000
TRUE AT 71W

NARRAGANSETT-BUZZARDS BAYS

FIGURE 1.

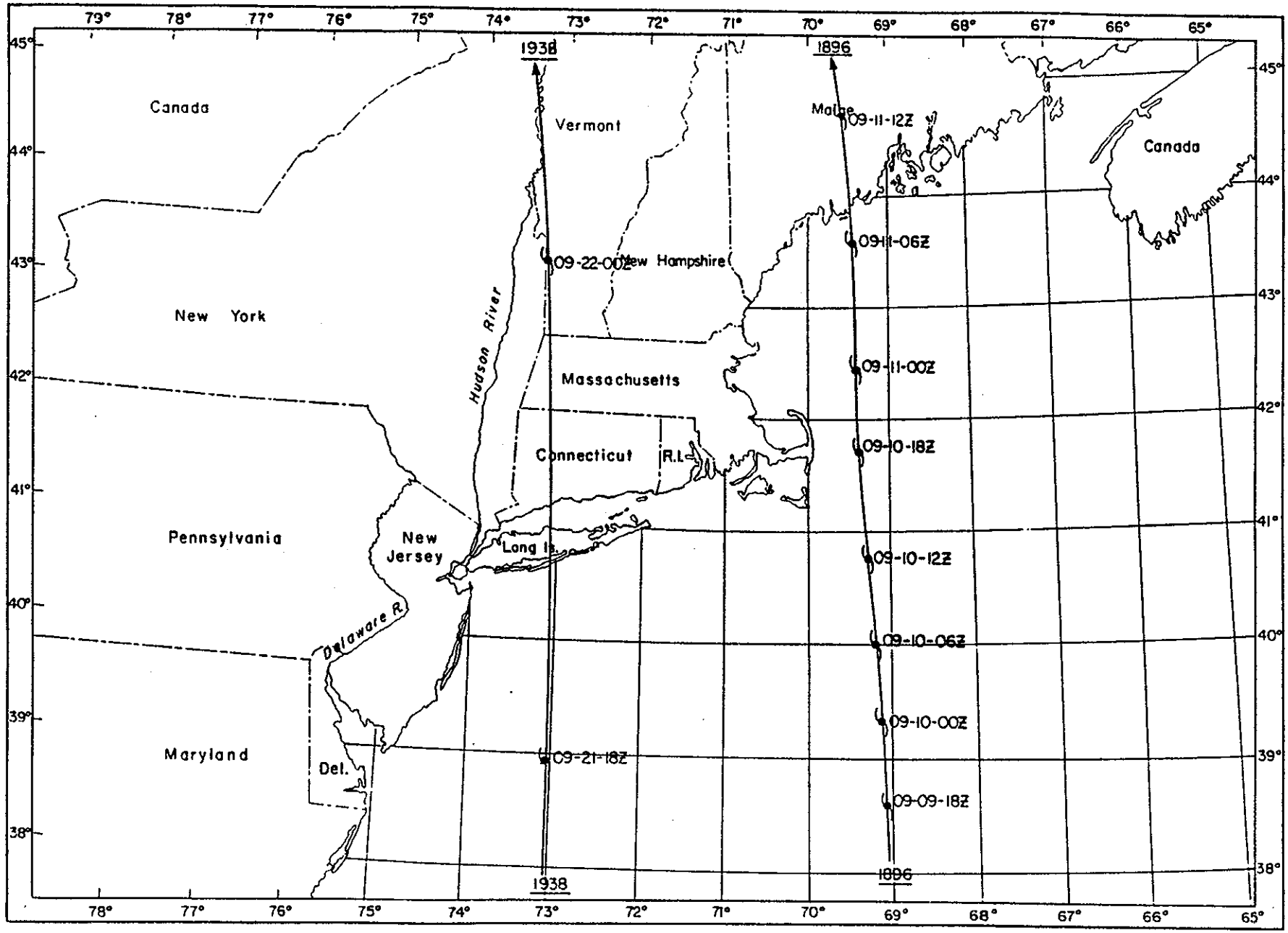

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FIGURE 2.

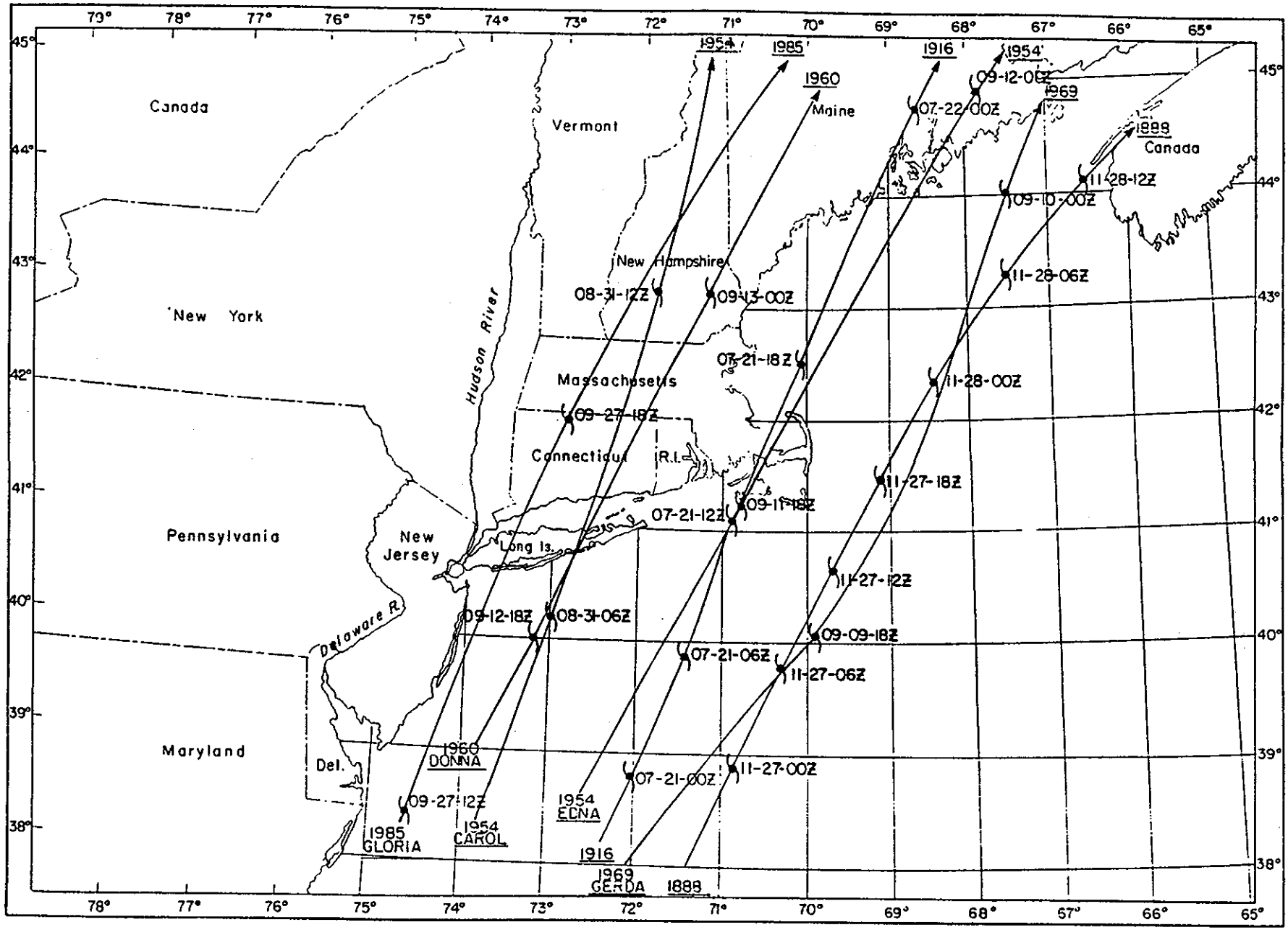
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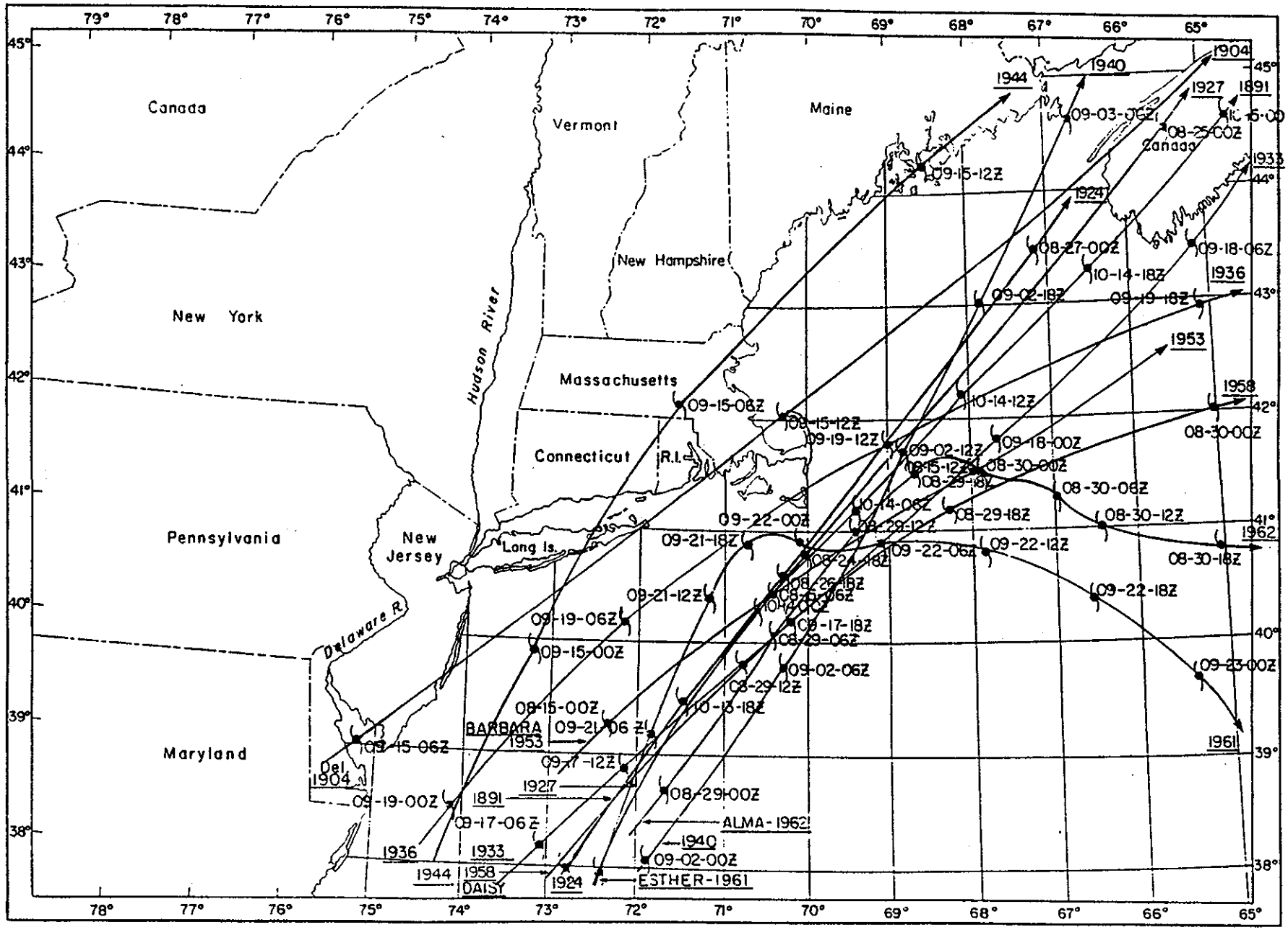
FIGURE 3.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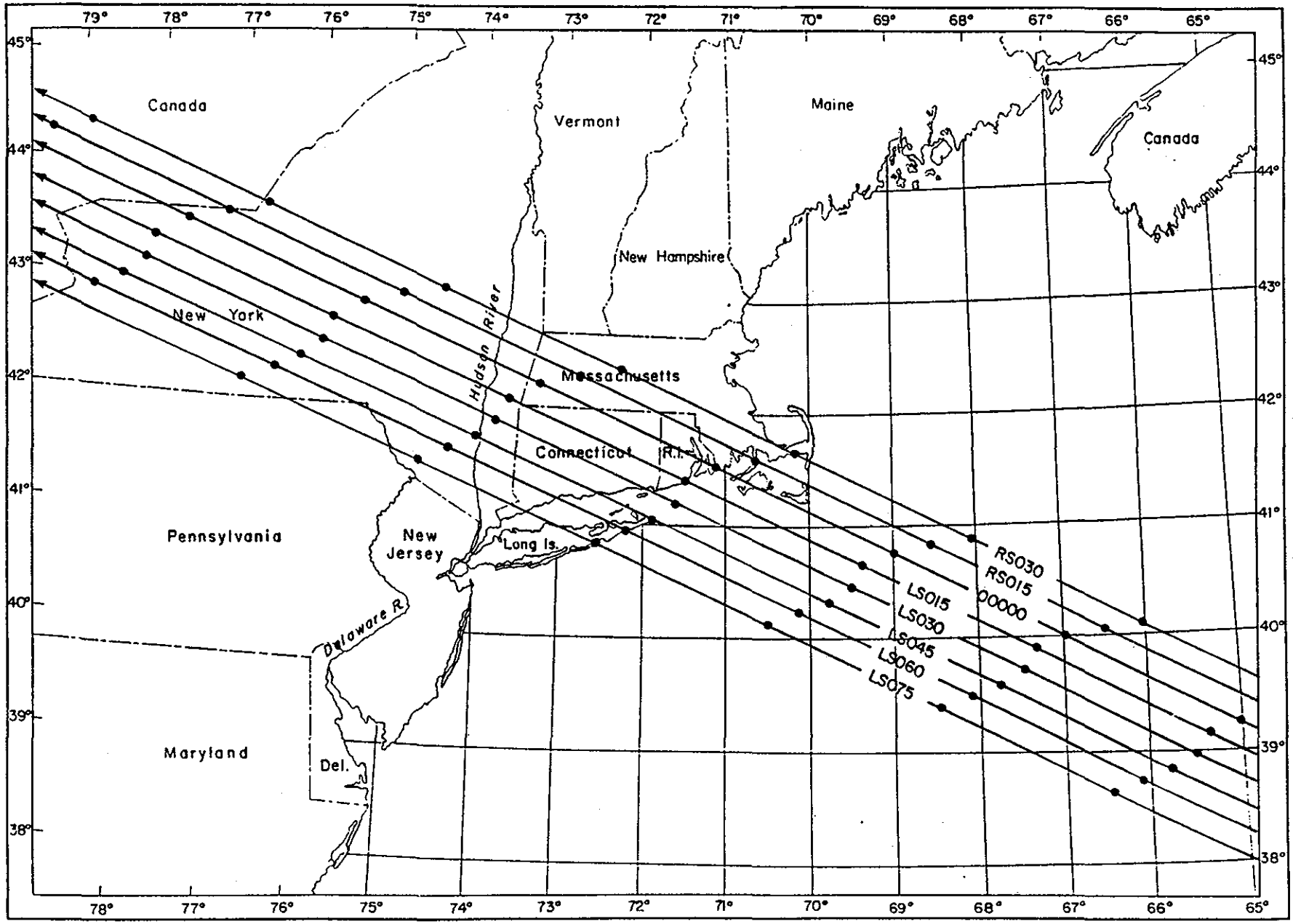
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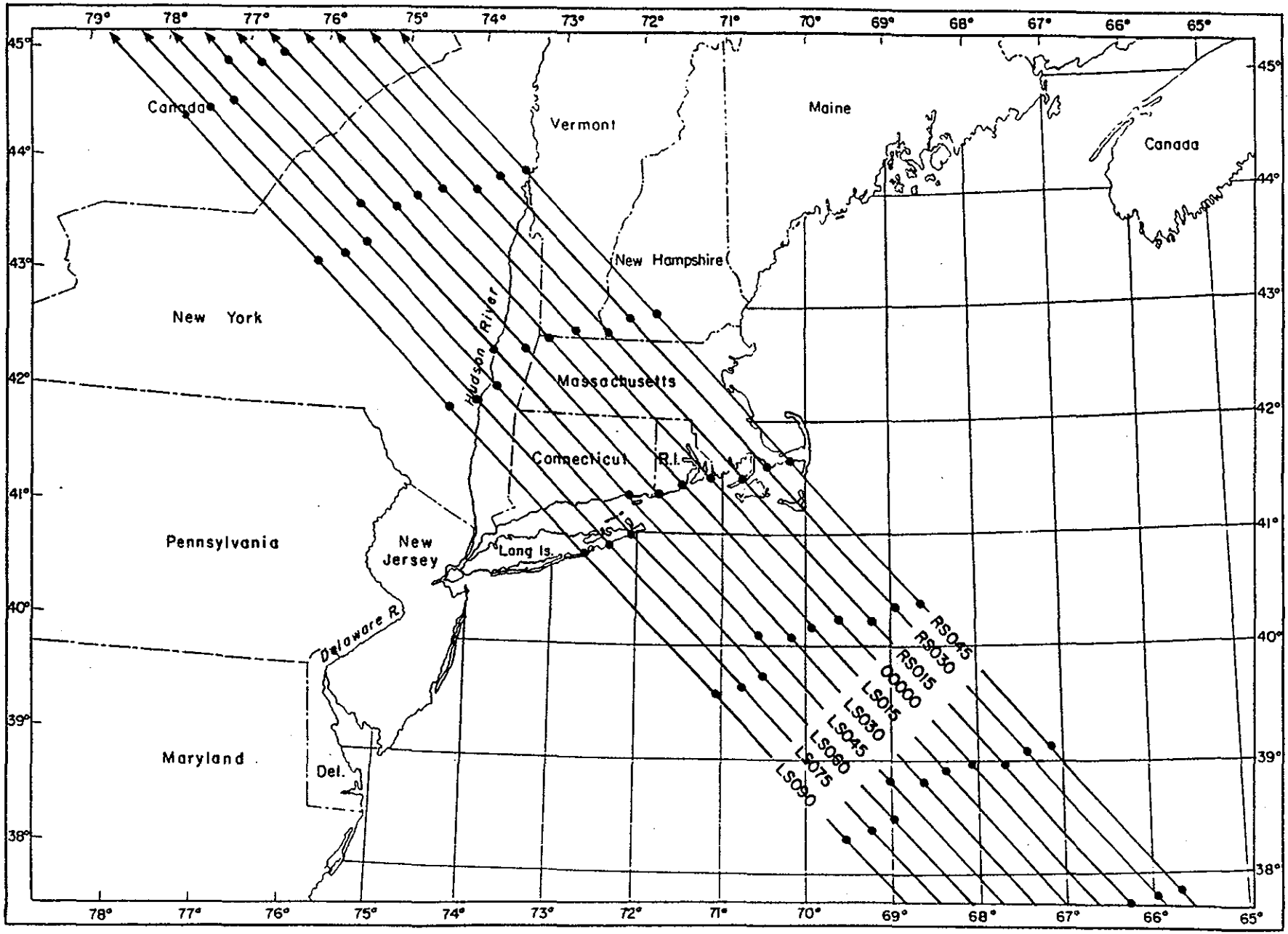
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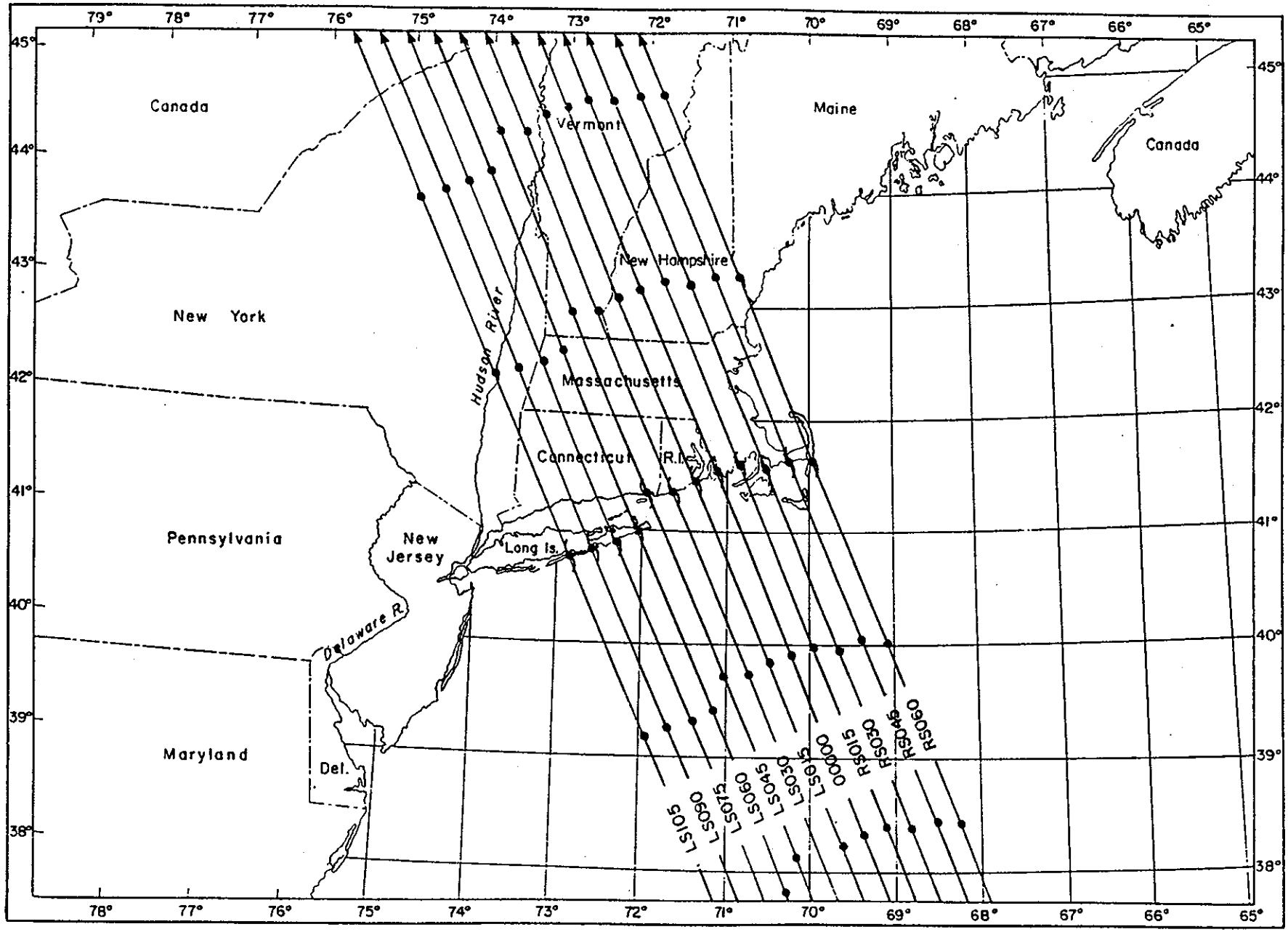
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FIGURE 7.

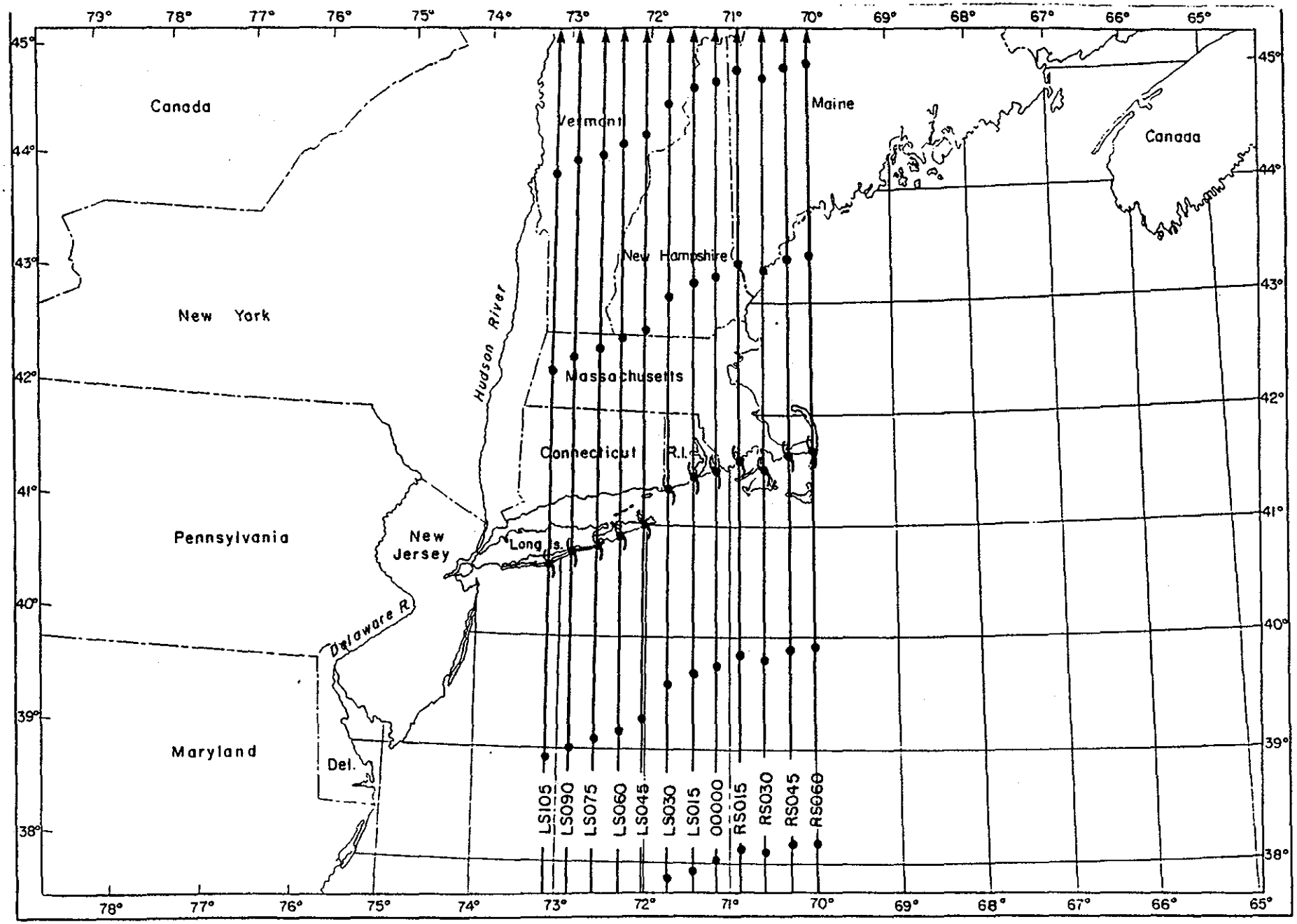
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FIGURE 8.

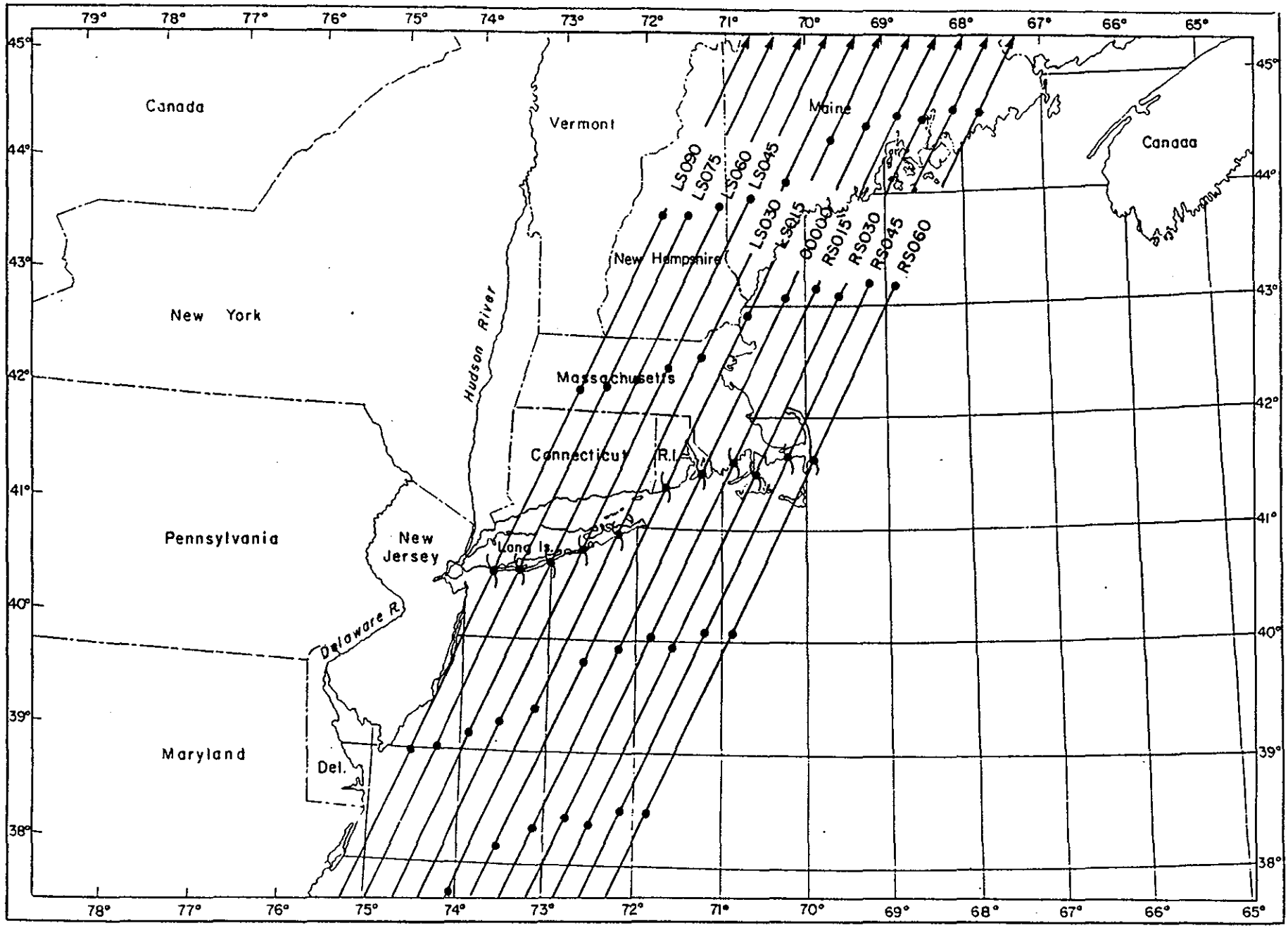
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FIGURE 9.

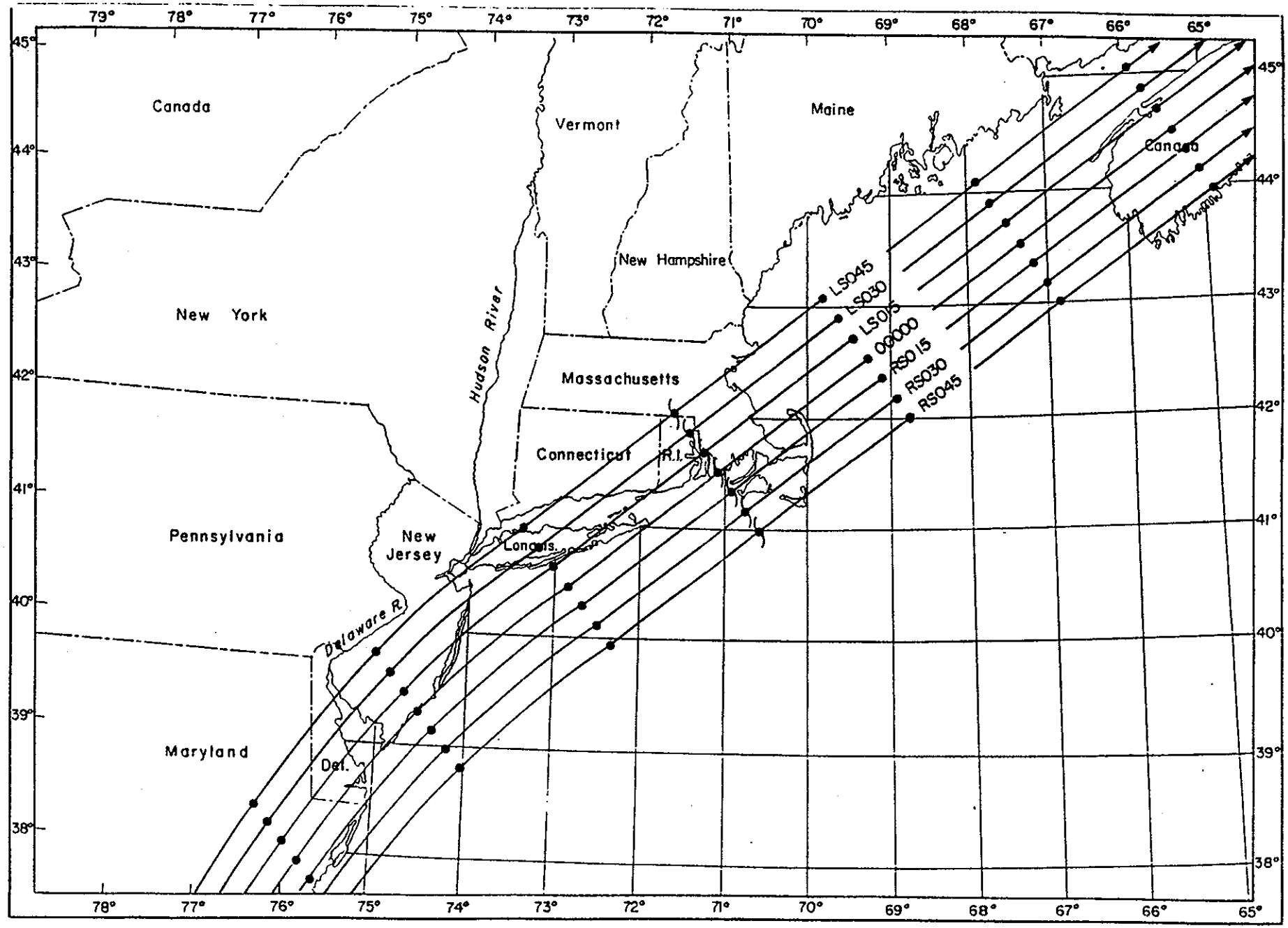
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FIGURE 10.

APPENDIX B

Storm Surge Atlas for the Boston Bay, Massachusetts Area

A STORM SURGE ATLAS FOR THE BOSTON BAY, MASSACHUSETTS AREA

Storm Surge Group
National Hurricane Center
National Oceanic and Atmospheric Administration
Coral Gables, Florida 33146

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1. INTRODUCTION

Storm surge is the abnormal rise in water level caused by wind and pressure forces of a hurricane. Storm surge produces most of the flood damage and drownings associated with tropical storms that make landfall or that closely approach a coastline (Anthes, 1982).

A numerical storm surge model developed by Jelesnianski (1967, 1972), Jelesnianski and Taylor (1973) and Jelesnianski *et al.* (1992) has been applied to the Boston Bay area. The model calculates sea, lake and overland surges from hurricanes and has the acronym "SLOSH." It is a pairing of a model of a hurricane coupled to a model for storm surge. Crawford (1979) discussed some preliminary results using the SLOSH model in the southeast Louisiana region.

The purpose of this atlas is to provide maps of SLOSH-modeled heights of storm surge and extent of flood inundation, for various combinations of hurricane strength, forward speed of storm and direction of storm motion. Strength is modeled by use of the central pressure and storm eye size using four of the five categories of storm intensity (Table 1), developed by Saffir and Simpson (Simpson and Riehl, 1981). Six storm-track headings and two or three speeds were selected as being representative of storm behavior in this region, on the basis of observations by forecasters at NOAA's National Hurricane Center.

The maps in this atlas summarize surge calculations made using the SLOSH model, when initialized with observed values (depths of water and heights of terrain and barriers) in the region centered on the Boston Bay, Massachusetts area.

2. THE GRID FOR THE SLOSH MODEL OF THE BOSTON BAY AREA

Figure 1 illustrates the area covered by the grid for the Boston Bay SLOSH model. The area covered by the grid is called a "basin"--the Boston Bay Basin." The grid is a telescoping polar coordinate system with 80 arc lengths ($1 \leq I \leq 80$) and 65 radials ($1 \leq J \leq 65$). Unlike a true polar coordinate grid, which would have radial increment (ΔR) that was invariant with radius, this grid uses a ΔR that increases with increasing distance from the grid's pole. The result is that in each grid of the mesh, the increment of arc length (ΔS) of the side of a grid "square" is approximately equal to the radial increment of the "square," or $\Delta S \approx \Delta R$.

The telescoping grid is a compromise between conflicting needs. What is desired is that the model domain include a large geographical area, but also that small, detailed topography be included in the model. In a Cartesian coordinate system, this combination of big area, but spatially-small grid increment, requires that a computational mesh with many grid squares be used. A large mesh requires a computer with a large central processing unit as well as more time to perform calculations in the more numerous grid squares. The telescoping grid, by comparison, permits a resolution of these conflicting needs: over land, which is the area of greatest interest, it has an acceptably small spatial resolution. Thus, each grid

Table 1. Saffir/Simpson hurricane intensity categories.

	Central Pressure		Wind Speed		
Category	Millibars	Inches (Hg)	Miles per Hour	Knots	Damage
1	≥ 980	≥ 28.9	74 - 95	64 - 83	Minimal
2	965 - 979	28.5 - 28.9	96 - 110	84 - 96	Moderate
3	945 - 964	27.9 - 28.5	111 - 130	97 - 113	Extensive
4	920 - 944	27.2 - 27.9	131 - 155	114 - 135	Extreme
5	< 920	< 27.2	> 155	> 135	Catastrophic

square closest to the pole (at I=1) represents an area of about 0.2 square miles. This permits inclusion in the model of topographic details such as highway and railroad embankments, causeways, levees, and dikes in harbors. But, with increasing distance from the pole, the range increment and arc lengths which border each grid "square" become progressively larger: at maximum distance from the pole (I=80) each grid square contains about 23 square miles. As a result, a large geographic area is included in the model, so that the effects of the model's boundaries on the dynamics of the storm are diminished and the storm's physics are better emulated.

The telescoping grid has some disadvantages. Primarily, these stem from the distortion that occurs when the basin is remapped onto a display that has constant-sized increments in the vertical and horizontal, as happens when the basin is printed out by a conventional (computer) line printer. This distortion from remapping produces some difficulties in "reading" the results by the uninitiated. For example, neither latitude nor longitude lines remain uncurved and "parallels" become non-parallel. However, the projection is conformal. To surmount these disadvantages, the storm surge results have been reanalyzed onto a conventional map projection. They are presented in the Appendix.

The grid is tangent to the earth at the basin center at 42°37'N and 70°40'W. There, the grid increment is 1.5 statute miles. The pole (or origin) of the grid is located at 41°50'N and 71°22'W.

3. SLOSH MODEL

A. Hurricane Model and Input

The hurricane model which drives the storm surge model was developed by Jelesnianski and Taylor (1973). It is a trajectory model of a stationary vortex and it balances the forces from pressure gradient, centrifugal, Coriolis and surface frictional effects. Adjustments are made to the computed vector wind to incorporate the hurricane's forward motion. The model's input includes the radius of maximum wind (RMW) and the difference (ΔP) in sea-level pressure between the ambient value and the minimum value in the storm's center. Directly measured wind vectors are not used. The model also requires input of the coordinates of the storm's center. Thus, input data include 13 sets of latitude, longitude, ΔP and RMW, at six-hour increments, beginning 48 hours before storm landfall and ending 24 hours after landfall. These 13 sets are then linearly interpolated into values/positions at hourly (or smaller) time increments. The model then generates the meteorological forces--surface stress and the gradient of atmospheric pressure--that drive the underlying ocean.

B. Storm Surge Model

Storm surge is the response by the ocean to meteorological forces. The model's governing equations are those given by Jelesnianski (1967), except now for the inclusion of the finite amplitude effect.

Coefficients for surface drag, eddy viscosity and bottom slip are the same as those used in an earlier model (Jelesnianski, 1972). There is no calibration or tuning to force agreement between observed and computed surges; coefficients are fixed, and do not vary from one geographical region to another.

Special techniques are incorporated to model two-dimensional inland inundation, routing of surges inland when barriers are overtopped, the effect of trees, the movement of the surge up rivers, and flow through channels, cuts and over submerged sills. Besides surge, other processes affect water height (section 4B), but are not incorporated in the model.

Not surprisingly, the accuracy of modeled surge values increases as the accuracy of the input terrain and storm data improves.

4. OUTPUT AND INTERPRETATION OF THE MODEL RESULTS

A. Output from the SLOSH Model

The output for the Boston Bay "SLOSH" model consists of maps of water heights. At each grid point, the water height is the maximum value that was computed at that point during the 72 (maximum) hours of model time. Thus, the map displays the highest water levels and does not display events at any particular instant in time. The analyzed envelopes of high water show shaded areas that represent dry land which has been inundated and contours of high water relative to mean sea level (MSL). Height of water above terrain was not calculated because terrain height varies within a grid square. For example, the altitude of a grid square may be assigned a value of 6-ft MSL, but this value represents an average of land heights that may include values ranging from 3 ft to 9 ft MSL. In this case, a surge value of 8 ft in this square, implying 2 ft average depth of water over the grid's terrain, would include some terrain without inundation and other parts with as much as 5 ft of overlying water. Therefore, the depth of surge flooding above terrain at a specific site in the grid square is deduced by subtracting the actual terrain height from the model-generated storm surge height in that square.

Besides maps, printout lists of values of surge height, wind speed and wind direction for each of 70 sites are supplied. The values of wind speed and direction are ten-minute averages, every 30 minutes. These are useful for determining the time of onset of gale force winds and rates of change of surge heights, for evacuation planning.

B. Interpretation of Results

Even if the model is supplied accurate data on storm positions, intensities and sizes, the computed surges may contain errors of ±20% of observed water levels. These primarily stem from:

(1) Maps that are outdated: The maps used to initialize the model with heights of terrain and depths of water sometimes did not include changes, often man-made, that had been made to the heights and

positions of barriers (e.g., highway and railway embankments) and depths and locations of channels. Inaccuracies of topography or bathymetry will contribute directly to errors in the modeling of all storm surges.

(2) Anomalous water heights: Sea level can be at an altitude different from "mean sea level," days or even weeks before a storm is actually affecting a basin. The value of the actual, local sea level--the "local datums" for pre-storm anomaly in Boston Bay and the Atlantic Ocean--must be supplied to the model, before calculations are initiated.

(3) Local processes, such as waves, astronomical tides, rainfall and flooding from overflowing rivers: These processes are often included in "observations" of storm surge height, but are not surge and are not calculated by the SLOSH model.

Factors such as the foregoing must be considered when comparisons are made between modeled and observed values of storm surge.

5. HURRICANE CLIMATOLOGY

A. Tracks

Between 1886 and 1993, 20 tropical cyclones of hurricane intensity passed within 125 statute miles of Boston, Massachusetts (Neumann *et al.*, 1987), for an average of one hurricane within the 125-mile circle every 5.4 years (see Table 2).

The tracks of these 20 storms with hurricane force winds are displayed as follows: storms heading north are in Figure 2; north-northeast moving storms are in Figure 3; and north moving storms are in Figure 4. In Figures 2-4, the tracks are labelled at six-hour intervals, with month/day/hour (GMT).

The tracks represent "best estimates" and are based on a variety of data sources. Historically, storm location, motion and strength were only inferred, from analyses of wind, pressure and cloud observations made at ships and land stations being influenced by the storm. In 1943, aircraft reconnaissance of hurricanes began. Not until 1959 were there land-based weather radars, as now at Chatham, Massachusetts, New York City, or Portland, Maine, which could be used to observe and record structure, development and motion of precipitation fields, and help infer center location and radius of maximum winds. The 1960's saw the advent of surveillance of tropical storms from weather satellites. Observations by aircraft, radar and satellite have shown that the tracks of centers of hurricanes contain wobbles, gyrations and cycloidal motions (Lawrence and Mayfield, 1977) and that there often are rapid changes in size and intensity of rain bands, contractions of eyewall diameter and formation of concentric ("double") eyewalls. These factors, poorly documented even today, indicate asymmetries in the storm's dynamical structure and can affect the storm's surge. But they usually are smoothed out of analyses, as in Figures 2-4.

Table 2. Hurricanes passing within 125 statute mile circle centered on Boston, Massachusetts (42.4°N, 71.0°W), during 1886-1993.

>>> At Closest Point of Approach: (@CPA) <<<									
Index (1)	Date (@CPA) (2)	Storm Name (3)	Range/Bearing (Miles/Degrees) (To CPA) (4)	/	(5)	Wind (In Circle) (mph) (6)	Storm Motion (@CPA) (Dir / mph) (7)	/	(8)
1	1888 Nov 27	Unnamed	114	/	120	98	NNE	/	11
2	1891 Oct 14	Unnamed	114	/	133	98	NE	/	15
3	1893 Aug 24	Unnamed	97	/	302	90	NNE	/	24
4	1893 Aug 29	Unnamed	82	/	313	74	NE	/	37
5	1896 Sep 10	Unnamed	82	/	092	107	N	/	10
6	1904 Sep 15	Unnamed	44	/	124	75	NE	/	61
7	1916 Jul 21	Unnamed	39	/	124	89	NNE	/	18
8	1924 Aug 26	Unnamed	101	/	120	102	NE	/	43
9	1927 Aug 24	Unnamed	107	/	124	104	NE	/	58
10	1936 Sep 19	Unnamed	88	/	147	92	NE	/	32
11	1938 Sep 21	Unnamed	108	/	282	86	N	/	51
12	1940 Sep 2	Unnamed	122	/	111	81	NNE	/	21
13	1944 Sep 15	Unnamed	13	/	345	81	NE	/	37
14	1954 Aug 31	Carol	53	/	290	94	NNE	/	35
15	1954 Sep 11	Edna	48	/	136	94	NNE	/	50
16	1960 Sep 12	Donna	31	/	302	98	NNE	/	39
17	1961 Sep 26	Esther	147	/	102	124	N	/	27
18	1962 Aug 29	Alma	123	/	130	92	NE	/	9
19	1985 Sep 27	Gloria	70	/	280	86	NNE	/	48
20	1991 Aug 19	Bob	12	/	135	100	NNE	/	32

Notes:

(1) Storm number for this list.

(2) Year, month and date that storm had maximum winds exceeding 74 mph and was closest to center of Boston, Massachusetts.

(3) Storms were not formally named before 1950.

(4)-(5) Distance (statute miles) and direction (degrees) from center of Boston, Massachusetts to storm when it passed abeam.

(6) Maximum sustained wind speed near storm center while center was within 125 statute miles from center of Boston, Massachusetts. This is not necessarily the wind recorded at a given site.

(7)-(8) Storm heading and forward speed (mph) at hour of closest point of approach.

B. Intensities

Hurricane intensity is usually defined by measurements at sea level of the maximum sustained wind speed and/or by minimum barometric pressure. Neither of these is easily obtained. Accurate estimates of these parameters at sea level were acquired only when a ship or land station was traversed by the storm's "eye." Minimum central pressure was gotten only when a barometer was in the precise path of the storm's center. Because the area covered by the strongest winds is much larger than that covered by the pressure minimum, strength of many older storms was deduced from measurements of wind speed. However, with the advent of aircraft reconnaissance, measurements made at flight level of meteorological parameters allow the calculation of barometric pressure at sea level. By comparison, winds at sea level are not so readily deduced from flight level data. For all the storm tracks in Figures 2-4, an estimate was made of the maximum wind speed at intervals of six hours. For some, only very indirect evidence exists of actual speeds. From the hourly values of the maximum wind speed inside the 125 mile circle, the largest value was selected. This maximum sustained wind speed for the hurricane is listed in Table 2 under the heading of "wind (in circle)." Storm heading and forward speed at hour of closest point of approach are listed in the last two columns.

The values listed in column 6 sometimes are poor estimates of the maximum wind speed; the following must be considered:

(1) Actual wind speeds and directions exhibit gustiness.

(2) The "average wind speed" has been calculated with a variety of time intervals over the years; thus, one can find historical wind records that have used time periods such as 1 hour, or 10 or 5 minutes or 1 minute as the "standard" period of measurement. Given the same record from a recording anemometer, the use of each of these measurement periods would likely yield a different average wind speed, with shorter periods probably giving higher average speeds.

(3) The platforms for measuring maximum surface wind speed have changed over the years; data from ship and land stations now are supplemented by remotely-sensed data from aircraft, satellites and radar. However, the remote platforms, especially the last two, observe the motions of clouds or precipitation echoes, and these motions are not wind speed, nor are they at sea level.

Because of these limitations in determination of maximum wind speed, the SLOSH model uses storm-center, sea-level pressure as a measure of storm intensity in modeling the Boston Bay basin.

6. MAPS OF MAXIMUM ENVELOPE OF WATER ("MEOW") FROM SLOSH RUNS USING DATA FOR HYPOTHETICAL HURRICANES

A. Hypothetical Storm Tracks and Populations

The skill of the SLOSH model was evaluated by Jarvinen and Lawrence (1985), who compared modeled and observed surges at 523 sites during 10 hurricanes. They found that the mean absolute error in surge height calculated by SLOSH was 1.4 ft. Although the error range was from -7.1 ft to +8.8 ft, the standard deviation was only 2.0 ft and 79% of the errors lay within one standard deviation of the mean error, -0.3 ft. (On the average, modeled values were slightly less than those observed.)

Because of this skill in calculating storm surge, the SLOSH model was used to create maps of surge flooding in the Boston Bay basin for use in evacuation planning. The model was supplied with data from hypothetical storms and the resulting surge calculations were composited to produce maps of the maximum envelope of water. This section describes why these calculations were made and how the compositing was done.

Storm surge height partly depends on distance between the location of a particular site and the storm's center. For a single storm, the model would produce a map of surge height for the modeled period of time (usually 72 hours), with values valid for only that particular storm track. If there were two storms, identical in every respect except that one followed a track parallel to, but separated from the other by 50 miles,[1] and if the model was run with first one and then the other set of storm parameters, and a comparison made of surge values, then very likely there would be geographical sites having surge values from one storm differing markedly from those modeled for the other storm. This dependency of surge height on storm track can be troublesome when preparing plans for emergency evacuation. Maps are needed for basin-wide surge flooding potential--maps showing surge height for each one of the combinations of storm intensity, storm speed and storm direction. We created such maps for this basin by making surge calculations for each of an ensemble of 9 to 13 storms; in an ensemble, all storms had the same intensity and speed and had parallel headings, separated by 15 miles. Then at each grid square, the maximum surge value that was calculated from any storm in the ensemble was extracted and saved. After this procedure was performed for all grid squares, the result was a basin map depicting the "maximum envelope of water," or MEOW, for the specified storm category, direction and speed. For the Boston Bay basin, the hypothetical storms were specified to move in one of six directions, at 20 mph,

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[1]A difference ("error") of 50 miles in storm track is not very large when compared to the vagaries of tracks of real hurricanes. The average error or 12-hour forecast landfall position, for U.S. Atlantic coast tropical cyclones, during 1970-1979, was about 59 statute miles, while for 24-hour forecasts, landfall position error was about 125 statute miles (Neumann and Pelissier, 1981). Thus, if a storm were forecast to make (eye) landfall at Boston, Massachusetts, in 24 hours, and if, in fact, it made landfall *anywhere* between New Haven, Connecticut and Boothbay Harbor, Maine, the error in forecast landfall position would be no worse than average.

40 mph, or 60 mph, as summarized in Table 3. There were 13 tracks for the west-northwestward (WNW) moving storms (Figure 5), 12 tracks for the northwestbound (NW) storms (Figure 6), 10 tracks for the north-northwestward (NNW) moving storms (Figure 7), 9 tracks for the northbound (N) storms (Figure 8), 9 tracks for the north-northeastward (NNE) moving storms (Figure 9), and 10 tracks for the northeastward (NE) storm headings (Figure 10). In total, 516 hypothetical storms were run with the SLOSH model to create the results to be presented below. The selection of intensities, directions and speeds was based on advice of hurricane specialists at NOAA's National Hurricane Center.

B. Intensities and Radii of Maximum Winds of Hypothetical Storms

Most hurricanes weaken after making landfall because the central pressure increases (the storm "fills") and the RMW tends to increase. Table 4 summarizes pressure filling and RMW increases with time. These rates of change were based partly on the work of Schwerdt *et al.* (1979).

C. Initial Water Height

Based on observations from tide gauges in the area of this basin, tidal anomalies of about +2 ft MSL before arrival of a hurricane are not uncommon. Furthermore, to simulate conditions at high tide, an additional 3 ft was included. Thus, all SLOSH runs of hypothetical hurricanes were supplied with initial datums of +5 ft MSL, and the resulting calculations of storm surge represent conditions at time of high tide.

D. The "MEOW" Figures

There are 52 MEOWS presented in the Appendix. They are grouped by direction: west-northwestbound storms' MEOWS are in Figures A1-A4, northwestbound storms' MEOWS are in Figures A5-A8, north-northwestbound storms' MEOWS are in Figures A9-A20, MEOWS for northbound storms are in Figures A21-A32, Figures A33-A44 depict MEOWS for north-northeastbound storms, and northeast-moving storms' MEOWS are in Figures A45-A52. In the figures, the contours represent the height of water above mean sea level, in 1-ft increments, while the shaded areas indicate land areas that were modeled to have been inundated.

Table 3. Boston Bay basin's hypothetical storms: Directions, speeds, (Saffir/ Simpson) intensities, number of tracks, number of runs, and number of MEOWS.

Direction	Speed (mph)	Intensities	Tracks	Runs	MEOWS
WNW	20, 40	1 and 2	13	52	4
NW	20, 40	1 and 2	12	48	4
NNW	20, 40, 60	1 through 4	10	120	12
N	20, 40, 60	1 through 4	9	108	12
NNE	20, 40, 60	1 through 4	9	108	12
NE	20, 40	1 through 4	10	80	8
			Totals:	516	52

Table 4. Time change of pressure difference and radius of maximum wind for hypothetical hurricanes in Boston Bay basin.

Values of pressure difference (ΔP, millibars) and radius of maximum wind (RMW, statute miles), beginning at time of landfall (LF) of center of storm and every six hours after LF.

	Landfall		LF + 6		LF + 12		LF + 18		LF + 24	
Category	ΔP	RMW	ΔP	RMW	ΔP	RMW	ΔP	RMW	ΔP	RMW
1	20	30	14	30	10	30	10	35	10	40
2	40	30	31	30	22	30	13	35	10	40
3	60	30	48	30	36	30	24	35	12	40
4	80	30	65	30	50	30	35	35	20	40

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8. APPENDIX: MAXIMUM ENVELOPES OF WATER (MEOW)

Figure	MEOW
A-1	West-northwestbound, 20 mph, category 1 hurricane.
A-2	West-northwestbound, 20 mph, category 2 hurricane.
A-3	West-northwestbound, 40 mph, category 1 hurricane.
A-4	West-northwestbound, 40 mph, category 2 hurricane.
A-5	Northwestbound, 20 mph, category 1 hurricane.
A-6	Northwestbound, 20 mph, category 2 hurricane.
A-7	Northwestbound, 40 mph, category 1 hurricane.
A-8	Northwestbound, 40 mph, category 2 hurricane.
A-9	North-northwestbound, 20 mph, category 1 hurricane.
A-10	North-northwestbound, 20 mph, category 2 hurricane.
A-11	North-northwestbound, 20 mph, category 3 hurricane.
A-12	North-northwestbound, 20 mph, category 4 hurricane.
A-13	North-northwestbound, 40 mph, category 1 hurricane.
A-14	North-northwestbound, 40 mph, category 2 hurricane.
A-15	North-northwestbound, 40 mph, category 3 hurricane.
A-16	North-northwestbound, 40 mph, category 4 hurricane.
A-17	North-northwestbound, 60 mph, category 1 hurricane.
A-18	North-northwestbound, 60 mph, category 2 hurricane.
A-19	North-northwestbound, 60 mph, category 3 hurricane.
A-20	North-northwestbound, 60 mph, category 4 hurricane.
A-21	Northbound, 20 mph, category 1 hurricane.
A-22	Northbound, 20 mph, category 2 hurricane.
A-23	Northbound, 20 mph, category 3 hurricane.
A-24	Northbound, 20 mph, category 4 hurricane.
A-25	Northbound, 40 mph, category 1 hurricane.
A-26	Northbound, 40 mph, category 2 hurricane.
A-27	Northbound, 40 mph, category 3 hurricane.
A-28	Northbound, 40 mph, category 4 hurricane.
A-29	Northbound, 60 mph, category 1 hurricane.
A-30	Northbound, 60 mph, category 2 hurricane.
A-31	Northbound, 60 mph, category 3 hurricane.
A-32	Northbound, 60 mph, category 4 hurricane.

A-33 North-northeastbound, 20 mph, category 1 hurricane.

A-34 North-northeastbound, 20 mph, category 2 hurricane.

A-35 North-northeastbound, 20 mph, category 3 hurricane.

A-36 North-northeastbound, 20 mph, category 4 hurricane.

A-37 North-northeastbound, 40 mph, category 1 hurricane.

A-38 North-northeastbound, 40 mph, category 2 hurricane.

A-39 North-northeastbound, 40 mph, category 3 hurricane.

A-40 North-northeastbound, 40 mph, category 4 hurricane.

A-41 North-northeastbound, 60 mph, category 1 hurricane.

A-42 North-northeastbound, 60 mph, category 2 hurricane.

A-43 North-northeastbound, 60 mph, category 3 hurricane.

A-44 North-northeastbound, 60 mph, category 4 hurricane.

A-45 Northeastbound, 20 mph, category 1 hurricane.

A-46 Northeastbound, 20 mph, category 2 hurricane.

A-47 Northeastbound, 20 mph, category 3 hurricane.

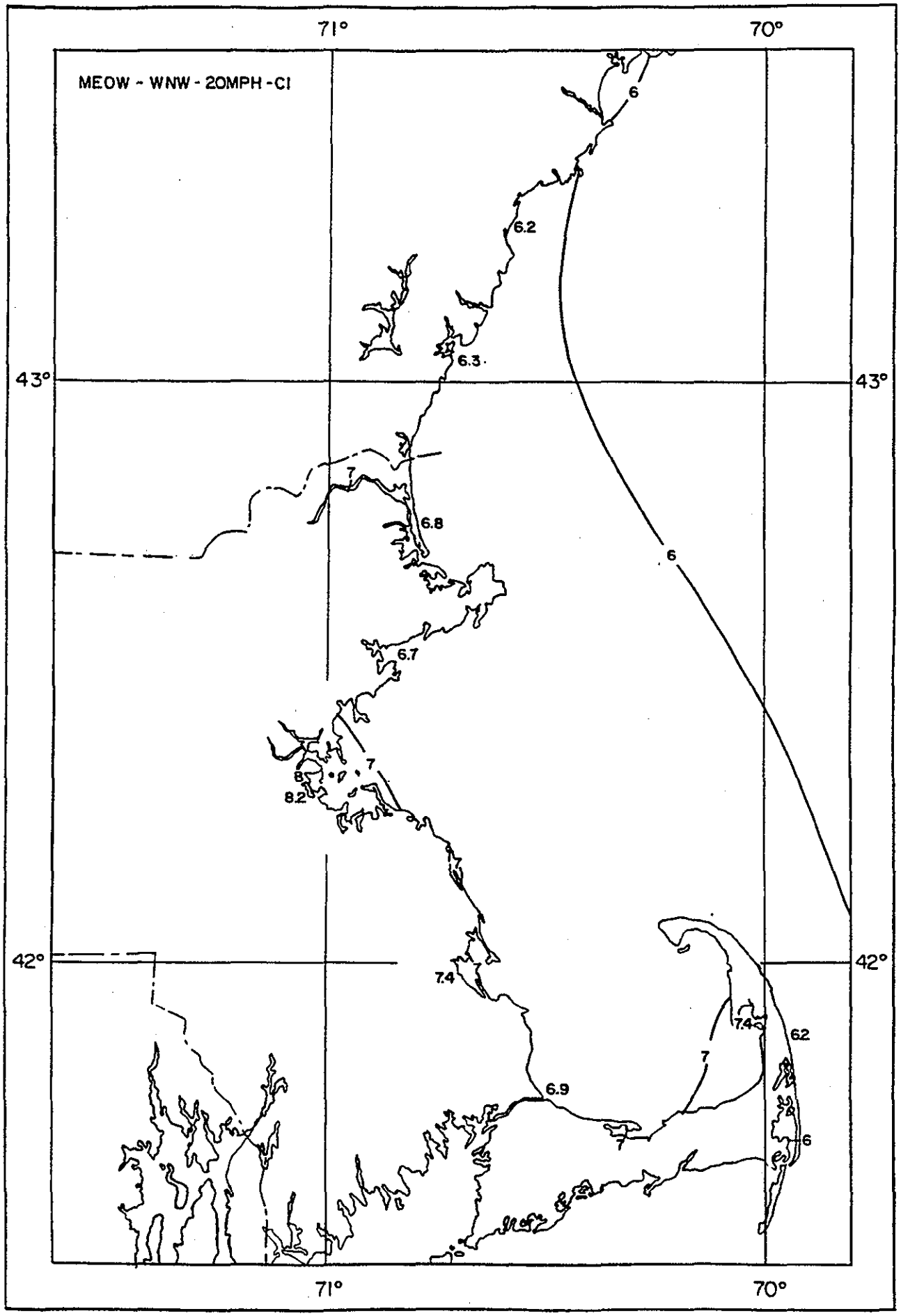
A-48 Northeastbound, 20 mph, category 4 hurricane.

A-49 Northeastbound, 40 mph, category 1 hurricane.

A-50 Northeastbound, 40 mph, category 2 hurricane.

A-51 Northeastbound, 40 mph, category 3 hurricane.

A-52 Northeastbound, 40 mph, category 4 hurricane.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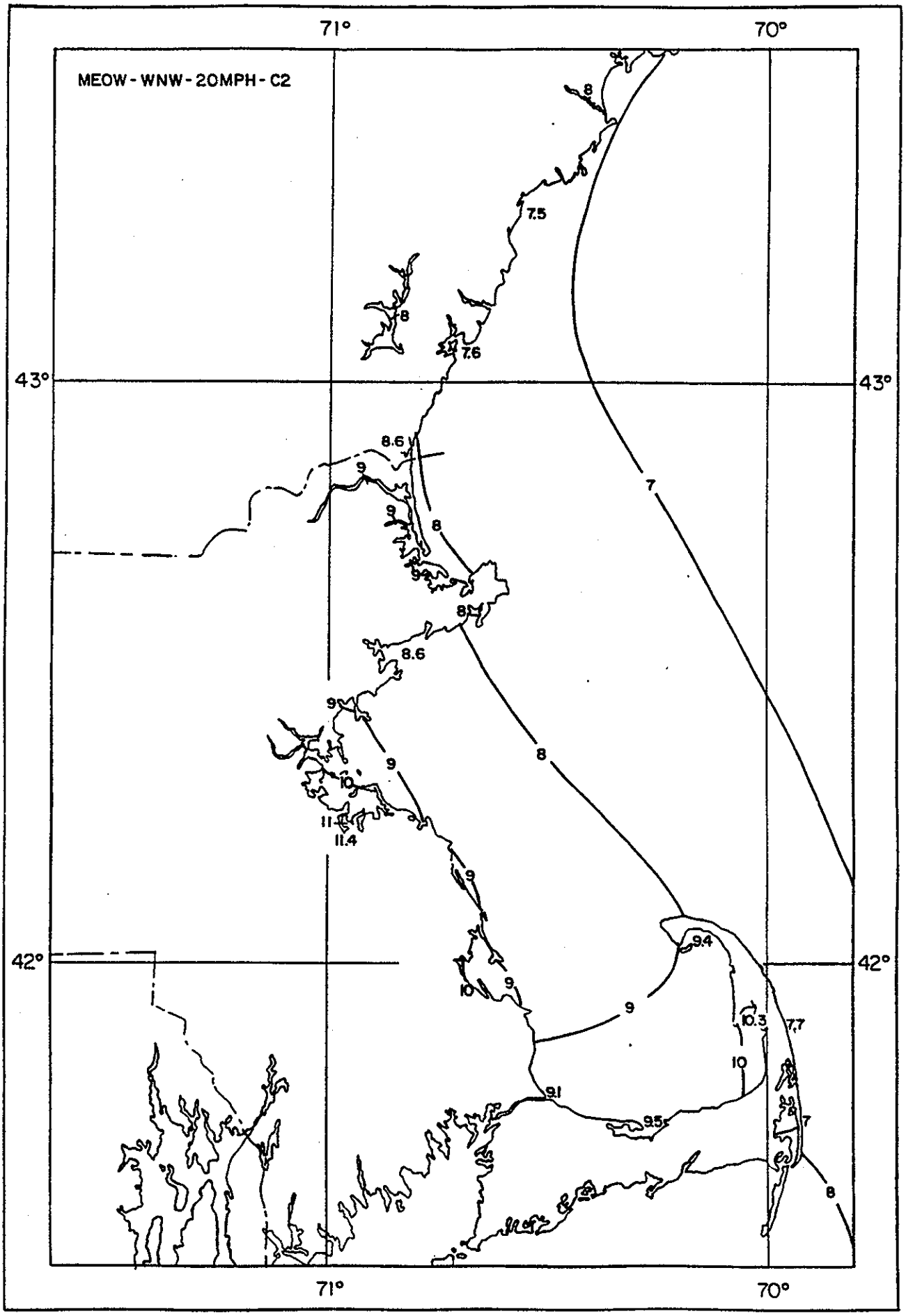
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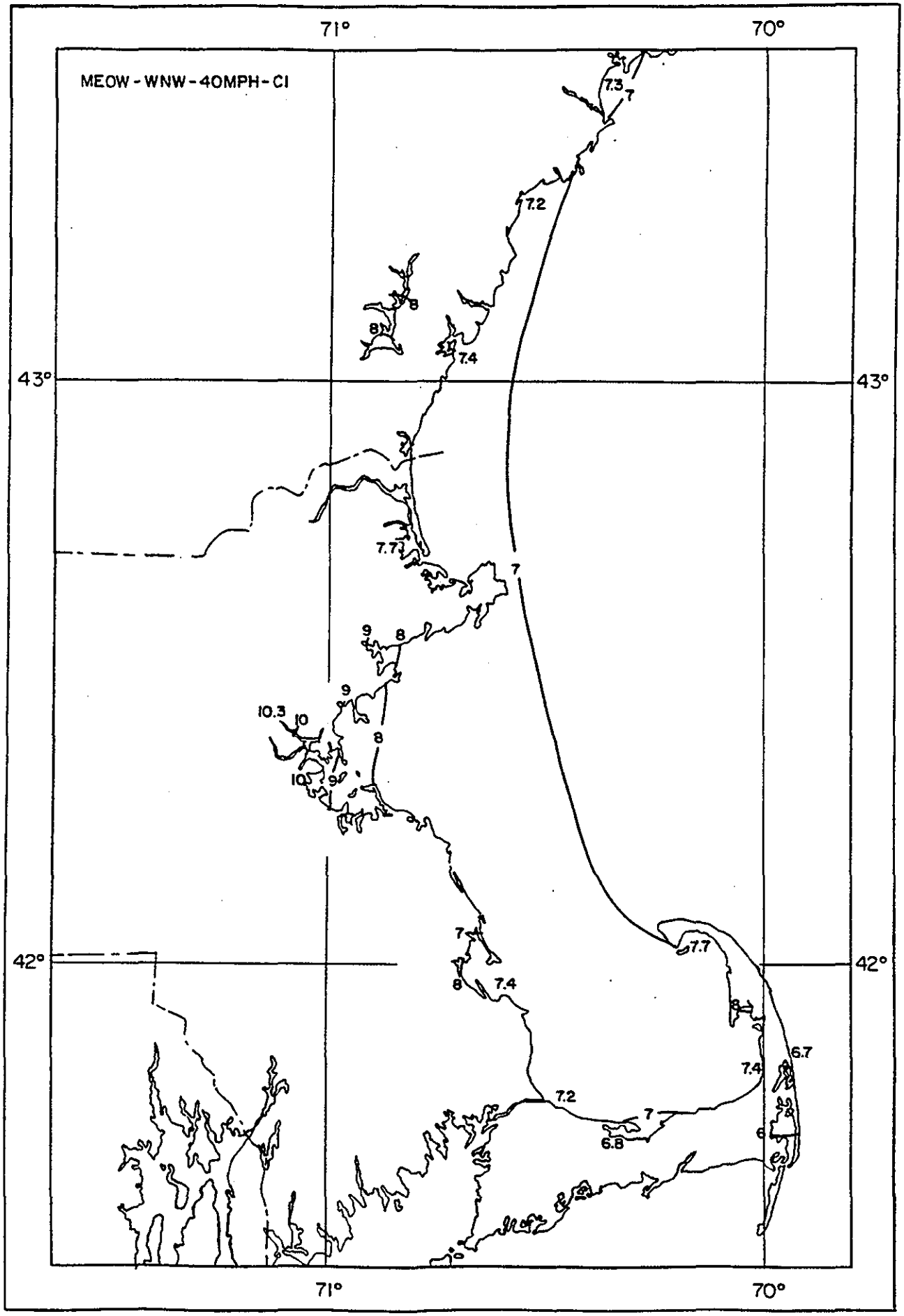
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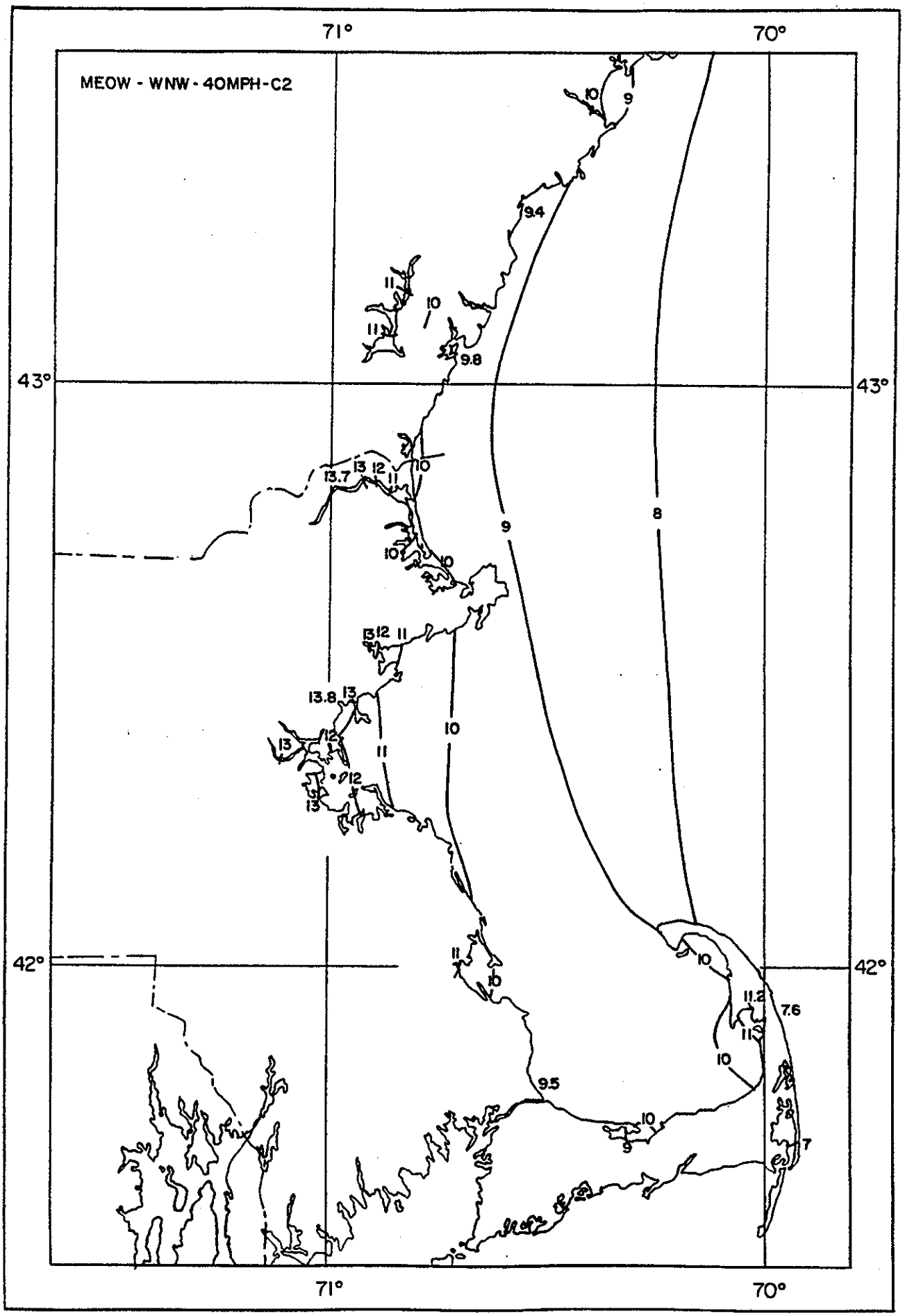
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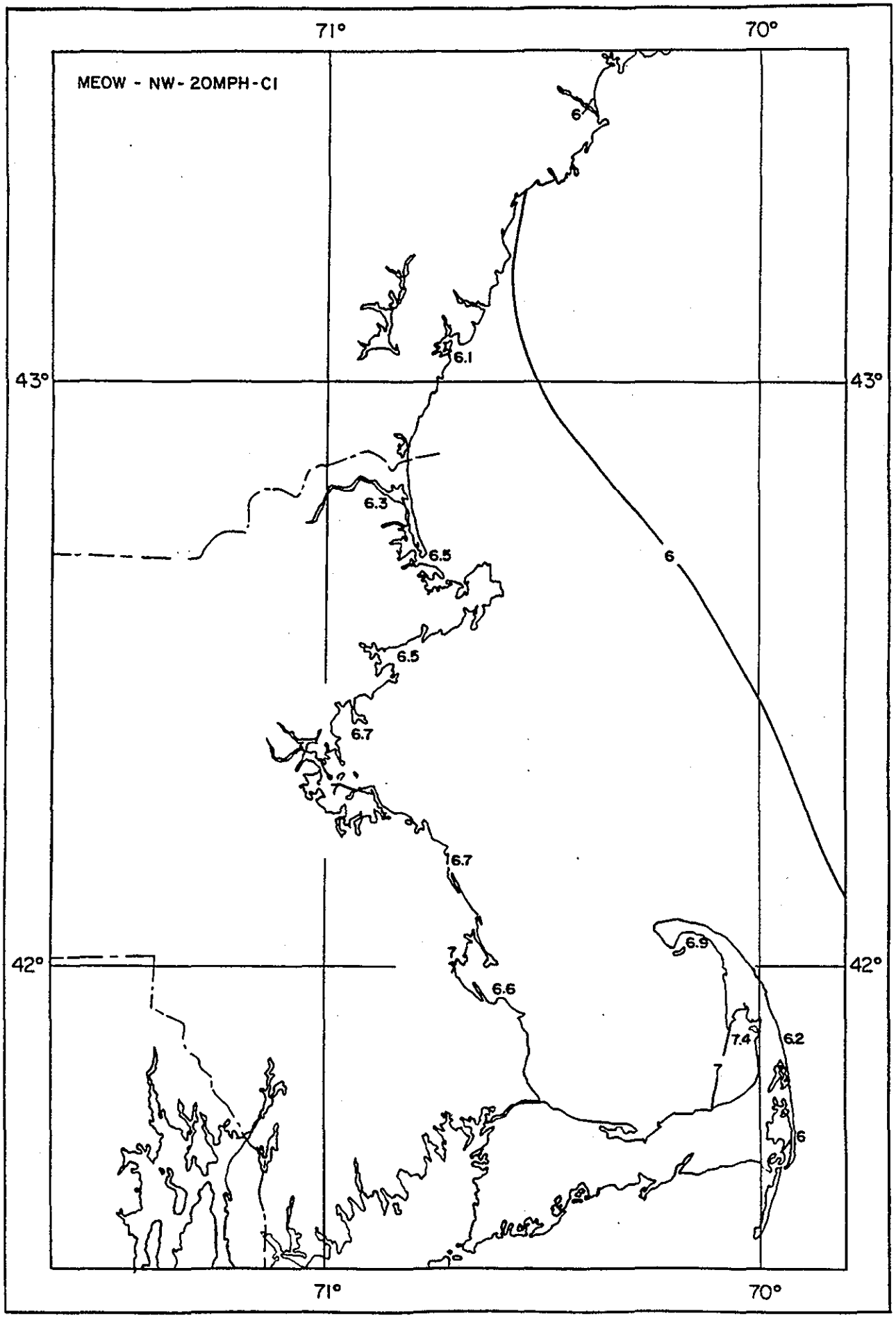
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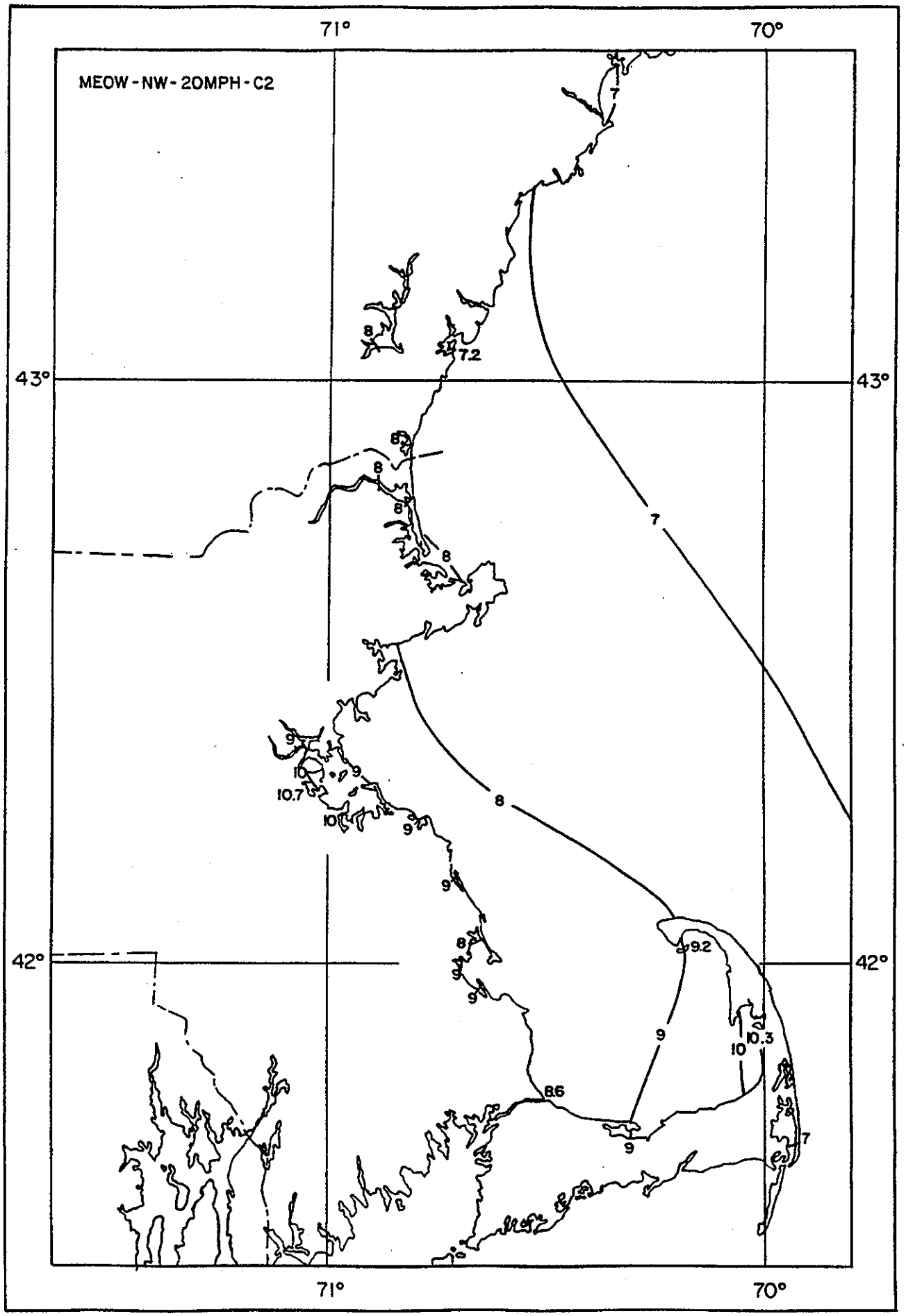
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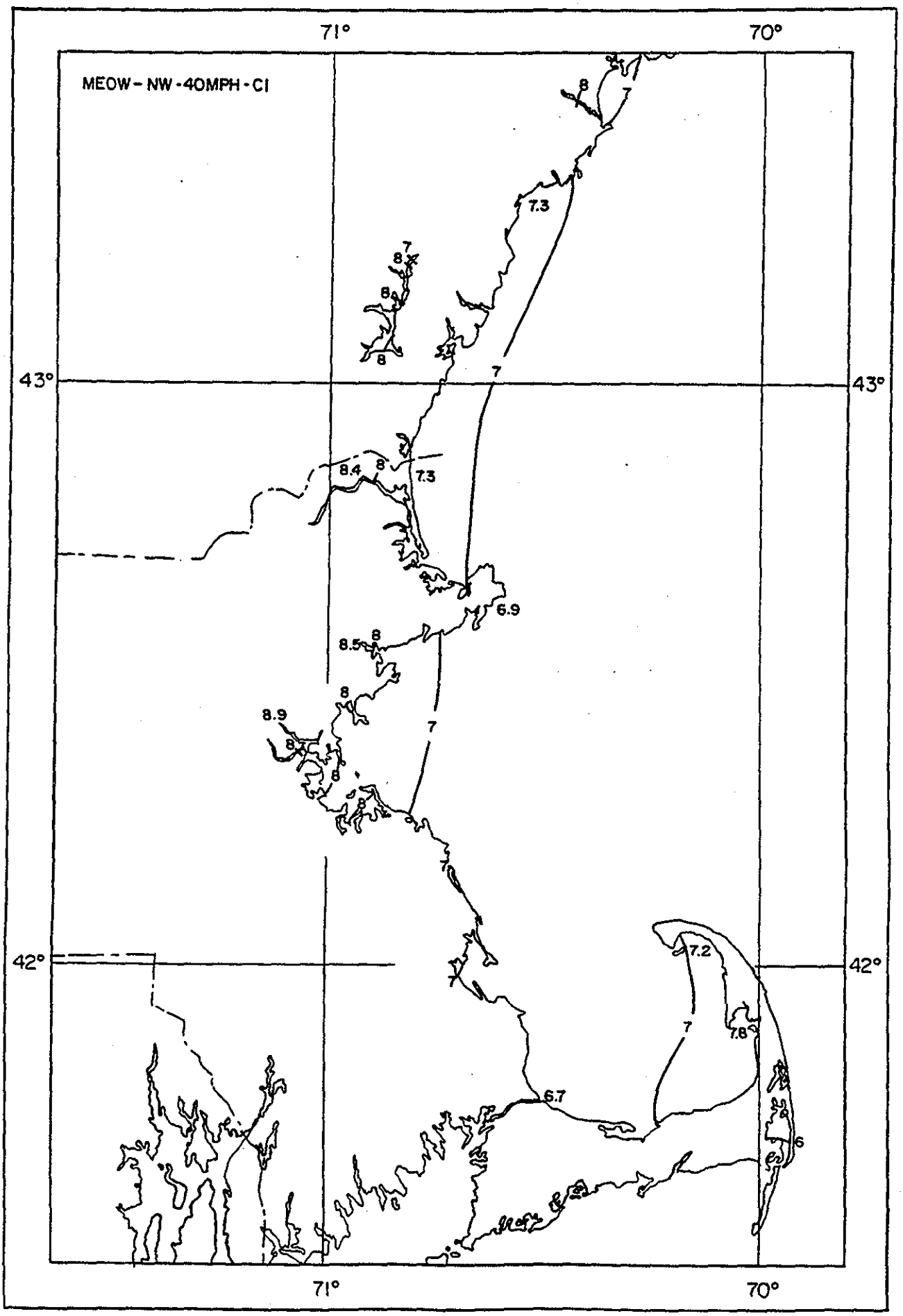
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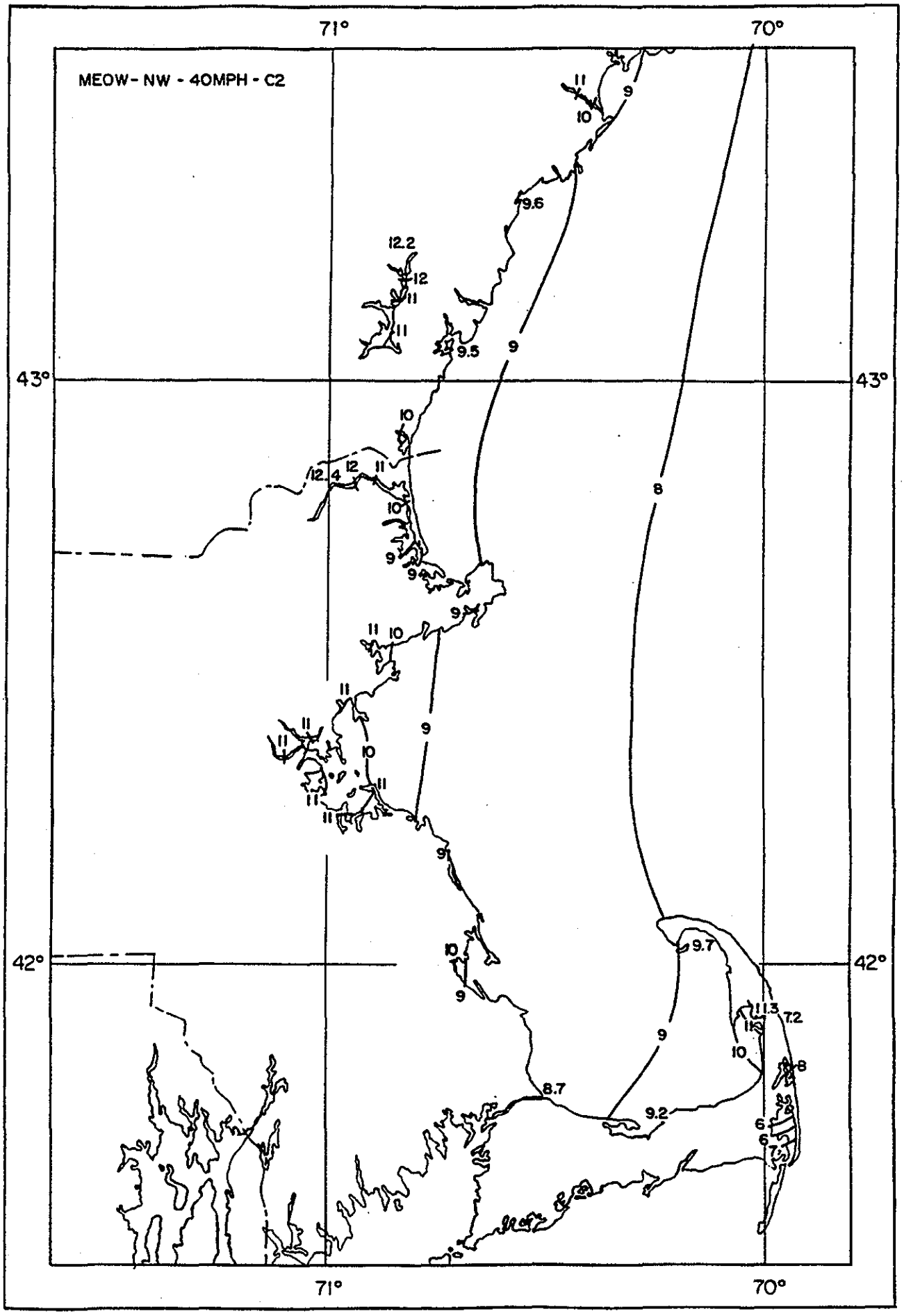
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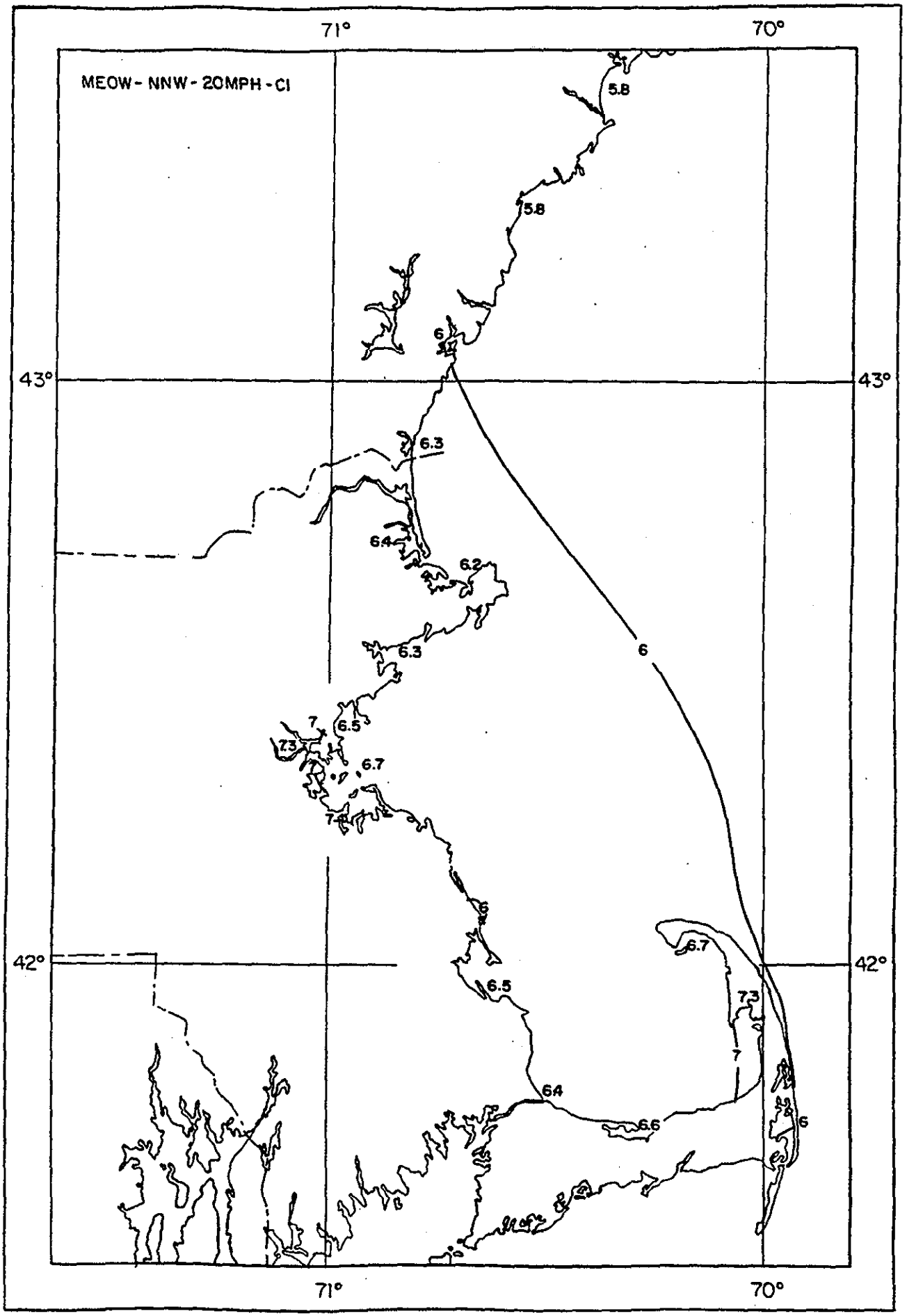
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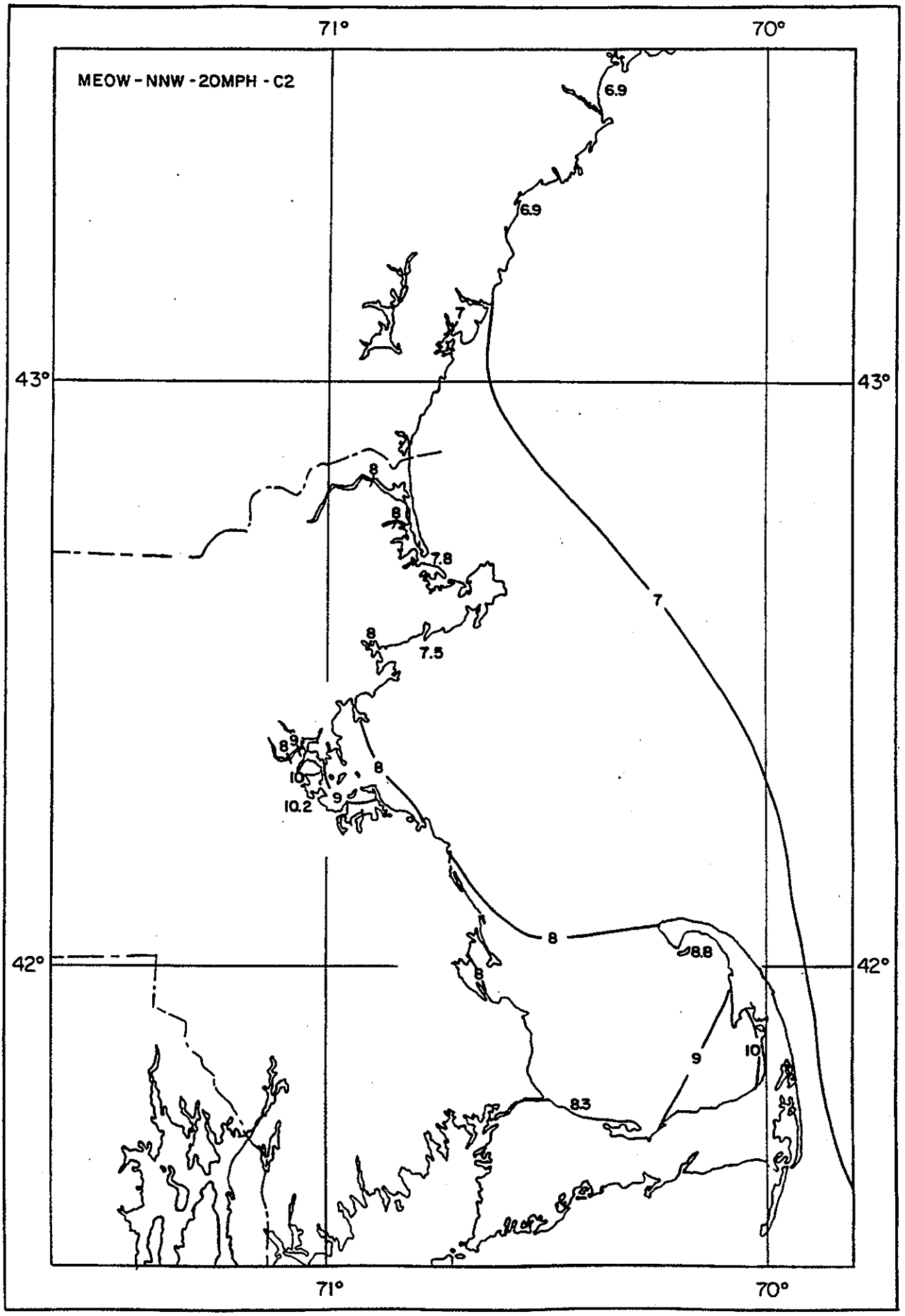
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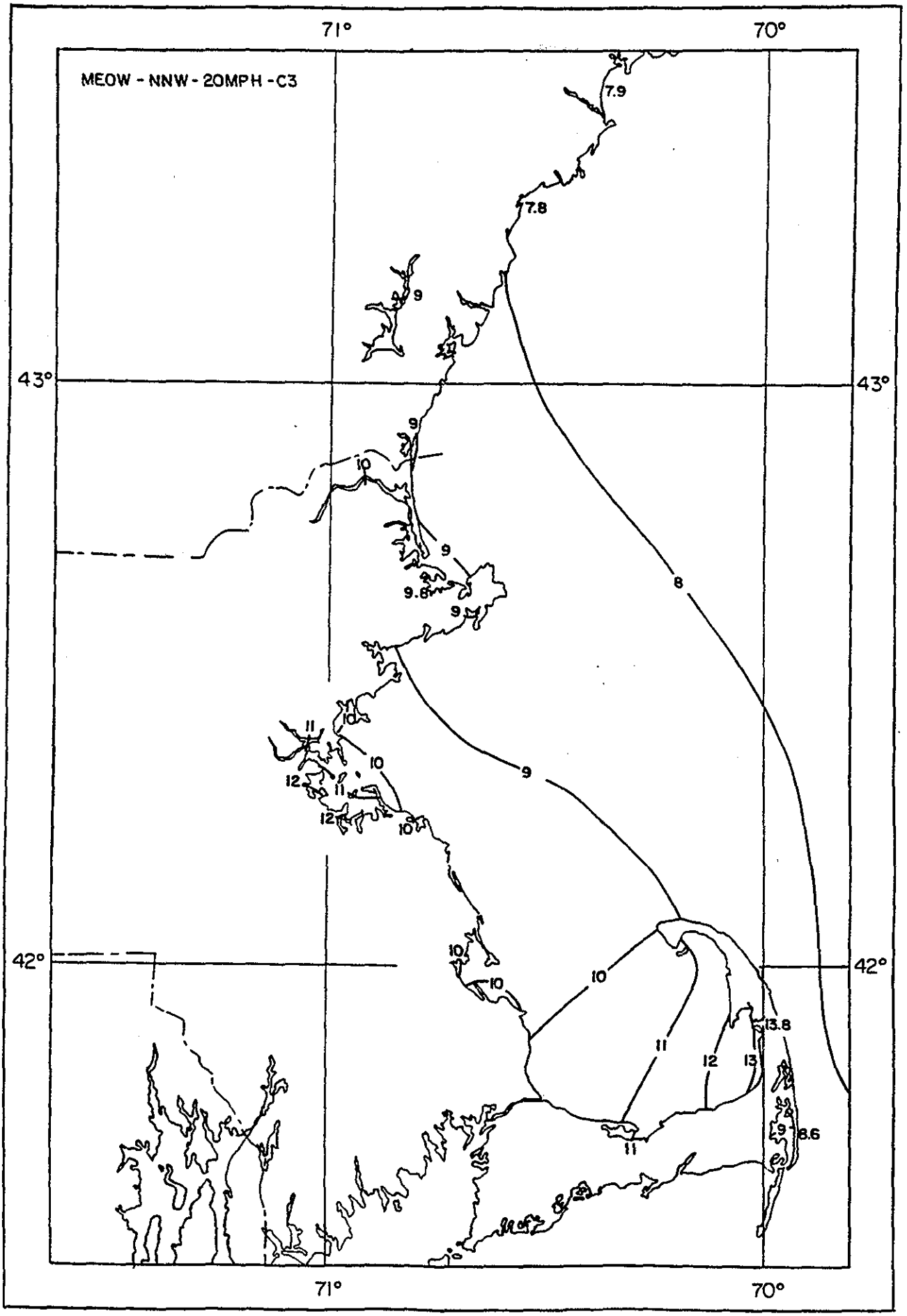
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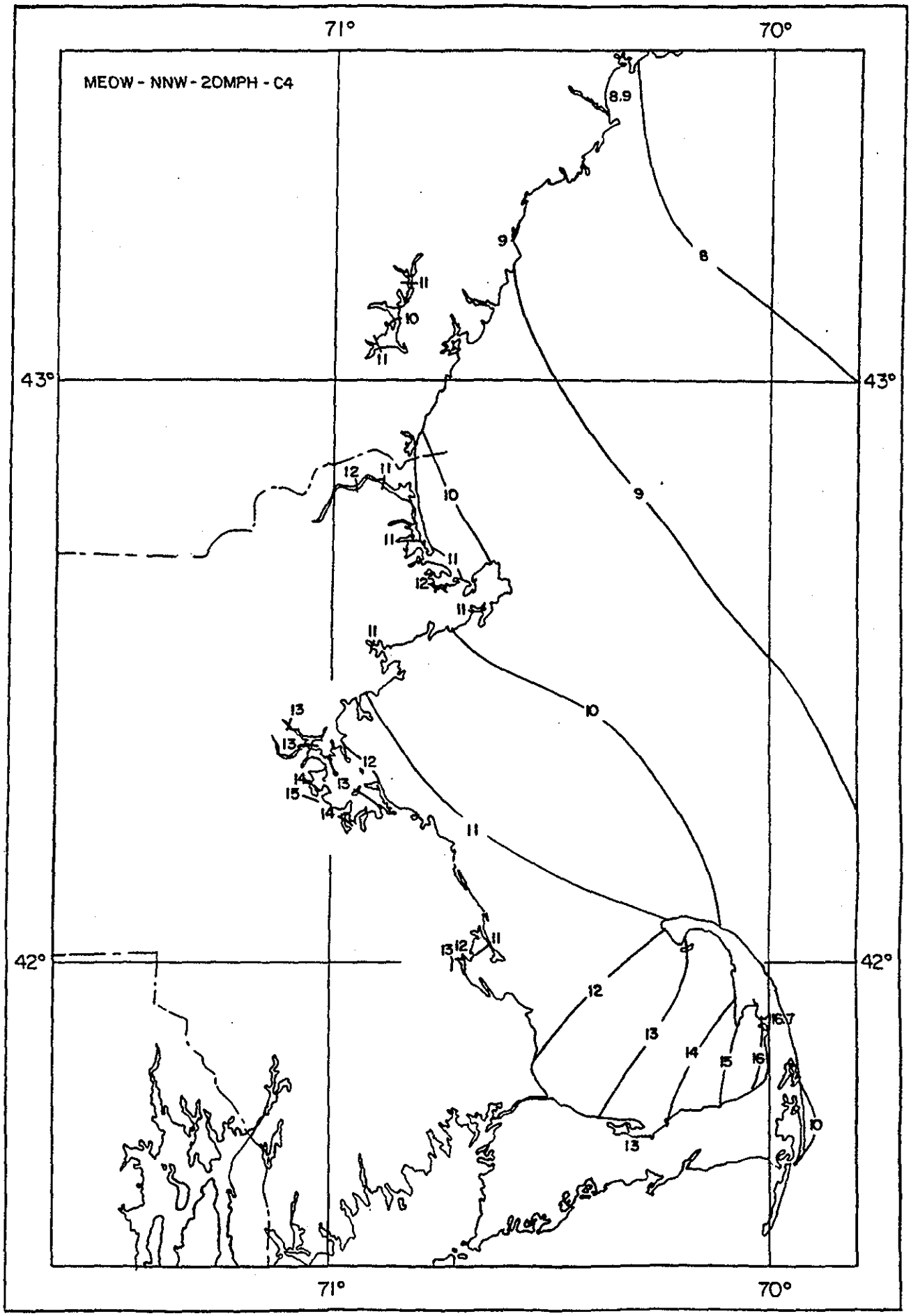
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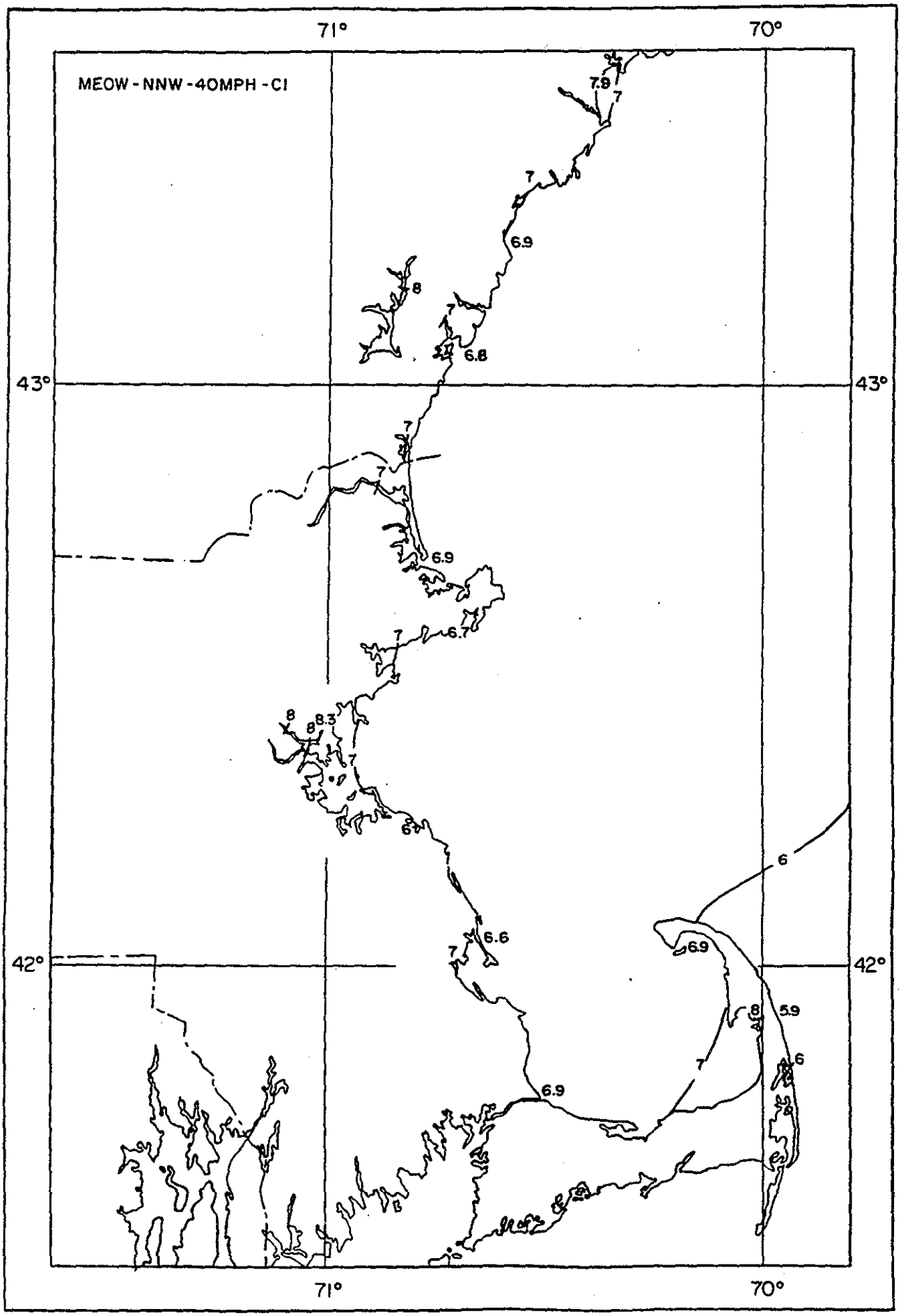
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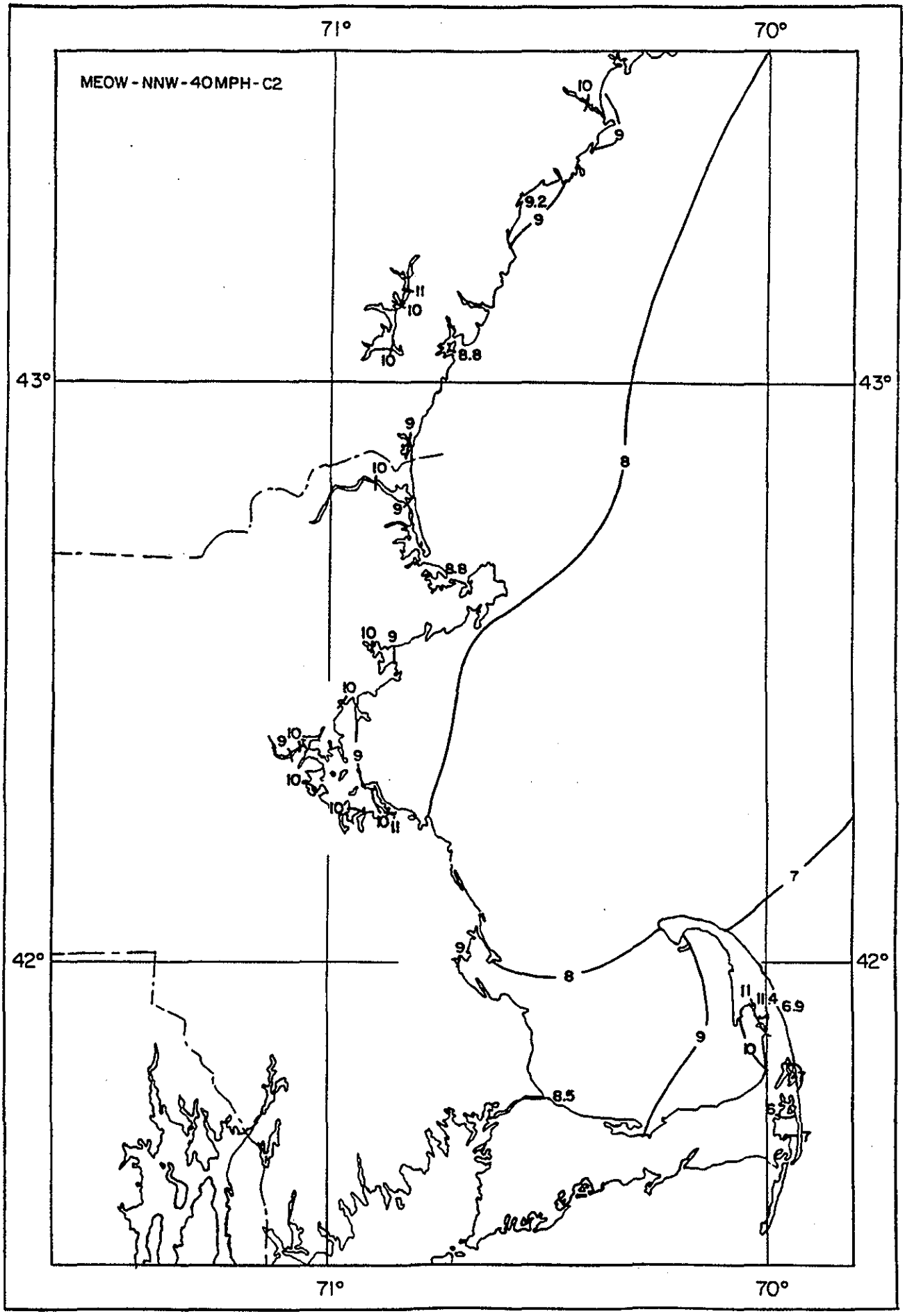
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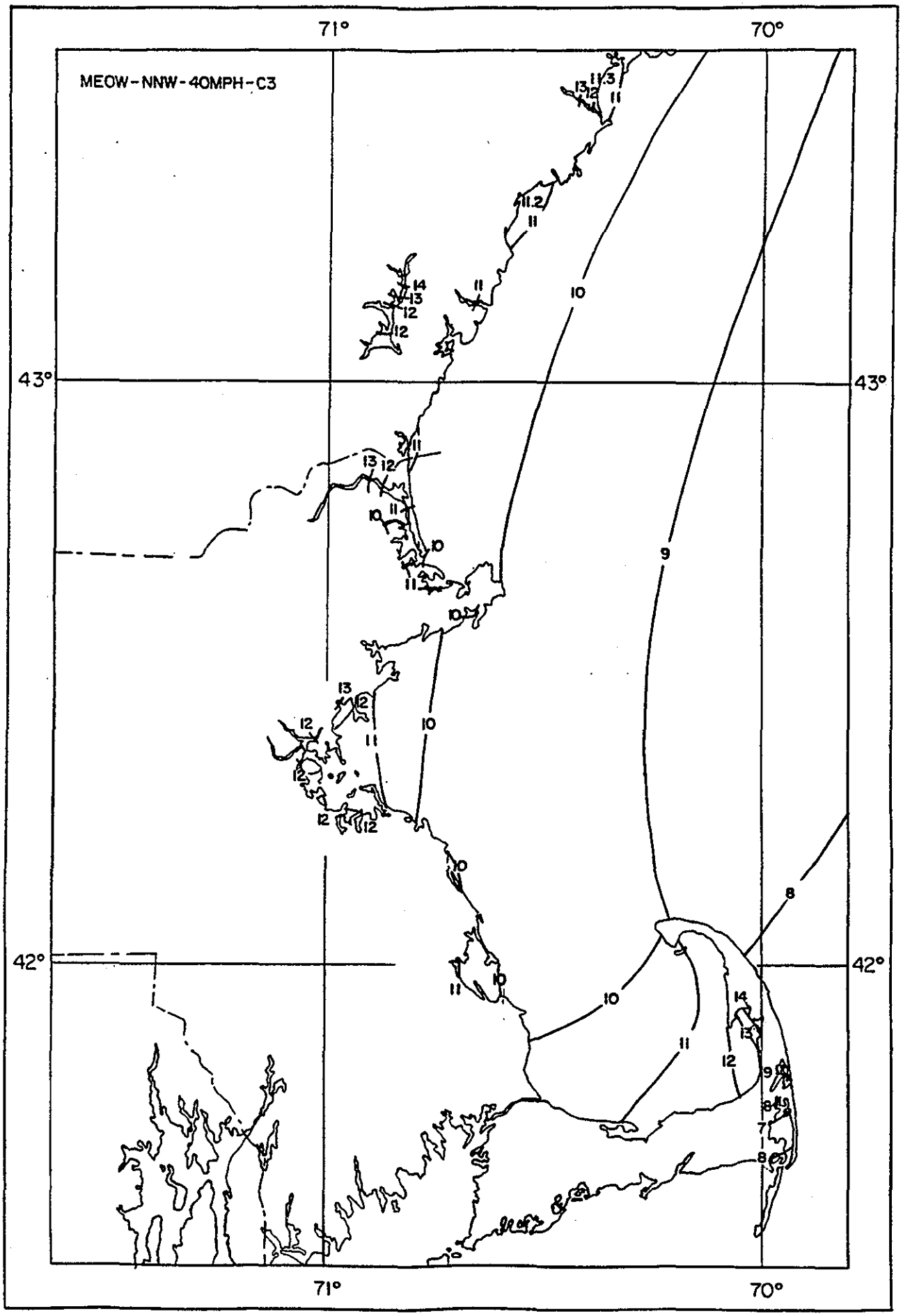
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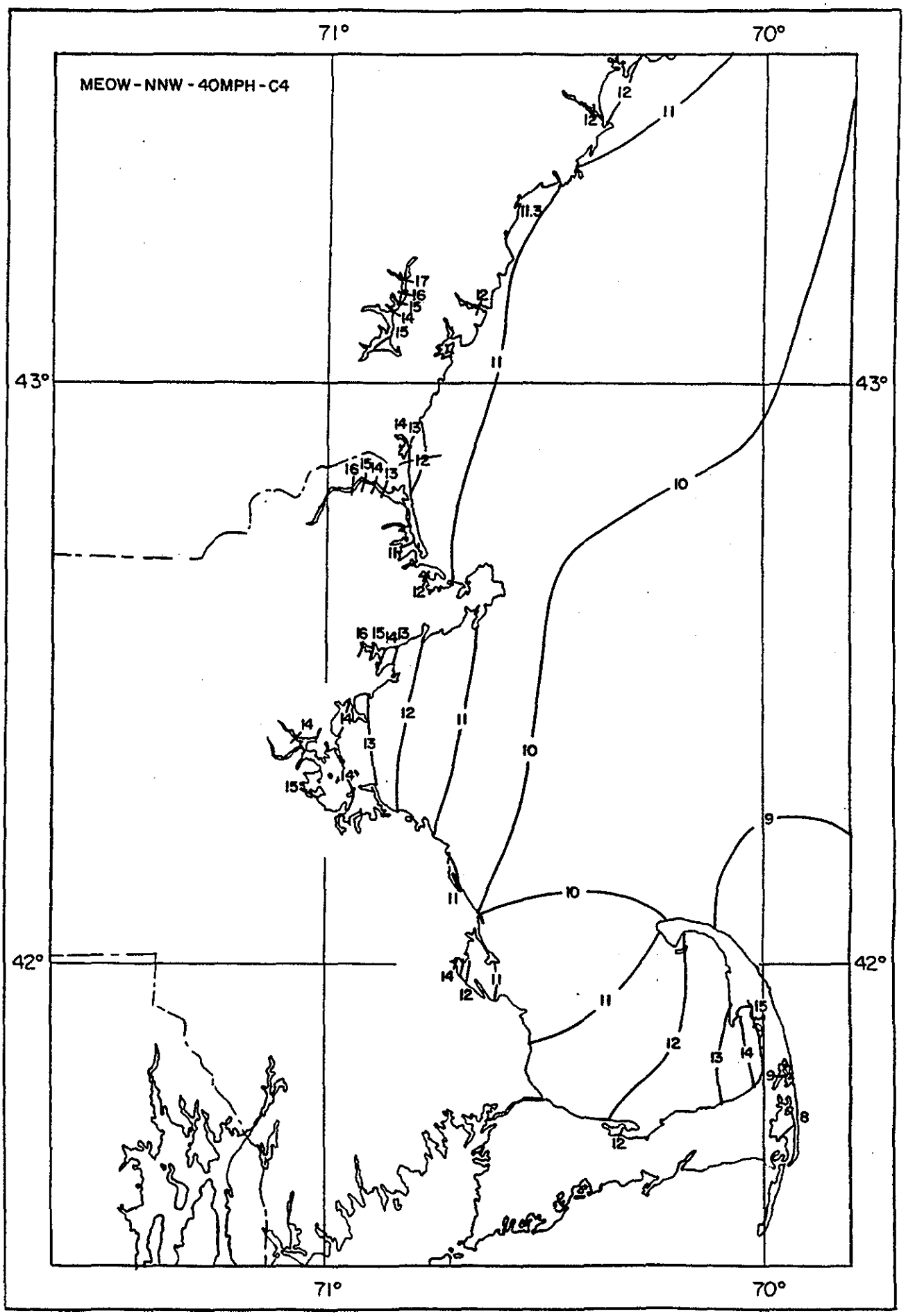
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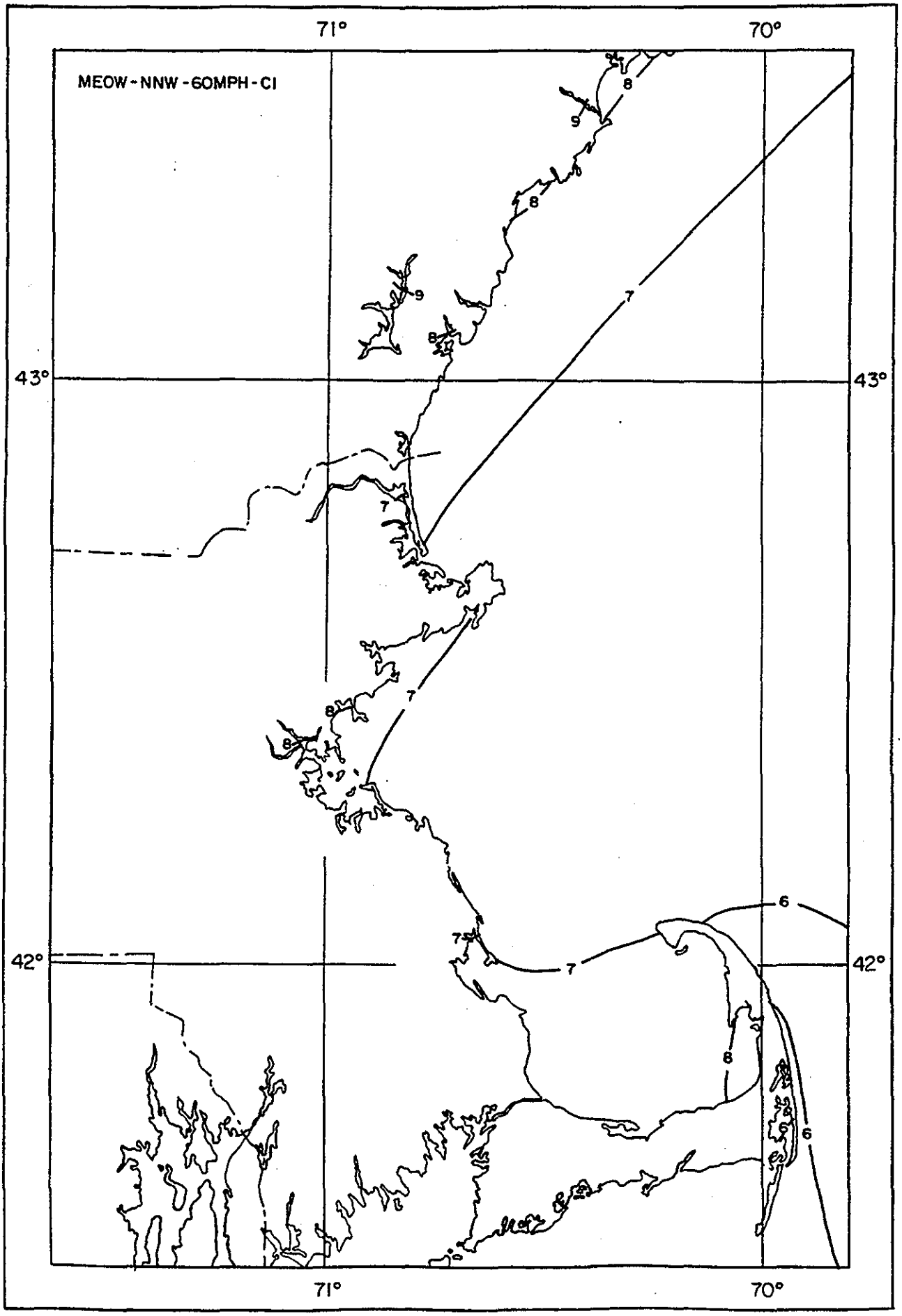
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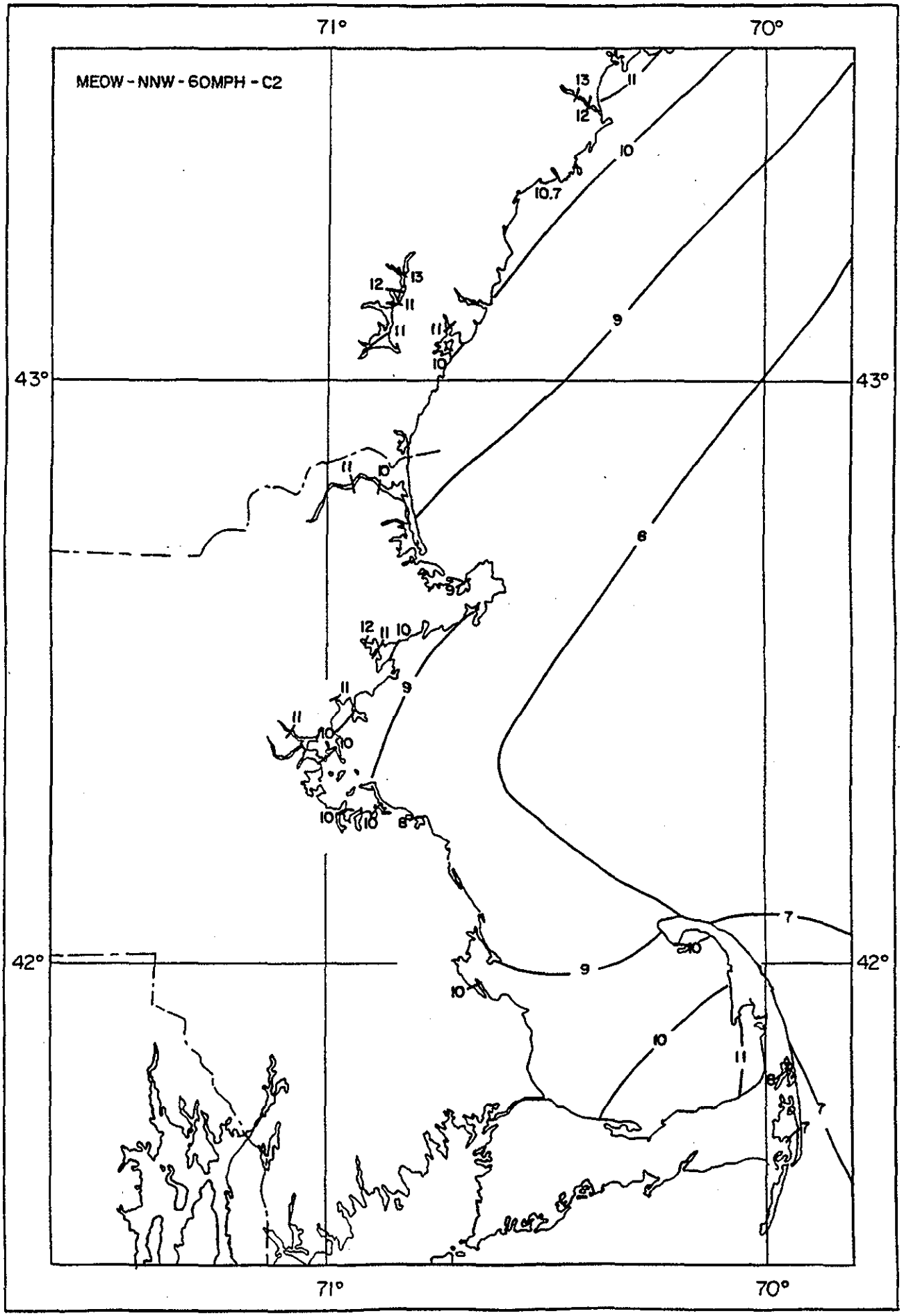
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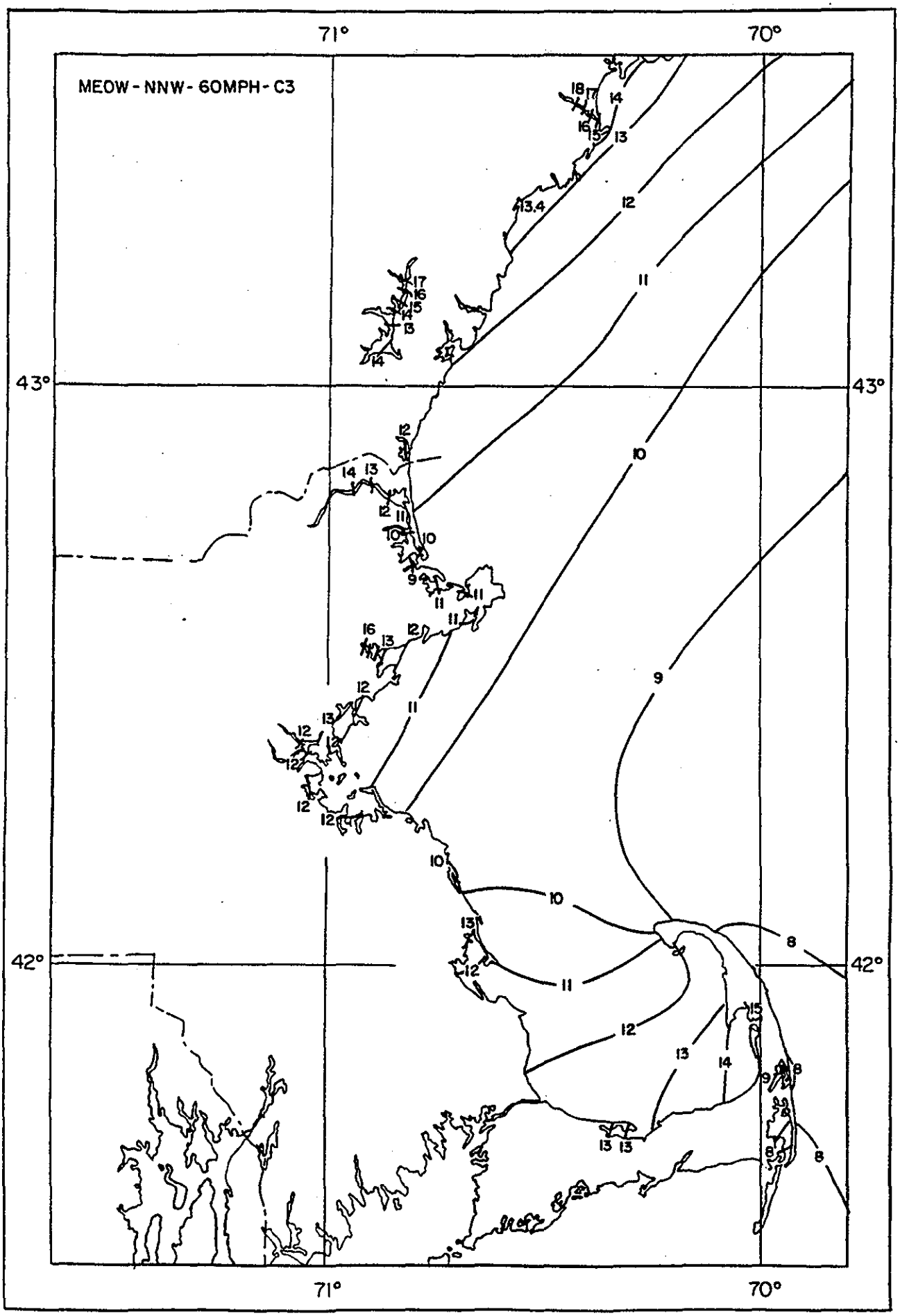
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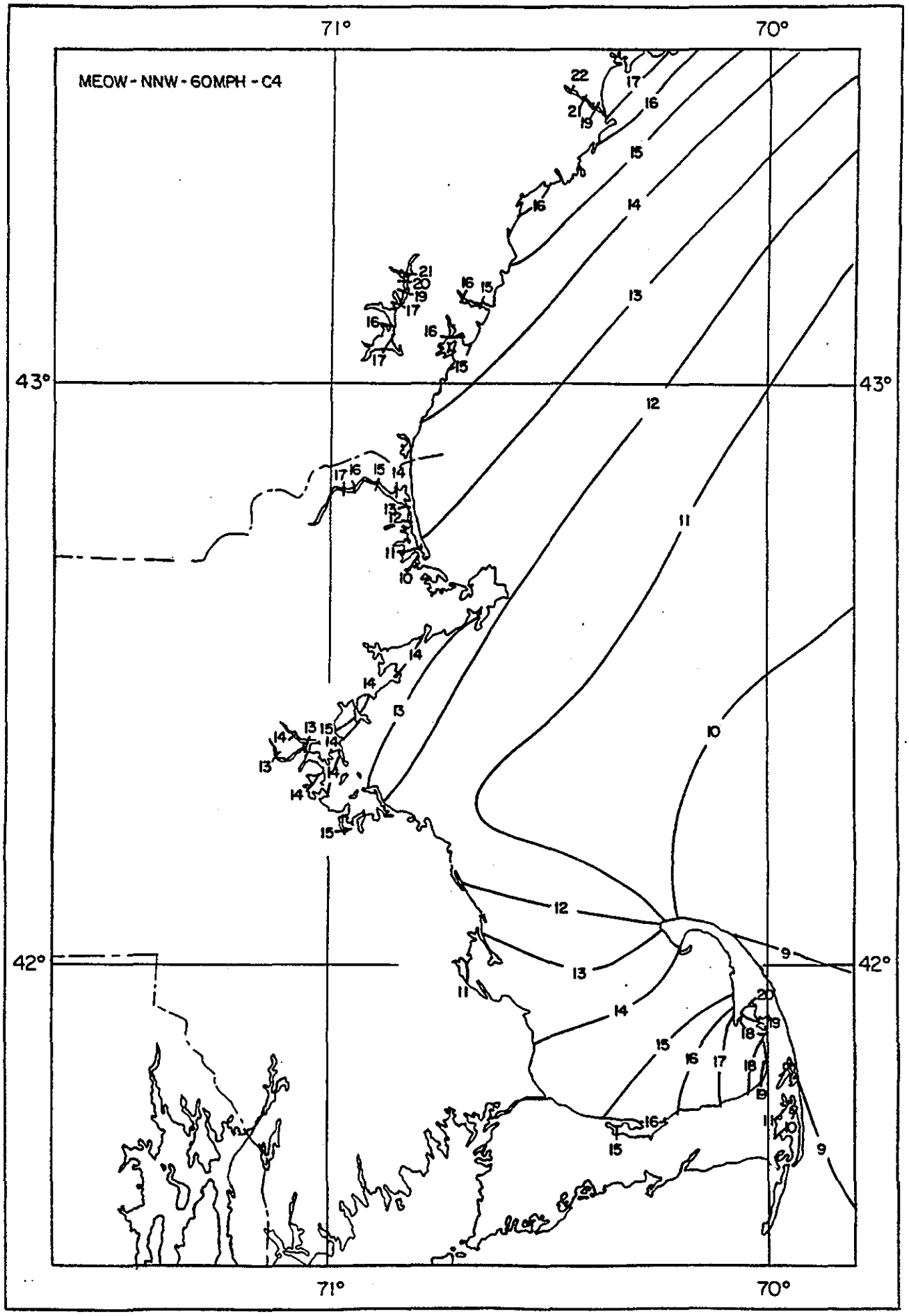
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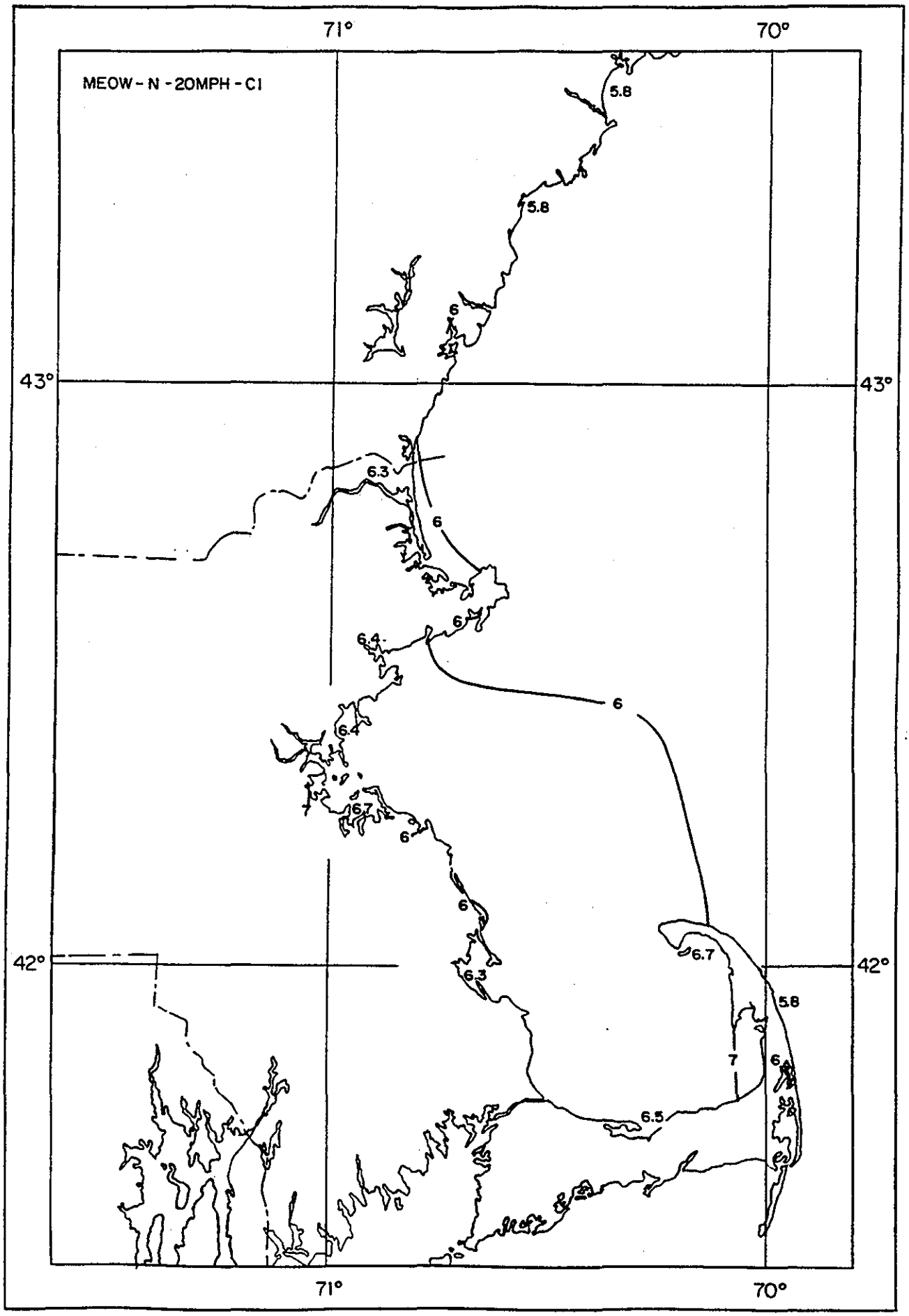
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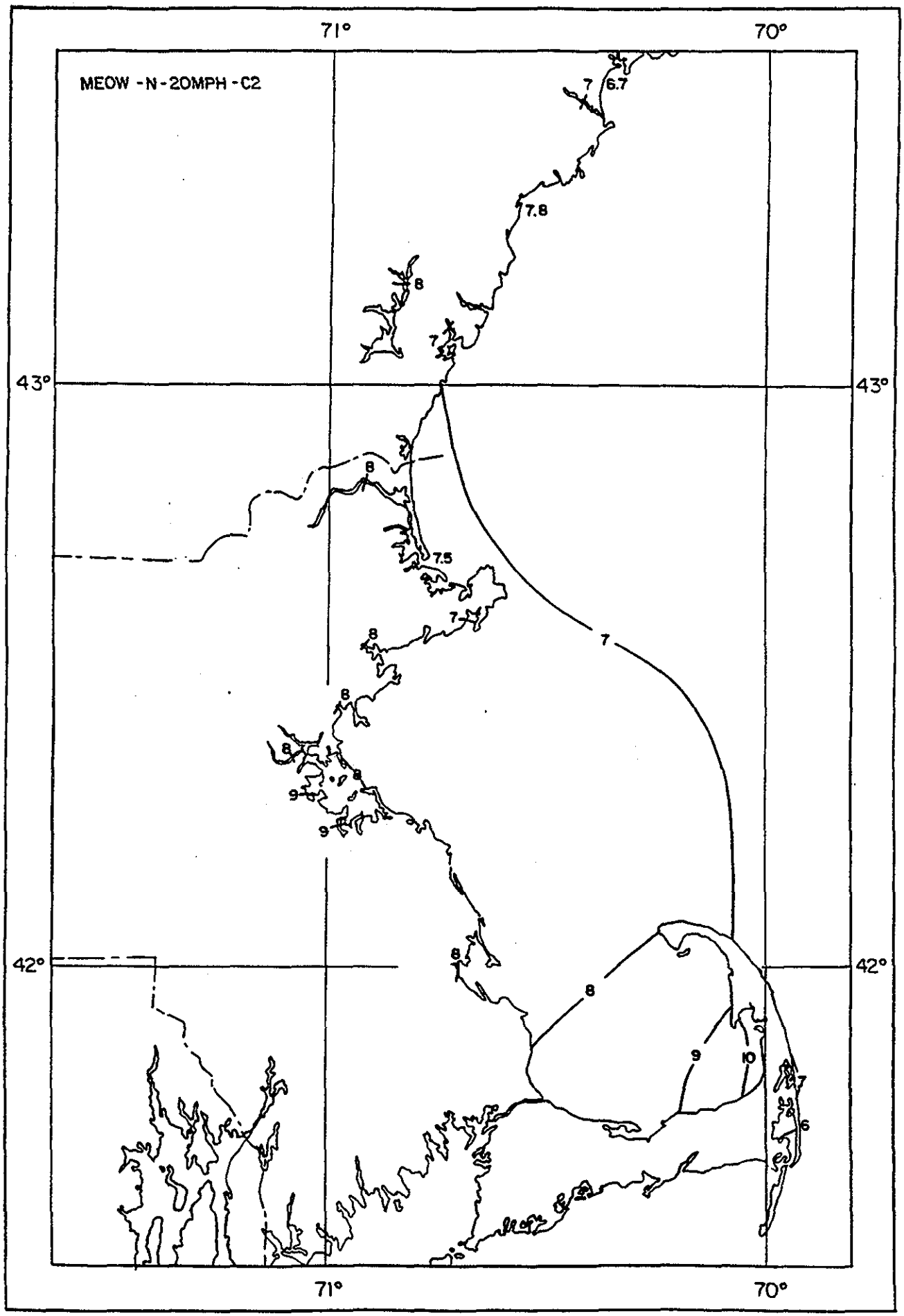
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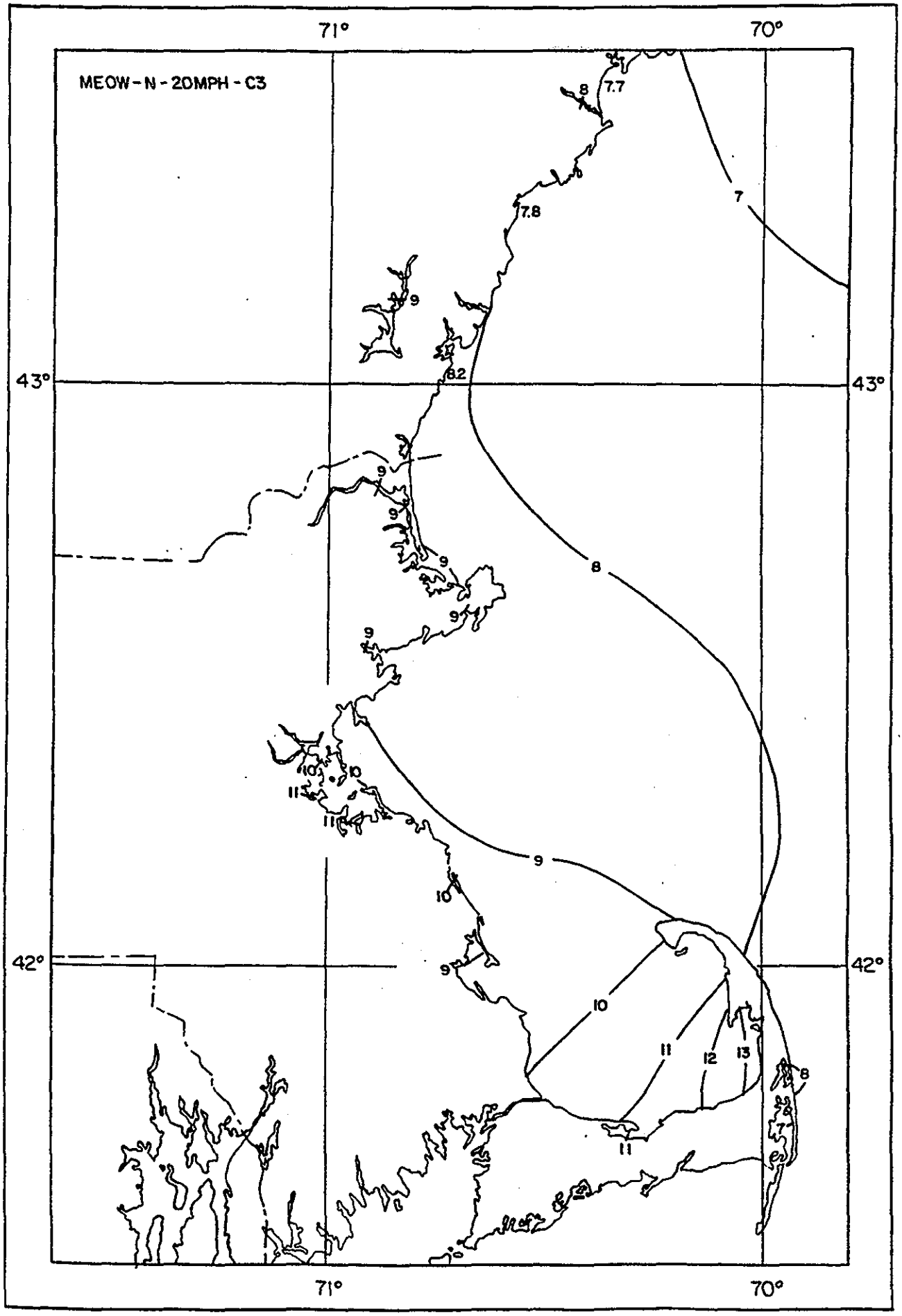
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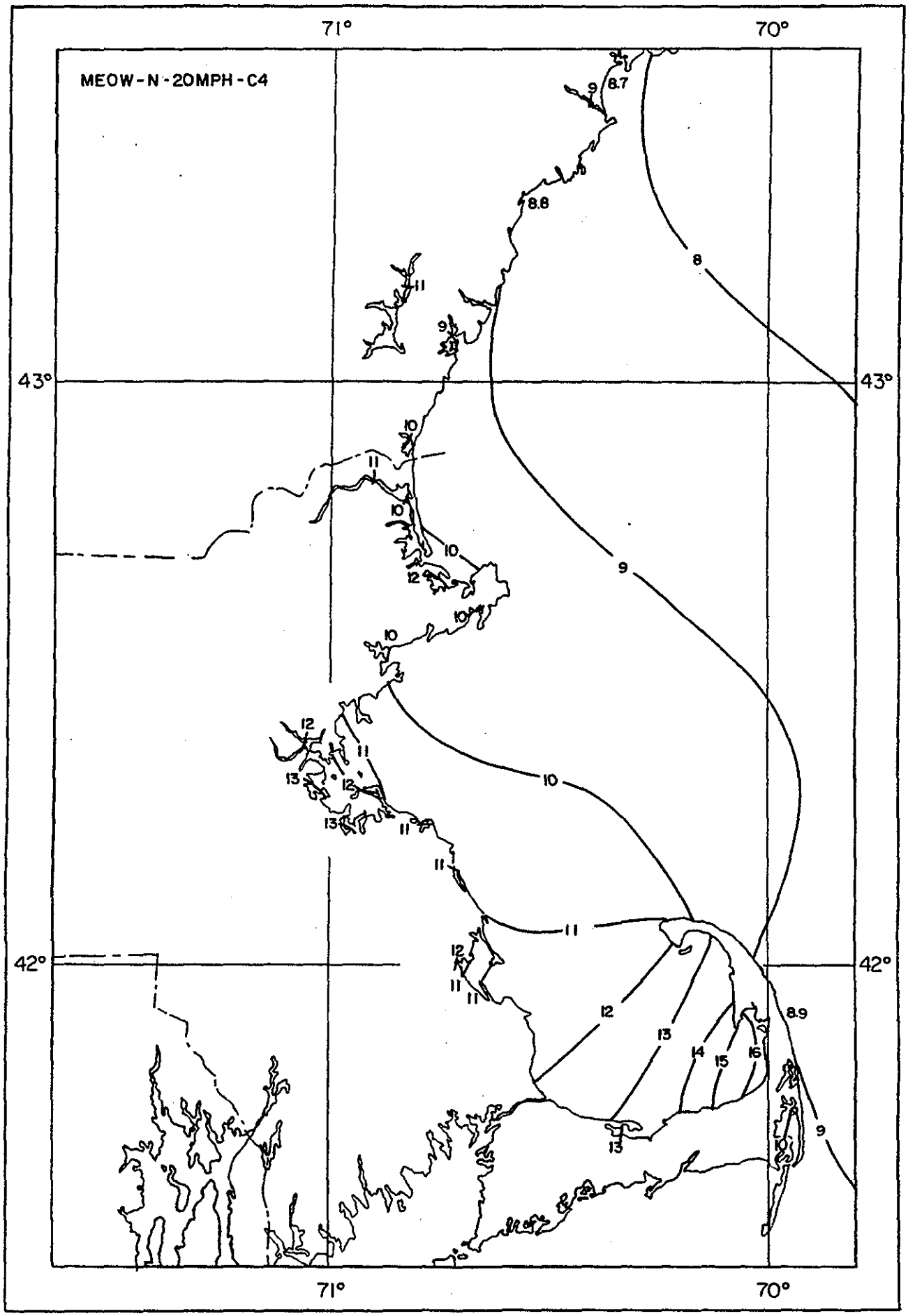
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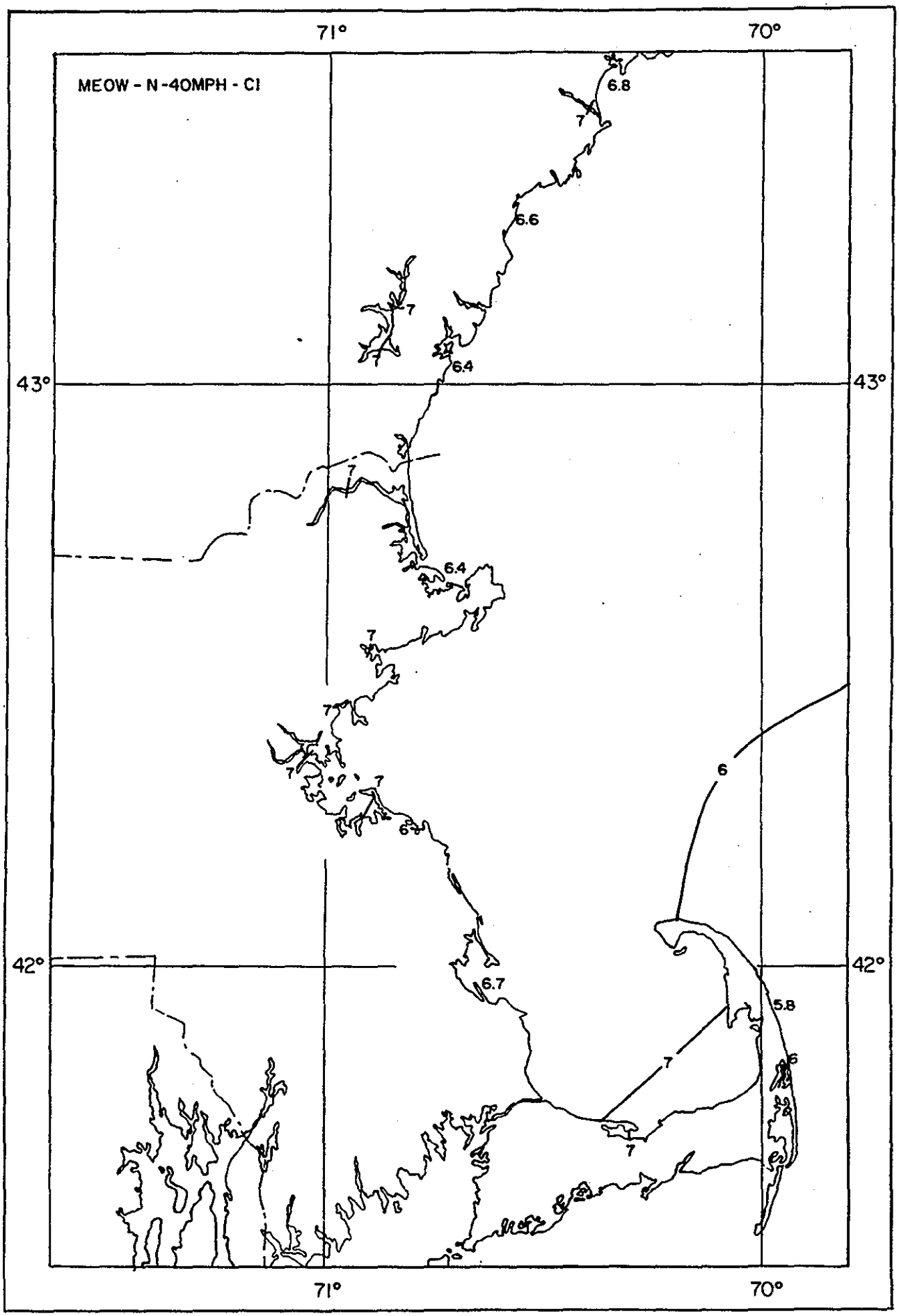
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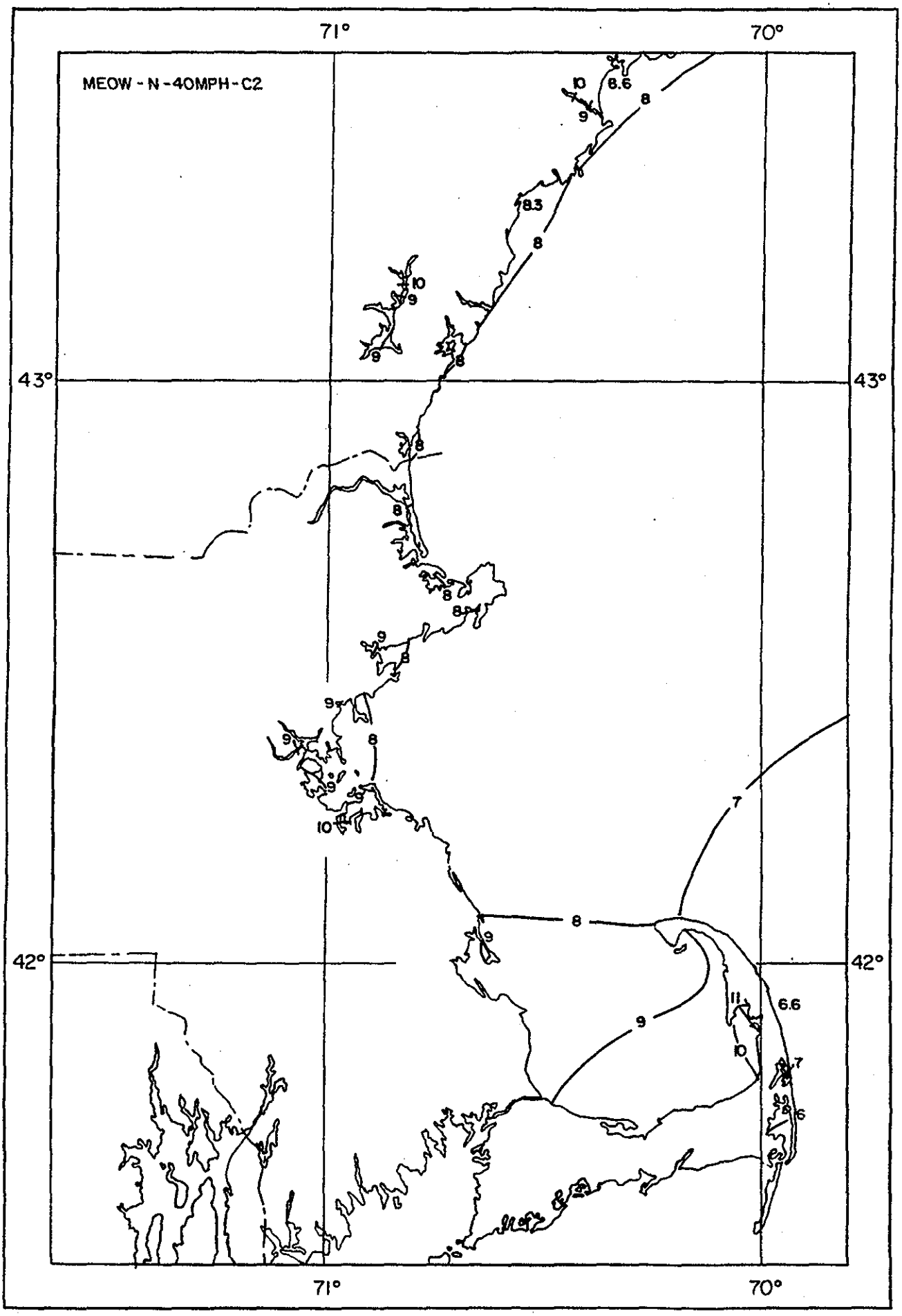
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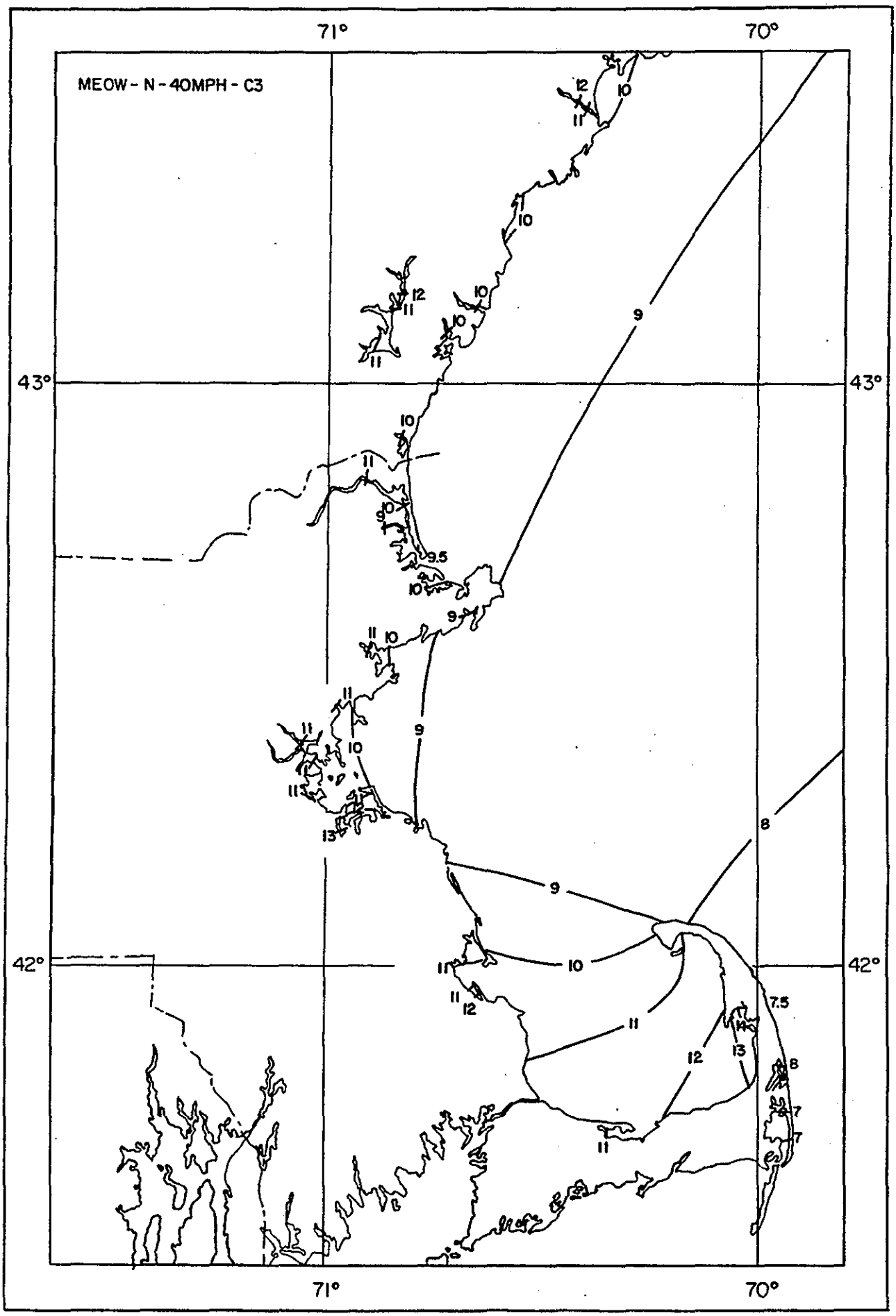
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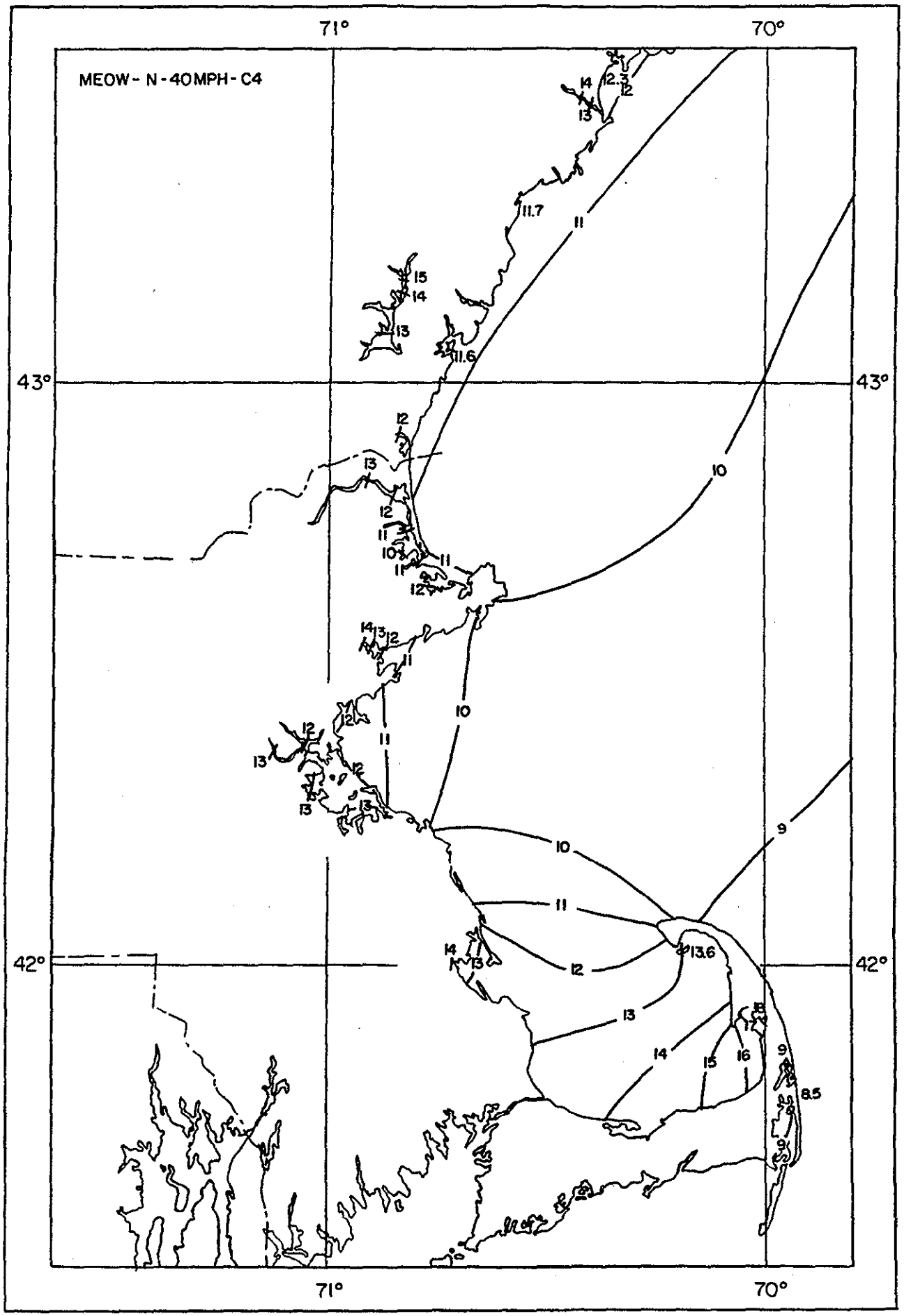
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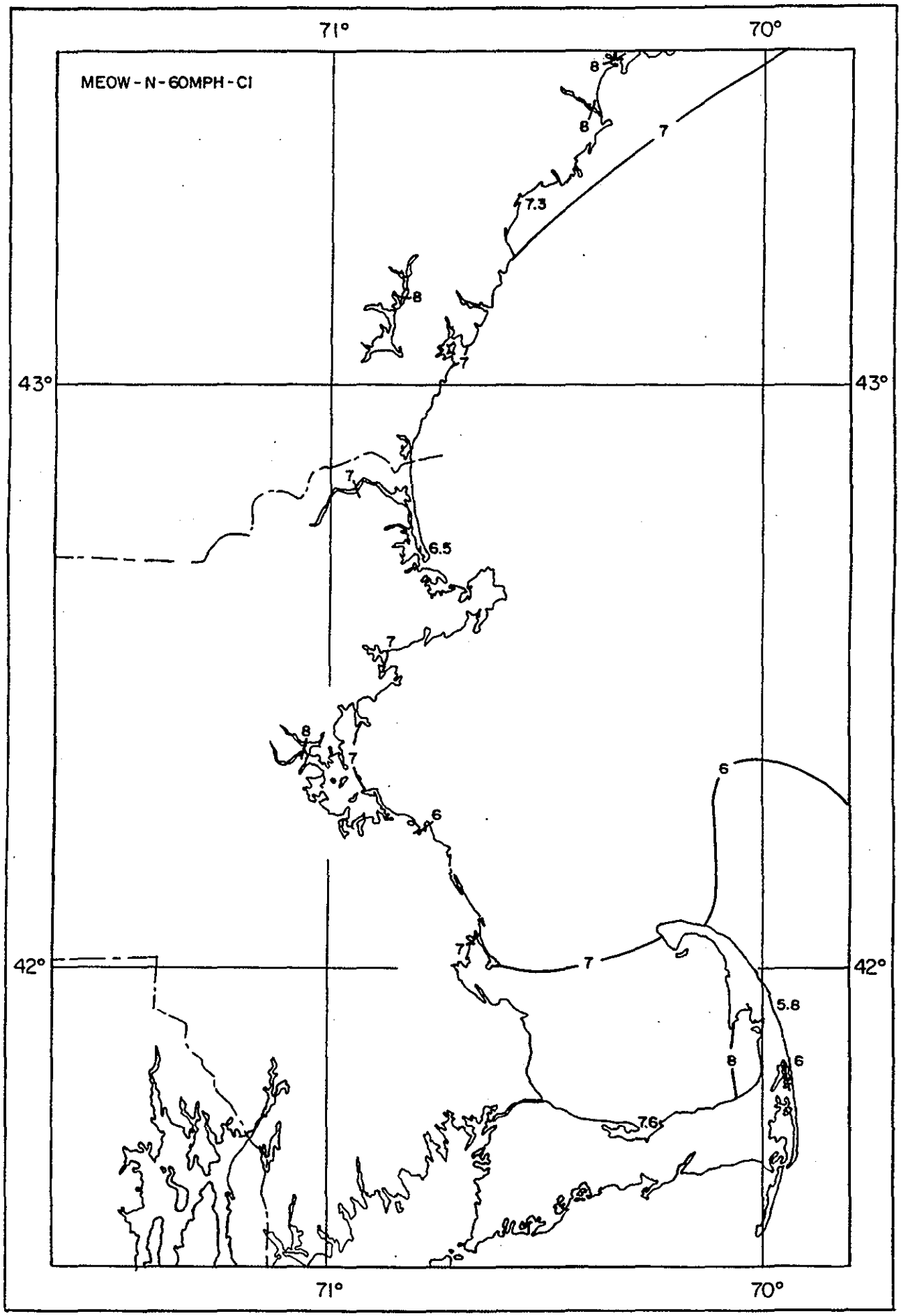
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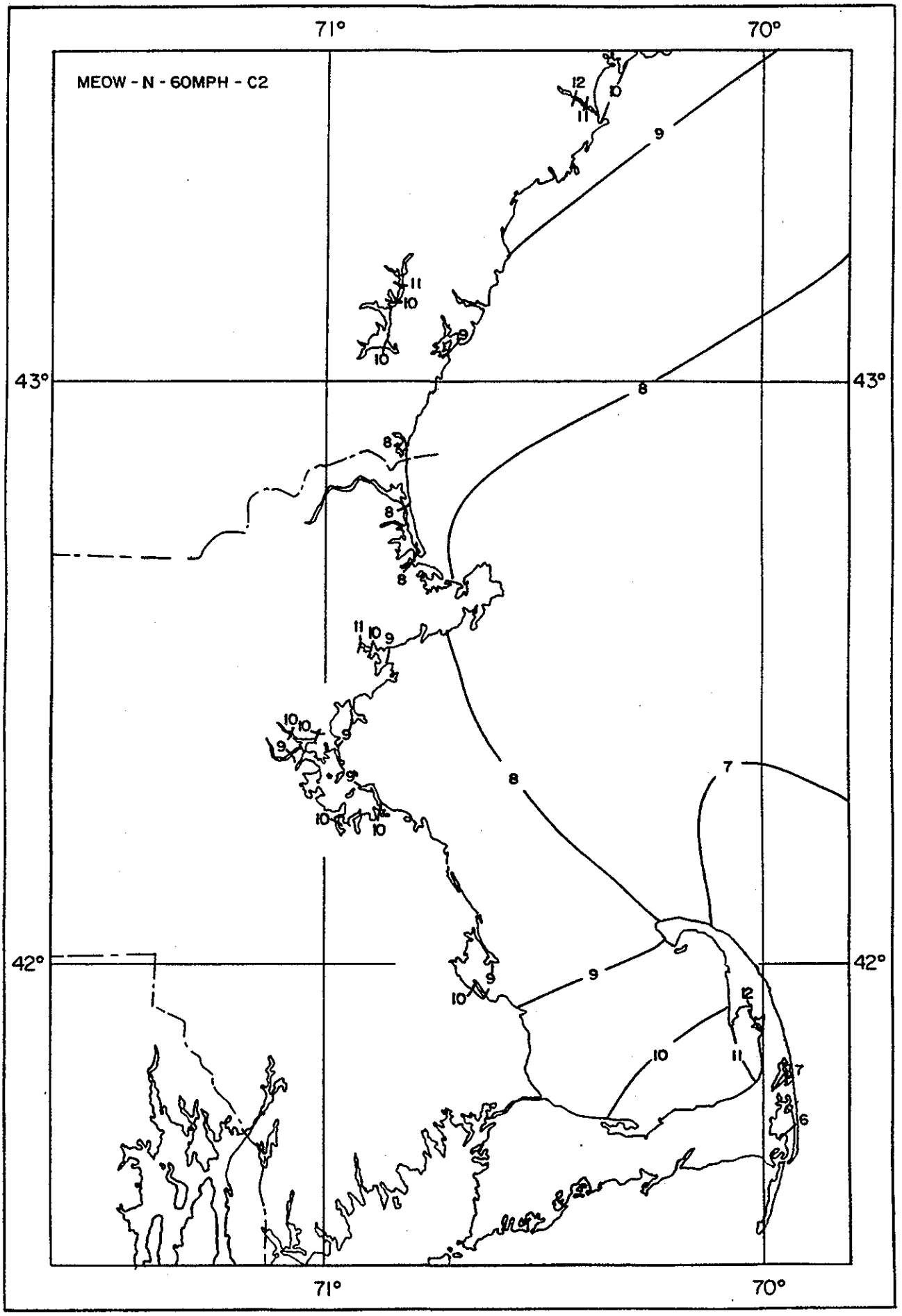
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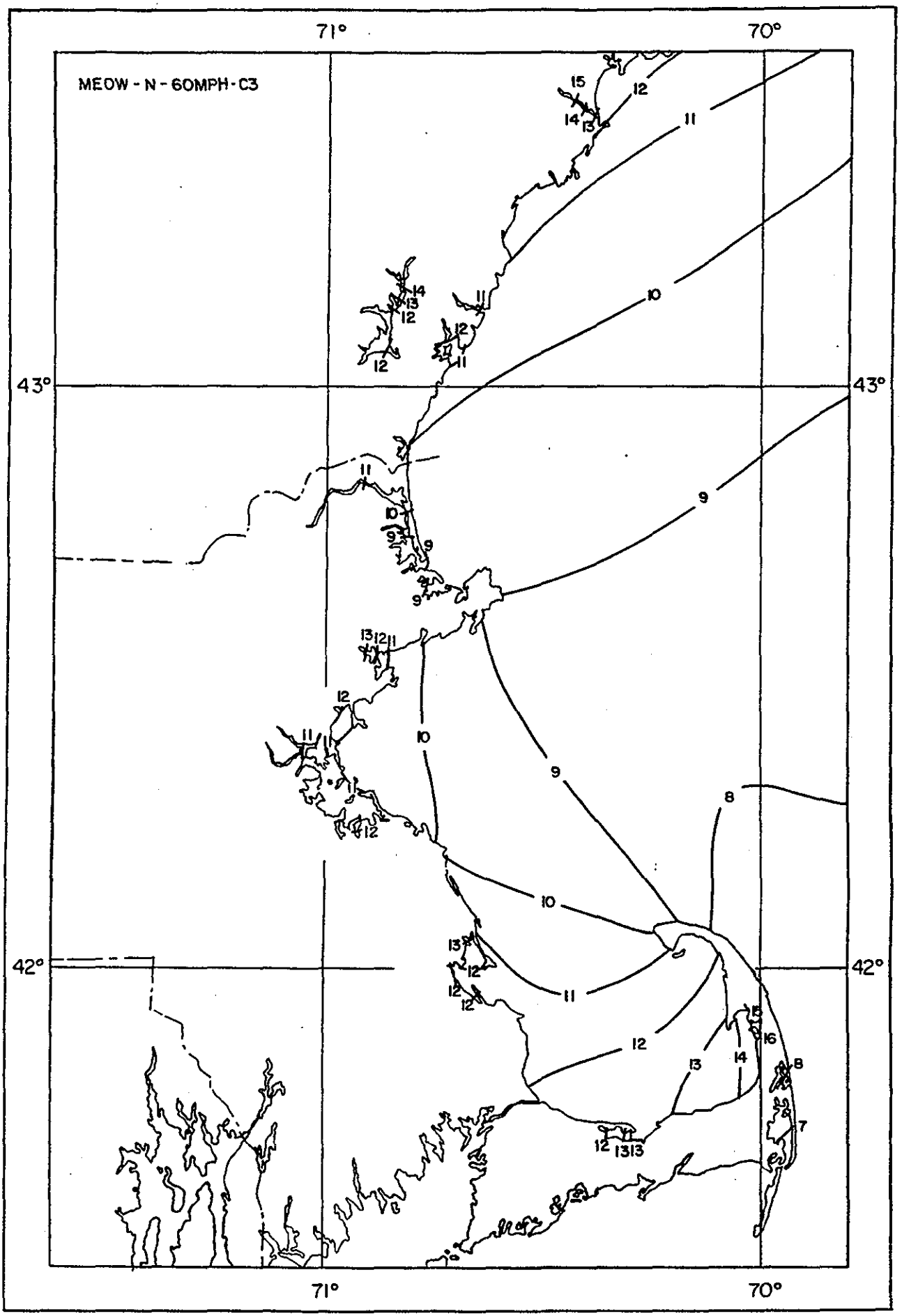
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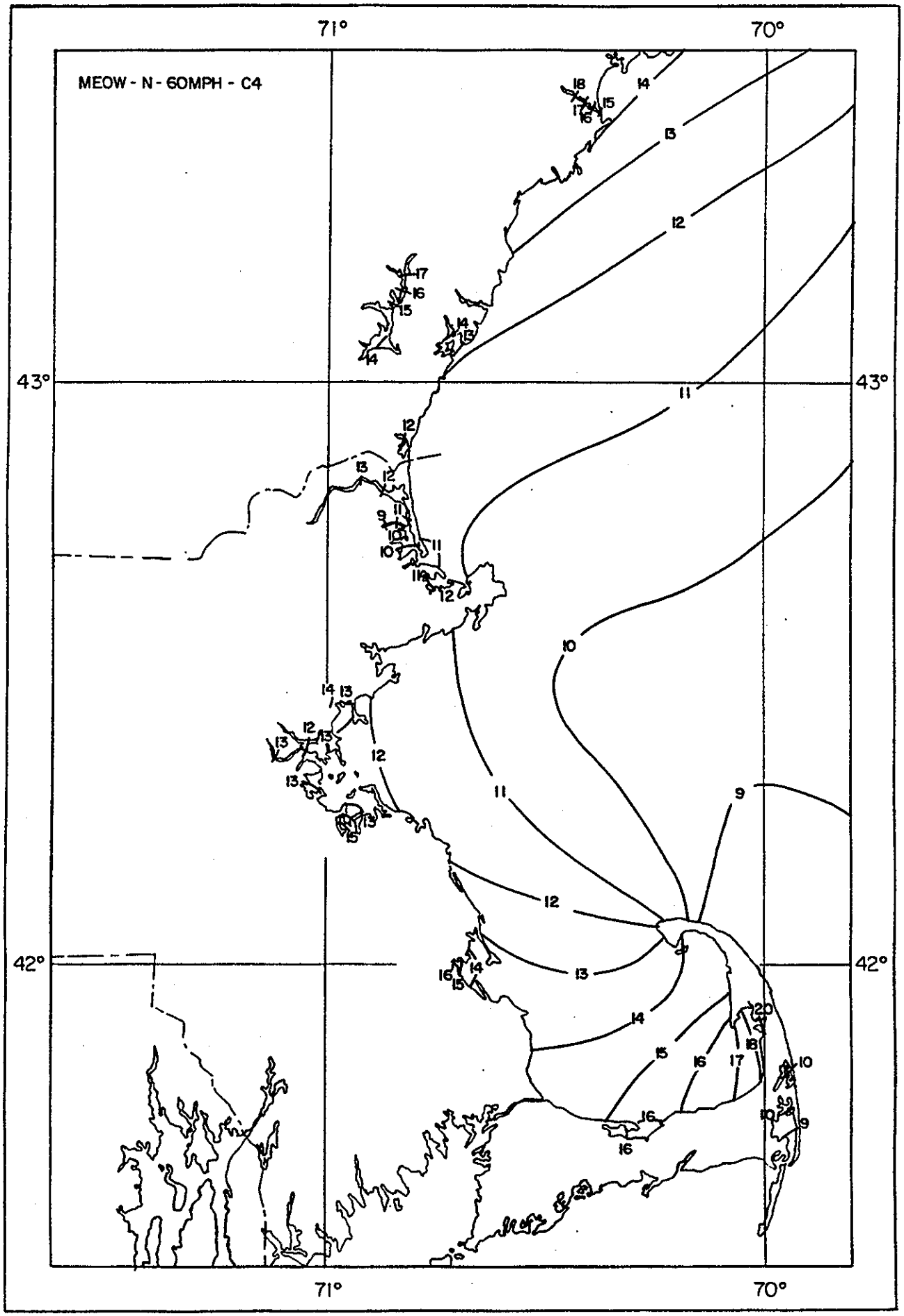
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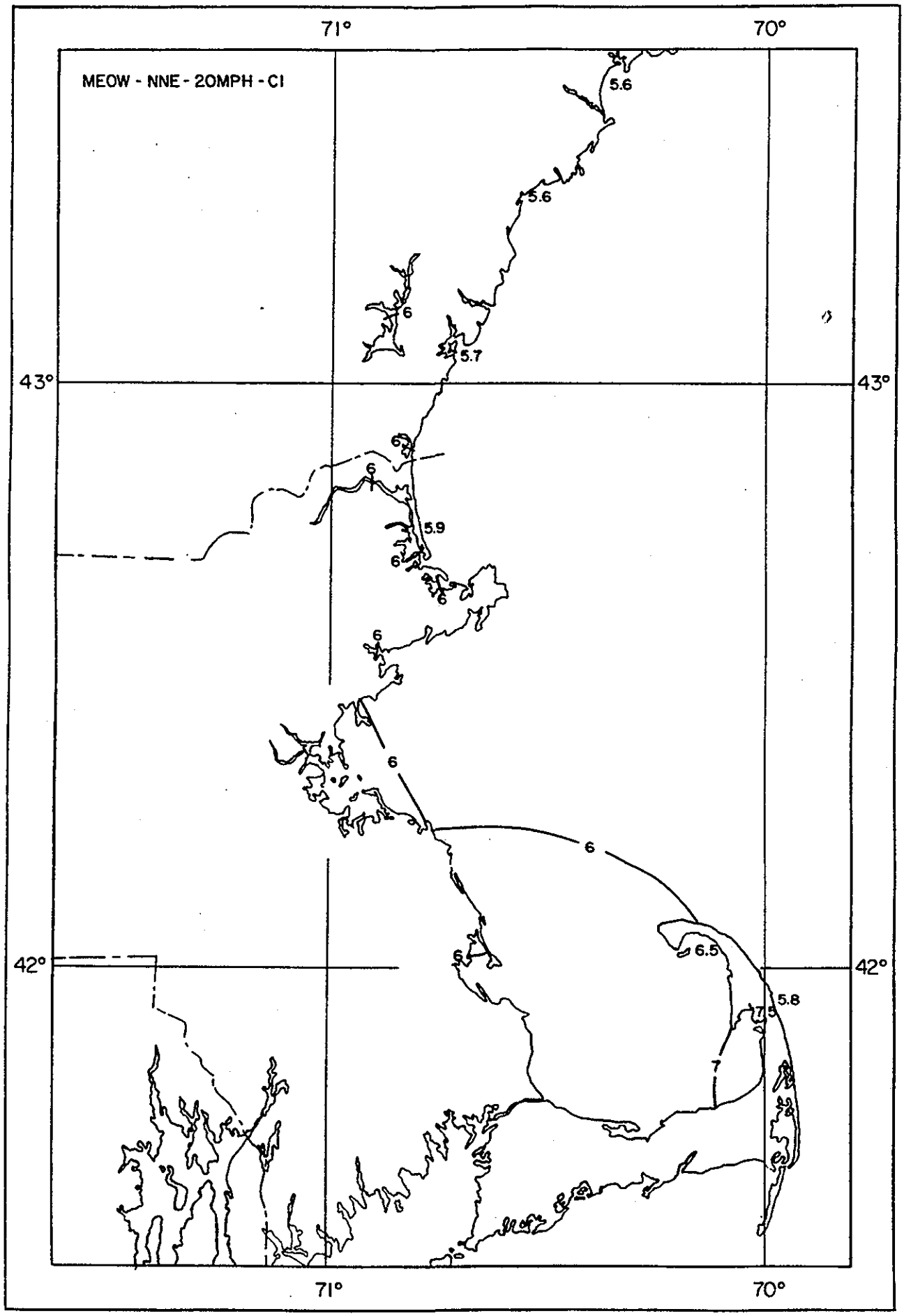
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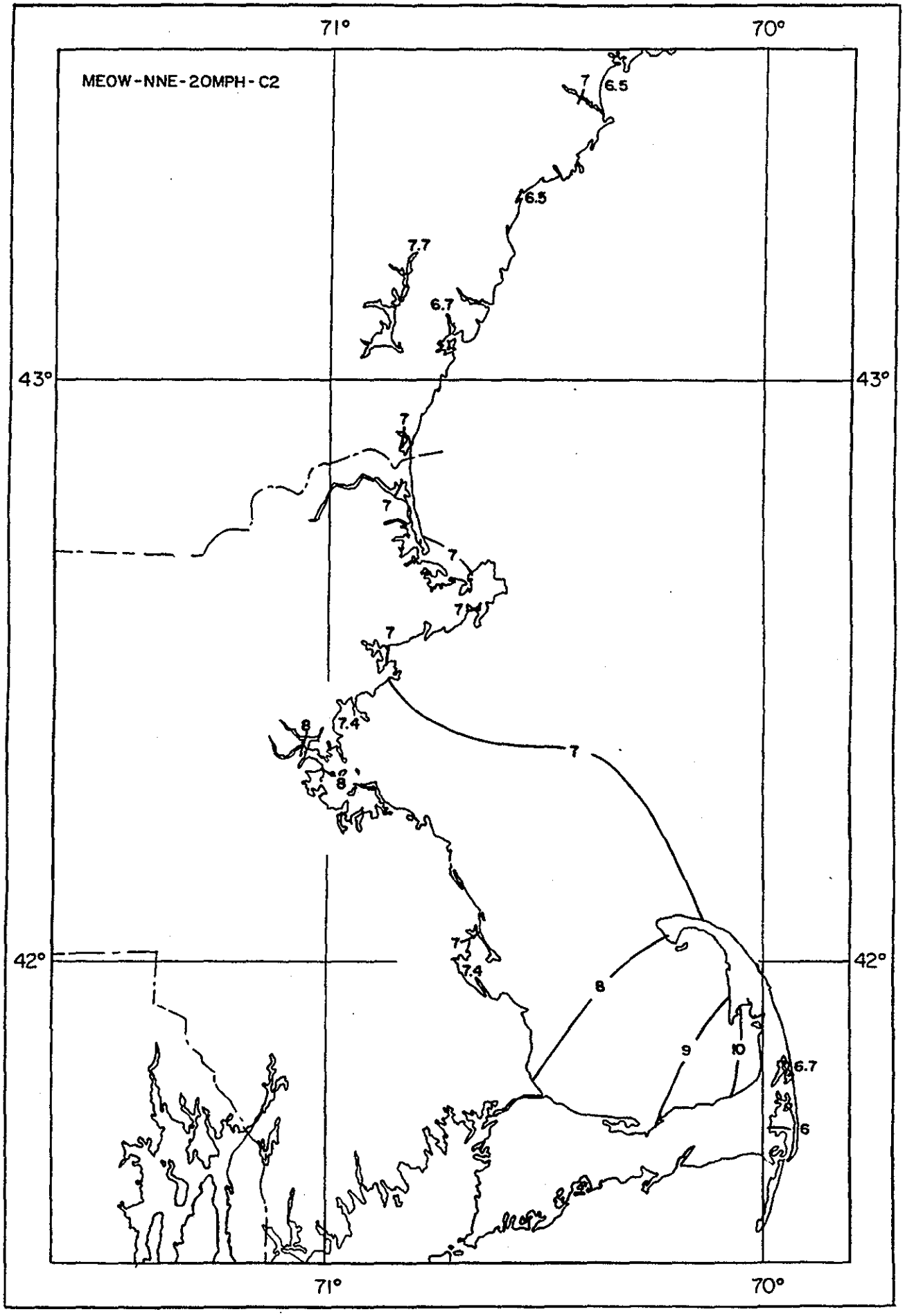
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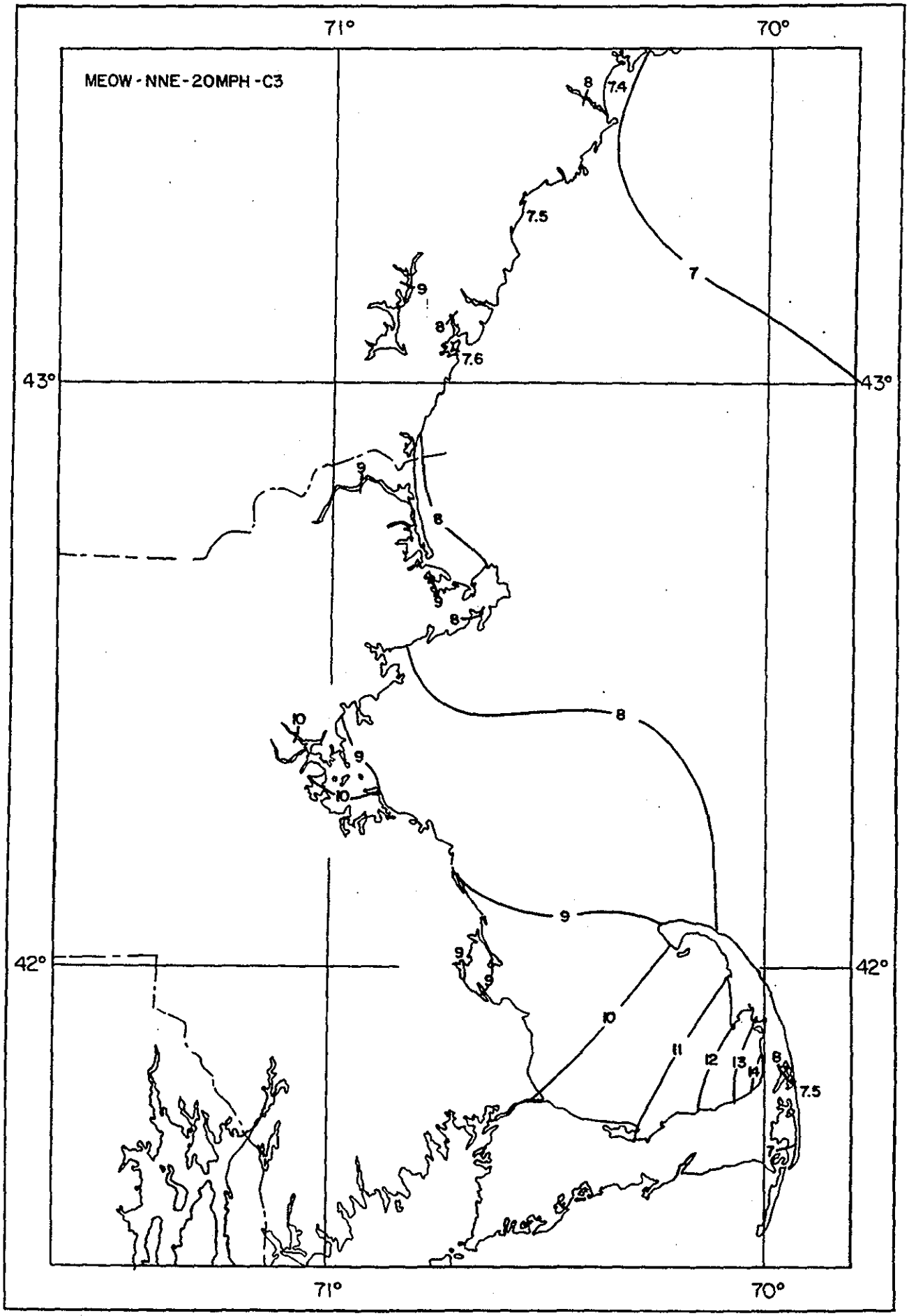
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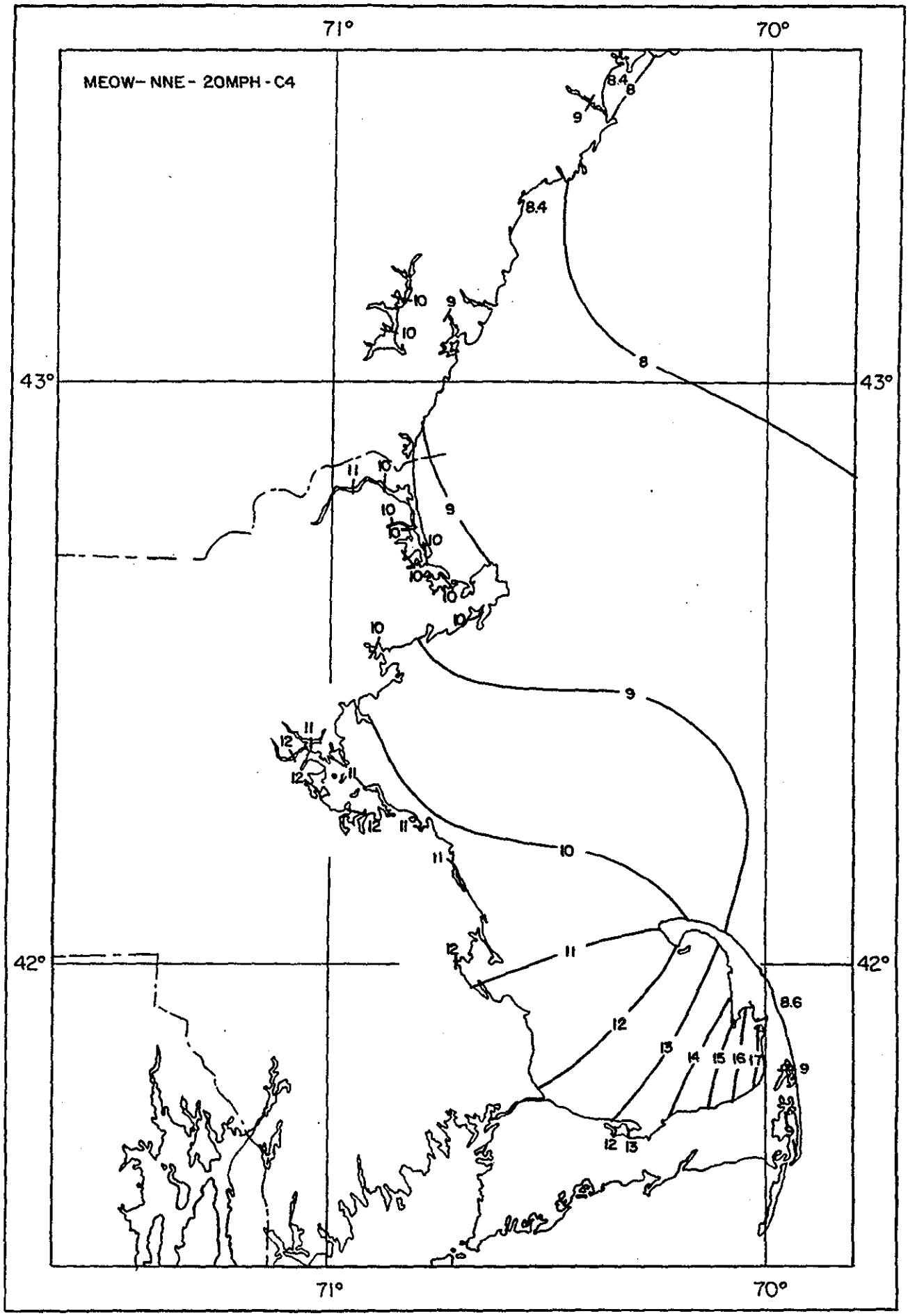
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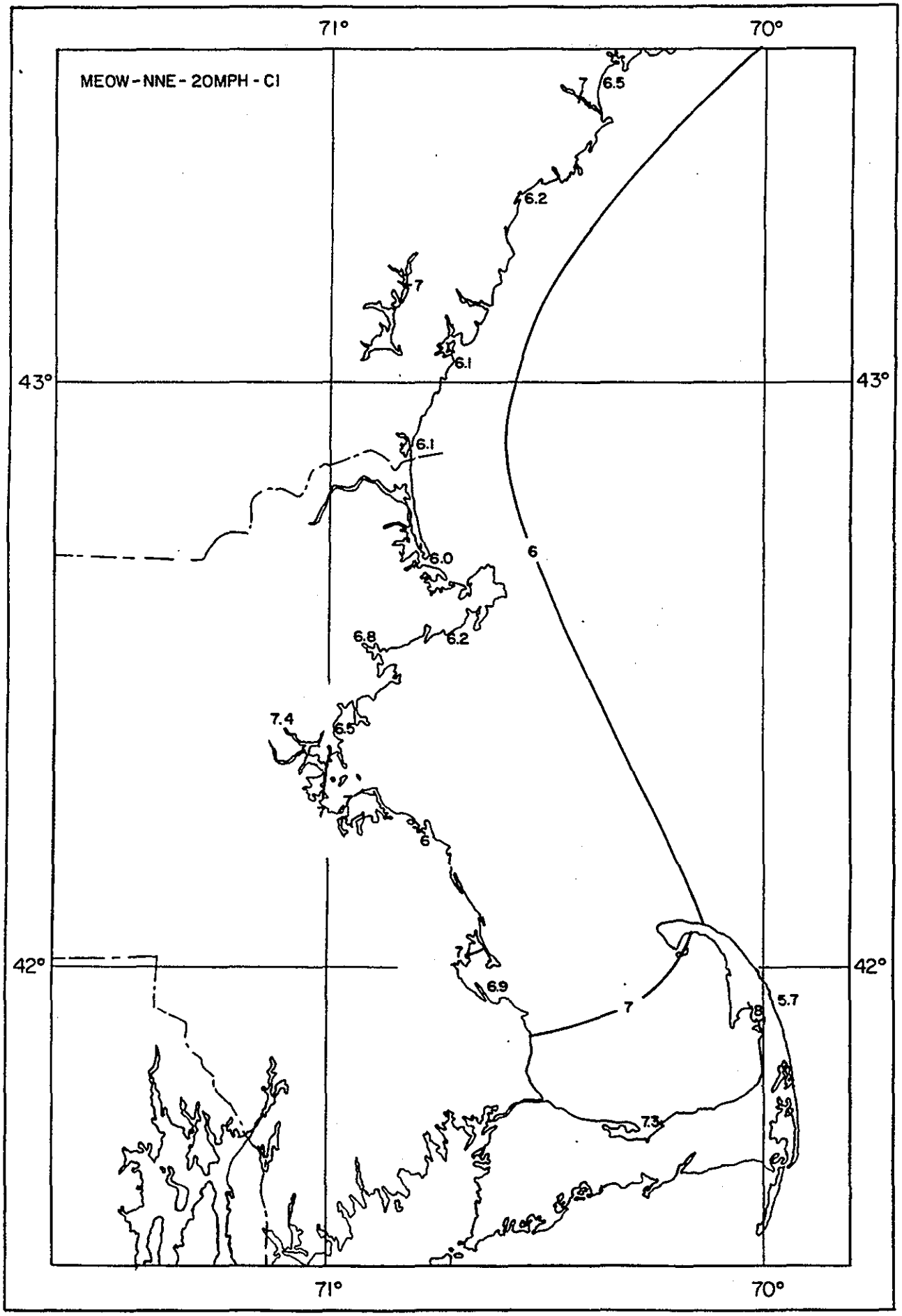
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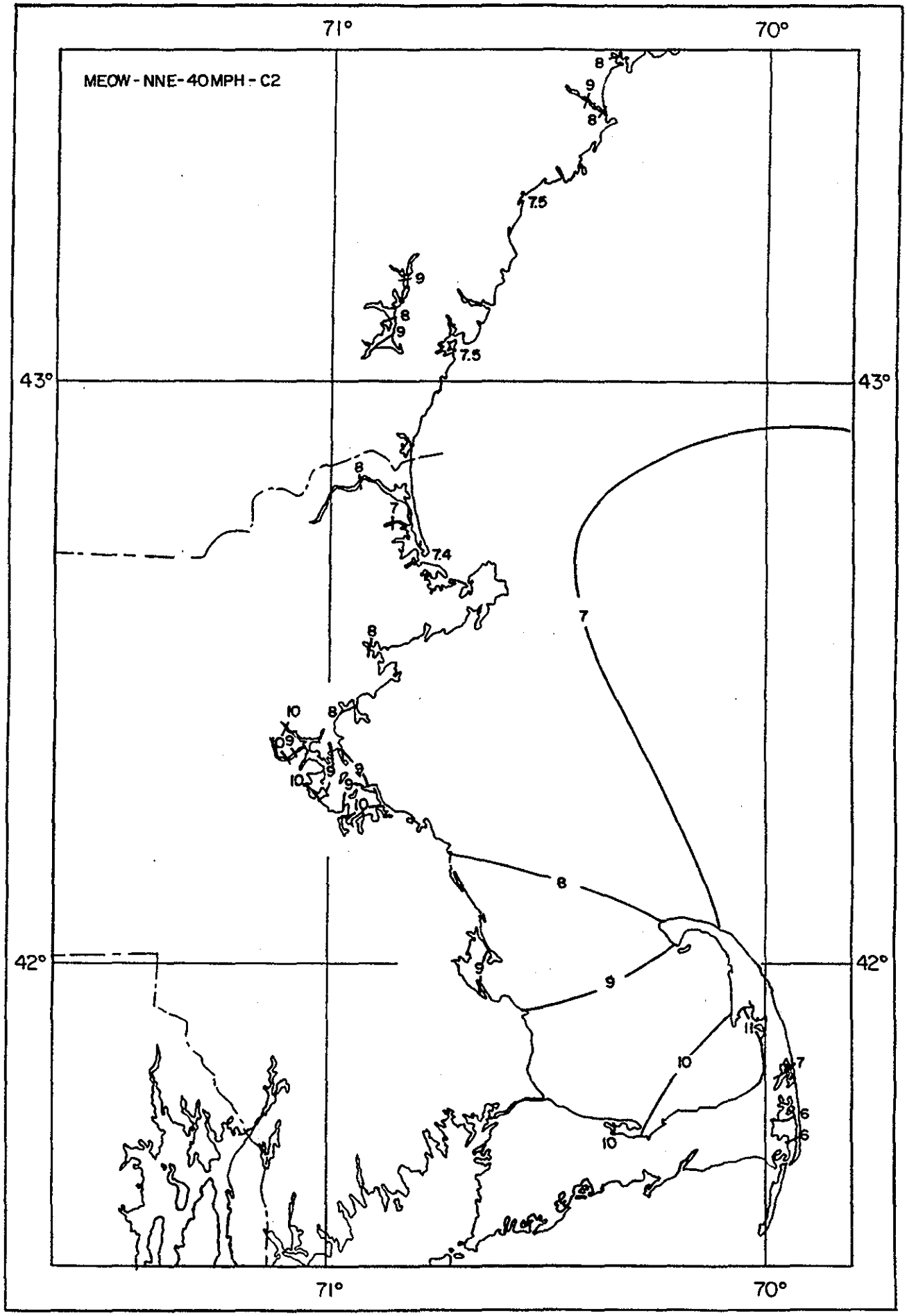
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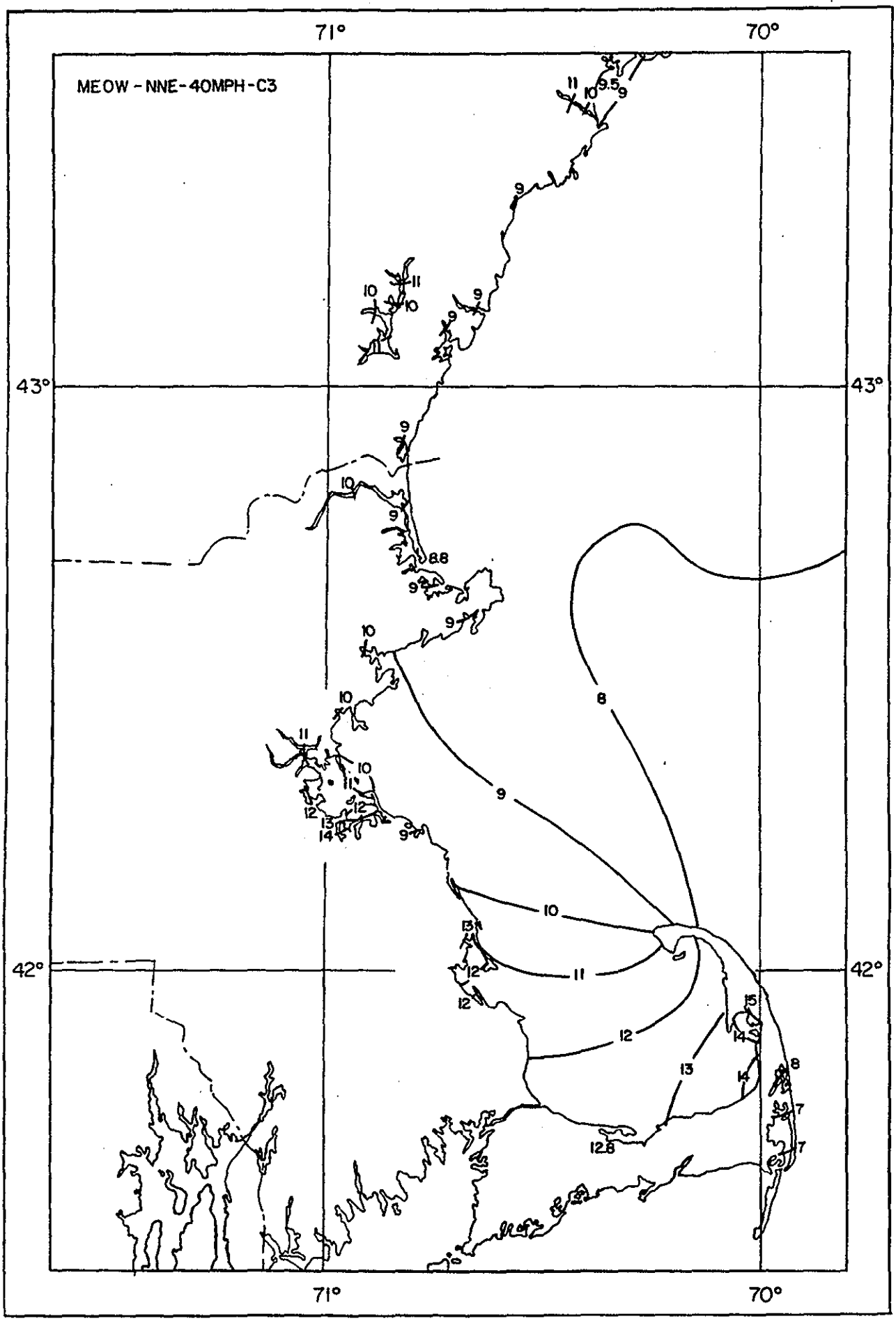
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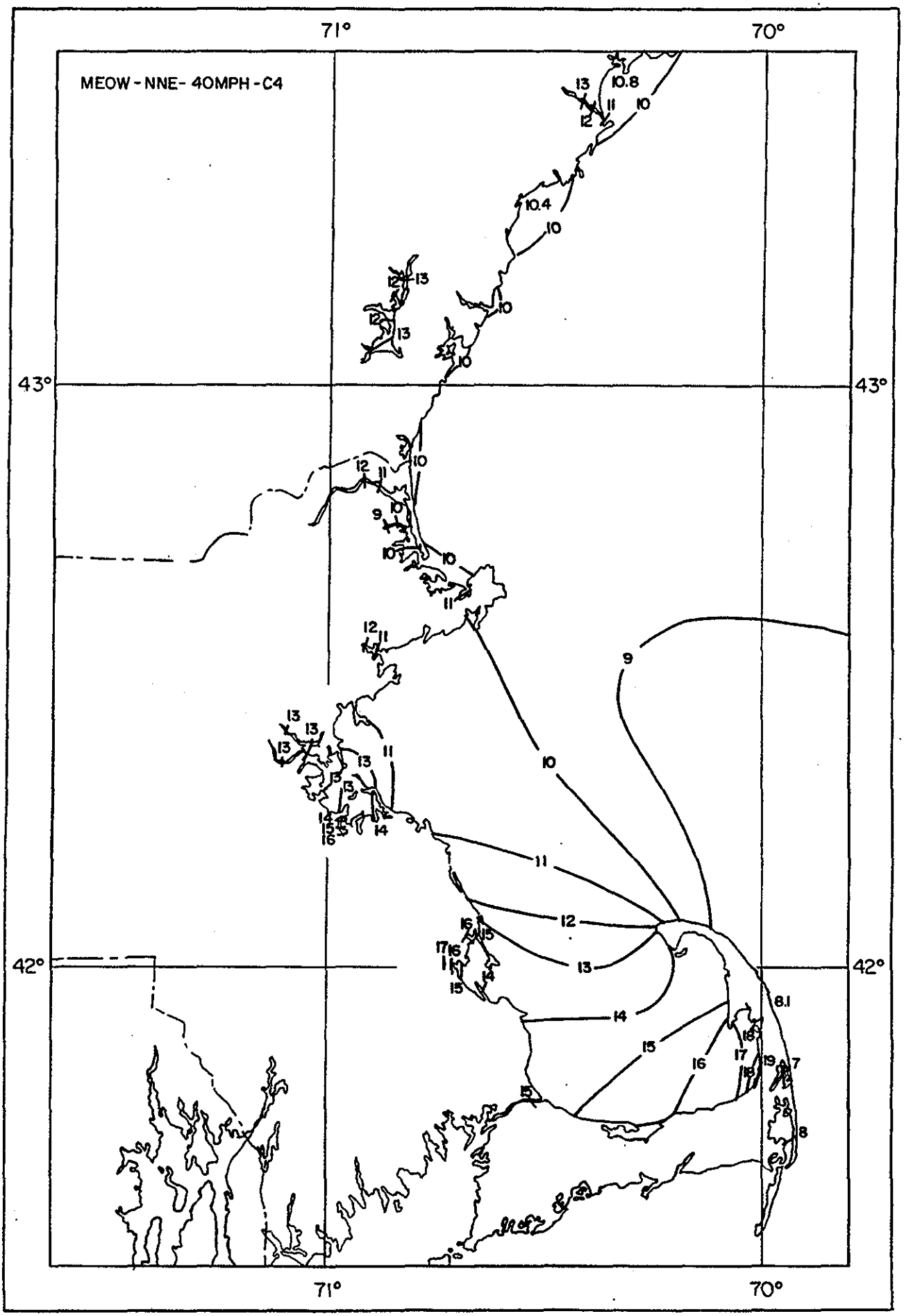
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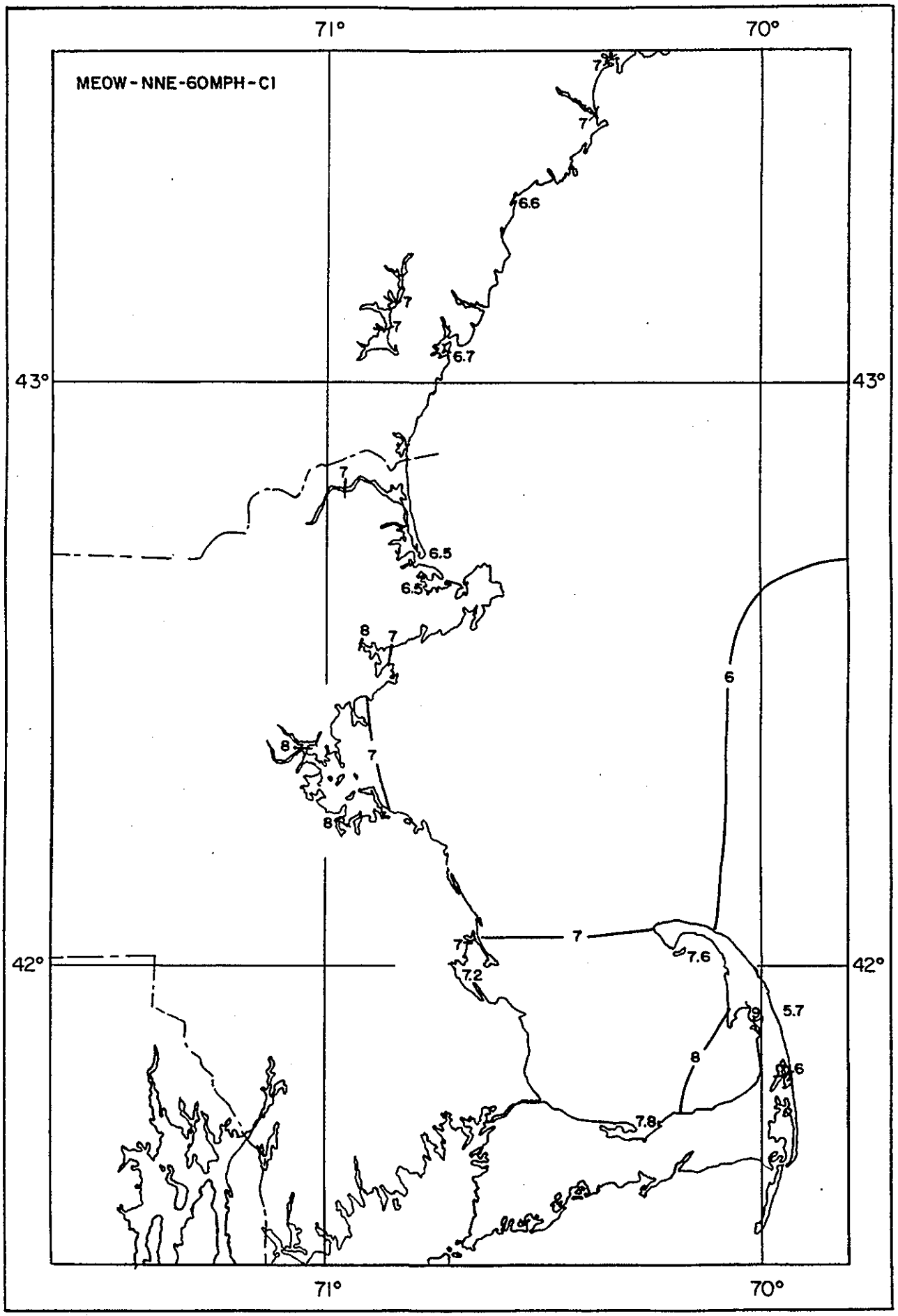
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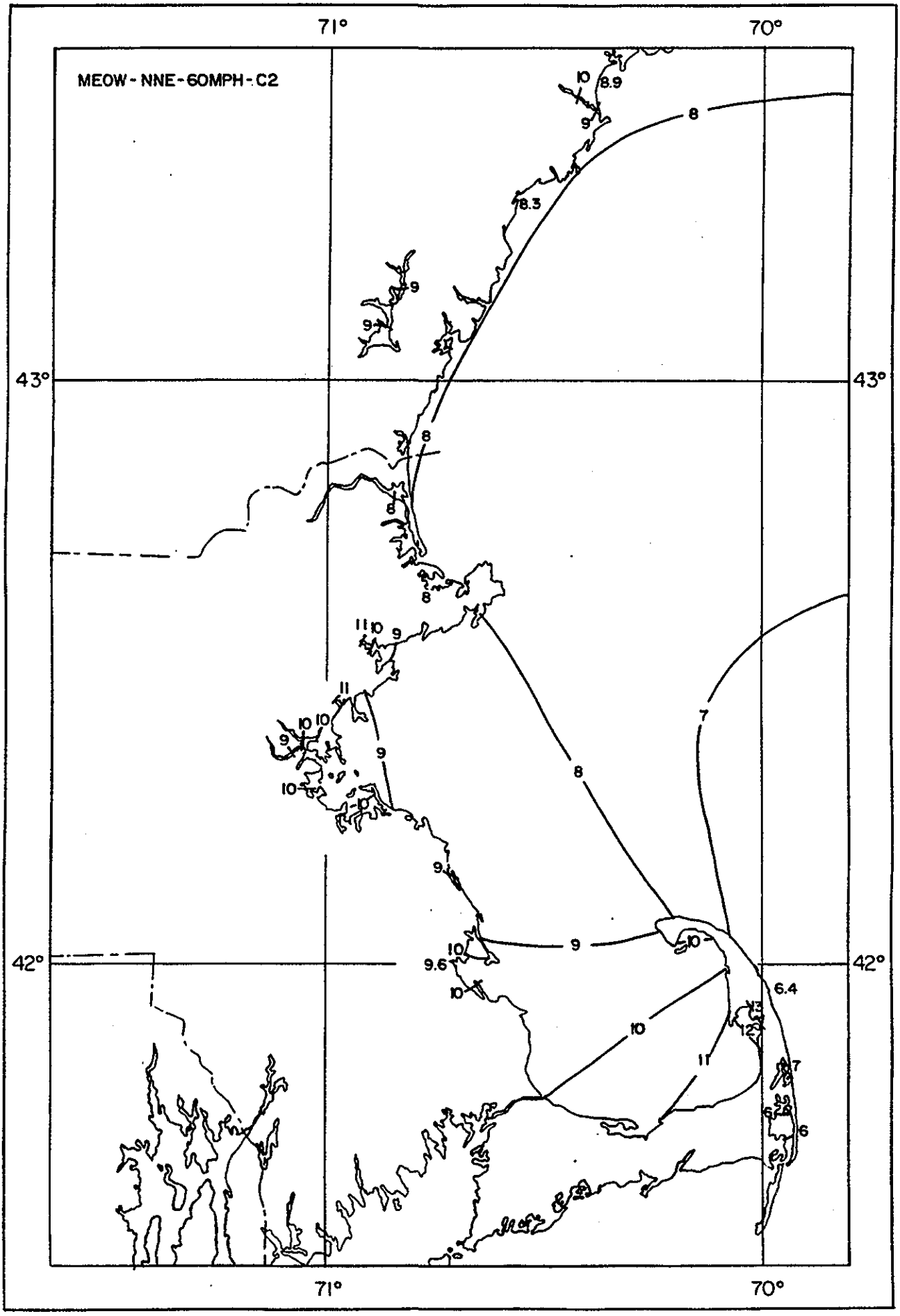
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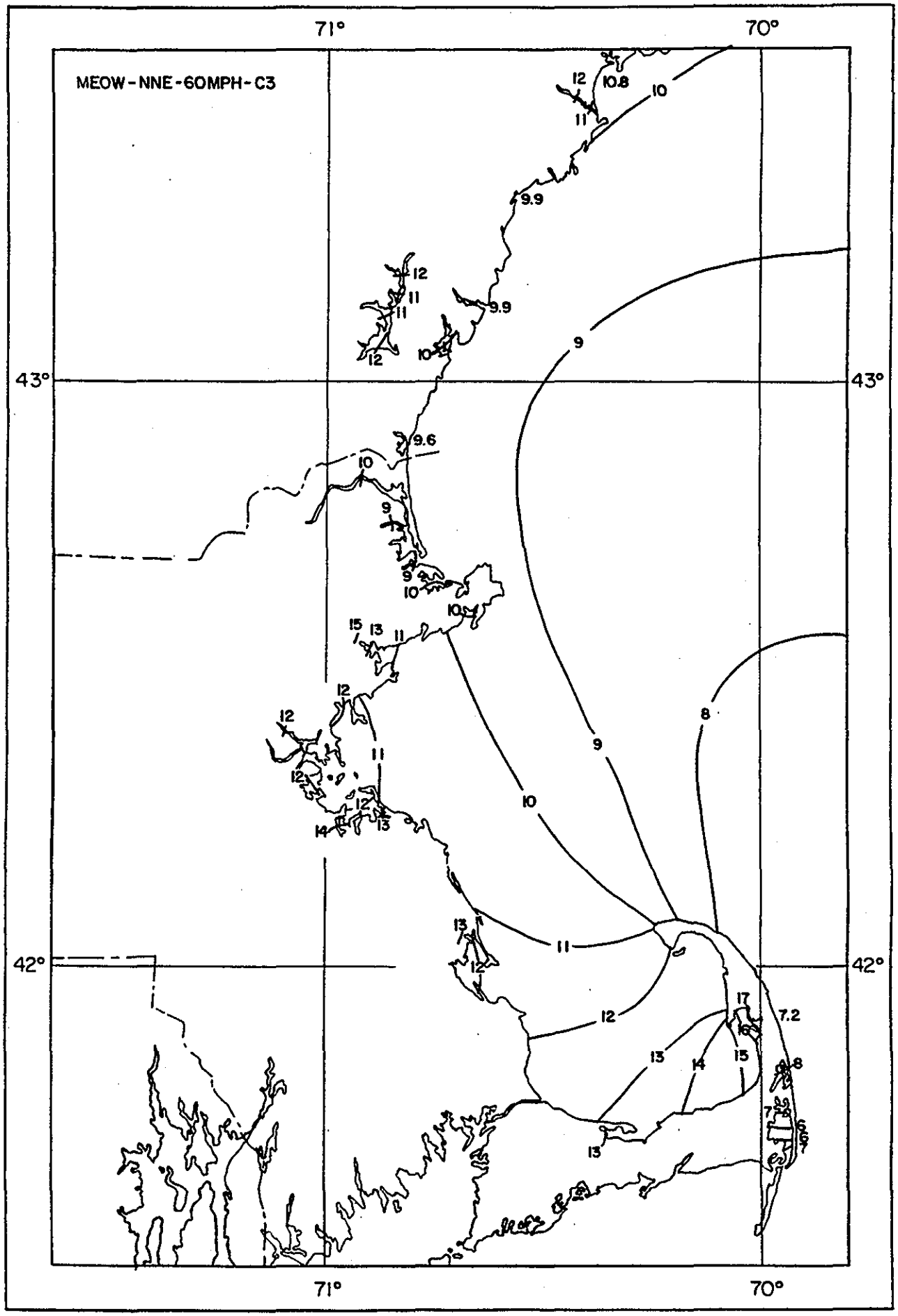
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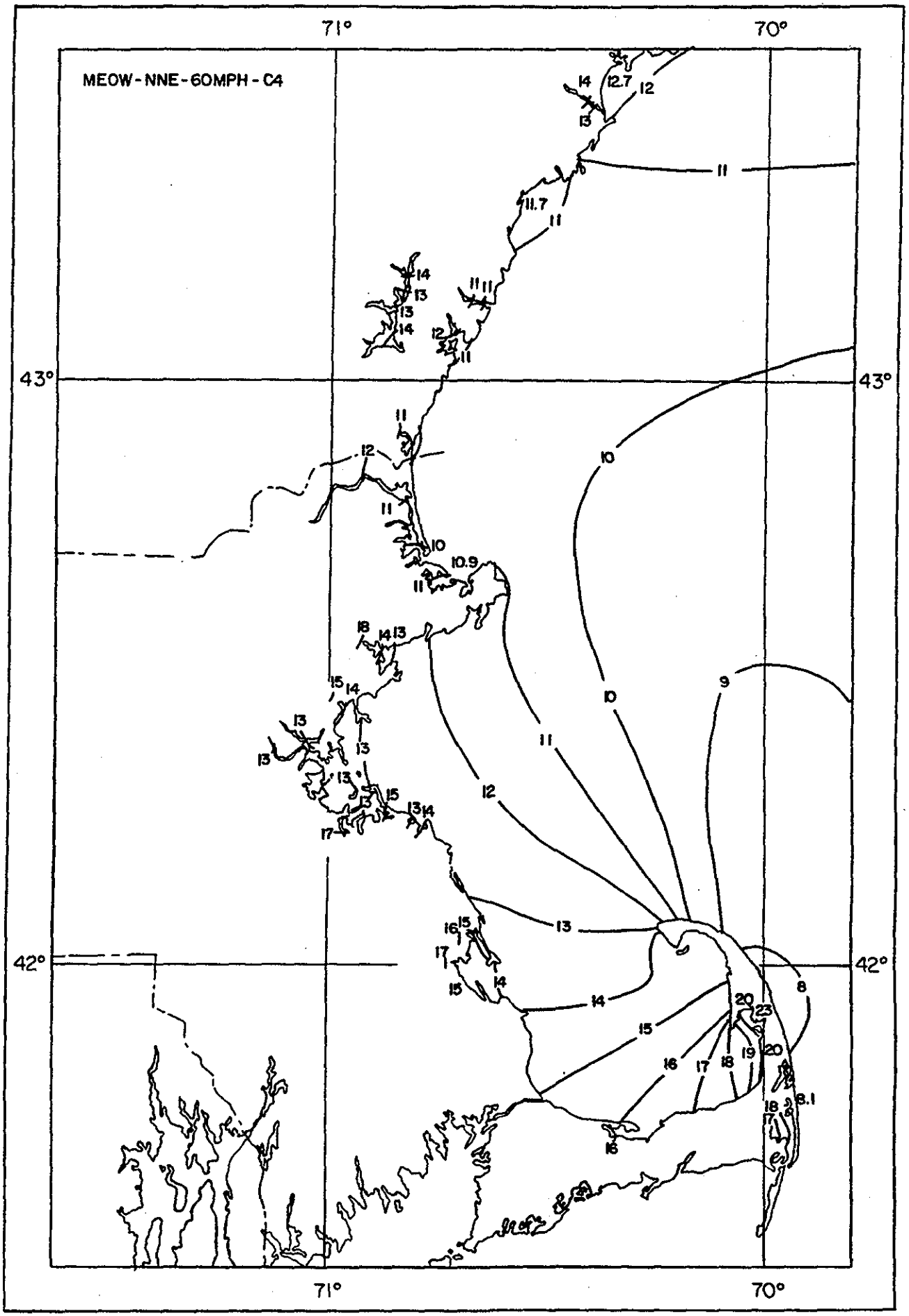
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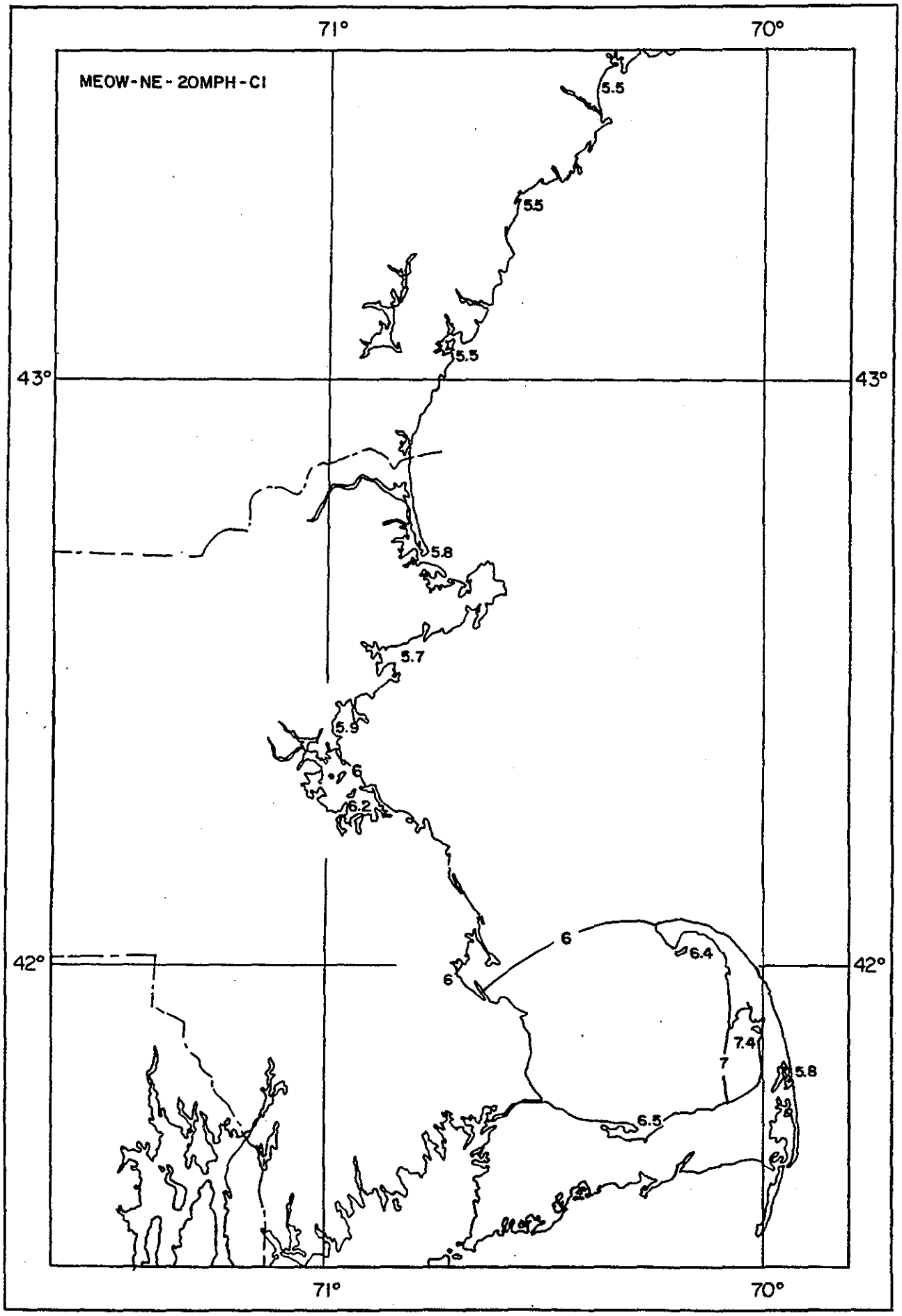
MEOW-NE-20MPH-CI
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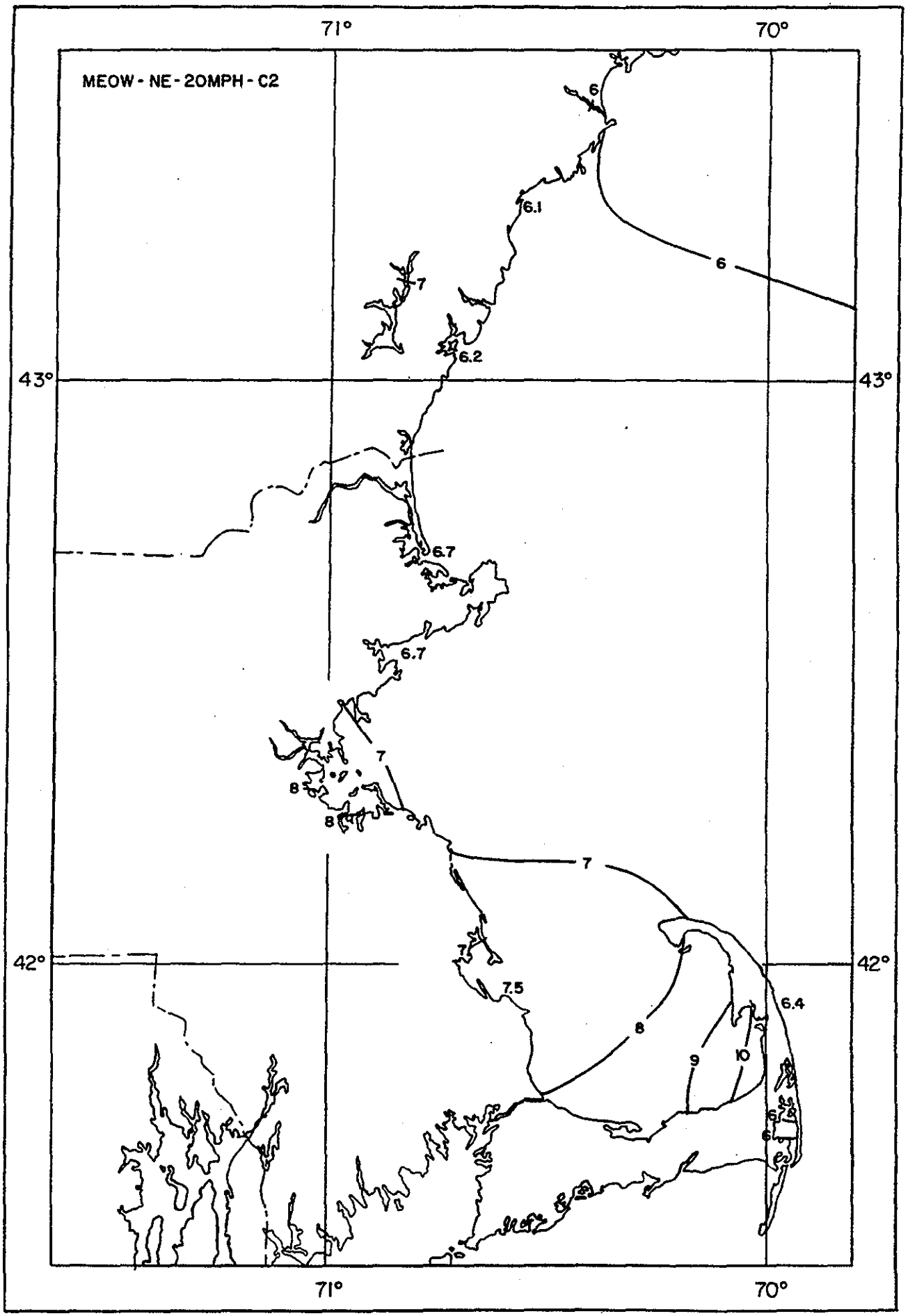
MEOW - NE - 20MPH - C2
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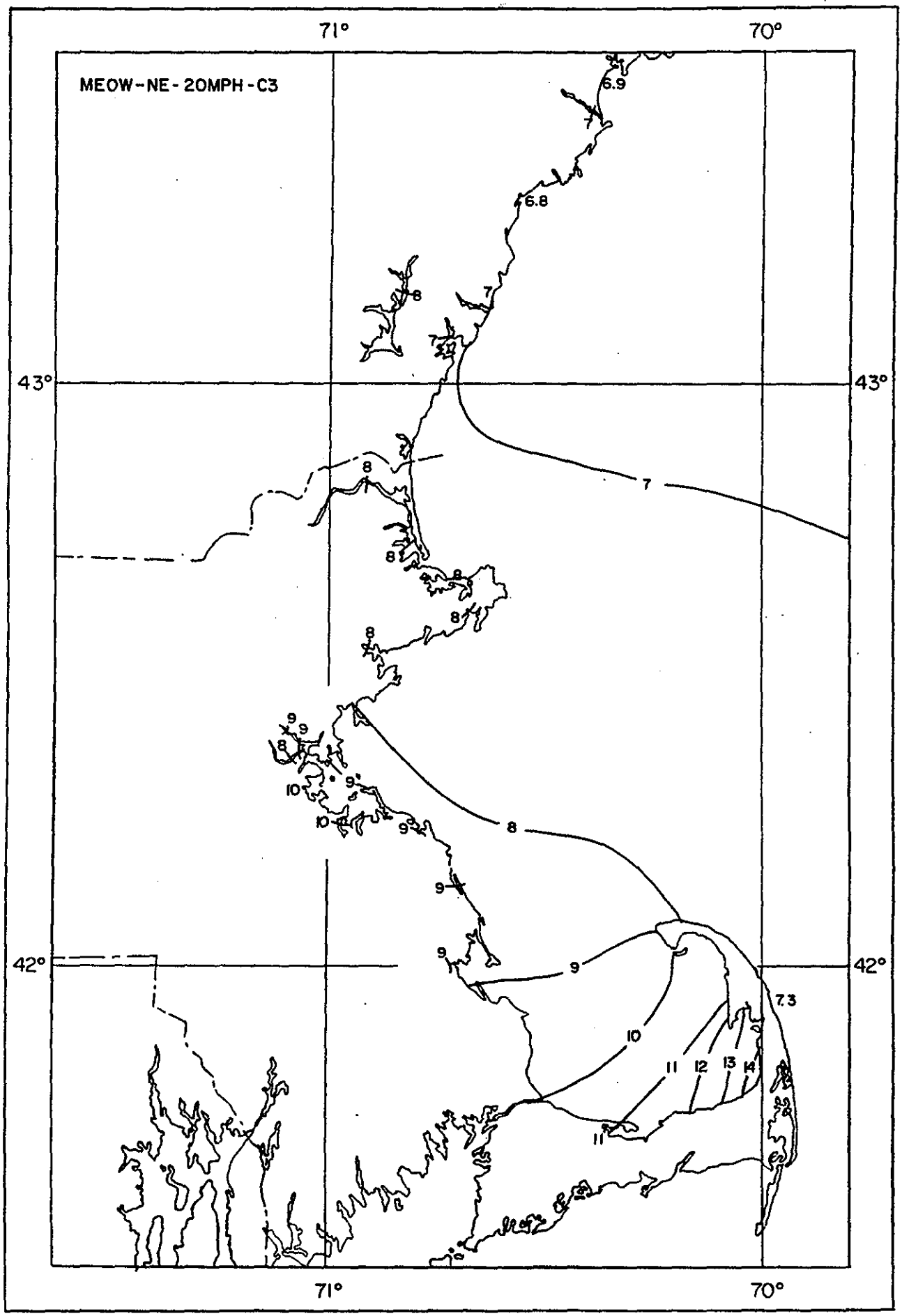
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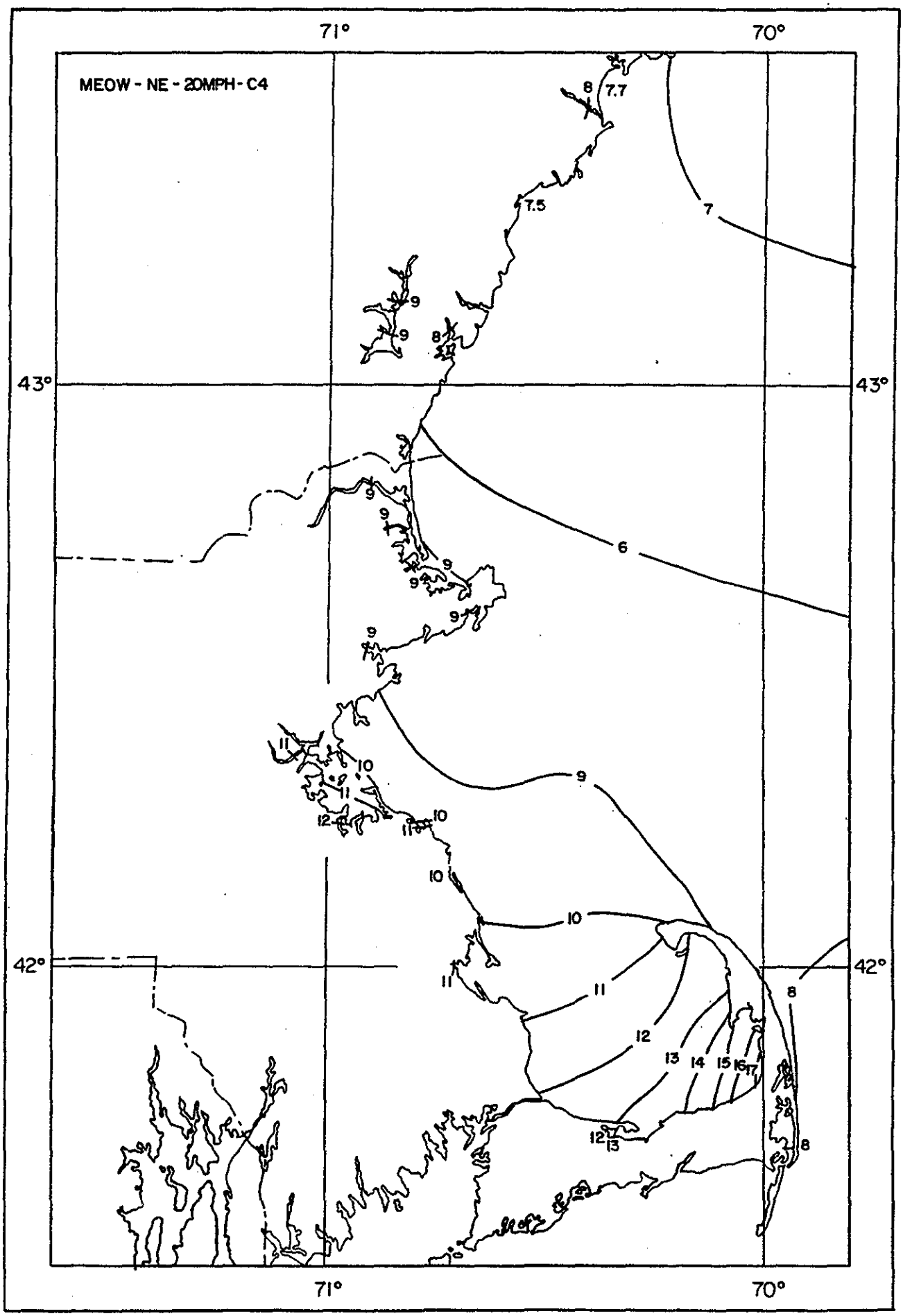
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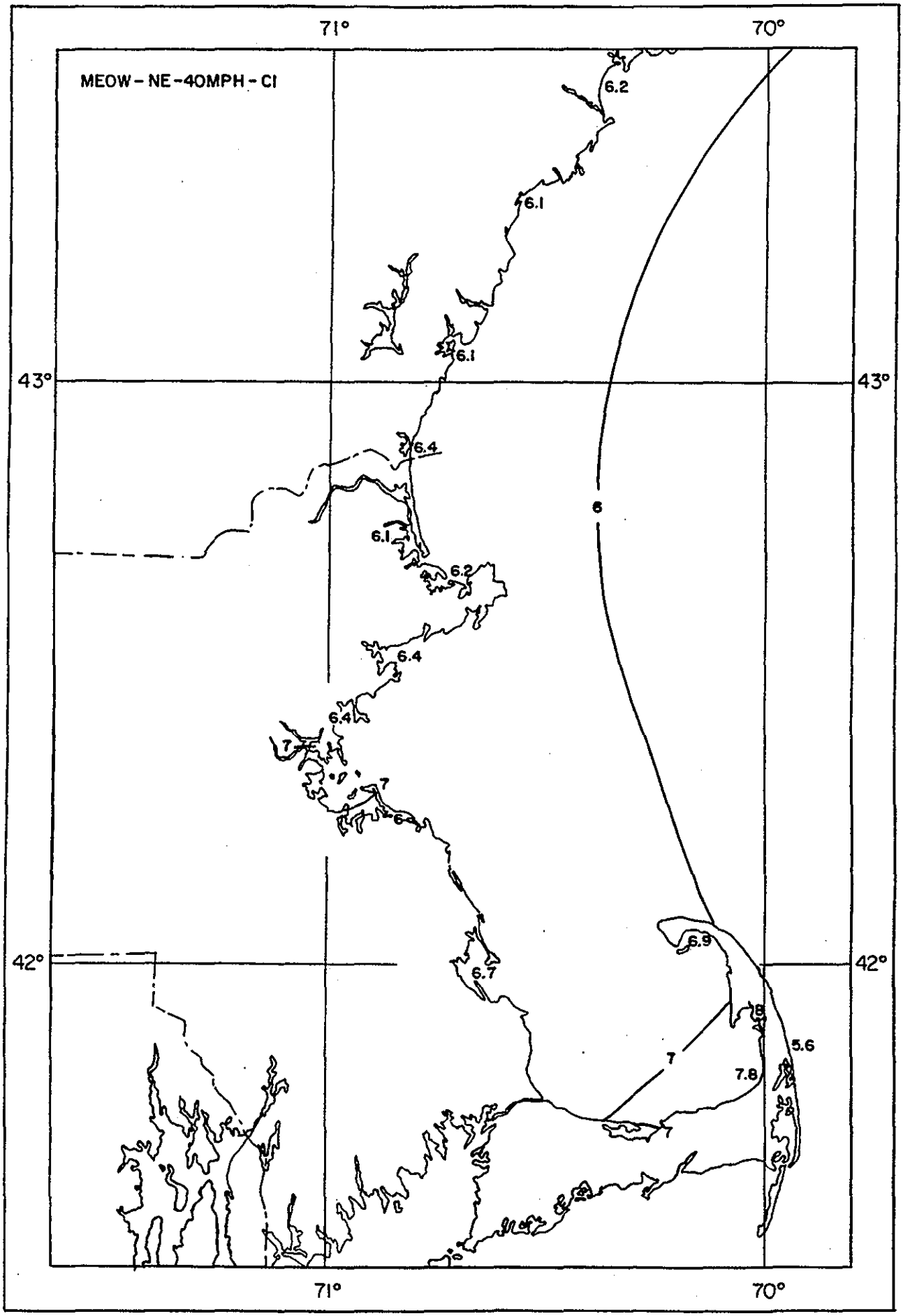
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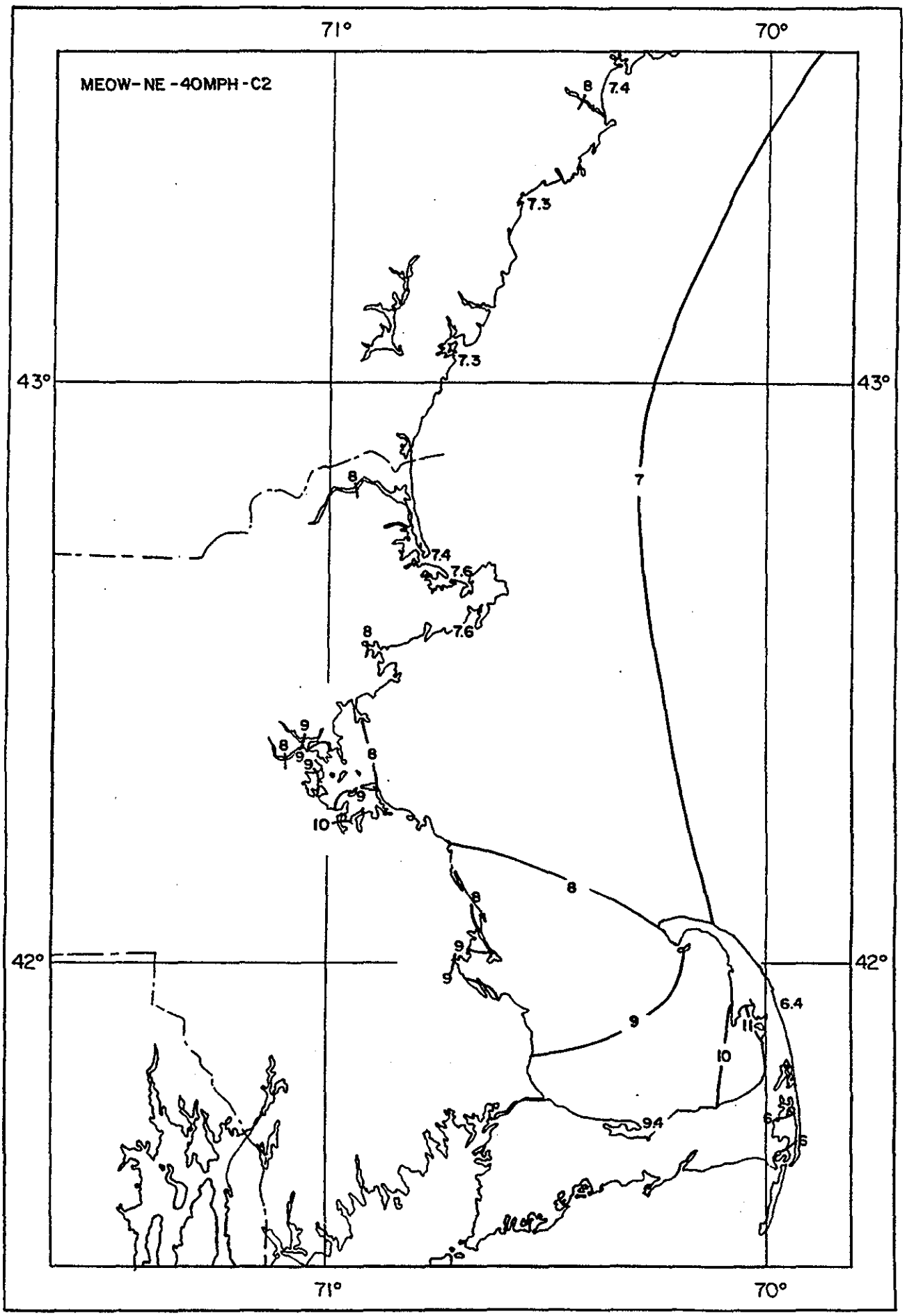
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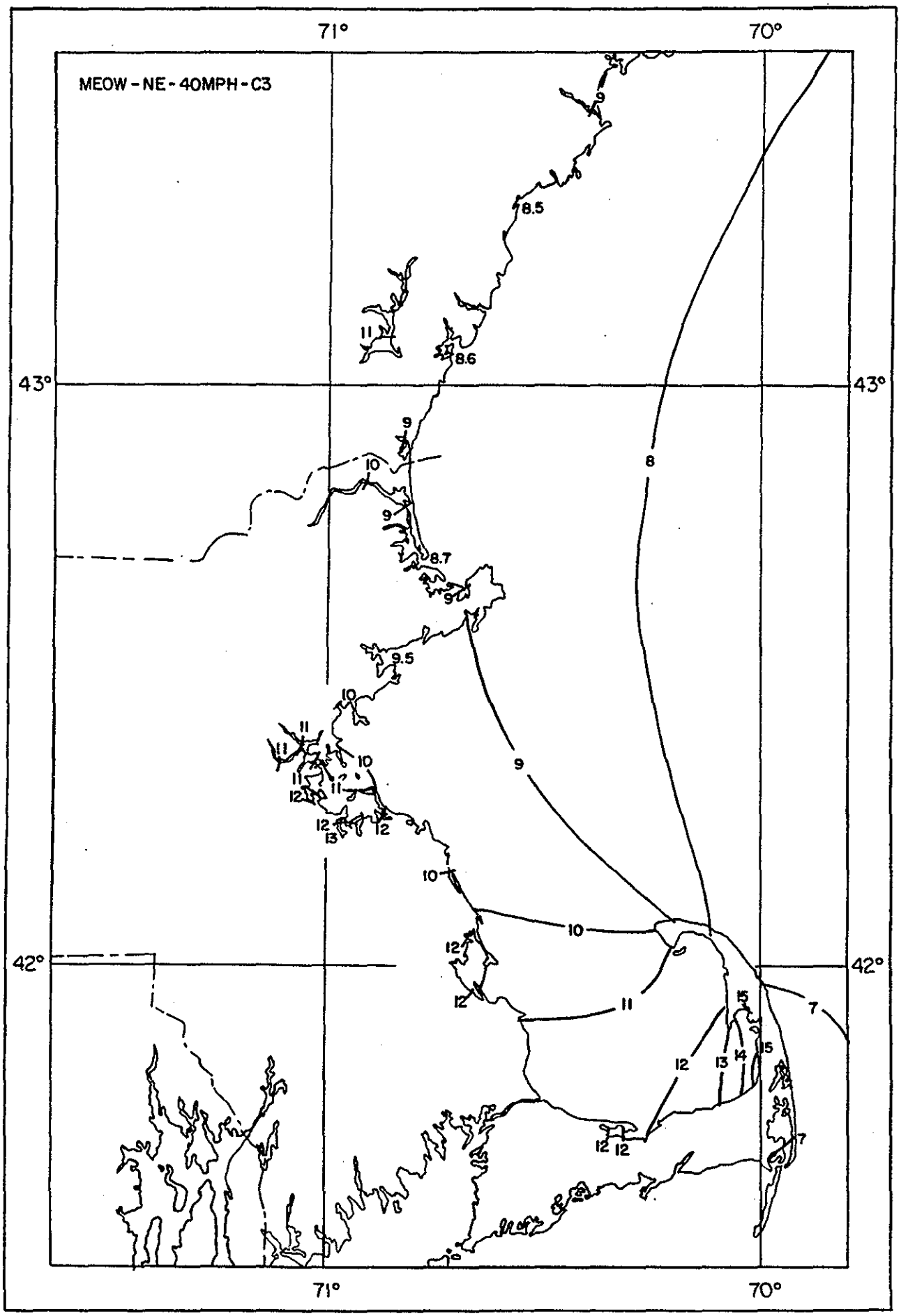
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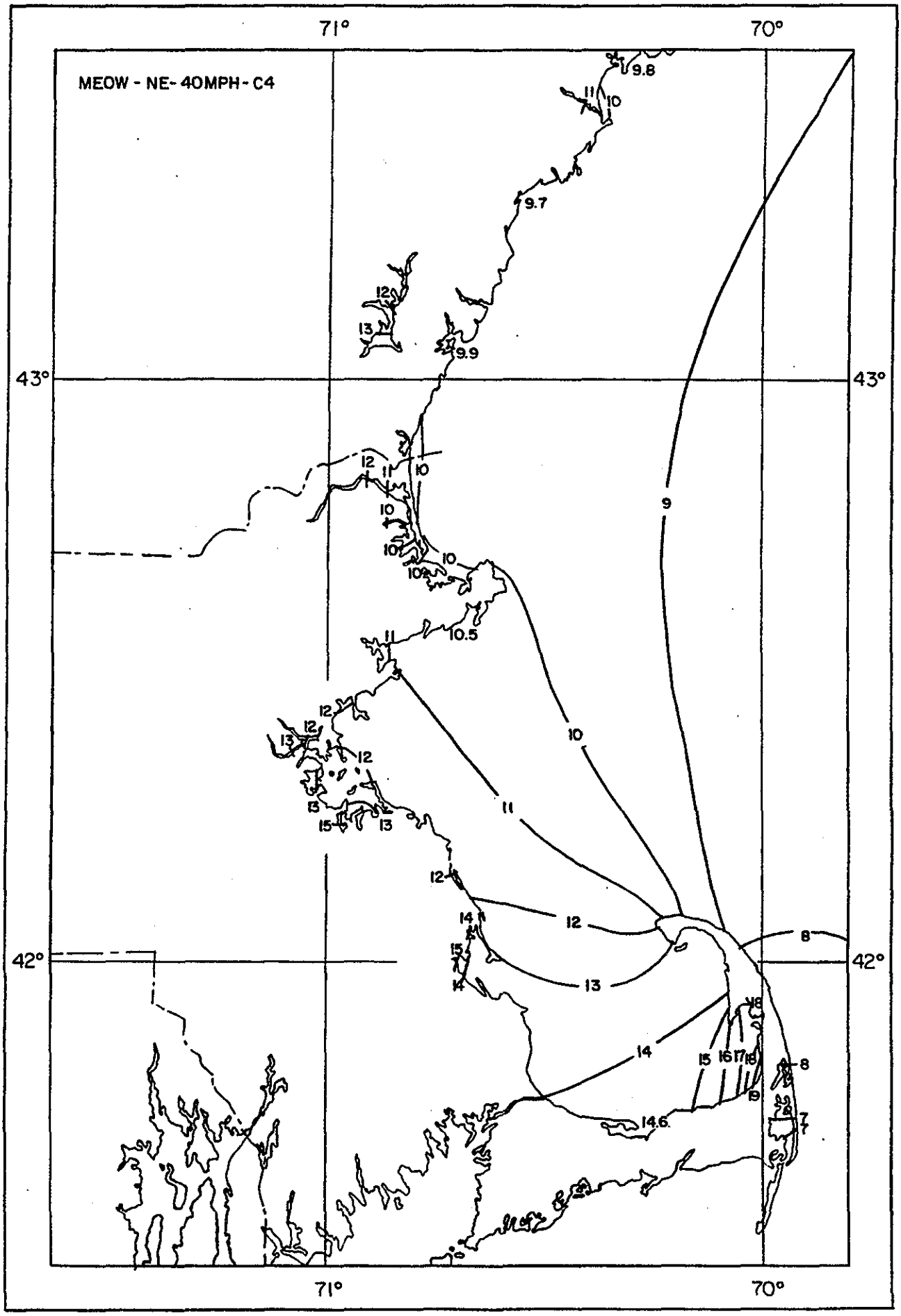
MEOW - NE- 40MPH - C4
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14.6

9. FIGURE CAPTIONS

Figure 1. Grid mesh for SLOSH model for Boston Bay basin.

Figure 2. Tracks of hurricanes (1886-1993) passing within 125 statute miles of Boston, Massachusetts: northbound storms only.

Figure 3. Same as Figure 2, but north-northeast moving storms only.

Figure 4. Same as Figure 2, but northeastward moving storms only.

Figure 5. Tracks of the hypothetical hurricanes that were used for calculating the maximum envelope of water (MEOW). Dots are eye positions at six-hour increments (at 20 mph). Tracks are identified by the distance in miles to the left side (LS) or right side (RS) of the track through Boston, Massachusetts. Hurricane symbol is at point of landfall of eye of storm. Storms heading west-northwestward (WNW) only.

Figure 6. Same as Figure 5, but only for northwestbound (NW) storms.

Figure 7. Same as Figure 5, but for north-northwestward (NNW) moving storms only.

Figure 8. Same as Figure 5, but only for northbound (N) storms.

Figure 9. Same as Figure 5, but for north-northeastward (NNE) moving storms only.

Figure 10. Same as Figure 5, except for northeastbound (NE) storms only.

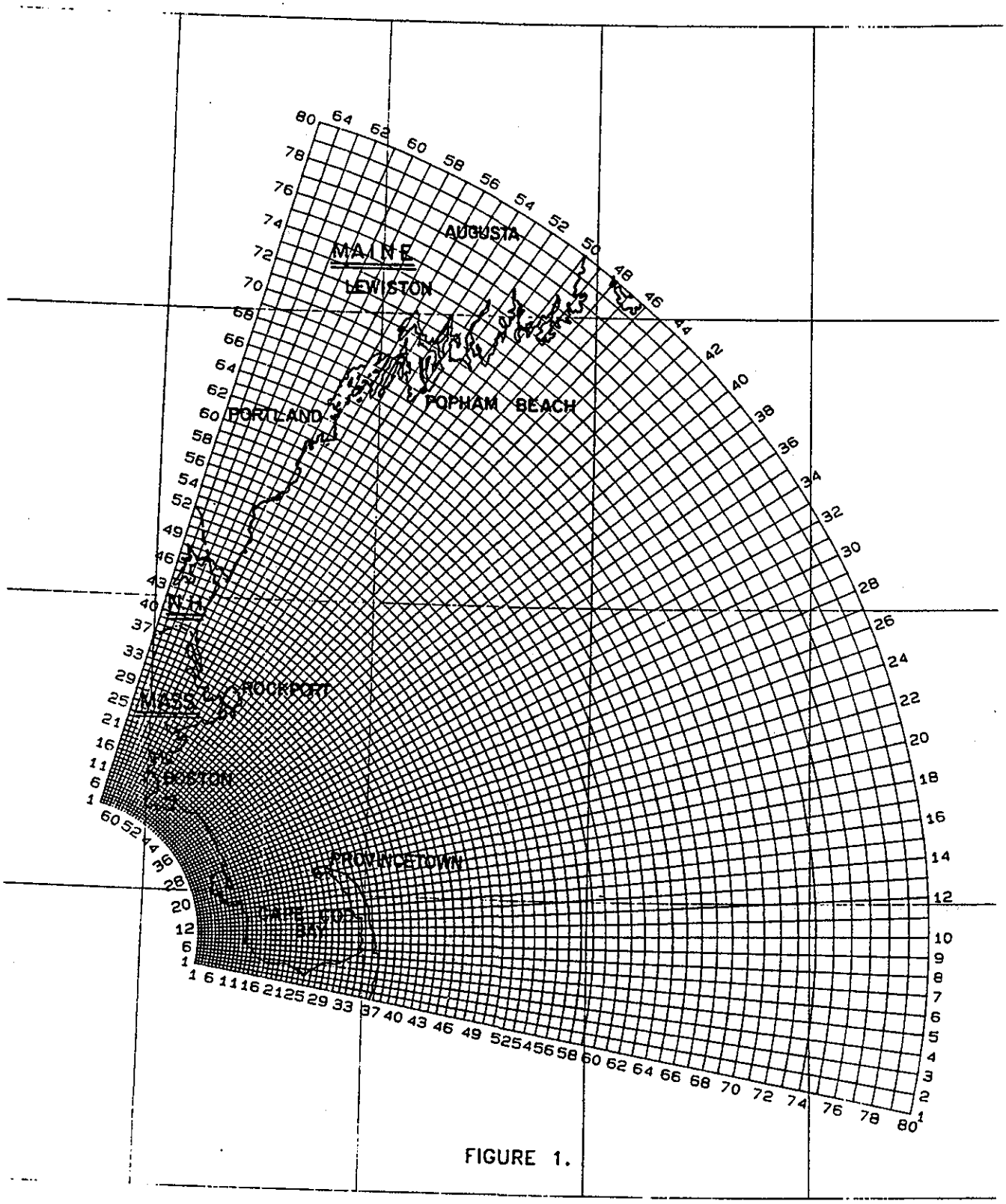
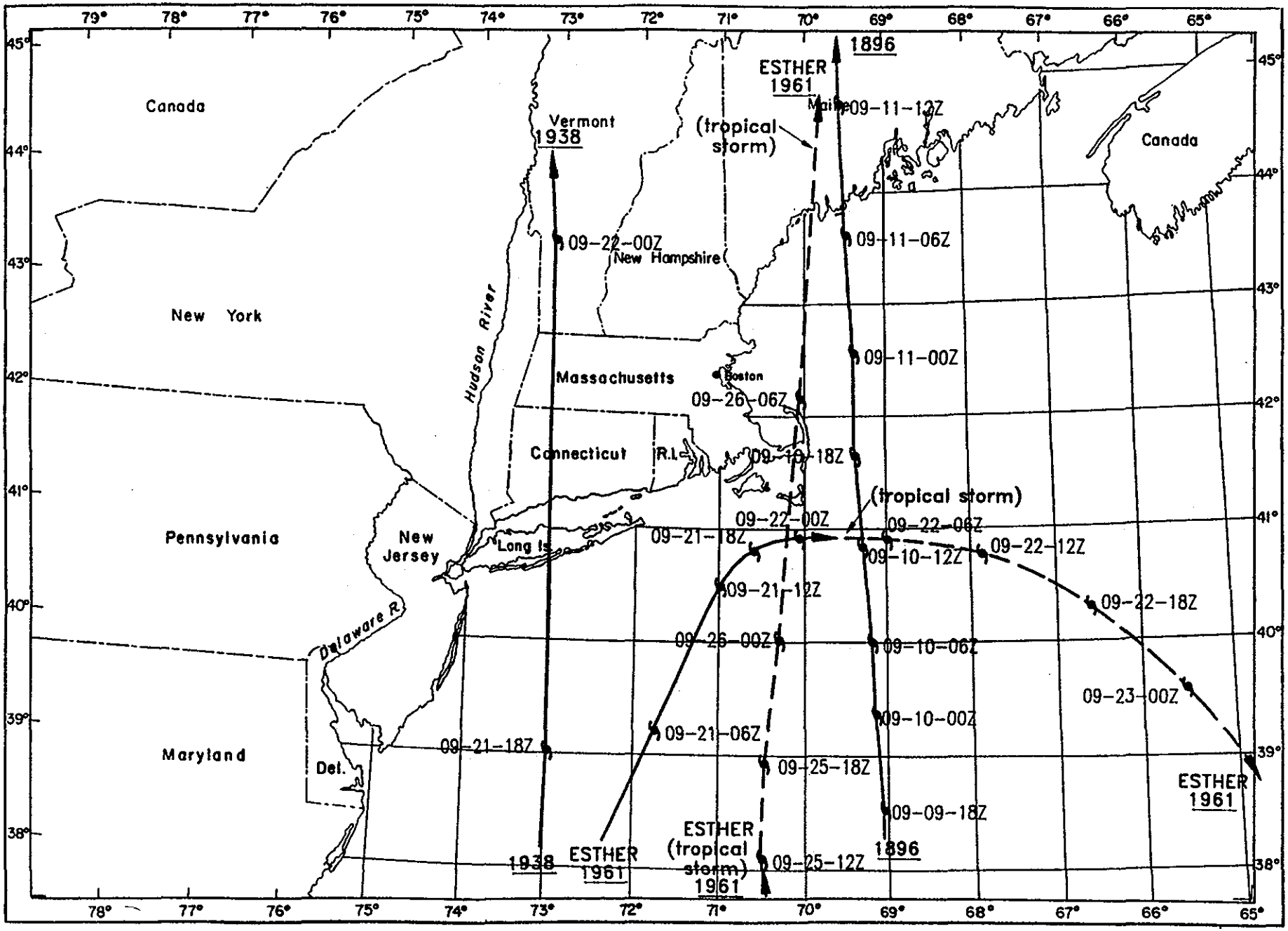

MAINE
AUGUSTA
LEWISTON
POPHAM BEACH
PORTLAND
N.H.
MASS.
ROCKPORT
BOSTON
PROVINCETOWN
WHITE HILL BAY

FIGURE 1.


Canada
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Canada
1938
ESTHER 1961
1896
(tropical storm)
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09-21-18Z
09-21-12Z
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FIGURE 2.

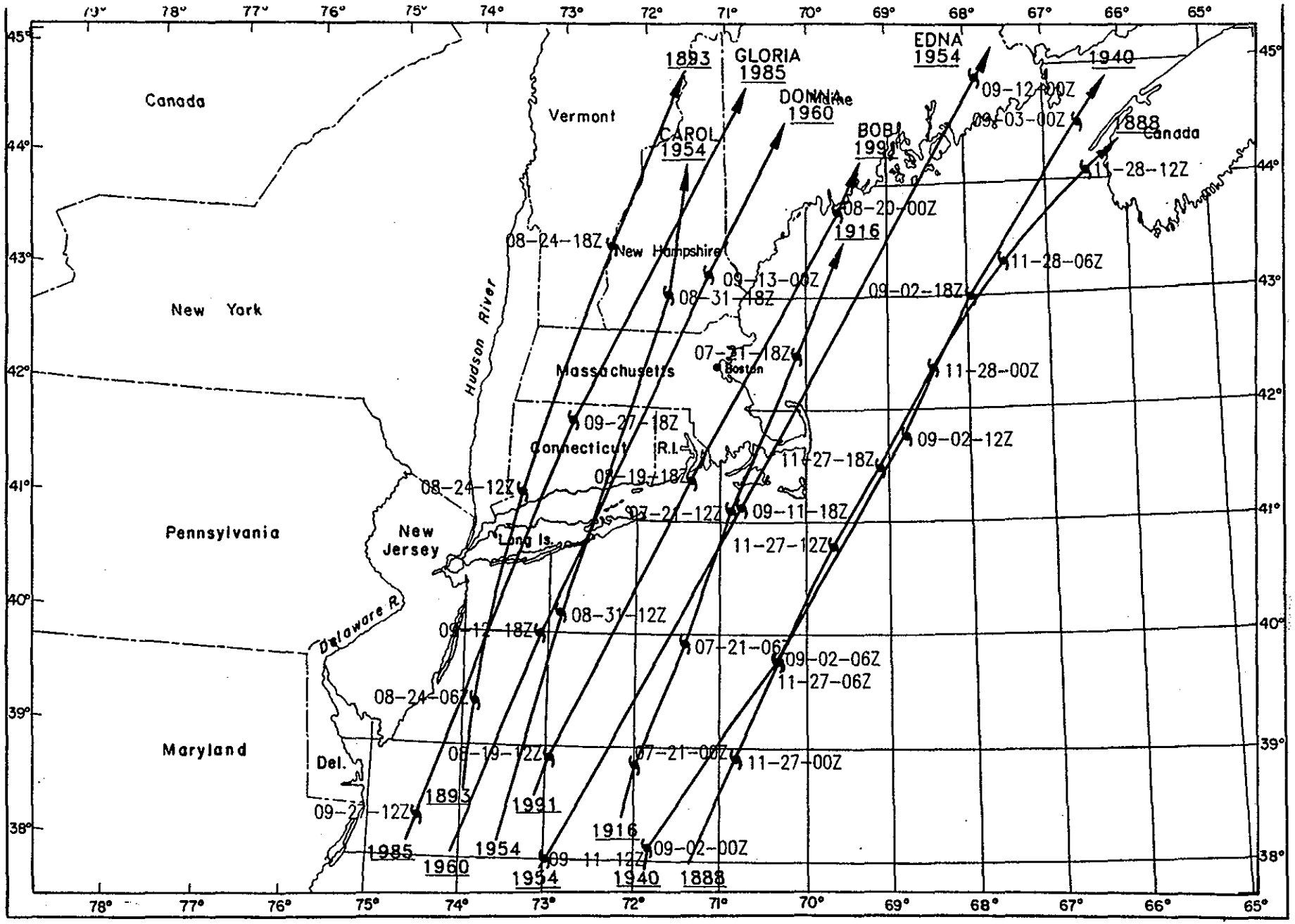
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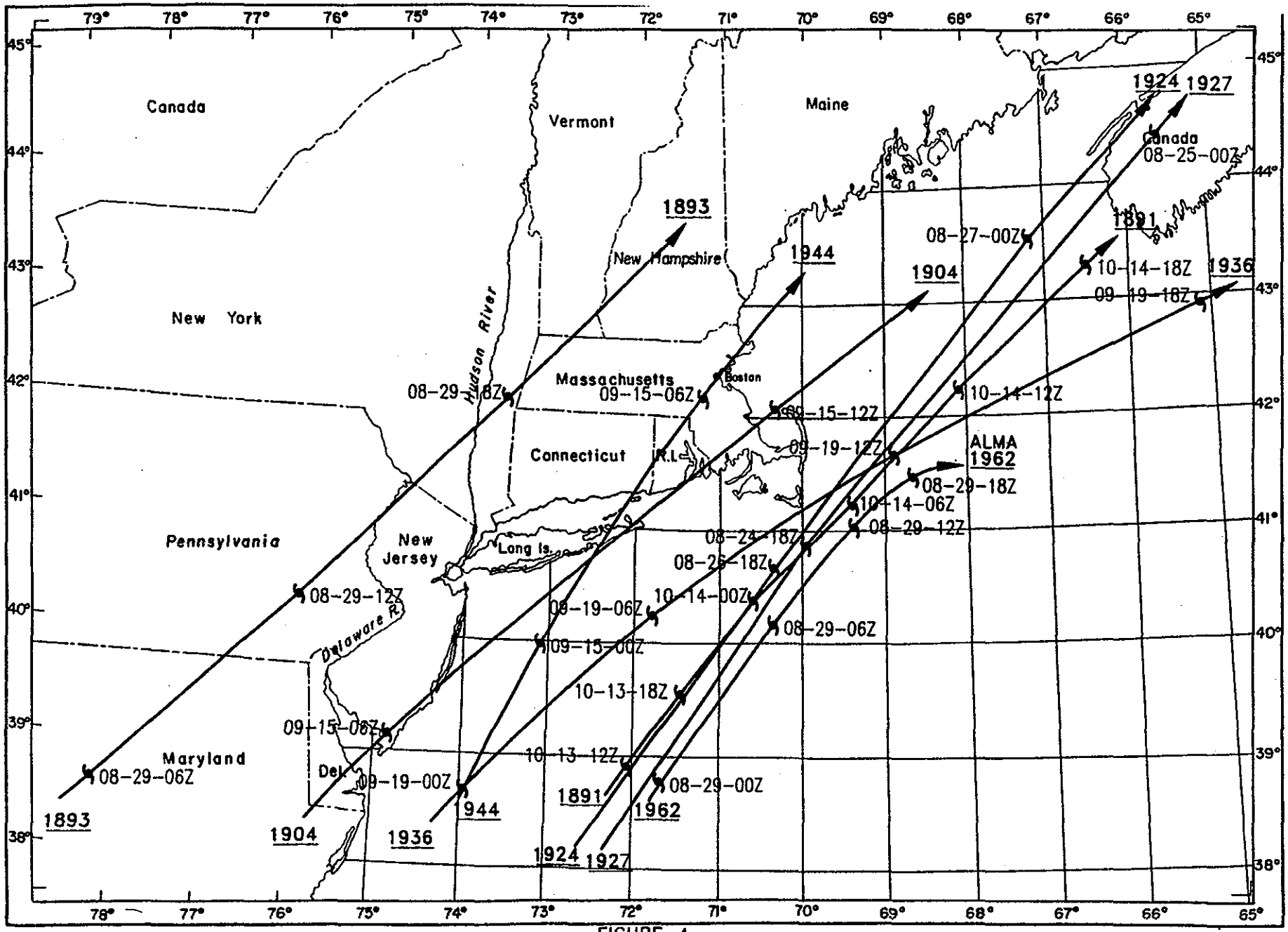
FIGURE 3.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09-15-06Z
09-19-00Z
09-15-00Z
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FIGURE 4.

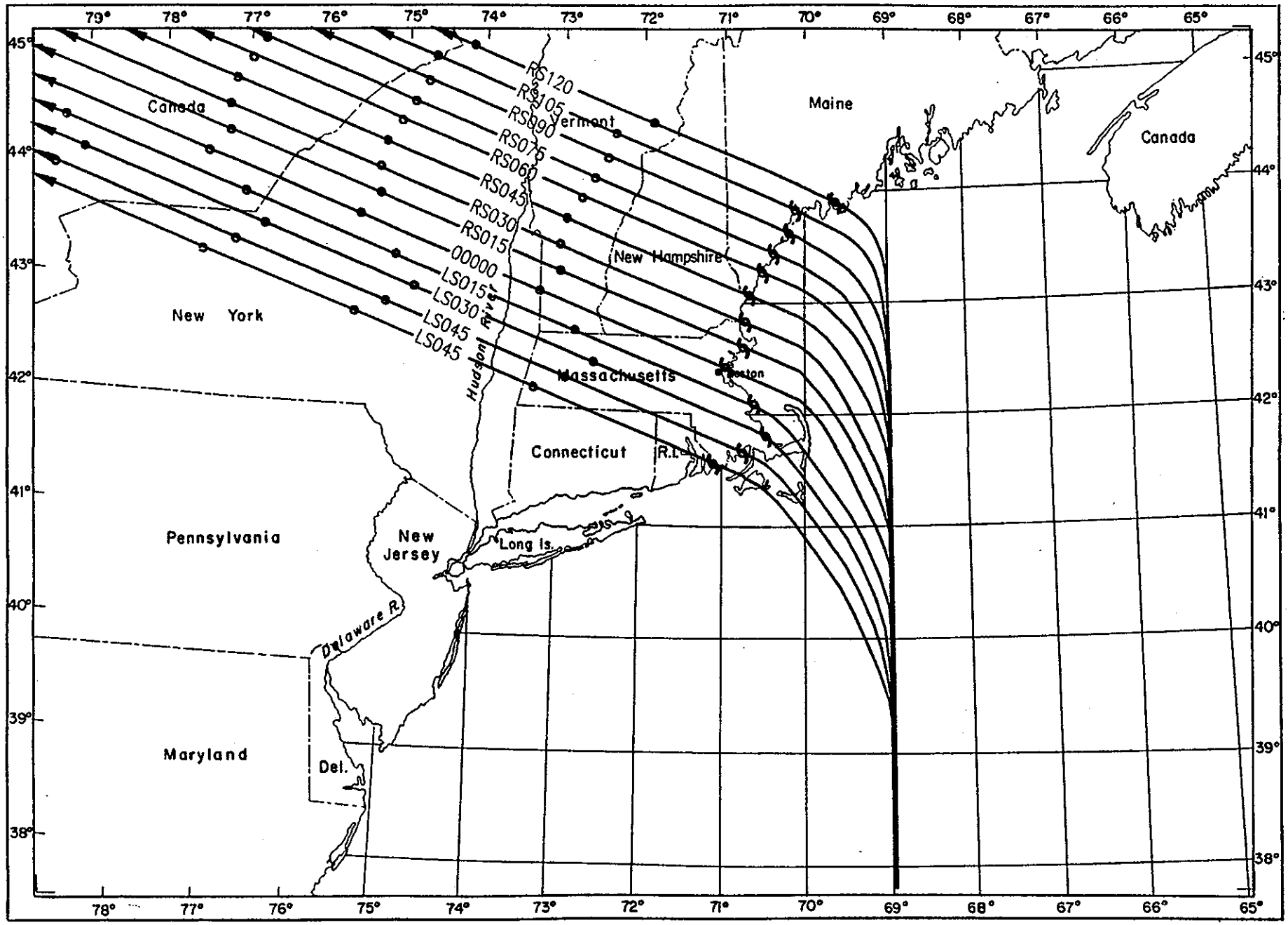
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FIGURE 5.

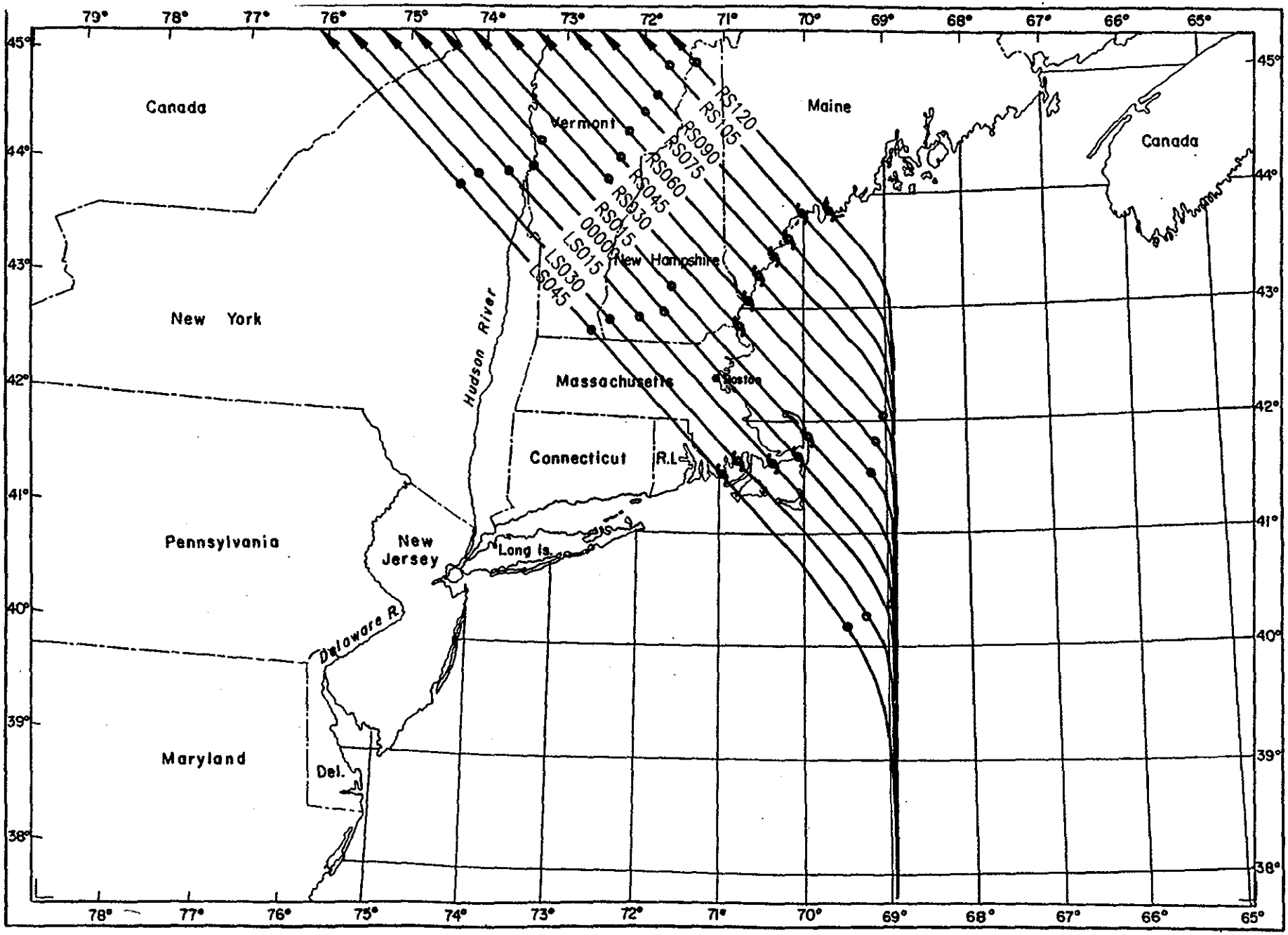
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FIGURE 6.

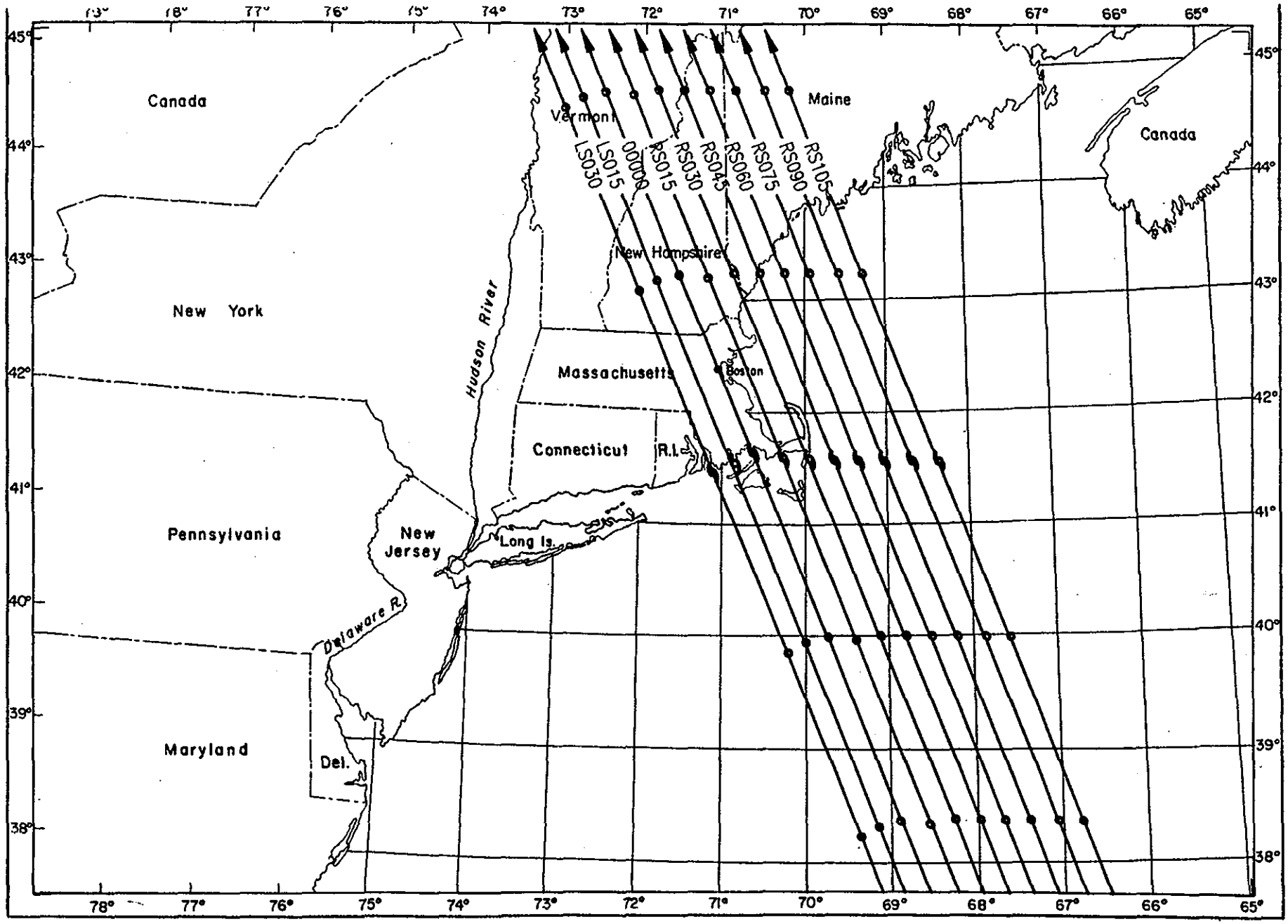
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FIGURE 7.

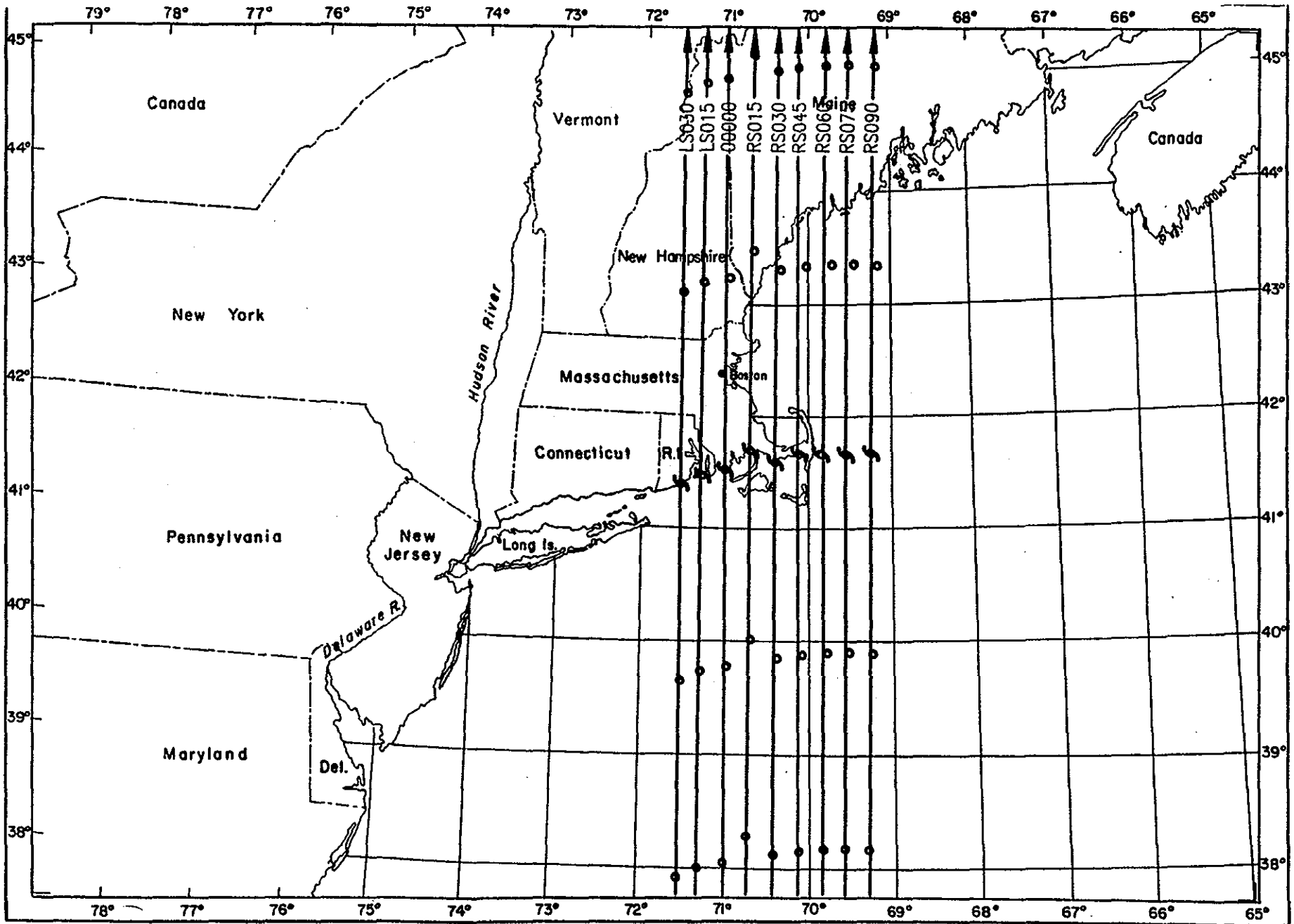
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FIGURE 8.

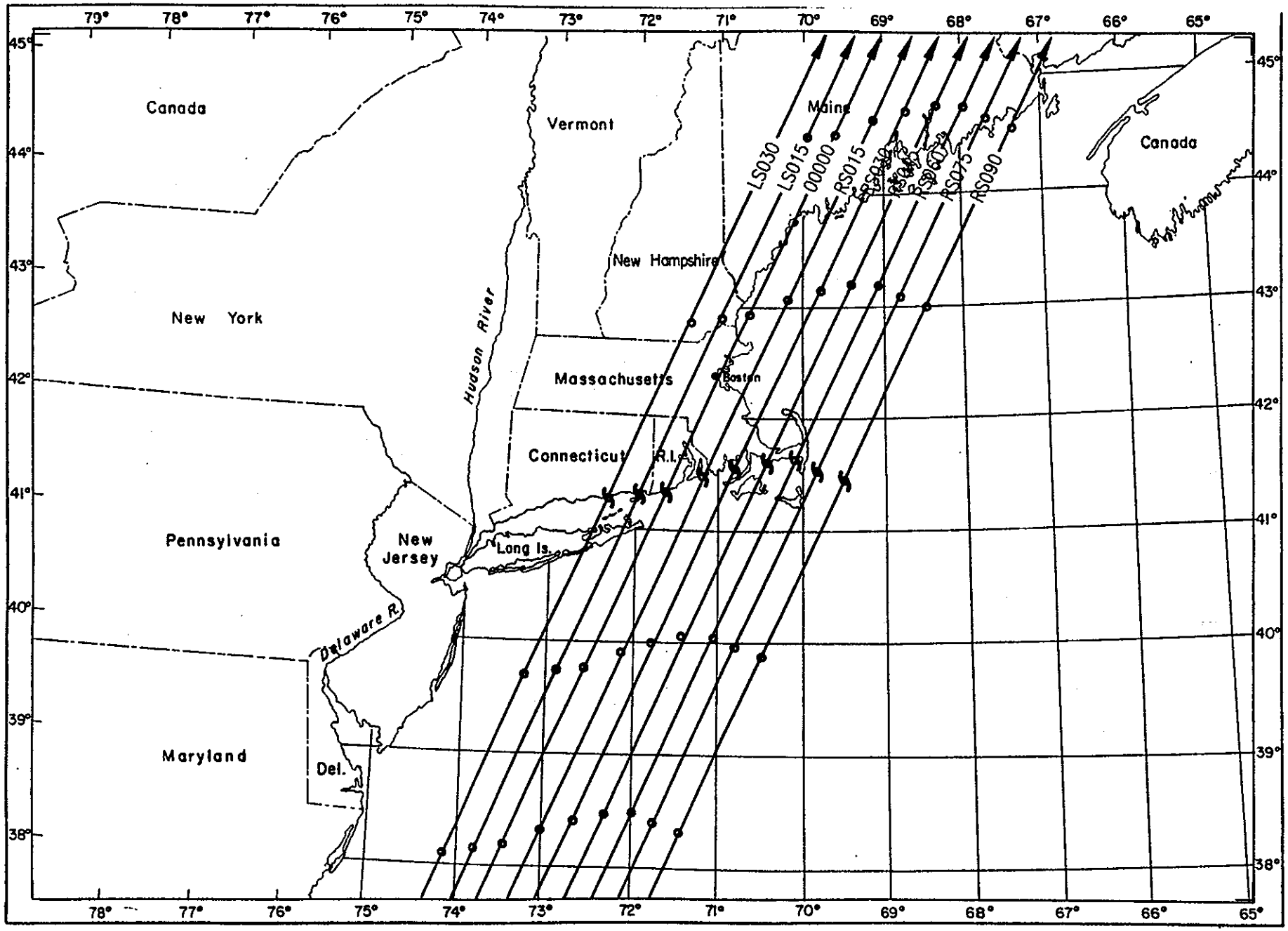
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FIGURE 9.

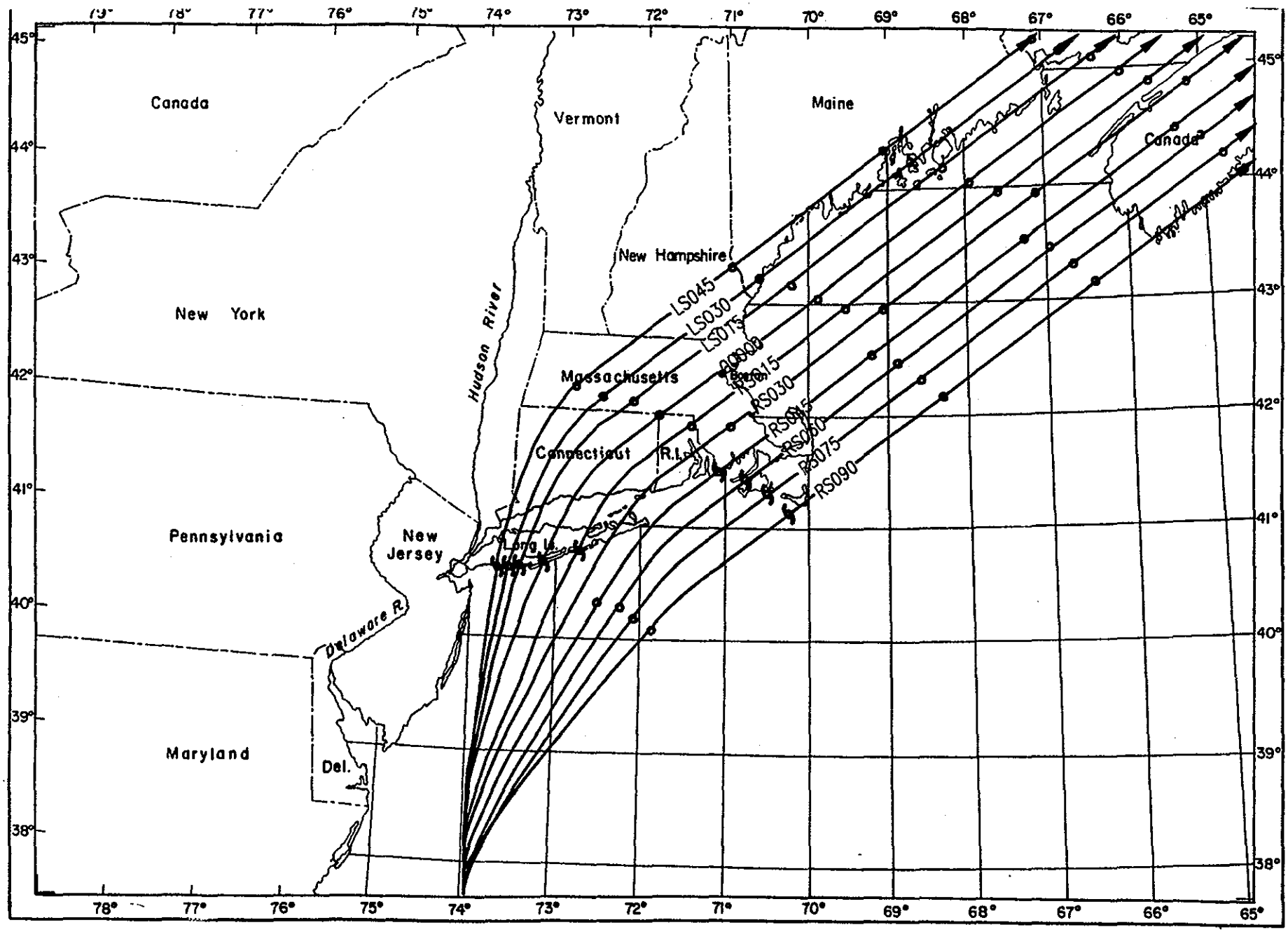
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FIGURE 10.

APPENDIX C

Behavioral Analysis Support Documentation

Hurricane Evacuation Behavioral Assumptions for Massachusetts

Appendix to
Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States

Prepared by

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Tallahassee, FL 32308
(904) 893-8993

For

U.S. ARMY CORPS OF ENGINEERS

October, 1988

Preface

This document is accompanied by a lengthier report titled *Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States*, referred to hereafter as the "Main Report". That volume provides background information relevant to understanding the following discussion. In particular the Main Report describes methodology and data which form the basis for many of the recommendations included in this volume. On occasion this report will make reference to "MR-Fig. *x*", meaning a particular figure in the Main Report.

Sample survey results for Wareham are reported in this document, but the reader should be aware that they are included as "tests" of the general response model's applicability to Wareham rather than to provide actual figures for evacuation planning. Even for Wareham response in future hurricanes could be considerably different than that observed in Gloria.

Evacuation Rates Among Residents

Thirty-six percent left from Wareham (MR-Fig. 8). This does not necessarily mean, however, that more should have left. About half the sample lived within a block of water (MR-Fig. 7), but Gloria was forecast to pass well to the west of Wareham. If the track had become more easterly more Wareham probably would have left, especially if officials became more aggressive about urging their evacuation.

Thirty-four percent said they were told to evacuate (MR-Fig. 10). People hearing that they should leave were almost twice as likely to do so (48% vs. 28%) (MR-Fig. 11). Only 5% of the sample believed they heard a mandatory evacuation order (MR-Fig. 12), but all of them left. The total number of people involved in Wareham alone was too small to draw meaningful conclusions, but taking the Connecticut, Rhode Island, and Wareham samples together, 94% believing the notice was mandatory evacuated.

Thirty-one percent of those who *didn't* leave said they felt safe staying where they were (MR-Fig. 18). About half of all respondents perceived their houses to be safe in hurricanes (MR-Fig. 15).

Response in Gloria in Wareham conforms to patterns predicted by the general response model. Table 1 summarizes the general guidelines for use in assigning evacuation rates to specific locations elsewhere in Massachusetts. The table varies response on the basis of four variables.

Severe Storm Evacuation Ordered in High/Mod. Risk Areas, and Mobile Homes			Weak Storm Evacuation Ordered in High Risk Areas Only, and Mobile Homes		
Risk Area					
High	*Mod*	*Low*	*High*	*Mod*	*Low*
Housing Other Than Mobile Homes					
90+%	80%	30%	80%	40%	20%
Mobile Homes					
90+%	85%	60%	90%	75%	55%

Note:

Figures will be lower if officials are not successful in communicating orders.

Table 1. Evacuation rates to be used for planning in Massachusetts.

Storm Severity

The table addresses two storm scenarios. The first is a strong storm, a category 3 or worse. The second storm is weaker. The difference obviously is that more people are at risk in the more severe storm, and evacuation will be greater from moderate-risk and low-risk locations.

Action by Officials

It is assumed that officials will tell people to leave from high-risk and moderate-risk locations and tell all mobile home dwellers in coastal counties to evacuate in the severe storm. In the weaker storm only mobile home residents and people who live in high-risk locations are told to leave.

It is also assumed that officials are successful at communicating the evacuation notices to residents. The Gloria data attests to the greater likelihood of people leaving if they believe officials have told them to. The only way to ensure that everyone will hear the notice is to have it disseminated door-to-door. If that is not possible, vehicles with loudspeakers are the second best method. If officials cannot disseminate the evacuation notices in either of those manners, evacuation rates will be 25% lower in high-risk areas and 50% lower in moderate-risk and low-risk areas.

Risk Area

High-risk areas refer primarily to barrier islands and other land areas exposed to the open ocean where wave battering and scour are major hazards in addition to flooding. Moderate-risk areas are subject to flooding in moderate to strong storms but do not experience significant battering and scour. Low-risk areas are subject only to wind and are adjacent to moderate-risk locations. Most of the sample households in Wareham are located in high-risk to moderate-risk locations.

Housing

Table 1 distinguishes between mobile homes and other housing. Neither of the survey locations contained a large percentage of mobile homes, but they should be considered separately for planning. Evacuation will be greater from mobile homes than from other housing, all other factors being the same.

Evacuation Timing By Residents

With so few evacuees in the sample, it's difficult to make very confident statements about the exact time evacuees left. The matter is further complicated by the fact that interviewees were being asked to recall fairly precise information from something that occurred two years previously.

Evacuation timing, however, will vary greatly from storm to storm, and little can be generalized from Gloria. For planning purposes three different sets of assumptions depicted in Figure 1 should be analyzed. The three curves in Figure 1 reflect three different rates at which evacuees leave, reflecting in turn three different levels of urgency.

The left-most curve represents response when forecasts are early and residents are told to evacuate with plenty of warning. That scenario should probably be called optimistic. The middle curve is probably more typical. Warning is not quite so early in relation to landfall. Finally, the right-hand curve will pertain when a storm accelerates, intensifies, or changes course unexpectedly. People will leave very promptly if it is made clear to them that they must. All three curves should be used for planning because all three will occur eventually.

Fewer than 20% of eventual evacuees will leave before being told to leave. When told, however, people will leave as promptly as they believe they must. Given the luxury of time, most people will not evacuate late at night and will wait until morning if they haven't left by 11 pm or midnight. People <u>will</u> leave in the middle of the night if officials make it clear that circumstances make it imperative that they do so. People from high-risk locations (barrier islands) tend to leave earlier than other evacuees.

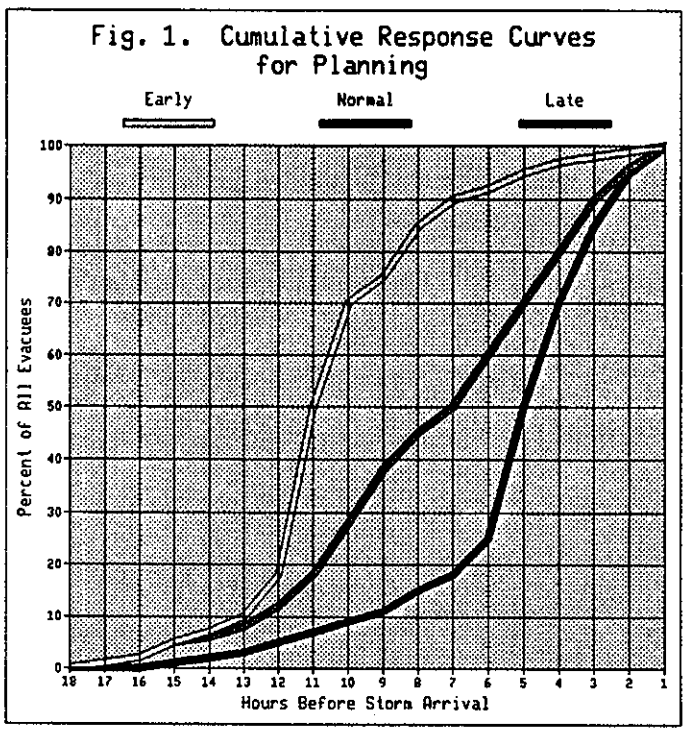

Fig. 1. Cumulative Response Curves for Planning

Demand for Public Shelters by Residents

Few evacuees (22%) used public shelters (MR-Fig. 25). Residents of beach communities and waterfront locations usually have higher incomes and choose not to stay at public shelters and can afford motels if arrangements can't be made with friends and relatives. They also tend to leave earlier and go farther.

Late night evacuation tends to maximize shelter use, primarily because it is occurring with a sense of urgency, leaving no time to make alternative arrangements with friends, relatives, and motels or leaving too little time to travel the distance necessary to go out-of-town, particularly at night.

Hypothetical shelter use among non-evacuees was greater than actual use among evacuees (31% vs. 22%) (MR-Fig. 27). These hypothetical responses are typical of the overestimation normally observed when comparing intended to actual shelter use.

Table 2, showing guidelines for projecting normal shelter demand, reflects these patterns. Late, urgent evacuations, which will roughly double normal shelter demand, are not a function of location. It should also be noted that emergency management officials in some communities encourage shelter use more than others, and such policies should be taken into account in planning, because officials can take actions which either increase or decrease shelter use. Other factors to note are that retirees living in "retirement areas" are more likely to use public shelters than other groups, some communities have churches and other organizations which reduce "public" shelter use by being more active than normal in providing their own shelters, and some housing developments and mobile home parks provide onsite shelter which will alleviate demand for public shelter.

	Risk Area		
	High	*Mod*	*Low*
Income			
High	5%	10%	10%
Med.	10%	20%	20%
Low	-	30%	30%

Note:

Figures will be higher if officials encourage use of public shelters.

Figures will be lower for developments with on-site shelters (e.g., clubhouses).

Figures will be lower where churches and other organizations shelter members.

Table 2. Evacuees going to public shelters: planning assumptions for Massachusetts.

Evacuation Out-of-Town by Residents

Only 33% of the people evacuating went out-of-town (MR-Fig. 30). All but 17% said they required 30 minutes or less to reach their destinations, suggesting that evacuees travelled very short distances (MR-Fig. 31).

Differences are usually accounted for primarily by income (low income residents don't go as far), evacuation timing (late night, urgent evacuees don't go as far), and risk area (evacuees from high-risk beach areas go farther). Table 3 reflects these generalizations. Note too, that emergency management officials can influence this response. In some locations agencies have policies to discourage evacuees from staying in the local area. Communities which aggressively provide and publicize public shelters will have fewer evacuees leaving the local area.

Very Strong Storm, Early Evacuation			Weak Storm Typical Timing		
Risk Area			Risk Area		
High	*Mod*	*Low*	*High*	*Mod*	*Low*
60%	35%	15%	40%	30%	10%

Note:

Figures will be lower for low income and elderly retired evacuees.

Figures will be lower for last minute evacuations.

Figures will be higher if officials encourage evacuees to leave area.

Table 3. Percent of evacuees leaving local area: planning assumptions for Massachusetts.

Vehicle Use by Residents

The average number of vehicles used per evacuating household in Gloria was 1.5 (MR-Fig. 37). Only 3% used no vehicles at all, probably walking short distances to friends or to shelters or riding with someone else (MR-Fig. 36).

Normally 65% to 75% of the vehicles available to a household are used in evacuations, and Wareham fell near the upper end of that range in Gloria (76%). **For planning purposes it would be reasonable to assume that approximately 75% of available vehicles will be used in most evacuations.**

No one in either sample said they required assistance from public agencies in evacuating (MR-Fig. 41), and no one said they used public transportation (MR-Fig. 38). Of those respondents who did *not* evacuate in Gloria, 5% said they would have needed agency assistance if they had evacuated (MR Fig. 42). Normally, however, even in communities where agencies prepare lists of people and addresses needing evacuation assistance, it is common to find that those people have already been provided for by friends and relatives when public vehicles arrive to collect them. None of the stayers in both sites said they would use public transportation if they evacuated (MR-Fig. 40). Three percent of the stayers said they had no cars of their own available (MR-Fig. 39).

Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States

Analysis of Response in Gloria, Intended Responses, and Applicability of Generalizations from other Regions

Prepared by

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2308 Carrick Court
Tallahassee, FL 32308
(904) 893-8993

For

U.S. ARMY CORPS OF ENGINEERS

July, 1988

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Survey Method	9
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Evacuation Timing	43
Types of Refuge Used	46
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Appendix I: Questionnaire	72

Background and Approach: Behavioral Science and Hurricane Evacuation Planning

Evacuation outcomes depend upon many factors, including how the public responds to the event, and in hurricane evacuation planning, one must make assumptions about those factors. If one makes unreasonable assumptions, an actual evacuation is unlikely to proceed as anticipated. The public responses having the greatest impact upon an evacuation are

1. The number of people who evacuate.
2. The number of vehicles used in the evacuation.
3. How promptly evacuees leave.
4. The number of evacuees who leave or attempt to leave the local area and where they go.
5. The number of evacuees who seek refuge in public shelters.

Deriving Correct Assumptions

Regardless of how detailed, formal, or quantitative an evacuation plan appears, it contains assumptions about behaviors such as those discussed above. Even if the assumptions are not deliberately and explicitly addressed, there are implicit or implied values for them. For example, planners who say they make no assumptions at all regarding whether people outside the recommended evacuation zone will evacuate are in fact assuming that none of those people will leave. Any time an evacuation plan is "tested" to ascertain the length of time required to complete an evacuation under the plan, the test includes quantitative assumptions

regarding behavioral factors. The issue is not whether such assumptions should be made, because they must; the issue is what the assumptions should be.

There are at least three basic ways to derive behavioral assumptions:

1. Conduct interviews with people in a large number of locations asking what they did in multiple hurricane threats, documenting patterns of behavior under various conditions (general response model).
2. Conduct interviews asking people what they did in one particular evacuation (single event survey).
3. Conduct interviews asking people what they would do during a hurricane threat (hypothetical survey).

An Integrated Approach

Building a Quantitative General Response Model

A response model can be constructed to indicate quantitative values of specific responses, given a particular set of circumstances which the planner specifies. The extent of shadow evacuation in hurricanes, for example, can be forecast by specifying the severity of the storm, hazardousness of the neighborhood, and actions taken by public officials.

This is the heart of HMG's approach to formulating behavioral assumptions for hurricane evacuation planning. We are fortunate to have amassed actual response data from many hurricane evacuations spanning a wide geographical area and a variety of hurricane threat circumstances over a period of roughly three decades. Figure 1 shows locations where post-hurricane sample surveys have been administered. Multiple markers at a location indicates that more than one survey has been conducted.

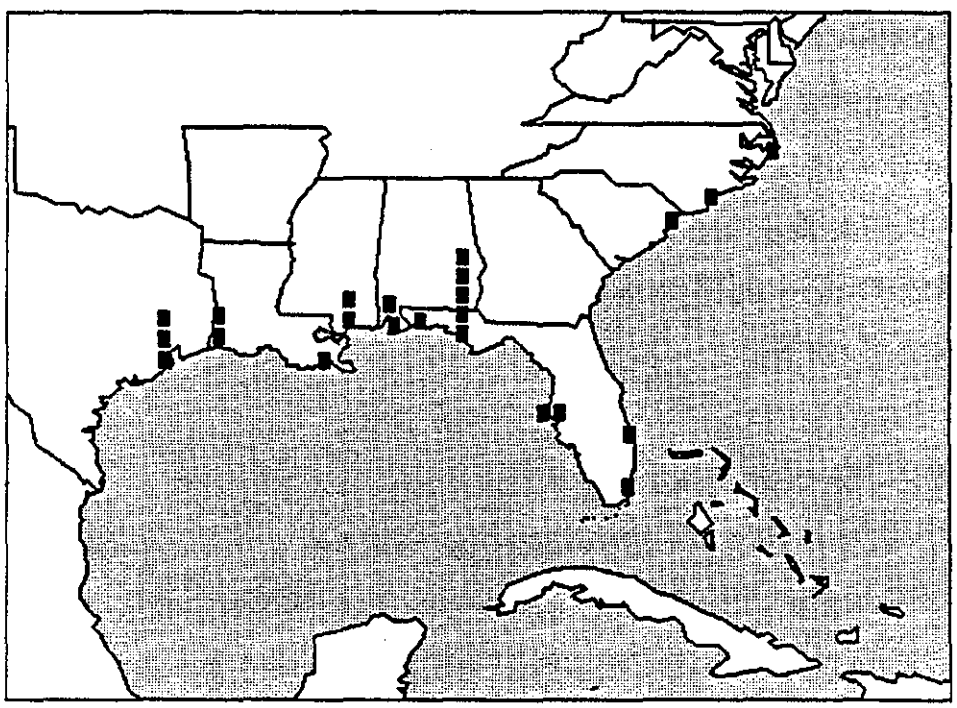

FIG. 1

HMG's general response model has been used successfully in evacuation plans along the Gulf and Atlantic coasts. Thus, for each of the behaviors to be anticipated, the model predicts a quantitative value, depending upon specific situations and circumstances specified. The structure of the general response model, including the variables affecting the principal behaviors, appears in Figure 2.

A common concern expressed about the general response model is that it is based upon responses of people in "other places" and that "our people are different." Actually the strength of the general model is that it accounts for differences in responses as they vary because of demographic characteristics of the population, actions by emergency management personnel, physical hazardousness of the study area, and so forth. Evidence of the model's validity lies in its history of accurately explaining and forecasting actual response behavior observed in a variety of places.

Single Event Actual Response Data

It is tempting to overgeneralize from a single evacuation in a particular location. Even the same people will respond differently in different sets of circumstances. Single event data can be very useful if not overused, however. If an evacuation occurs late at night, for example, and the evacuation is urgent, those circumstances tend to lead to fewer people leaving the local area than other circumstances. Thus, if the single event was a late night, urgent evacuation, it should provide an indication of the "worst case" to expect in that location for certain types of behaviors.

Single events also provide opportunities to validate the use of the general response model for forecasting in a specific location. Actual behavior in a single event can be documented and compared to that which would have been predicted

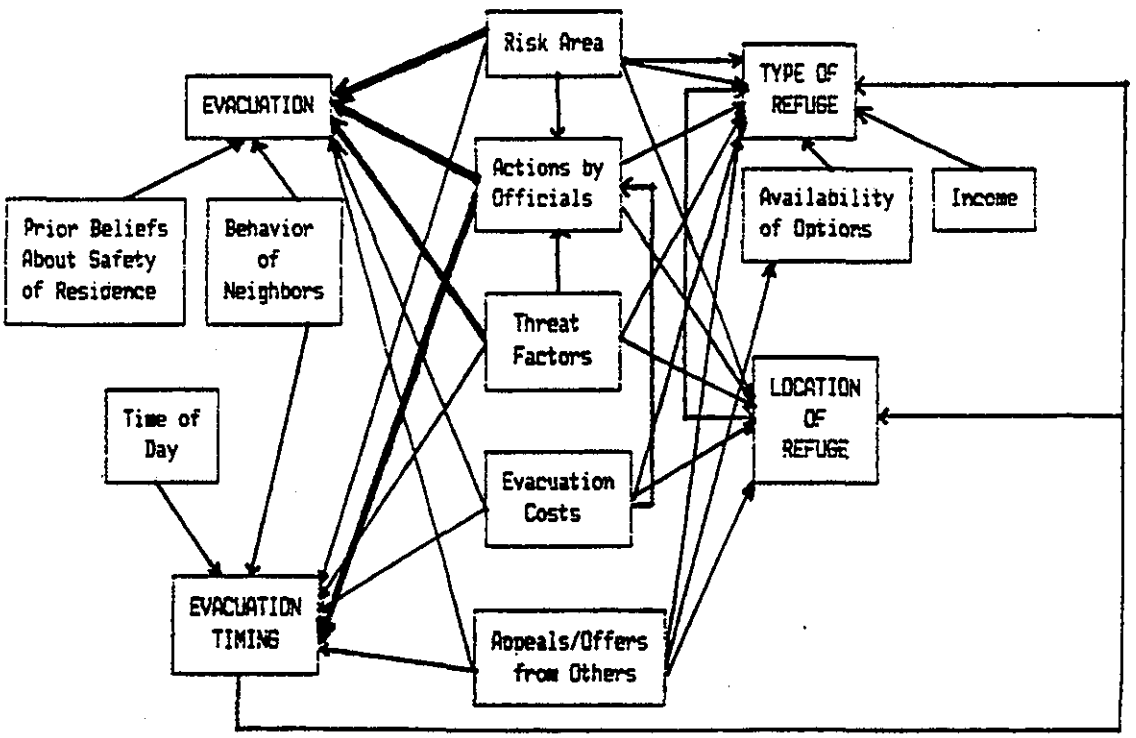
Risk Area
EVACUATION
TYPE OF REFUGE
Actions by Officials
Availability of Options
Income
Prior Beliefs About Safety of Residence
Behavior of Neighbors
Threat Factors
LOCATION OF REFUGE
Time of Day
Evacuation Costs
EVACUATION TIMING
Appeals/Offers from Others

FIG. 2

by the general response model. Its "fit" gives a clue to how much the model would have to be adjusted to work for the specific location and hazard.

Single event data was collected in this study documenting how residents responded during hurricane Gloria in 1985. This marks the first time actual response data has been collected systematically in the study area. The Gloria results will be compared to patterns predicted by the general response model to assess the model's applicability to the region. It is tempting to overgeneralize from any single evacuation, and response to future hurricane threats could vary substantially from the Gloria findings.

Hypothetical Responses

Although hypothetical response data can hardly ever be used literally for quantitative forecasts, HMG has collected much data of this nature, and it does have utility in experienced, knowledgeable hands. There are certain consistent biases in hypothetical response data, for example. People are more likely to say they would evacuate in "low risk" situations than they usually do, more likely to say they would leave early than they usually do, and more likely to say they would use public shelters than they usually do. Hypothetical response data can be adjusted to account for those sorts of known biases. Hypothetical data in one location can be compared with that collected elsewhere for an indication of relative variation between the samples. If more people in one location say they would refuse to leave than in another, they probably really are more likely to refuse. At least more effort will be required to have them move. So, although the magnitude of people saying they wouldn't leave might not be quantitatively valid, it at least gives a relative indication. This can be particularly useful when actual response data is also available in the second location.

Many respondents to the Gloria survey did not evacuate in response to the threat. That information is useful in assessing evacuation rates forecast by the general response model, but provides no information concerning other behaviors such as shelter use by those respondents. Therefore residents not evacuating in Gloria were asked hypothetical questions about what they believe they would do in future hurricane threats or what they would have done if they had evacuated in Gloria. The hypothetical responses will be compared to intended response data collected elsewhere and to actual response by other respondents in Gloria.

Vacationers

Unfortunately, the general response model is well developed only for residents. Actual response data is virtually nonexistent concerning how tourists, including RV operators, respond during hurricane threats.

HMG collected hypothetical response data with many vacationers in both North and South Carolina, but that data has most of the same weaknesses as hypothetical response data from residents. In addressing vacationer response we base most of our conclusions upon interviews conducted with tourism officials, hotel/motel managers, and campground operators following hurricane threats elsewhere.

Purpose of This Report

Methodology and results of the post-Gloria survey will be presented in the following sections of this report. Findings for all 19 survey sites will be included, with consistencies and differences noted among sites. The results will be compared to results normally observed in other hurricane prone areas to assess the

applicability of the general response model to the study area. The survey data will be used in supplementary reports for each state to refine the general response model if necessary for use in deriving planning assumptions for each state.

Survey Methodology

Sampling

Corps of Engineers representatives from Norfolk, Baltimore, Philadelphia, New York, and New England districts worked with HMG and state and local emergency management officials to select survey sites and sample sizes in each state from Virginia through Massachusetts. Criteria for selection varied from state to state, but in most instances the locations were important in and of themselves because of evacuation concerns at those sites or because the places were representative of other areas to which generalizations could be extended. The sample sites are displayed in Figure 3.

Virginia Beach, Virginia

Approximately 100 telephone interviews were completed with households having telephone prefixes 420, 427, and 428. Phone numbers were selected from the local telephone directory.

Norfolk, Virginia

Approximately 100 telephone interviews were completed with households having telephone prefixes 480, 489, 583, 587, and 588. Phone numbers were selected from the local telephone directory.

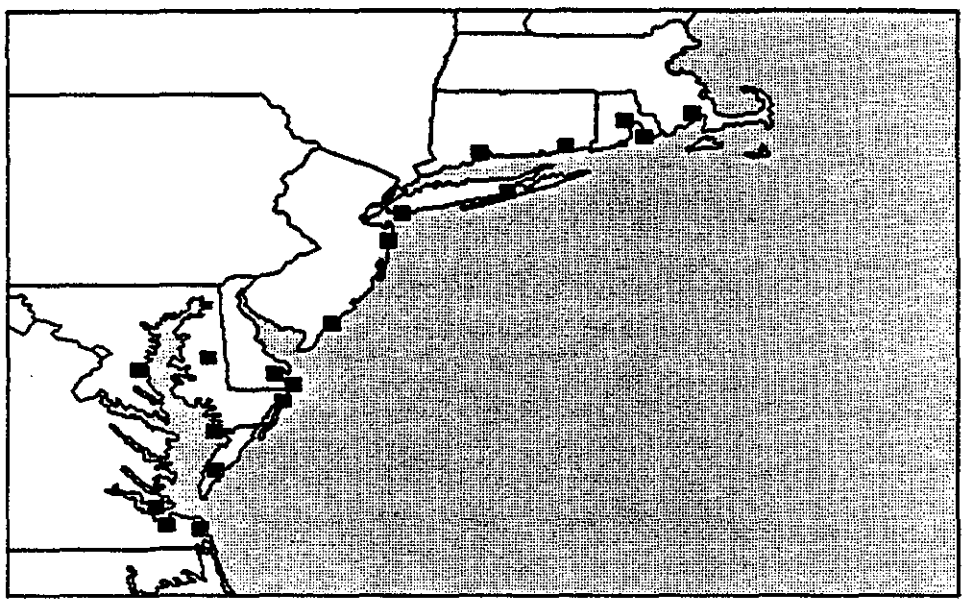

FIG. 3

Newport News, Virginia

Approximately 100 telephone interviews were completed with households having telephone prefixes 245 at addresses south of 39th street and east of Jefferson Avenue. Phone numbers were selected from the local telephone directory.

Virginia Eastern Shore

Approximately 100 telephone interviews were completed with households in a number of Northampton and Accomack County towns suggested by local emergency management officials. Phone numbers were selected from the local telephone directory after cross referencing the addresses with elevation maps of the area. Predominant prefixes were 331, 787, 442, 336, 824, and 891.

Chrisfield, Maryland

Approximately 100 telephone interviews were completed with households having telephone prefix 968 and having a Chrisfield address. Phone numbers were selected from the local telephone directory.

Anne Arundel County, Maryland

Approximately 100 telephone interviews were completed with households having telephone prefixes 741, 798, 867 and having an address in one of several specific towns on or near Chesapeake Bay south of Annapolis (including Deale, Avalon Shores, Rose Haven). Phone numbers were selected from the local telephone directory.

Denton, Maryland

Approximately 100 telephone interviews were completed with households having telephone prefix 479 and having an address in Denton or West Denton. Phone numbers were selected from the local telephone directory.

Ocean City, Maryland

Approximately 100 telephone interviews were completed with households having telephone prefixes 250, 289, 524, 723 and having an address in Ocean City. Phone numbers were selected from the local telephone directory.

Delaware "Beach"

Approximately 100 telephone interviews were completed with households having telephone prefix 539 and having an address in Bethany Beach or South Bethany. Phone numbers were selected from the local telephone directory.

Delaware "Mainland"

Approximately 100 telephone interviews were completed with households having telephone prefix 945, which included Millsboro and nearby towns. Phone numbers were selected from the local telephone directory.

"Southern" New Jersey

Approximately 100 telephone interviews were completed with households in Ocean City having telephone prefixes 390, 391, 398, and 399. Phone numbers were selected from the local telephone directory.

"Northern" New Jersey

Approximately 100 telephone interviews were completed with households in Ocean Grove, Bradley Beach, and Avon having telephone prefixes 774, 775, 776, 918, 922, and 988. Phone numbers were selected from the local telephone directory.

"Rockaway" New York

Approximately 200 telephone interviews were completed with households in the Far Rockaway, Belle Harbor, Edgemere areas of Queens. The area is referred to as Zone 13 in the NYNEX directory and includes several prefixes (318, 327, 337, 471, 474, 634, and 945). Phone numbers were selected from the local telephone directory.

"Suffolk" New York

Approximately 200 telephone interviews were completed with households in Quoge and Westhampton Beach in Suffolk County on Long Island (with prefixes 635 and 288). Phone numbers were selected from the local telephone directory.

"Fairfield" Connecticut

Approximately 100 telephone interviews were completed with households in Fairfield, Bridgeport, Stratford, and Milford. Phone numbers were selected from Hill-Donnelly directories after identifying streets from maps provided by the New England District showing Category 2 surge inundation areas.

"Groton" Connecticut

Approximately 100 telephone interviews were completed with households in Groton, Stonington, and Mystic. Phone numbers were selected from Hill-Donnelly

directories after identifying streets from maps provided by the New England District showing Category 2 surge inundation areas.

Warwick, Rhode Island

Approximately 100 telephone interviews were completed with households in Warwick. Phone numbers were selected from the Polk directory after identifying streets from Flood Insurance maps provided by the New England District.

Newport, Rhode Island

Approximately 100 telephone interviews were completed with households in Newport. Phone numbers were selected from the Cole directory after identifying streets from Flood Insurance maps provided by the New England District.

Wareham, Massachusetts

Approximately 100 telephone interviews were completed with households in Wareham. Phone numbers were selected from the New Bedford and vicinity Cole directory after identifying streets from Flood Insurance maps provided by the New England District.

Sample Size Considerations

There is always some probability of error when generalizing from a sample to the larger population from which it was drawn. If 100 residents of the surge prone area of Warwick, Rhode Island are selected randomly and interviewed, those 100 people are referred to as a sample. All people living within the Warwick surge zone from which the sample was selected constitute the population to which we attempt to generalize from information gained only from the sample.

A sample of 100 provides figures which, 90% of the time, will be within 5 to 8 percentage points of the actual population values. A sample of 200 will be within 3 to 5 percentage points of the true population value 90% of the time. This is true even if the population includes millions of people. For some purposes such small samples are not adequately reliable. In this case, however, the survey data is but one component in a broader, more important methodology and provides sufficient precision for the comparative purposes intended for it. The responses obtained in this survey are compared to response patterns observed under the general response model to assess whether the two are generally consistent. Small differences are not of consequence.

One should be especially cautious when generalizing from subsets of the samples of 100. For example, in many locations only about a third of the respondents evacuated. Therefore, in those sites only about 35 people were asked what sort of shelter they used. Answers based on interviews with 35 people are usually reliable within only 11 percentage points, which is a substantial margin of uncertainty.

One point to keep in mind, therefore, is that sample differences are not necessarily indicative of differences within the population. For example, if 70% of 100 respondents in one site left the local area when evacuating in Gloria, and only 60% of 100 respondents in a second site left the local area, that would probably not be sufficient evidence to conclude that people in the former location were more likely overall to leave the local area than people in the latter location. Figures of 70% and 50%, however, would usually indicate population differences in that example.

At times it is useful to ascertain whether, for example, wealthy evacuees were any less likely to use public shelters than low income evacuees. To answer those sorts of questions reliably, samples must sometimes be fairly large.

Therefore, to analyze those kinds of crosstabulations, the individual site samples will be aggregated in this report. Samples from Virginia through New Jersey are lumped into a single group which will be referred to as the southern sample, and New York through Massachusetts are grouped into a northern sample.

In all the tables presenting survey results, sample sizes are included. The reader is advised to always note the sample size before deciding how much confidence to place in a particular result.

Interview Questions

The questions asked of respondents are included as Appendix I. Questions 8a, 14a, 16a, 17a, and 17b were asked in the northern area only. Question 17 was asked in both areas, but in the northern area the response categories were made more specific.

Sample Characteristics

Age

Four questions were asked which could provide background information useful in explaining variations in response to Gloria and to the hypothetical questions. Figure 4 shows the age distribution of respondents across the 19 sites. From a behavioral perspective the most meaningful age group is probably people over 65. At a few of the sites a third of the sample is over 65. Warwick has the smallest percentage (10%) over 65.

Income

Respondents were asked to indicate which of five categories described their annual family income. Income categories were used to make the information less specific and therefore to increase the willingness to provide the information. Nevertheless roughly 15% of the respondents refused to reveal their income. Moreover, there is no way of knowing whether other respondents were candid and accurate in their responses.

Based upon answers provided, Figure 5 indicates incomes at the 19 sites. Chrisfield, MD and Newport News, VA had the greatest incidence of low income interviewees. More than a third in those locations reported incomes below $10,000.

Housing

The vast majority of respondents lived in single-family detached housing units (Figure 6). The only two exceptions were Rockaway, NY were 39% said they lived in high-rise apartments and on the Delaware mainland where 55% lived in

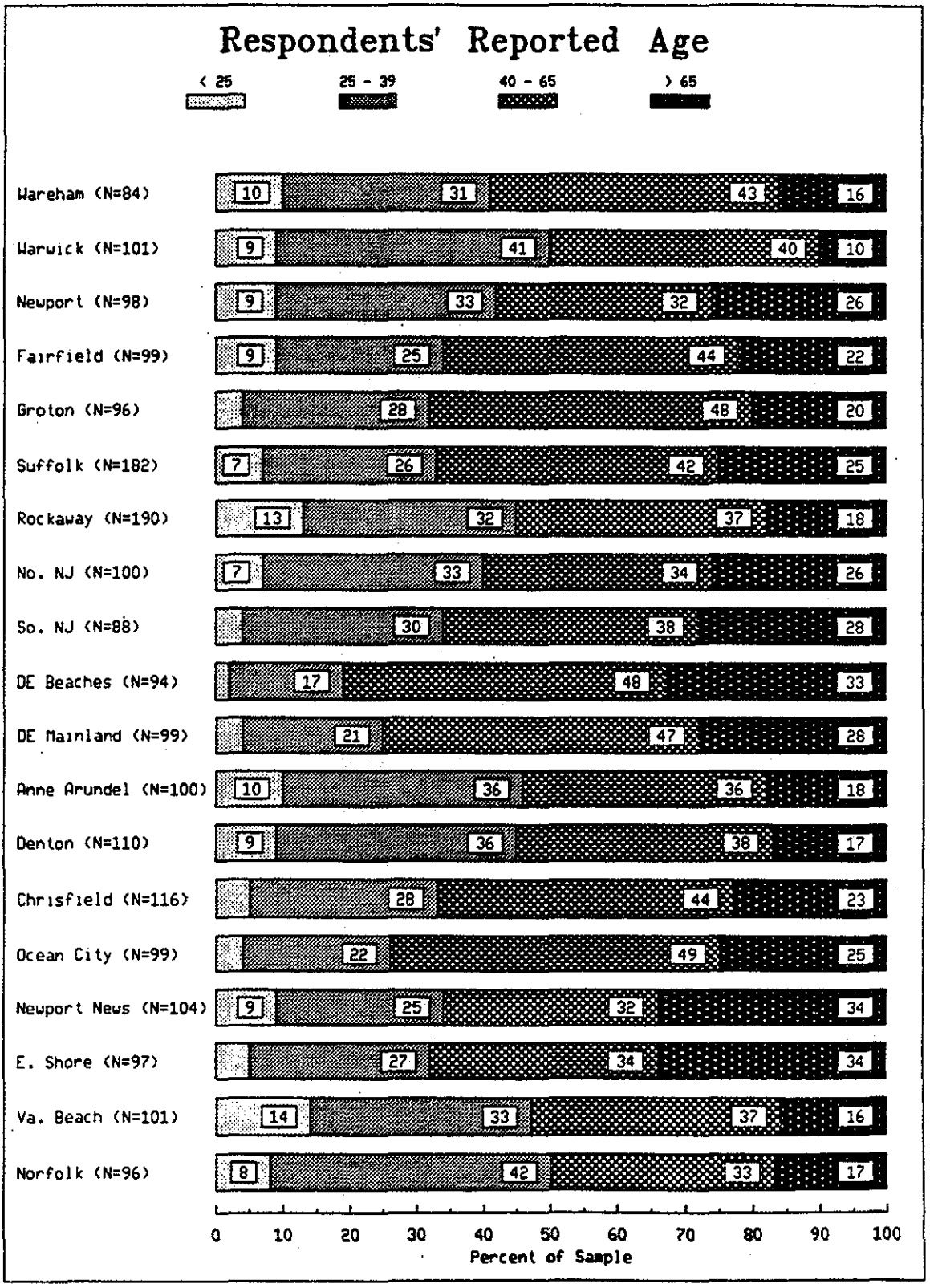
Respondents' Reported Age
< 25
25 - 39
40 - 65
> 65
Wareham (N=84) 10 31 43 16
Warwick (N=101) 9 41 40 10
Newport (N=98) 9 33 32 26
Fairfield (N=99) 9 25 44 22
Groton (N=96) 28 48 20
Suffolk (N=182) 7 26 42 25
Rockaway (N=190) 13 32 37 18
No. NJ (N=100) 7 33 34 26
So. NJ (N=88) 30 38 28
DE Beaches (N=94) 17 48 33
DE Mainland (N=99) 21 47 28
Anne Arundel (N=100) 10 36 36 18
Denton (N=110) 9 36 38 17
Chrisfield (N=116) 28 44 23
Ocean City (N=99) 22 49 25
Newport News (N=104) 9 25 32 34
E. Shore (N=97) 27 34 34
Va. Beach (N=101) 14 33 37 16
Norfolk (N=96) 8 42 33 17
0 10 20 30 40 50 60 70 80 90 100
Percent of Sample

FIG. 4

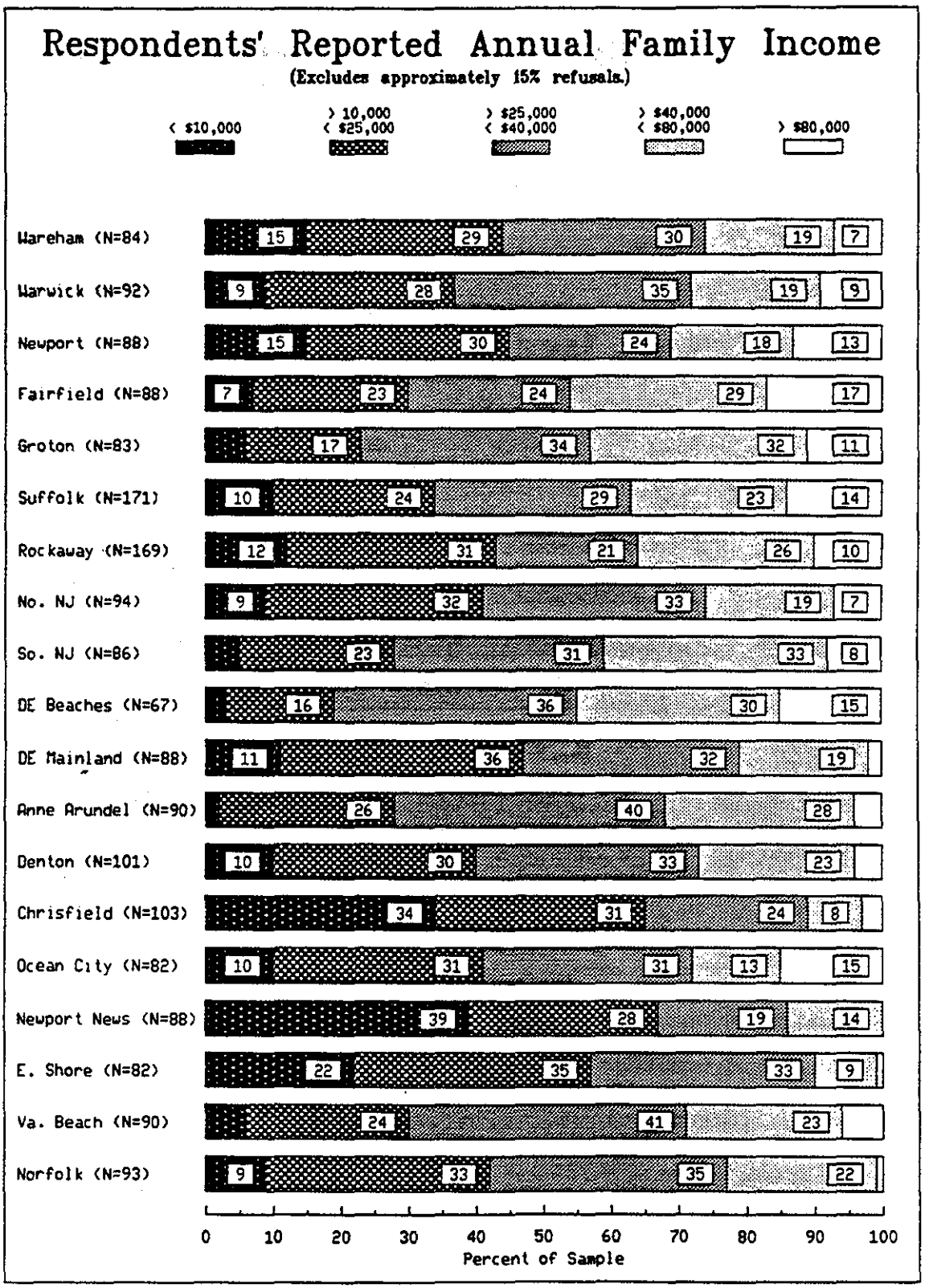
Respondents' Reported Annual Family Income
(Excludes approximately 15% refusals.)
< $10,000
> 10,000 < $25,000
> $25,000 < $40,000
> $40,000 < $80,000
> $80,000
Wareham (N=84) 15 29 30 19 7
Warwick (N=92) 9 28 35 19 9
Newport (N=88) 15 30 24 18 13
Fairfield (N=88) 7 23 24 29 17
Groton (N=83) 17 34 32 11
Suffolk (N=171) 10 24 29 23 14
Rockaway (N=169) 12 31 21 26 10
No. NJ (N=94) 9 32 33 19 7
So. NJ (N=86) 23 31 33 8
DE Beaches (N=67) 16 36 30 15
DE Mainland (N=88) 11 36 32 19
Anne Arundel (N=90) 26 40 28
Denton (N=101) 10 30 33 23
Chrisfield (N=103) 34 31 24 8
Ocean City (N=82) 10 31 31 13 15
Newport News (N=88) 39 28 19 14
E. Shore (N=82) 22 35 33 9
Va. Beach (N=90) 24 41 23
Norfolk (N=93) 9 33 35 22
0 10 20 30 40 50 60 70 80 90 100
Percent of Sample

FIG. 5

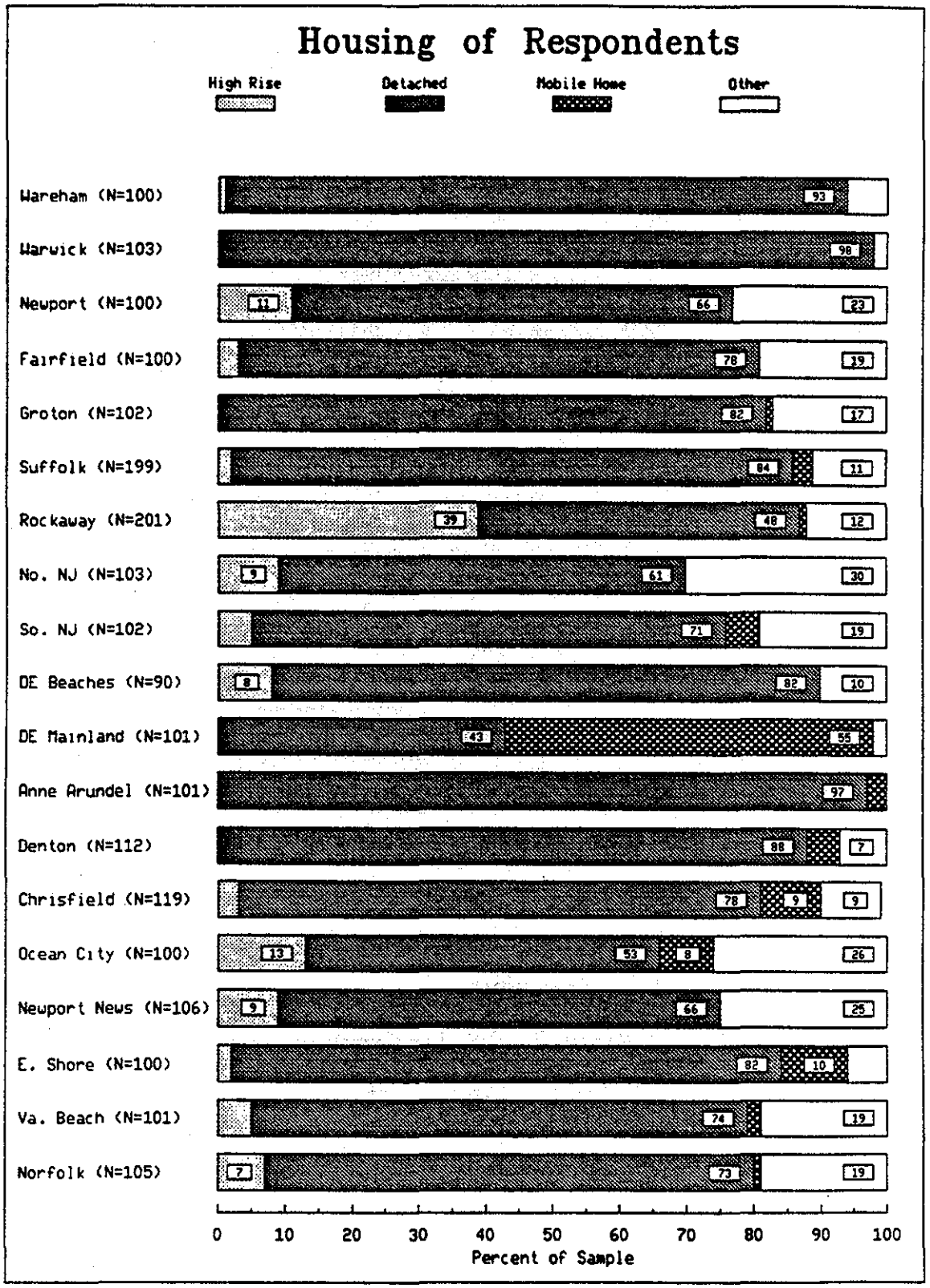
Housing of Respondents
High Rise
Detached
Mobile Home
Other
Wareham (N=100)
93
Warwick (N=103)
98
Newport (N=100)
11
66
23
Fairfield (N=100)
78
19
Groton (N=102)
82
17
Suffolk (N=199)
84
11
Rockaway (N=201)
39
48
12
No. NJ (N=103)
9
61
30
So. NJ (N=102)
71
19
DE Beaches (N=90)
8
82
10
DE Mainland (N=101)
43
55
Anne Arundel (N=101)
97
Denton (N=112)
88
7
Chrisfield (N=119)
78
9
9
Ocean City (N=100)
13
53
8
26
Newport News (N=106)
9
66
25
E. Shore (N=100)
82
10
Va. Beach (N=101)
74
19
Norfolk (N=105)
7
73
19
0
10
20
30
40
50
60
70
80
90
100
Percent of Sample

FIG. 6

mobile homes. "Other" refers primarily to duplexes and medium density apartments or condos.

Proximity to Water

The sample sites themselves vary in terms of flooding propensity and proximity to water, but there is also variation within the sites (Fig. 7). At most interview locations between 25% and 50% of the respondents said they lived within a block of a water body (ocean, harbor, bay, sound). As many as 31% (Groton) said they lived adjacent to such a water body. Many of the sites also had a substantial portion of the respondents living more than a mile from any water.

To some extent measurement of this variable is subject to judgment on the part of people answering the question. Most people underestimate distances, for example, so some of the individuals saying they lived more than a block but less than a mile from water might actually live more than a mile from water. Overall, though, it's reasonable to assume that most people in the "more than a mile" category are in fact farther from water than most in the other categories.

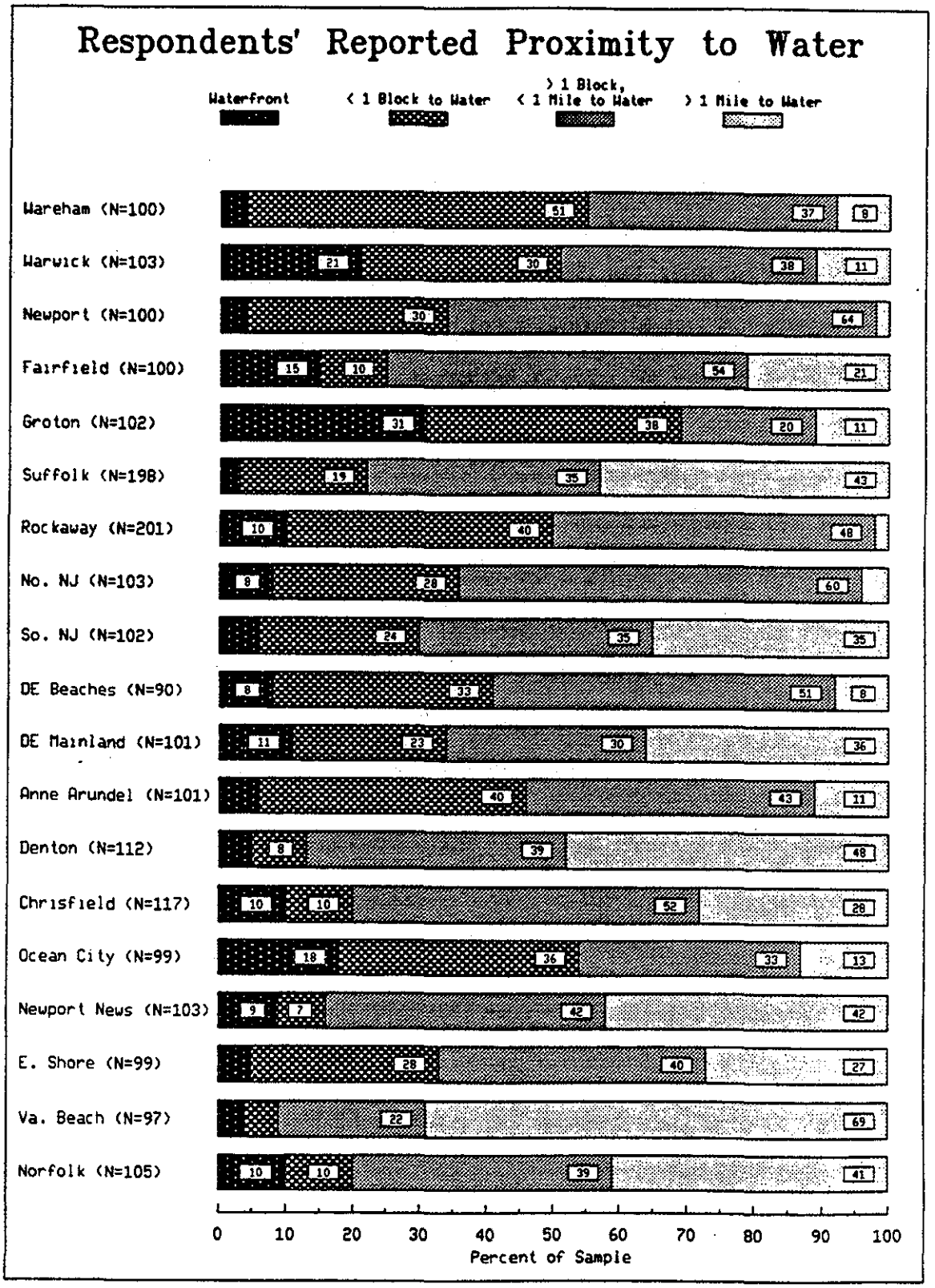
Respondents' Reported Proximity to Water
Waterfront
< 1 Block to Water
> 1 Block, < 1 Mile to Water
> 1 Mile to Water
Wareham (N=100)
51
37
8
Warwick (N=103)
21
30
38
11
Newport (N=100)
30
64
Fairfield (N=100)
15
10
54
21
Groton (N=102)
31
38
20
11
Suffolk (N=198)
19
35
43
Rockaway (N=201)
10
40
48
No. NJ (N=103)
8
28
60
So. NJ (N=102)
24
35
35
DE Beaches (N=90)
8
33
51
8
DE Mainland (N=101)
11
23
30
36
Anne Arundel (N=101)
40
43
11
Denton (N=112)
8
39
48
Chrisfield (N=117)
10
10
52
28
Ocean City (N=99)
18
36
33
13
Newport News (N=103)
9
7
42
42
E. Shore (N=99)
28
40
27
Va. Beach (N=97)
22
69
Norfolk (N=105)
10
10
39
41
0
10
20
30
40
50
60
70
80
90
100
Percent of Sample

FIG. 7

Evacuation

In only 5 of the 19 survey sites did a majority of respondents evacuate: Delaware beaches, Delaware mainland, Ocean City, MD, Southern New Jersey, and Warwick, RI (Figure 8). Denton, MD had by far the lowest evacuation rate (8% and too small to break down in a number of subsequent figures). These figures alone, however, are not useful in evaluating the applicability of the general response model to the region. For that, response variations in the sample must be analyzed.

Reasons Given for Evacuating

Figure 9 depicts the reasons given for leaving. It should be noted that these answers were in response to an open-ended question in which people simply volunteered reasons. Asking specifically whether each factor played a role in their decision to leave would have almost certainly resulted in more people attributing their decision to these factors.

It should also be noted that this is not the most reliable procedure for ascertaining what actually determined evacuation behavior. Most people are poor at articulating the factors which truly cause their behavior.

Reasons fall into two general types of response: information sources and information itself. Most evacuees in all 19 sites indicated that they left because of information from public officials, the National Weather Service, police, media, or friends and relatives. The proportions vary from place to place, but the media was mentioned more than other sources in most locations.

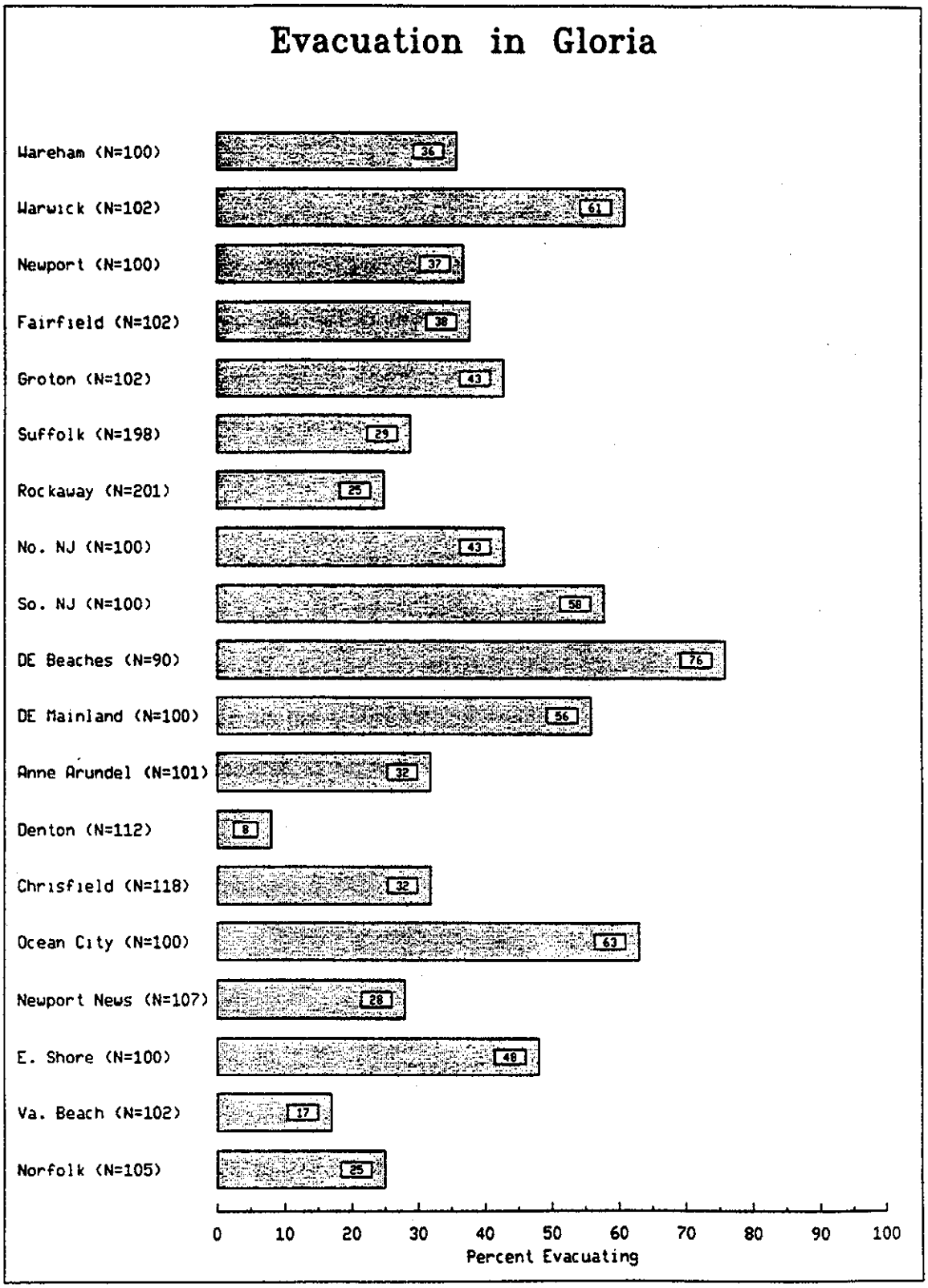
Evacuation in Gloria
Wareham (N=100)
36
Warwick (N=102)
61
Newport (N=100)
37
Fairfield (N=102)
38
Groton (N=102)
43
Suffolk (N=198)
29
Rockaway (N=201)
25
No. NJ (N=100)
43
So. NJ (N=100)
58
DE Beaches (N=90)
76
DE Mainland (N=100)
56
Anne Arundel (N=101)
32
Denton (N=112)
8
Chrisfield (N=118)
32
Ocean City (N=100)
63
Newport News (N=107)
28
E. Shore (N=100)
48
Va. Beach (N=102)
17
Norfolk (N=105)
25
0
10
20
30
40
50
60
70
80
90
100
Percent Evacuating

FIG. 8

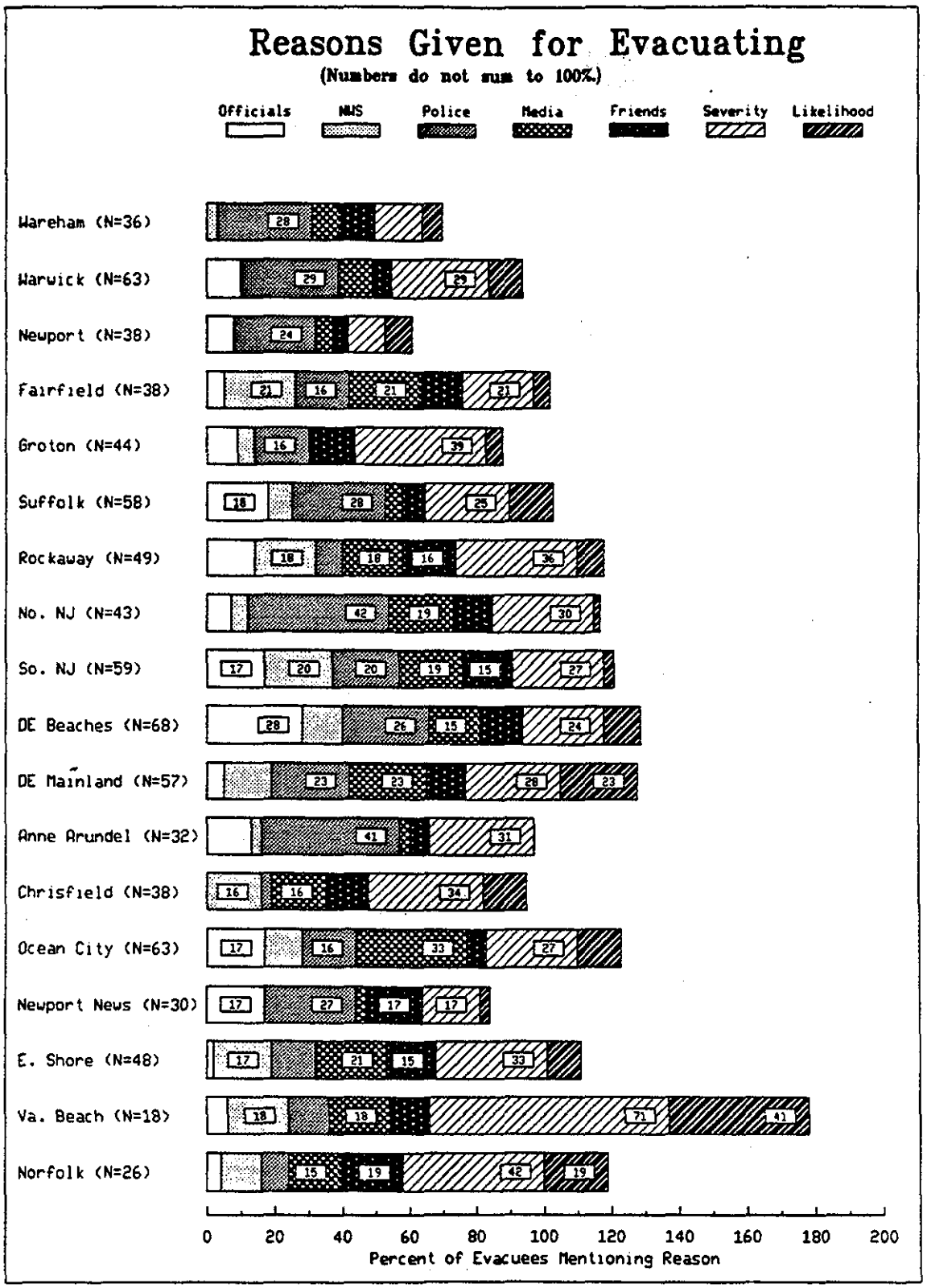
Reasons Given for Evacuating
(Numbers do not sum to 100%.)
Officials
NWS
Police
Media
Friends
Severity
Likelihood
Wareham (N=36)
Warwick (N=63)
Newport (N=38)
Fairfield (N=38)
Groton (N=44)
Suffolk (N=58)
Rockaway (N=49)
No. NJ (N=43)
So. NJ (N=59)
DE Beaches (N=68)
DE Mainland (N=57)
Anne Arundel (N=32)
Chrisfield (N=38)
Ocean City (N=63)
Newport News (N=30)
E. Shore (N=48)
Va. Beach (N=18)
Norfolk (N=26)
0
20
40
60
80
100
120
140
160
180
200
Percent of Evacuees Mentioning Reason

FIG. 9

The two sorts of information mentioned concerned either the severity of hurricane Gloria or the likelihood that the storm would strike the respondent's location. Severity was cited more frequently than likelihood of hitting.

Effect of Evacuation Notices

Figure 10 shows the percentage of interviewees who, when asked explicitly, said they that public officials in their area said they should evacuate. Affirmative responses do not necessarily mean that officials actually said the respondents should leave, but the respondents believed that to have been the case. At 7 sites more than 45% said they heard officials say to leave. The beach area of the Delaware sample was highest at 74%. Denton was by far the lowest at 6%. It is no coincidence that the Delaware beach sample also had the highest evacuation rate and Denton the lowest.

Figure 11 illustrates the point even more clearly. In every survey site, people who said they heard evacuation notices from officials were substantially more likely to evacuate than those who said they didn't hear such notices. Only in Delaware and Ocean City, MD were the differences small, but in those instances a high percentage of both groups left. Overall, as indicated by the two sets of bars at the bottom of the graph, people hearing from officials that they were supposed to evacuate were three times as likely to evacuate as others.

Most people saying they heard an official evacuation notice understood the notice to be a recommendation rather than a mandatory order (Fig. 12). Respondents believing they were being ordered to evacuate were much more likely to leave than those who believed the notice was advisory (Fig. 13). In the northern sample 93% "hearing" an order evacuated, as did 84% in the southern area.

The effect of perceived notices and orders in Gloria was exactly the effect observed elsewhere in other hurricanes. If officials want residents to evacuate, they must tell them. But if they tell them, compliance will be good.

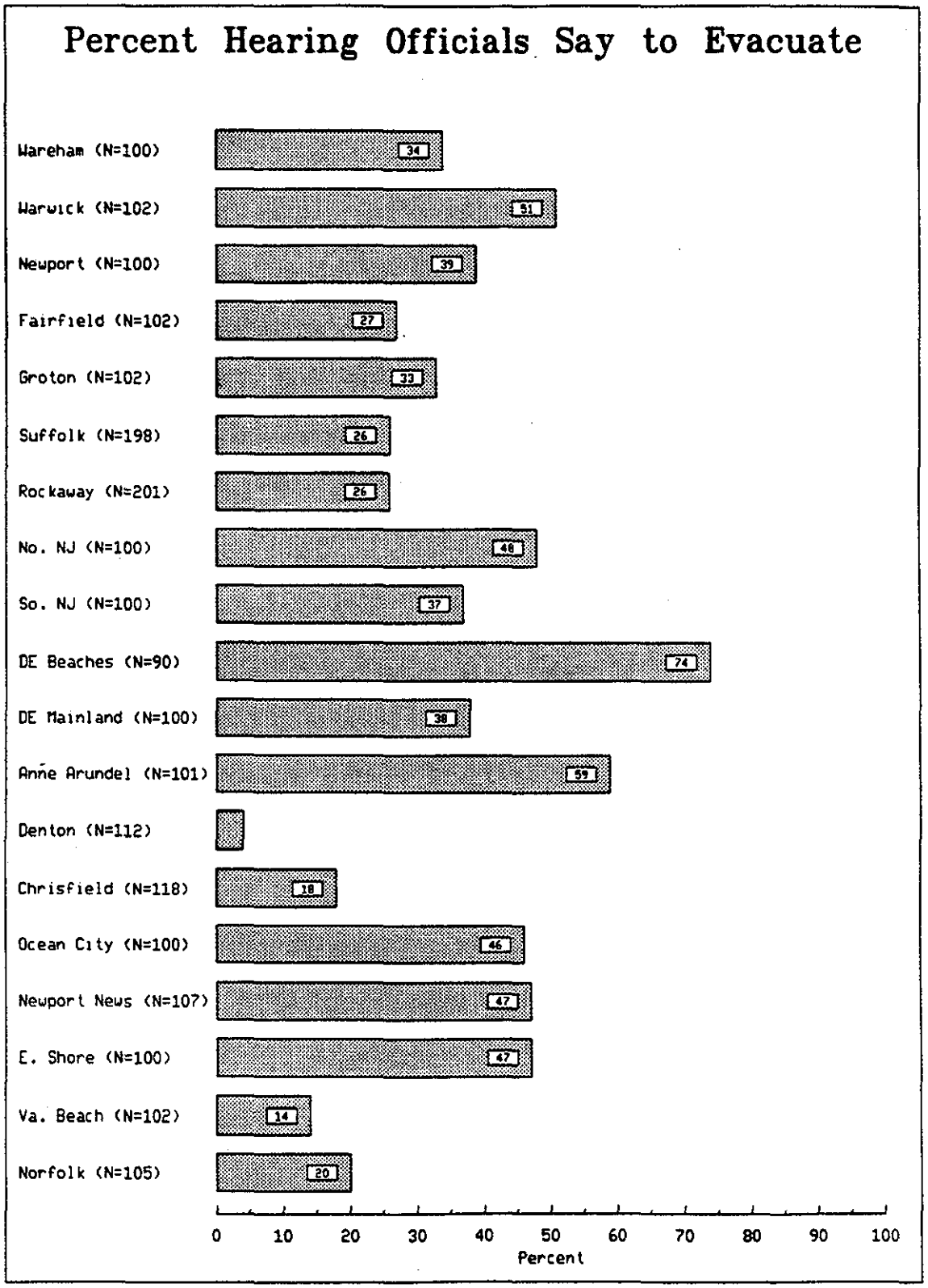
Percent Hearing Officials Say to Evacuate
Wareham (N=100)
34
Warwick (N=102)
51
Newport (N=100)
39
Fairfield (N=102)
27
Groton (N=102)
33
Suffolk (N=198)
26
Rockaway (N=201)
26
No. NJ (N=100)
48
So. NJ (N=100)
37
DE Beaches (N=90)
74
DE Mainland (N=100)
38
Anne Arundel (N=101)
59
Denton (N=112)
Chrisfield (N=118)
18
Ocean City (N=100)
46
Newport News (N=107)
47
E. Shore (N=100)
47
Va. Beach (N=102)
14
Norfolk (N=105)
20
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 10

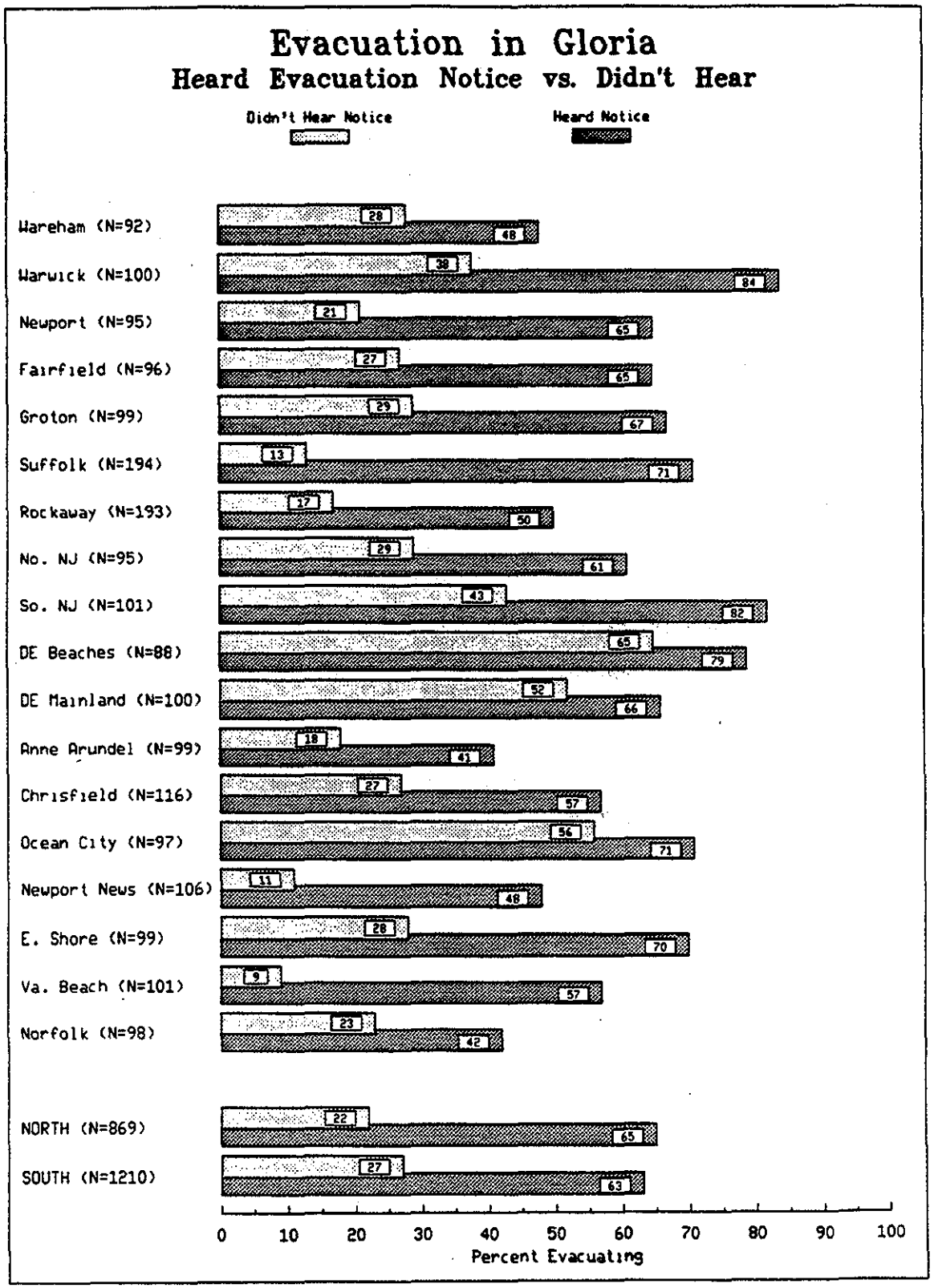
Evacuation in Gloria
Heard Evacuation Notice vs. Didn't Hear
Didn't Hear Notice
Heard Notice
Wareham (N=92)
28
48
Warwick (N=100)
38
84
Newport (N=95)
21
65
Fairfield (N=96)
27
65
Groton (N=99)
29
67
Suffolk (N=194)
13
71
Rockaway (N=193)
17
50
No. NJ (N=95)
29
61
So. NJ (N=101)
43
82
DE Beaches (N=88)
65
79
DE Mainland (N=100)
52
66
Anne Arundel (N=99)
18
41
Chrisfield (N=116)
27
57
Ocean City (N=97)
56
71
Newport News (N=106)
11
48
E. Shore (N=99)
28
70
Va. Beach (N=101)
9
57
Norfolk (N=98)
23
42
NORTH (N=869)
22
65
SOUTH (N=1210)
27
63
0
10
20
30
40
50
60
70
80
90
100
Percent Evacuating

FIG. 11

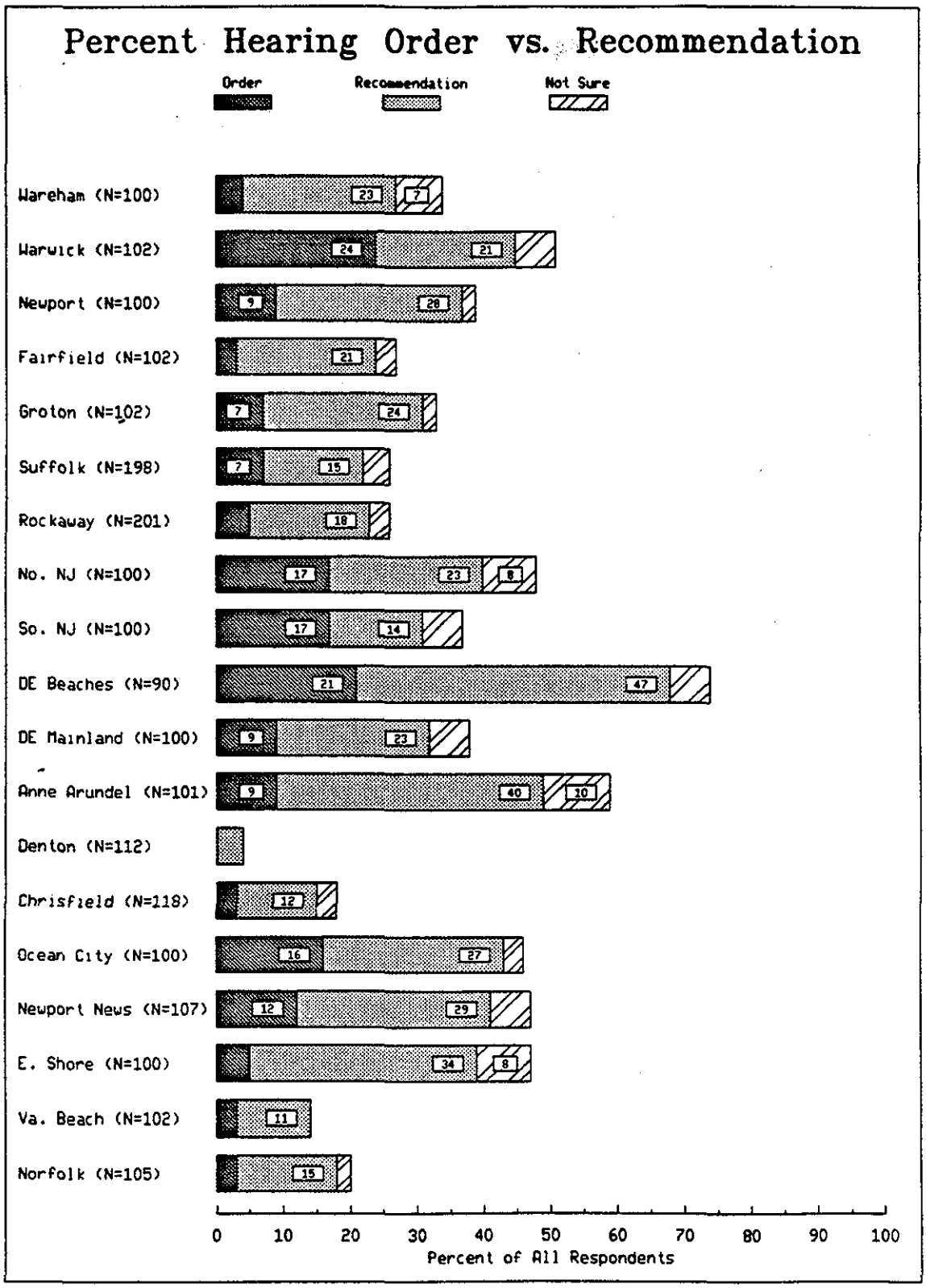
Percent Hearing Order vs. Recommendation
Order
Recommendation
Not Sure
Wareham (N=100)
23
7
Warwick (N=102)
24
21
Newport (N=100)
9
20
Fairfield (N=102)
21
Groton (N=102)
7
24
Suffolk (N=198)
7
15
Rockaway (N=201)
18
No. NJ (N=100)
17
23
8
So. NJ (N=100)
17
14
DE Beaches (N=90)
21
47
DE Mainland (N=100)
9
23
Anne Arundel (N=101)
9
40
10
Denton (N=112)
Chrisfield (N=118)
12
Ocean City (N=100)
16
27
Newport News (N=107)
12
29
E. Shore (N=100)
34
8
Va. Beach (N=102)
11
Norfolk (N=105)
15
0
10
20
30
40
50
60
70
80
90
100
Percent of All Respondents

FIG. 12

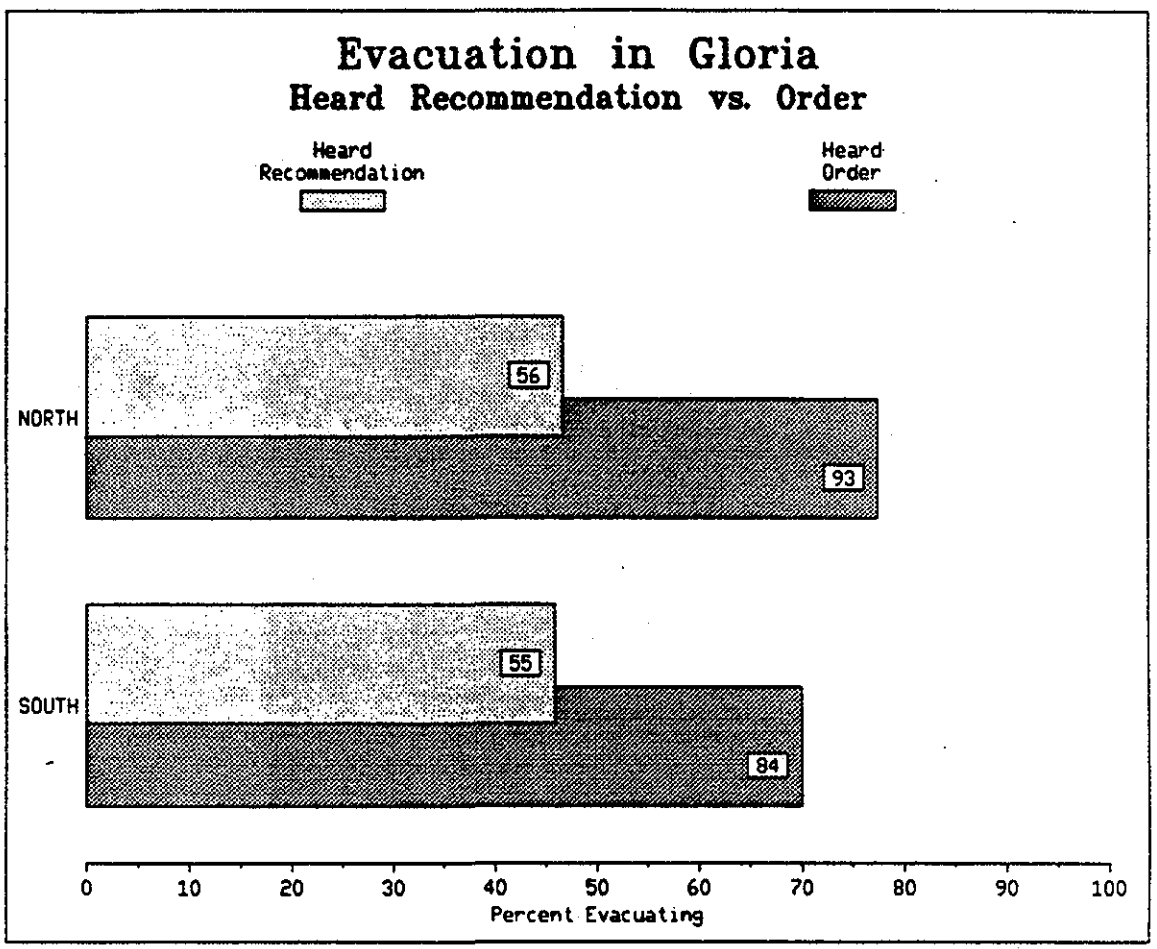
Evacuation in Gloria
Heard Recommendation vs. Order
Heard Recommendation
Heard Order
NORTH
56
93
SOUTH
55
84
0
10
20
30
40
50
60
70
80
90
100
Percent Evacuating

FIG. 13

It is also important that roughly 25% of the people not hearing official evacuation notices also left. The "shadow" evacuation phenomenon, whereby more people leave than actually need to, is common.

Effect of Perceived Safety

Proximity to water is not a perfect surrogate for hazardousness of a dwelling because elevation might rise quickly only a short distance from the shore or flooding might extend miles inland. In general, though, people who lived closer to the water were more likely to evacuate than other people (Fig. 14). The only confusion in the trend was in the southern sample where people living within a block of water appeared slightly more likely to evacuate than waterfront residents.

This pattern is common in hurricane evacuations and predicted by the general response model. Officials are more likely to tell people in more hazardous locations to evacuate, but residents of those areas are also more aware of the risk they take in staying.

Interviewees in the northern sample were asked whether they felt their house would be safe in a hurricane. A majority in all sites except Warwick felt their home would be safe, but in all locations a substantial minority considered their dwellings unsafe (Fig. 15). People believing their house was unsafe were more than twice as likely to evacuate as others (Fig. 16). The fact that only about half those saying their home would be unsafe evacuated in Gloria attests to the fact that more than belief that one's dwelling is dangerous is necessary to compel people to evacuate. Figure 17 depicts the association between belief one's house is safe (unsafe) and proximity to water.

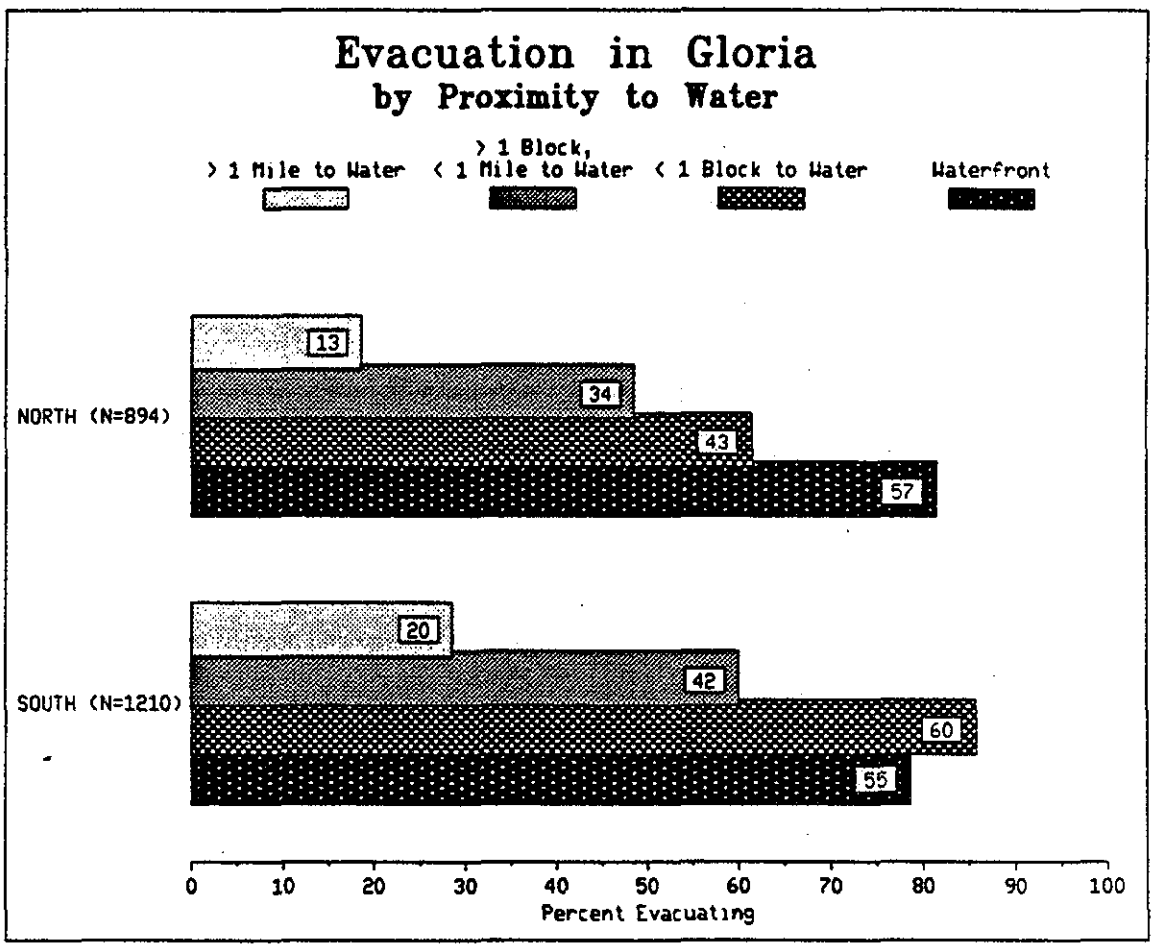
Evacuation in Gloria
by Proximity to Water
> 1 Mile to Water
> 1 Block, < 1 Mile to Water
< 1 Block to Water
Waterfront
NORTH (N=894)
13
34
43
57
SOUTH (N=1210)
20
42
60
55
0
10
20
30
40
50
60
70
80
90
100
Percent Evacuating

FIG. 14

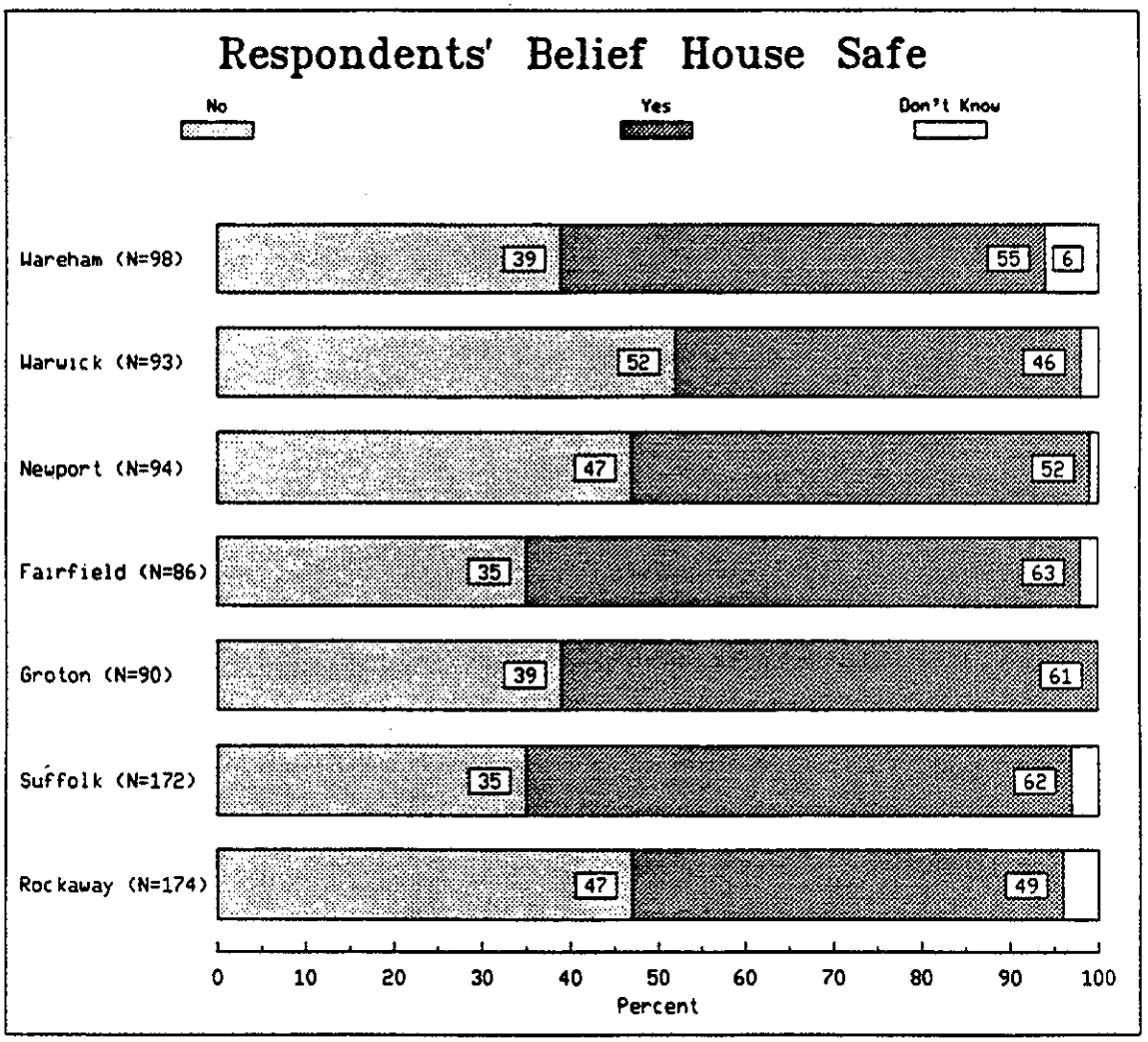
Respondents' Belief House Safe
No
Yes
Don't Know
Wareham (N=98)
39
55
6
Warwick (N=93)
52
46
Newport (N=94)
47
52
Fairfield (N=86)
35
63
Groton (N=90)
39
61
Suffolk (N=172)
35
62
Rockaway (N=174)
47
49
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 15

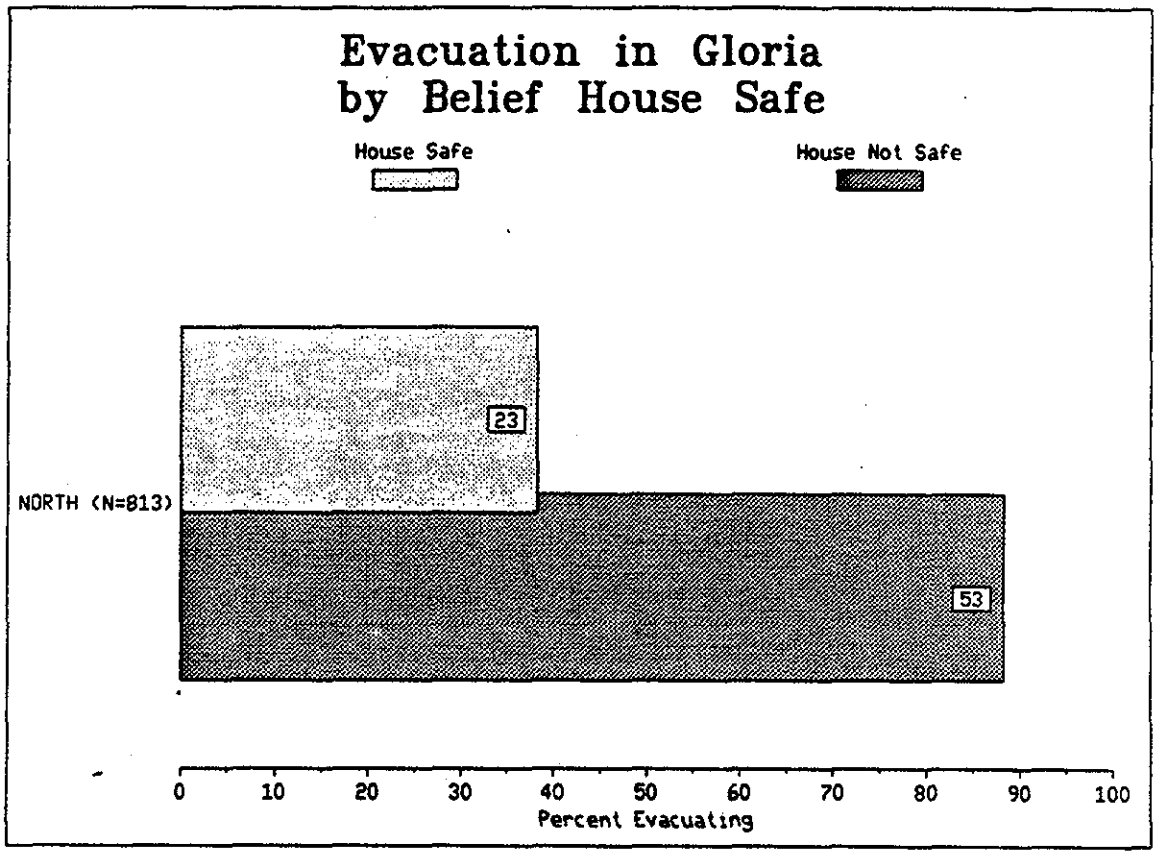
Evacuation in Gloria
by Belief House Safe
House Safe
House Not Safe
NORTH (N=813)
23
53
0
10
20
30
40
50
60
70
80
90
100
Percent Evacuating

FIG. 16

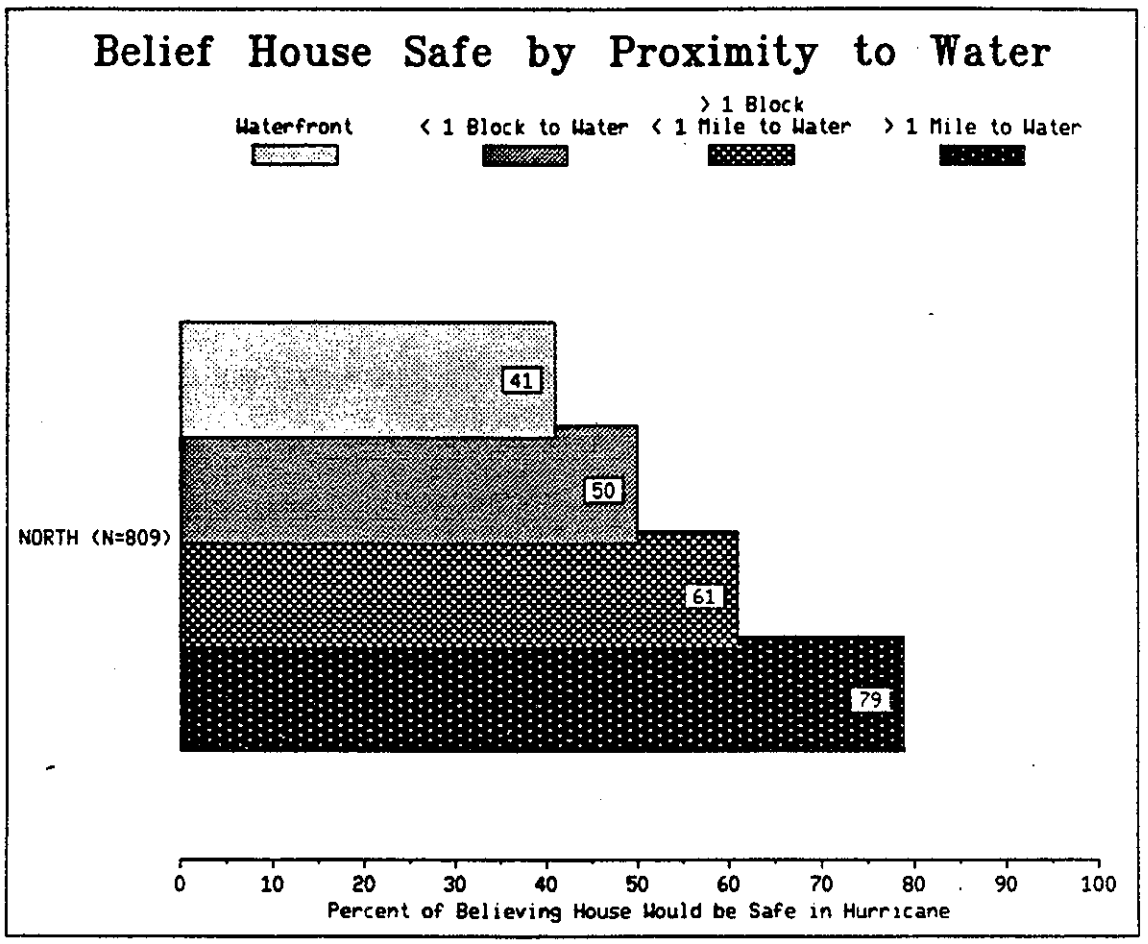
Belief House Safe by Proximity to Water
Waterfront
< 1 Block to Water
> 1 Block < 1 Mile to Water
> 1 Mile to Water
NORTH (N=809)
41
50
61
79
0
10
20
30
40
50
60
70
80
90
100
Percent of Believing House Would be Safe in Hurricane

FIG. 17

Reasons Given for Not Evacuating

The most common reason given for not evacuating in Gloria was that respondents felt safe staying where they were -- either they didn't believe the storm was severe enough to threaten their dwelling or the storm wouldn't strike their area (Fig. 18). A variety of other reasons were also volunteered.

Reasons attributing the decision to not evacuate to specific types or sources of information are graphed in Figure 19. As many as 19% (in Denton) said they stayed because officials didn't tell them to leave. Many respondents said they stayed for reasons having nothing to do with safety or information (Fig. 20). In only three survey locations (Rockaway, Denton, and Ocean City, MD) did anyone say they failed to evacuate because they had no transportation. A number in most places, however, said they stayed because they had no place to go.

There are no clear differences in reasons given across the region as a whole to distinguish the area from other locations in other hurricane threats.

Other Predictors and Non-predictors

Housing varied too little to test for response differences in all but two locations. Thirty-nine percent of the Rockaway sample contained high-rise residents, and only 8% of them evacuated, compared to 40% of single-family homes. In the Delaware mainland sample 45% of the dwellings were mobile homes, 75% of which were evacuated, whereas only 35% of other housing was evacuated. The mobile home finding is common, but there has been little comparative evidence elsewhere concerning high-rise dwellings.

Neither income nor age were associated with whether people evacuated. Income is seldom found to predict evacuation in other parts of the nation. Age is usually a factor only in areas where there are a large number of retirees such as south Florida.

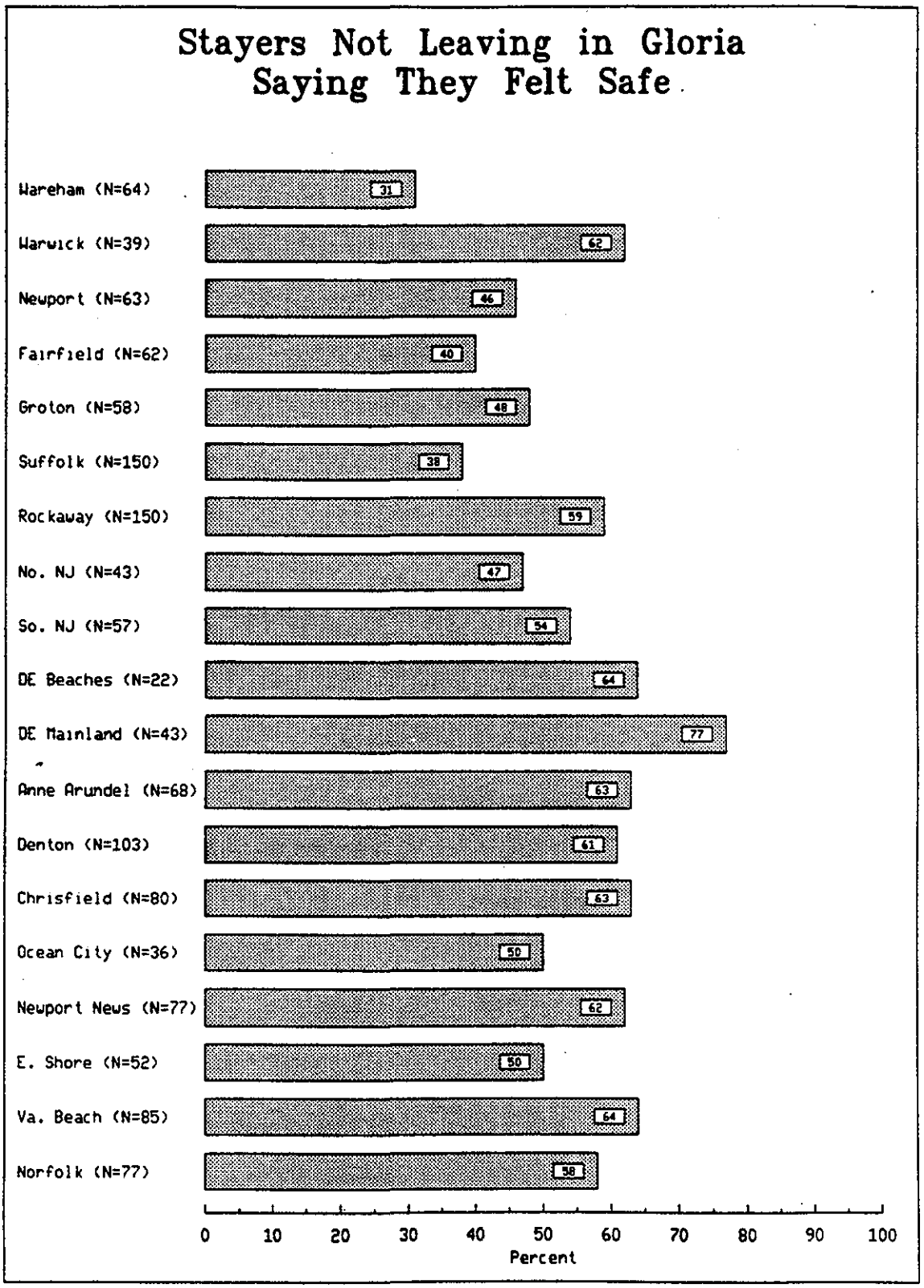
Stayers Not Leaving in Gloria
Saying They Felt Safe
Wareham (N=64)
31
Warwick (N=39)
62
Newport (N=63)
46
Fairfield (N=62)
40
Groton (N=58)
48
Suffolk (N=150)
38
Rockaway (N=150)
59
No. NJ (N=43)
47
So. NJ (N=57)
54
DE Beaches (N=22)
64
DE Mainland (N=43)
77
Anne Arundel (N=68)
63
Denton (N=103)
61
Chrisfield (N=80)
63
Ocean City (N=36)
50
Newport News (N=77)
62
E. Shore (N=52)
50
Va. Beach (N=85)
64
Norfolk (N=77)
58
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 18

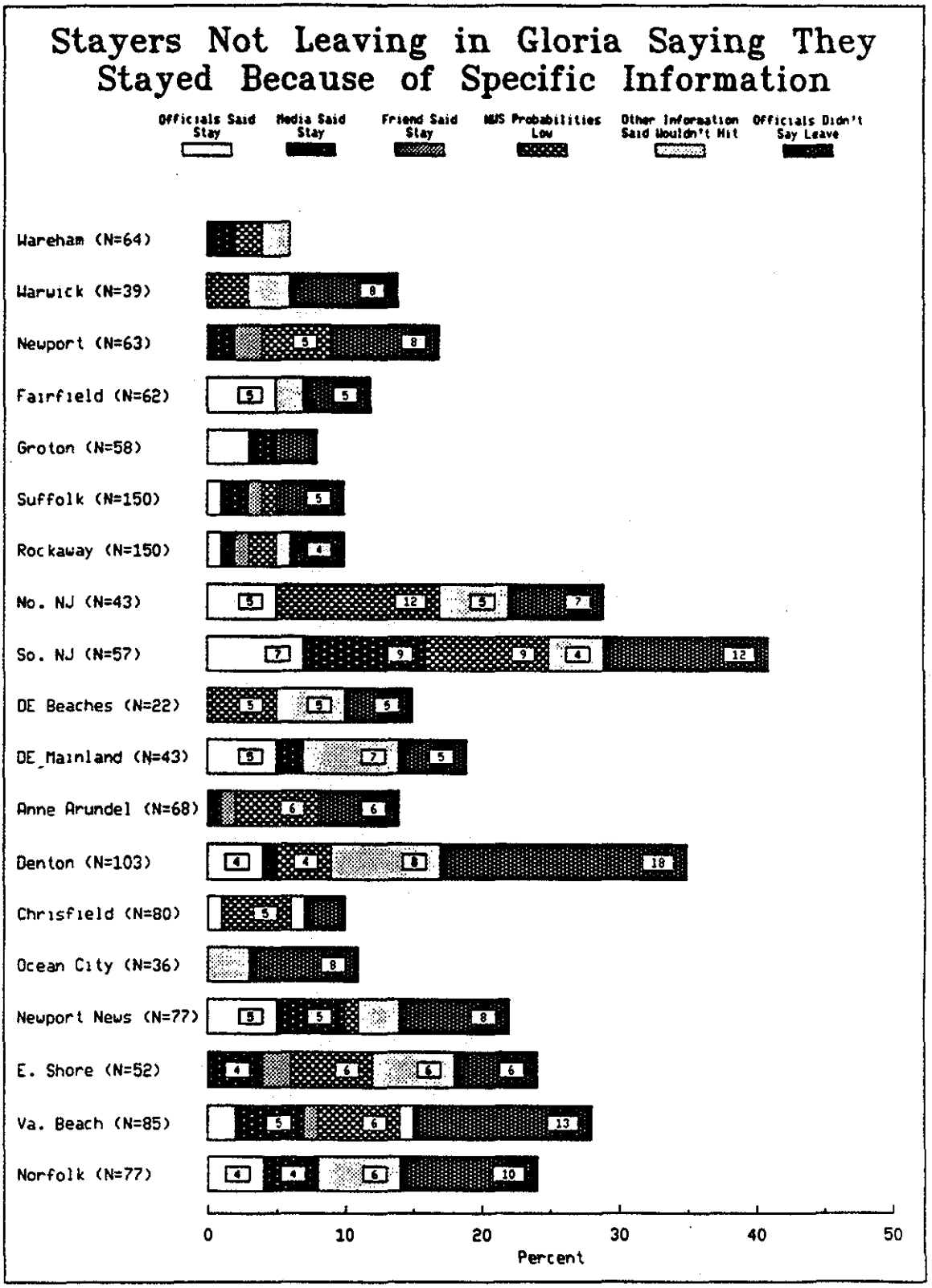
Stayers Not Leaving in Gloria Saying They Stayed Because of Specific Information
Officials Said Stay
Media Said Stay
Friend Said Stay
NWS Probabilities Low
Other Information Said Wouldn't Hit
Officials Didn't Say Leave
Wareham (N=64)
Warwick (N=39)
Newport (N=63)
Fairfield (N=62)
Groton (N=58)
Suffolk (N=150)
Rockaway (N=150)
No. NJ (N=43)
So. NJ (N=57)
DE Beaches (N=22)
DE Mainland (N=43)
Anne Arundel (N=68)
Denton (N=103)
Chrisfield (N=80)
Ocean City (N=36)
Newport News (N=77)
E. Shore (N=52)
Va. Beach (N=85)
Norfolk (N=77)
0
10
20
30
40
50
Percent

FIG. 19

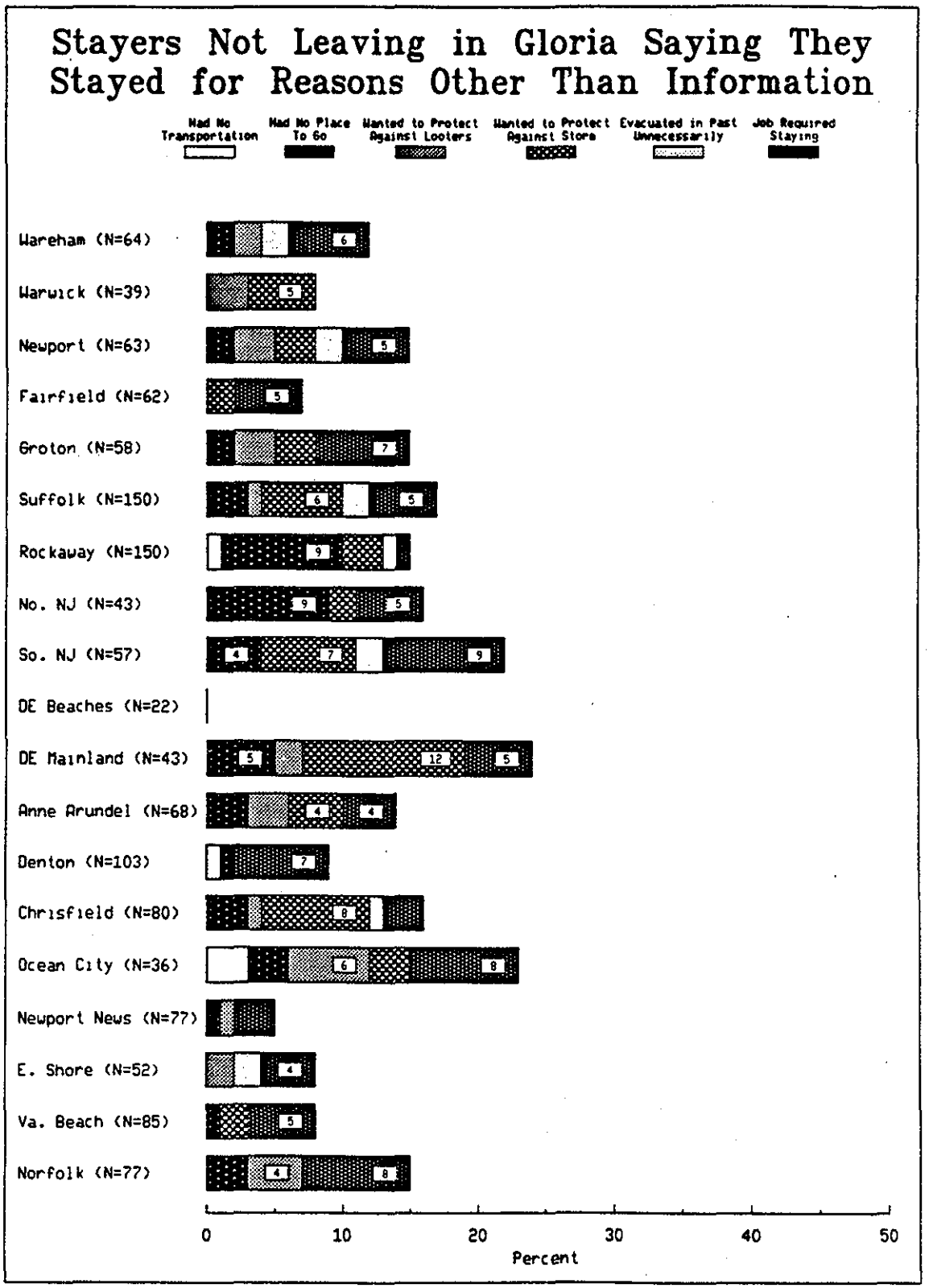
Stayers Not Leaving in Gloria Saying They Stayed for Reasons Other Than Information
Had No Transportation
Had No Place To Go
Wanted to Protect Against Looters
Wanted to Protect Against Store
Evacuated in Past Unnecessarily
Job Required Staying
Wareham (N=64)
Warwick (N=39)
Newport (N=63)
Fairfield (N=62)
Groton (N=58)
Suffolk (N=150)
Rockaway (N=150)
No. NJ (N=43)
So. NJ (N=57)
DE Beaches (N=22)
DE Mainland (N=43)
Anne Arundel (N=68)
Denton (N=103)
Chrisfield (N=80)
Ocean City (N=36)
Newport News (N=77)
E. Shore (N=52)
Va. Beach (N=85)
Norfolk (N=77)
0
10
20
30
40
50
Percent

FIG. 20

In the northern area income was not correlated at all with proximity to water, and in the southern area, the association wasn't strong (Figure 21). In neither area was age related to water proximity. Elderly residents were slightly more likely to say their house would be safe in a hurricane than other respondents (Fig. 22).

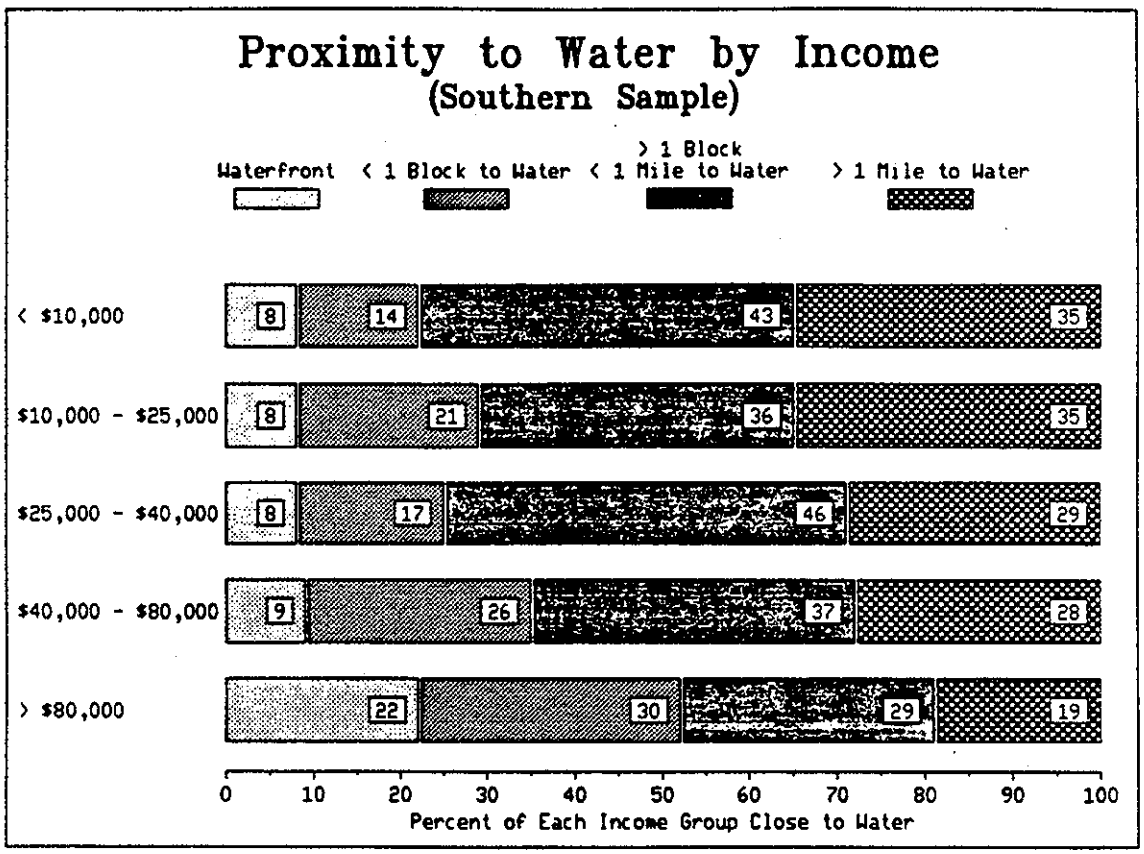
Proximity to Water by Income
(Southern Sample)
Waterfront
< 1 Block to Water
> 1 Block
< 1 Mile to Water
> 1 Mile to Water
< $10,000
8
14
43
35
$10,000 - $25,000
8
21
36
35
$25,000 - $40,000
8
17
46
29
$40,000 - $80,000
9
26
37
28
> $80,000
22
30
29
19
0
10
20
30
40
50
60
70
80
90
100
Percent of Each Income Group Close to Water

FIG. 21

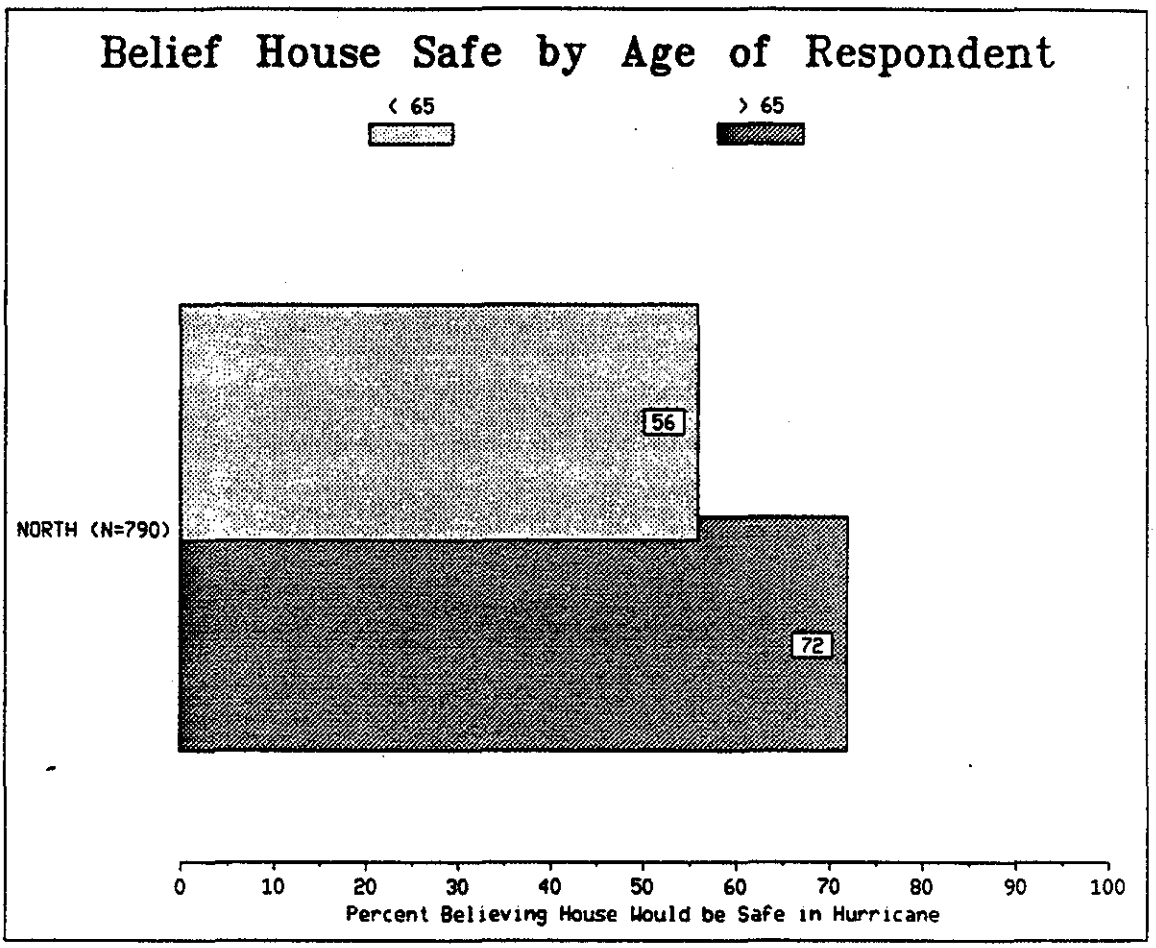
Belief House Safe by Age of Respondent
< 65
> 65
NORTH (N=790)
56
72
0
10
20
30
40
50
60
70
80
90
100
Percent Believing House Would be Safe in Hurricane

FIG. 22

Evacuation Timing

Evacuation timing is concerned with how many of the eventual evacuees leave at various times after (or before) being told to evacuate or relative to the arrival of a hurricane. Figure 23 shows the date on which Gloria evacuees said they evacuated. Clearly and understandably, people left earlier in the southern area than in the northern. This was undoubtedly a consequence of the fact that the storm threatened southern sites earlier and officials told people earlier to leave.

Evacuees were also asked what time of day they left. Plotting that data yields a cumulative evacuation curve like the ones in Figure 24 for the two Delaware survey locations. In this particular case, such curves could be misleading, however. Respondents are being asked to recall the time of day they did something two years earlier, and recall might not be good enough to place great confidence in such specific information. Even if people could remember accurately, the sample sizes make the exact shape of the plotted curves suspect.

These considerations present no difficulty in deriving planning assumptions for the region, however. Other evidence has already shown that most people didn't evacuate in Gloria without being told to do so by officials. The timing of evacuation notices, therefore, will be the primary determinant of evacuation timing, just as it is in other locations. Just how promptly people will leave after being told can't be generalized from a single evacuation in any case. People will leave as promptly or as leisurely as they believe they must, based upon information available during a particular threat. Planning recommendations, therefore, will contain three different response timing curves, each fitting a set of circumstances which are plausible at each study location.

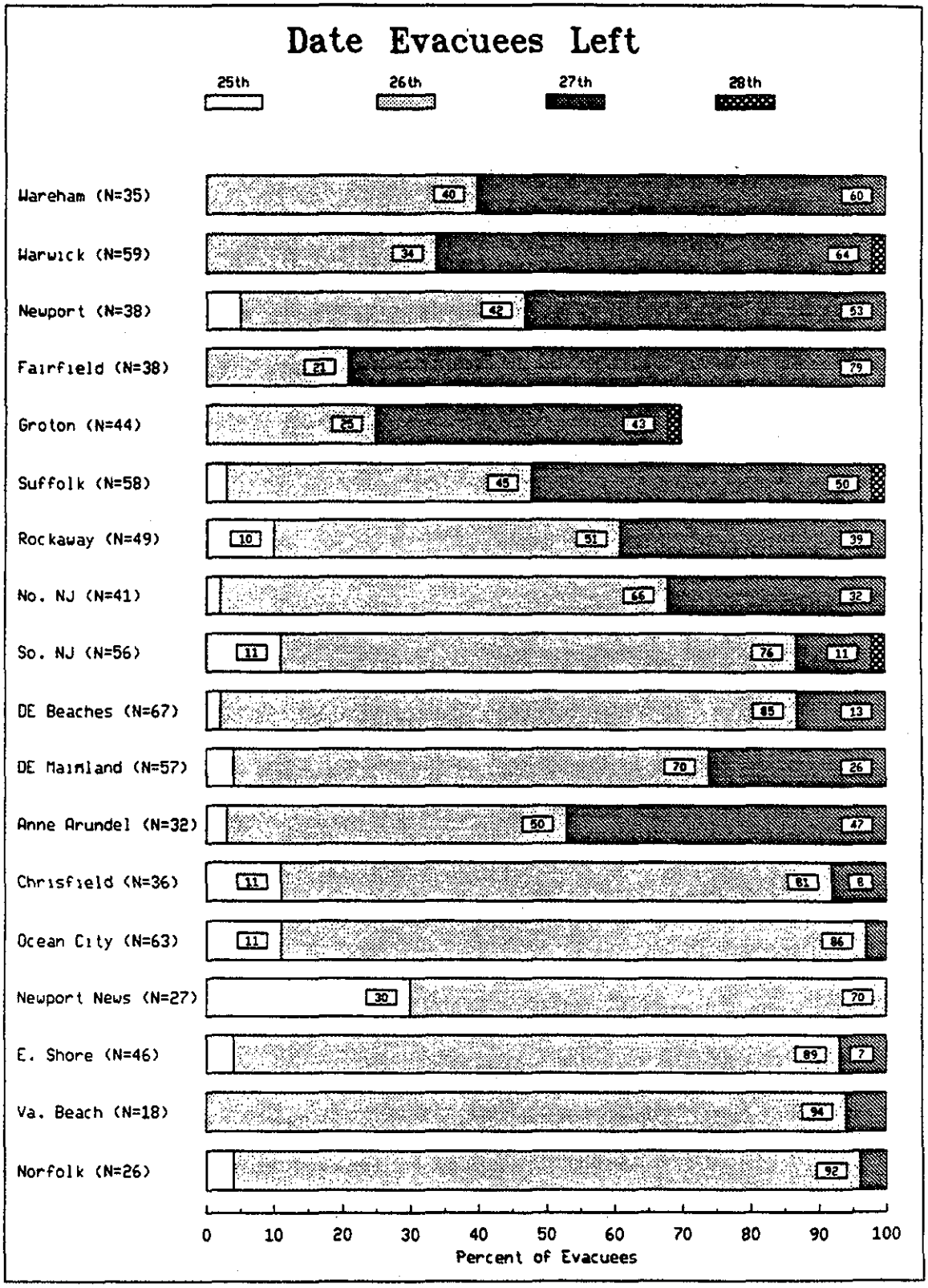
Date Evacuees Left
25th
26th
27th
28th
Wareham (N=35)
40
60
Warwick (N=59)
34
64
Newport (N=38)
42
53
Fairfield (N=38)
21
79
Groton (N=44)
25
43
Suffolk (N=58)
45
50
Rockaway (N=49)
10
51
39
No. NJ (N=41)
66
32
So. NJ (N=56)
11
76
11
DE Beaches (N=67)
85
13
DE Mainland (N=57)
70
26
Anne Arundel (N=32)
50
47
Chrisfield (N=36)
11
81
8
Ocean City (N=63)
11
86
Newport News (N=27)
30
70
E. Shore (N=46)
89
7
Va. Beach (N=18)
94
Norfolk (N=26)
92
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuees

FIG. 23

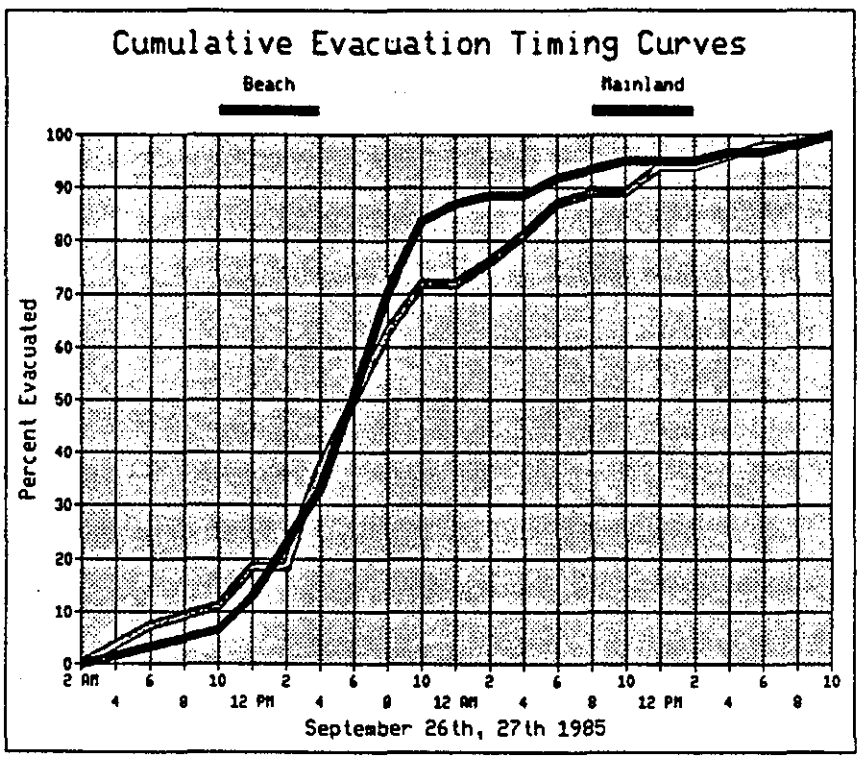
Cumulative Evacuation Timing Curves
Beach
Mainland
Percent Evacuated
100
90
80
70
60
50
40
30
20
10
0
2 AM
4
6
8
10
12 PM
2
4
6
8
10
12 AM
2
4
6
8
10
12 PM
2
4
6
8
10
September 26th, 27th 1985

FIG. 24

Types of Refuge Used

Response in Gloria

Figure 25 indicates the types of refuge used by evacuees in Gloria. Bear in mind that in most of the samples fewer than 50 people evacuated, yielding only marginally reliable data on this variable. (A sample of 50 will yield data accurate within 10 percentage points of the population value 90% of the time.)

In all but five survey sites a fourth or fewer of all evacuees went to public shelters, but there was widespread variation from site to site. Anne Arundel and Newport News had the highest shelter use rates, at 49% and 45% respectively, but both also had relatively few total evacuees (33 and 29). Newport, RI had the lowest use of public shelters, but Warwick, Rockaway, southern New Jersey, and Norfolk also had very low shelter use rates. Very few people evacuating out of their own town went to public shelters, but more did so in the southern sample than in the northern (Figure 26).

The "other" category was large in some locations. The most common of these responses was going to a second home the respondent owned, their place of work, or to a church not being operated as a Red Cross shelter.

(Non)Predictors of Shelter Use

Common predictors of public shelter use were not verified in the Gloria data. It is unclear whether the region is different, Gloria was different, or idiosyncrasies of the data set simply make verification impossible.

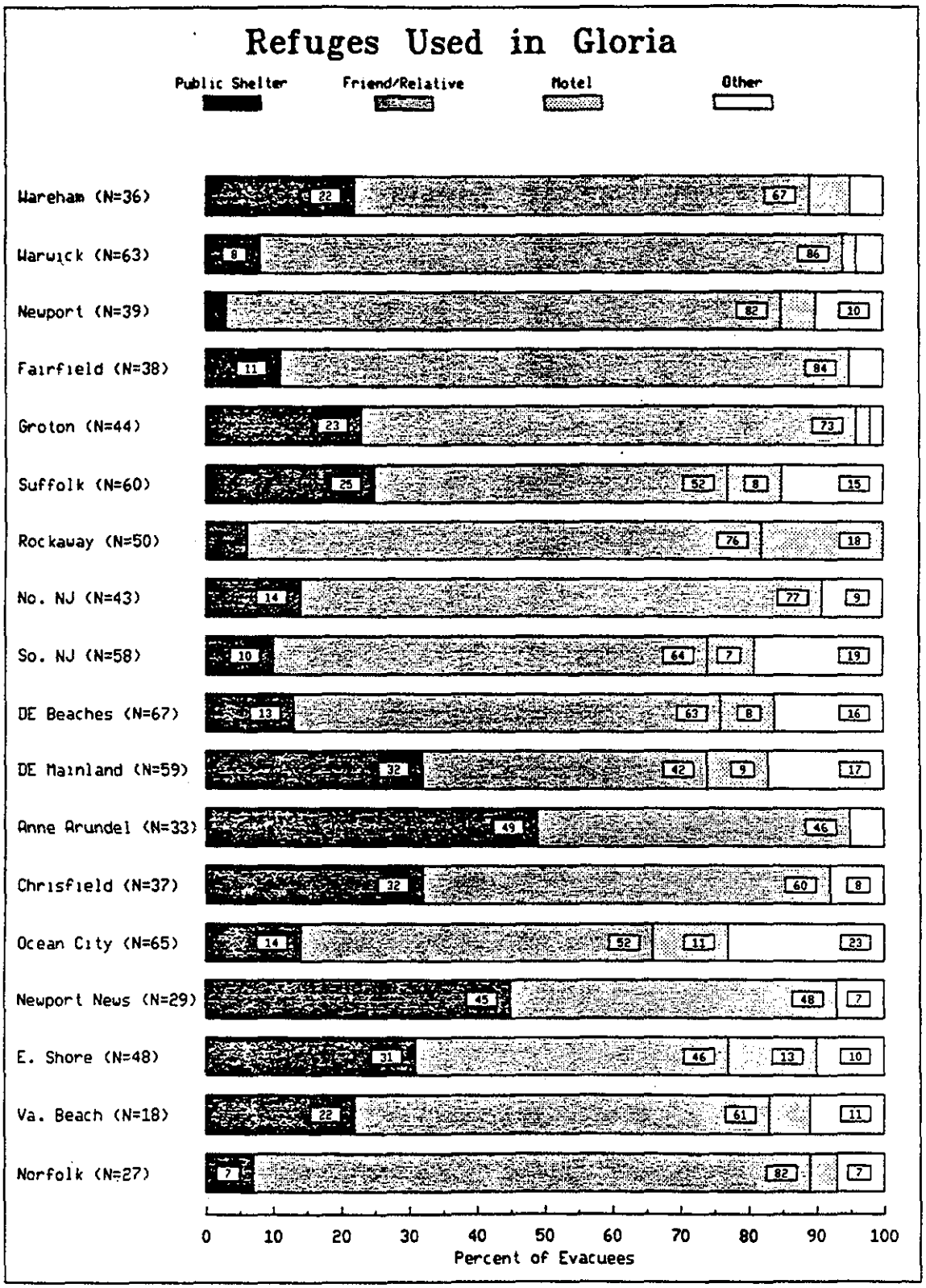
Refuges Used in Gloria
Public Shelter
Friend/Relative
Motel
Other
Wareham (N=36)
22
67
Warwick (N=63)
8
86
Newport (N=39)
82
10
Fairfield (N=38)
11
84
Groton (N=44)
23
73
Suffolk (N=60)
25
52
8
15
Rockaway (N=50)
76
18
No. NJ (N=43)
14
77
9
So. NJ (N=58)
10
64
7
19
DE Beaches (N=67)
13
63
8
16
DE Mainland (N=59)
32
42
9
17
Anne Arundel (N=33)
49
46
Chrisfield (N=37)
32
60
8
Ocean City (N=65)
14
52
11
23
Newport News (N=29)
45
48
7
E. Shore (N=48)
31
46
13
10
Va. Beach (N=18)
22
61
11
Norfolk (N=27)
7
82
7
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuees

FIG. 25

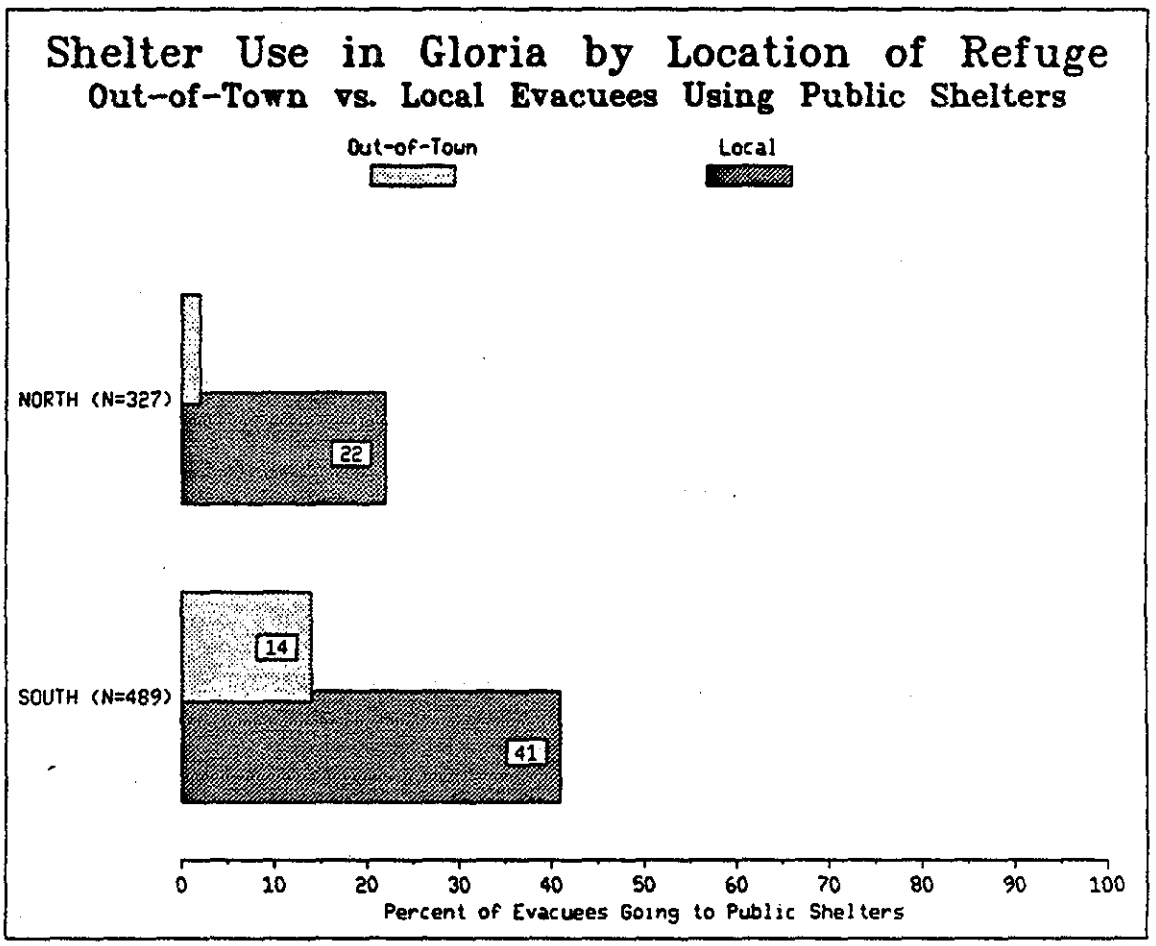
Shelter Use in Gloria by Location of Refuge
Out-of-Town vs. Local Evacuees Using Public Shelters
Out-of-Town
Local
NORTH (N=327)
22
SOUTH (N=489)
14
41
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuees Going to Public Shelters

FIG. 26

For example, income is normally associated with shelter use: low income evacuees are usually more likely to go to public shelters than more affluent evacuees. There is some evidence to support the notion in the Gloria data. Newport News and Chrisfield, with the highest incidence of low income residents in the samples, had two of the highest rates of public shelter use. Anne Arundel, however, with the highest shelter use rate, also had the lowest percentage of surveyed households reporting incomes below $10,000/yr.

Because of the small number of evacuees and even smaller number of public shelter users at each interview location it was not possible to test reliably for associations between income and shelter use in each location. When the samples were aggregated into northern and southern areas to increase sample sizes, no relationship was found between income and shelter use. Aggregating samples, however, can sometimes obscure relationships which exist at lower levels, and that could be occurring in this case. For example, actions by local officials can either encourage or discourage shelter use at the local level. As such actions undoubtedly varied from site to site in Gloria, lumping all the sites together would tend to make it more difficult to detect the effect of other factors such as income. There is also the larger question of whether respondents were candid about their actual incomes and whether the refusal of many people to answer that question might have affected these tests.

Another common predictor of shelter use is hazardousness of one's location. Evacuees from dangerous places such as barrier islands are less likely to use public shelters than evacuees from low-risk areas. Again, there is evidence of this at one scale in the Gloria data: Evacuees from the Delaware beach sample were much less likely to use public shelters than Delaware mainland evacuees. Other beach sample areas such as Ocean City, MD, and the New Jersey samples had some of the lowest shelter use rates.

Sample sizes were too small in individual survey sites to test whether people living farther from water bodies were more likely to use public shelters. When the data was aggregated into northern and southern areas, no relationship was found.

Age is not usually associate with shelter use except in retirement areas, and this proved also to be the case in Gloria.

Hypothetical Refuge Use

Respondents who didn't evacuate in Gloria were asked what sort of refuge they would have sought if they had evacuated. As indicated in Figure 27, hypothetical shelter use was much higher than actual use in most locations. An initial interpretation might be to infer that the people who didn't evacuate in Gloria were actually more prone to use public shelters than those who did evacuate. This relationship between hypothetical and actual shelter use is common, however, and the very same individuals who say they would use public shelters are actually about half as likely to as they themselves believe. Figure 28 compares intended and actual shelter use in a number of locations and storms.

In some surveys people who said they would use public shelters were then asked whether they had friends or relatives in safe locations with whom they could stay if necessary. Most answered affirmatively. Those were then asked whether they might not actually stay with those friends and relatives rather than going to a public shelter. Again, most answered affirmatively, indicating the tenuousness and instability of the hypothetical response.

One reason that actual shelter use tends to be lower than hypothetical is that during hurricane threats, people tend to contact one another, with residents in safe locations often inviting and even urging friends and relatives to come to their houses. Thus options become available that might not have been assumed during a

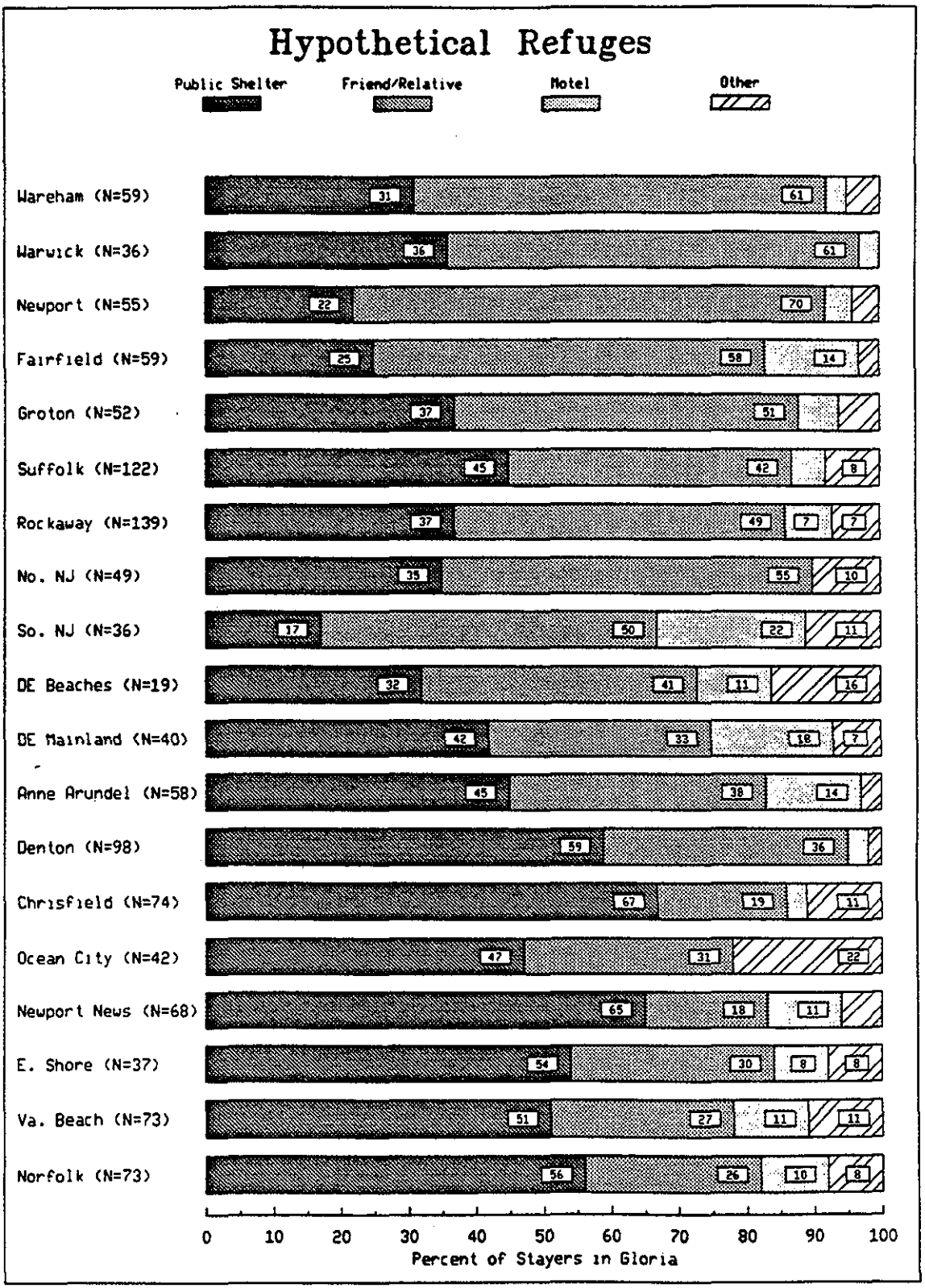
Hypothetical Refuges
Public Shelter
Friend/Relative
Motel
Other
Wareham (N=59)
31
61
Warwick (N=36)
36
61
Newport (N=55)
22
70
Fairfield (N=59)
25
58
14
Groton (N=52)
37
51
Suffolk (N=122)
45
42
8
Rockaway (N=139)
37
49
7
7
No. NJ (N=49)
35
55
10
So. NJ (N=36)
17
50
22
11
DE Beaches (N=19)
32
41
11
16
DE Mainland (N=40)
42
33
18
7
Anne Arundel (N=58)
45
38
14
Denton (N=98)
59
36
Chrisfield (N=74)
67
19
11
Ocean City (N=42)
47
31
22
Newport News (N=68)
65
18
11
E. Shore (N=37)
54
30
8
8
Va. Beach (N=73)
51
27
11
11
Norfolk (N=73)
56
26
10
8
0
10
20
30
40
50
60
70
80
90
100
Percent of Stayers in Gloria

FIG. 27

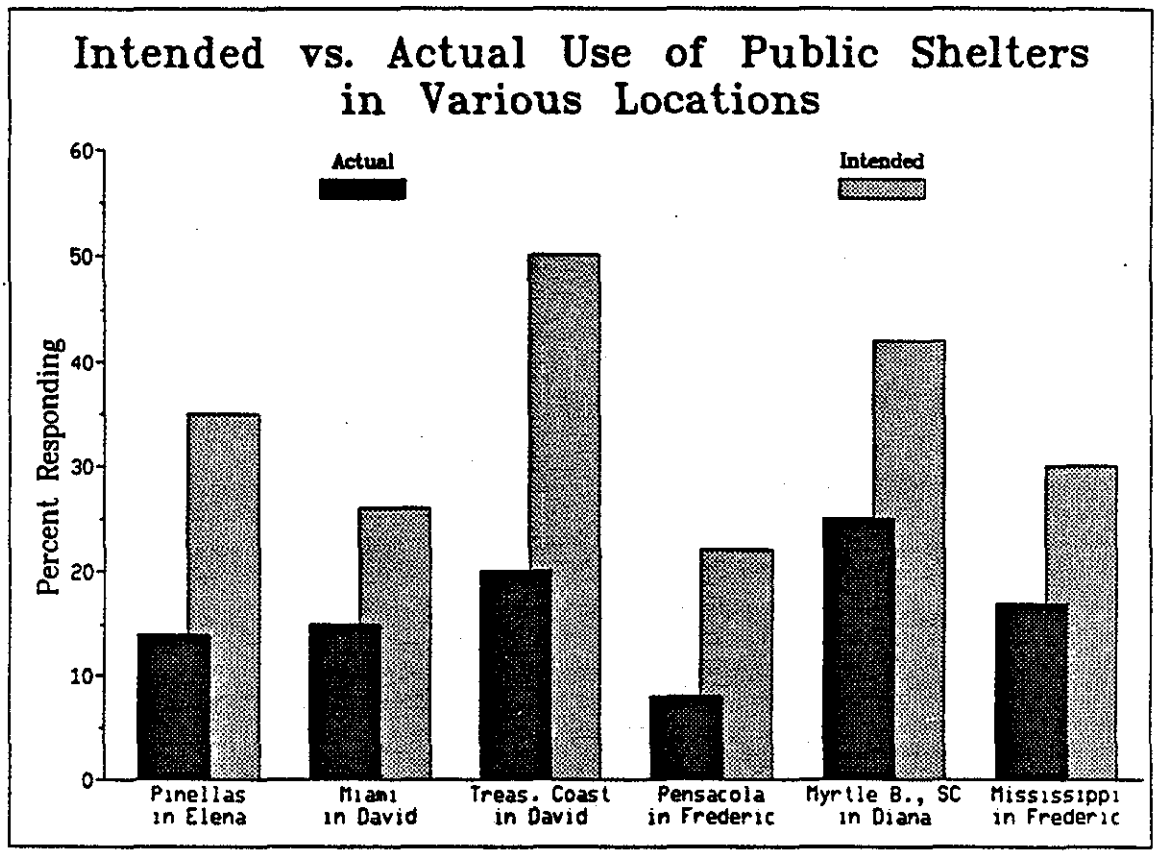
Intended vs. Actual Use of Public Shelters in Various Locations
Actual
Intended
Percent Responding
60
50
40
30
20
10
0
Pinellas in Elena
Miami in David
Treas. Coast in David
Pensacola in Frederic
Myrtle B., SC in Diana
Mississippi in Frederic

FIG. 28

hypothetical interview. It is also likely that as evacuation nears, people consider the pro's and con's of public shelters more carefully, with many deciding in retrospect that public shelter conditions are not so attractive after all.

Although hypothetical shelter use figures are not reliable in the absolute sense, they do have some validity in a relative sense. That is, if more people in one location say they would use public shelters than people in a second location, more of them probably will actually use public shelters in an evacuation, although the hypothetical numbers from both groups are inflated. More people in the southern area sample said they would use public shelters than in the northern sample, for example. This also appeared true, but less definitely, in the actual response data.

It's interesting that the income vs. shelter use relationship discussed earlier and not verified in Gloria is clearly present with hypothetical shelter use data (Figure 29). This gives a bit more reason for applying the generalization when deriving planning assumptions for the region.

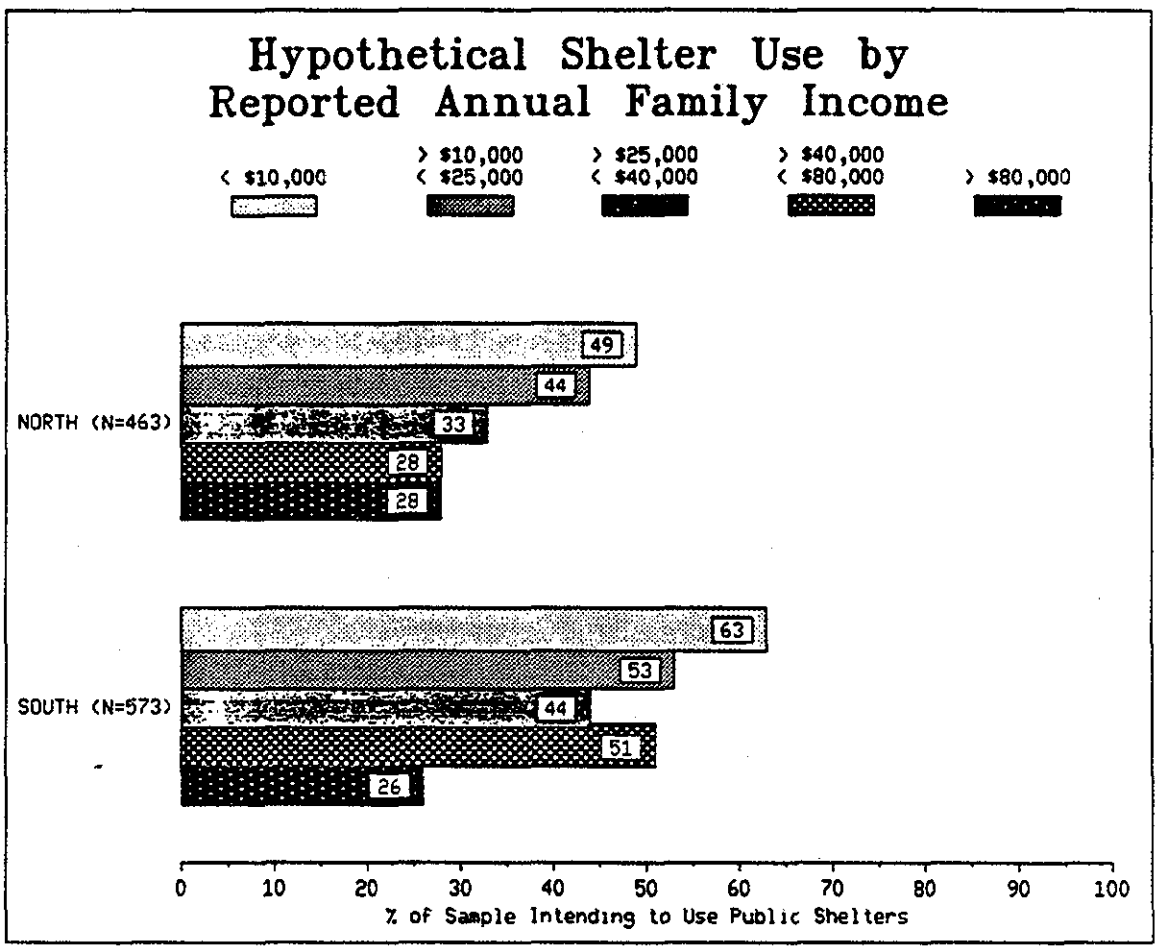
Hypothetical Shelter Use by
Reported Annual Family Income
< $10,000
> $10,000
< $25,000
> $25,000
< $40,000
> $40,000
< $80,000
> $80,000
NORTH (N=463)
49
44
33
28
28
SOUTH (N=573)
63
53
44
51
26
0
10
20
30
40
50
60
70
80
90
100
% of Sample Intending to Use Public Shelters

FIG. 29

Evacuation Destinations

Response in Gloria

There was much variation from site to site with respect to whether evacuees in Gloria left their local areas (usually meaning towns) or sought refuge nearby (Figure 30). Only 7% of the evacuees in Newport News left their local area, compared to 88% in the southern New Jersey area. In half the locations more than 50% of the evacuees went out-of-town.

Figure 31 suggests, though, that most evacuees didn't go very far, even if it was out-of-town. In 13 of 18 sites more than half the evacuees said they reached their destination in 30 minutes or less. In the New England states between 83% and 100% of the evacuees took less than 30 minutes.

It was noted previously that very few of the people going out of their local area went to public shelters, and that is common throughout the Gulf and Atlantic coasts. In most locations people in the highest risk locations (barrier islands primarily) are more likely to go out-of-town than evacuees from lower-risk areas. The proximity-to-water test tends to verify that generalization for Gloria in the southern area but not in the northern area (Fig. 32). Proximity to water, however, is not a good surrogate for hazardousness in all locations or when comparing one site to another. When simply looking at interview sites consisting primarily of beach areas (Delaware beaches, southern New Jersey, Ocean City, MD, etc.), it appears that those locations had substantially more evacuees leaving the local area and taking more than 30 minutes to reach their destinations than did most other sites.

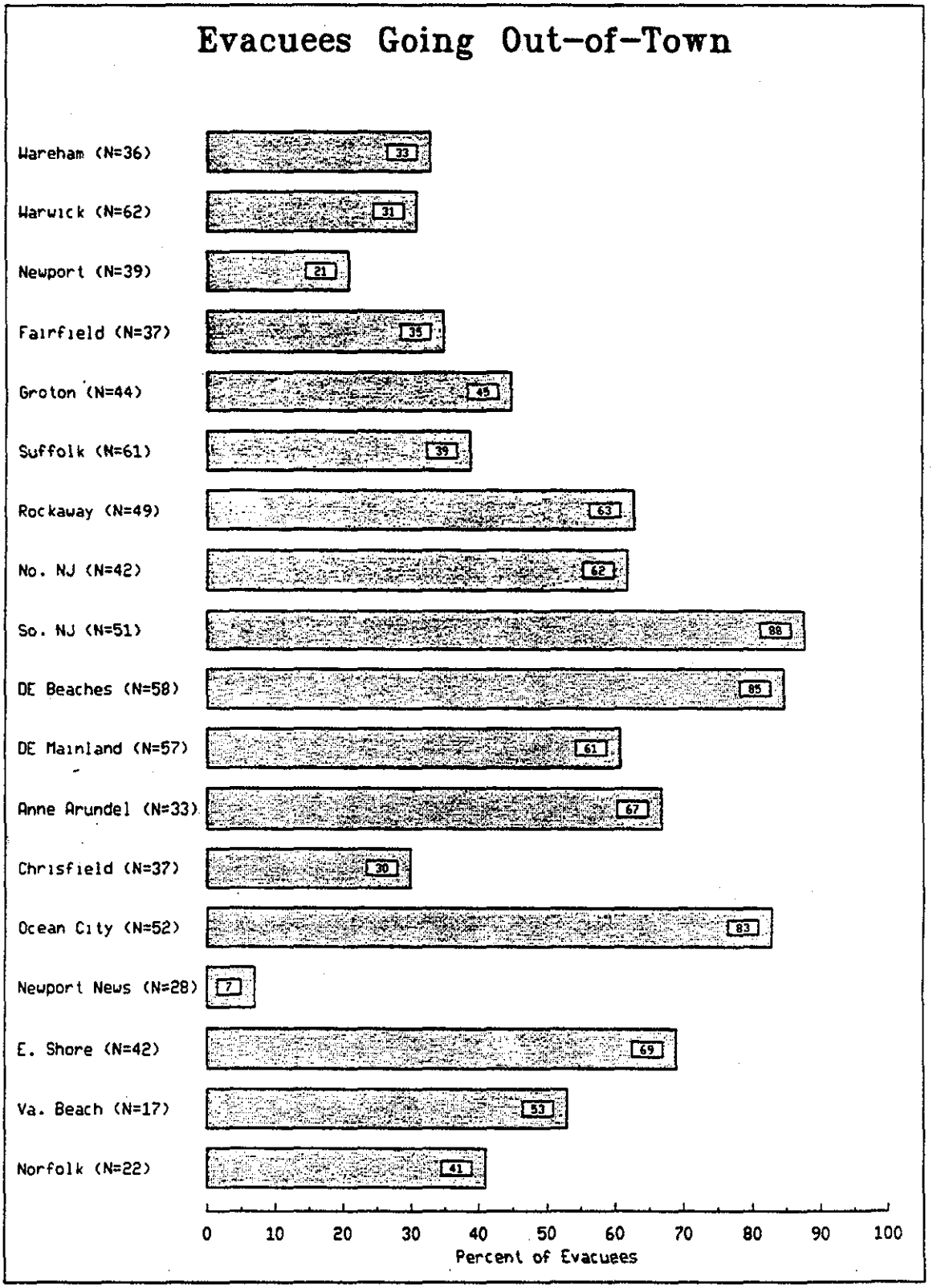
Evacuees Going Out-of-Town
Wareham (N=36)
33
Warwick (N=62)
31
Newport (N=39)
21
Fairfield (N=37)
35
Groton (N=44)
45
Suffolk (N=61)
39
Rockaway (N=49)
63
No. NJ (N=42)
62
So. NJ (N=51)
88
DE Beaches (N=58)
85
DE Mainland (N=57)
61
Anne Arundel (N=33)
67
Chrisfield (N=37)
30
Ocean City (N=52)
83
Newport News (N=28)
7
E. Shore (N=42)
69
Va. Beach (N=17)
53
Norfolk (N=22)
41
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuees

FIG. 30

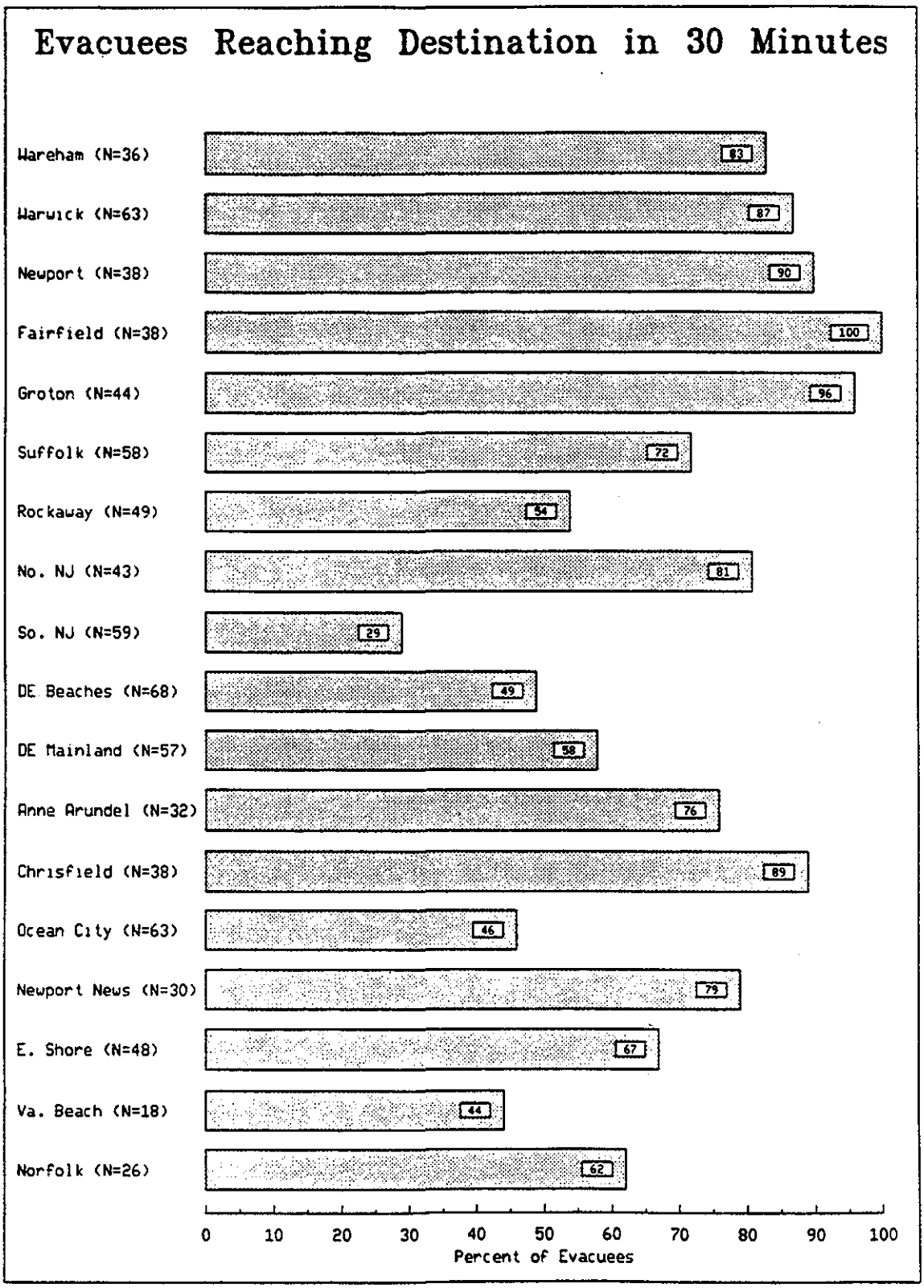
Evacuees Reaching Destination in 30 Minutes
Wareham (N=36)
83
Warwick (N=63)
87
Newport (N=38)
90
Fairfield (N=38)
100
Groton (N=44)
96
Suffolk (N=58)
72
Rockaway (N=49)
54
No. NJ (N=43)
81
So. NJ (N=59)
29
DE Beaches (N=68)
49
DE Mainland (N=57)
58
Anne Arundel (N=32)
76
Chrisfield (N=38)
89
Ocean City (N=63)
46
Newport News (N=30)
79
E. Shore (N=48)
67
Va. Beach (N=18)
44
Norfolk (N=26)
62
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuees

FIG. 31

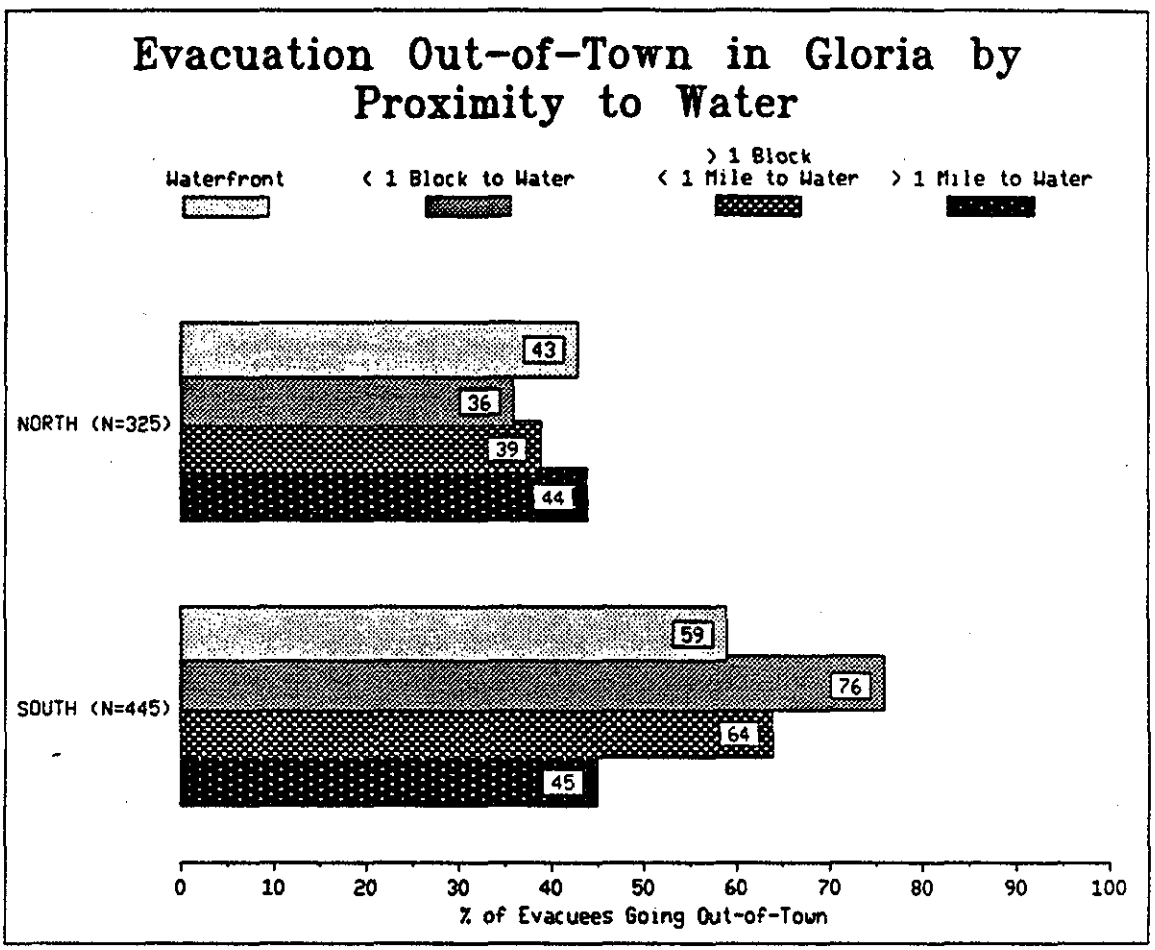
Evacuation Out-of-Town in Gloria by Proximity to Water
Waterfront
< 1 Block to Water
> 1 Block < 1 Mile to Water
> 1 Mile to Water
NORTH (N=325)
43
36
39
44
SOUTH (N=445)
59
76
64
45
0
10
20
30
40
50
60
70
80
90
100
% of Evacuees Going Out-of-Town

FIG. 32

Income can also be a clue to whether evacuees will leave their local area. This probably results from the fact that people with higher incomes are more likely to live near the beach, they are less likely to use public shelters, and they can more easily afford motels. In the Gloria data there was no income vs. out-of-town evacuation relationship in the southern sample, but there was in the northern area (Fig. 33).

Hypothetical Responses

In the northern area people who didn't evacuate in Gloria were asked where they thought they would have gone if they had evacuated. The results were fairly consistent with actual response data for the sites (Fig. 34). Higher income respondents were somewhat more likely to say they would leave the local area (Fig. 35).

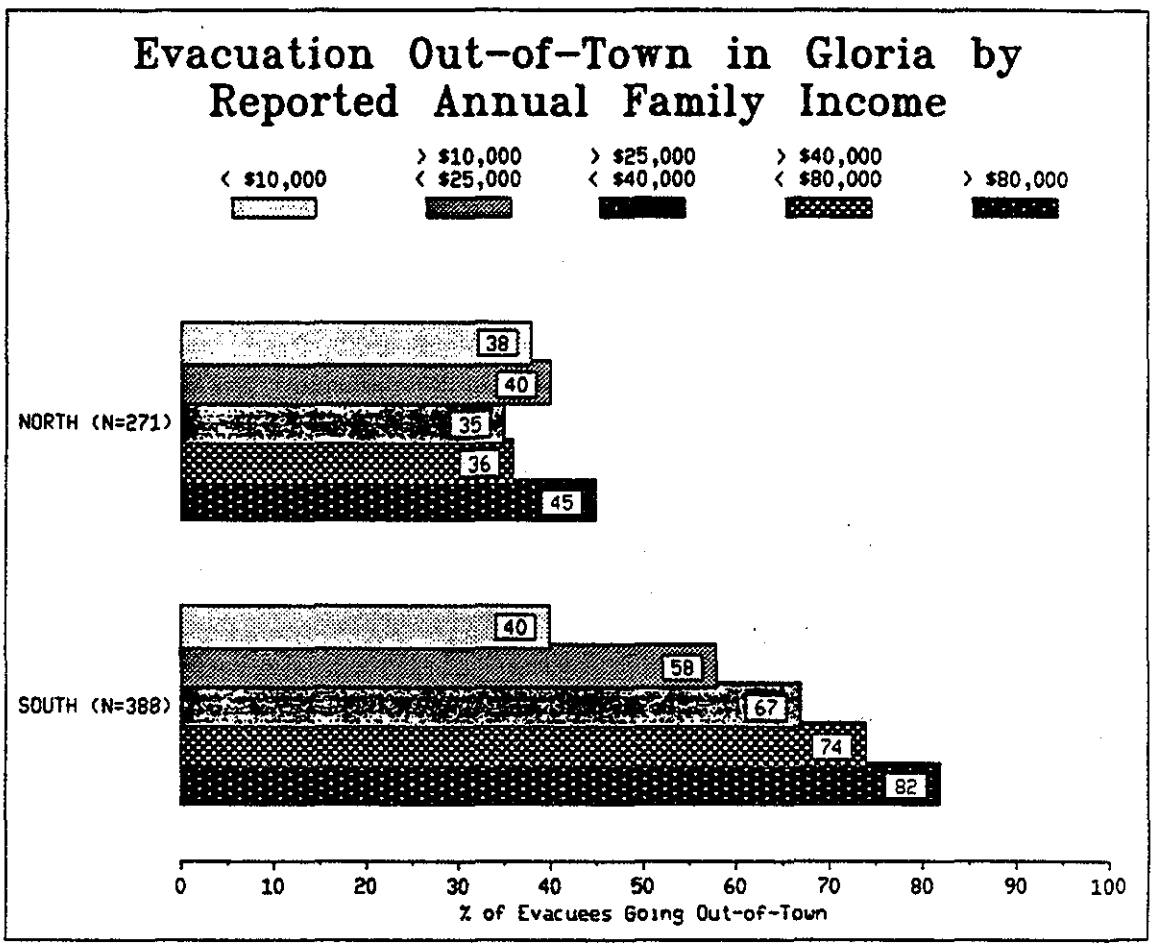
Evacuation Out-of-Town in Gloria by Reported Annual Family Income
< $10,000
> $10,000 < $25,000
> $25,000 < $40,000
> $40,000 < $80,000
> $80,000
NORTH (N=271)
38
40
35
36
45
SOUTH (N=388)
40
58
67
74
82
0
10
20
30
40
50
60
70
80
90
100
% of Evacuees Going Out-of-Town

FIG. 33

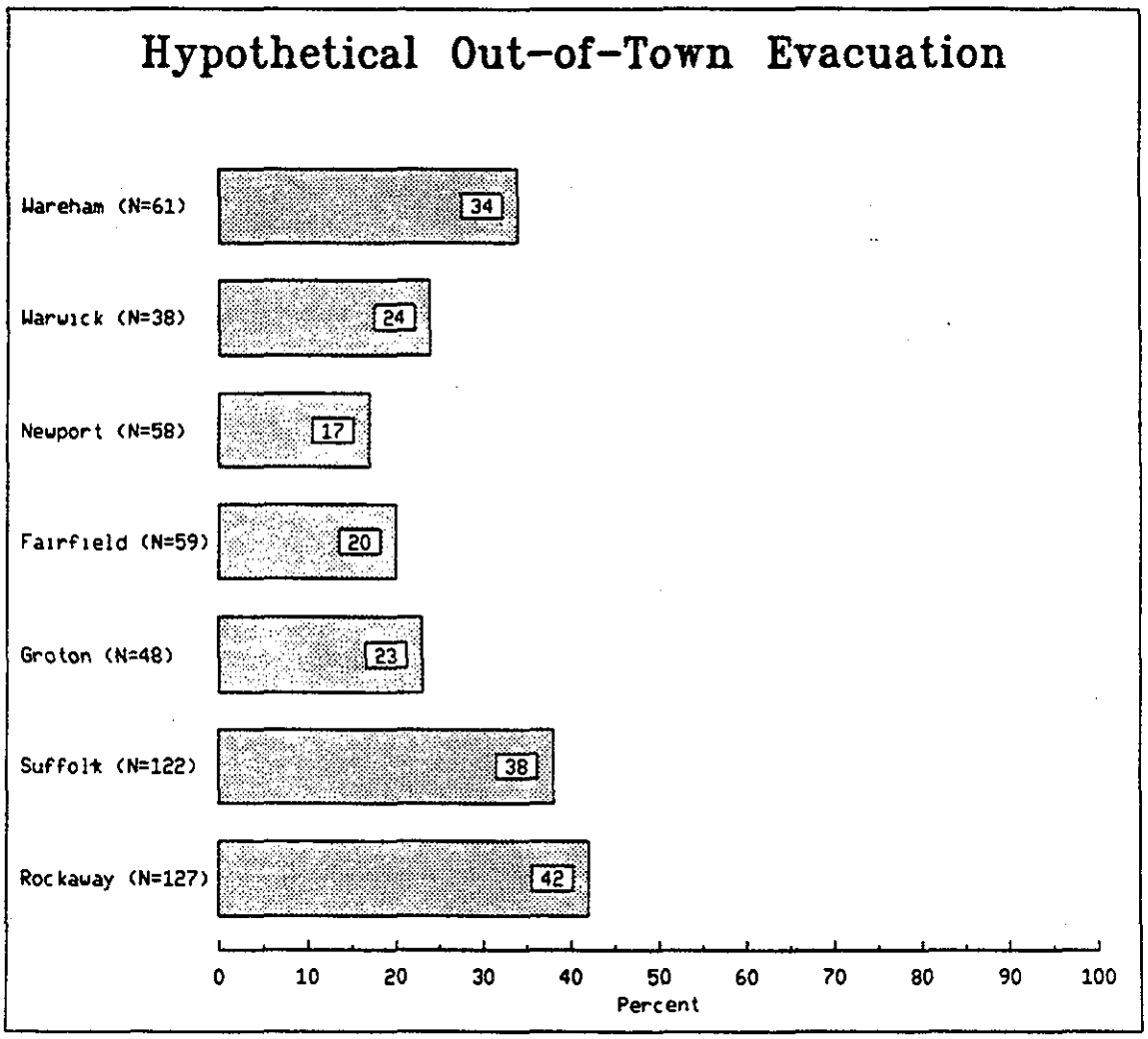
Hypothetical Out-of-Town Evacuation
Wareham (N=61)
34
Warwick (N=38)
24
Newport (N=58)
17
Fairfield (N=59)
20
Groton (N=48)
23
Suffolk (N=122)
38
Rockaway (N=127)
42
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 34

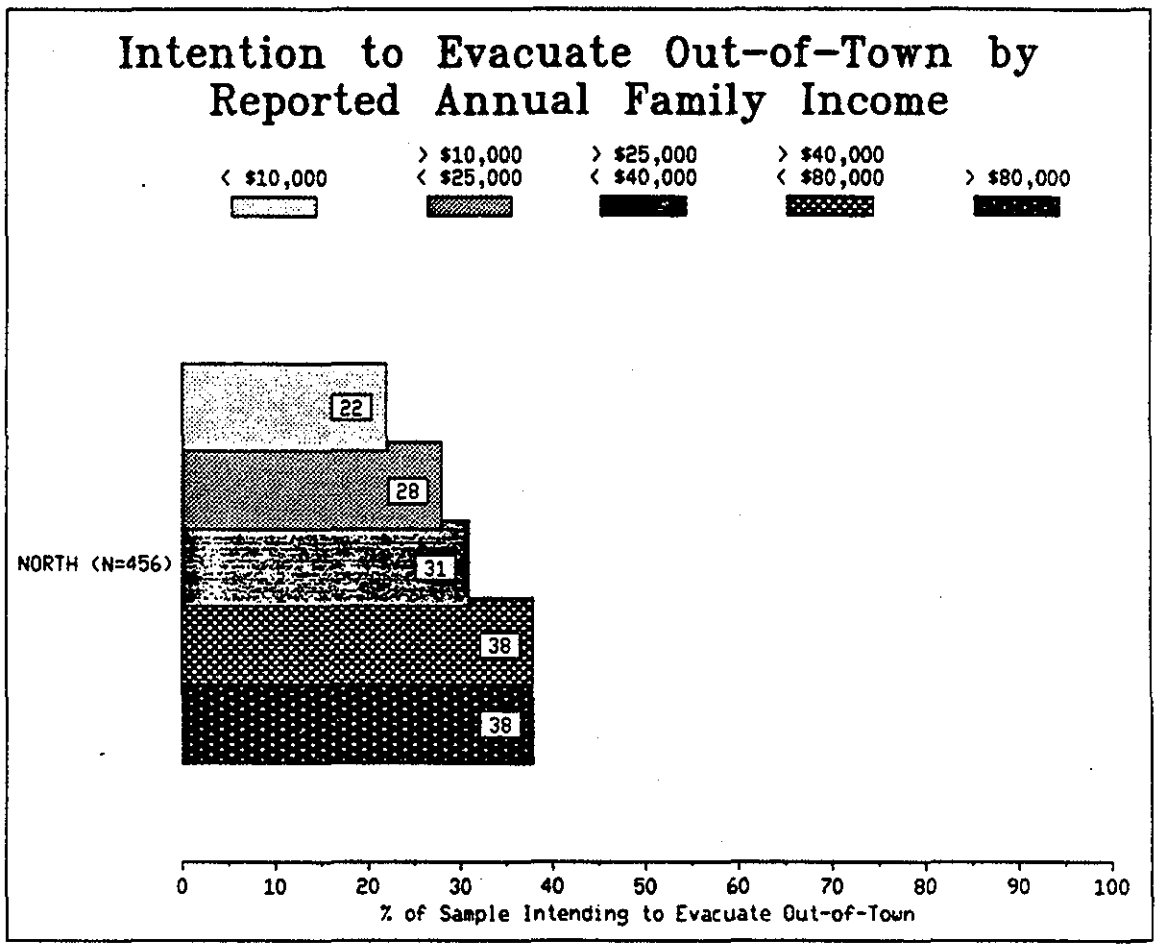
Intention to Evacuate Out-of-Town by Reported Annual Family Income
< $10,000
> $10,000 < $25,000
> $25,000 < $40,000
> $40,000 < $80,000
> $80,000
NORTH (N=456)
22
28
31
38
38
0
10
20
30
40
50
60
70
80
90
100
% of Sample Intending to Evacuate Out-of-Town

FIG. 35

Vehicle Use

Household Transportation

The great majority of evacuees in Gloria used only one vehicle, although some used more (Figure 36). That is almost always the case in hurricane evacuations. Figure 37 shows two additional variables: the percentage of available vehicles actually used by evacuating households and the average number of vehicles used per evacuating household. The average ranged from 1.0 to 1.5. In most cases between 65% and 75% of the vehicles available to households are actually used in evacuating. Fourteen of eighteen Gloria sites were within one percentage point of that range. The Delaware beach sample was abnormally high, and Virginia Beach and Anne Arundel were unusually low. Not all vehicles are used in evacuations because families want to avoid separating any more than necessary.

Public Transportation

In the northern area evacuees were asked what sort of transportation they used (Fig. 38). Almost everyone said they left in their own vehicle. Only in Rockaway did anyone mention using public transportation. Northern area respondents not leaving in Gloria were asked whether they had a car available in which to evacuate if they had chosen to (Fig. 39). Only in Rockaway, and to a much lesser degree Newport, did people say no. Recall also that people in only three sites said they didn't leave because of a lack of transportation (Ocean City,

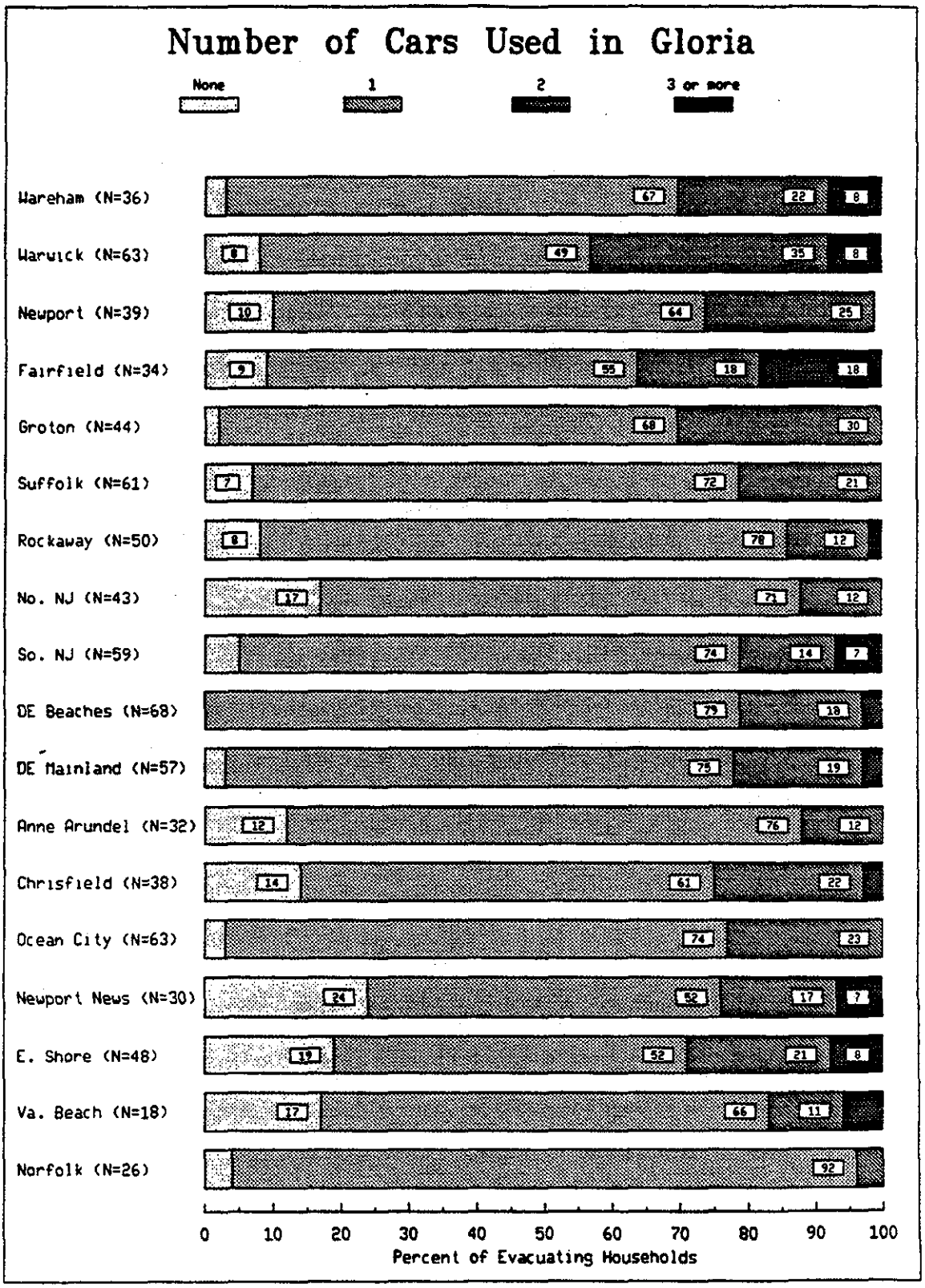
Number of Cars Used in Gloria
None
1
2
3 or more
Wareham (N=36)
67
22
8
Warwick (N=63)
8
49
35
8
Newport (N=39)
10
64
25
Fairfield (N=34)
9
55
18
18
Groton (N=44)
68
30
Suffolk (N=61)
7
72
21
Rockaway (N=50)
8
78
12
No. NJ (N=43)
17
71
12
So. NJ (N=59)
74
14
7
DE Beaches (N=68)
79
18
DE Mainland (N=57)
75
19
Anne Arundel (N=32)
12
76
12
Chrisfield (N=38)
14
61
22
Ocean City (N=63)
74
23
Newport News (N=30)
24
52
17
7
E. Shore (N=48)
19
52
21
8
Va. Beach (N=18)
17
66
11
Norfolk (N=26)
92
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuating Households

FIG. 36

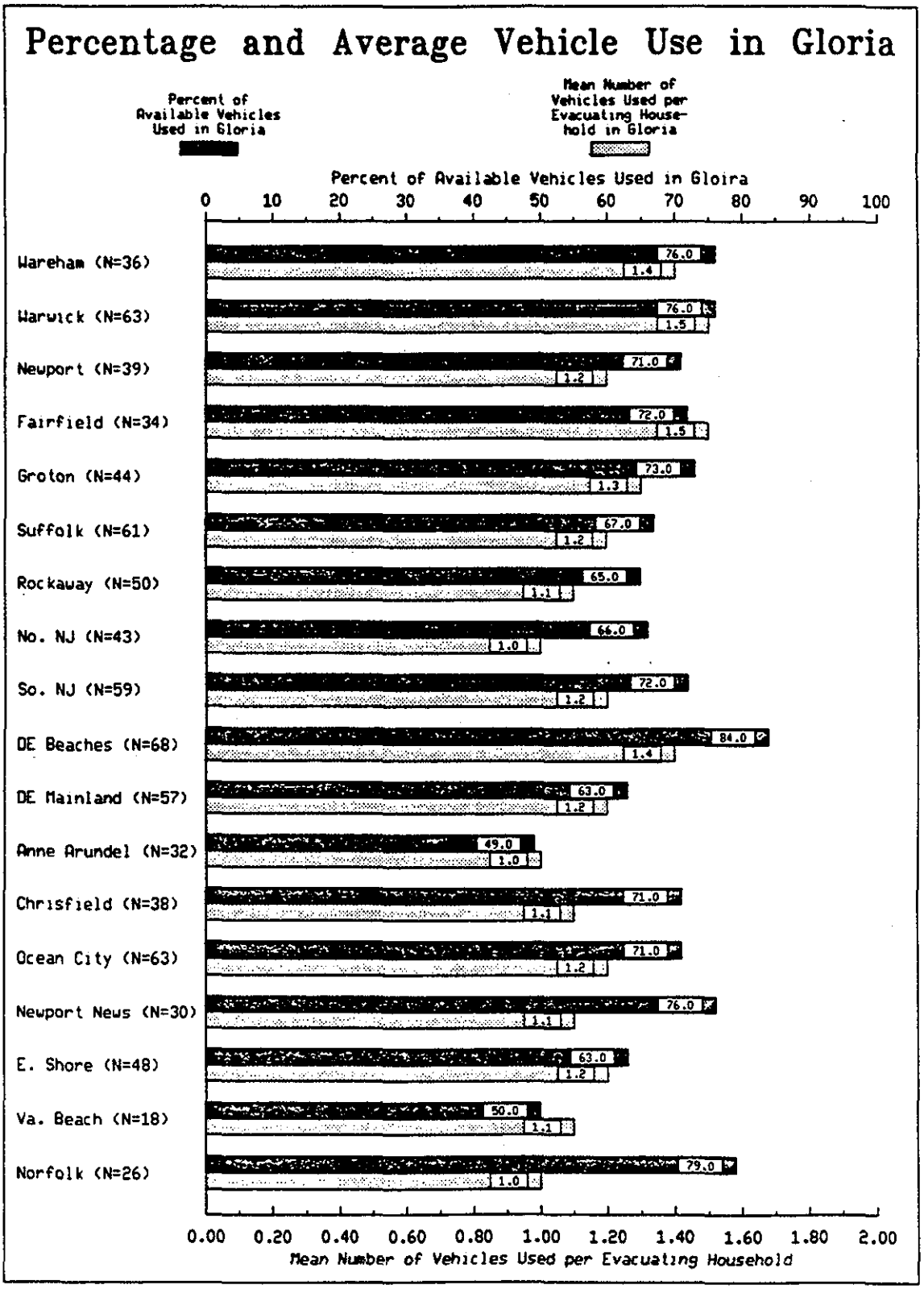
Percentage and Average Vehicle Use in Gloria
Percent of Available Vehicles Used in Gloria
Mean Number of Vehicles Used per Evacuating Household in Gloria
Percent of Available Vehicles Used in Gloira
0 10 20 30 40 50 60 70 80 90 100
Wareham (N=36) 76.0 1.4
Warwick (N=63) 76.0 1.5
Newport (N=39) 71.0 1.2
Fairfield (N=34) 72.0 1.5
Groton (N=44) 73.0 1.3
Suffolk (N=61) 67.0 1.2
Rockaway (N=50) 65.0 1.1
No. NJ (N=43) 66.0 1.0
So. NJ (N=59) 72.0 1.2
DE Beaches (N=68) 84.0 1.4
DE Mainland (N=57) 63.0 1.2
Anne Arundel (N=32) 49.0 1.0
Chrisfield (N=38) 71.0 1.1
Ocean City (N=63) 71.0 1.2
Newport News (N=30) 76.0 1.1
E. Shore (N=48) 63.0 1.2
Va. Beach (N=18) 50.0 1.1
Norfolk (N=26) 79.0 1.0
0.00 0.20 0.40 0.60 0.80 1.00 1.20 1.40 1.60 1.80 2.00
Mean Number of Vehicles Used per Evacuating Household

FIG. 37

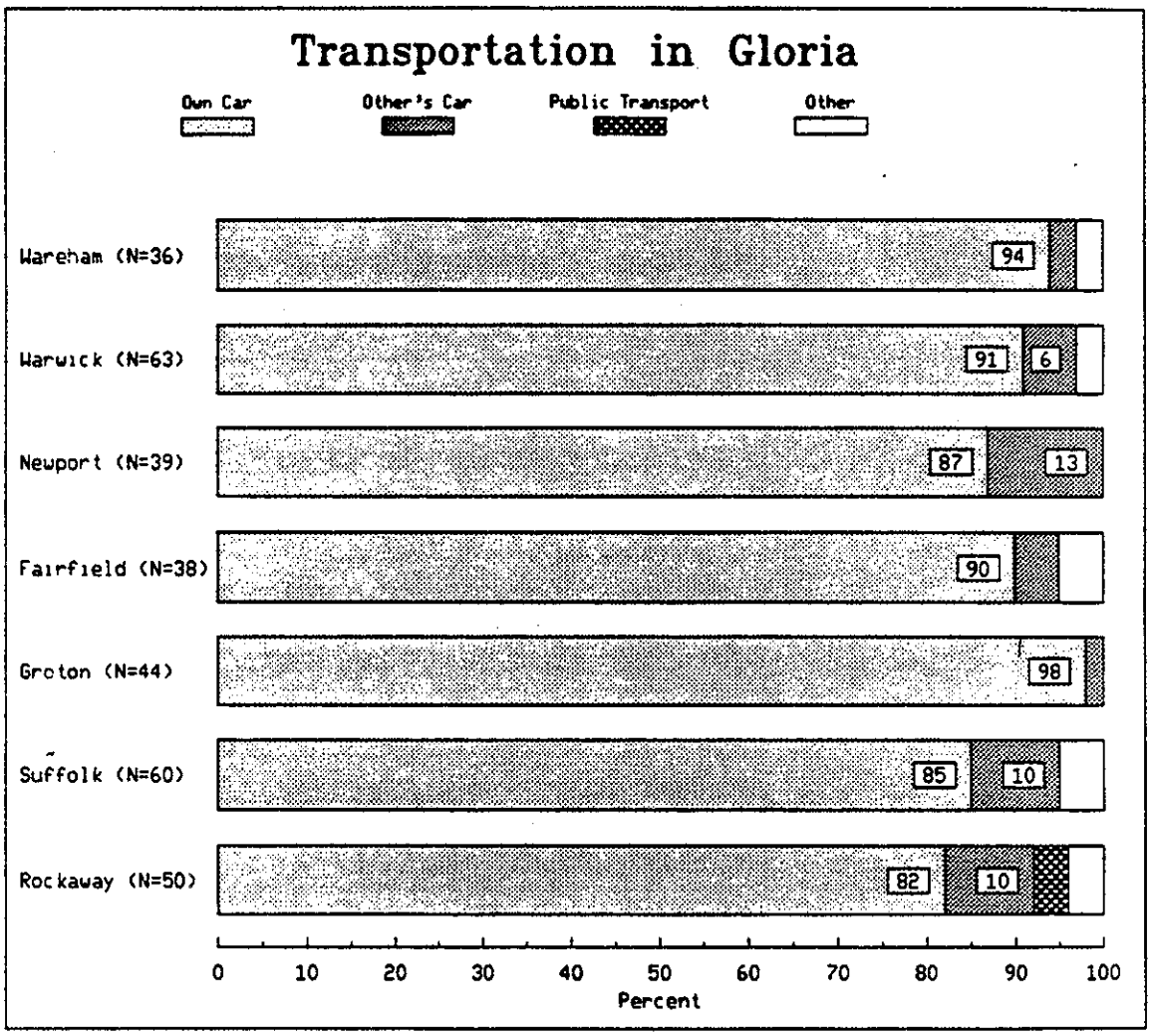
Transportation in Gloria
Own Car
Other's Car
Public Transport
Other
Wareham (N=36)
94
Warwick (N=63)
91
6
Newport (N=39)
87
13
Fairfield (N=38)
90
Groton (N=44)
98
Suffolk (N=60)
85
10
Rockaway (N=50)
82
10
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 38

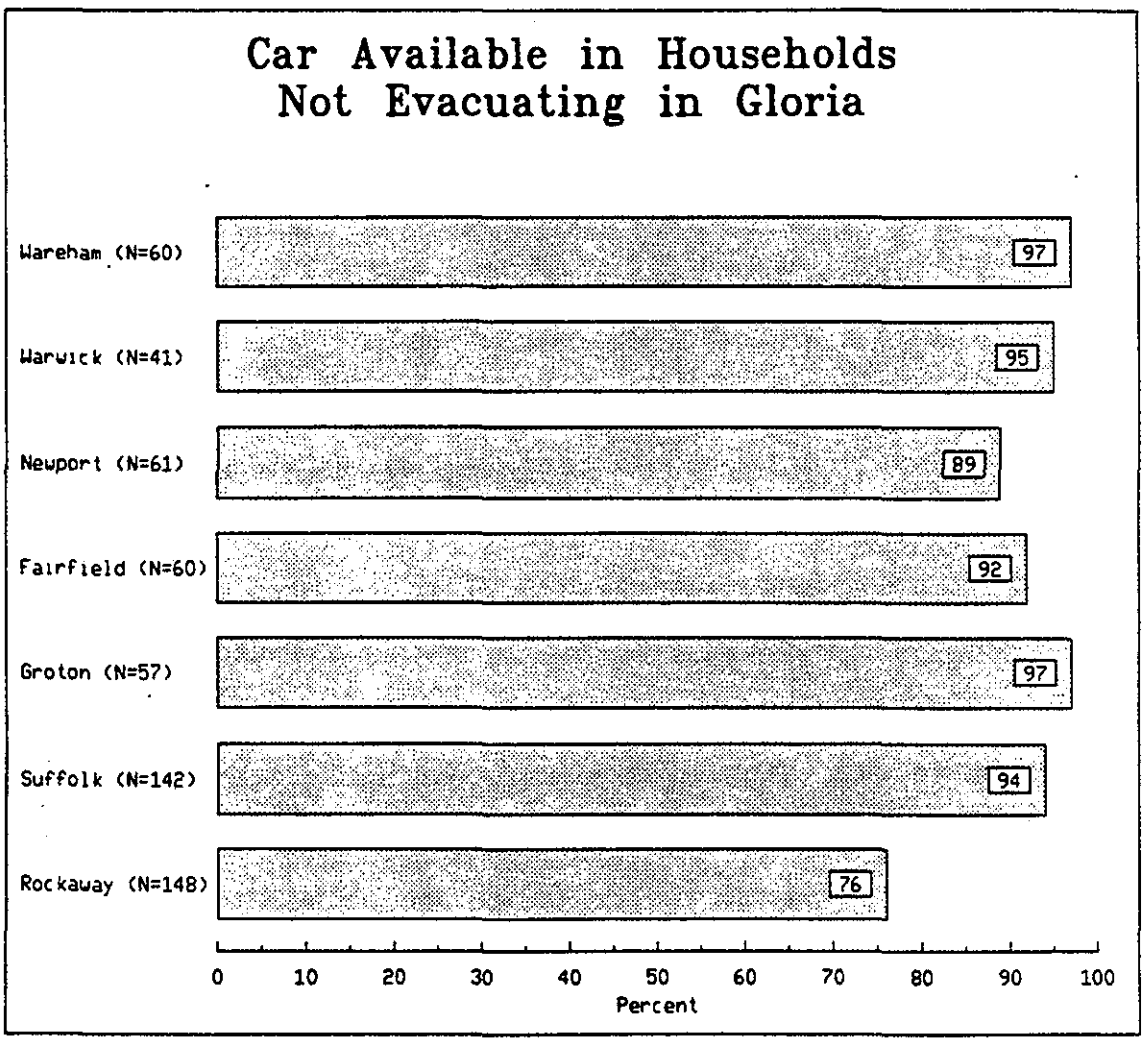
Car Available in Households
Not Evacuating in Gloria
Wareham (N=60)
97
Warwick (N=41)
95
Newport (N=61)
89
Fairfield (N=60)
92
Groton (N=57)
97
Suffolk (N=142)
94
Rockaway (N=148)
76
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 39

MD, Denton, and Rockaway) and in those cases it was 5% or fewer (of the nonevacuees). Rockaway (the question being asked only in the northern area) also had the greatest incidence of people saying they would need to use public transportation if they evacuated (Fig. 40).

Evacuation Assistance

Evacuees in all sites were asked whether they required outside assistance in evacuating in Gloria (Fig. 41). Very few said they did. In most locations no one said they needed help from an agency to evacuate, and of those who did, the figure was 5% or less every place except Chrisfield where it was 11% (+ or - 10% points).

Respondents not evacuating in Gloria were asked whether they would need help if they evacuated (Fig. 42). The question was asked the same way in the northern and southern areas, but responses were coded in more detail in the northern area. Thus, in the southern area there is the "yes, general" category, whereas in the northern area it is broken down into "yes, agency" and "yes, other." Variation in response was substantial from site to site. Where they could be specific, few said they would need agency assistance. In the southern area it's probably reasonable to assume that agency dependence would be comparable to that mentioned in the northern area. Newport News had the highest overall percentage saying help would be needed from someone outside the home.

These figures are not unusual. Most help from outside the household usually comes from friends and relatives. Even when residents believe they would require agency assistance, friends or relatives usually fill the need instead.

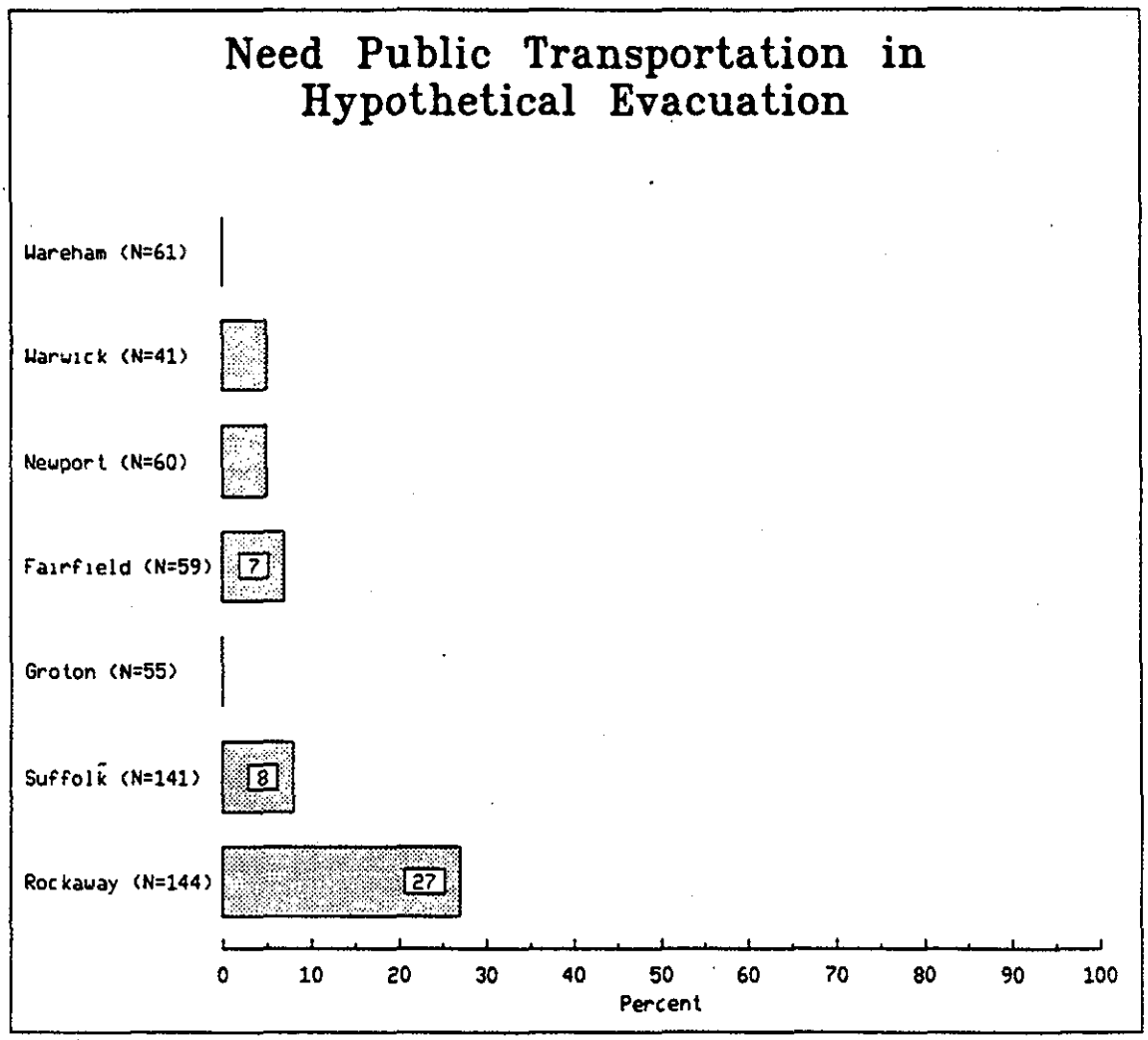
Need Public Transportation in Hypothetical Evacuation
Wareham (N=61)
Warwick (N=41)
Newport (N=60)
Fairfield (N=59)
7
Groton (N=55)
Suffolk (N=141)
8
Rockaway (N=144)
27
0
10
20
30
40
50
60
70
80
90
100
Percent

FIG. 40

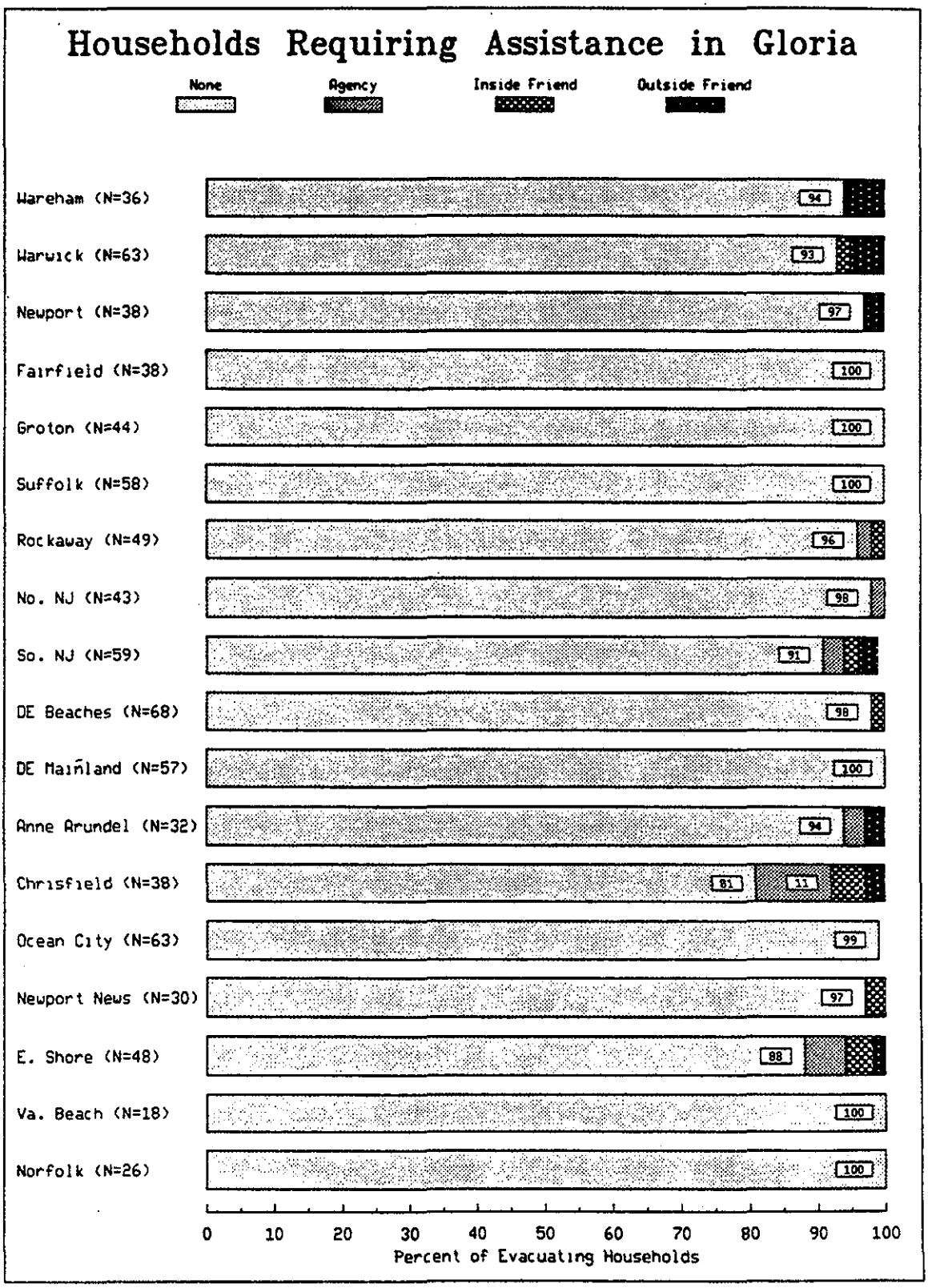
Households Requiring Assistance in Gloria
None
Agency
Inside Friend
Outside Friend
Wareham (N=36)
94
Warwick (N=63)
93
Newport (N=38)
97
Fairfield (N=38)
100
Groton (N=44)
100
Suffolk (N=58)
100
Rockaway (N=49)
96
No. NJ (N=43)
98
So. NJ (N=59)
91
DE Beaches (N=68)
98
DE Mainland (N=57)
100
Anne Arundel (N=32)
94
Chrisfield (N=38)
81
11
Ocean City (N=63)
99
Newport News (N=30)
97
E. Shore (N=48)
88
Va. Beach (N=18)
100
Norfolk (N=26)
100
0
10
20
30
40
50
60
70
80
90
100
Percent of Evacuating Households

FIG. 41

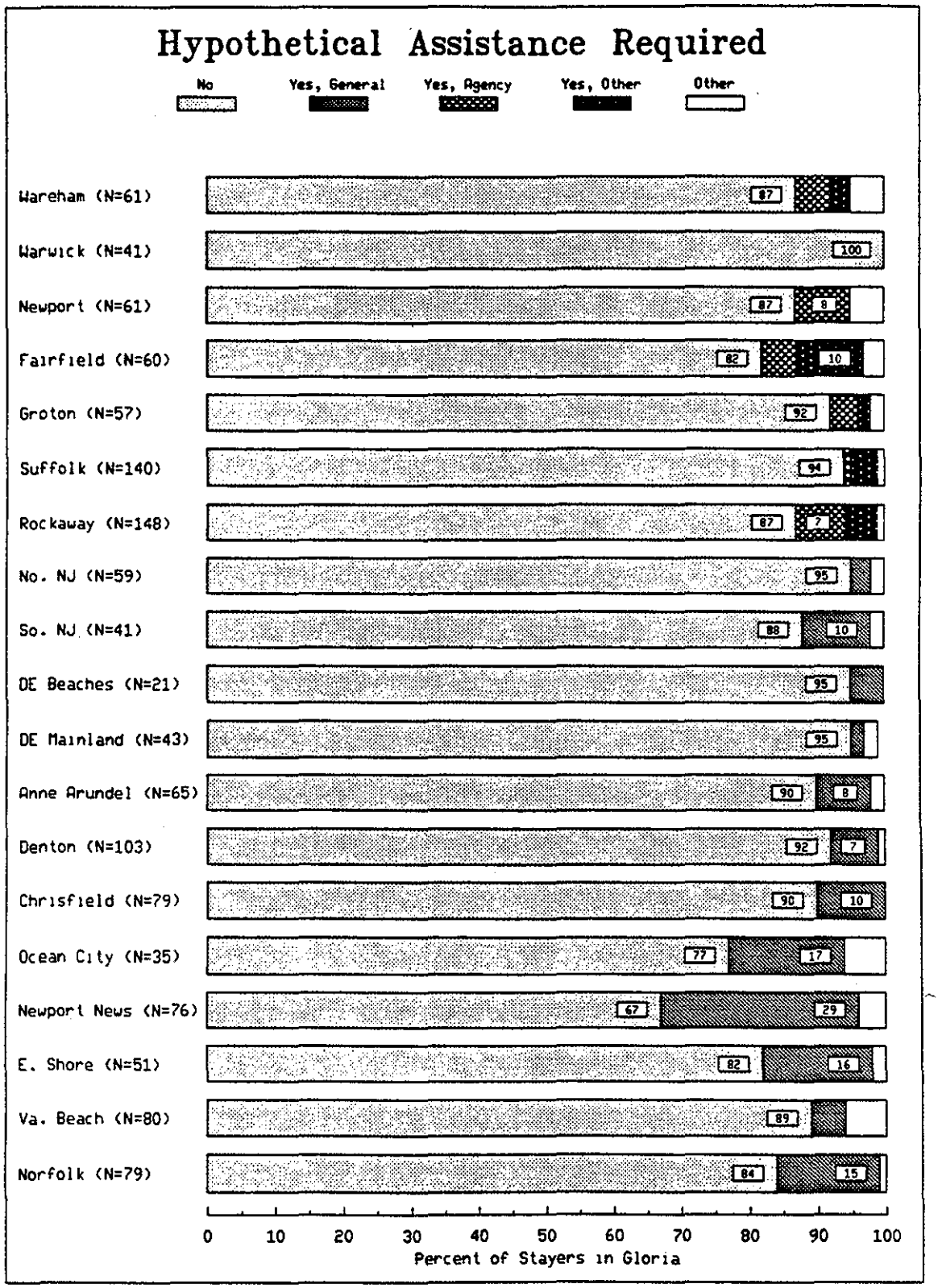
Hypothetical Assistance Required
No
Yes, General
Yes, Agency
Yes, Other
Other
Wareham (N=61)
87
Warwick (N=41)
100
Newport (N=61)
87
8
Fairfield (N=60)
82
10
Groton (N=57)
92
Suffolk (N=140)
94
Rockaway (N=148)
87
7
No. NJ (N=59)
95
So. NJ (N=41)
88
10
DE Beaches (N=21)
95
DE Mainland (N=43)
95
Anne Arundel (N=65)
90
8
Denton (N=103)
92
7
Chrisfield (N=79)
90
10
Ocean City (N=35)
77
17
Newport News (N=76)
67
29
E. Shore (N=51)
82
16
Va. Beach (N=80)
89
Norfolk (N=79)
84
15
0
10
20
30
40
50
60
70
80
90
100
Percent of Stayers in Gloria

FIG. 42

Appendix I

Questionnaire Used in Survey

HURRICANE GLORIA/MID-ATLANTIC/NORTHEAST SURVEY
PHASE II
NOVEMBER, 1987

1. Did you leave your home to go someplace safer in response to the hurricane threat?

--------- 1 Yes (GO TO Q.2)
| 5 No (SKIP TO Q.11)
| 7 Other (GO TO Q.2, IF APPLICABLE)
|
---> 2. Did you go to a:

1 Public Shelter
3 Friend or Relative's Home
5 Hotel/Motel
7 Other (_____)

3. Where was that located?

1 Locally (in same town as residence)
5 Out-of-town (_____)
(Specify name of town)

4. What convinced you to go someplace safer? (CODE UP TO 3 RESPONSES)

22 Advice or order by elected officials
33 Advice from Weather Service
44 Advice/order from police or fireman
55 Advice from media
66 Advice from friend/relative
77 Concern about severity of storm
88 Concern that storm might hit
91 Heard probability (odds) of hit
95 Other: (_____)
(Specify)

5. When did you leave your home to go someplace safer?

TIME: [ ][ ] : [ ][ ] AM [ ]

PM [ ]

DATE:

M	T	W	R	F	SA	SU
23	24	25	26	27	28	29

6. How long did it take you to get to where you were going?

__ __.__ Hrs (to nearest 1/2 hr)

(Never reached original destination=99.9)

7. When did you first return home from the place to which you evacuated?

T	W	R	F	SA	SU	M	T
24	25	26	27	28	29	30	31

8. Did you or anyone in your household require special assistance in evacuating?

   1 No
   3 Yes, by agency
   5 Yes, by friend or relative within household
   7 Yes, by friend or relative outside household
   9 Don't Know/Not Sure

8a. Did your household use your own vehicle(s) in evacuating, leave with someone else in theirs, or did you use public transportation?

   1 Own
   3 Other's
   5 Public Transportation
   7 Other _____

9. How many vehicles did your household take in evacuating?

   ____

10. How many vehicles were available to take in evacuating?

   ____ (GO TO Q.12)

NON-EVACUEES ONLY

11. What made you decide not to go anyplace else? (CODE UP TO 3 RESPONSES)

   05 Storm not severe/house adequate
   20 Officials said evacuation unnecessary
   30 Media said evacuation unnecessary
   35 Friend/relative said evacuation unnecessary
   45 Probabilities indicated low chance of hit
   55 Information indicated storm wouldn't hit
   60 No Officials said to evacuate
   65 Had no transportation
   70 Had no place to go
   75 Wanted to protect against looters
   80 Wanted to protect against storm
   85 Left unnecessarily in past
   90 Job required staying
   95 Other:_____

FOR EVERYONE:

12. Did you hear from anyone in an official position -- civil defense, the mayor's office, the governor, police -- that you should evacuate to a safer place?

1 Yes
-------- 5 No (GO TO Q.14)
-------- 9 Don't Know (GO TO Q.14)

13. Did they say that you should evacuate or that you must evacuate?

1 Should
5 Must
9 Don't Know

-->14. How well do you think the warning and evacuation process was handled in the Gloria threat?

11 Good/OK
22 Traffic a problem
33 Not enough information
55 Shouldn't have been told to evacuate
66 Shelters bad, crowded, etc.
77 Other: _____

14a. Do you think your home would be safe to stay in if a major hurricane were to strike this area directly?

1 No
3 Yes
5 Don't Know

15. Would you do anything differently if you were in the same situation again? (CODE UP TO 3 RESPONSES)

11 Would evacuate
22 Wouldn't evacuate
33 Would leave earlier
44 Would wait later to leave
55 Would go further away
66 Wouldn't go as far
77 Would go to public shelter
88 Wouldn't go to public shelter
90 No
95 Other _____

EVACUEES, SKIP TO Q.18

NON-EVACUEES ONLY

16. If you evacuate in a future hurricane, would you go to:

1 A Friend/Relative's Home
3 A Hotel/Motel
5 A Public Shelter
7 Other
9 Don't Know/Not Sure

16a. Where specifically would you go if you evacuated, someplace local or someplace out-of-town?

1 Local (same town/borough as residence)
5 Out-of-town (borough) (_____)
9 Don't Know

17. Would you or anyone in your household need special assistance from anyone outside the household in evacuating?

1 Yes, from government agency
3 Yes, from other
5 No
7 Other _____

17a. Do you have a car or other vehicle to use in evacuating?

1 Yes
3 No
5 Other

17b. If you evacuated, would you need to use public transportation?

1 Yes
3 No
5 Other
7 Don't Know

ASK OF ALL RESPONDENTS

The following questions are for statistical purposes only.

18. Which of the following structures do you live in?

1 High-rise (6 or more stories) Condo or Apartment
3 Detached Single Family Building
5 Mobile Home
7 Other
9 Don't Know/Refused

19. *How far is your home from the water?*

1 Waterfront on beach
3 Waterfront on Sound
5 Other Waterfront
2 Less than 1 block from beach
4 Less than 1 block from bay
6 Less than 1 block from water
7 More than 1 block, less than 1 mile from water
8 More than 1 mile from water
9 Don't Know/Refused

20. Which of the following ranges describes your household income for a year?

1 Less than $10,000
3 $10,000 to $24,999
5 $25,000 to $39,999
7 $40,000 to $79,999
8 over $80,000
9 Don't Know/Refused

21. How old were you on your last birthday?

1 Under 25
3 25 to 39
5 40 to 65
7 Over 65
9 Refused

Thank you, that completes our survey. Good Bye!

APPENDIX D

Transportation Analysis Support Documentation

January 1997

SOUTHERN MASSACHUSETTS HURRICANE EVACUATION STUDY

Transportation Analysis Support Documentation

Prepared for:
US Army Corps of Engineers
424 Trapelo Road
Waltham, MA 02254

Prepared by:
EARTH TECH, INC. (formerly HMM Associates, Inc.)
53 Regional Drive
Concord, NH 03301

Rev. 2, 1/97

SOUTHERN MASSACHUSETTS HURRICANE EVACUATION STUDY

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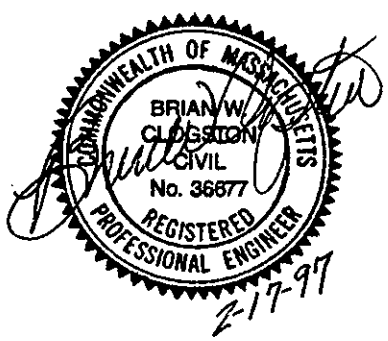

Submitted By:

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SECTION ONE

INTRODUCTION

1.1 PURPOSE

The purpose of the Transportation Analysis is to estimate roadway clearance times for coastal communities in Southern Massachusetts under a variety of hurricane evacuation scenarios. Clearance time is defined as the amount of time required for all vehicles to clear the roadways after a regional or state level hurricane evacuation recommendation is disseminated to the public. During an evacuation, a large number of vehicles have to travel on a road system in a relatively short period of time. A number of different vehicle trips are possible, varying by trip origination, time of departure, and trip destination. The number of vehicle trips becomes particularly significant for an area such as the Southern Massachusetts coast because of its available roadway network, large seasonal population, and high number of transient visitors (particularly on Cape Cod). The number of evacuating vehicles varies depending upon the intensity of the hurricane, actions taken by local authorities, and certain human behavioral response characteristics of the area's population. Motorists evacuating their homes and intermixing with traffic from a variety of trip purposes (i.e., background traffic) can lead to significant traffic congestion and backups, ultimately delaying the evacuation.

The Transportation Analysis is one element of a much broader study entitled the Southern Massachusetts Hurricane Evacuation Study (HES). The Southern Massachusetts HES Technical Data Report presents the results of several technical analyses to provide emergency management officials with realistic data quantifying the major factors involved in hurricane evacuation decision-making. The technical data presented in the Study is not intended to replace the detailed operations plans developed by the State and communities. Rather, the data is intended to provide a framework within which each jurisdiction can update and revise hurricane evacuation plans, and from which operations procedures and guides can be developed for future hurricane threats. Because the Transportation Analysis builds upon results from other analyses of the Study, in this report, reference is frequently made to information that is presented in the Technical Data Report (TDR).

A transportation modeling methodology and a roadway representation were developed for all coastal communities in the Southern Massachusetts Study Area to conduct the analysis and estimate clearance times. This analysis establishes the clearance time portions of evacuation times. Clearance time is one component of the total time required for a regional hurricane evacuation to be completed. An additional time component, which considers the amount of time necessary for public officials to notify people to evacuate, must be combined with clearance time to determine the total evacuation time. More information on how decision-makers can use the results of this analysis is discussed in detail in Chapter Eight of the TDR, Decision Analysis.

1.2 STUDY AREA

The study area for the Transportation Analysis includes all of Barnstable County and portions of Plymouth and Bristol Counties, as illustrated in Figure 1-1. The vastness of the Southern Massachusetts study area required that the region be divided into two approximately equal sized areas and analyzed individually. The two networks were defined as the "Cape Cod" network and the "Buzzards Bay" network. The towns included in the Buzzards Bay network are: Fall River, Westport, Dartmouth, New Bedford, Acushnet, Fairhaven, Mattapoisett, Marion and Rochester.

The Bristol County, Massachusetts communities of Seekonk, Rehoboth, Swansea, and Somerset were included in the East Bay Massachusetts network of the Rhode Island Study. These communities were not included in the Buzzards Bay network of this study for the following reasons:

- The Taunton River is assumed to be a representative western endpoint for evacuating traffic from the Buzzards Bay network because it is assumed that most evacuating traffic will choose routes that avoid going through a major urban area, such as Fall River, for less congested routes that will get them inland faster.

- The percentage increase in summer traffic for Bristol County routes east of the Taunton River is generally greater than the percentage increase of summer traffic for communities west of the Taunton River. This observation provides justification for the assertion that the Buzzards Bay background traffic behaves in a transitional manner between that of Rhode Island, which has a relatively small percentage increase in summer versus average daily traffic, and Cape Cod, which has the greatest percentage increase in summer versus average daily traffic.

Clearance times for Seekonk, Rehoboth, Swansea, and Somerset were calculated in the Rhode Island Hurricane Evacuation Study, and were compared to clearance times simulated for the Buzzards Bay network of this study.

The Cape Cod network consists of the following towns: Provincetown, Truro, Wellfleet, Eastham, Orleans, Chatham, Brewster, Harwich, Dennis, Yarmouth, Barnstable, Sandwich, Mashpee, Falmouth, Bourne and Wareham. The towns of Little Compton and Tiverton, Rhode Island were also included in the Buzzards Bay network because of the interdependence and inseparability of the eastern Rhode Island and Southern Massachusetts roadway systems.

The study area does not include the islands of Martha's Vineyard and Nantucket. It is the intention of these communities that those desiring to leave the island would do so in advance of an evacuation warning. Residents on the island would be accommodated at designated shelter locations.

The road system under examination includes State highways and major roadways on Cape Cod and the Buzzards Bay area. The analysis assumes evacuees originate from the various coastal communities, and that safe destinations include locations within coastal communities as well as locations farther inland, or

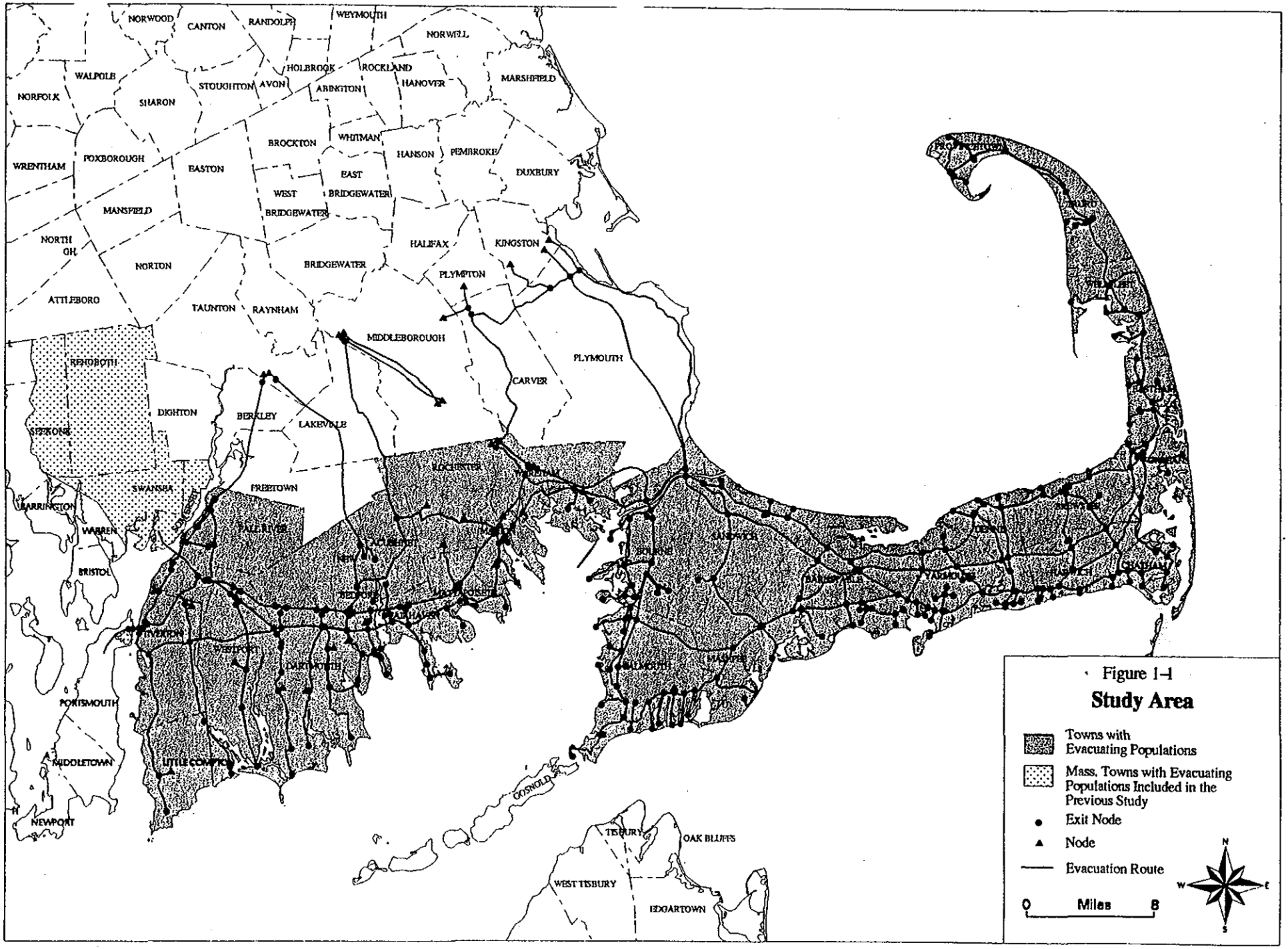


Figure 1-1
Study Area

Date: 24 Dec 96 08:22:49 Tuesday
/usr2/acos/area.map

in adjacent States. The Transportation Analysis was done at a regional level, or macro scale, rather than at a community level because the intermixing of traffic from one community to the next was considered to be a potential leading contributor to delays in evacuations.

1.3 METHODOLOGY

The Behavioral Analysis discussed in Chapter Four of the TDR presents information about likely evacuee route choices during an evacuation in Southern Massachusetts. The analysis concludes that people who evacuate surge areas in the Buzzards Bay network are most likely to seek safe destinations at public shelters, friends'/relatives' homes, or hotels/motels. For the Cape Cod network, a greater proportion of evacuees leaving surge zones are likely to leave Cape Cod, because of the proportionally high tourist population there during the summer. Although behavioral data provided in Chapter Four can give some guidance in predicting the actual geographic areas people will evacuate to and the evacuation routes people may use to reach their destinations, assumptions of this nature tend to be subjective. This is caused by the vast number of possible destinations and alternative routes available to evacuees in highly populated areas. Clearance time calculations are further complicated by the affects of significant and varying amounts of "background" traffic that will be present on roadways as an evacuation progresses ("background" traffic refers to local traffic, traffic associated with people who travel through the region, and trips made by people preparing for the arrival of hurricane conditions or engaged in normal activities).

The study considered several approaches to estimate clearance times for the Southern Massachusetts study area. The first approach considered was the one used by the Corps of Engineers and the Federal Emergency Management Agency (FEMA) to complete hurricane evacuation studies in the Gulf and southern Atlantic coast states. This approach assigns destinations and evacuation routes for the evacuating population by matching probable evacuee destinations (determined by a behavioral analysis) with the land uses known for the region. A mathematical model of the study area's roadway system is then used to calculate clearance times based on the trip distributions assumed for the evacuation. The time required for all evacuees to reach their predetermined destination is considered the clearance time. As reported in a post-hurricane assessment of Hurricane Hugo in 1989, the transportation analyses conducted for the North Carolina and South Carolina Hurricane Evacuation Studies were found to be very accurate in that the clearance times experienced during evacuations were very near predicted times. These results give evidence that this approach is accurate for study areas with limited alternative roadway systems and where adequate behavioral data and landuse information is suitable to identify evacuation routes and predict the destinations of evacuees. The following paragraphs explain some differences in the Southern Massachusetts study area in comparison to other areas, and give the reasons why the Corps of Engineers employed an alternative transportation modeling approach for Southern Massachusetts.

One concern in using the transportation modeling approach used for the Gulf and Atlantic coast states for the Southern Massachusetts study area was the appropriateness of assuming specific zonal evacuee destinations and evacuation routes. Inundation areas in Southern Massachusetts are relatively narrow, but densely populated. On Cape Cod, evacuation travel is mostly defined by the capacities of the Bourne Bridge and Sagamore Bridge (and the Bourne and Sagamore rotaries). Off-Cape, the complex system of

interconnecting highways, undivided state routes, and numerous local streets offer evacuees, and others on the roadways, many possible travel routes to reach their destinations. The region is generally characterized by diverse land uses in small geographic areas. Hotels and motels are sporadically located in most communities, friends' and relatives' homes could well be distributed over the entire area, and Southern Massachusetts communities tend to open public shelters to accommodate their individual demands. Furthermore, due to the high level of seasonal residents and transient population in the area (particularly on Cape Cod), destinations are highly variable. The study concluded that it was not practical to use the behavioral information developed for the Gulf and Atlantic coast states to derive specific assumptions about evacuee destinations and evacuation routes in Southeastern Massachusetts. The study did conclude that the behavioral response curves presented in the Behavioral Analysis, and used in other hurricane evacuation studies, are useful when estimating the general response and destinations sought by residents who live in surge vulnerable areas.

The second concern in using the modeling approach used in other studies was the representation of the relationship between the number of people evacuating from vulnerable areas in comparison to the number of background vehicles that would be on the roadways during evacuations. Although surge areas are densely populated, the relatively small land areas that they encompass include only a fraction of the region's total population. When viewing the region's roadways as an entire transportation system, most of the traffic on roadways during initial and mid stages of an evacuation is likely to be from daily vehicles passing through the region for a variety of trip purposes. The problem during evacuations is that evacuating vehicles are forced to compete for roadway capacity with a larger amount of background traffic. This can cause increased congestion, potentially delaying the overall evacuation. Because background traffic will travel in both directions on nearly all roadways during evacuations, the Study determined that the transportation methodology for Southern Massachusetts should not focus on assuming assigned evacuation routes as has been done in other study areas. Instead, the methodology should focus on analyzing the influence that background traffic can have on the overall evacuation.

To address the unique behavioral and transportation issues of the Southern Massachusetts study area, an alternative modeling strategy was used. A mathematical model of the road system was developed and calibrated to simulate the traffic flows of a normal week day. Empirical traffic engineering studies and local traffic count data from the Massachusetts Highway Department (MHD) were used to establish various existing traffic flow conditions within the study area. The transportation modeling methodology used for this study assumes that the preferences of evacuees to travel on given routes are related to the traffic patterns of a normal August day, except where it is clear that evacuees will travel directly to public shelters. The large portion of vehicles associated with background traffic enables the methodology to neglect assigning specific destinations and evacuation routes to evacuees traveling to hotels/motels and friends'/relatives' homes. Large background traffic due primarily to seasonal and transient visitors and confined hurricane surge areas in most coastal communities in Southern Massachusetts will give rise to evacuations governed by background traffic rather than evacuating traffic. Analysis of traffic data collected on the days of Hurricanes Gloria and Bob further support this assumption. Accordingly, the modeling strategy used in the Southern Massachusetts study focuses on estimating clearance times which qualitatively measure how competition by evacuating traffic may affect, and possibly delay, the movement of all traffic during an evacuation.

1.4 NETVAC2 TRAFFIC SIMULATION SOFTWARE

The NETVAC2 evacuation simulation software was used to create a mathematical model representing the study area's road system. NETVAC2 is a special purpose, network evacuation computer model designed by the Massachusetts Institute of Technology in cooperation with HMM Associates, Incorporated (now EARTH TECH). It was specifically designed to represent traffic flows over a transportation system during an emergency evacuation. This particular model was selected from several available models because it can be easily applied to model hurricane evacuations conducted in areas with complex roadway systems such as that in coastal Southern Massachusetts.

NETVAC2 represents roadways as links, and represents intersections connecting two or more roadways as nodes. Physical characteristics about representative links and nodes, and the logic connecting them are inputs to the model used in computing vehicle capacity constraints and legal turning movements. Traffic flows at nodes are subject to intersection approach capacity constraints, whereas traffic flow assignments on outbound links are subject to the volume capacities of the modeled roads. Capacities are based on the Highway Capacity Manual (Highway Research Board) and Interim Material on Highway Capacity (Transportation Research Board).

A complementary program for use with NETVAC2, entitled POPDIS, converts the population that is assigned to enter onto roadways to an equivalent number of vehicles. The user enters the vehicle occupancy rates and the number of people assigned to enter the network at each node. As many as five different population types can be specified. POPDIS aggregates the population input for each entry node and in turn computes the effective average vehicle loading rate per minute at each node.

As vehicles are modeled to move throughout the road networks, NETVAC2 utilizes dynamic programming theory to update vehicle densities, speeds, flows, queues, spillbacks and other relevant traffic information at a fixed time step prescribed by the user. Traffic assignments from links entering and emanating from nodes are made with each time step. One main feature of the model is that link assignments are made based upon the relative combinations of route preferences input for each node. The model also uses dynamic route selection such that route preferences are modified if significant backups exist at one or more emanating links. Vehicles preferring to travel on links undergoing heavy flows or large queues will be rerouted to another link of secondary preference. This is an important consideration when simulating hurricane evacuations because evacuees are not likely to wait in traffic for long periods of time if less restrictive, alternate routes are available to them.

Simulations terminate after vehicles exit the road system. NETVAC2 model results include computer print files of node and link time history flow and queue data, departing vehicle summaries, total simulation time, and total vehicles on the road system at specified report intervals.

SECTION TWO

MODEL DEVELOPMENT

2.1 GENERAL

The following sections discuss the coding assumptions made in applying NETVAC2 for modeling the hurricane evacuations in Southern Massachusetts. The NETVAC2 User's Manual[2] gives specific data format instructions and a complete description of all parameters required by the model.

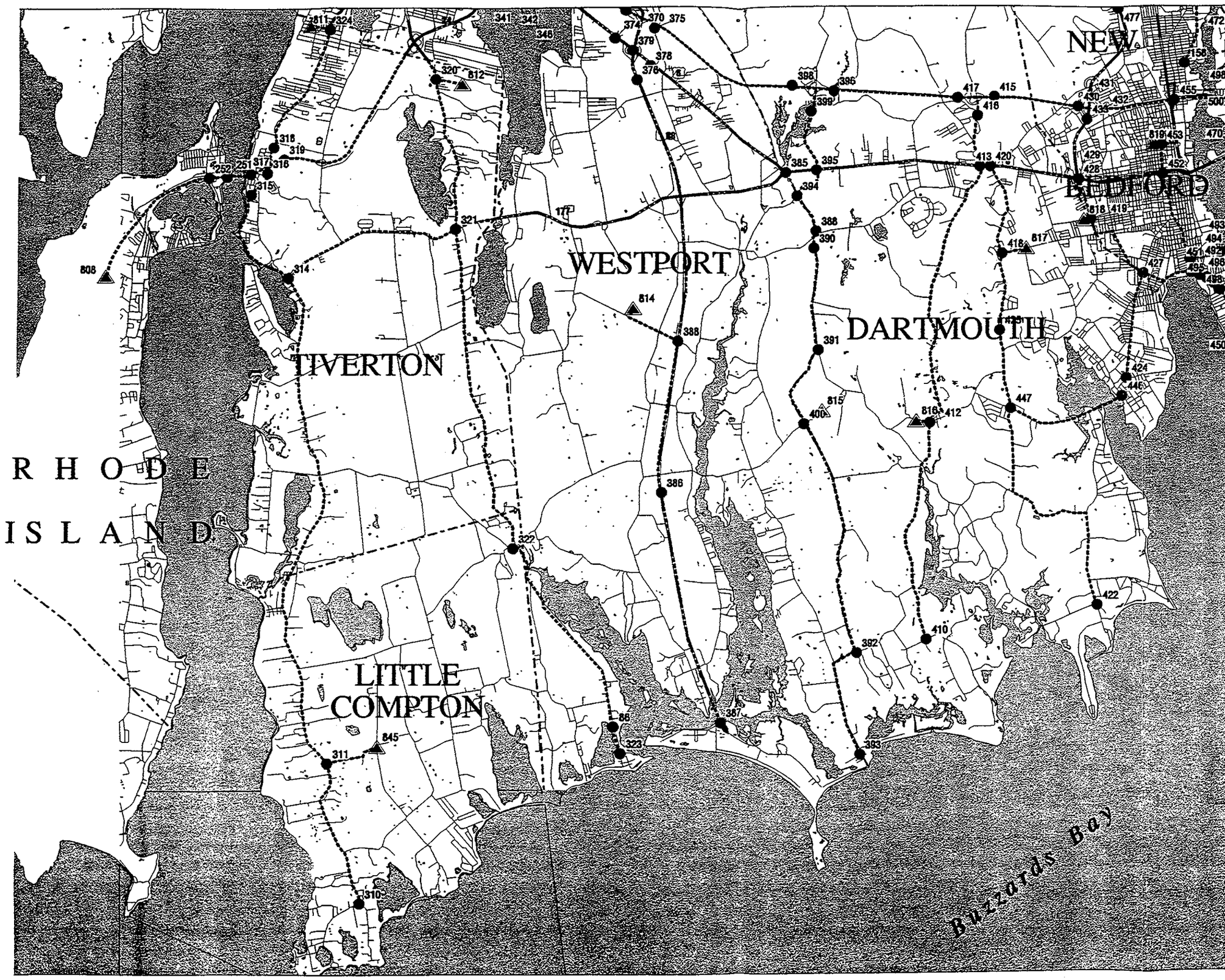
The MHD and Cape Cod Commission provided information for the roadway and intersection data used for model development. Roadway and intersection data were collected from field studies of the area. The data included detailed information such as the number of travel lanes and auxiliary lanes, lane widths, and intersection approach widths. The total length of each road segment was measured from a scaled map of the roadway network.

2.2 ROAD NETWORKS

The NETVAC2 program allows networks with up to 500 links and 1000 nodes to be constructed. The vastness of the Southern Massachusetts study area required that the region be divided into two approximately equal sized areas and analyzed individually. The two networks were defined as the "Buzzards Bay" network and the "Cape Cod" network. The Buzzards Bay network extends from East of the Taunton River to Marion. The Cape Cod network extends from Wareham to Provincetown. In the NETVAC2 model, roadways and intersections in the study area are represented by a link-node network, as illustrated in Figures 2-1 through 2-10.

For each link, the actual number of lanes, lane widths, total roadway length in feet, roadway type, surrounding land use, and lateral clearances from roadside obstructions were entered into a computer link file. Values for roadway lateral clearances were input such that link capacities were not influenced by roadside obstructions except in cases where a particular link represented a highway bridge with a restrictive road shoulder. The logical turning movements from one link to the next and route preferences controlling traffic flow onto each link were also specified.

Single nodes were used to identify intersections of two or more undivided state roads, or to represent significant changes in roadway characteristics. Traffic flowing through intersections modeled using single nodes is forced to compete for the right of way with opposing traffic from other approaches. Major interchanges connecting divided and undivided highways, or connecting two undivided highways were modeled with four nodes per interchange. A greater number of nodes at these interchanges were needed to replicate non-opposing continuous traffic flow characteristic of highway on-ramps and off-ramps.



EARTH TECH

890 Exit Node

123 Internal Node

Key Map

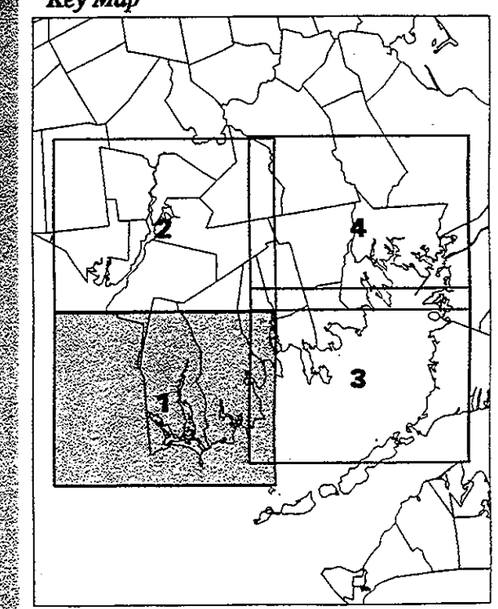


FIGURE 2-1:
BUZZARDS BAY NETWORK: TILE 1 OF 4

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Buzzards Bay Network

0 1½ 3
Miles

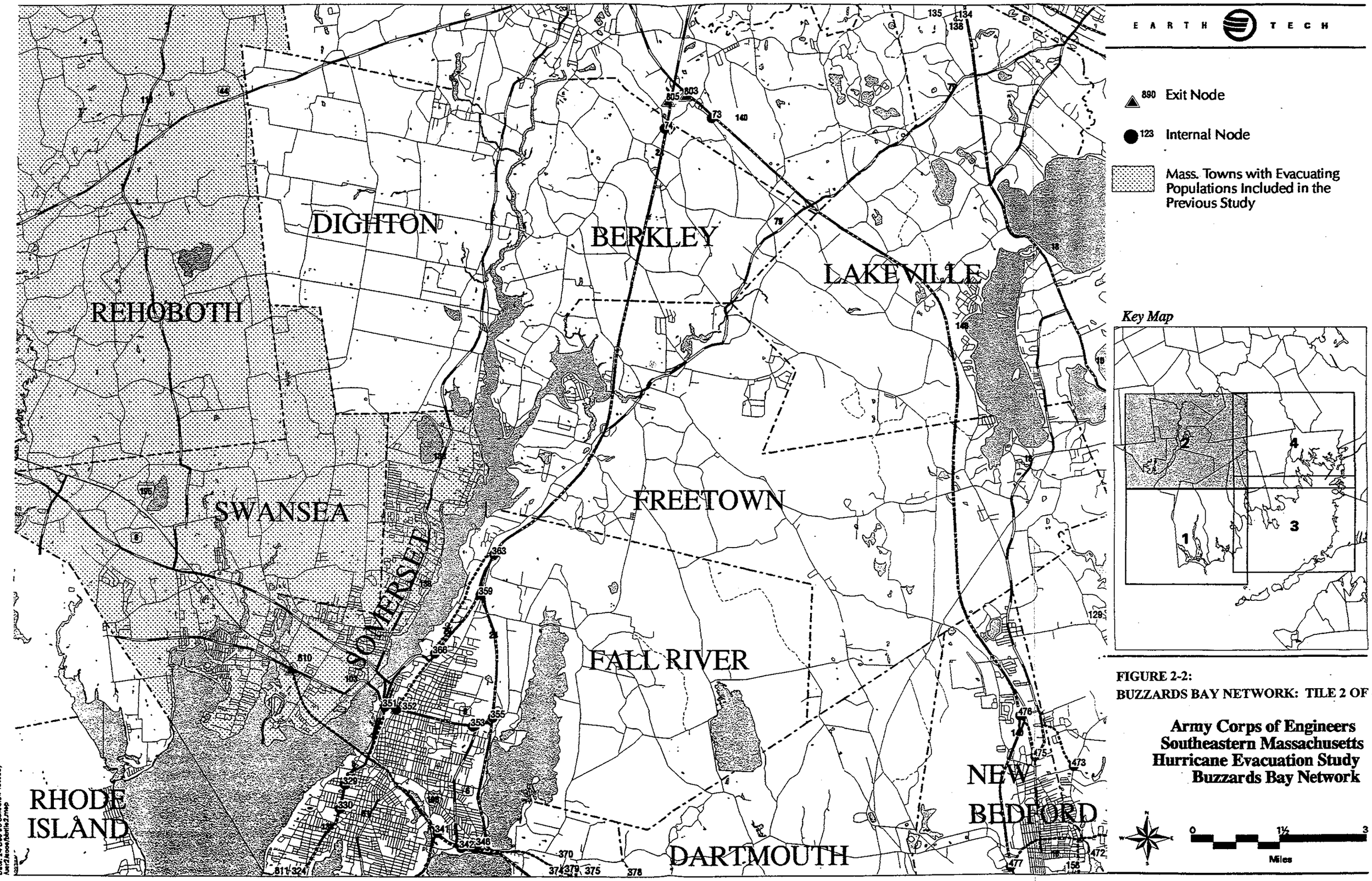


FIGURE 2-2:
BUZZARDS BAY NETWORK: TILE 2 OF 4

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Buzzards Bay Network

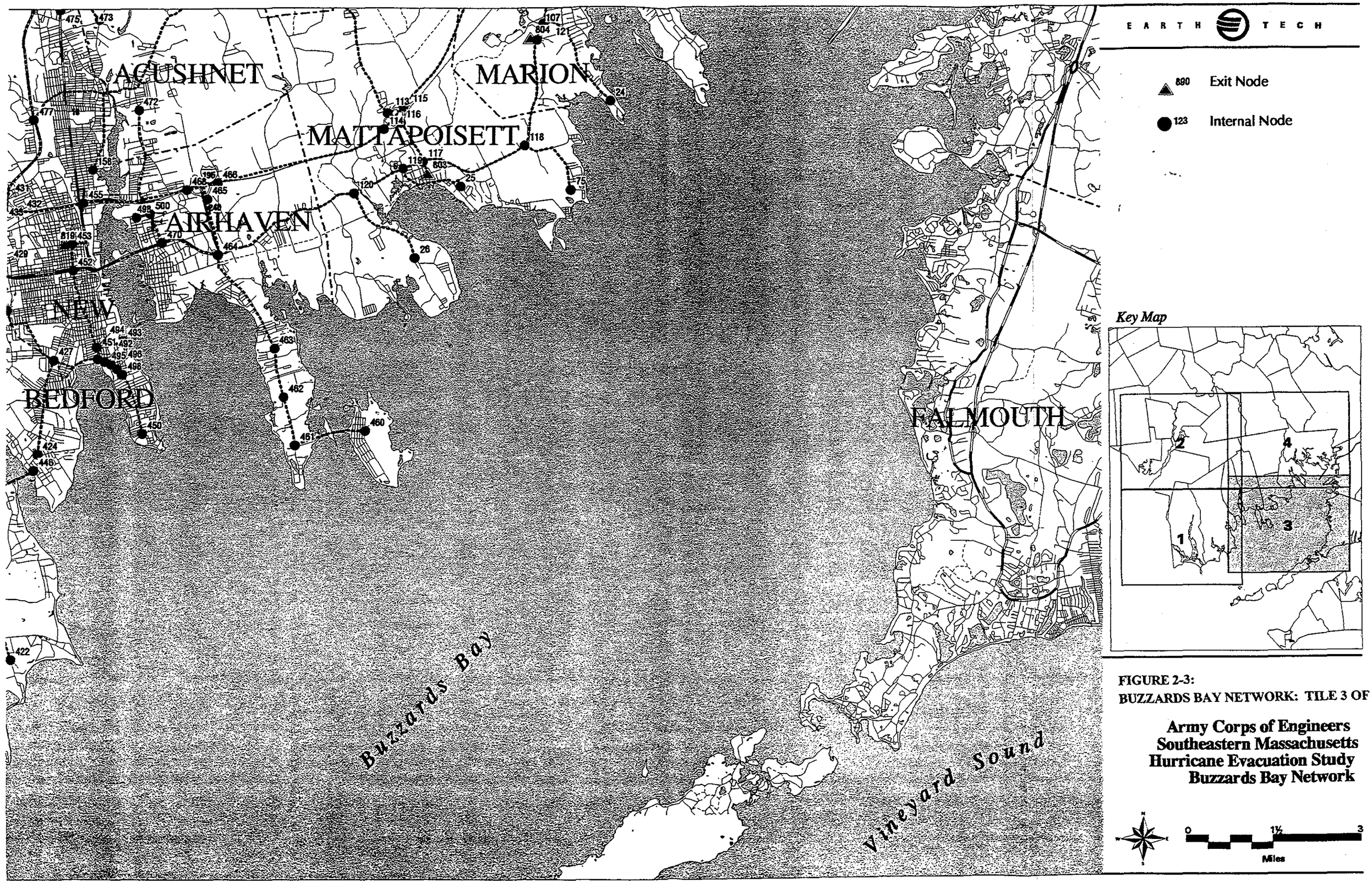
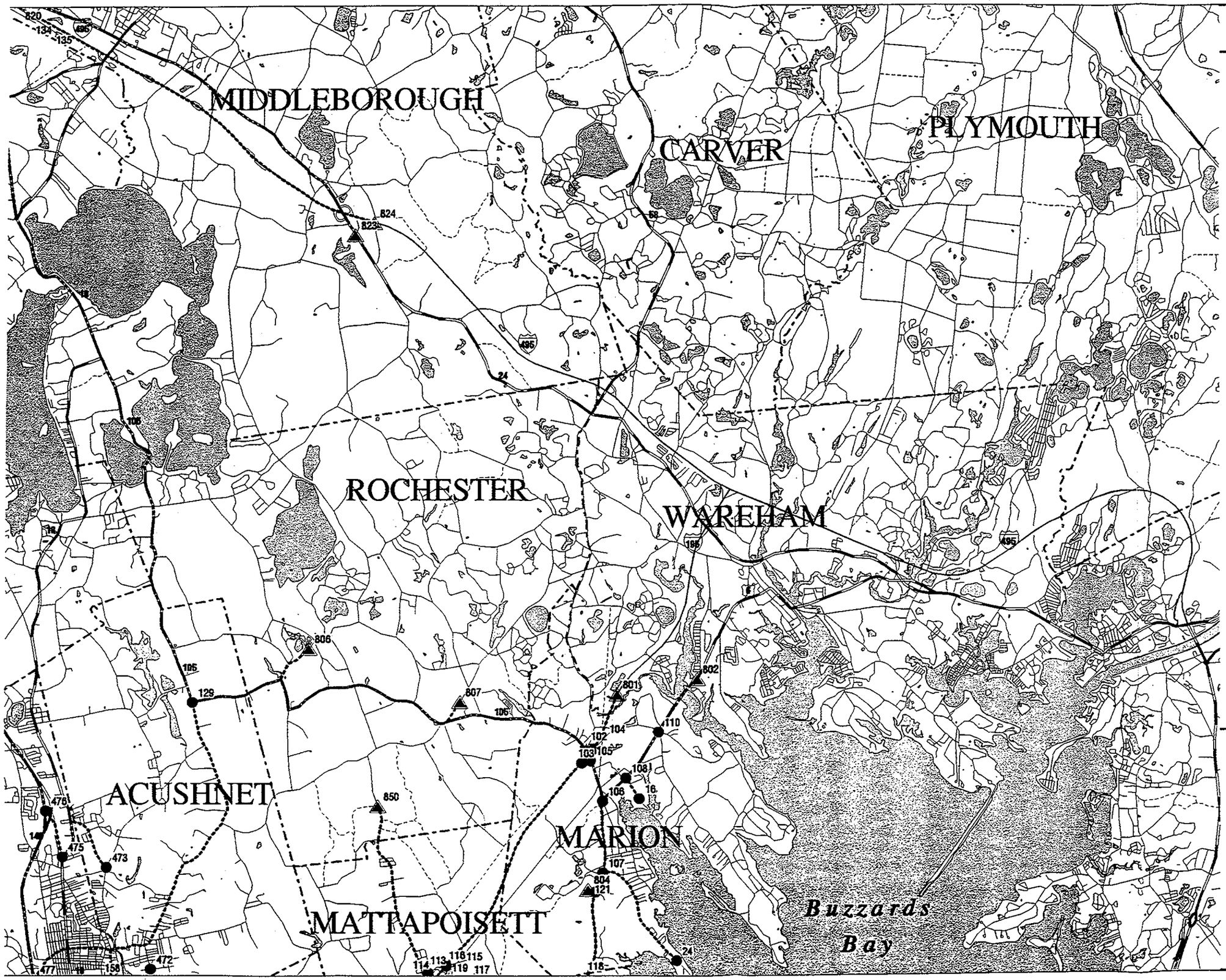


FIGURE 2-3:
BUZZARDS BAY NETWORK: TILE 3 OF 4

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Buzzards Bay Network



EARTH TECH

890 Exit Node

123 Internal Node

Key Map

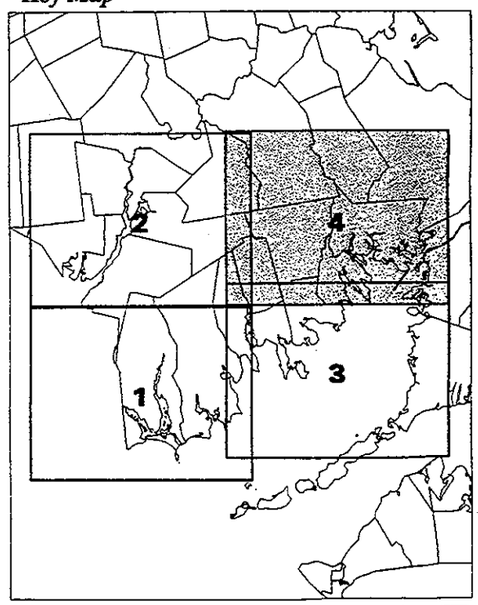
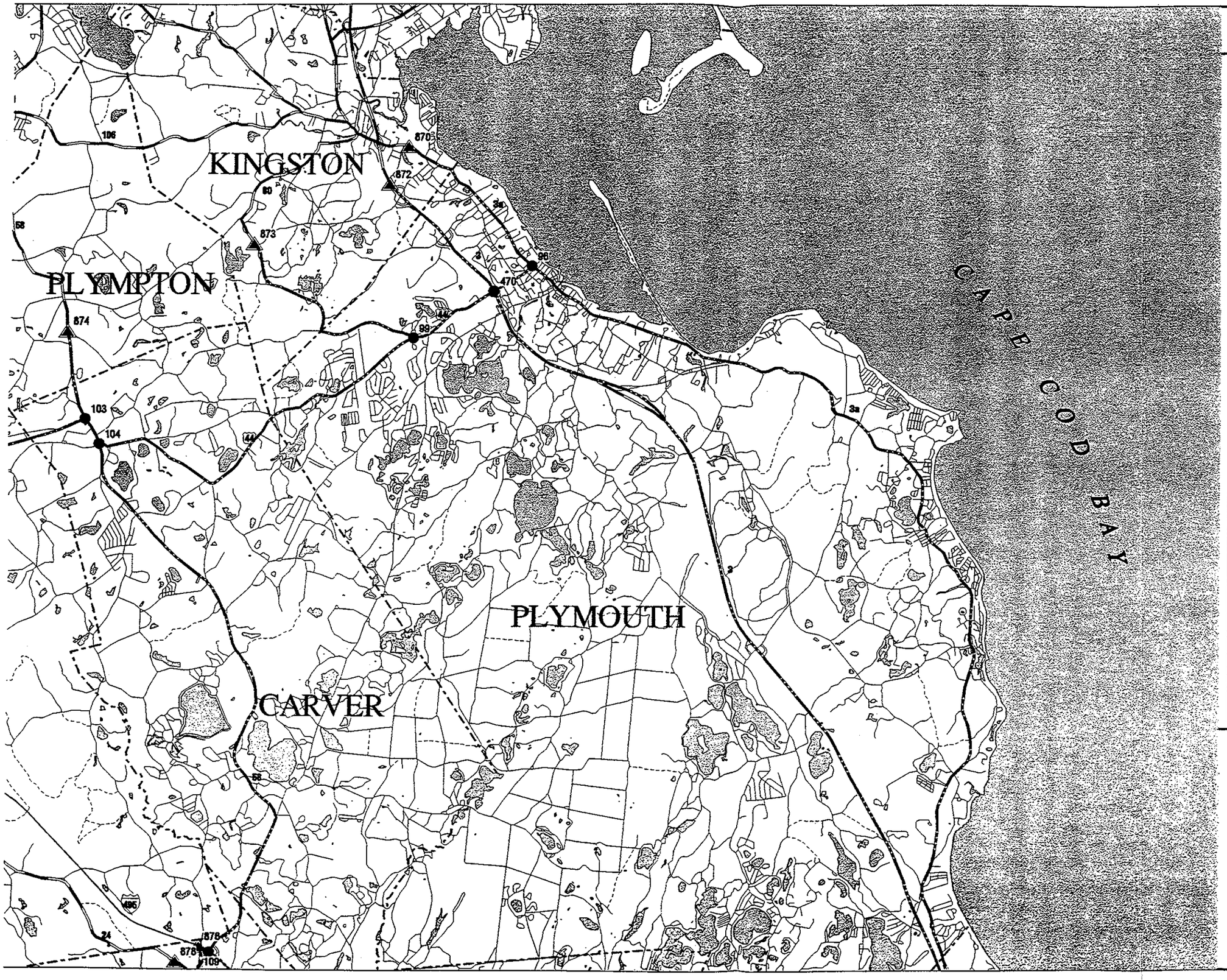


FIGURE 2-4
BUZZARDS BAY NETWORK: TILE 4 OF 4

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Buzzards Bay Network

0 1½ 3
Miles



EARTH TECH

890 Exit Node

123 Internal Node

Key Map

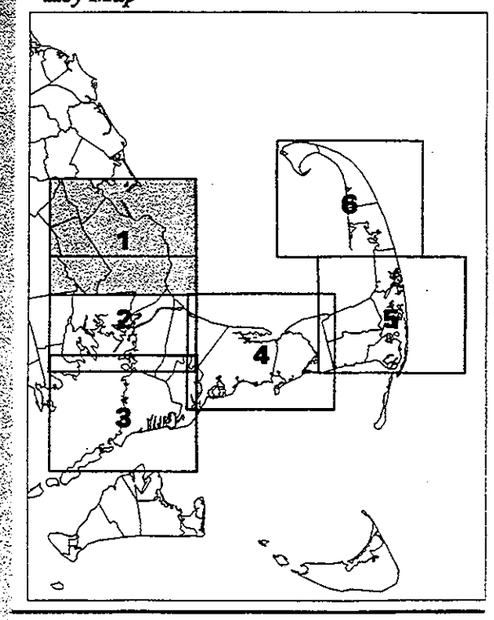


FIGURE 2-5
CAPE COD NETWORK: TILE 1 OF 6

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Cape Cod Network

0 1½ 3
Miles

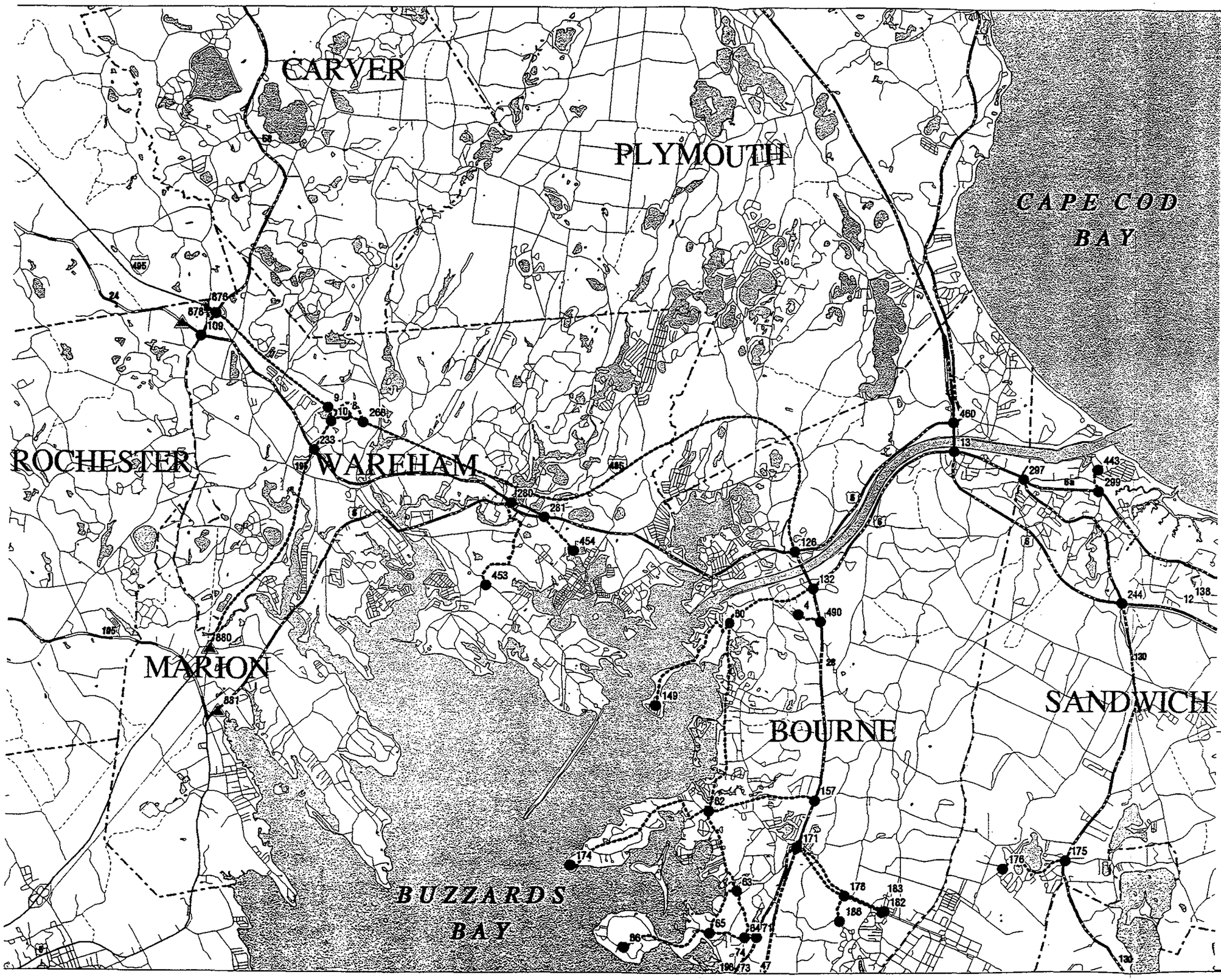


FIGURE 2-6
CAPE COD NETWORK: TILE 2 OF 6

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Cape Cod Network

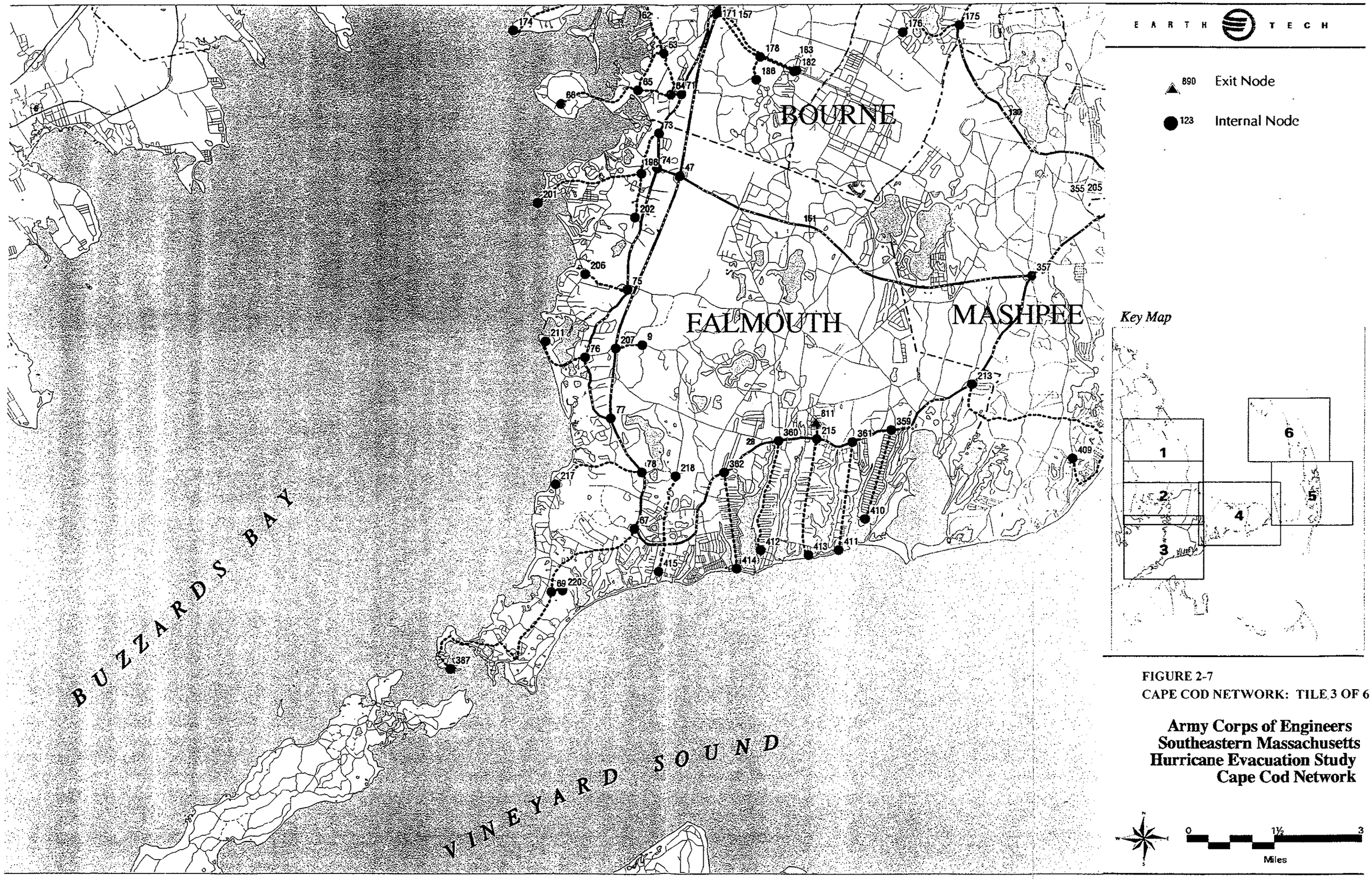


FIGURE 2-7
CAPE COD NETWORK: TILE 3 OF 6

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Cape Cod Network

EARTH TECH

890 Exit Node

123 Internal Node

CAPE COD BAY

SANDWICH

BARNSTABLE

YARMOUTH

DENNIS

MASHPEE

NANTUCKET SOUND

Key Map

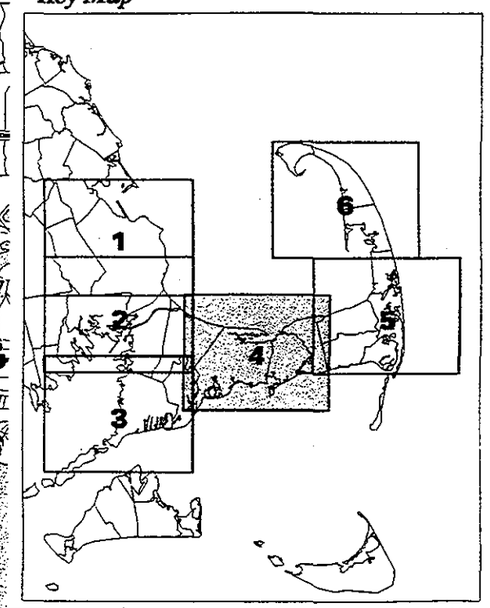
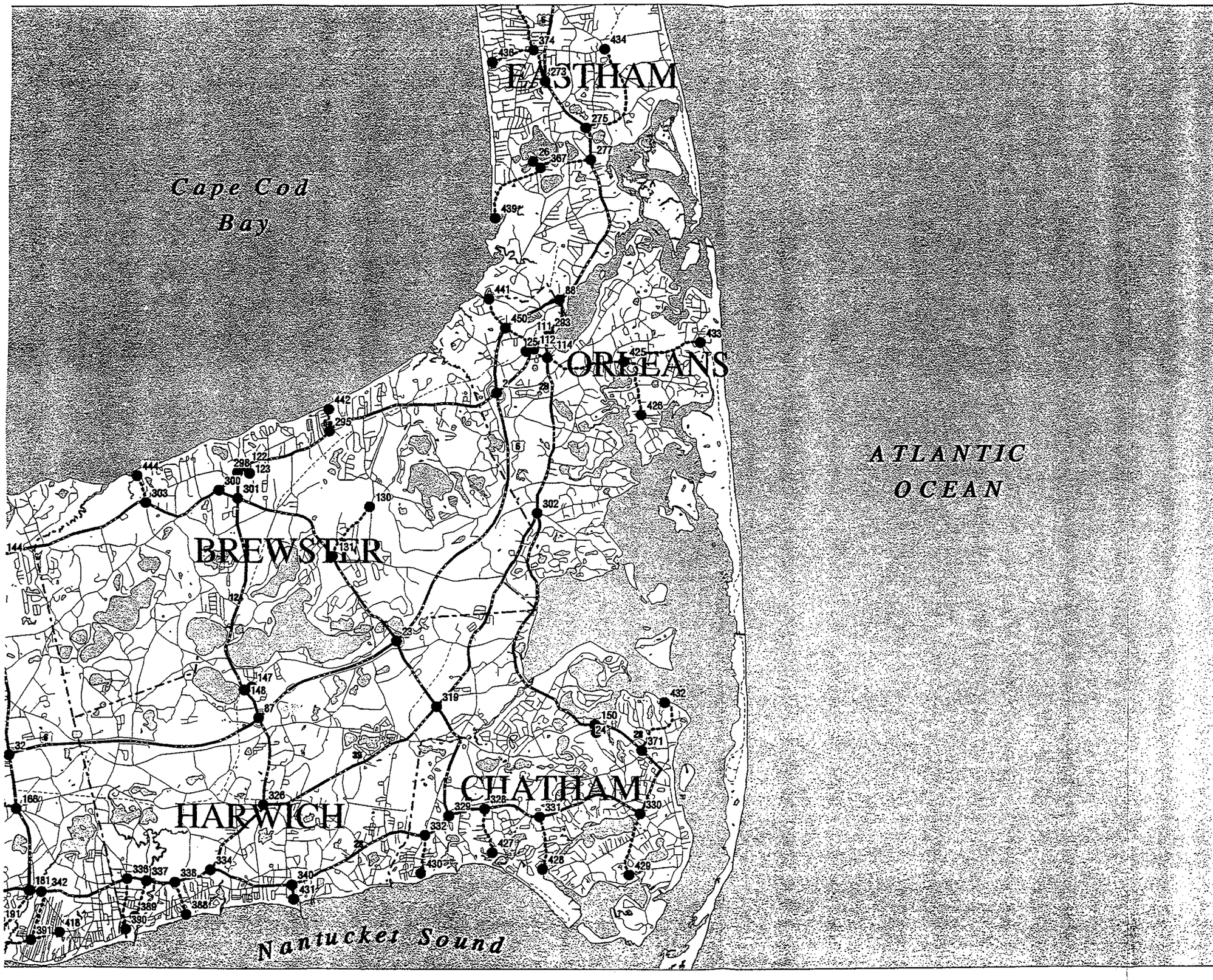


FIGURE 2-8
CAPE COD NETWORK: TILE 4 OF 6

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Cape Cod Network

0 1½ 3
Miles



EARTH TECH

890 Exit Node

123 Internal Node

Key Map

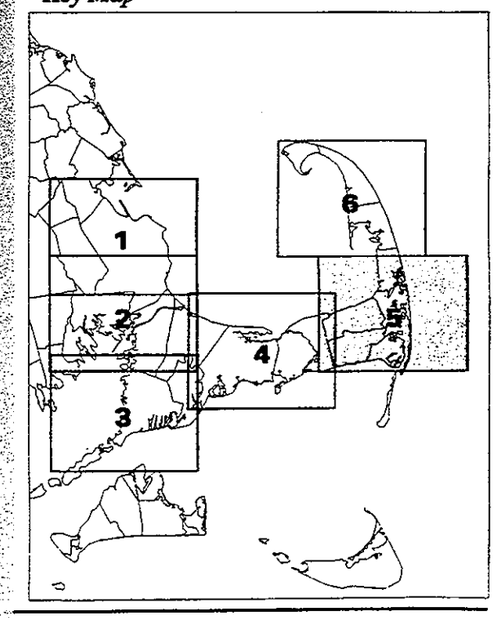
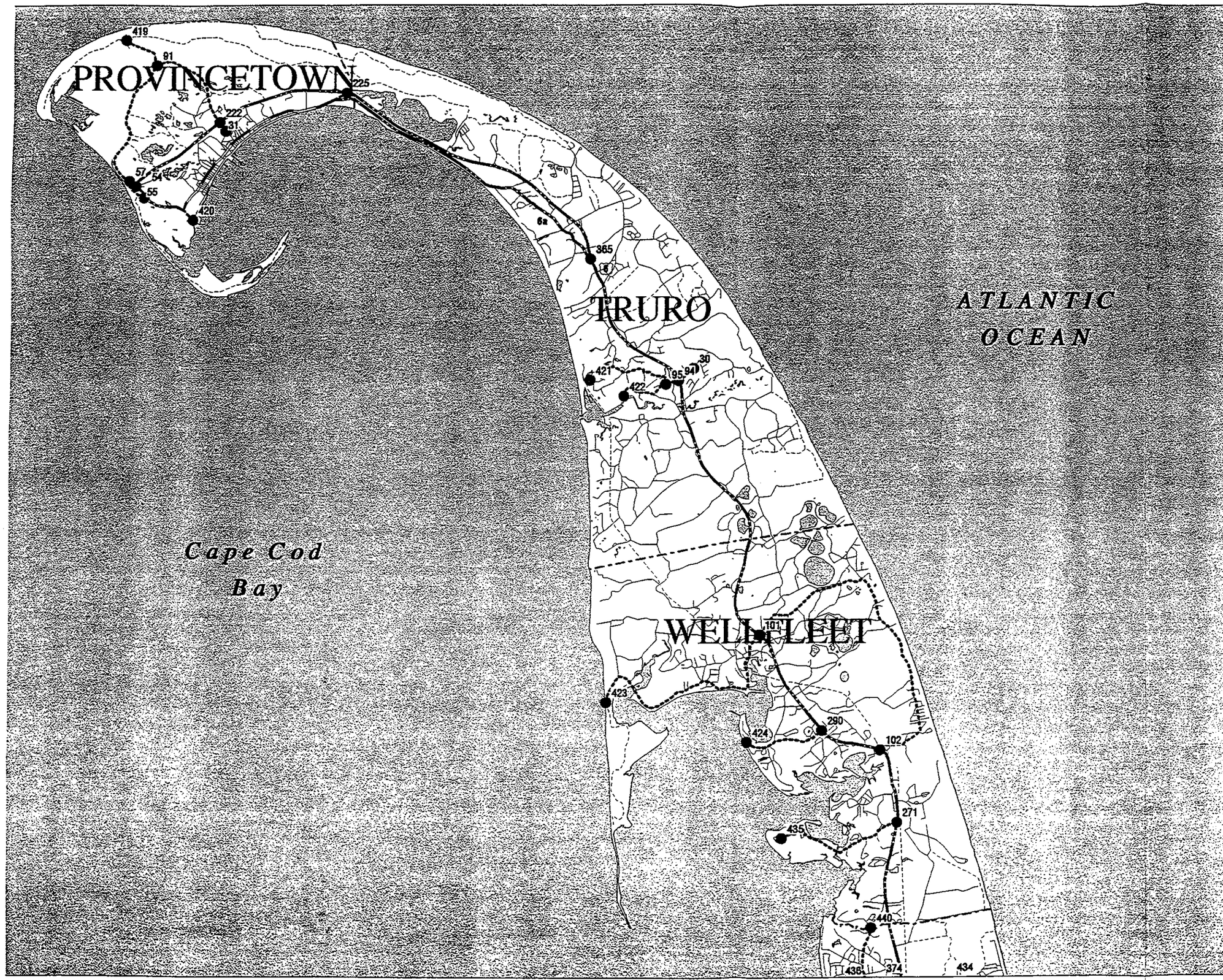


FIGURE 2-9
CAPE COD NETWORK: TILE 5 OF 6

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Cape Cod Network

0 1½ 3
Miles



EARTH TECH

890 Exit Node

123 Internal Node

Key Map

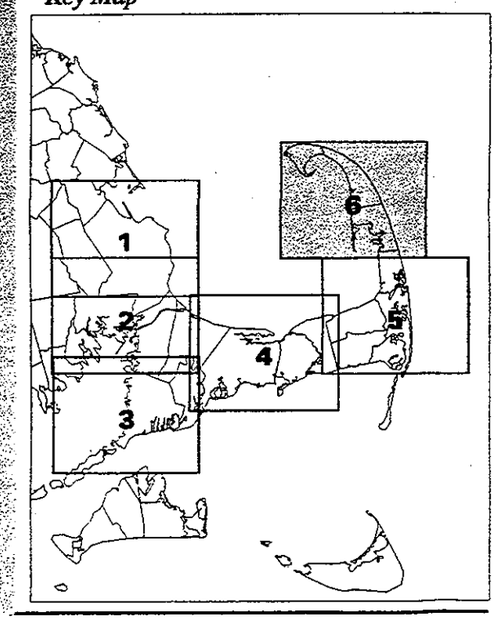
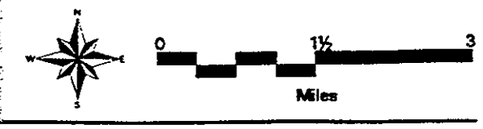


FIGURE 2-10
CAPE COD NETWORK: TILE 6 OF 6

Army Corps of Engineers
Southeastern Massachusetts
Hurricane Evacuation Study
Cape Cod Network



Because areas along the immediate coast lack direct access to state routes, evacuees leaving these areas would first travel on local streets before entering onto state routes. Therefore, areas immediately along the coast, which do not have state routes passing nearby, were provided network access by links representing local streets. The information entered for these links idealized the capacities of several local streets rather than any particular street. The majority of evacuees were programmed to enter networks from local streets extending into coastal areas. However, some evacuees were assigned to enter directly onto the networks at nodes positioned along state routes near the coast.

As a starting point, intersection approaches were all initially coded as equal priority. Coding the model in this manner assumes that at signalized intersections the green time for a particular intersection approach is directly proportional to the relative amount of traffic volume from its approach, relative to the cumulative volume of traffic from all other approaches. In turn, this forces vehicles to compete for the right-of-way which is typical of normal traffic conditions. Accordingly, more green time is allotted to approaches with the highest volumes.

NETVAC2 allows vehicles to exit networks at specified nodes, designated as sink nodes. Exits were created within each study area's interior to represent locations of available public shelters (locations are illustrated by the triangles in Figures 2-1 through 2-10).

The following presents the rationale used to develop an estimate of the general destinations of evacuees from study area communities. The report entitled Hurricane Evacuation Behavior in the Middle Atlantic and Northeast States indicated the following:

- In the Northeast, 55 to 79% of the evacuating population stay within their local town.
- In the Northeast, between 83 and 100% of the evacuating population reach their destination in approximately 30 minutes.
- In the Northeast between 3 and 23% of the evacuating population uses public shelters.

A second source, the Federal Emergency Management Agency (FEMA), has a standard for public sheltering capacity of 20%. The Corps of Engineers held a meeting with the Massachusetts Emergency Management Agency and EARTH TECH to discuss the behavioral assumptions to be used for this study. After considering the above information, the parties jointly determined that the following approach would be used to determine which exit nodes are assigned priorities for both networks:

- For both the Buzzards Bay network and the Cape Cod network assign 15% of the evacuating population to exit nodes corresponding to public shelters within the community.
- Assign 40% of the evacuating population to exit nodes within the community from which they evacuate for the Buzzards Bay network. Because of the high proportion of tourist traffic on Cape Cod, 25% of the evacuating population was assigned to this category. For both networks, this brings the total evacuating population that stays within their community to 55% and 40%, respectively. For the Buzzards Bay network, this is

consistent with the 55-79% that stay within their town. The lower Cape Cod network percentage of 40% reflects the high proportion of tourist evacuee traffic.

- Assign 25% of the evacuating population to interior exit nodes outside the affected communities but within 15 miles of the coast (corresponding to 30 minute travel time) for the Buzzards Bay network. For the Cape Cod network, 20% of the evacuating traffic was assigned to this category. This brings the total within 30 minutes travel time up to 80% for the Buzzards Bay network. The total up to this category for the Cape Cod network is 60%. Because of the restricting nature of the Bourne and Sagamore Bridge, the assumed travel time of 30 minutes is probably on the order of 1-2 hours.

- For the Buzzards Bay network, assign 20% of the evacuating population to exterior exit nodes, roughly 15 miles or more from the inundation areas. Because of the high proportion of tourist traffic on Cape Cod, 40% of the evacuating population in the Cape Cod network was assigned to this category.

2.3 MODEL CALIBRATION

Before evacuation simulations were run, each network was first calibrated for its study area. Calibration is performed for two primary reasons. First, it establishes the route preferences that will be used by all vehicles during an evacuation simulation. Route preferences control the numbers of vehicles assigned to travel on each road. Second, calibration determines how many vehicles must be loaded at a given loading rate to achieve traffic patterns typical of a normal August day. Before an evacuation takes place, the modeling methodology assumes traffic patterns of a normal August day occur. Therefore, NETVAC2 was programmed to simulate normal traffic patterns at peak, mid-peak, and off-peak conditions at the start of all model runs. Only after a hurricane threat becomes imminent, and people begin responding to warnings, are changes in normal day traffic anticipated. The following paragraphs describe how traffic counts recorded for average daily periods were used to calibrate each study area network.

Average Daily Traffic (ADT) volume data (i.e., 24-hour period) are collected along most state and interstate roadways in Massachusetts by MHD[4] and the Cape Cod Commission[5]. In addition to the 24-hour counts, detailed hourly counts are conducted on a continuous basis at central stations in Massachusetts[6].

The following sources of data were used to develop estimates of the existing, typical August traffic volume levels along the Cape Cod and Buzzards Bay network roadways. Note that annual ADTs adjusted for August were used because hourly traffic count data in Mattapoisett indicates summer traffic, particularly in August, is as much as 40% greater than in the winter months and the Cape Cod Commission reports that summer traffic is as much as double winter traffic on Cape Cod. In addition, August traffic was believed to be representative of traffic during the usual hurricane season.

The following sources of data were used to develop estimates of the existing, typical traffic volume levels along Buzzards Bay network roadways:

- "1993 Traffic Volumes for the Commonwealth of Massachusetts", Massachusetts Highway Department, 1994

- Automatic Traffic Counter Records (hourly summaries from the Massachusetts Highway Department) for the following locations from the MHD:

  - Route 195, Dartmouth eastbound
  - Route 195, Dartmouth westbound

  - Rout 195 Mattapoisett eastbound
  - Route 195 Mattapoisett westbound

The Buzzards Bay network traffic patterns are likely more influenced by commuter traffic than by tourist traffic. Figure 2-11 shows the Buzzards Bay 24-hour traffic distribution.

The following sources of data were used to develop estimates of the existing, typical summer traffic volumes along the Cape Cod network roadways.

- "1993 Traffic Volumes for the Commonwealth of Massachusetts", Massachusetts Highway Department, 1994.

- "Cape Cod Traffic Counting Report 1994", Cape Cod Commission, 1994.

- Automatic Traffic Counter Records (hourly summaries) for the following locations, from the MHD:

  - Route 6, Sagamore Bridge outbound
  - Route 6, Sagamore Bridge inbound

  - Route 28, Bourne Bridge inbound
  - Route 28, Bourne Bridge outbound

  - Route 6, Barnstable eastbound
  - Route 6, Barnstable westbound

  - Route 28, Barnstable eastbound
  - Route 28, Barnstable westbound

The Cape Cod network traffic patterns are likely somewhat influenced by tourist traffic. Figure 2-12 shows the Cape Cod 24-hour traffic distribution.

FIGURE 2-11: AVERAGE OF HOURLY AUGUST ADT ALONG MAJOR ROUTES IN BRISTOL COUNTY, MASSACHUSETTS (BUZZARDS BAY NETWORK)

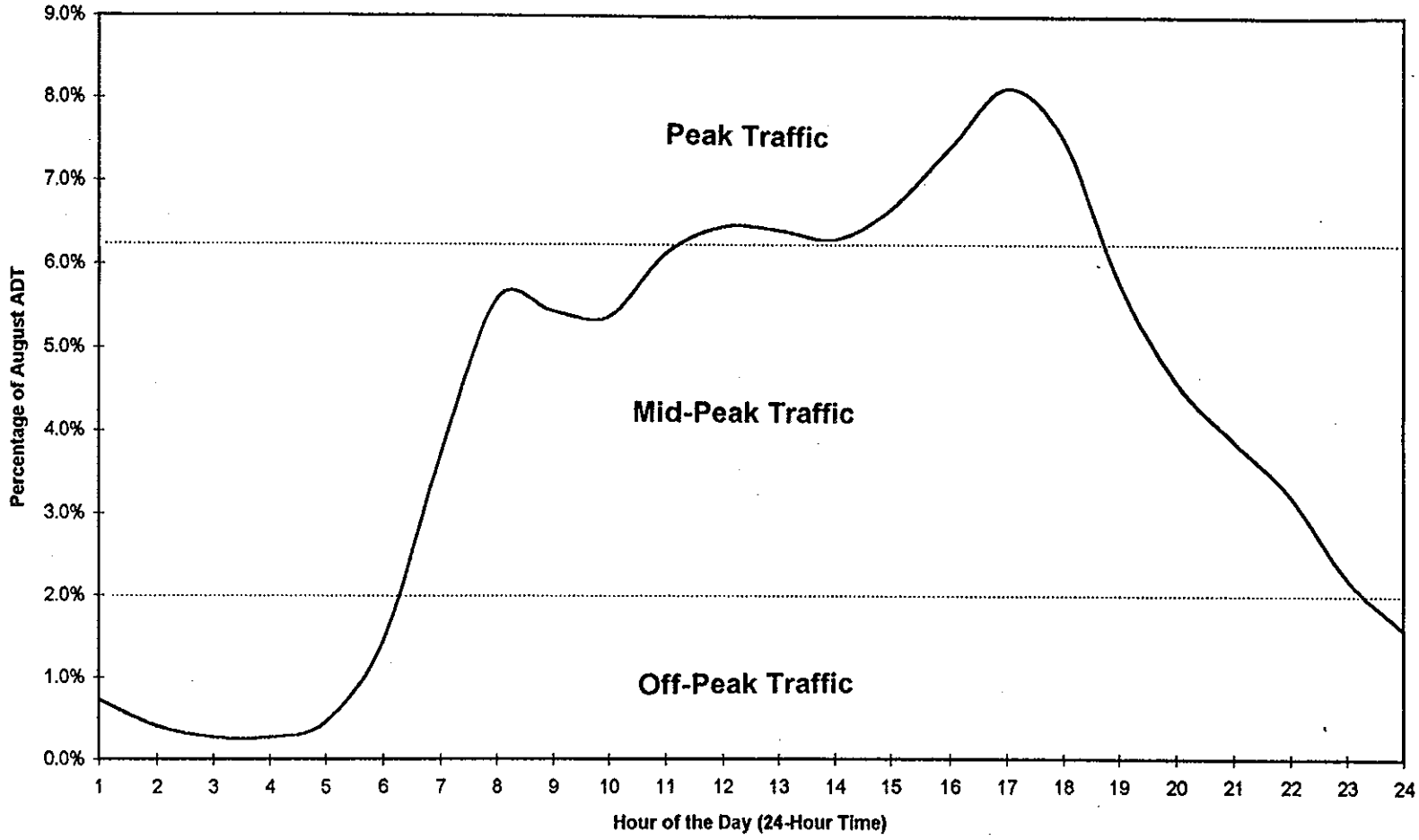
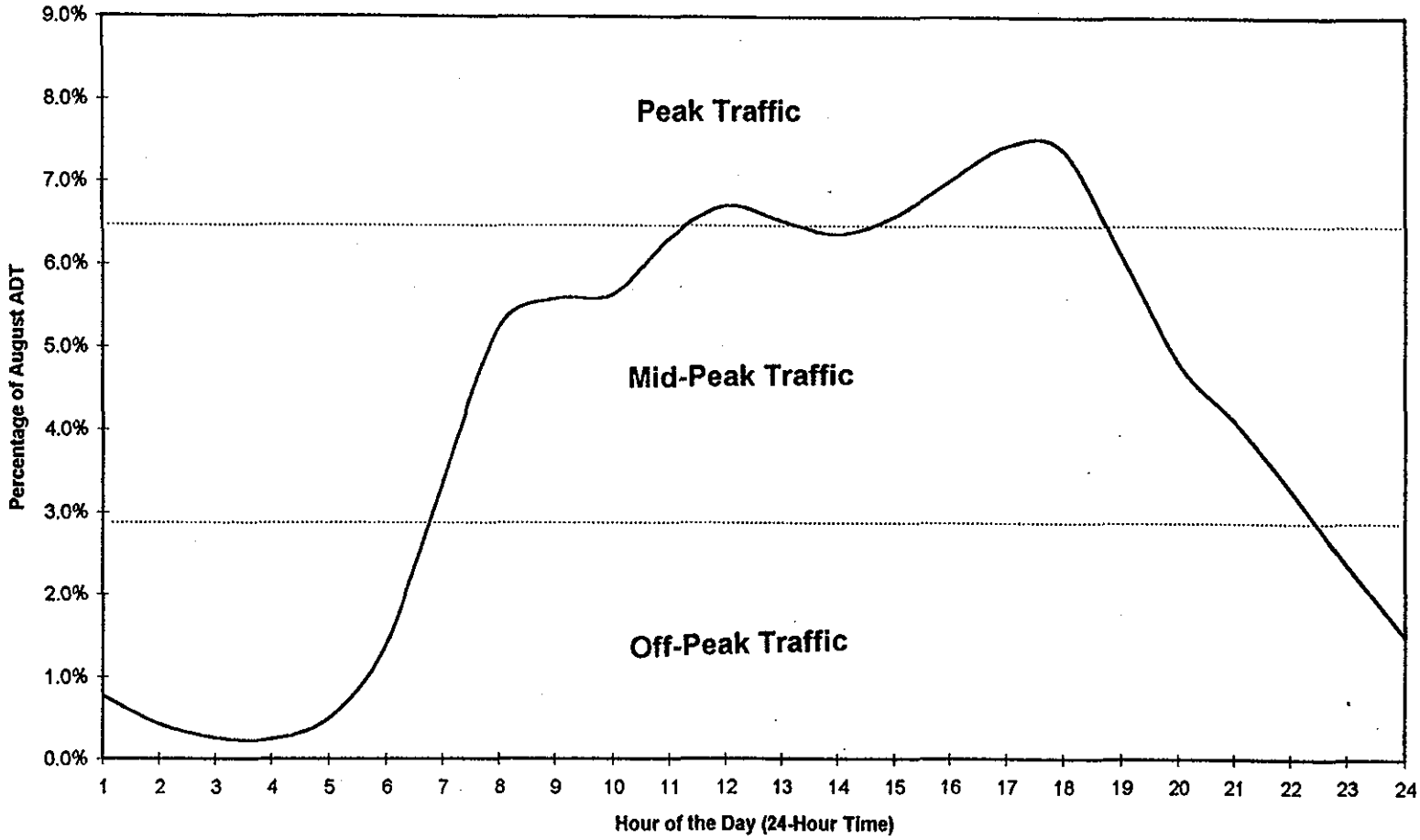


FIGURE 2-12: AVERAGE OF HOURLY ADT ALONG MAJOR ROUTES IN BARNSATBLE COUNTY (CAPE COD NETWORK)



In Figures 2-11 and 2-12, dashed lines delineate approximate levels of ADT corresponding to off-peak, mid-peak, and peak traffic. For the most part, off-peak traffic refers to light traffic volumes that typically occur late at night or in the early morning. Mid-peak traffic refers to moderate traffic conditions similar to that generally experienced in the late morning or early afternoon on weekdays, or on weekend days. Peak traffic represents the volume of traffic that is typical during weekday afternoon rush hour.

Although the distribution of ADT in Figures 2-11 and 2-12 may not reflect all of the local traffic patterns for each road in the study area, it does provide a reasonable representation of how most of the vehicle trips in the Buzzards Bay and Cape Cod networks are distributed over a normal summer day. Therefore, Figures 2-11 and 2-12 were used as a basis by which all the roadways within the Buzzards Bay and Cape Cod networks, respectively, were calibrated.

For the final calibration tests, focus was placed on 26 key roadway links in Southern Massachusetts and Cape Cod to evaluate overall results. The actual unidirectional ADT at exterior nodes was entered as vehicles, and programmed to flow throughout each system. As simulation progressed, printouts every hour of simulation time reported the cumulative link departures and link speeds, as well as any spill backs and queues found at nodes. Calibration was accomplished using an iterative process of running NETVAC2, comparing modeled two-way ADTs to actual two-way ADTs for the 26 links, then adjusting link preference factors and adding traffic onto the network where appropriate before rerunning the model. During this process, a loading distribution that approximated average actual conditions was developed. The entire portion of major corridors such as I-195 and Route 6 were also reviewed in detail to ensure that the identified "check" locations were not isolated spots where ADT was correlated. The transportation methodology assumed calibration was complete when the volume of vehicles on each of the 26 links matched its corresponding actual two-way ADT by ±10% for Principal Arterials and 15% for Major Collectors, and the distribution of hourly traffic approximated actual conditions.

The results of the calibrated network analyses for these key links are represented in Tables 2-1 and 2-2, for the Buzzards Bay and Cape Cod networks.

As an additional check on the network calibration, final evacuation simulation 2-way ADTs were compared to traffic volumes for Hurricane Bob for both bridges. Both bridges were within ±10% of actual ADTs for the day prior to the Hurricane.

TABLE 2-1: BUZZARDS BAY NETWORK CALIBRATION ANALYSIS

BUZZARDS BAY NETWORK CHECKPOINTS

ROUTE	TOWN	AUGUST ACTUAL ADT*	MODELED ADT*	% DIFFERENCE
77	Little Compton	3,000	3,281	+9%
87	Tiverton	3,600	3,971	+10%
177	Westport	5,500	5,940	+8%
6	Dartmouth	17,400	16,133	-7%
195	Dartmouth	69,600	76,697	+9%
6	Fairhaven	31,000	34,045	+10%
195	Fairhaven	48,000	52,057	+8%
24	Berkley	32,000	32,390	+1%
6	Marion	12,400	11,646	-6%
195	Marion	27,800	25,004	-10%
495	Middleborough	43,200	39,682	-8%

* Both directions of travel

TABLE 2-2: CAPE COD NETWORK CALIBRATION ANALYSIS

CAPE COD MASSACHUSETTS NETWORK CHECKPOINTS

Route	Town	Actual ADT*	Modeled ADT*	% Difference
28	Bourne Bridge	28,014	30,262	+8%
6	Sagamore Bridge	30,986	32,567	+5%
130	Sandwich	9,068	8,999	-1%
151	Mashpee	19,066	20,348	+7%
28	Falmouth	24,852	23,263	-6%
28	Barnstable	32,936	32,797	0%
6	Yarmouth	58,096	54,222	-7%
6	Harwich	33,196	35,327	+6%
6	Brewster	25,914	27,838	+7%
28	Chatham	20,288	19,218	-5%
6	Wellfleet	27,796	27,477	-1%
6	Wareham	12,734	12,510	-2%
195	Wareham	13,354	12,753	-5%

* Both directions of travel

SECTION THREE

DEVELOPMENT OF TRAFFIC DATA

3.1 CLASSIFICATION OF MOTORISTS

After road networks were developed, the next steps of the analysis were to estimate the total number of vehicles that will load onto roadways, and determine the rates at which vehicles will load onto roadways over the course of an evacuation. To facilitate the development of this information, vehicles were classified as belonging to one of four major categories listed below:

(1) Surge Vulnerable Evacuees: Permanent and seasonal residents living in evacuation zones who evacuate when directed to do so by authorities.

(2) Non-Surge Vulnerable Evacuees: Permanent and seasonal residents, excluding mobile home residents, living outside evacuation zones who choose to evacuate. Most of the evacuees of this category leave their homes because of perceived dangers and not necessarily because of real flooding threats. However, in some cases, officials may deem it necessary to evacuate small groups of people who live in substandard housing units particularly vulnerable to hurricane winds, or those who live in or near areas that may be exposed to freshwater flooding.

(3) Mobile Home Evacuees: All permanent and seasonal mobile home residents of coastal communities. The analysis assumes all mobile home residents will be told to evacuate by local officials due to the high risk of wind damage from storms of even modest intensities.

(4) Background Vehicles: The population associated with all remaining vehicle trip purposes. Examples are: Trips made by people who leave work early and return home, people who travel through the region, and trips made by persons preparing for the arrival of hurricane conditions or engaged in normal activities. This traffic can also include transit vehicles (vans/buses) used to pick up evacuees without personal transportation.

The number of vehicles assumed to participate during an evacuation from each group listed is an important factor in estimating clearance times. Human behavioral information developed in Chapter Four, Behavioral Analysis, in the TDR, gives clear estimates of the participation that can be expected from the first three groups. The fourth group, Background Vehicles, is not addressed by the Behavioral Analysis. However, motorists belonging to this group mostly comprise of people making shopping trips or commuting, which is related to the ADT distribution shown in Figures 2-11 and 2-12 for the Buzzards Bay and Cape Cod networks, respectively.

Tables 3-1 through 3-6 list estimates made of the numbers of permanent and seasonal people who are assumed to evacuate their homes by population type for two levels of hurricane threat for Bristol, Plymouth and Barnstable Counties, Massachusetts. Estimates were made by applying evacuation participation behavioral assumptions to community population data (see TDR). The evacuating population for Little Compton and Tiverton, Rhode Island, was determined in the Rhode Island Hurricane Evacuation Study[7].

TABLE 3-1:
BRISTOL COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Acushnet	9,550	30	9,580	0	160	600	760
Dartmouth	27,240	1,130	28,370	2,700	490	120	3,310
Fairhaven	16,130	1,150	17,280	3,850	100	60	4,010
Fall River	92,700	150	92,850	2,520	1,760	100	4,380
New Bedford	99,920	140	100,060	2,790	960	90	3,840
Rehoboth	8,660	50	8,710	410	160	10	580
Seekonk	13,050	50	13,100	330	250	0	580
Somerset	17,660	50	17,710	2,960	280	0	3,240
Swansea	15,410	170	15,580	4,270	210	10	4,490
Westport	13,850	1,830	15,680	1,550	270	80	1,900
TOTALS	314,170	4,750	318,920	21,380	4,640	1,070	27,090

TABLE 3-2
BRISTOL COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Acushnet	9,550	30	9,580	820	400	600	1,820
Dartmouth	27,240	1,130	28,370	3,200	1,240	120	4,560
Fairhaven	16,130	1,150	17,280	11,100	250	60	11,410
Fall River	92,700	150	92,850	4,370	4,400	100	8,870
New Bedford	99,920	140	100,060	18,180	1,590	90	19,860
Rehoboth	8,660	50	8,710	580	400	10	990
Seekonk	13,050	50	13,100	480	630	0	1,110
Somerset	17,660	50	17,710	3,320	700	0	4,020
Swansea	15,410	170	15,580	4,810	510	10	5,330
Westport	13,850	1,830	15,680	1,740	680	80	2,500
TOTALS	314,170	4,750	318,920	48,600	10,800	1,070	60,470

TABLE 3-3
PLYMOUTH COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Marion	4,500	1,130	5,630	4,250	0	0	4,250
Mattapoisett	5,850	1,650	7,500	4,530	30	20	4,580
Rochester	3,920	110	4,030	170	80	10	260
Wareham	19,230	18,800	38,030	20,210	210	2,190	22,610
TOTALS	33,500	21,690	55,190	29,160	320	2,220	31,700

TABLE 3-4
PLYMOUTH COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Marion	4,500	1,130	5,630	5,080	0	0	5,080
Mattapoisett	5,850	1,650	7,500	5,510	70	20	5,600
Rochester	3,920	110	4,030	270	190	10	470
Wareham	19,230	18,800	38,030	22,850	520	2,190	25,560
TOTALS	33,500	21,690	55,190	33,710	780	2,220	36,710

TABLE 3-5
BARNSTABLE COUNTY
EVACUATING POPULATION
WEAK HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Barnstable	40,950	28,780	69,730	7,990	1,170	20	9,180
Bourne	16,060	13,120	29,180	9,770	330	180	10,280
Brewster	8,440	16,510	24,950	1,790	440	20	2,250
Chatham	6,580	16,490	23,070	5,010	330	0	5,340
Dennis	13,860	42,070	55,930	17,260	620	170	18,050
Eastham	4,460	15,930	20,390	3,550	300	0	3,850
Falmouth	27,960	33,760	61,720	21,260	660	20	21,940
Harwich	10,280	19,800	30,080	6,210	400	10	6,620
Mashpee	7,880	19,270	27,150	7,170	350	400	7,920
Orleans	5,840	9,580	15,420	3,890	210	0	4,100
Provincetown	3,560	8,500	12,060	2,470	150	20	2,640
Sandwich	15,490	7,220	22,710	3,420	370	30	3,820
Truro	1,570	8,090	9,660	990	170	10	1,170
Wellfleet	2,490	13,540	16,030	4,780	160	540	5,480
Yarmouth	21,170	28,350	49,520	12,410	580	210	13,200
TOTALS	186,590	281,010	467,600	107,970	6,240	1,630	115,840

TABLE 3-6
BARNSTABLE COUNTY
EVACUATING POPULATION
SEVERE HURRICANE SCENARIO

Community	Population of Town			Evacuating Population			
	Permanent	Seasonal	Total	Surge Areas	Non-Surge Areas	Mobile Homes	Total
Barnstable	40,950	28,780	69,730	9,900	2,930	20	12,850
Bourne	16,060	13,120	29,180	11,360	820	180	12,360
Brewster	8,440	16,510	24,950	2,610	1,100	20	3,730
Chatham	6,580	16,490	23,070	6,030	820	0	6,850
Dennis	13,860	42,070	55,930	22,360	1,550	170	24,080
Eastham	4,460	15,930	20,390	4,900	750	0	5,650
Falmouth	27,960	33,760	61,720	25,650	1,660	20	27,330
Harwich	10,280	19,800	30,080	9,010	1,000	10	10,020
Mashpee	7,880	19,270	27,150	8,520	860	400	9,780
Orleans	5,840	9,580	15,420	4,380	530	0	4,910
Provincetown	3,560	8,500	12,060	4,290	360	20	4,670
Sandwich	15,490	7,220	22,710	3,840	920	30	4,790
Truro	1,570	8,090	9,660	1,130	420	10	1,560
Wellfleet	2,490	13,540	16,030	6,720	400	540	7,660
Yarmouth	21,170	28,350	49,520	18,350	1,450	210	20,010
TOTALS	186,590	281,010	467,600	139,050	15,570	1,630	156,250

3.2 BEHAVIORAL RESPONSE OF MOTORISTS

Perhaps one of the most critical assumptions that must be considered when estimating clearance times is the timing at which evacuees load onto roadways. Behavioral data from research obtained from past hurricane evacuations show that mobilization and actual departures of the evacuating population occur over a period of many hours and sometimes several days[3]. For Southern Massachusetts evacuation simulations were tested for three evacuation rates that are summarized by the response curves in Figure 3-1. Behavioral response curves describe the percentages of the evacuating population who leave their homes and load onto roadways at hourly intervals relative to when an evacuation recommendation is disseminated to the public.

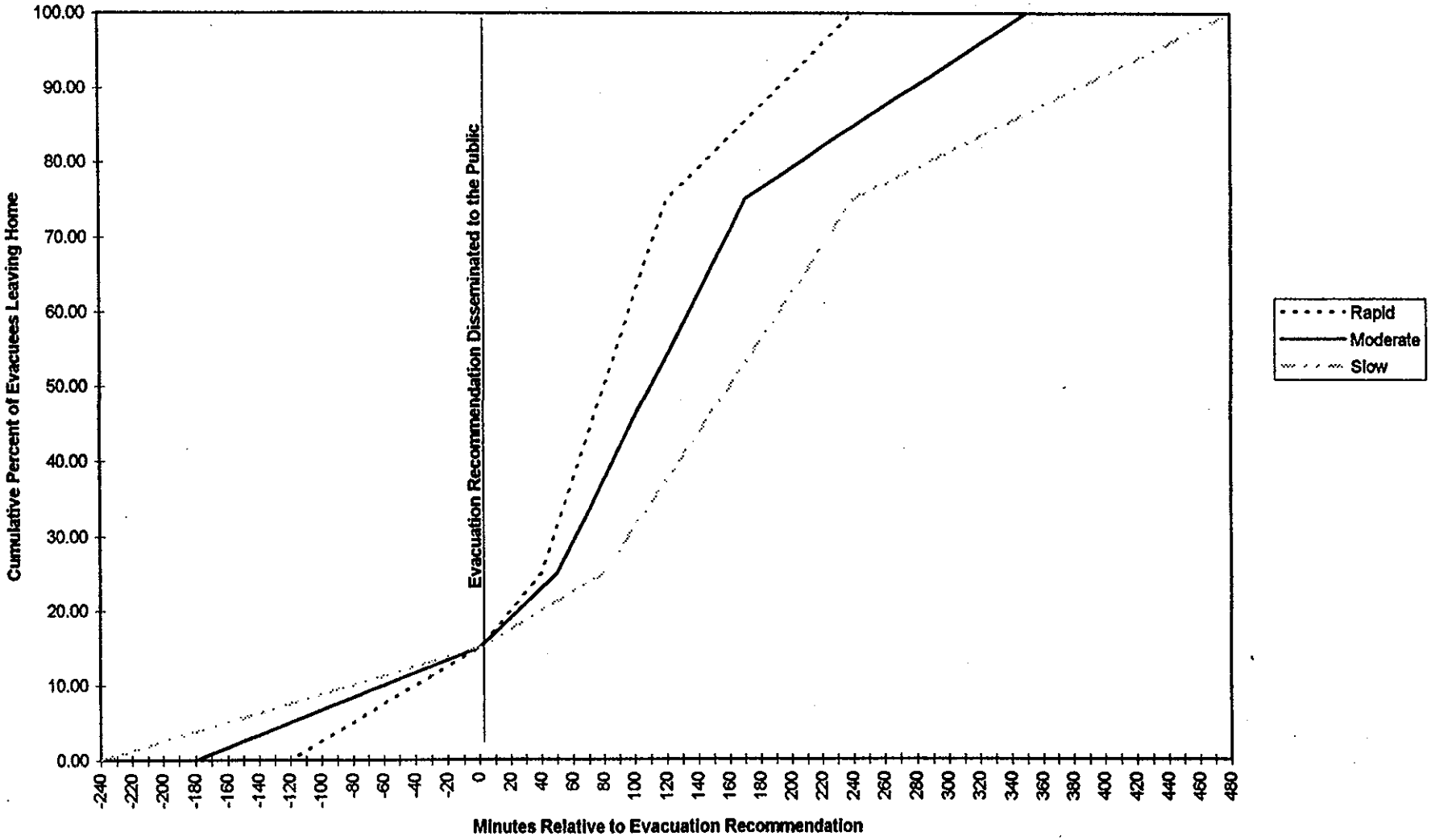
The behavioral response curves are intended to include the most probable range of public responses that will be experienced in a future hurricane evacuation. The rapid response curve depicts the quickest mobilization response by evacuating households. For analysis purposes, the rapid response curve includes two hours of response time occurring before the evacuation recommendation is disseminated to the public and four hours after it is disseminated. For the moderate response curve, three hours of response time is assumed before dissemination of the evacuation recommendation, and six hours after. The slow response curve includes four hours of response time before notification of the evacuation recommendation, and eight hours after. The public's response before evacuation accounts for people who choose to evacuate their homes before being directed to do so by authorities. Regardless of the behavioral response curve used, 85 percent of all people who will eventually leave their homes are assumed to leave after being directed to do so by officials. This is an important point because people's timeliness in responding to a hurricane evacuation is extremely dependent upon the aggressiveness of authorities to encourage them to leave[3].

3.3 VEHICLE USAGE

The behavioral analysis conducted for Southern Massachusetts estimated that approximately 75 percent of the vehicles available to evacuees will be used during future evacuations[3]. For the most part, families usually evacuate using one vehicle for fear of separation, but some households evacuate using two or more vehicles depending upon how many are available to them. Differences in vehicle ownership may vary with variations in access to public transportation, household income, and other socio-economic characteristics of the region.

The first column of Table 3-7 list permanent population for Bristol County, Massachusetts by community. The second and third columns list the numbers of available vehicles per owner and renter - occupied housing units, respectively. This information was obtained from socio-economic data reported in the 1990 census[8]. The fourth column of the Table gives the number of available vehicles per person, and the fifth column gives the calculated average numbers of people that will travel in each evacuating vehicle, assuming 75 percent of the available vehicles are used. Similar information for Plymouth and Barnstable Counties is provided in Tables 3-8 and 3-9.

FIGURE 3-1: BEHAVIORAL RESPONSE CURVES



A sample calculation of the assumed persons per evacuating vehicle for the Town of Barnstable, Massachusetts is shown below.

Permanent Population	= 40,950 people	
Available vehicles	= 21,080 + 6,000	= 27,080 vehicles
Vehicles per person	$= \frac{27{,}080 \text{ vehicles}}{40{,}950 \text{ person}}$	$= 0.66 \frac{\text{vehicles}}{\text{person}}$

Persons per evacuating vehicle, assuming 75% usage	=	$\frac{1}{0.66 \text{ vehicles/person} \times 0.75}$
	=	2.02 persons per vehicle

The transportation methodology used the information in Tables 3-1 through 3-9 to determine the number of vehicles that would load onto roadways during evacuations. The user enters the vehicle occupancy rates and the number of people assigned to enter the network at each node. NETVAC2's complimentary program, POPDIS, aggregates the population input for each entry node and in turn computes the effective average vehicle loading rates per minute to be input into NETVAC2 at network entry locations.

TABLE 3-7
BRISTOL COUNTY
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons Per Evacuating Vehicle (75% Usage)
Acushnet	9,550	5,820	690	0.68	1.96
Dartmouth	27,240	13,970	2,180	0.59	2.26
Fairhaven	16,130	7,840	2,290	0.63	2.12
Fall River	92,700	20,450	24,590	0.49	2.72
New Bedford	99,920	27,130	19,430	0.47	2.84
Rehoboth	8,660	5,730	520	0.72	1.85
Seekonk	13,050	8,730	820	0.73	1.83
Somerset	17,660	10,800	1,540	0.70	1.90
Swansea	15,410	9,930	800	0.70	1.90
Westport	13,850	8,510	1,480	0.72	1.85

TABLE 3-8
PLYMOUTH COUNTY
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons Per Evacuating Vehicle (75% Usage)
Marion	4,500	2,450	700	0.70	1.90
Mattapoisett	5,850	3,300	800	0.70	1.90
Rochester	3,920	2,670	100	0.71	1.88
Wareham	19,230	9,600	2,280	0.62	2.15

TABLE 3-9
BARNSTABLE COUNTY
ASSUMED VEHICLE USAGE RATES BY COMMUNITY

Community	Permanent Population	Available Vehicles in Owner Occupied Housing Units	Available Vehicles in Renter Occupied Housing Units	Vehicles Per Person	Persons Per Evacuating Vehicle (75% Usage)
Barnstable	40,950	21,080	6,000	0.66	2.02
Bourne	16,060	7,090	3,030	0.63	2.12
Brewster	8,440	4,800	1,160	0.71	1.88
Chatham	6,580	3,810	800	0.70	1.90
Dennis	13,860	7,290	2,230	0.69	1.93
Eastham	4,460	2,550	810	0.75	1.78
Falmouth	27,960	14,510	4,220	0.67	1.99
Harwich	10,280	5,980	1,320	0.71	1.88
Mashpee	7,880	3,900	1,300	0.66	2.02
Orleans	5,840	3,240	1,040	0.73	1.83
Provincetown	3,560	1,100	770	0.53	2.52
Sandwich	15,490	9,120	1,480	0.68	1.96
Truro	1,570	990	260	0.80	1.67
Wellfleet	2,490	1,500	480	0.80	1.67
Yarmouth	21,170	11,140	3,520	0.69	1.93

SECTION FOUR

EVACUATION SCENARIOS

Since all hurricanes differ from one another in some respect, it becomes necessary to set forth clear assumptions about storm characteristics and evacuees' expected response before transportation modeling can begin. Not only does a storm vary in its track, intensity and size, but also in the way it is perceived by residents in potentially vulnerable areas. These factors cause a wide variance in the behavior of the vulnerable population. Even the time of day at which a storm makes landfall influences the time parameters of an evacuation response. The transportation analysis computes clearance times based on sets of assumed conditions and behavioral responses. It is likely that an actual storm will differ from a simulated storm for which clearance times are calculated in this report. Therefore, key input parameters were varied to derive a range of evacuation scenarios idealizing many possible situations officials may have to contend with. The three major parameters that were varied with each simulation are described below.

(1) Hurricane Severity: Storms are classified as either weak or severe hurricanes. Evacuating population estimates (see Tables 3-1 through 3-6) are significantly greater for an evacuation due to severe hurricanes when compared with that for weak hurricanes.

(2) Behavioral Response: The time in which evacuees mobilize to leave their homes and enter onto the roadway system is characterized by the behavioral response curves shown in Figure 3-1. Behavioral response curves are defined for rapid, moderate, and slow responses.

(3) Background Traffic Condition: The traffic condition at the start of an evacuation will depend upon the time of day the evacuation begins as well as other factors that may influence initial traffic conditions. As the NETVAC2 models were run, initial traffic conditions corresponding to off-peak, mid-peak, and peak ADT levels were analyzed. Figures 4-1a through 4-1c and 4-2a through 4-2c illustrate background vehicle distributions assumed for the following three conditions on the Buzzards Bay and Cape Cod networks, respectively.

a. **Off-peak**: The off-peak traffic condition refers to light traffic volumes that typically occur late at night or in the early morning.

b. **Mid-peak**: The mid-peak traffic condition refers to moderate traffic conditions similar to that generally experienced in the two hour period occurring before and after the AM and PM peak conditions.

c. **Peak**: The peak traffic condition replicates the "rush hour" volume of traffic that is typical of the two hour period from 4:00 - 6:00 PM.

As noted above, background vehicles refer to motorists who travel roadways during an evacuation with trip purposes other than for evacuating their homes. At the start of an evacuation, the number of background vehicles assumed to exist on a particular road was taken as the ADT for that road on a normal day. As an

evacuation progressed, the initial ADT assumed was slowly decreased until approximately zero background vehicles were on the roads at the completion of the evacuation.

Referring to the ADT distribution shown in Figures 2-11 and 2-12, the Transportation Analysis simulated evacuations occurring coincident with rush hour by programming evacuees to load onto roadways that were initially set at peak ADT volumes. Conversely, an evacuation occurring at times of light traffic, such as late at night or in the early morning, was modeled by running the model with background vehicles initially set at off-peak ADT volumes. Simulations run with background traffic at mid-peak ADT volumes represented moderate traffic volumes typical of mid-morning and mid-afternoon on weekdays or weekends.

The Transportation Analysis assumed the background traffic distributions shown in Figures 4-1a through 4-1c for the Buzzards Bay network and Figures 4-2a through 4-2c for the Cape Cod network to apply to evacuations assuming a moderate behavioral response by evacuees. Background traffic distributions used for evacuations assuming a rapid or a slow behavioral response (not shown) follow the same curves shown in Figures 4-1a through 4-1c for the Buzzards Bay network and Figures 4-2a through 4-2c for the Cape Cod network. The only exception is that evacuees are programmed to load onto roadways slightly before or after background traffic starts its decline because it is assumed that the behavior of background traffic will be influenced by knowledge of the approaching storm. The number of background vehicles on any roadway during a model run will vary depending upon each road's particular ADT and the hourly percentage of ADT assumed for the traffic condition modeled. A key point in using Figures 2-11 and 2-12 to derive background traffic conditions is that all traffic conditions are derived from actual traffic patterns observed for areas in the Buzzards Bay and Cape Cod networks, respectively rather than assumed hypothetical conditions.

Combinations of these key input parameters were used in developing 18 possible scenarios for each network. For each of the networks, simulations were run for evacuations assuming weak hurricanes and severe hurricanes. Initial traffic conditions imparted on the road network followed the background distributions for off-peak, mid-peak, and peak traffic. Evacuees entered road networks at prescribed time intervals defined by the rapid, moderate, and slow behavioral responses.

Seasonal resident population and transient population visiting the area (i.e., tourism) varies widely in the study area, especially on Cape Cod, based upon the time of year, weather conditions, etc. The evacuating population used during simulations included seasonal residents as estimated from the 1990 census[8] from seasonal housing unit information. Although the varying transient conditions were not specifically evaluated for all scenarios, they were inherently addressed in a sensitivity analysis which focused on an evaluation of varying increases in study area population (refer to Section 5.3).

Figure 4-1a: Off-Peak Background Distribution, Buzzards Bay Network

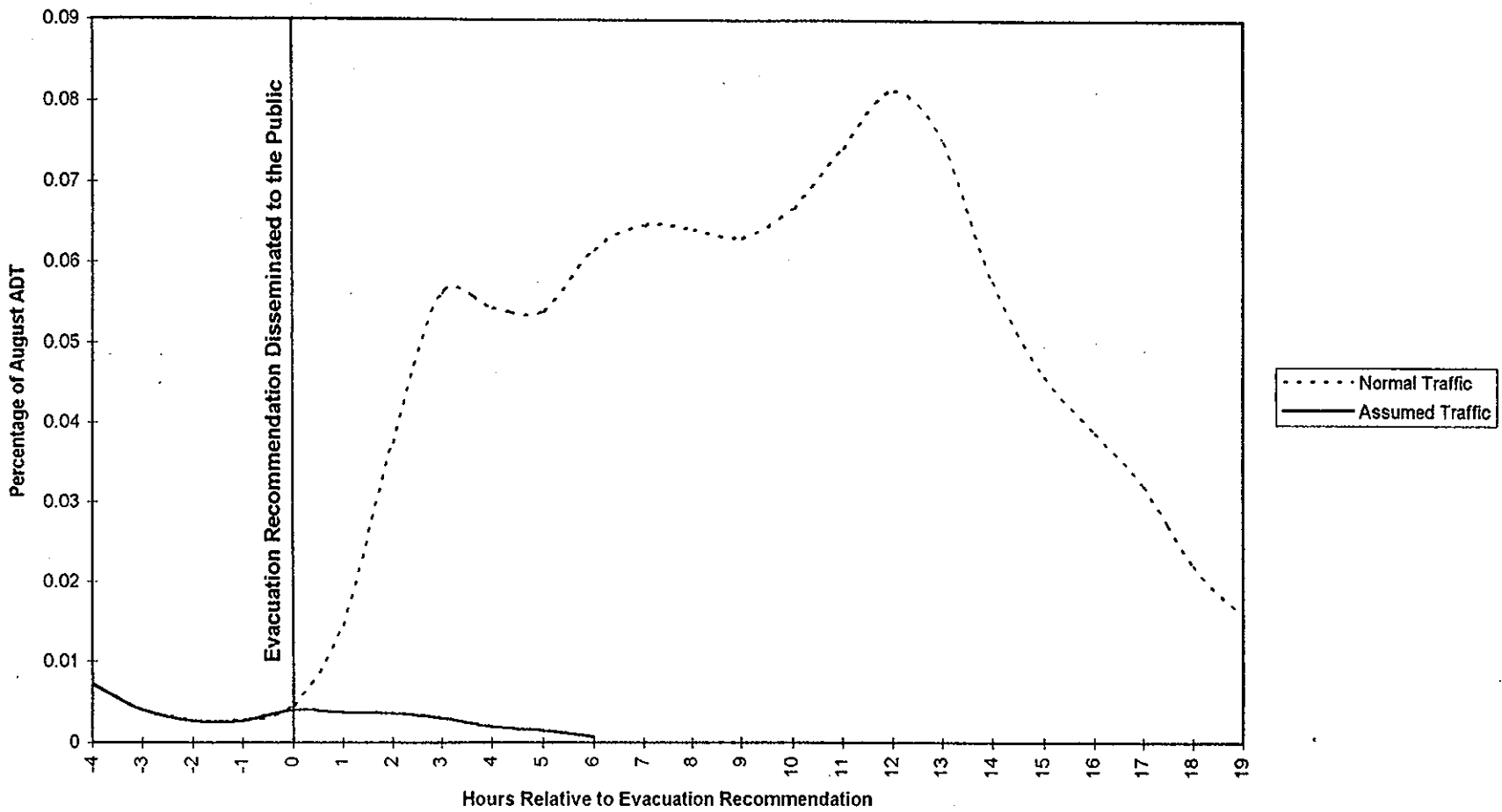


Figure 4-1b: Mid-Peak Background Distribution, Buzzards Bay Network

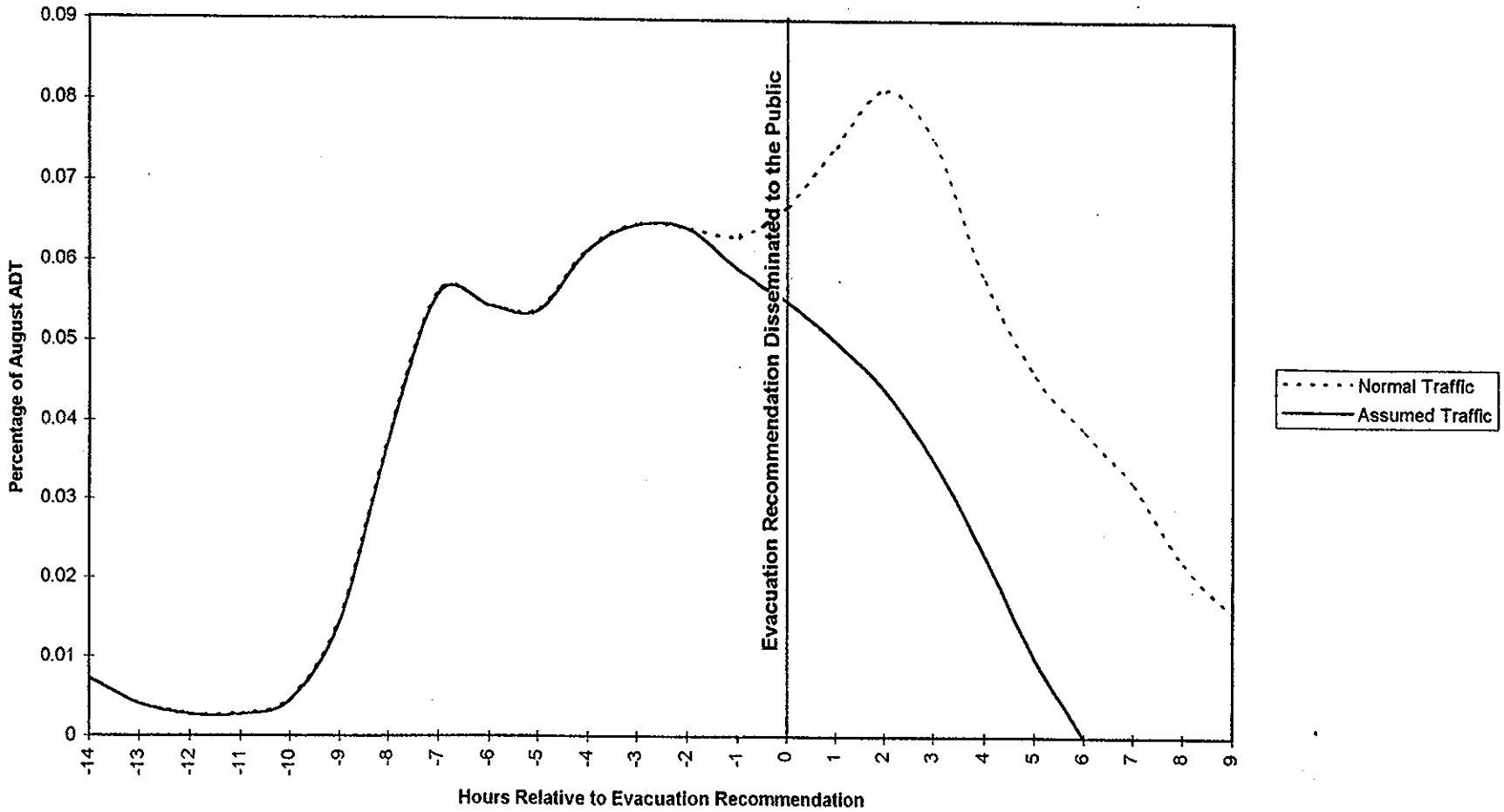


Figure 4-1c: Peak Background Distribution, Buzzards Bay Network

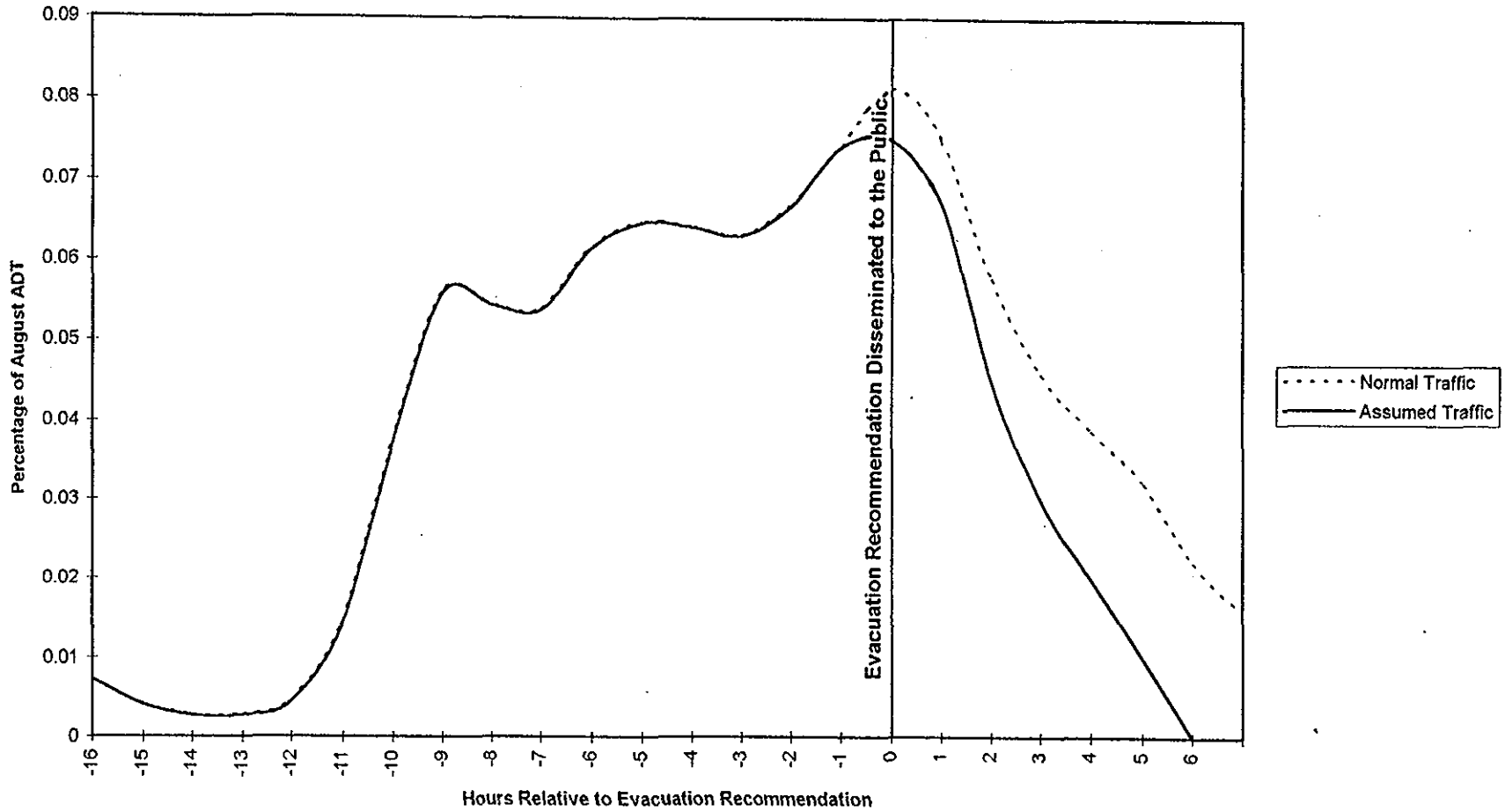


Figure 4-2a: Off-Peak Background Distribution Cape Cod Network

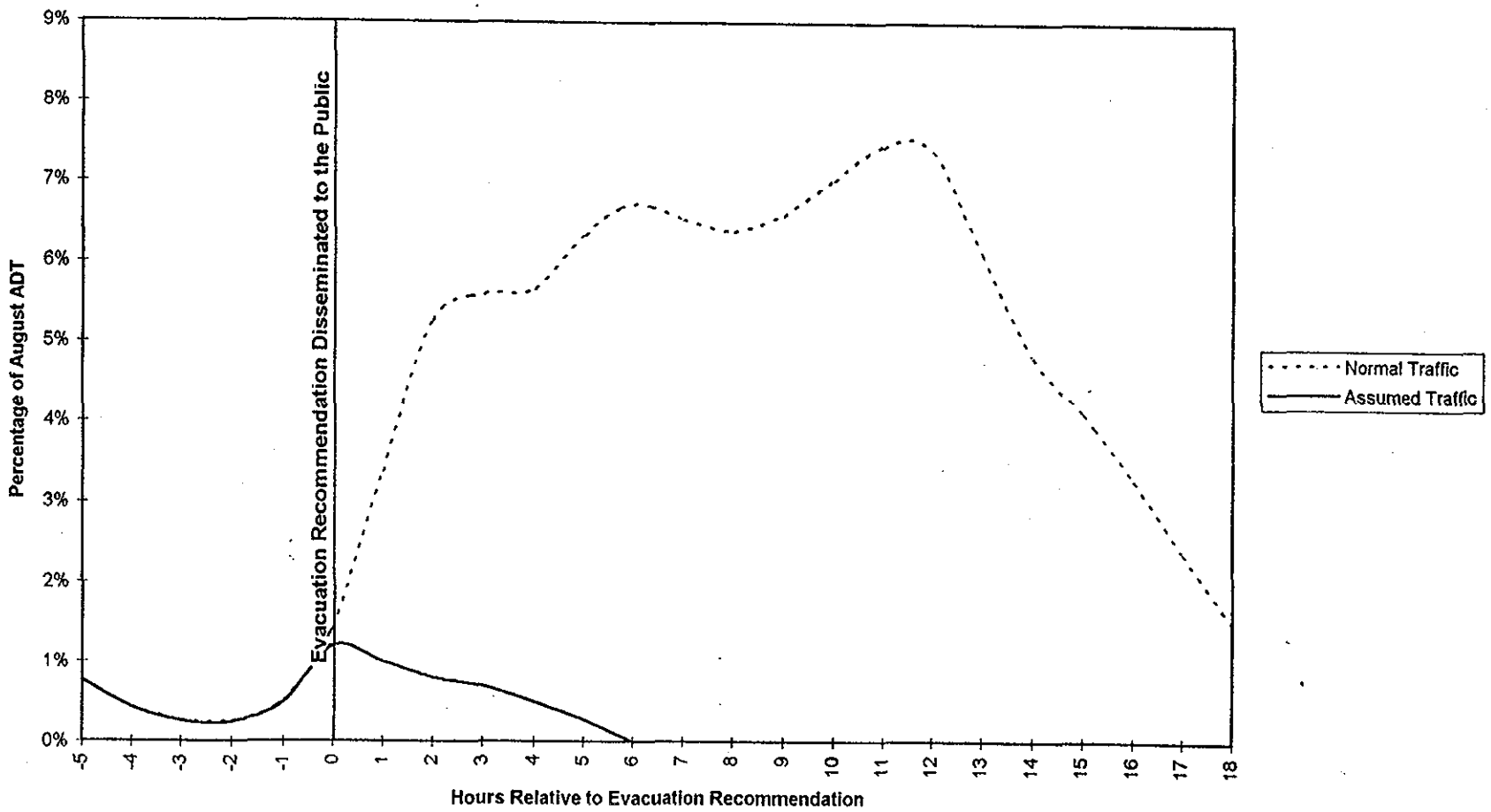


Figure 4-2b: Mid-Peak Background Distribution, Cape Cod Network

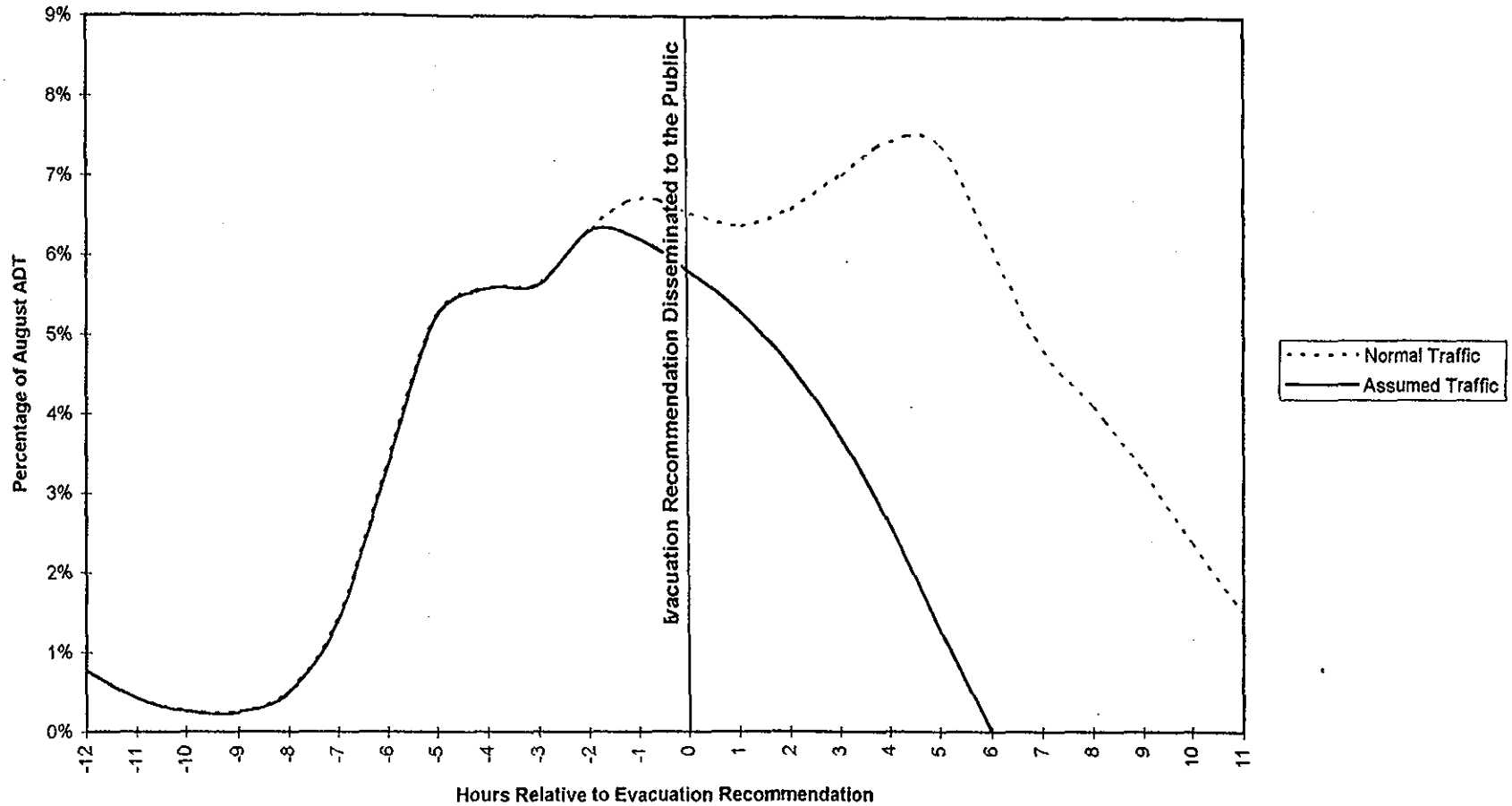
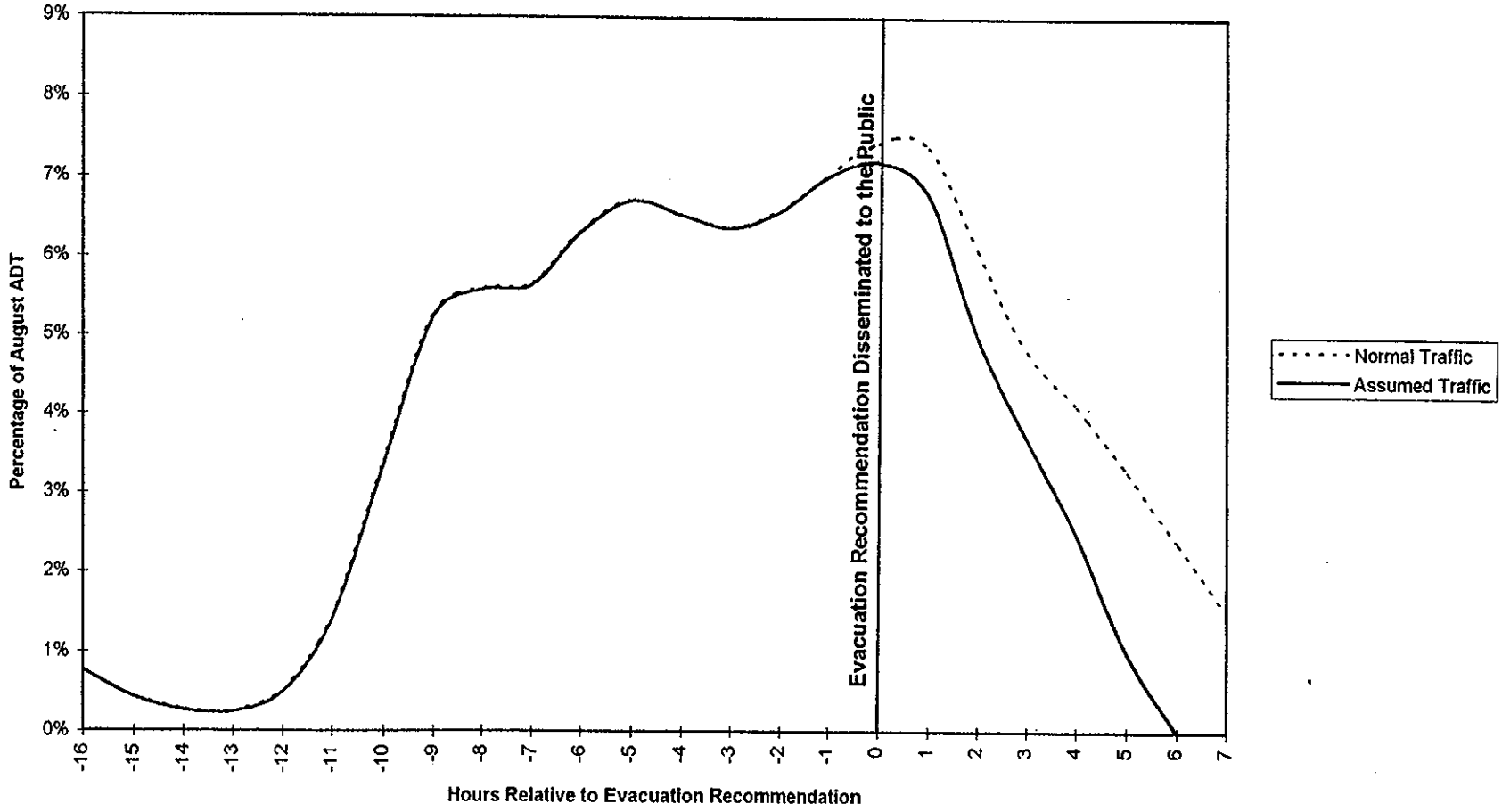


Figure 4-2c: Peak Background Distribution, Cape Cod Network



SECTION FIVE

ANALYSIS

5.1 GENERAL

Clearance time and dissemination time are two major considerations in deciding when an evacuation recommendation should be issued. The combination of these times defines a region's total evacuation time. Clearance time begins when an evacuation recommendation is clearly disseminated to the threatened public, and ends when the last evacuees clear the road system. This time includes the time required by evacuees to secure their homes and prepare to leave (mobilization time), the time spent by evacuees traveling along the road network (travel time), and the time lost due to traffic congestion (queuing delay time). Clearance time does not relate solely to the time any one vehicle spends traveling on the road system.

Dissemination time is the amount of time required by officials to notify the public to evacuate after the decision has been made. Dissemination time may differ by region depending on the communication and warning procedures utilized by State and local officials in their areas, and can best be estimated by the responsible state and local officials. The times calculated by the Transportation Analysis include only the clearance time component of evacuation time, and officials using this information must determine the dissemination time appropriate for their areas. Failure to add dissemination time to clearance time will underestimate total evacuation time, which could result in insufficient time for all evacuees to safely clear the hazard area.

Evacuations should be completed before the arrival of gale force winds (34 knot/39 mph) and/or storm surge. Vehicle accidents and reduced travel speeds from inclement weather can impede traffic flows, and potentially disrupt the evacuation. Therefore, the transportation modeling assumes that evacuations will occur well enough before a hurricane to preclude possible delays caused by significant weather. Moreover, the analysis assumes that provisions would be made for removal of vehicles in distress during the evacuation. The Decision Arc Method, outlined in Chapter Eight of the TDR, explains how the clearance times, used in conjunction with the dissemination times specified by officials, can provide guidance in hurricane evacuation decision-making. The time at which gale force winds arrive has been incorporated into the decision-making process of the Decision Arc Method and, therefore, does not need to be factored into the calculation of clearance time.

Evacuations for 18 combinations of storm strength, background traffic conditions, and evacuee response were simulated using the NETVAC2 computer model for both the Buzzards Bay and Cape Cod networks. The simulated evacuations were reviewed to identify locations and duration of vehicle queuing delays (congestion), as well as to determine clearance times. The results of the simulated evacuations are presented below.

5.2 RESULTS

The NETVAC2 program presents information on traffic operations throughout the course of the simulated evacuation, including reports on vehicle arrivals and departures, roadway link speeds, and the total number of vehicles on the network for each reporting interval specified by the user. The total number of vehicles on a network can be plotted versus time to display graphically how quickly vehicles evacuate the roadway network. Figures 5-1 through 5-4 are such graphs, plotted from analysis results for the Buzzards Bay and Cape Cod networks under weak and severe hurricane evacuation scenarios, respectively. A moderate behavioral response curve was assumed for all scenarios presented in these figures. In each graph, the curves depict the numbers of vehicles remaining on a network, throughout the course of the evacuation, for evacuations starting with off-peak, mid-peak, and peak background traffic conditions.

For modeling purposes, evacuations were considered complete when the evacuating vehicles reached safe destinations. One limitation when calibrating networks to traffic patterns of a normal day is that near the completion of simulations, when most of the vehicles on the network are from evacuees rather than background traffic, vehicles adhere to turning movements of a normal day instead of seeking the most logical exit nodes. The remaining percentage on the network (2 percent) accounts for this difference. It is expected that evacuees leaving homes immediately before storm arrival will seek safe destinations of the shortest travel time. Free flow conditions are verified up to one hour before model termination to ensure the last evacuees experience light traffic free from queuing.

Tables 5-1 and 5-2 present the clearance times estimated for the Buzzards Bay and Cape Cod networks for weak and severe hurricane scenarios, respectively. Times are organized by intensity of hurricane, by the rate of response of the evacuating population, and by the level of background traffic at the start of the evacuation.

The times shown in parentheses next to the Buzzards Bay clearance times are the clearance times for the East Bay/Massachusetts network that were included in the Rhode Island Hurricane Evacuation Study. Comparison of these two networks shows that most times for corresponding scenarios are within 30 minutes, all times are within 45 minutes, and the times for the Buzzards Bay network were mostly greater than or equal to the times for the East Bay/ Massachusetts network. Although the four Bristol County communities of Seekonk, Rehoboth, Swansea, and Somerset are very close to the Buzzards Bay Network, the traffic assumptions made for the Rhode Island Hurricane Evacuation Study most closely approximate the traffic conditions in these 4 communities. Therefore, the times shown for the Rhode Island Hurricane Evacuation Study will be used in those 4 communities.

The clearance times were calculated assuming that each community is capable of sheltering their individual demands. The Transportation Analysis assessed how inadequate shelter capacity might influence clearance times, through sensitivity testing discussed in Section 5.3. Results showed that deficiencies in shelter capacity have a minimal affect on clearance time. This point is explained by the fact that the number of vehicles determined to travel to public shelters is very small in comparison to all vehicles on roadways.

FIGURE 5-1:
BUZZARDS BAY NETWORK PLOTTED RESULTS
FOR MODERATE BEHAVIORAL RESPONSE (WEAK HURRICANE)

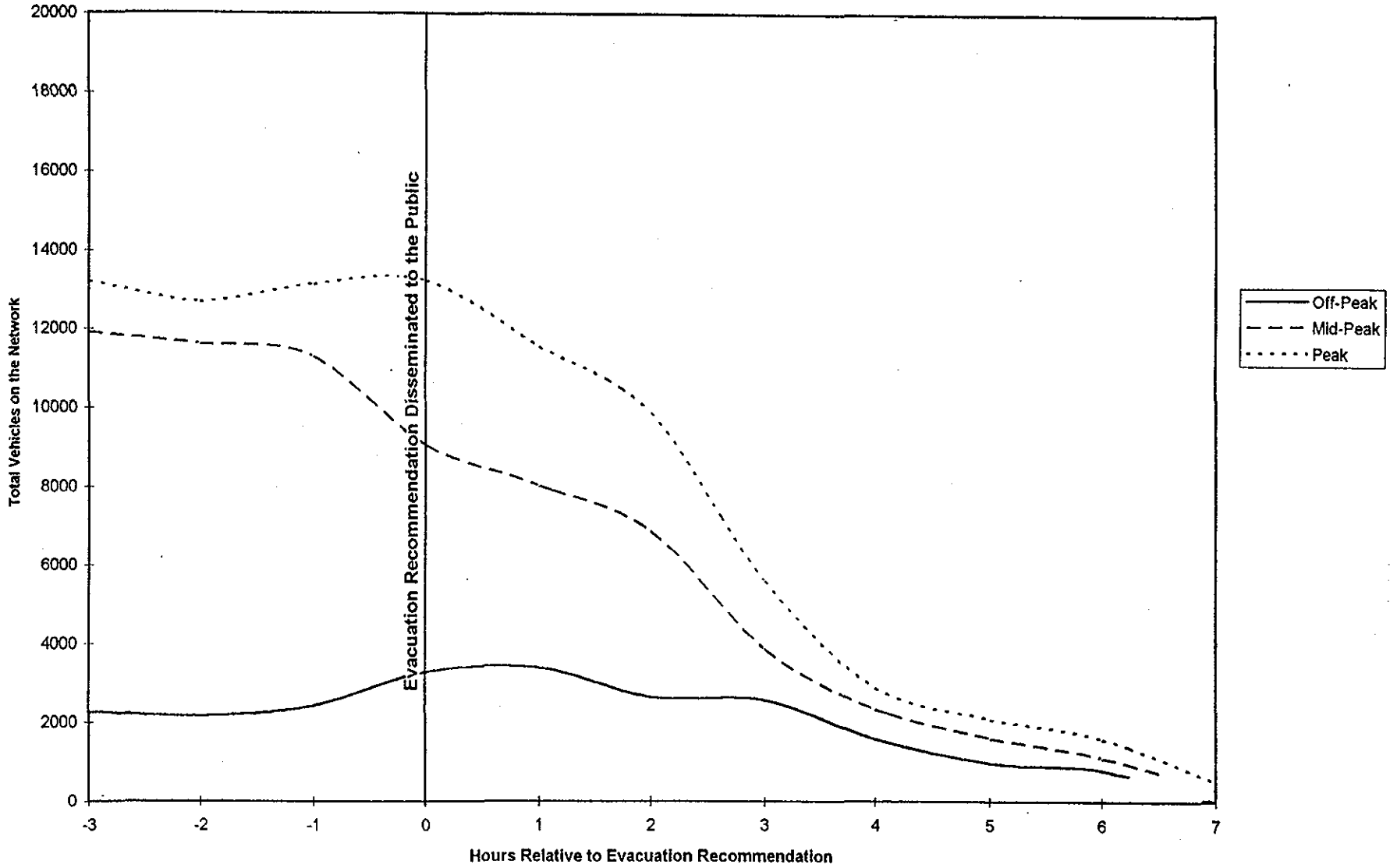


FIGURE 5-2:
BUZZARDS BAY NETWORK PLOTTED RESULTS
FOR MODERATE BEHAVIORAL RESPONSE (SEVERE HURRICANE)

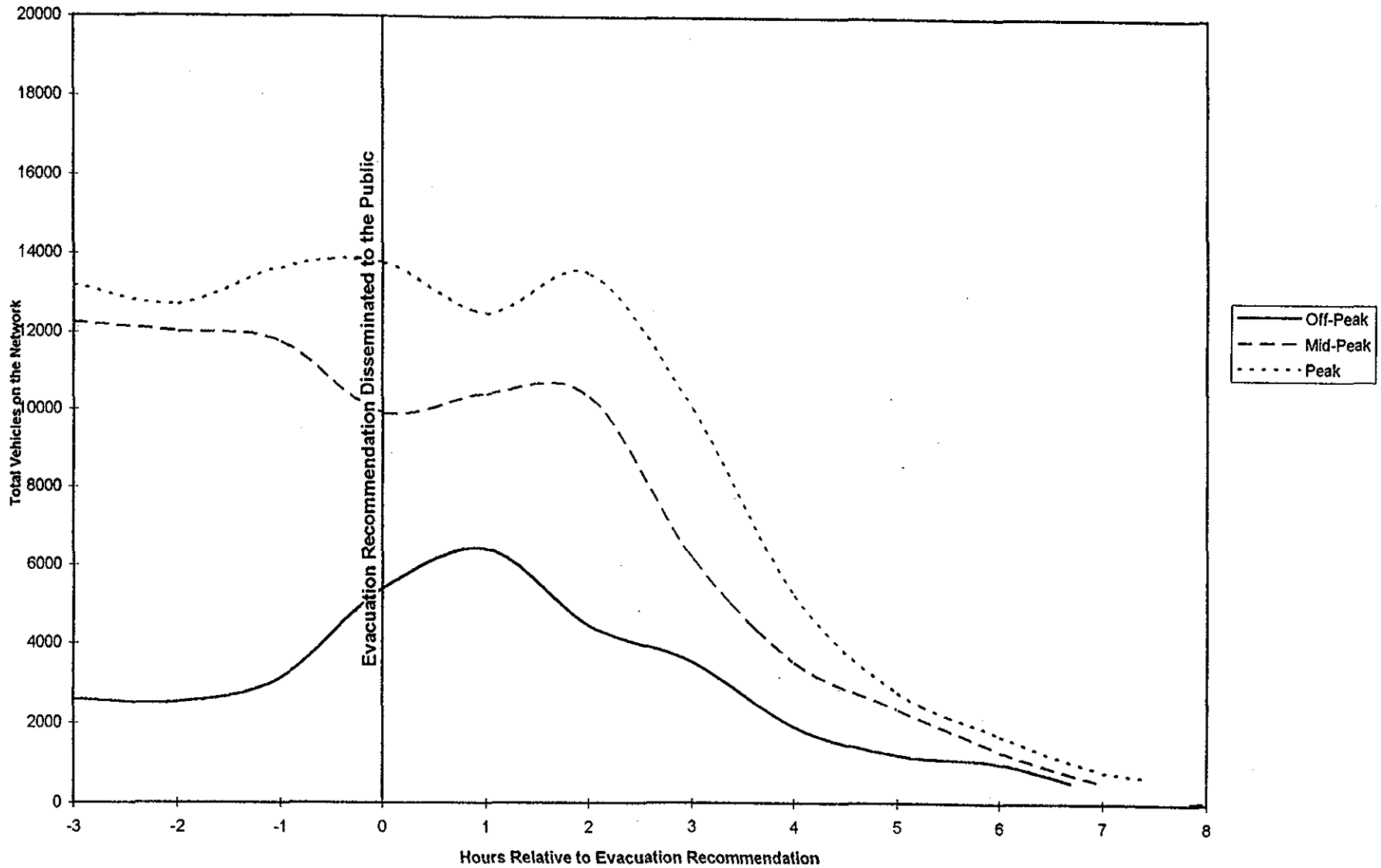


FIGURE 5-3:
CAPE COD NETWORK PLOTTED RESULTS
FOR MODERATE BEHAVIORAL RESPONSE (WEAK HURRICANE)

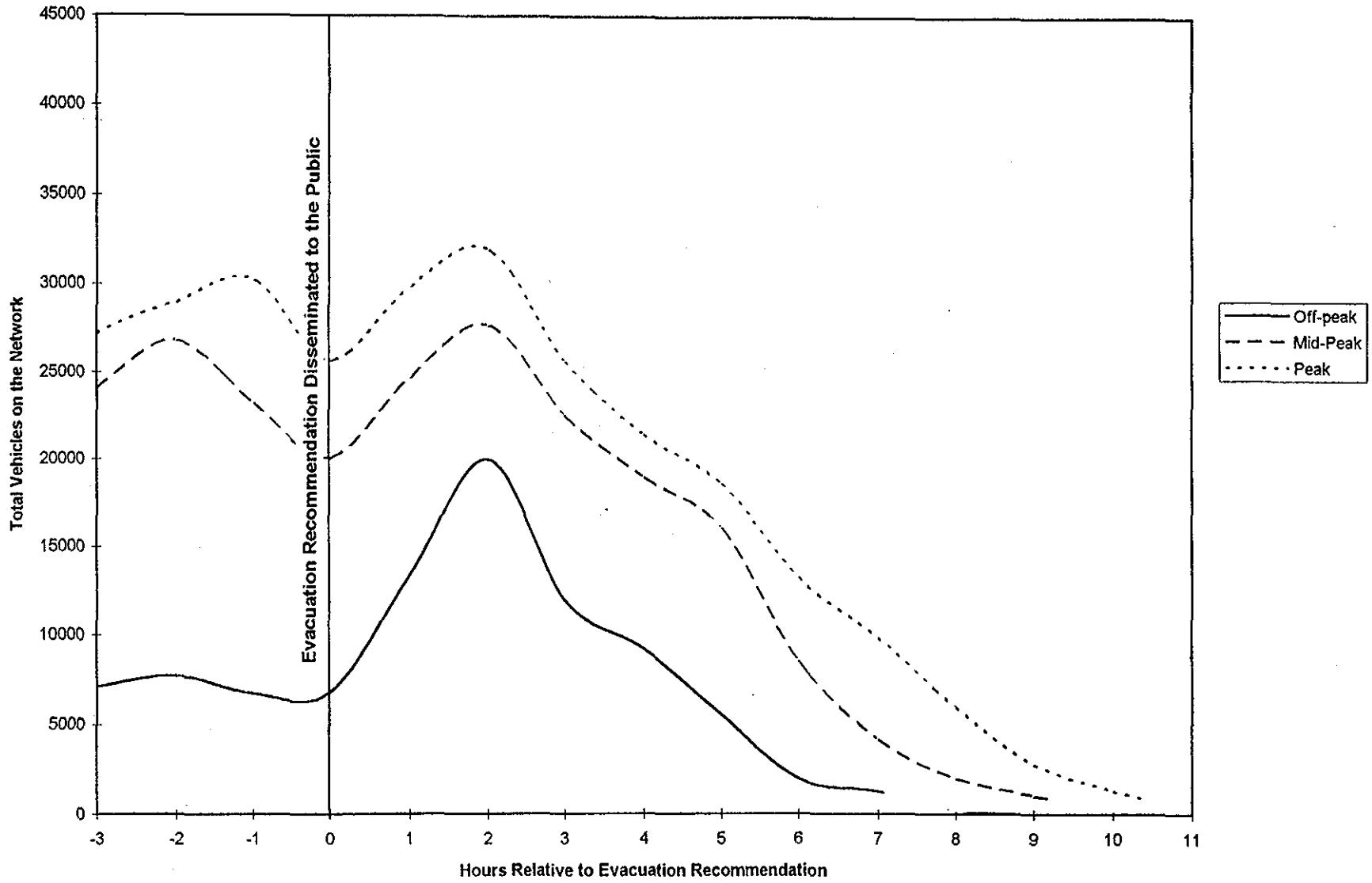


FIGURE 5-4:
CAPE COD NETWORK PLOTTED RESULTS
FOR MODERATE BEHAVIORAL RESPONSE (SEVERE HURRICANE)

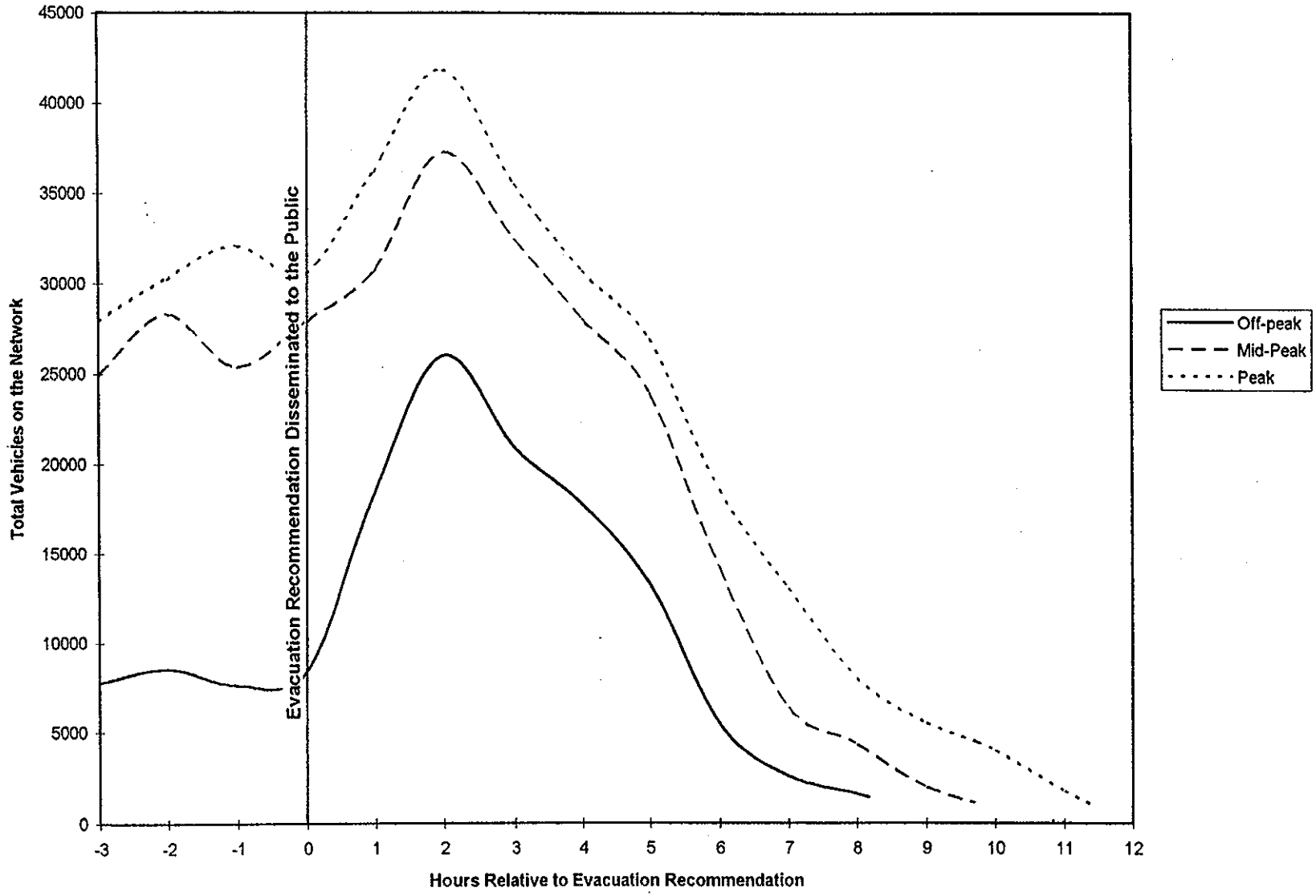


TABLE 5-1
SUMMARY OF CLEARANCE TIMES (Weak Hurricane Scenario)

	BACKGROUND TRAFFIC CONDITION		
	Off-peak	Mid-peak	Peak
BUZZARDS BAY NETWORK	Hrs:Min	Hrs:Min	Hrs:Min
Rapid Response (4 hrs.)	4:30 (4:21)	5:15 (4:24)	5:30 (4:42)
Moderate Response (6 hrs.)	6:15 (6:10)	6:30 (6:11)	7:00 (6:43)
Slow Response (8 hrs.)	8:00 (8:04)	8:30 (8:04)	8:45 (8:38)
CAPE COD NETWORK			
Rapid Response (4 hrs.)	6:15	7:30	9:15
Moderate Response (6 hrs.)	7:00	9:15	10:45
Slow Response (8 hrs.)	8:45	10:30	12:30

TABLE 5-2
SUMMARY OF CLEARANCE TIMES (Severe Hurricane Scenario)

	BACKGROUND TRAFFIC CONDITION		
	Off-peak	Mid-peak	Peak
BUZZARDS BAY NETWORK	Hrs:Min	Hrs:Min	Hrs:Min
Rapid Response (4 hrs.)	5:00 (4:35)	5:30 (4:42)	5:45 (5:33)
Moderate Response (6 hrs.)	6:45 (6:10)	7:00 (6:13)	7:30 (7:37)
Slow Response (8 hrs.)	8:15 (8:04)	8:45 (8:04)	9:00 (9:36)
CAPE COD NETWORK			
Rapid Response (4 hrs.)	8:00	8:30	10:00
Moderate Response (6 hrs.)	8:15	9:45	11:30
Slow Response (8 hrs.)	9:15	11:15	13:00

NOTE: The numbers shown in parentheses are the results reported for the East Bay/Massachusetts network of the Rhode Island Hurricane Evacuation Study. They are for reference purposes only.

Clearance times ranged from a minimum of approximately 4 hours and 30 minutes for an off-peak traffic condition under a weak hurricane scenario, to a maximum of about 13 hours for a peak traffic condition under a severe hurricane scenario. Clearance times for the Cape Cod network were longer due to congestion near the Bourne and Sagamore Bridges as well as congestion along Routes 6 and 28 along the mid-Cape.

A summary of the evacuation clearance times for the Buzzards Bay and Cape Cod networks is presented in Tables 5-1 and 5-2.

Cape Cod Network

For the Cape Cod network, clearance times range from a minimum of 6 hours 15 minutes to a maximum of about 13 hours. The evacuation clearance times for all conditions are substantially longer than the response times of 4 to 8 hours, indicating that the evacuating traffic conditions are the primary factor influencing total clearance time for all conditions. The relative significance of background traffic, evacuating traffic, and response time is explained later in this section.

Evacuation traffic conditions during the weak storm scenario for all three background traffic conditions result in slow traffic and queuing along sections of Routes 6 and 28 in Orleans, Brewster, Chatham (Route 28 only), Harwich, and Yarmouth (Route 28 only). Route 28 and its connector routes through Falmouth, Bourne, over the Bourne Bridge and into Wareham also experience low travel speeds of 15-30 mph and extended congestion. Speeds across the Bourne Bridge slow to 20-25 mph during peak traffic conditions due to traffic from Route 28. The Sagamore Bridge slows to around 35 mph during peak traffic conditions with significant congestion extending along Route 6 behind the bridge, especially in Yarmouth, Dennis, Harwich and Brewster. Speeds along Route 6A are consistently in the 25-30 mph range. Much of the observed intermittent congestion corresponds to the loading intervals for evacuating traffic, indicating that the intermittent congestion is directly related to the assumed rate at which evacuees load onto roadways. The same observations are true for the severe hurricane scenario, only the magnitude of the congestion and size of the queues in the same areas increases.

<u>Background Traffic</u>

The ratio of evacuating traffic vehicles to background traffic vehicles for the Cape Cod network is the highest of all four networks from both the Rhode Island Study and this study combined. For the off-peak background condition, there is still enough capacity on the modeled roadway system to handle the volumes with delays of 2 hours or less. However, the increased background traffic volumes experienced during mid-peak background traffic conditions combined with the relatively high ratio of evacuating traffic compared to the other three networks results in capacity constraints being exceeded, and delays of over 3 hours are experienced. The situation worsens for the peak background condition where delays of up to 5 hours are experienced. Model simulations performed during the calibration of the model show that the network can clear within about six to seven hours of the end of traffic loading, which is consistent with the methodology used in the Rhode Island Study.

Evacuating Traffic

As stated in the background traffic subsection above, the ratio of evacuating traffic vehicles to background traffic vehicles for the Cape Cod network is the highest for all four of the networks from both the Rhode Island Study and this study. For the off-peak background condition, the addition of the evacuating traffic to the background traffic results in up to two hour delays. The addition of evacuating traffic to the mid-peak and off-peak background traffic conditions causes serious capacity exceedances that extend delays up to 5 hours. This observation leads to the conclusion that the addition of evacuating traffic has a much greater influence over clearance times than does the background traffic. Comparison of the weak and strong scenario clearance times also shows increased evacuating traffic causes increased capacity exceedances and therefore influences clearance times more than background traffic conditions.

Response Time

For the Cape Cod network, clearance times exceed response times by 1.5 to 6 hours in all cases, which is much greater than for the other three networks. Since the ratio of evacuating to background traffic is so high compared to the other three networks, and the capacity of the major evacuation routes on Cape Cod cannot easily handle the background and evacuating traffic, response time does not have as much of an influence on clearance time.

In summary, evacuation clearance times for the Cape Cod network for all conditions are greatly influenced by evacuating traffic under both weak and strong hurricane scenarios. This is especially true for peak background conditions where evacuating traffic can add up to 6 hours to the clearance time.

A comparison of clearance times for the Cape Cod network shows that the difference in evacuating population between a weak and a severe storm, which increases the number of evacuating vehicles by approximately 30% would add 30 minutes to 1 hour and 45 minutes to the total clearance time. This indicates that for all conditions, the volume of evacuating traffic is a substantial component of overall clearance time.

Buzzards Bay Network

For the Buzzards Bay network, clearance times range from a minimum of 4 hours and 30 minutes, to a maximum of approximately 9 hours. The evacuation clearance times for off-peak and mid-peak conditions under the weak hurricane scenario are not much higher than the response times. This indicates that the response time is the primary factor influencing total clearance times for these conditions. The relative significance of background traffic, evacuating traffic, and response time is explained below later in this section.

Evacuation traffic for all three response scenarios result in basically free flow conditions. The exceptions are Routes 24 and 6 through Fall River, and Route 6 through New Bedford. Along these routes, the congestion corresponds to the loading intervals for evacuating traffic.

Background Traffic

The ratio of evacuating to background traffic in the Buzzards Bay network is comparable to that of the Rhode Island study networks. Also, since there is a relatively high roadway capacity in this network, background traffic clears relatively easily compared to the Cape Cod network. Only during peak conditions does capacity become exceeded enough to cause delays up to 1 hour and 45 minutes. This observation leads to the conclusion that background traffic only has an appreciable influence on clearance times only during the peak condition.

Evacuating Traffic

Since there is sufficient roadway capacity in the off-peak and mid-peak conditions to handle both background and evacuating traffic with delays of one hour or less, the volume of evacuating traffic does not have an appreciable impact on evacuation times. The network capacity is strained enough in the peak condition by the evacuating traffic to cause delays of up to 1 hour and 45 minutes, meaning the evacuating traffic volume is the main cause of delays during the peak condition scenarios. Comparison of the weak and strong scenario clearance times also shows there is sufficient roadway capacity in the off-peak and mid-peak conditions to handle both background and evacuating traffic.

The network capacity is strained during both the weak and strong scenarios, also leading to the conclusion that evacuating traffic volume is the main cause of delays during peak condition scenarios.

Response Time

The variation of clearance times once all evacuating traffic has been loaded on the network is one hour or less. This leads to the conclusion that response time is the main influence on clearance times for all background conditions for the Buzzards Bay network.

Results for the severe hurricane scenarios show greater congestion problems along routes 24 and 6 in Fall River and Route 6 in New Bedford. This intermittent congestion also corresponds to the loading intervals for evacuating traffic.

For peak conditions under the weak hurricane scenario, and all conditions under the severe hurricane scenario, vehicle congestion is expected along portions of Route 24 and Route 6 in Fall River and Route 6 in New Bedford. Congestion is also predicted along connecting routes to Routes 24 and 6 in Fall River and New Bedford.

In summary, evacuation clearance times for the Buzzards Bay network for the off-peak and mid-peak, slow response conditions under both weak and strong scenarios are mostly defined by the 8-hour response time. The remaining weak and strong storm conditions indicated that vehicle queuing and congestion have a greater impact in defining overall clearance times. Congestion and vehicle queuing predicted along two major arterials in the vicinity of Fall River and New Bedford adds up to 1 hour and 45 minutes over the response time to the rapid response scenario.

Analysis of predicted clearance times for the Buzzards Bay network shows that the difference in evacuating population between a weak and severe storm would add less than 30 minutes to the total clearance time, even through the number of evacuating vehicles approximately doubles.

5.3 SENSITIVITY ANALYSIS

5.3.1 Overview

The purpose of the sensitivity analysis was to evaluate the impact on simulated clearance times of key parameters that may vary from the 18 scenarios discussed earlier. The key parameters considered in this analysis are:

- Population - To evaluate the impact of increased levels of the evacuating population on simulated clearance times
- Response Time - To assess the sensitivity of a reduced response time for the rapid response condition
- Evacuation Shelter Use To see how a reduction in community shelter use would impact simulated clearance times. This analysis was done only for the Buzzards Bay network. Shelter use for the Cape Cod network was already considered to be low in the basic analysis since most evacuating tourists were assumed to leave the Cape rather than stay in shelters.
- Traffic Control Measures - To evaluate the possible effect of traffic control measures in the vicinity of the Bourne and Sagamore Bridges. The capacity of the bridges and their rotaries are the major factors controlling exit from Cape Cod.

The intent of the sensitivity analysis was not to assess all cases and scenarios, but to evaluate a range of conditions which would define appropriate bounds from which conclusions for all conditions could be drawn.

Simulations for these four sensitivity analysis conditions were evaluated first for the severe hurricane scenario. If appropriate, for cases where a significant impact was found, the weak hurricane scenario would be considered. To limit the number of simulations, only scenarios that could be considered as defining the "upper" and "lower" bounds of clearance time were considered. From the base condition results, these scenarios were determined to be rapid and slow evacuee conditions during off-peak and peak background scenarios.

5.3.2 Sensitivity to Population Increases

The effect of population increases of up to 20% on clearance times were evaluated for the conditions outlined above. The simulated results for the cases analyzed are presented in Tables 5-3 and 5-4.

TABLE 5-3:

SUMMARY OF CLEARANCE TIME SENSITIVITY TO A 20% INCREASE IN EVACUATING TRAFFIC (SEVERE HURRICANE SCENARIO)

	BACKGROUND TRAFFIC CONDITION					
	Off-peak		Mid-peak		Peak	
BUZZARDS BAY NETWORK	B.C.*	S.A.**	B.C.*	S.A.**	B.C.*	S.A.**
Rapid Response	5:00	6:00	5:30	***	5:45	6:15
Moderate Response	6:45	***	7:00	***	7:30	***
Slow Response	8:15	8:30	8:45	***	9:00	9:30
CAPE COD NETWORK						
Rapid Response	8:00	9:15	8:30	***	10:00	11:00
Moderate Response	8:15	***	9:45	***	11:30	***
Slow Response	9:15	10:15	11:15	***	13:00	13:30

TABLE 5-4

SUMMARY OF CLEARANCE TIME SENSITIVITY TO A 20% INCREASE IN EVACUATING TRAFFIC (WEAK HURRICANE SCENARIO)

	BACKGROUND TRAFFIC CONDITION					
	Off-peak		Mid-peak		Peak	
BUZZARDS BAY NETWORK	B.C.*	S.A.**	B.C.*	S.A.**	B.C.*	S.A.**
Rapid Response	4:30	5:15	5:15	***	5:30	5:45
Moderate Response	6:15	***	6:30	***	7:00	***
Slow Response	8:00	8:15	8:30	***	8:45	9:00
CAPE COD NETWORK						
Rapid Response	6:15	7:00	7:30	***	9:15	10:00
Moderate Response	7:00	***	9:15	***	10:30	***
Slow Response	8:15	9:30	10:30	***	12:30	12:45

* B.C. = Base Condition

** S.A. = Sensitivity Analysis

*** = Scenario was not simulated

The results indicate that, for the severe hurricane scenario, several analysis conditions are sensitive to population increases of this magnitude. The most significant increases would be associated with the off-peak, rapid response conditions (up to 1 hour for the Buzzards Bay network, and up to 1 hour and 15 minutes for the Cape Cod network). For the off-peak slow response scenario, the 20% increase in population for the severe hurricane scenario had up to 30 minutes increase for the Buzzards Bay network, and up to 1 hour for the Cape Cod network. For the weak hurricane scenario a 20% increase in evacuating population had up to a 45 minute increase for both the Buzzards Bay and Cape Cod networks.

In summary, an increase of total evacuating population of 20% for the severe hurricane scenario is expected to increase clearance times 15 minutes to 1 hour for the Buzzards Bay network and 15 minutes to 1 hour and 15 minutes for the Cape Cod network. For the weak hurricane scenario, a 20% increase in evacuating population results in up to a 45 minute increase in evacuation times. A 10% increase in evacuating population is expected to increase clearance times a maximum of 1 hour.

5.3.3 Sensitivity to Shorter Rapid Response Time

A shorter rapid response time was evaluated to determine how sensitive the assumptions on rapid response were to clearance times. A 2-hour decrease in rapid response time (or a total response time of 2 hours) was used for the sensitivity analysis, for the severe hurricane scenario. The results of the sensitivity analysis simulations are presented in Table 5-5.

The results indicate that, under the severe hurricane scenario, for both the Buzzards Bay and Cape Cod network, reduced rapid response assumptions have little effect on overall clearance times. For both off-peak and peak conditions, the shorter response times produced results within approximately 30 minutes of the base condition results. This shows that when the response time is decreased, the roadway network and capacity constraints become more of a constraining factor influencing total clearance time.

It can be concluded that for the Buzzards Bay and Cape Cod networks, a reduction in the assumed rapid response time will have little effect on the overall clearance times.

5.3.4 Sensitivity to a Reduction in Community Shelter Use

An analysis was also performed to determine if the assumption on the number of persons expected to use community shelters could have an appreciable effect on the clearance times. Specifically, the intent was to determine if the additional traffic on the evacuating roadways would have a significant effect on the clearance times if less evacuees used the shelters than predicted.

As stated earlier, this analysis was done only for the Buzzards Bay network since it was assumed in the base condition that the population evacuating to community shelters on Cape Cod would be small in comparison to the population evacuating off Cape.

The analysis was conducted assuming that only 75% of the evacuees assumed to use shelters under the base condition would actually use the shelters. The results, presented in Table 5-6, indicate that the

TABLE 5-5:

SUMMARY OF CLEARANCE TIME SENSITIVITY TO A 2-HOUR DECREASE IN RAPID RESPONSE TIME (SEVERE HURRICANE SCENARIO)

	BACKGROUND TRAFFIC CONDITION					
	Off-peak		Mid-peak		Peak	
BUZZARDS BAY NETWORK	B.C.*	S.A.**	B.C.*	S.A.**	B.C.*	S.A.**
Rapid Response	5:00	5:00	5:30	***	5:45	6:00
CAPE COD NETWORK						
Rapid Response	8:00	8:30	8:30	***	10:00	10.30

TABLE 5-6:

SUMMARY OF CLEARANCE TIME SENSITIVITY TO A 25% REDUCTION IN COMMUNITY SHELTER USE (SEVERE HURRICANE SCENARIO)

	BACKGROUND TRAFFIC CONDITION					
	Off-peak		Mid-peak		Peak	
BUZZARDS BAY NETWORK	B.C.*	S.A.**	B.C.*	S.A.**	B.C.*	S.A.**
Rapid Response	5:00	5:30	5:30	6:00	5:45	6:15
Moderate Response	6:45	***	7:00	***	7:30	***
Slow Response	8:15	8:45	8:45	9:15	9:00	9:30
CAPE COD NETWORK (Analysis not done)						

* B.C. = Base Condition

** S.A. = Sensitivity Analysis

*** = Scenario was not simulated

impact would be less than 30 minutes for all scenarios. Accordingly, it can be concluded that for most conditions under the severe hurricane scenario, the impact of a 25% reduction in community shelter use will not have an appreciable impact on clearance times.

It can also be concluded that for the weak hurricane scenario conditions, a reduction in community shelter use would generally have a smaller impact on clearance times than for the strong storm scenarios.

5.3.5 Sensitivity to Traffic Controls over the Bourne and Sagamore Bridges

Analysis of the clearance times for the 18 conditions modeled for the Cape Cod network showed that the capacity of the Bourne and Sagamore Bridges and their rotaries greatly influence clearance times from the Cape. Consideration was given to modeling the Bourne and Sagamore Bridges with three lanes off Cape and one lane onto the Cape. However, this would not address bottlenecking at the rotaries, and does not allow for the limiting of available routes to those which allow the most efficient flow of traffic.

Through coordination with the Massachusetts Emergency Management Agency and the Massachusetts State Police, it was determined that traffic flow could be improved at the rotaries by limiting turning movements. This will increase through-capacity and traffic speeds since competition will be reduced.

The sensitivity analysis assumes the following:

- At the Bourne Bridge rotary, traffic from Routes 6 and 28 would be allowed to proceed north across the Bourne Bridge, but traffic from Trowbridge Road would be routed south on Route 28 and would turn north onto Route 28 at the Bourne landfill turn-off. Emergency vehicles would be allowed to travel in any direction. It is assumed that State Police would be stationed at the rotary, on Route 28 at the landfill turn-off, and at other locations as needed to facilitate traffic flow.

- At the Sagamore Bridge rotary, traffic from the bridge and Meetinghouse Road would be allowed to proceed around the rotary and onto Route 3 North. Traffic entering the rotary from the Bourne Scenic Highway would be required to exit the rotary at the first turn which would put them south-bound across the Sagamore Bridge. Emergency vehicles would be allowed to travel in any direction. It is assumed that State Police would be stationed at the rotary and at other locations as needed to facilitate traffic flow.

The results indicate that network clearance time can be significantly reduced by enacting the traffic flow options above (See Table 5-7 and 5-8). For the peak, slow response conditions under the severe hurricane scenario, clearance time was reduced by 1 hour 30 minutes. The reduction in clearance time for the off-peak, rapid response scenario was 30 minutes, still significant enough to consider implementing the recommended traffic controls near the Bourne and Sagamore Bridges. For the weak hurricane scenarios, the reduction in clearance times were also significant but not as large (30 minutes for rapid response, off-peak conditions and 1 hour and 15 minutes for the slow response, peak condition).

TABLE 5-7:

SUMMARY OF CLEARANCE TIME SENSITIVITY TO TRAFFIC CONTROLS AT SAGAMORE AND BOURNE BRIDGE ROTARIES (SEVERE HURRICANE SCENARIOS)

	BACKGROUND TRAFFIC CONDITION					
	Off-peak		Mid-peak		Peak	
BUZZARDS BAY NETWORK (Analysis not done)	B.C.*	S.A.**	B.C.*		B.C.*	S.A.**
CAPE COD NETWORK						
Rapid Response	8:00	7:30	8:30	***	10:00	***
Moderate Response	8:15	***	9:45	***	11:30	***
Slow Response	9:15	***	11:15	***	13:00	11.30

TABLE 5-8:

SUMMARY OF CLEARANCE TIME SENSITIVITY TO TRAFFIC CONTROLS AT SAGAMORE AND BOURNE BRIDGE ROTARIES (WEAK HURRICANE SCENARIOS)

	BACKGROUND TRAFFIC CONDITION					
	Off-peak		Mid-peak		Peak	
BUZZARDS BAY NETWORK (Analysis not done)	B.C.*	S.A.**	B.C.*		B.C.*	S.A.**
CAPE COD NETWORK						
Rapid Response	6:15	5:45	7:30	***	9:15	***
Moderate Response	7:00	***	9:15	***	10:30	***
Slow Response	8:45	***	10:30	***	12:30	11:15

* B.C. = Base Condition
** S.A. = Sensitivity Analysis
*** = Scenario was not simulated

SECTION SIX

SUMMARY

The Southern Massachusetts Transportation Analysis is one element of a more comprehensive study entitled the Southern Massachusetts Hurricane Evacuation Study. Two major considerations in hurricane evacuation planning are: 1) how much time it will take to notify people that they must leave their homes after authorities have determined an evacuation is necessary (dissemination time), and 2) how much time it will take for people who evacuate their homes to travel roadways and reach safe destinations (clearance time). Evacuation time is defined as the combination of these two times. The overall objective of the Transportation Analysis is to develop estimates of clearance times under a variety of hurricane evacuation scenarios for Southern Massachusetts. Clearance times and the results from other technical analyses are compiled in the Technical Data Report of the Southern Massachusetts Hurricane Evacuation Study offering State and local officials state-of-the-art information from which hurricane preparedness plans can be updated.

An evacuation simulation computer model entitled NETVAC2 was used to create a mathematical representation of the road system in Bristol, Plymouth, and Barnstable Counties, Massachusetts. The model was calibrated to the traffic patterns of a normal day (a day for which no hurricanes are forecasted) using traffic and roadway data obtained from the Massachusetts Highway Department, the Cape Cod Commission, and Rhode Island Department of Transportation. Estimates of and the numbers of seasonal and permanent residents that would evacuate prior to future hurricanes were made using estimates of the total vulnerable population and application of human behavioral characteristics assumed for the study area. During evacuation simulations, evacuating vehicles were programmed to enter roadways at prescribed loading rates and compete for roadway and intersection capacities with other vehicles of different trip purposes.

Evacuation scenarios, idealizing some of the possible situations officials may be faced with while contending with the decision to issue an evacuation, were outlined. Key parameters of evacuation scenarios include the intensity or severity of the hurricane, the behavioral response of evacuees to mobilize and leave their homes, and the time of day an evacuation takes place. Because the study area supports an industrial, commercial and service base (especially on Cape Cod) employing and serving many people in and near inundation areas, evacuations are complicated by the presence of commuter traffic which varies at different times of the day. A total of 18 different scenarios formulated from combinations of key parameters were analyzed using the NETVAC2 model.

Buzzards Bay Network

For the Buzzards Bay network, results showed that in situations where people left their homes over a moderate to long period of time (within 6 to 8 hours after being told to do so by authorities), the density and capacity of the roadway system are such that evacuating traffic clears the network in up to 1 hour 30 minutes beyond the response times. For the rapid response condition (where people leave their homes within 4 hours of being told to do so by authorities) during peak background traffic, vehicle queuing and congestion can add up to 1 hour and 45 minutes to the clearance time.

For off-peak conditions under both weak and severe hurricane scenarios, simulated traffic conditions are mostly free flow with no long-term congestion throughout the network. However, clearance times for all of the mid-peak and peak conditions reflect greater congestion and lower travel speeds on major routes and connecting routes in Fall River and New Bedford. The lowest clearance time calculated was approximately 4 hours and 30 minutes for the weak hurricane scenario assuming rapid response and off-peak background traffic in the Buzzards Bay network.

Cape Cod Network

For the Cape Cod network, results showed that in situations where people left their homes over moderate to long periods of time, the density and capacity of the roadway system (especially at the Bourne and Sagamore Bridges) are such that evacuating traffic clears the network in up to 5 hours beyond the response times. For the rapid response condition, during peak background traffic, vehicle queuing and congestion (especially near the Bourne Bridge) can add up to 2 hours to the clearance times.

For all background conditions under both weak and severe hurricane scenarios, simulated traffic conditions show significant congestion in the mid-Cape area, and in the vicinity of the Bourne and Sagamore Bridges). The extent of the congestion increases from off-peak to mid-peak to peak background traffic conditions. The congestion near the Bourne and Sagamore Bridges is worse during peak background conditions, while the congestion on the mid-Cape is nearly constant under all background conditions. The highest clearance time of about 13 hours was calculated for the Cape Cod network, for the severe hurricane scenario assuming slow evacuee response during peak background traffic conditions.

Sensitivity Analysis

A sensitivity analysis was performed to evaluate the impact of key assumptions and parameters to evacuation clearance times. This analysis indicated the following:

- An increase of total evacuating population of 20% for the severe hurricane scenario would add up to about 1 hour 30 minutes to the clearance times for the Buzzards Bay network and up to 1 hour to the clearance times for the Cape Cod network.

- Reduced rapid response time will result in a small increase in clearance times for the Buzzards Bay network and about a 30 minute increase in clearance time on the Cape Cod network. This shows that the roadway network and capacity constraints become more of a constraining factor influencing the total clearance time as response time is decreased.

- For the Buzzards Bay network, a reduction in the assumed use of community shelters will generally have little effect on clearance times for most conditions. The increase in clearance times for the conditions analyzed is about 30 minutes.

- For the Cape Cod network, implementation of traffic controls at the Bourne and Sagamore Bridge rotaries is estimated to reduce network clearance times by 1 hour 30

minutes for the severe hurricane scenario, slow response condition, and about 30 minutes for the off-peak, rapid response condition.

As stated before, the clearance times calculated in the analysis comprise only a portion of total evacuation times. An additional time component is required for officials to effectively disseminate evacuation recommendations to the public. Dissemination time may differ by region depending on communication and warning procedures utilized by State and local officials in a particular area, and can best be estimated by the responsible state and local officials. Failure to add this component to clearance times will underestimate evacuation times which could result in insufficient time for all evacuees to safely clear the hazard area. Evacuation times can be determined by adding an appropriate amount of time for dissemination to the clearance times estimated for Southern Massachusetts in this analysis. This topic is discussed more fully in Chapter Seven of the Technical Data Report, Evacuation Times.

REFERENCES

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5. Cape Cod Commission Transportation Staff, Cape Cod Traffic Counting Report, 1994; 1995.

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8. US Department of Commerce, Bureau of the Census, 1990 Census of Population and Housing Summary Tape Files; 1990.

ANNEX A:
BUZZARDS BAY NETWORK COMPUTER INPUT FILES

001	100	4250	36	12	6	3	1	8	4	50	100	101	102		
003	004	1000	12	12	6	1	1	1	4	25	10	465			
003	005	1000	36	12	6	3	1	8	4	50	90	006			
004	005	9000	36	12	6	3	1	8	4	50	50	006			
004	465	1000	11	11	4	1	1	7	2	45	50	464			
005	006	2100	36	12	6	3	1	1	4	50	100	007			
006	007	2100	36	12	6	3	1	1	4	50	90	008			
006	431	1000	11	11	2	1	1	1	2	25	20	477			
007	008	5100	36	12	6	3	1	8	2	55	70	009			
008	00911400		36	12	6	3	1	8	2	55	100	010			
009	01014250		36	12	6	3	1	8	2	55	45	011			
010	011	7500	36	12	6	3	1	8	2	55	50	012	344		
011	344	1000	12	12	6	1	1	1	2	40	05	355			
012	013	4500	36	12	6	3	1	8	2	55	100	014	340		
013	014	1000	36	12	6	3	1	8	2	55	100	810			
014	810	5000	36	12	6	3	1	8	2	55	100				
024	107	2000	11	11	4	1	1	4	2	40	100		106	121	
025	119	2000	11	11	4	1	1	4	2	40	100		117	120	
026	120	2000	11	11	4	1	1	4	2	40	100		119	469	
027	31710000		24	12	6	2	1	8	4	55	100	319	316		
028	35850000		36	12	6	3	1	8	2	55	100	341	340		
029	13810000		24	12	6	2	1	8	2	55	100	135	134		
030	133	5280	11	11	4	1	1	4	2	40	100	140	132		
031	14410000		36	12	6	3	1	8	2	55	100	145	140		
033	14120000		11	11	4	1	1	4	2	40	100	140	143		
035	363	9300	24	12	6	2	1	8	4	55	40	365			
035	80536750		24	12	6	2	1	8	4	35	45				
035	809	1000	11	11	2	1	1	1	1	25	15				
036	329	7800	11	11	4	1	1	7	2	45	50	330			
036	35310000		11	11	4	1	1	4	2	40	50	354	342		
074	03536750		24	12	6	2	1	8	4	55	100	363	809		
075	118	2000	11	11	4	1	1	4	2	40	100		121	117	
081	327	6000	12	12	4	1	1	5	4	40	100	320			
082	413	3000	22	11	2	2	1	6	2	30	100	395			
083	385	3000	22	11	6	2	1	6	2	40	100	395			
084	452	3000	22	11	2	2	1	6	2	30	100	499			
085	396	5000	36	12	6	3	1	8	2	55	100	417			
086	32218000		10	10	4	1	1	5	4	40	100	321			
087	38621000		11	11	4	1	1	7	2	35	100	388			
094	314	3000	11	11	4	1	1	5	4	35	100	380			
095	484	3000	11	11	4	1	1	5	4	35	100	482			
096	431	3000	24	12	6	2	1	8	2	55	100	477			
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100	102	1000	11	11	2	1	1	1	4	25	10		127	105	
101	11121150		36	12	6	3	1	8	4	55	100	112	113		
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102	105	1000	11	11	4	1	1	7	2	50	50	106			
102	12712900		11	11	4	1	1	7	2	50	50	128		113	
103	104	1000	36	12	6	3	1	8	4	55	90	801			
103	105	1000	11	11	2	1	1	1	4	25	10		106	102	
104	801	4200	36	12	6	3	1	8	4	55	100				
105	102	1000	11	11	4	1	1	7	2	50	25	127			
105	104	1000	11	11	2	1	1	1	4	25	50	801			
105	106	2600	11	11	4	1	1	7	2	50	25		107	108	
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106	107	6300	22	11	4	2	1	7	2	50	30	121			
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113	12725600		11	11	4	1	1	7	2	40	35		102	128	
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115	10321150		36	12	6	3	1	8	4	55	100	104	105		
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116	115	1000	11	11	2	1	1	1	4	25	40	103			
116	117	3700	11	11	4	1	1	7	2	40	30	803	119	118	

117	116	3700	11	11	4	1	1	7	2	40	30	113	115		
117	11810600		22	11	4	2	1	7	2	50	30	121			
117	119	2100	22	11	4	2	1	7	2	50	20	120			
117	803	1000	11	11	2	1	1	5	2	25	20				
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118	121	2000	22	11	4	2	1	7	2	50	50	107		804	
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120	46914800		22	11	4	2	1	7	4	35	50	464			
121	107	5000	22	11	4	2	1	7	2	50	50	106			
121	118	5000	22	11	4	2	1	7	2	50	50	117			
121	804	1000	11	11	2	1	1	1	4	25	50				
122	454	1000	22	11	4	2	1	7	4	50	100	480			
123	006	5808	36	12	6	3	1	8	4	55	90	007	431		
123	122	1000	11	11	2	1	1	1	4	25	10	454			
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124	454	1000	11	11	2	1	1	1	4	25	5	480			
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130	12921000		11	11	4	1	1	4	2	40	40	457		128	
130	13121150		11	11	4	1	1	4	2	40	40	132		474	
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310	31111400		11	11	4	1	1	5	4	35	100	312	845		
311	312	9000	11	11	4	1	1	5	4	35	80	313			
311	845	3900	11	11	4	1	1	5	4	25	20				
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312	31315750		11	11	4	1	1	5	4	35	60	314			
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313	31416500		11	11	4	1	1	5	4	35	50	315	380		
314	31316500		11	11	4	1	1	5	4	35	30	312			
314	315	9000	11	11	4	1	1	5	4	35	40	316			
314	38012750		11	11	4	1	1	5	4	35	30	321		813	

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315 314 9000 11 11  4 1 1 5 4 35    50 313            380
315 316 1200 11 11  4 1 1 5 4 35    50 318      319
316 315 1200 11 11  4 1 1 5 4 35    40 314
316 318 1000 11 11  2 1 1 5 4 35    30 324
316 319 1000 11 11  2 1 1 1 4 25    30          328
317 316 1000 11 11  2 1 1 1 4 25    10          315
317 319 1000 24 12  6 2 1 8 2 55    60 328
317 808 4800 24 12  6 2 1 8 4 55    30
318 316 1000 11 11  4 1 1 5 4 35    40 315      319
318 317 1000 11 11  4 1 1 1 2 30    10 808
318 32410500 11 11  4 1 1 5 2 40    50 330            811
319 317 1000 24 12  6 2 1 8 2 55    45 808
319 318 1000 11 11  2 1 1 1 4 25    10          324
319 32815750 24 12  6 2 1 8 2 55    45 326
320 32112600 12 12  4 1 1 5 4 40    40 322      380   482
320 327 2400 12 12  4 1 1 5 4 40    40          326
320 812 1000 11 11  2 1 1 5 4 25     5
321 32012600 12 12  4 1 1 5 4 40    10 327      812
321 32233000 11 11  4 1 1 5 4 35    10                890
321 380 1000 12 12  4 1 1 5 4 40    40 314      813
321 48218000 11 11  4 1 1 5 4 35    40 484      483
322 32133000 11 11  4 1 1 5 4 35    80 320      482   380
322 890 1000 11 11  2 1 1 5 4 25    20
323 32218000 10 10  4 1 1 5 4 40   100 321
324 31810500 11 11  4 1 1 5 2 40    30 316      317
324 330 9900 11 11  3 1 1 5 2 40    50 329
324 811 1000 11 11  2 1 1 5 4 25    20
326 328 2700 24 12  6 2 1 8 2 55    20 319
326 340 6900 24 12  6 2 1 8 2 55    80        341
327 320 2400 12 12  4 1 1 5 4 40    50 321
327 326 2100 11 11  2 1 1 1 2 25    50 340
328 31915750 24 12  6 2 1 8 2 55    50 317      318
328 326 3000 24 12  6 2 1 8 2 55    50 340
329 330 3000 11 11  4 1 1 7 2 45    10 324
329 825 8100 11 11  4 1 1 7 2 45   100
330 324 9900 11 11  4 1 1 7 2 45    10 318      811
330 329 3000 11 11  4 1 1 7 2 45    90 825
340 326 6750 24 12  6 2 1 8 2 55    20 328
340 341 1000 11 11  2 1 1 1 2 25    40 346
341 346 4500 36 12  6 3 1 8 2 55   100 347      344
342 343 1500 24 12  6 2 1 8 2 55    40 377
342 344 1000 11 11  2 1 1 1 4 25    30 355
342 35312000 11 11  4 1 1 4 2 40    30          354   825
343 342 1500 22 11  4 2 1 8 2 55    30 353
343 344 1000 11 11  2 1 1 1 2 25    40 355
343 377 7500 24 12  6 2 1 8 2 55    30 378      376
344 012 1000 12 12  6 1 1 8 2 40    40 013
344 347 1000 24 12  6 2 1 8 2 55    40 370
344 35512000 24 12  6 2 1 8 2 55    20 357
346 347 1000 36 12  6 3 1 8 2 55    50 370
347 370 7500 36 12  6 3 1 8 2 55    40 375      891
350 351 2100 24 12  6 2 1 7 2 45    50 329            352
351 329 5000 11 11  4 1 1 7 2 45    30 330
351 352 5000 24 12  6 2 1 7 2 45    90 353
352 353 5000 24 12  6 2 1 7 2 45   100 354
353 34212000 11 11  4 1 1 4 2 40    30 343
353 354 1000 24 12  6 2 1 7 2 35    40 357
353 82510000 11 11  4 1 1 4 2 40    40
354 353 3750 12 12  6 1 1 7 2 35    10 825
354 355 1000 12 12  6 1 1 4 2 40    40 344
354 357 4000 12 12  2 1 1 1 4 40    50 359
355 34412000 24 12  6 2 1 8 2 55   100 347      012
355 357 3000 24 12  6 2 1 8 4 55    90 359
357 354 4000 11 11  2 1 1 1 4 25    50 353
357 355 3000 24 12  6 2 1 8 4 55    50 344
357 35910500 24 12  6 2 1 8 2 55   100 365
358 340 1000 11 11  2 1 1 1 2 25    05 326
358 341 1000 36 12  6 3 1 8 2 55    45 346
359 35711500 24 12  6 2 1 8 2 55    40 355      354
359 365 2250 24 12  6 2 1 8 2 55    60 363
362 363 1000 11 11  2 1 1 1 4 25   100                035
363 035 9300 24 12  6 2 1 8 4 55    40 805      809
363 365 1000 11 11  2 1 1 1 4 25    40 359
365 359 2250 24 12  6 2 1 8 2 55    20 357
365 363 1000 11 11  2 1 1 1 4 25    80 035
```

366	362	9750	11	11	2	1	1	5	2	25	100		363	
367	36510500		24	12	6	2	1	8	2	55	50	363		
367	366	1000	11	12	2	1	1	5	2	25	50	362		
370	374	1000	11	11	2	1	1	1	4	25	27	379		
370	375	6000	36	12	6	3	1	8	2	55	80	398		
370	891	1000	24	12	6	2	1	8	2	55	30			
374	010	7200	24	12	6	2	1	8	4	55	35	011		
374	375	1000	11	11	2	1	1	1	4	25	35		398	
374	379	3000	22	11	2	2	1	1	4	40	40	376	377	
375	39814250		36	12	6	3	1	8	2	55	40	396	892	
376	378	1000	11	11	2	1	1	1	4	25	40		385	
376	379	2700	11	11	4	1	1	7	4	45	40	374		
376	48511000		11	11	4	1	1	7	2	35	30	483	482	
377	343	9000	22	11	4	2	1	8	3	55	40	342	344	
377	376	1000	11	11	4	1	1	1	3	25	20	485		
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378	377	1000	22	11	4	2	1	8	4	55	45	343		
378	379	1000	11	11	2	1	1	1	4	25	100	374		
378	38515750		22	11	6	2	1	7	2	40	20	395		
379	374	3000	22	11	2	2	1	1	4	40	40	010	375	
379	376	2700	11	11	4	1	1	7	4	45	60	485	378	
379	377	1000	11	11	2	1	1	1	4	25	10	343		
380	31412750		11	11	4	1	1	5	4	35	40		315	313
380	321	2250	11	11	4	1	1	5	4	35	40	482	322	320
380	813	1000	11	11	2	1	1	5	4	25	20			
385	37815750		22	12	4	2	1	6	4	55	45	377	379	
385	395	2250	22	11	6	2	1	7	2	40	45	413		399
385	484	9000	11	11	2	1	1	5	4	35	8	482	485	
386	38810800		11	11	4	1	1	7	2	35	100	483		814
386	890	1000	11	11	2	1	1	5	4	25	20			
387	38621000		11	11	4	1	1	7	2	35	100	388		
388	38610800		11	11	4	1	1	7	2	35	40		890	
388	48312000		11	11	4	1	1	7	2	35	40	485	484	
388	814	1000	11	11	2	1	1	1	4	25	5			
389	390	1000	11	11	4	1	1	7	4	35	10			391
389	394	3900	11	11	4	1	1	7	4	35	90		395	
390	389	1000	11	11	4	1	1	7	4	35	90			394
390	391	9300	11	11	4	1	1	7	4	35	10		400	
391	390	9300	11	11	4	1	1	7	4	35	80		389	
391	400	6750	11	11	4	1	1	7	4	35	20			815
392	40025800		11	11	4	1	1	7	4	35	100	391	815	
393	392	9600	11	11	4	1	1	7	4	35	100			400
394	395	3000	11	11	4	1	1	7	4	35	100	399	413	385
395	385	2250	22	11	6	2	1	7	2	40	45	378		484
395	399	6000	12	12	6	1	1	5	2	45	10	009	396	
395	41314400		22	11	6	2	1	7	2	40	50	420	411	416
396	41711400		36	12	6	3	1	8	2	55	30	415		
398	396	2400	36	12	6	3	1	8	4	55	45	417		
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398	892	1000	24	12	6	2	1	8	2	55	34			
399	009	1000	11	11	2	1	1	1	4	25	40	010		
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400	815	1000	11	11	2	1	1	5	4	25	20			
410	41218000		11	11	4	1	1	7	4	35	100	411		816
411	412	1500	11	11	4	1	1	7	4	35	20		816	
411	41321000		11	11	4	1	1	7	4	35	80	416	420	395
412	411	1500	11	11	4	1	1	7	4	35	80			413
412	816	1000	11	11	2	1	1	5	4	25	29			
413	39514400		22	11	6	2	1	7	2	40	40	385	399	
413	41121000		11	11	2	1	1	7	4	35	10		412	
413	416	5250	12	12	6	1	1	5	2	45	5		415	
413	420	1000	22	11	6	2	1	7	2	40	45	428	418	
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418	817	1000	11	11	2	1	1	1	4	25	20			
419	428	3300	10	10	4	1	1	4	2	30	80		429	420
419	818	1000	11	11	2	1	1	1	4	25	20			
420	413	1000	22	11	6	2	1	7	2	35	40	395	416	
420	418	7500	11	11	4	1	1	7	4	35	5			817
420	428	3300	22	11	6	2	1	7	2	35	40	429		

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421	423	6000	11	11	4	1	1	7	4	35	100		447		
422	421	7200	11	11	4	1	1	7	4	35	100			423	
423	447	6900	11	11	4	1	1	7	4	35	100	425			
424	426	4500	10	10	4	1	1	4	2	30	100	427			
425	418	7800	11	11	4	1	1	7	4	35	100	420	817		
426	427	4500	10	10	4	1	1	4	2	30	100		491	419	
427	419	6000	10	10	4	1	1	4	2	30	75	428		818	
427	491	1500	10	10	4	1	1	4	2	30	25	490			
428	420	3300	22	11	2	2	1	7	4	35	50	413	899		
428	429	1000	22	11	2	2	1	7	4	35	50	452			
429	428	1000	22	11	2	2	1	7	2	30	45	420			
429	433	2700	24	12	4	2	1	8	2	55	10	431	432		
429	452	7200	24	12	6	2	1	7	2	35	45	499		453	
430	432	2100	36	12	6	2	1	8	2	55	30	455			
430	433	1000	11	11	2	1	1	1	4	25	10	429			
431	007	1000	11	11	2	1	1	1	4	25	50	008			
431	477	9750	24	12	6	2	1	1	2	55	50	476			
432	455	5300	36	12	6	3	1	8	2	55	90	467			
432	431	1000	11	11	2	1	1	1	4	25	10	477			
433	429	2700	24	12	4	2	1	8	2	55	50			452	
433	431	2100	24	12	6	2	1	8	2	55	75	477			
433	432	1000	11	11	2	1	1	1	4	25	25	455			
446	447	9900	10	10	4	1	1	4	4	30	100		425		
447	425	4500	10	10	4	1	1	4	4	30	100	418			
448	496	1000	10	10	4	1	1	4	2	30	100	495			
449	452	3600	10	10	4	1	1	4	2	30	100	453	499		
450	448	4500	10	10	4	1	1	4	2	30	100	496			
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453	452	3300	10	10	4	1	1	4	2	30	30		429	499	
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454	455	1000	11	11	2	1	1	1	2	25	100		467		
454	480	1000	22	11	4	2	1	7	4	50	100	453			
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457	458	5280	11	11	4	1	1	4	1	40	25	122			
457	475	6300	11	11	4	1	1	4	1	40	25	474		476	
457	477	6900	12	12	4	1	1	5	2	30	25		476		
458	12210000		12	12	4	1	1	5	2	30	50				
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459	449	2250	10	10	4	1	1	4	2	30	100	452			
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461	462	3900	10	10	2	1	1	4	2	30	100	463			
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464	465	5250	10	10	2	1	1	4	2	30	10	004	466		
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464	497	3300	22	11	4	2	1	7	2	35	55	470			
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465	466	1000	11	11	2	1	1	1	4	25	40	114			
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 480 454 1800 10 10  4 1 1 4 2 30    100          455
 480 453 1000 10 10  4 1 1 4 2 30    100 452
 482 32118000 11 11  4 1 1 5 4 35     40          320      322
 482 483 1000 11 11  2 1 1 1 4 25     70 388
 482 484 1000 11 11  4 1 1 5 4 35     30 385      485
 483 38812000 11 11  4 1 1 7 2 35     20 386
 483 484 1000 11 11  4 1 1 1 2 25     10 385
 483 485 1000 11 11  4 1 1 7 2 35     40 376      482
 484 385 9000 11 11  4 1 1 5 4 35     50 395
 484 482 1000 11 11  4 1 1 5 4 35     40 321      483
 484 485 1000 11 11  4 1 1 1 2 25     10 376
 485 37611000 11 11  4 1 1 7 2 35     50 379      378
 485 482 1000 11 11  4 1 1 1 2 25     10 321
 485 483 1000 11 11  4 1 1 7 2 35     40 388      484
 490 451 1200 10 10  4 1 1 4 2 30     50                   494
 490 491 3000 10 10  4 1 1 4 2 30     50 427
 491 427 1500 10 10  4 1 1 4 2 30     75 419
 491 490 1500 10 10  4 1 1 4 2 30     25 451
 492 451 1000 10 10  4 1 1 4 2 30    100 490      494
 493 494 2100 10 10  4 1 1 4 2 30    100          459
 494 459 1000 10 10  4 1 1 4 1 30    100 449
 495 492 1000 10 10  4 1 1 4 2 30    100 451
 496 495 1000 10 10  4 1 1 4 2 30    100 492
 497 464 3300 22 11  4 2 1 7 2 35     50 469                465
 497 470 2250 22 11  4 2 1 7 2 35     50 499
 498 500 1000 10 10  2 1 1 4 4 30    100          470
 499 452 6750 22 11  4 2 1 7 1 30     50 429
 499 470 1500 22 11  4 2 1 7 2 35     50 497
 500 470 4500 10 10  2 1 1 4 4 30    100          499      497
 011 012 1000 24 12  6 2 1 8 4 50     90 013
 013 340 6750 24 12  6 2 1 8 2 55      1 326
 475 476 3750 11 11  4 1 1 4 4 30    100 865
 073 47610000 24 12  6 2 1 8 4 50    100 477                475
 346 344 2000 12 12  6 1 1 8 4 30      5 355
 340 014 5000 24 12  6 2 1 8 4 50     30 810
99999
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ACOE8716 Buzzards Bay, Off-peak Condition, Rapid Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout1.dat'
outprint='popout1.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=240 int1(2)=360.0 int1(3)=400.0 int1(4)=480.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay Off-peak Condition, Moderate Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout2.dat'
outprint='popout2.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=60.0 int1(2)=240.0 int1(3)=300.0 int1(4)=420.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay Off-peak Condition, Slow Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout3.dat'
outprint='popout3.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=0.0 int1(2)=120.0 int1(3)=200.0 int1(4)=360.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
```

```
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay strong storm, Mid-Peak Condition, Rapid Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout4.dat'
outprint='popout4.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.29 frc(3,4)=0.03
/
&timeint
int1(1)=780.0 int1(2)=900.0 int1(3)=940.0 int1(4)=1020.0 int1(5)=1140.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay strong storm, Moderate Response, Mid-peak
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout5.dat'
outprint='popout5.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.29 frc(3,4)=0.03
/
&timeint
int1(1)=600.0 int1(2)=780.0 int1(3)=840.0 int1(4)=960.0 int1(5)=1140.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay strong storm, Mid-Peak, Slow Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout6.dat'
outprint='popout6.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.29 frc(3,4)=0.03
/
&timeint
```

```
int1(1)=420.0 int1(2)=660.0 int1(3)=740.0 int1(4)=900.0 int1(5)=1140.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, strong storm, Peak, Rapid Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout7.dat'
outprint='popout7.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.35 frc(3,4)=0.17
/
&timeint
int1(1)=960.0 int1(2)=1080.0 int1(3)=1120.0 int1(4)=1200.0 int1(5)=1320.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, strong storm, Peak Condition, Moderate Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout8.dat'
outprint='popout8.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.35 frc(3,4)=0.17
/
&timeint
int1(1)=840.0 int1(2)=960.0 int1(3)=1020.0 int1(4)=1100.0 int1(5)=1320.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, strong storm, Peak Condition, Slow Response
/
&files
filename(1)='strong_b.dat'
filename(2)='mnsst_b.dat'
filename(3)='back_bb.dat'
outfile='popout9.dat'
outprint='popout9.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
```

```
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.35 frc(3,4)=0.17
/
&timeint
int1(1)=600.0 int1(2)=840.0 int1(3)=920.0 int1(4)=1080.0 int1(5)=1320.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzards Bay, Weak Storm, Off-peak Condition, Rapid Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout10.dat'
outprint='popout10.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=240 int1(2)=360.0 int1(3)=400.0 int1(4)=480.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, Weak Storm, Off-peak Condition, Moderate Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout11.dat'
outprint='popout11.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=60.0 int1(2)=240.0 int1(3)=300.0 int1(4)=420.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, Weak Storm, Off-peak Condition, Moderate Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout11.dat'
outprint='popout11.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
```

```
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=60.0 int1(2)=240.0 int1(3)=300.0 int1(4)=420.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, Weak Storm, Off-peak Condition, Slow Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout12.dat'
outprint='popout12.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.11
/
&timeint
int1(1)=0.0 int1(2)=120.0 int1(3)=200.0 int1(4)=360.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay weak storm, Mid-Peak Condition, Rapid Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout13.dat'
outprint='popout13.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.29 frc(3,4)=0.03
/
&timeint
int1(1)=780.0 int1(2)=900.0 int1(3)=940.0 int1(4)=1020.0 int1(5)=1140.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay weak storm, Moderate Response, Mid-peak
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout14.dat'
outprint='popout14.prt'
/
&poptype
atype(1)='vulnerable'
```

```
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.29 frc(3,4)=0.03
/
&timeint
int1(1)=600.0 int1(2)=780.0 int1(3)=840.0 int1(4)=960.0 int1(5)=1140.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay weak storm, Mid-Peak, Slow Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout15.dat'
outprint='popout15.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.29 frc(3,4)=0.03
/
&timeint
int1(1)=420.0 int1(2)=660.0 int1(3)=740.0 int1(4)=900.0 int1(5)=1140.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, weak storm, Peak, Rapid Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout16.dat'
outprint='popout16.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.35 frc(3,4)=0.17
/
&timeint
int1(1)=960.0 int1(2)=1080.0 int1(3)=1120.0 int1(4)=1200.0 int1(5)=1320.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, weak storm, Peak Condition, Moderate Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout17.dat'
outprint='popout17.prt'
```

```
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.35 frc(3,4)=0.17
/
&timeint
int1(1)=840.0 int1(2)=960.0 int1(3)=1020.0 int1(4)=1100.0 int1(5)=1320.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029

ACOE8716 Buzzard's Bay, weak storm, Peak Condition, Slow Response
/
&files
filename(1)='weak_b.dat'
filename(2)='mnsw_b.dat'
filename(3)='back_bb.dat'
outfile='popout18.dat'
outprint='popout18.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='mobile+non-surge'
atype(3)='background'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.08 frc(3,2)=0.35 frc(3,3)=0.35 frc(3,4)=0.17
/
&timeint
int1(1)=600.0 int1(2)=840.0 int1(3)=920.0 int1(4)=1080.0 int1(5)=1320.0
int2(1)=0.0 int2(2)=180.0 int2(3)=420.0 int2(4)=800.0 int2(5)=1000.0
/
074,027,033,030,315,310,086,081,087,376,036,111,083,084,014,082,028,085,001,073,096,094,09
5,031,029
```

Background Traffic

24SOUTH	3	25500	1.00	074	100							
24NORTH	3	25000	1.00	027	100							
28NORTH	3	2000	1.00	033	100							
28SOUTH	3	2000	1.00	030	100							
77SOUTH	3	1500	1.00	315	100							
77NORTH	3	1500	1.00	310	100							
81NORTH	3	2000	1.00	086	100							
81SOUTH	3	2000	1.00	081	100							
88NORTH	3	4000	1.00	087	100							
88SOUTH	3	4000	1.00	376	100							
6EASTFR	3	5000	1.00	036	100							
6DART	3	5000	1.00	413	100							
6EAST	3	20000	1.00	111	45	083	13	084	42			
6WEST	3	23000	1.00	014	85	082	15					
195EAST	3	33150	1.00	028	99	085	1					
195WEST	3	15375	1.00	001	100							
140SOUTH	3	2000	1.00	073	100							
140NORTH	3	2000	1.00	096	100							
177EAST	3	2000	1.00	094	100							
177WEST	3	2000	1.00	095	100							
495north	3	20000	1.00	031	100							
495SOUTH	3	20000	1.00	029	100							

Severe Storm Surge Vulnerable Population File

414	1	869	1.63	311	100									
416.01	1	337	1.80	324	100									
416.02	1	592	1.80	319	100									
417	1	1197	1.80	313	50	314	50							
5411	1	270	1.70	127	100									
5601	1	5509	1.70	075	33	025	33	026	34					
5611	1	5082	1.70	024	99	124	1							
6403	1	394	2.72	324	100									
6404	1	82	2.72	330	100									
6405	1	257	2.72	330	100									
6409	1	653	2.72	329	25	330	74	125	1					
6410	1	841	2.72	329	100									
6420	1	613	2.72	351	100									
6421	1	1392	2.72	366	34	367	33	350	33					
6422	1	138	2.72	366	99	252	1							
6461	1	1744	1.85	387	50	323	50							
6503	1	849	2.84	457	100									
6504	1	372	2.84	458	100									
6506	1	712	2.84	458	100									
6507	1	525	2.84	455	100									
6511	1	23	2.84	455	100									
6512	1	1053	2.84	454	50	455	50							
6513	1	37	2.84	453	100									
6518	1	314	2.84	452	100									
6519	1	1639	2.84	449	50	459	50							
6520	1	1618	2.84	449	50	459	50							
6521	1	100	2.84	449	100									
6524	1	1433	2.84	451	50	490	50							
6525	1	2661	2.84	427	34	490	33	491	33					
6526	1	3006	2.84	492	34	493	33	494	33					
6527	1	2176	2.84	495	34	496	33	448	33					
6528	1	1190	2.84	448	25	450	75							
6532	1	157	2.26	426	50	393	50							
6533	1	3043	2.26	421	16	422	16	423	17	410	17	424	17	446 17
6541	1	681	1.96	473	100									
6542	1	133	1.96	472	100									
6551	1	1161	2.12	465	50	470	50							
6552	1	2890	2.12	498	34	499	33	500	33					
6553	1	2627	2.12	464	25	497	25	499	25	470	25			
6554	1	4419	2.12	460	20	461	20	462	20	463	20	469		

Weak Storm Surge Vulnerable Population File

414	1	652	1.63	311	100				
416.01	1	174	1.80	324	100				
416.02	1	526	1.80	319	100				
417	1	974	1.80	313	50	314	50		
5411	1	5	1.70	127	100				
5601	1	4528	1.70	075	33	025	33	026	34

Weak Storm Surge Vulnerable Population File (Cont'd)

5611	1	4226	1.70	024	99	124	1										
6403	1	253	2.72	324	100												
6404	1	46	2.72	330	100												
6405	1	182	2.72	330	100												
6409	1	293	2.72	329	25	330	74	125	1								
6410	1	554	2.72	329	100												
6420	1	273	2.72	351	100												
6421	1	855	2.72	366	34	367	33	350	33								
6422	1	61	2.72	366	99	252	1										
6461	1	1550	1.85	387	50	323	50										
6503	1	1	2.84	457	100												
6504	1	1	2.84	458	100												
6506	1	1	2.84	458	100												
6507	1	1	2.84	455	100												
6511	1	1	2.84	455	100												
6512	1	1	2.84	454	50	455	50										
6513	1	1	2.84	453	100												
6518	1	1	2.84	452	100												
6519	1	1	2.84	449	50	459	50										
6520	1	1	2.84	449	50	459	50										
6521	1	1	2.84	449	100												
6524	1	374	2.84	451	50	490	50										
6525	1	1	2.84	427	34	490	33	491	33								
6526	1	1	2.84	492	34	493	33	494	33								
6527	1	243	2.84	495	34	496	33	448	33								
6528	1	1058	2.84	448	25	450	75										
6532	1	140	2.26	426	50	393	50										
6533	1	2560	2.26	421	16	422	16	423	17	410	17	424	17	446	17		
6541	1	1	1.96	473	100												
6542	1	1	1.96	472	100												
6551	1	1032	2.12	465	50	470	50										
6552	1	1	2.12	498	34	499	33	500	33								
6553	1	1	2.12	464	25	497	25	499	25	470	25						
6554	1	2815	2.12	460	20	461	20	462	20	463	20	469	20				

Severe Storm Mobile Home and Non-Surge Vulnerable Population File

ACUSHN	2	980	1.96	471	33	472	33	473	34	476							
DARTMH	2	1360	2.26	394	20	418	20	412	20	392	20	391	20				
FAIRH	2	300	2.12	463	25	464	25	497	25	469	25						
FALLR	2	4490	2.72	344	20	352	20	035	20	012	20	013	20				
NEWBED	2	4180	2.84	432	20	007	20	431	20	477	20	415	20				
WEST	2	770	1.85	388	33	386	33	400	34								
L.COMP	2	340	1.63	311	50	312	50										
TIVER	2	1300	1.80	321	33	319	33	320	34								
ROCHES	2	196	1.70	418	100												
MARION	2	4	1.90	101	100												
MATTAP	2	89	1.89	117	100												

Weak Storm Mobile Home and Non-Surge Vulnerable Population File

ACUSHN	2	830	1.96	471	33	472	33	473	34	476							
DARTMH	2	620	2.26	394	20	418	20	412	20	392	20	391	20				
FAIRH	2	150	2.12	463	25	464	25	497	25	469	25						
FALLR	2	1850	2.72	344	20	352	20	035	20	012	20	013	20				
NEWBED	2	1770	2.84	432	20	007	20	431	20	477	20	415	20				
WEST	2	360	1.85	388	33	386	33	400	34								
L.COMP	2	250	1.63	311	50	312	50										
TIVER	2	950	1.80	321	33	319	33	320	34								
ROCHES	2	85	1.70	418	100												
MARION	2	4	1.90	101	100												
MATTAP	2	49	1.89	117	100												

ANNEX B:

CAPE COD NETWORK COMPUTER INPUT FILES

001	081	5321	12	12	6	1	1	8	4	55	100	088			
002	001	1000	11	11	2	1	1	1	4	25	10	081			
002	004	1000	11	11	2	1	1	7	4	40	100	294			
002	112	4649	22	11	2	2	1	7	4	40	90	293			
003	004	1000	11	11	2	1	1	1	4	25	30	294			
003	006	1000	12	12	6	1	1	8	4	55	90	83			
004	002	1000	11	11	2	1	1	7	4	40	90	112			
004	006	1000	11	11	2	1	1	1	4	25	10	083			
004	294	1585	11	11	2	1	1	7	4	40	100	295			
005	001	1000	12	12	6	1	1	8	4	55	90	081			
005	002	1000	11	11	2	1	1	1	4	25	1	112			
006	083	7306	12	12	6	1	1	8	4	55	100	019	835		
008	38316000		24	12	6	2	1	8	2	55	100	860			
009	010	1510	11	11	2	1	1	1	2	25	7	234	886		
009	011	1500	24	12	6	2	1	8	2	55	90	270			
010	234	1511	24	12	6	2	1	8	2	55	100	239	278		
010	886	1000	24	12	6	2	1	8	2	55	20				
011	27029067		36	12	6	3	1	8	2	55	100	269			
012	008	1500	11	11	2	1	1	1	2	25	70	383			
012	011	1855	11	11	2	1	1	1	2	25	30	270			
013	015	1000	11	11	2	1	1	7	4	40	30	120			461
013	124	9283	11	11	2	1	1	7	4	40	95	132			
013	242	7900	24	12	6	2	1	8	4	55	40	245			
013	834	1000	11	11	2	1	1	7	4	40	40				
015	013	1000	22	11	2	2	1	7	4	40	20	124			242
015	120	3739	11	11	2	1	1	7	4	40	10	297			
015	461	2300	24	12	6	2	1	8	4	55	45	228			
017	126	2600	48	12	6	3	1	8	4	55	100	132	018		460
018	126	1000	22	10	2	3	1	4	4	35	50	460			267
018	28121881		22	11	2	2	1	7	2	40	50	280			
019	314	1000	11	11	2	1	1	1	2	25	5	131			
019	021	1000	12	12	6	1	1	8	4	55	95	024	858		
020	45110000		24	12	6	2	1	8	4	55	90	005			
020	836	1000	11	11	2	1	1	7	4	40	50				
021	02412800		12	12	6	1	1	8	4	55	90	079	148		
021	858	1000	11	11	2	1	1	1	4	25	20				
022	020	1000	12	12	6	1	1	8	4	55	85	451	836		
022	023	1000	11	11	2	1	1	1	4	25	5	319			
023	020	1000	11	11	2	1	1	1	4	25	30	451			
023	314	1000	11	11	2	1	1	7	4	40	60	131			
023	319	6150	11	11	2	1	1	7	4	40	1	321	326		313
024	079	1000	12	12	6	1	1	8	4	55	90	086			
024	148	2379	11	11	2	1	1	7	4	40	1	315			
025	02212793		12	12	6	1	1	8	4	55	90	020	023		
025	841	1000	11	11	2	1	1	7	4	40	30				
026	025	1000	12	12	6	1	1	8	4	55	65	022	841		
026	452	1000	11	11	2	1	1	1	4	25	35	326			
027	029	1000	11	11	2	1	1	1	2	25	100	255			
027	031	1000	10	10	2	1	1	4	2	35	1	166			
027	145	9170	10	10	2	1	1	4	2	35	5	144			818
028	027	1000	11	11	2	1	1	1	2	25	10	145			
028	029	1000	24	12	6	2	1	8	2	55	90	255			
029	255	4250	24	12	6	2	1	8	2	55	90	034			
030	031	1000	11	11	2	1	1	1	2	25	30	166			
030	032	1000	24	12	6	2	1	8	2	55	70	250			
031	027	1000	10	10	2	1	1	4	2	35	90	145			
031	032	1000	11	11	2	1	1	1	2	25	90	250			
031	166	4185	20	10	2	2	1	7	2	35	40	181	895		
032	250	5621	24	12	6	2	1	8	2	55	90	087	888		
033	035	845	11	11	2	1	1	1	4	25	90	040			
033	037	1000	24	12	6	2	1	8	2	55	10	172			
033	159	6130	10	10	2	1	1	4	4	35	10		317		163
034	033	1579	11	11	2	1	1	1	4	25	1	159			
034	035	1000	24	12	6	2	1	8	4	55	90	040			
035	040	9973	24	12	6	2	1	8	4	55	90	039	038		
036	037	1208	11	11	2	1	1	1	4	25	10	172			
036	259	1000	24	12	6	2	1	8	4	55	90	251			
037	033	1000	24	12	6	2	1	8	2	55	10	159			
037	172	5303	10	10	2	1	1	4	4	35	1	368			
037	259	1000	11	11	2	1	1	1	4	25	90	251			
038	039	1000	11	11	2	1	1	1	4	25	1	262			
038	045	1000	10	10	2	1	1	4	4	35	1	177			
038	163	5209	10	10	2	1	1	4	4	35	1		159		
039	26220000		24	12	6	2	1	8	2	55	90	265	327		
040	038	1000	11	11	2	1	1	1	4	25	1	163			

040	039	1000	24	12	6	2	1	8	4	55	90	262			
041	04620600		24	12	6	2	1	8	2	55	90	044	045		
042	041	1000	11	11	2	1	1	1	2	25	90	046			
042	170	1000	11	11	2	1	1	7	2	40	90	369			
042	327	1000	11	11	2	1	1	7	2	40	5	324			
043	041	1000	24	12	6	2	1	8	2	55	90	046			
043	042	1134	11	11	2	1	1	1	2	25	5	170			
044	03610417		24	12	6	2	1	8	4	55	90	259	037		
045	038	1000	10	10	2	1	1	4	4	35	5	163			
045	044	1000	11	11	2	1	1	1	4	25	90	036			
045	177	5102	10	10	2	1	1	4	4	35	100	190			
046	044	1000	24	12	6	2	1	8	2	55	90	036			
046	045	1000	11	11	2	1	1	1	4	25	1	177			
047	048	1000	11	11	2	1	1	1	2	25	1	074			
047	051	1000	24	12	6	2	1	8	2	55	90	077			
048	051	1000	11	11	2	1	1	1	2	25	80	077			
048	052	1000	22	11	2	2	1	7	2	40	20	197			
048	074	1800	11	11	2	1	1	7	2	40	1		073		
050	283	4000	24	12	6	2	1	8	2	55	100	171			
051	07722929		22	11	2	2	1	7	2	40	90	078			
051	07730000		24	12	6	2	1	8	2	55	100	078			
052	048	1000	22	11	2	2	1	7	2	40	20	074			
052	050	1000	10	10	2	1	1	4	2	35	80	283			
052	197	1000	10	10	2	1	1	4	2	35	1	358			
053	050	1000	22	11	2	2	1	7	2	40	30	283			
053	052	1000	11	11	2	1	1	1	2	25	70	197			
054	058	1000	11	11	2	1	1	1	2	25	10	224	059		
055	054	1718	11	11	2	1	1	1	4	25	100	058			
055	057	2001	10	10	2	1	1	4	4	35	1	091			
057	09111115		10	10	2	1	1	4	4	35	100	222	883		
058	059	1000	11	11	2	1	1	1	4	25	10	831			
058	224	1000	12	12	6	1	1	8	4	55	40	225			
059	831	1000	11	11	2	1	1	1	4	25	100				
060	06215179		10	10	2	1	1	5	4	30	1				157
060	840	8000	10	10	2	1	1	4	4	35	100				
062	06015179		10	10	2	1	1	5	4	30	100		840		
062	063	7476	10	10	2	1	1	5	4	30	100	064			
062	157	9122	10	10	2	1	1	4	4	35	90		490		
063	062	7476	10	10	2	1	1	5	4	30	90	060	157		
063	064	4058	10	10	2	1	1	5	4	30	1				071
064	063	4058	10	10	2	1	1	5	4	30	90	062			
064	071	1026	10	10	2	1	1	4	4	35	90				070
065	063	4637	10	10	2	1	1	4	4	35	90				062
065	064	3340	10	10	2	1	1	5	4	30	90	071			
066	065	8209	20	10	2	2	1	5	4	30	100	064			
067	068	9000	20	10	2	2	1	5	2	30	1	362			
067	078	5427	20	10	2	2	1	7	2	30	90	077			
068	067	3467	20	10	2	2	1	7	2	30	90	078			
068	362	9789	22	11	2	2	1	7	2	40	100	360			
069	067	9598	22	11	2	2	1	7	2	30	90				078
069	810	1200	11	11	2	1	1	1	4	25	100				
070	071	8639	10	10	2	1	1	5	4	30	1	072			
070	171	1000	10	10	2	1	1	4	4	35	90	157			
070	48511300		24	12	6	2	1	8	2	55	100	047			
071	064	1026	10	10	2	1	1	4	4	35	1				063
071	070	8639	20	10	2	2	1	7	4	30	90	171			
071	072	3283	10	10	2	1	1	5	4	30	90	073			
072	071	3283	10	10	2	1	1	5	4	30	90	070			064
072	073	1000	10	10	2	1	1	5	2	30	1	074			
073	072	1000	10	10	2	1	1	5	2	30	90	071			
073	074	3225	10	10	2	1	1	5	2	30	90	075			048
074	048	1800	11	11	2	1	1	7	2	40	90	052	051		
074	073	3225	10	10	2	1	1	5	2	30	90	072			
074	07511122		10	10	2	1	1	5	2	30	1	076			
075	07411122		10	10	2	1	1	5	2	30	90	073	048		
075	076	7888	10	10	2	1	1	5	2	30	1	077			
076	075	7888	10	10	2	1	1	5	2	30	90	074			
076	077	6857	10	10	2	1	1	5	2	30	1		078		207
077	076	6857	10	10	2	1	1	5	2	30	1	075			
077	078	5819	11	11	2	1	1	7	2	40	1	067			
077	207	6440	22	11	2	2	1	7	2	40	90	053	809		
078	067	5427	20	10	2	2	1	7	2	30	90	068			
078	077	5819	22	11	2	2	1	7	2	40	90	207			076
079	086	1000	24	12	6	2	1	8	4	55	100	249			
081	111	2530	10	10	2	1	1	4	2	35	10	112			825

081	088	5000	12	12	6	1	1	8	4	55	100	277			
083	01915509		12	12	6	1	1	8	4	55	90	021	314		
083	835	1000	11	11	2	1	1	7	2	40	45				
086	249	1000	12	12	6	1	1	8	4	55	100	028			
087	026	500	12	12	6	1	1	8	4	55	90	025	452		
087	896	1000	10	10	2	1	1	4	2	35	20				
088	27713211		22	11	2	2	1	7	4	40	30	275			
088	293	1000	22	11	2	2	1	7	4	40	20	112			114
088	450	4847	12	12	6	1	1	8	4	55	75	003			
091	222	7798	20	10	2	2	1	4	4	35	75	059			
091	883	1000	20	10	2	2	1	4	4	35	25				
093	055	3508	20	10	2	2	1	4	4	35	100	054			
094	28814756		11	11	2	1	1	7	4	40	100	101			
094	36512500		11	11	2	1	1	7	4	40	95	366			
094	830	1000	11	11	2	1	1	1	4	25	30				
095	094	1000	10	10	2	1	1	4	2	35	100	830	288		365
096	38014347		11	11	2	1	1	7	4	40	95	870			
096	473	3700	10	10	2	1	1	4	4	35	5	472	097		
096	29130000		24	12	6	2	1	8	4	55	100	116			
097	37813044		24	12	6	2	1	8	4	55	100	871			
098	471	1000	24	12	6	2	1	8	4	55	100	227			
098	472	1000	11	11	2	1	1	1	4	25	100	099			
099	10014210		10	10	2	1	1	4	4	35	100	104			
099	37713487		10	10	2	1	1	4	4	35	50	873			
099	472	7000	10	10	2	1	1	4	4	35	50	473			
100	09914210		10	10	2	1	1	4	4	35	100	472			377
100	10418170		10	10	2	1	1	4	4	35	100		103		
101	288	9927	11	11	2	1	1	7	4	40	30	094			
101	290	6000	11	11	2	1	1	7	4	40	90	102			828
102	10123887		10	10	2	1	1	4	4	35	5				288
102	271	5636	11	11	2	1	1	7	4	40	95	272			
102	290	6013	11	11	2	1	1	7	4	40	100	101	828		
103	104	2369	10	10	2	1	1	4	4	35	100	107			100
103	375	8552	10	10	2	1	1	4	4	35	50	890			
103	376	5892	10	10	2	1	1	4	4	35	50	874			
104	10018170		10	10	2	1	1	4	4	35	80	099			
104	103	2369	10	10	2	1	1	4	4	35	50	376			375
104	10750327		10	10	2	1	1	4	2	35	50	108			
105	272	8213	22	11	2	2	1	7	4	40	100	271			
105	273	2612	22	11	2	2	1	7	4	40	100	275			
107	10450327		10	10	2	1	1	4	2	35	100	103			
107	108	1000	10	10	2	1	1	4	2	35	100	109			
108	107	1000	20	10	2	2	1	4	2	35	100	104			
108	109	2101	20	10	2	2	1	7	4	35	100		381		278
109	108	2101	10	10	2	1	1	4	4	35	70	107			
109	27818000		22	11	2	2	1	7	4	40	100	279	239		
109	381	3762	22	11	2	2	1	7	4	40	100	875			
109	803	1000	10	10	2	1	1	4	4	35	35				
111	112	1000	20	10	2	2	1	7	4	35	80		002		293
111	825	1000	11	11	2	1	1	1	4	25	20				
112	002	4649	11	11	2	1	1	7	4	40	10	004	001		
112	111	1000	10	10	2	1	1	4	4	35	50				825
112	293	1950	22	11	2	2	1	7	4	40	100	088			
114	293	2178	22	11	2	2	1	7	4	40	50	088			
114	30213217		22	11	2	2	1	7	4	40	50	313			142
115	116	2128	10	10	2	1	1	4	4	35	100		291		461
116	291	6166	22	11	2	2	1	7	4	40	80	096			
116	461	2100	22	11	2	2	1	7	4	40	20	460	228		
116	806	2100	11	11	2	1	1	1	4	25	30				
120	015	3739	11	11	2	1	1	7	4	40	10	013	461		
120	297	1900	11	11	2	1	1	7	4	40	100	299	134		
120	805	1100	10	10	2	1	1	4	4	35	90				
122	295	5793	11	11	2	1	1	7	4	40	100	294			
122	298	2807	11	11	2	1	1	7	4	40	100	300			
122	819	1800	11	11	2	1	1	1	4	25	20				
123	122	1756	10	10	2	1	1	4	4	35	100		295		298
124	013	9283	11	11	2	1	1	7	4	40	100	015	242		
124	132	7386	11	11	2	1	1	7	4	40	100	060	126		141
124	838	2100	11	11	2	1	1	1	4	25	10				
126	018	1000	10	10	2	1	1	4	4	35	90	281			
126	132	3000	22	11	2	2	1	7	2	40	40	141	060		124
126	267	9798	36	12	6	3	1	8	4	55	100	268			
126	46017600		11	11	2	1	1	7	4	40	40	461			
128	30311000		22	11	2	2	1	7	4	40	100	300			
128	305	3000	22	11	2	2	1	7	4	40	100	144			

128	820	1000	11	11	2	1	1	1	4	25	10			
130	131	7723	10	10	2	1	1	4	4	35	100		301	314
131	301	9949	11	11	2	1	1	7	4	40	100	300		
131	314	6988	11	11	2	1	1	7	4	40	100	023	021	
132	060	8000	11	11	2	1	1	7	4	40	10			062
132	124	7386	11	11	2	1	1	7	4	40	20	013	838	
132	126	3000	22	11	2	2	1	7	4	40	13	267	460	018
132	141	3000	22	11	2	2	1	7	4	40	10	158	804	
134	137	1000	11	11	2	1	1	7	4	40	80	167		
134	243	1000	11	11	2	1	1	1	4	25	100	241		
134	29714761		11	11	2	1	1	7	4	40	100	120		
137	134	1000	11	11	2	1	1	7	4	40	80	297		
137	16718627		11	11	2	1	1	7	4	40	80	175	813	
137	246	1000	11	11	2	1	1	1	4	25	100	248		
137	887	1000	11	11	2	1	1	1	4	25	20			
138	29918117		11	11	2	1	1	7	4	40	100	297		
138	310	1000	11	11	2	1	1	7	4	40	100	312		
138	812	1000	11	11	2	1	1	1	4	25	20			
141	132	2700	33	11	2	3	1	7	4	40	70	126	124	
141	15814778		22	11	2	2	1	7	4	40	80	070		
141	804	1100	11	11	2	1	1	1	4	25	50			
142	302	8325	11	11	2	1	1	7	4	40	100	114	313	
142	318	7242	11	11	2	1	1	7	4	40	100	150		
144	145	6000	10	10	2	1	1	4	4	35	50	027	818	
144	305	4601	11	11	2	1	1	7	2	40	100	128		
144	306	4601	11	11	2	1	1	7	2	40	95	154		
144	437	1000	11	11	2	1	1	7	2	40	100	876		
145	027	9170	10	10	2	1	1	4	2	35	90	031	029	
145	144	7031	10	10	2	1	1	4	2	35	90	437	305	306
145	818	1000	11	11	2	1	1	1	4	25	10			
148	079	1000	11	11	2	1	1	1	4	25	50	086		
148	315	3500	11	11	2	1	1	7	2	40	100	301		
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148	822	1000	11	11	2	1	1	1	4	25	20			
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154	306	4223	11	11	2	1	1	7	2	40	45	144		
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157	49014778		22	11	2	2	1	7	4	40	90	132		
158	070	4100	24	12	6	2	1	8	2	55	95	485	071	
159	033	6130	10	10	2	1	1	4	4	35	10	037	035	
159	163	7968	11	11	2	1	1	7	4	40	45	322		038
159	31710509		11	11	2	1	1	7	4	40	45	311		
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166	15415000		10	10	2	1	1	4	2	35	50		306	311
166	895	1000	10	10	2	1	1	4	2	35	20			
167	13718627		11	11	2	1	1	7	4	40	90	134	246	
167	175	3734	11	11	2	1	1	7	4	40	90	355		
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169	170	1606	20	10	2	2	1	7	2	35	70		369	042
169	193	9500	10	10	2	1	1	4	2	35	100		200	
169	18921592		10	10	2	1	1	4	2	35	30		325	353
170	042	1000	11	11	2	1	1	7	2	40	80	327	041	
170	169	1606	10	10	2	1	1	4	2	35	20	189		193
170	36910099		11	11	2	1	1	7	2	40	100	180	814	
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175	167	3734	11	11	2	1	1	7	4	40	100	137	813	
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176	175	8557	10	10	2	1	1	4	4	35	100		355	167
177	045	5102	10	10	2	1	1	4	4	35	100	038	044	
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183	178	3593	20	10	2	2	1	4	4	35	100	171					
184	185	2423	20	10	2	2	1	7	4	35	100	195					
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188	185	4271	20	10	2	2	1	7	4	35	100	195					
189	16921592		20	10	2	2	1	7	2	35	5	170					
189	32514565		22	11	2	2	1	7	2	40	90	252	258				
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193	349	5055	22	11	2	2	1	7	2	40	100	346					
195	351	2513	22	11	2	2	1	7	4	40	100	350					
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225	22624537		24	12	6	2	1	8	4	55	100	094					
226	09412000		10	10	2	1	1	4	2	35	100	288	830				
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240	235	1000	24	12	6	2	1	8	2	55	100	012					
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244	243	1000	24	12	6	2	1	8	4	55	80	241					
245	137	1000	11	11	2	1	1	1	4	25	25	167	887				
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253	325 458	11	11	2	1	1	1	2	25	5	189				
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266	008 2179	36	12	6	3	1	8	2	55	70	383				
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269	017 7126	36	12	6	3	1	8	4	55	100	126				
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273	105 2612	22	11	2	2	1	7	4	40	100	272				
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291	116 6166	11	11	2	1	1	7	4	40	95	461		806		
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294	29513115	11	11	2	1	1	7	4	40	100	122				
295	122 5793	11	11	2	1	1	7	4	40	100	298	819			
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297	13414761	11	11	2	1	1	7	4	40	100	137	243			
297	299 6641	11	11	2	1	1	7	4	40	100	138				
298	122 2807	11	11	2	1	1	7	4	40	100	295	819			
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298	301 2123	11	11	2	1	1	7	4	40	100	315		131		
299	13818117	11	11	2	1	1	7	4	40	100	310	812			
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325	18914565		11	11	2	1	1	7	2	40	100	353		
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337	338	2381	22	11	2	2	1	7	4	40	100	334			
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338	337	2381	22	11	2	2	1	7	4	40	100	336			
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340	334	7080	22	11	2	2	1	7	4	40	100	338			326
343	181	8000	22	11	2	2	1	7	4	40	80	342			166
342	181	1000	22	11	2	2	1	7	2	40	100	343			
342	336	6477	22	11	2	2	1	7	2	40	100	337			
343	35214750		22	11	2	2	1	7	4	40	50	195			
343	368	2957	20	10	2	2	1	4	4	35	40	172			
343	827	3100	22	11	2	2	1	7	4	40	60				
346	180	5000	11	11	2	1	1	7	2	40	30	369			
346	190	3664	22	11	2	2	1	7	2	40	100	348			
346	34912336		22	11	2	2	1	7	2	40	70	193			
348	190	1544	22	11	2	2	1	7	2	40	100	346			177
348	350	4319	22	11	2	2	1	7	4	40	100	351	884		
349	193	5055	22	11	2	2	1	7	2	40	100	200	169		
349	34612336		22	11	2	2	1	7	2	40	100		190		180
350	348	4319	22	11	2	2	1	7	4	40	100	190			
350	351	2604	22	11	2	2	1	7	4	40	100	195			
350	884	1000	22	11	2	2	1	7	4	40	25				
351	195	2513	22	11	2	2	1	7	4	40	100	352			
351	350	2604	22	11	2	2	1	7	4	40	100	348	884		
352	195	1000	22	11	2	2	1	7	4	40	100	351			
352	34314750		22	11	2	2	1	7	4	40	100	181			827
353	189	4800	11	11	2	1	1	7	2	40	50	325	169		
353	200	2798	22	11	2	2	1	7	2	40	50	193	199		
353	20512000		22	11	2	2	1	7	2	40	100	355			
355	175	1000	11	11	2	1	1	7	2	40	80	167			
355	205	1000	22	11	2	2	1	7	2	40	20	353			
355	356	2738	22	11	2	2	1	7	2	40	100	357			
356	355	2738	11	11	2	1	1	7	2	40	100	205			
356	357	9219	22	11	2	2	1	7	2	40	100	213			358
357	21314000		22	11	2	2	1	7	2	40	100	359			
357	356	9219	22	11	2	2	1	7	2	40	100	355			
357	35812070		22	11	2	2	1	7	2	40	50	197			
357	829	1000	22	11	2	2	1	7	4	25	30				
358	19723041		11	11	2	1	1	7	2	40	100	052	899		
358	35712070		22	11	2	2	1	7	2	40	100	829	356		213
359	213	8984	22	11	2	2	1	7	2	40	100	357			
359	361	3715	22	11	2	2	1	7	2	40	100	215			
360	215	3561	22	11	2	2	1	7	2	40	100	361			811
360	362	5980	22	11	2	2	1	7	2	40	100	068			
361	215	3573	22	11	2	2	1	7	2	40	100	360	811		
361	359	3715	22	11	2	2	1	7	2	40	100	213			
362	068	2500	22	11	2	2	1	7	2	40	100	067			
362	360	5980	22	11	2	2	1	7	2	40	100	215			
364	286	8000	10	10	2	1	1	4	2	35	100	280			
364	881	1000	10	10	2	1	1	4	2	35	100				
364	881	1000	10	10	2	1	1	4	2	35	100				
365	36636866		24	12	6	2	1	8	4	55	100	223	898		
366	223	1000	12	12	6	1	1	8	4	55	100	057			
366	898	1000	10	10	2	1	1	4	2	35	20				
366	897	1000	10	10	2	1	1	4	2	35	25				
367	277	3696	22	10	2	2	1	7	4	35	100		088		275
367	826	1000	10	10	2	1	1	4	2	35	10				
368	172	3106	20	10	2	2	1	4	4	35	100	037			
368	343	2957	20	10	2	2	1	7	4	35	100		552		181
368	827	1000	11	11	2	1	1	1	4	25	100				
369	17010099		22	11	2	2	1	7	2	40	100	042			
369	180	605	11	11	2	1	1	7	2	40	100	346			
369	814	1000	11	11	2	1	1	1	4	25	25				
371	150	5002	11	11	2	1	1	7	4	40	100	318			
371	330	6325	11	11	2	1	1	7	4	40	100	331			
374	273	1000	11	11	2	1	1	1	4	25	100	275			
375	890	1000	10	10	2	1	1	4	4	35	100				
375	103	8552	10	10	2	1	1	4	4	35	100		104		376
376	103	5892	10	10	2	1	1	4	4	35	100	104			
376	874	1000	10	10	2	1	1	4	4	35	100				
377	09913487		10	10	2	1	1	4	4	35	100		472		100
377	873	1000	10	10	2	1	1	4	4	35	100				
378	871	1000	24	12	6	2	1	8	4	55	100				
379	09813071		24	12	6	2	1	8	4	55	100	471	472		
380	09614347		11	11	2	1	1	7	4	40	100	291	473		

380	870	1000	11	11	2	1	1	7	4	40	100				
381	109	3762	22	11	2	2	1	7	4	40	100	278	803	108	
381	875	1000	22	11	2	2	1	7	4	40	100				
382	00913000	.24	12		6	2	1	8	2	55	100	011	010		
383	860	1000	24	12	6	2	1	8	2	55	100				
364	881	1000	10	10	2	1	1	4	2	35	100				
385	24019230		24	12	6	2	1	8	4	55	100	235	279		
386	880	1000	10	10	2	1	1	4	2	35	100				
387	06919764		20	10	2	2	1	5	2	30	100	067	810		
388	338	2907	20	10	2	2	1	4	4	35	100	334	337		
389	337	3065	20	10	2	2	1	7	4	35	100	338	336		
390	336	4697	20	10	2	2	1	7	4	35	100	337	342		
391	191	2597	20	10	2	2	1	7	2	35	100		181		
391	342	4264	20	10	2	2	1	7	2	35	100		336	181	
392	191	1164	20	10	2	2	1	7	2	35	100	181			
393	349	3836	20	10	2	2	1	7	2	35	100		346	193	
394	393	1871	20	10	2	2	1	7	2	35	100			349	
395	394	3091	20	10	2	2	1	7	2	35	100	393			
396	350	2715	20	10	2	2	1	7	4	35	100	348			
397	348	4767	20	10	2	2	1	7	4	35	100	190			
398	351	4070	20	10	2	2	1	7	4	35	100	350			
399	394	4964	20	10	2	2	1	7	2	35	100	393			
400	193	7553	20	10	2	2	1	4	2	35	100	169	349	200	
401	393	8276	20	10	2	2	1	7	2	35	100	349			
402	401	4391	20	10	2	2	1	4	2	35	100	393			
403	199	6946	20	10	2	2	1	4	2	35	100	200	816		
404	35211412		20	10	2	2	1	7	4	35	100	195			
405	204	7368	20	10	2	2	1	4	2	35	100	205	817		
407	213	1032	20	10	2	2	1	7	2	35	100	359			
408	407	1152	20	10	2	2	1	7	2	35	100	213			
409	407	7408	20	10	2	2	1	7	2	35	100	213			
410	359	8258	20	10	2	2	1	4	2	35	100	361			
411	361	9950	20	10	2	2	1	4	2	35	100	215			
412	36011064		20	10	2	2	1	4	2	35	100	362			
413	21510959		20	10	2	2	1	4	2	35	100	360			
414	362	8877	20	10	2	2	1	7	2	35	100	068			
415	068	5000	20	10	2	2	1	7	2	35	100	362	067		
416	401	2652	20	10	2	2	1	4	2	35	100	393			
417	191	4117	20	10	2	2	1	7	2	35	100	181			
418	391	3327	20	10	2	2	1	4	2	35	100	191	342		
419	091	4471	10	10	2	1	1	4	4	35	100			222	
420	093	1000	10	10	2	1	1	4	4	35	100	055			
421	095	7954	20	10	2	2	1	4	4	35	100	094			
422	095	4748	20	10	2	2	1	4	4	35	100	094			
423	10113443		20	10	2	2	1	4	4	35	100	290	288		
424	290	6582	20	10	2	2	1	4	4	35	100	102	101		
425	114	6611	20	10	2	2	1	7	4	35	100		293	302	
426	425	5564	20	10	2	2	1	7	4	35	100	114			
427	328	4407	20	10	2	2	1	4	4	35	100	329			
428	331	4456	20	10	2	2	1	4	4	35	100	328			
429	330	5271	20	10	2	2	1	4	4	35	100	331			
430	332	3523	20	10	2	2	1	7	4	35	100	329	340		
431	340	1703	10	10	2	1	1	4	4	35	100	332	334		
432	371	5724	20	10	2	2	1	4	4	35	100	330			
433	425	7627	20	10	2	2	1	7	4	35	100	114			
434	275	4000	22	11	2	2	1	7	4	25	50	273	277		
435	27111976		20	10	2	2	1	4	4	35	100	272	102		
436	374	4369	20	10	2	2	1	4	4	35	100	273			
437	144	3450	10	10	2	1	1	4	2	35	100	145	306	305	
437	876	1000	20	10	2	2	1	4	4	35	100				
438	311	8659	20	10	2	2	1	4	2	35	100	317	154		
439	367	7120	20	10	2	2	1	4	4	35	100	277		826	
440	374	7396	20	10	2	2	1	4	4	35	100	273			
441	111	4000	20	10	2	2	1	4	4	35	100	112	825		
442	295	1500	20	10	2	2	1	4	4	35	100		122	294	
443	299	4481	20	10	2	2	1	4	4	35	100	297	138		
444	303	2562	20	10	2	2	1	4	4	35	100	128	300		
445	306	3374	20	10	2	2	1	4	2	35	100	154	144		
446	310	1500	22	11	2	2	1	1	4	25	100	138	312		
447	312	3446	20	10	2	2	1	4	4	35	100	310	316		
448	159	4426	10	10	2	1	1	4	4	35	100	163	317		
450	003	5321	24	12	6	2	1	8	4	55	70	006	004		
451	005	4847	12	12	6	1	1	8	4	55	100	001	002		
452	025	1000	11	11	2	1	1	1	4	25	85	022			
452	148	6000	11	11	2	1	1	7	4	40	10	315	822		

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452 326 7200 11 11  2 1 1 7 4 40    100 334     821
453 280 2000 20 10  2 2 1 4 4 35    100 286
454 281 2000 20 10  2 2 1 4 4 35    100 280
455 108 2000 20 10  2 2 1 4 4 35    100 107     109
460 013 2300 24 12  6 2 1 8 4 55     55 242     124     015     834
460 12617600 11 11  2 1 1 7 4 40     95 018     267     132
460 461 1000 11 11  2 1 1 7 4 40     70 116             228
460 837 1000 11 11  2 1 1 7 4 40    100
461 116 2100 11 11  2 1 1 7 4 40    100 291     806
461 228 7900 24 12  6 2 1 8 4 55     70 470
461 460 1000 11 11  2 1 1 7 4 40     10 126             013
463 015 1000 24 12  6 2 1 8 4 55    100 461
464 460 1000 24 12  6 2 1 8 4 55    100 013
470 097 1000 24 12  6 2 1 8 4 55     90 378
470 473 1000 11 11  2 1 1 1 4 25     10 096
471 22770000 24 12  6 2 1 8 4 55    100 460
472 099 7000 10 10  2 1 1 4 4 35     10 100     377
472 471 1000 11 11  2 1 1 1 4 25     10 227
472 473 1000 10 10  2 1 1 4 4 35      5 096
473 096 3700 10 10  2 1 1 4 4 35      5         291     380
473 097 1000 11 11  2 1 1 1 4 25     90 378
473 472 1000 10 10  2 1 1 4 4 35     10 099
474 126 1000 22 11  2 2 1 7 2 40    100 132
475 343 1000 22 11  2 2 1 7 2 40    100 368
480 021 1000 12 12  6 1 1 8 4 55    100 024
481 025 1000 12 12  6 1 1 8 4 55    100 022
485 047 4000 24 12  6 2 1 8 2 55    100 051     048
486 353 1000 22 11  2 2 1 7 4 40    100 200
488 460 1000 36 12  6 2 1 8 2 55    100 013
487 286 1000 22 11  2 2 1 7 4 40    100 364
489 132 1000 33 11  2 3 1 7 4 40    100 126
490 132 2000 36 12  6 2 1 8 2 55    100 126     124
491 364 1000 22 11  2 2 1 7 4 40    100 286
492 381 1000 22 11  2 2 1 7 4 40    100 109
493 380 1000 22 11  2 2 1 7 4 40    100 096
494 346 1000 22 11  2 2 1 7 4 40    100 349
495 288 1000 22 11  2 2 1 7 4 40    100 101
496 302 1000 22 11  2 2 1 7 4 40    100 142
497 343 1000 22 11  2 2 1 7 4 40    100 352
498 362 1000 22 11  2 2 1 7 4 40    100 360
499 358 1000 22 11  2 2 1 7 4 40    100 357
99999
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POPOPT1 Cape Cod Strong Storm Off-Peak Traffic, Rapid Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout1.dat'
outprint='popout1.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.05
/
&timeint
int1(1)=240.0 int1(2)=360.0 int1(3)=400.0 int1(4)=480.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT2 Cape Cod Strong Storm Off-Peak Traffic, Moderate Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout2.dat'
outprint='popout2.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.05
/
&timeint
int1(1)=60.0 int1(2)=240.0 int1(3)=300.0 int1(4)=420.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT3 Cape Cod Strong Storm Off-Peak Traffic, Slow Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout3.dat'
outprint='popout3.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.05
/
&timeint
int1(1)=0.0 int1(2)=120.0 int1(3)=200.0 int1(4)=360.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT4 Cape Cod Strong Storm Mid-Peak Traffic, Rapid Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout4.dat'
outprint='popout4.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.51 frc(3,2)=0.01 frc(3,3)=0.00 frc(3,4)=0.00
/
&timeint
int1(1)=660.0 int1(2)=780.0 int1(3)=820.0 int1(4)=900.0 int1(5)=1020.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=990.0 int2(5)=1110.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT5 Cape Cod Strong Storm Mid-Peak Traffic, Moderate Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout5.dat'
outprint='popout5.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.51 frc(3,2)=0.01 frc(3,3)=0.00 frc(3,4)=0.00
/
&timeint
int1(1)=480.0 int1(2)=660.0 int1(3)=720.0 int1(4)=840.0 int1(5)=1020.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=990.0 int2(5)=1110.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT6 Cape Cod Strong Storm Mid-Peak Traffic, Slow Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout6.dat'
outprint='popout6.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.51 frc(3,2)=0.01 frc(3,3)=0.00 frc(3,4)=0.00
/
&timeint
int1(1)=300.0 int1(2)=540.0 int1(3)=620.0 int1(4)=780.0 int1(5)=1020.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=990.0 int2(5)=1110.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT7 Cape Cod Strong Storm Peak Traffic, Rapid Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout7.dat'
outprint='popout7.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.52 frc(3,2)=0.17 frc(3,3)=0.15 frc(3,4)=0.01
/
&timeint
int1(1)=1140.0 int1(2)=1260.0 int1(3)=1300.0 int1(4)=1380.0 int1(5)=1500.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=1140.0 int2(5)=1250.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT8 Cape Cod Strong Storm Peak Traffic, Moderate Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout8.dat'
outprint='popout8.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.52 frc(3,2)=0.17 frc(3,3)=0.15 frc(3,4)=0.01
/
&timeint
int1(1)=960.0 int1(2)=1140.0 int1(3)=1200.0 int1(4)=1320.0 int1(5)=1500.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=1140.0 int2(5)=1250.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
```

```
POPOPT9 Cape Cod Strong Storm Peak Traffic, Slow Response
&files
filename(1)='strong_c.dat'
filename(2)='mnss_c.dat'
filename(3)='backgr_c.dat'
outfile='popout9.dat'
outprint='popout9.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.52 frc(3,2)=0.17 frc(3,3)=0.15 frc(3,4)=0.01
/
&timeint
int1(1)=780.0 int1(2)=1020.0 int1(3)=1110.0 int1(4)=1260.0 int1(5)=1500.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=1140.0 int2(5)=1250.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT10 Cape Cod Weak Storm Off-Peak Traffic, Rapid Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout10.dat'
outprint='popout10.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.05
/
&timeint
int1(1)=240.0 int1(2)=360.0 int1(3)=400.0 int1(4)=480.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
```

POPOPT11 Cape Cod Weak Storm Off-Peak Traffic, Moderate Response

```
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout11.dat'
outprint='popout11.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.05
/
&timeint
int1(1)=60.0 int1(2)=240.0 int1(3)=300.0 int1(4)=420.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT12 Cape Cod Weak Storm Off-Peak Traffic, Slow Response

```
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout12.dat'
outprint='popout12.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.03 frc(3,2)=0.03 frc(3,3)=0.03 frc(3,4)=0.05
/
&timeint
int1(1)=0.0 int1(2)=120.0 int1(3)=200.0 int1(4)=360.0 int1(5)=600.0
int2(1)=0.0 int2(2)=75.0 int2(3)=150.0 int2(4)=225.0 int2(5)=540.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT13 Cape Cod Weak Storm Mid-Peak Traffic, Rapid Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout13.dat'
outprint='popout13.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.51 frc(3,2)=0.01 frc(3,3)=0.00 frc(3,4)=0.00
/
&timeint
int1(1)=660.0 int1(2)=780.0 int1(3)=820.0 int1(4)=900.0 int1(5)=1020.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=990.0 int2(5)=1110.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT14 Cape Cod Weak Storm Mid-Peak Traffic, Moderate Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout14.dat'
outprint='popout14.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.51 frc(3,2)=0.01 frc(3,3)=0.00 frc(3,4)=0.00
/
&timeint
int1(1)=480.0 int1(2)=660.0 int1(3)=720.0 int1(4)=840.0 int1(5)=1020.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=990.0 int2(5)=1110.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT15 Cape Cod Weak Storm Mid-Peak Traffic, Slow Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout15.dat'
outprint='popout15.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.51 frc(3,2)=0.01 frc(3,3)=0.00 frc(3,4)=0.00
/
&timeint
int1(1)=300.0 int1(2)=540.0 int1(3)=620.0 int1(4)=780.0 int1(5)=1020.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=990.0 int2(5)=1110.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT16 Cape Cod Weak Storm Peak Traffic, Rapid Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout16.dat'
outprint='popout16.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.52 frc(3,2)=0.17 frc(3,3)=0.15 frc(3,4)=0.01
/
&timeint
int1(1)=1140.0 int1(2)=1260.0 int1(3)=1300.0 int1(4)=1380.0 int1(5)=1500.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=1140.0 int2(5)=1250.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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POPOPT17 Cape Cod Weak Storm Peak Traffic, Moderate Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout17.dat'
outprint='popout17.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.52 frc(3,2)=0.17 frc(3,3)=0.15 frc(3,4)=0.01
/
&timeint
int1(1)=960.0 int1(2)=1140.0 int1(3)=1200.0 int1(4)=1320.0 int1(5)=1500.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=1140.0 int2(5)=1250.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489

POPOPT18 Cape Cod Weak Storm Peak Traffic, Slow Response
&files
filename(1)='weak_c.dat'
filename(2)='mnsw_c.dat'
filename(3)='backgr_c.dat'
outfile='popout18.dat'
outprint='popout18.prt'
/
&poptype
atype(1)='vulnerable'
atype(2)='nonvul+mob'
atype(3)='backgrd'
/
&fraction
frc(1,1)=0.15 frc(1,2)=0.10 frc(1,3)=0.50 frc(1,4)=0.25
frc(2,1)=0.15 frc(2,2)=0.10 frc(2,3)=0.50 frc(2,4)=0.25
frc(3,1)=0.52 frc(3,2)=0.17 frc(3,3)=0.15 frc(3,4)=0.01
/
&timeint
int1(1)=780.0 int1(2)=1020.0 int1(3)=1100.0 int1(4)=1260.0 int1(5)=1500.0
int2(1)=0.0 int2(2)=630.0 int2(3)=930.0 int2(4)=1140.0 int2(5)=1250.0
/
169,223,247,346,494,486,060,488,115,123,302,374,078,498,499,334,481,480,
377,496,088,419,096,375,376,055,493,379,176,495,382,385,235,487,491,492,
291,497,193,062,420,200,064,069,074,463,464,474,489
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Background Traffic

BARN	3	2000	1.00	169	100								
BARN6W	3	7500	1.00	223	100								
BARN6W	3	10000	1.00	247	100								
BARN28W	3	25000	1.00	346	35	193	30	200	35				
BARN28W	3	3400	1.00	494	100								
BARN28E	3	10300	1.00	486	100								
BOUR	3	10000	1.00	060	20	062	20	064	20	069	20	074	20
BOUR	3	5000	1.00	488	100								
BOUR3A	3	5000	1.00	115	100								
BOURSW	3	9000	1.00	463	100								
BOURSE	3	15000	1.00	464	100								
BOURBE	3	15000	1.00	474	100								
BOURBW	3	6000	1.00	489	100								
BREW6A	3	10000	1.00	123	100								
CHAT28	3	10000	1.00	302	100								
EASTH6	3	4000	1.00	374	100								
FAL28	3	5000	1.00	078	100								
FAL28E	3	4000	1.00	498	100								
FAL	3	9000	1.00	499	100								
HARW28	3	12000	1.00	334	100								
HARW6E	3	5000	1.00	481	100								
HARW6W	3	8000	1.00	480	100								
KINGS	3	3000	1.00	377	100								
ORLE28	3	4000	1.00	496	100								
ORLE6	3	15000	1.00	088	100								
PTN6W	3	1000	1.00	419	50	420	50						
PTN6	3	7500	1.00	096	100								
MDL B	3	3000	1.00	375	100								
PLYMP	3	3000	1.00	376	100								
PTN6W	3	2000	1.00	055	100								
KN3AS	3	10000	1.00	493	100								
KN3S	3	30000	1.00	379	100								
SAND130	3	2500	1.00	176	100								
WELL6W	3	10000	1.00	495	100								
WM495S	3	25000	1.00	382	100								
WM195E	3	5000	1.00	385	100								
WM195E	3	1700	1.00	235	100								
WM6W	3	4500	1.00	487	100								
WM6E	3	6000	1.00	491	100								
WM28E	3	10000	1.00	492	100								
YARM6E	3	10000	1.00	291	100								
YARM28W	3	2200	1.00	497	100								

Severe Storm Surge Vulnerable Population File

0143	1	5792	1.99	201	20	206	30	311	30	202	20		
0144	1	176	1.99	217	100								
0145	1	3349	1.99	410	100								
0146	1	2721	1.99	413	50	411	50						
0147	1	5921	1.99	414	50	412	50						
0148	1	4091	1.99	218	40	415	60						
0149	1	3599	1.99	387	70	415	30						
0151	1	1197	2.02	407	50	213	50						
0152	1	7322	2.02	408	10	409	10	357	50	358	30		
0133	1	1360	1.95	443	100								
0134	1	2482	1.95	446	50	447	50						
0137	1	4383	2.12	018	100								
0138	1	610	2.12	116	100								
0139	1	3049	2.12	174	50	149	50						
0140	1	3319	2.12	066	30	182	20	174	30	183	20		
0122	1	1507	2.02	179	100								
0124	1	199	2.02	404	25	398	25	396	25	397	25		
0125	1	2740	2.02	416	50	402	25	400	25				
0127	1	3016	2.02	395	50	399	50						
0130	1	1553	2.02	403	50	199	50						
0132	1	888	2.02	405	100								
0118	1	2449	1.93	397	30	184	30	188	30	418	10		
0120	1	5475	1.93	396	20	187	80						
0121	1	10430	1.93	398	20	404	15	396	15	475	50		
0113	1	1132	1.94	438	50	448	50						
0114	1	796	1.94	445	100								
0115	1	1130	1.94	437	50	173	50						
0116	1	12444	1.94	417	10	392	10	181	50	342	30		
0117	1	6861	1.94	368	100								

Severe Storm Surge Vulnerable Population File (cont'd)

0108	1	2068	1.89	444	100							
0109	1	542	1.89	442	100							
0110	1	3644	1.88	390	50	389	50					
0111	1	148	1.88	388	100							
0112	1	5220	1.88	431	50	430	50					
0106	1	1980	1.91	432	100							
0107	1	4055	1.91	428	25	427	25	430	25	429	25	
0104	1	1237	1.82	441	100							
0105	1	3141	1.82	433	50	426	50					
0103	1	4896	1.77	439	40	436	30	434	30			
0102	1	6721	1.68	423	30	424	30	435	30	440	10	
0102	1	1130	1.68	421	50	422	50					
0101	1	4288	2.54	091	50	093	50					
5451	1	3624	2.16	286	50	108	50					
5452	1	4020	2.16	455	100							
5453	1	7112	2.16	281	100							
5454	1	8094	2.16	453	50	454	50					

Weak Storm Surge Vulnerable Population File

0143	1	5140	1.99	201	20	206	30	311	30	202	20	
0144	1	156	1.99	217	100							
0145	1	2627	1.99	410	100							
0146	1	2316	1.99	413	50	411	50					
0147	1	5156	1.99	414	50	412	50					
0148	1	2776	1.99	218	40	415	60					
0149	1	3089	1.99	387	70	415	30					
0151	1	873	2.02	407	50	213	50					
0152	1	6299	2.02	408	10	409	10	357	50	358	30	
0133	1	842	1.95	443	100							
0134	1	1978	1.95	446	50	447	50					
0137	1	3835	2.12	018	100							
0138	1	542	2.12	116	100							
0139	1	2479	2.12	174	50	149	50					
0140	1	2911	2.12	066	30	182	20	174	30	183	20	
0122	1	1339	2.02	179	100							
0124	1	177	2.02	404	25	398	25	396	25	397	25	
0125	1	2306	2.02	416	50	402	25	400	25			
0127	1	2119	2.02	395	50	399	50					
0130	1	1260	2.02	403	50	199	50					
0132	1	790	2.02	405	100							
0118	1	1893	1.93	397	30	184	30	188	30	418	10	
0120	1	3950	1.93	396	20	187	80					
0121	1	6567	1.93	398	20	404	15	396	15	475	50	
0113	1	915	1.94	438	50	448	50					
0114	1	707	1.94	445	100							
0115	1	850	1.94	437	50	173	50					
0116	1	8922	1.94	417	10	392	10	181	50	342	30	
0117	1	5865	1.94	368	100							
0108	1	1337	1.89	444	100							
0109	1	448	1.89	442	100							
0110	1	2875	1.88	390	50	389	50					
0111	1	131	1.88	388	100							
0112	1	3204	1.88	431	50	430	50					
0106	1	1640	1.91	432	100							
0107	1	3366	1.91	428	25	427	25	430	25	429	25	
0104	1	1099	1.82	441	100							
0105	1	2792	1.82	433	50	426	50					
0103	1	3550	1.77	439	40	436	30	434	30			
0102	1	4781	1.68	423	30	424	30	435	30	440	10	
0102	1	987	1.68	421	50	422	50					
0101	1	2474	2.54	091	50	093	50					
5451	1	2668	2.16	286	50	108	50					
5452	1	2892	2.16	455	100							
5453	1	5238	2.16	281	100							
5454	1	5960	2.16	453	50	454	50					

Severe Storm Mobile Home and Non-Surge Vulnerable Population File

PTOWN	2	383	2.54	091	50	093	50
TRURO	2	433	1.68	421	100		
WELLF	2	972	1.68	435	100		
EASTH	2	750	1.77	439	100		
ORLEA	2	532	1.82	433	100		

Severe Storm Mobile Home and Non-Surge Vulnerable Population File (cont'd)

CHATH	2	822	1.91	330	100			
HARW	2	1009	1.88	326	100			
BREWS	2	1118	1.89	442	50	130	50	
DENNI	2	1720	1.94	445	100			
YARM	2	1663	1.93	184	100			
BARN	2	2958	2.02	399	100			
SAND	2	952	1.95	446	100			
MASH	2	1285	2.02	408	100			
FALM	2	1685	1.99	211	100			
BOURN	2	1006	2.12	066	100			
WAREH	2	2379	2.16	453	100			

Weak Storm Mobile Home and Non-Surge Vulnerable Population File

PTOWN	2	164	2.54	091	50	093	50	
TRURO	2	180	1.68	421	100			
WELLF	2	715	1.68	435	100			
EASTH	2	301	1.77	439	100			
ORLEA	2	215	1.82	433	100			
CHATH	2	331	1.91	330	100			
HARW	2	407	1.88	326	100			
BREWS	2	457	1.89	442	50	130	50	
DENNI	2	788	1.94	445	100			
YARM	2	789	1.93	184	100			
BARN	2	1197	2.02	399	100			
SAND	2	399	1.95	446	100			
MASH	2	754	2.02	408	100			
FALM	2	678	1.99	211	100			
BOURN	2	509	2.12	066	100			
WAREH	2	2400	2.16	453	100			