A NEW STORM SURGE ATLAS FOR THE PAMLICO SOUND, NORTH CAROLINA 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.* (1992) has been applied to the Pamlico Sound, North Carolina 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 the five categories of storm intensity (Table 1) developed by Saffir and Simpson (Simpson and Riehl, 1981). Seven storm-track headings and three or four 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 containing the Pamlico Sound, North Carolina area.

2. THE GRID FOR THE NEW SLOSH MODEL OF THE PAMLICO SOUND, NORTH CAROLINA AREA

Figure 1 illustrates the area covered by the grid for the Pamlico Sound, North Carolina SLOSH model. The area covered by the grid is called a "basin"--the Pamlico Sound Basin. The grid is a telescoping elliptical coordinate system with 180 arc lengths ($1 \leq I \leq 180$) and 130 radials ($1 \leq J \leq 130$). The 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 square closest to the pole (at I=1) represents an area of

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

about 0.1 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=150) each grid square contains about 1.4 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 35°39'58"N and 76°48'W. The basin center is located at 35°30'39"N and 74°16'52"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 Pamlico Sound "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 110 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 of seafloor and land 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 bays 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 1995, 67 tropical cyclones of hurricane intensity passed within 165 statute miles of Cape Hatteras, North Carolina (Neumann *et al.*, 1993), for an average of one hurricane within the 165-mile circle every 1.7 years (see Table 2).

The tracks of these 67 storms with hurricane force winds are displayed as follows: storms heading south, southwest, west-southwest, west, or west-northwest are in Figure 2; northwest or north-northwest moving storms are in Figure 3; northbound storms are in Figure 4; storms heading north-northeast are in Figure 5 (before 1944) and Figure 6 (1944 or later); storms heading northeastward are in Figure 7 (before 1948) and Figure 8 (1948 or later); and Figure 9 displays storms heading east-northeast or eastbound. In Figures 2-9, 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 Cape Hatteras, Wilmington, North Carolina or Charleston, South Carolina, 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 2-9.

Table 2. Hurricanes passing within 165 statute mile circle centered on Cape Hatteras, North Carolina (35.25°N, 75.55°W), during 1886-1995.

>>> 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	1886 Jul 20	Unnamed	75	/	148	81	ENE	/	22
2	1886 Aug 24	Unnamed	120	/	122	98	NNE	/	19
3	1887 Aug 21	Unnamed	38	/	117	106	NE	/	33
4	1887 Aug 24	Unnamed	119	/	138	121	NE	/	20
5	1888 Nov 25	Unnamed	123	/	124	98	NNE	/	15
6	1891 Oct 12	Unnamed	83	/	094	98	N	/	10
7	1893 Aug 23	Unnamed	104	/	075	98	N	/	23
8	1894 Sep 28	Unnamed	58	/	314	84	NE	/	8
9	1894 Oct 10	Unnamed	90	/	310	77	NE	/	29
10	1896 Oct 11	Unnamed	114	/	131	98	NE	/	12
11	1899 Aug 17	Unnamed	14	/	239	121	NW	/	4
12	1899 Oct 31	Unnamed	147	/	287	81	NNE	/	31
13	1901 Jul 11	Unnamed	44	/	321	98	SW	/	13
14	1903 Sep 16	Unnamed	142	/	074	98	NNW	/	21
15	1903 Oct 10	Unnamed	120	/	119	81	N	/	19
16	1904 Sep 15	Unnamed	144	/	308	75	NE	/	33
17	1906 Sep 17	Unnamed	149	/	197	123	WNW	/	16
18	1908 Jul 31	Unnamed	25	/	323	98	NE	/	14
19	1912 Oct 6	Unnamed	145	/	170	92	WSW	/	3
20	1912 Nov 23	Unnamed	157	/	106	75	NNE	/	29
21	1913 Sep 3	Unnamed	43	/	216	85	NW	/	4
22	1916 Jul 20	Unnamed	142	/	092	108	N	/	10
23	1924 Aug 26	Unnamed	32	/	131	127	NNE	/	22
24	1927 Aug 24	Unnamed	139	/	094	115	N	/	21
25	1930 Sep 12	Unnamed	58	/	137	85	NE	/	17
26	1933 Aug 23	Unnamed	21	/	047	109	NW	/	12
27	1933 Sep 16	Unnamed	17	/	284	121	NNE	/	17
28	1934 Sep 8	Unnamed	12	/	129	89	NNE	/	29
29	1935 Sep 6	Unnamed	97	/	327	77	ENE	/	22
30	1936 Sep 18	Unnamed	21	/	060	108	NNW	/	8
31	1938 Sep 21	Unnamed	137	/	106	121	NNE	/	37
32	1940 Sep 1	Unnamed	51	/	101	81	NNE	/	8
33	1944 Sep 14	Unnamed	9	/	063	108	NNE	/	33
34	1948 Aug 31	Unnamed	131	/	141	91	NE	/	13
35	1949 Aug 24	Unnamed	28	/	135	109	NE	/	18
36	1950 Aug 20	Able	64	/	114	137	NNE	/	30
37	1951 May 21	Able	63	/	108	115	NNE	/	14
38	1951 Oct 4	How	74	/	135	109	NE	/	10

Table 2. Hurricanes passing within 165 statute mile circle centered on Cape Hatteras, North Carolina (35.25°N, 75.55°W), during 1886-1995.

>>> 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)
39	1953 Aug 14	Barbara	21	/	271	109	NNE	/	13
40	1954 Aug 31	Carol	9	/	116	98	NNE	/	40
41	1954 Sep 11	Edna	33	/	119	121	NNE	/	19
42	1954 Oct 15	Hazel	164	/	276	104	N	/	47
43	1955 Aug 12	Connie	28	/	281	101	N	/	10
44	1955 Aug 17	Diane	153	/	250	86	NNW	/	13
45	1955 Sep 19	Ione	59	/	309	113	NE	/	15
46	1958 Aug 28	Daisy	84	/	095	127	N	/	18
47	1958 Sep 28	Helene	22	/	152	132	ENE	/	27
48	1960 Sep 12	Donna	52	/	315	109	NE	/	33
49	1961 Sep 20	Esther	129	/	097	138	N	/	13
50	1962 Aug 28	Alma	15	/	104	86	NE	/	22
51	1963 Oct 21	Ginny	77	/	164	92	ENE	/	5
52	1964 Oct 16	Isbell	51	/	272	75	N	/	13
53	1966 Jun 11	Alma	107	/	182	81	E	/	12
54	1967 Sep 17	Doria	40	/	275	75	S	/	10
55	1968 Oct 20	Gladys	18	/	122	84	NE	/	23
56	1969 Sep 9	Gerda	50	/	146	112	NE	/	29
57	1971 Sep 30	Ginger	75	/	226	98	NNW	/	6
58	1972 Sep 9	Dawn	62	/	074	77	S	/	8
59	1976 Aug 9	Belle	59	/	098	117	N	/	26
60	1981 Aug 22	Dennis	9	/	015	75	ENE	/	19
61	1984 Sep 14	Diana	31	/	342	132	ENE	/	16
62	1985 Sep 27	Gloria	9	/	195	104	N	/	27
63	1986 Aug 17	Charley	38	/	286	81	NNE	/	13
64	1991 Aug 19	Bob	29	/	092	115	NNE	/	23
65	1993 Aug 31	Emily	29	/	117	115	NNE	/	13
66	1994 Nov 18	Gordon	106	/	179	85	W	/	10
67	1995 Aug 17	Felix	150	/	090	75	W	/	3

Notes:

(1) Storm number for this list.

(2) Year, month and date that storm had maximum winds exceeding 74 mph and was closest to Cape Hatteras, North Carolina.

(3) Storms were not formally named before 1950.

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

(6) Maximum sustained wind speed near storm center while center was within 165 statute miles of Cape Hatteras. 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 2-9, 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 165 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 Pamlico Sound 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 Pamlico Sound 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 (using the categories defined by Safir and Simpson), storm speed, and storm direction. We created such maps for this basin by making surge calculations for each of an ensemble of 13 to 20 storms; in an ensemble, all storms had the same intensity and speed and had parallel headings, separated by 10 miles or less. 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 Pamlico Sound basin, the hypothetical storms were specified to move in one of seven directions at either 5, 15, 25, or 35 miles per hour, as summarized in Table 3. There were 20 tracks for the westbound (W) storms (Figure 10), 20 tracks for the west-northwestward

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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 Cape Hatteras in 24 hours, and if, in fact, it made landfall *anywhere* along the coast between the mouths of Chesapeake Bay and the New River, the error in forecast landfall position would be no worse than average.

Table 3. Pamlico Sound 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
W	5, 15, 25	1 through 5	20	300	15
WNW	5, 15, 25	1 through 5	20	300	15
NW	5, 15, 25, 35	1 through 5	20	400	20
NNW	5, 15, 25, 35	1 through 5	20	400	20
N	5, 15, 25, 35	1 through 5	20	400	20
NNE	5, 15, 25, 35	1 through 5	15	300	20
NE	5, 15, 25, 35	1 through 5	13	260	20
			Totals:	2,360	130

(WNW) moving storms (Figure 11), 20 tracks for the northwestbound (NW) storms (Figure 12), 20 tracks for the north-northwestward (NNW) moving storms (Figure 13), 20 tracks for the northbound (N) storms (Figure 14), 15 tracks for the north-northeastward (NNE) moving storms (Figure 15), and 13 tracks for the northeastward (NE) storm headings (Figure 16). In total, 2,360 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. But as seen in Figures 13 through 16, some tracks of hypothetical storms do not intersect the Carolina coastline. On some of these tracks the label "INV" is shown, which indicates that the ΔP and RMW used to model storms on this track were invariant for all 72 hours of model time. All other storms underwent pressure filling and RMW increases with time, as summarized in Table 4. 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 +1 ft MSL before arrival of a hurricane are not uncommon. Furthermore, to simulate conditions at high tide, an additional 2 ft was included. Thus, all SLOSH runs of hypothetical hurricanes were supplied with initial datums of +3 ft MSL (ocean) or 1 ft MSL (bays and lakes); the resulting calculations of storm surge represent conditions at time of high tide.

D. The "MEOW" Figures

There are 130 MEOWS and they are presented in the Appendix. The MEOW figures are grouped by direction: MEOWS for westbound storms are in Figures A1-A15, west-northwestbound storms' MEOWS are in Figures A16-A30, northwestbound storms' MEOWS are in Figures A31-A50, north-northwestbound storms' MEOWS are in Figures A51-A70, MEOWS for northbound storms are in Figures A71-A90, MEOWS in Figures A91-A110 are for storms moving towards the north-northeast, and MEOWS for northeastward moving storms are in Figures A111-A130. 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 4. Time change of pressure difference and radius of maximum wind for hypothetical hurricanes not labelled "invariant" in Pamlico Sound basin.

A) 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 6, 12, 18 and 24 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	20	12	30	10	35	10	40	10	45
2	40	20	22	30	14	35	11	40	10	45
3	60	20	35	25	22	30	16	35	12	40
4	80	20	38	20	24	30	17	35	13	40
5	100	20	40	20	25	25	17	30	13	40

B) Values of pressure difference (ΔP, millibars) at landfall (LF) and at each of the first six hours after LF.

	Landfall	LF+1	LF+2	LF+3	LF+4	LF+5	LF+6
Category	ΔP	ΔP	ΔP	ΔP	ΔP	ΔP	ΔP
1	20	18	16	15	14	13	12
2	40	37	34	31	28	25	22
3	60	54	50	45	41	38	35
4	80	63	56	51	47	43	38
5	100	67	58	53	48	44	40

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8. APPENDIX: MAXIMUM ENVELOPES OF WATER (MEOW)

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

A-33 Northwestbound, 5 mph, category 3 hurricane.

A-34 Northwestbound, 5 mph, category 4 hurricane.

A-35 Northwestbound, 5 mph, category 5 hurricane.

A-36 Northwestbound, 15 mph, category 1 hurricane.

A-37 Northwestbound, 15 mph, category 2 hurricane.

A-38 Northwestbound, 15 mph, category 3 hurricane.

A-39 Northwestbound, 15 mph, category 4 hurricane.

A-40 Northwestbound, 15 mph, category 5 hurricane.

A-41 Northwestbound, 25 mph, category 1 hurricane.

A-42 Northwestbound, 25 mph, category 2 hurricane.

A-43 Northwestbound, 25 mph, category 3 hurricane.

A-44 Northwestbound, 25 mph, category 4 hurricane.

A-45 Northwestbound, 25 mph, category 5 hurricane.

A-46 Northwestbound, 35 mph, category 1 hurricane.

A-47 Northwestbound, 35 mph, category 2 hurricane.

A-48 Northwestbound, 35 mph, category 3 hurricane.

A-49 Northwestbound, 35 mph, category 4 hurricane.

A-50 Northwestbound, 35 mph, category 5 hurricane.

A-51 North-northwestbound, 5 mph, category 1 hurricane.

A-52 North-northwestbound, 5 mph, category 2 hurricane.

A-53 North-northwestbound, 5 mph, category 3 hurricane.

A-54 North-northwestbound, 5 mph, category 4 hurricane.

A-55 North-northwestbound, 5 mph, category 5 hurricane.

A-56 North-northwestbound, 15 mph, category 1 hurricane.

A-57 North-northwestbound, 15 mph, category 2 hurricane.

A-58 North-northwestbound, 15 mph, category 3 hurricane.

A-59 North-northwestbound, 15 mph, category 4 hurricane.

A-60 North-northwestbound, 15 mph, category 5 hurricane.

A-61 North-northwestbound, 25 mph, category 1 hurricane.

A-62 North-northwestbound, 25 mph, category 2 hurricane.

A-63 North-northwestbound, 25 mph, category 3 hurricane.

A-64 North-northwestbound, 25 mph, category 4 hurricane.

A-65 North-northwestbound, 25 mph, category 5 hurricane.

A-66 North-northwestbound, 35 mph, category 1 hurricane.

A-67 North-northwestbound, 35 mph, category 2 hurricane.

A-68 North-northwestbound, 35 mph, category 3 hurricane.

A-69 North-northwestbound, 35 mph, category 4 hurricane.

A-70 North-northwestbound, 35 mph, category 5 hurricane.

A-71 Northbound, 5 mph, category 1 hurricane.

A-72 Northbound, 5 mph, category 2 hurricane.

A-73 Northbound, 5 mph, category 3 hurricane.

A-74 Northbound, 5 mph, category 4 hurricane.

A-75 Northbound, 5 mph, category 5 hurricane.

A-76 Northbound, 15 mph, category 1 hurricane.

A-77 Northbound, 15 mph, category 2 hurricane.

A-78 Northbound, 15 mph, category 3 hurricane.

A-79 Northbound, 15 mph, category 4 hurricane.

A-80 Northbound, 15 mph, category 5 hurricane.

A-81 Northbound, 25 mph, category 1 hurricane.

A-82 Northbound, 25 mph, category 2 hurricane.

A-83 Northbound, 25 mph, category 3 hurricane.

A-84 Northbound, 25 mph, category 4 hurricane.

A-85 Northbound, 25 mph, category 5 hurricane.

A-86 Northbound, 35 mph, category 1 hurricane.

A-87 Northbound, 35 mph, category 2 hurricane.

A-88 Northbound, 35 mph, category 3 hurricane.

A-89 Northbound, 35 mph, category 4 hurricane.

A-90 Northbound, 35 mph, category 5 hurricane.

A-91 North-northeastbound, 5 mph, category 1 hurricane.

A-92 North-northeastbound, 5 mph, category 2 hurricane.

A-93 North-northeastbound, 5 mph, category 3 hurricane.

A-94 North-northeastbound, 5 mph, category 4 hurricane.

A-95 North-northeastbound, 5 mph, category 5 hurricane.

A-96 North-northeastbound, 15 mph, category 1 hurricane.

A-97 North-northeastbound, 15 mph, category 2 hurricane.

A-98 North-northeastbound, 15 mph, category 3 hurricane.

A-99 North-northeastbound, 15 mph, category 4 hurricane.

A-100 North-northeastbound, 15 mph, category 5 hurricane.

A-101 North-northeastbound, 25 mph, category 1 hurricane.

A-102 North-northeastbound, 25 mph, category 2 hurricane.

A-103 North-northeastbound, 25 mph, category 3 hurricane.

A-104 North-northeastbound, 25 mph, category 4 hurricane.

A-105 North-northeastbound, 25 mph, category 5 hurricane.

A-106 North-northeastbound, 35 mph, category 1 hurricane.

A-107 North-northeastbound, 35 mph, category 2 hurricane.

A-108 North-northeastbound, 35 mph, category 3 hurricane.

A-109 North-northeastbound, 35 mph, category 4 hurricane.

A-110 North-northeastbound, 35 mph, category 5 hurricane.

A-111 Northeastbound, 5 mph, category 1 hurricane.

A-112 Northeastbound, 5 mph, category 2 hurricane.

A-113 Northeastbound, 5 mph, category 3 hurricane.

A-114 Northeastbound, 5 mph, category 4 hurricane.

A-115 Northeastbound, 5 mph, category 5 hurricane.

A-116 Northeastbound, 15 mph, category 1 hurricane.

A-117 Northeastbound, 15 mph, category 2 hurricane.

A-118 Northeastbound, 15 mph, category 3 hurricane.

A-119 Northeastbound, 15 mph, category 4 hurricane.

A-120 Northeastbound, 15 mph, category 5 hurricane.

A-121 Northeastbound, 25 mph, category 1 hurricane.

A-122 Northeastbound, 25 mph, category 2 hurricane.

A-123 Northeastbound, 25 mph, category 3 hurricane.

A-124 Northeastbound, 25 mph, category 4 hurricane.

A-125 Northeastbound, 25 mph, category 5 hurricane.

A-126 Northeastbound, 35 mph, category 1 hurricane.

A-127 Northeastbound, 35 mph, category 2 hurricane.

A-128 Northeastbound, 35 mph, category 3 hurricane.

A-129 Northeastbound, 35 mph, category 4 hurricane.

A-130 Northeastbound, 35 mph, category 5 hurricane.

9. FIGURE CAPTIONS

Figure 1. Grid mesh for the new SLOSH model of the Pamlico Sound, North Carolina basin.

Figure 2. Tracks of hurricanes (1886-1995) passing within 165 statute miles of Cape Hatteras, North Carolina: storms heading south, southwest, west-southwest, west, or west-northwest.

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

Figure 4. Same as Figure 2, but only northbound storms.

Figure 5. Same as Figure 2, but only storms before 1944 heading north-northeastward.

Figure 6. Same as Figure 2, but only for storms 1944 or later heading north-northeastward.

Figure 7. Same as Figure 2, but only storms before 1948 moving northeastward.

Figure 8. Same as Figure 2, but only for storms 1948 and later heading northeastward.

Figure 9. Same as Figure 2, but only storms heading east-northeast or eastbound.

Figure 10. Tracks of the hypothetical hurricanes that were used for calculating the maximum envelope of water (MEOW). Hurricane symbol is usually at point of "landfall" of eye of storm, and dots are eye positions at six-hour increments (at 15 mph). Tracks are identified by the distance in miles to the left side (LS) or right side (RS) of the track through Cape Hatteras, North Carolina. "INV" (for invariant) tracks had no changes in ΔP or RMW. Westbound (W) storms only.

Figure 11. Same as Figure 10, but only for west-northwestward (WNW) moving storms.

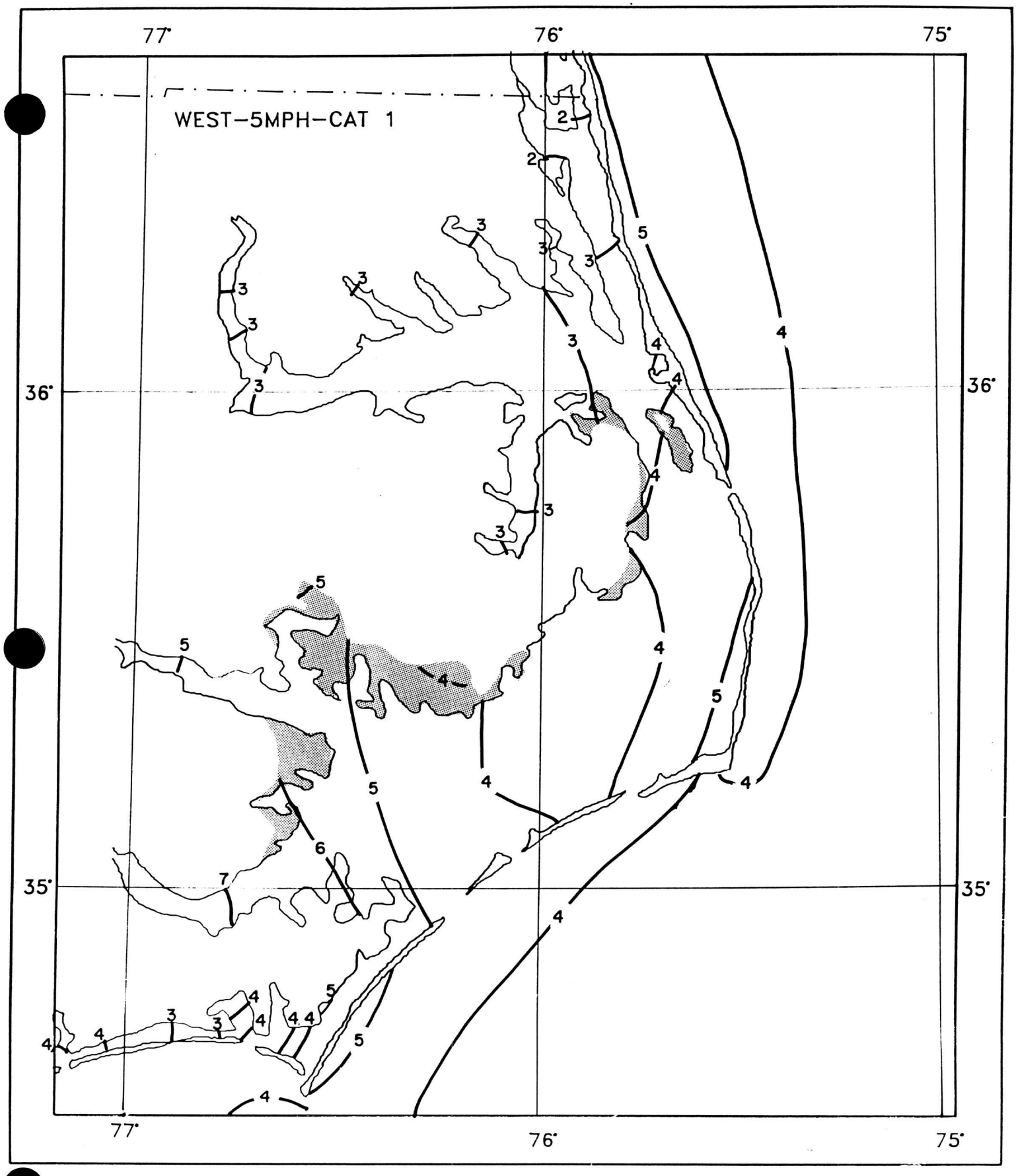
Figure 12. Same as Figure 10, but only for northwestbound (NW) storms.

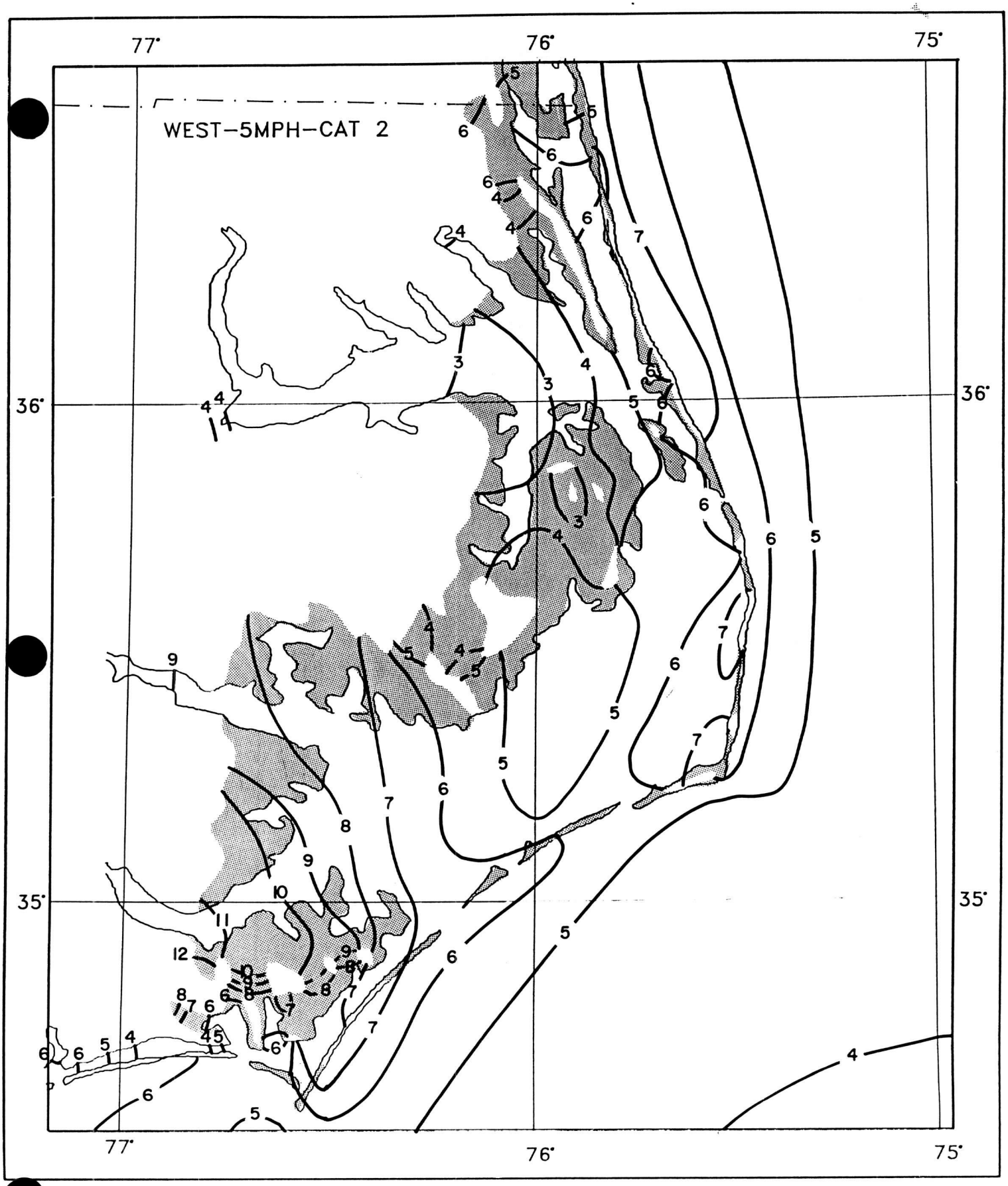
Figure 13. Same as Figure 10, but for north-northwestward (NNW) moving storms only.

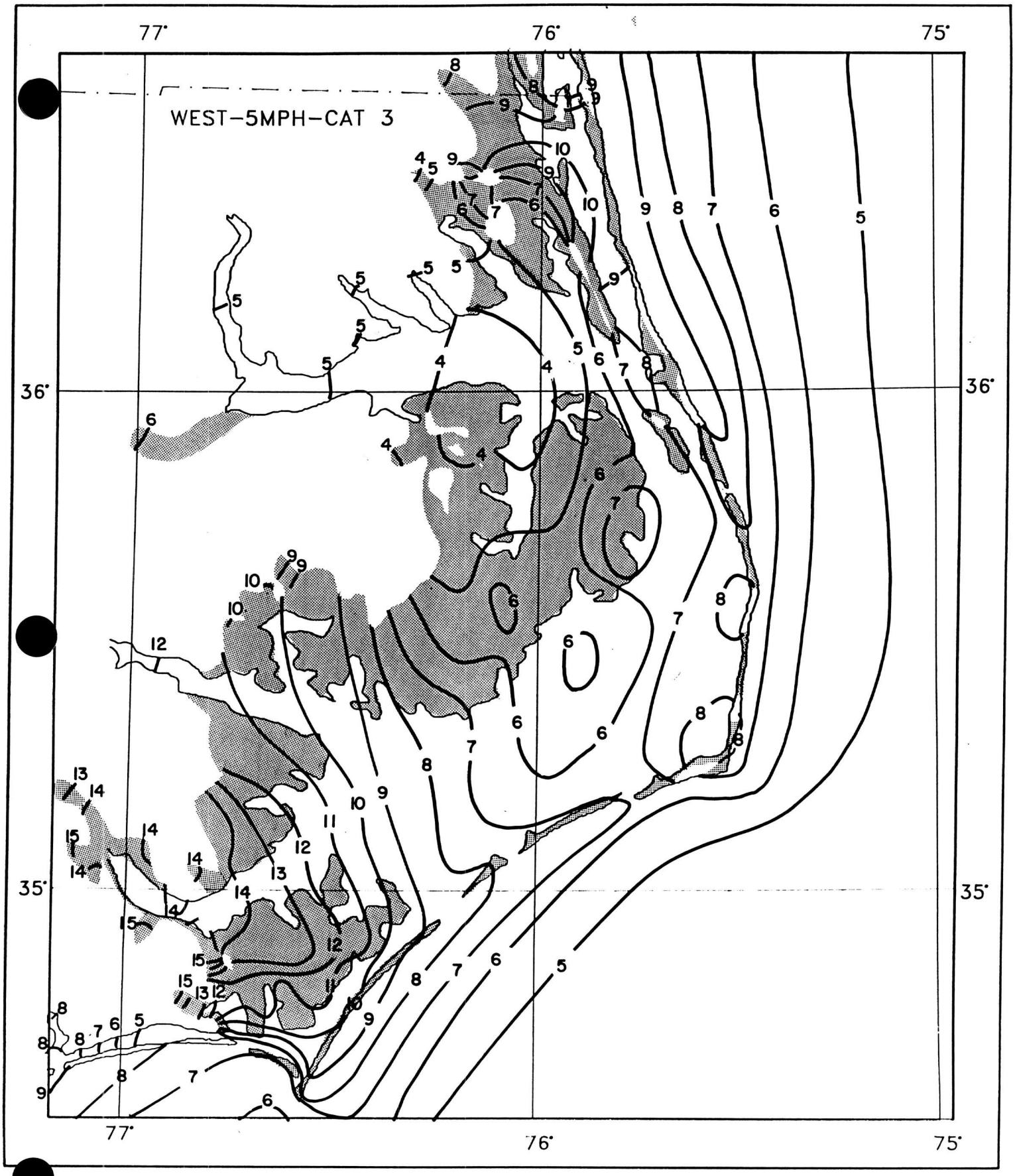
Figure 14. Same as Figure 10, but only for northbound (N) storms.

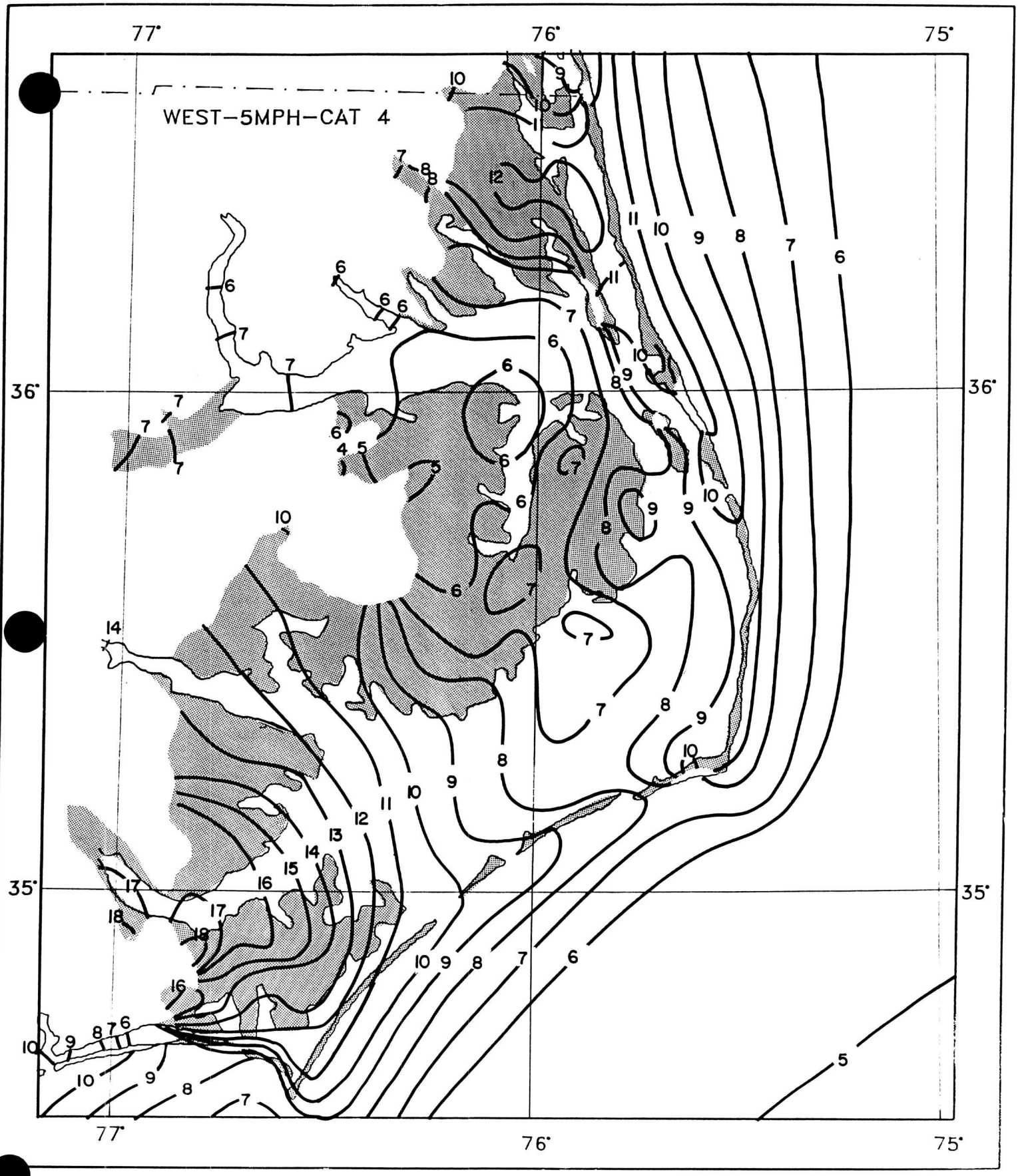
Figure 15. Same as Figure 10, but for north-northeastbound (NNE) moving storms only.

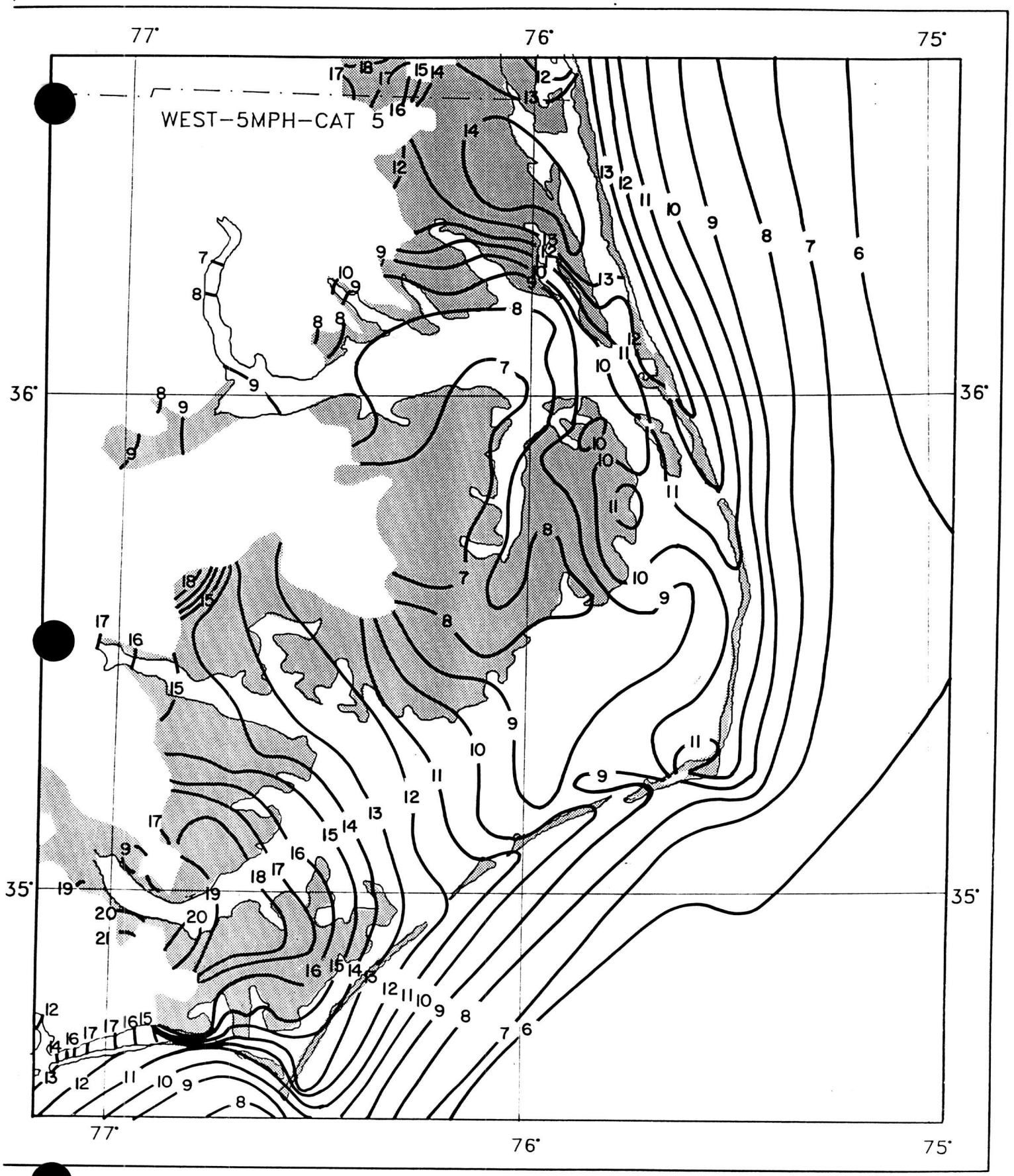
Figure 16. Same as Figure 10, except for northeastbound (NE) storms only.

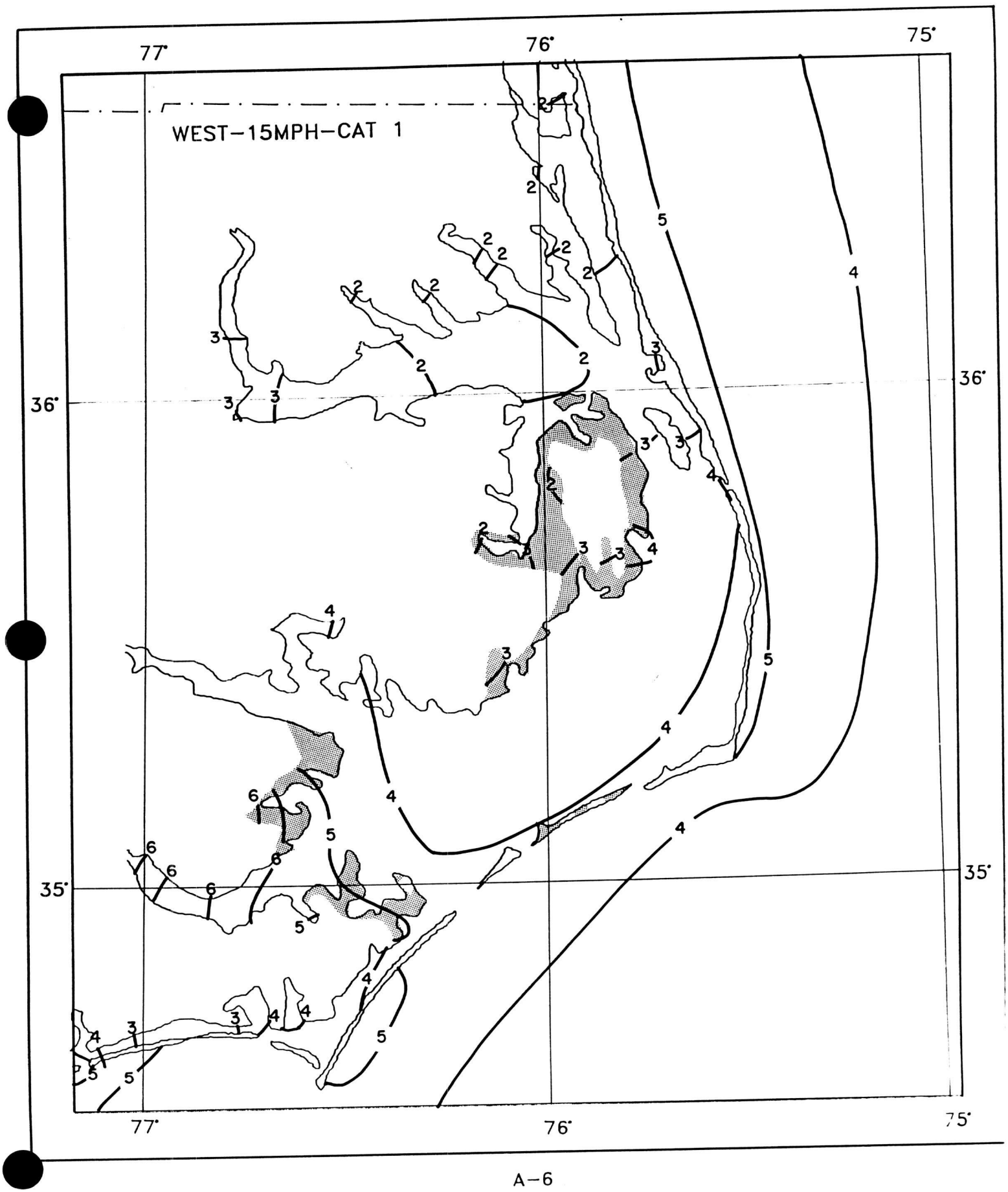

WEST–5MPH–CAT 1
77°
76°
75°
36°
35°

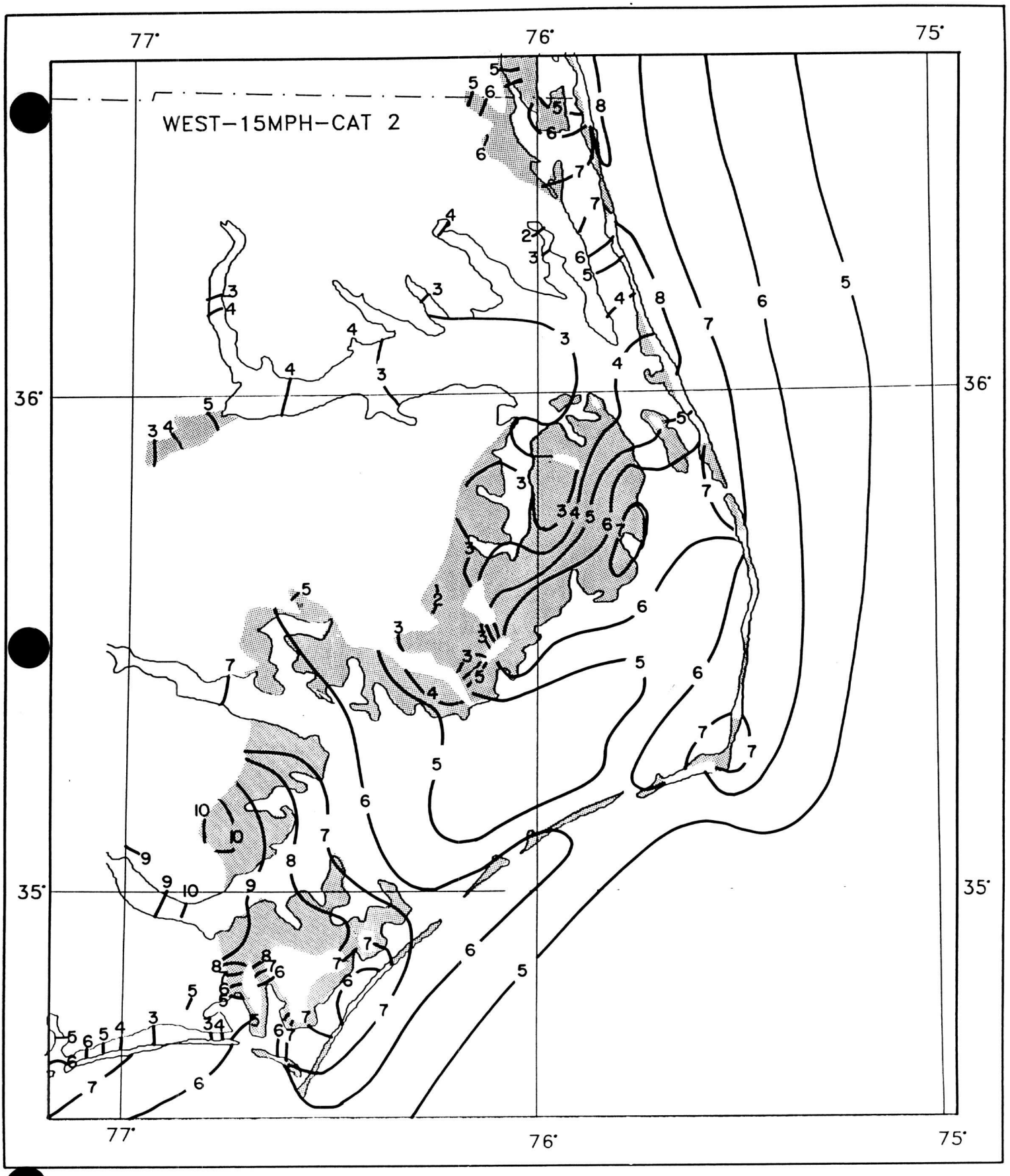

WEST–5MPH–CAT 2
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35°

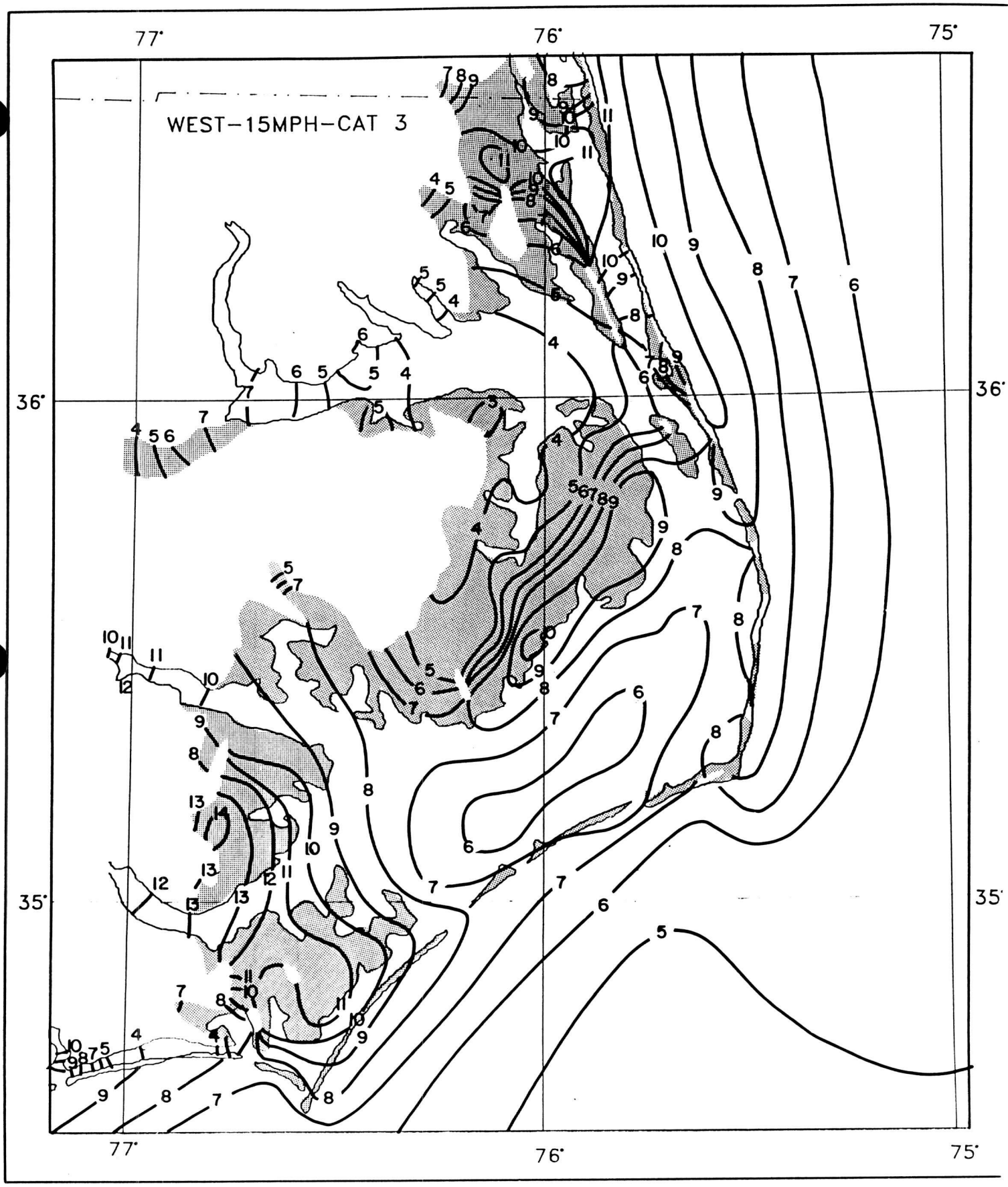

WEST–5MPH–CAT 3
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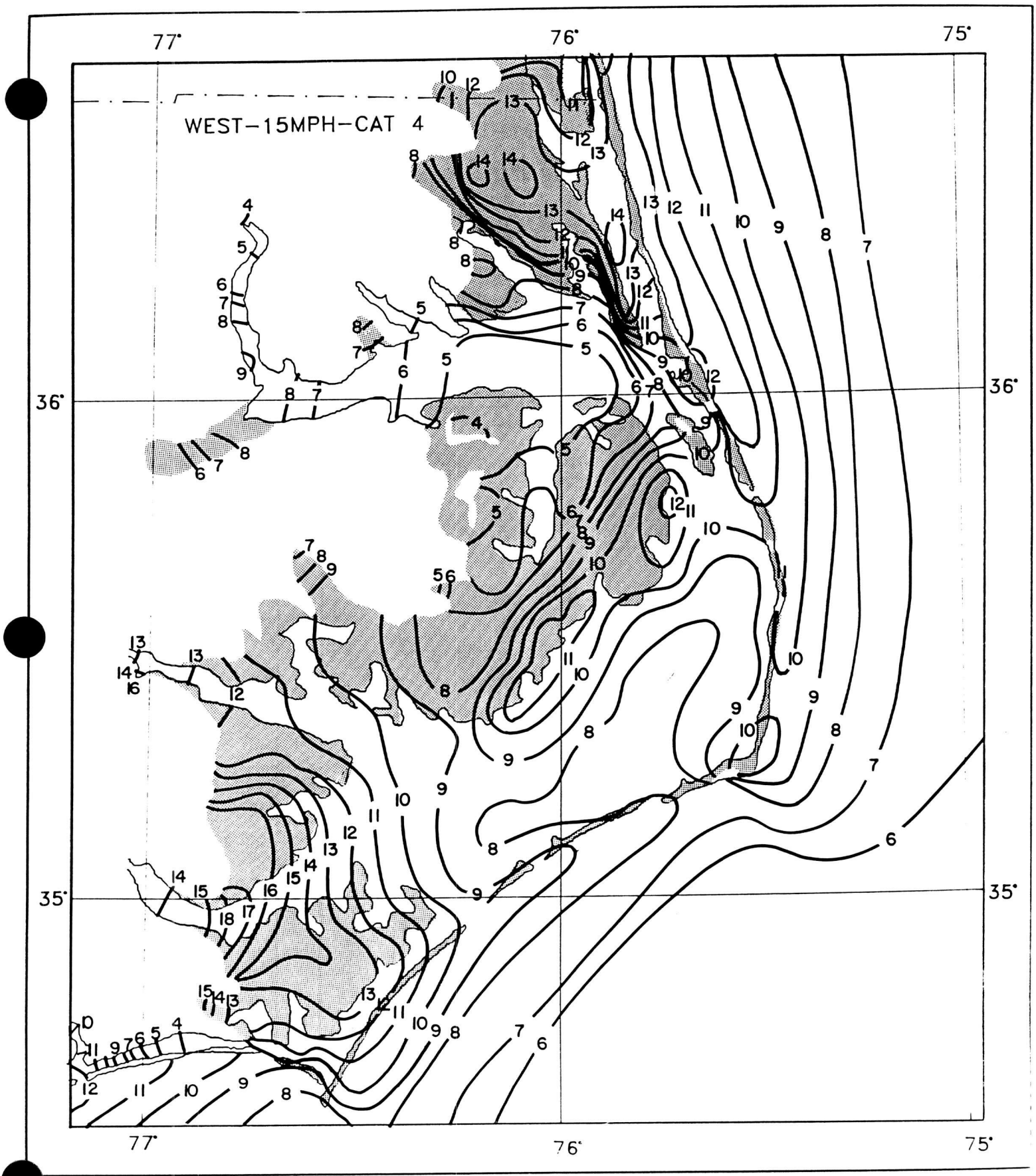

77°
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WEST–5MPH–CAT 4

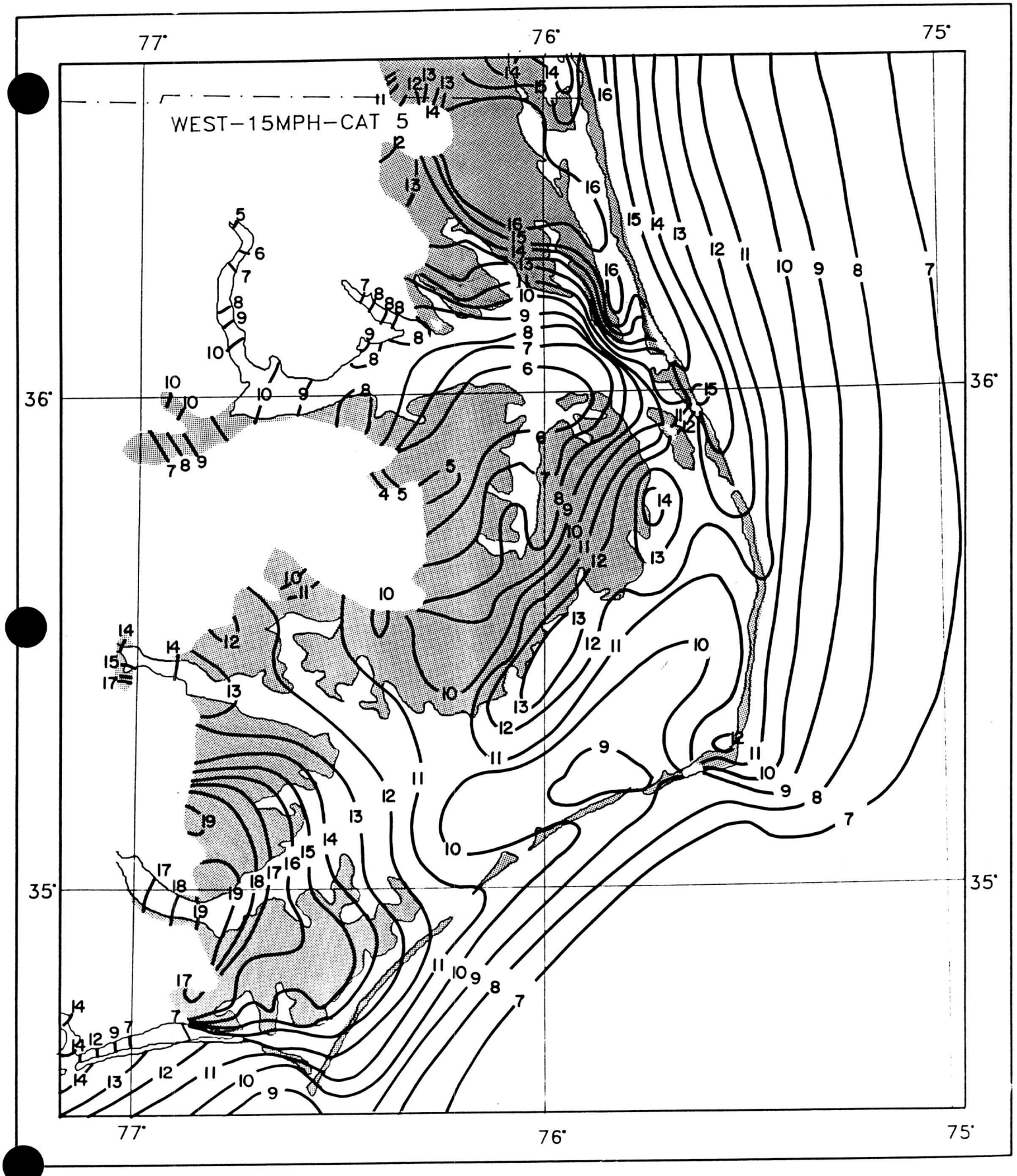

77°
76°
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WEST–5MPH–CAT 5
36°
35°

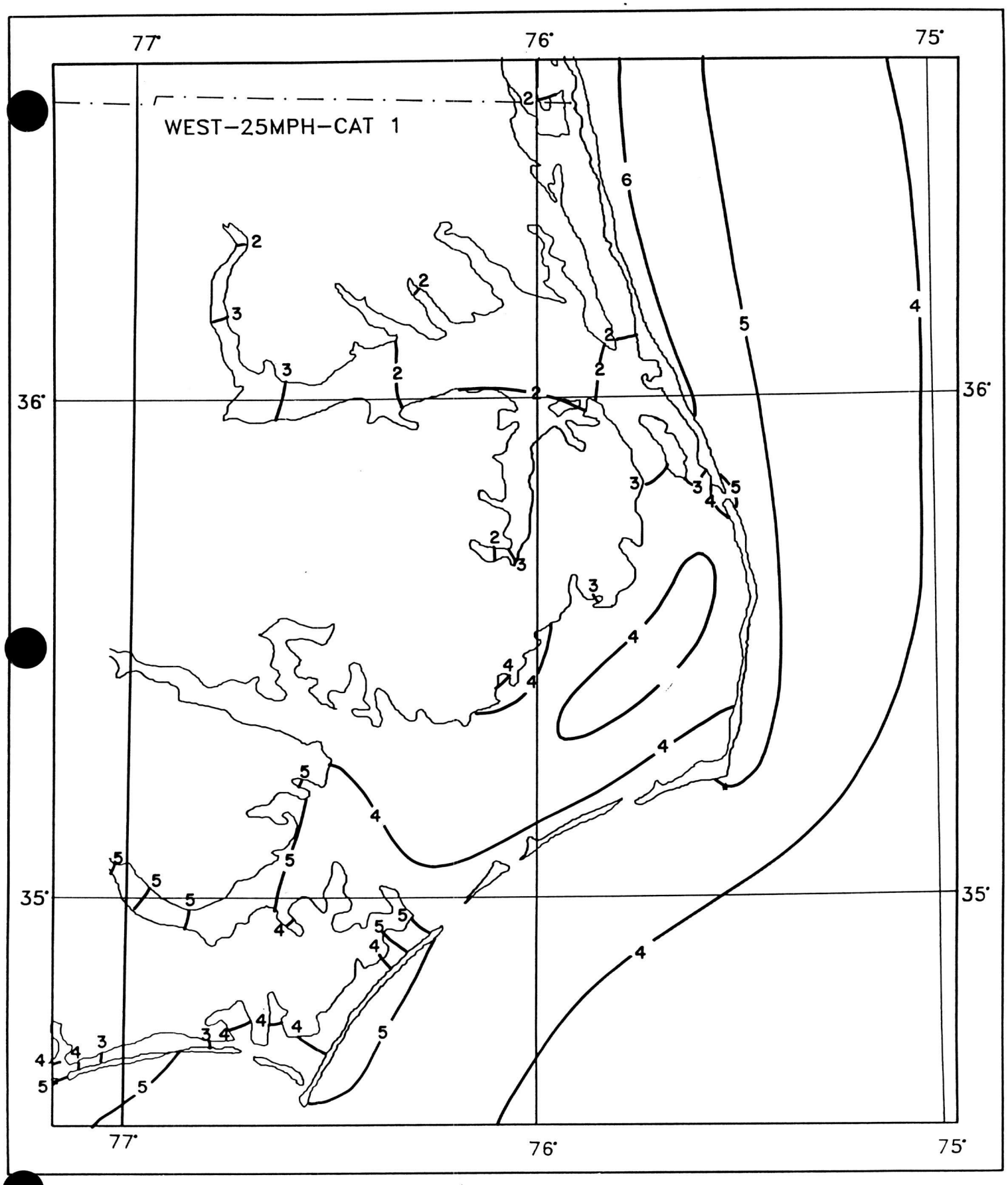

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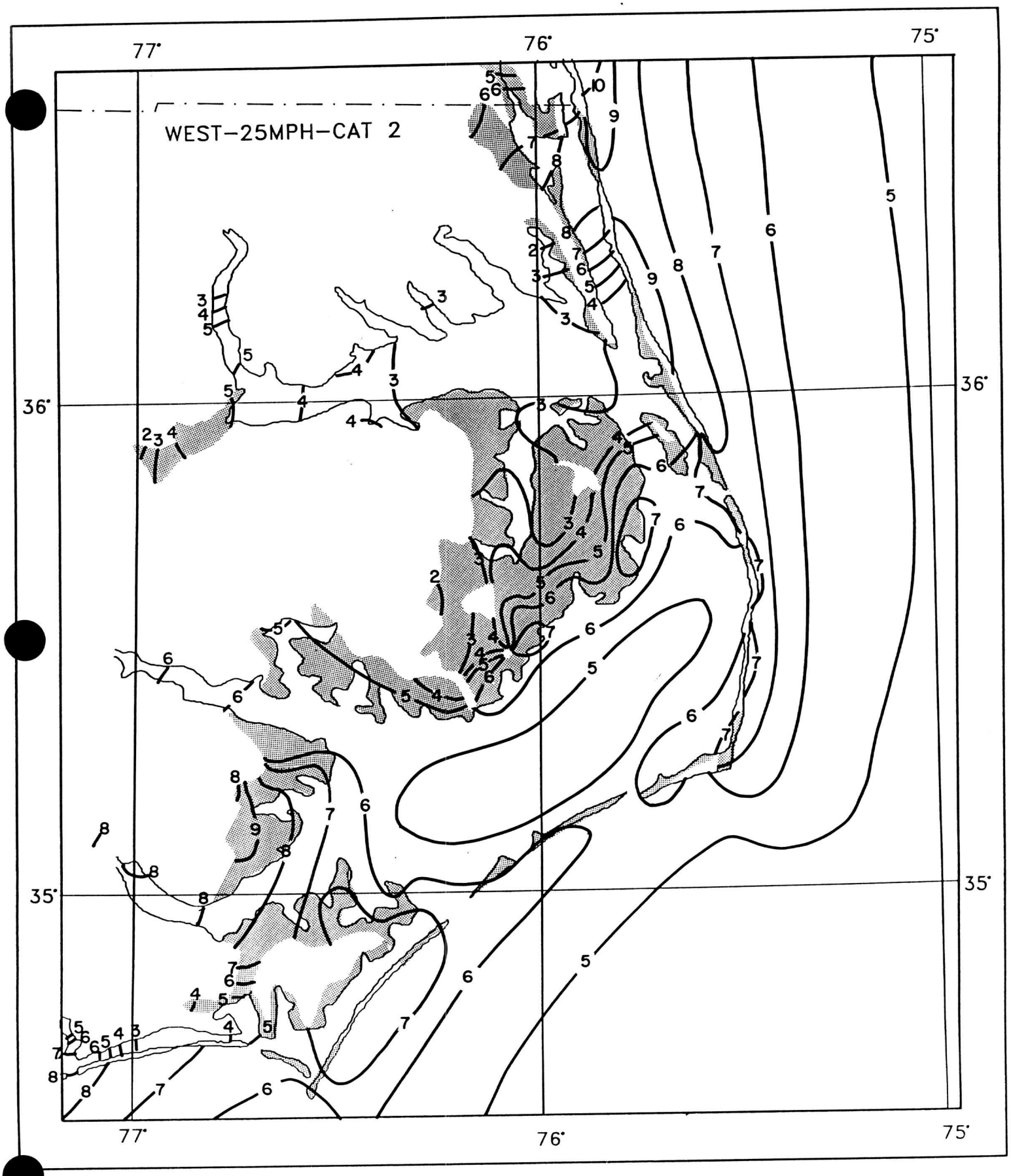

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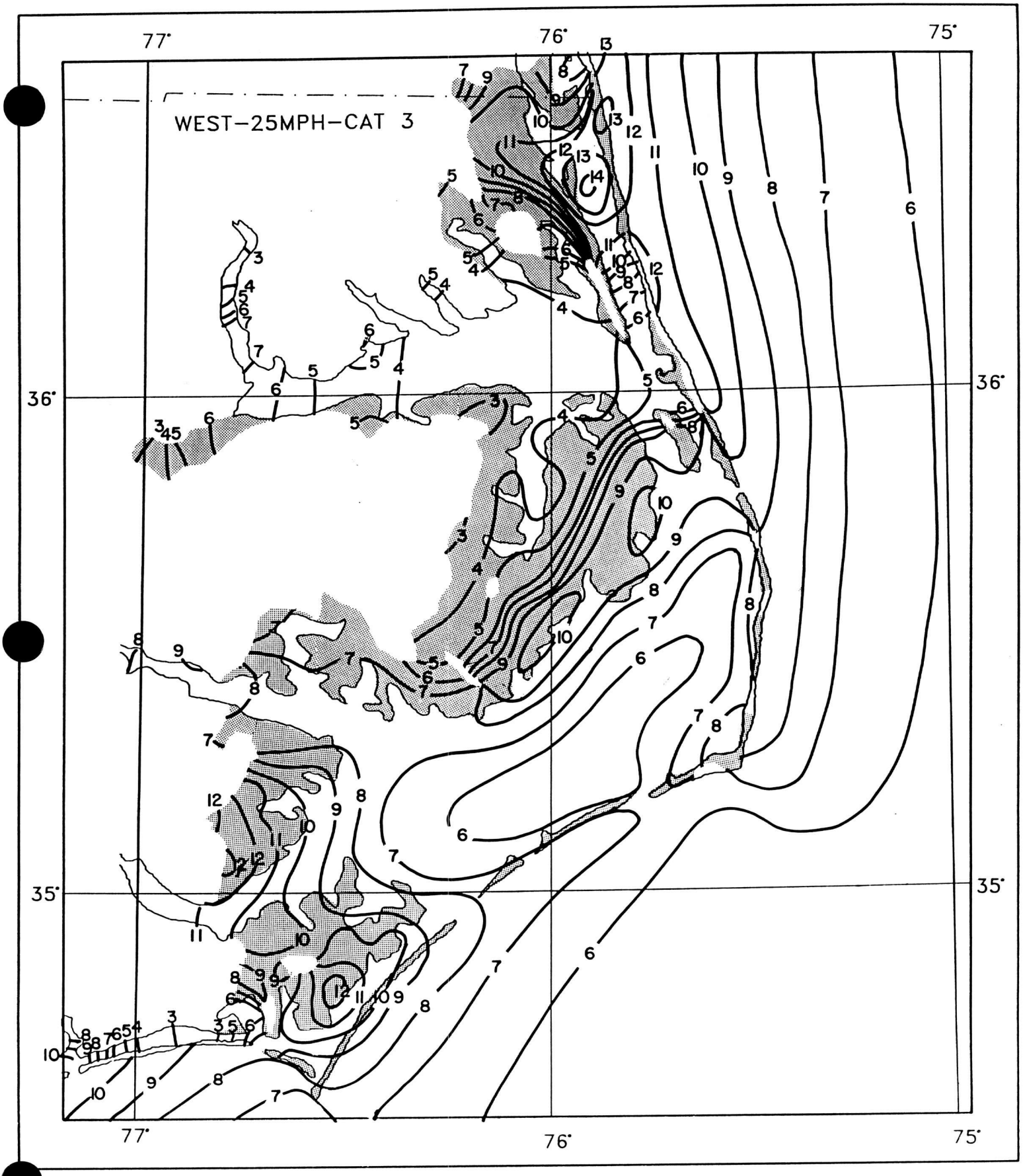

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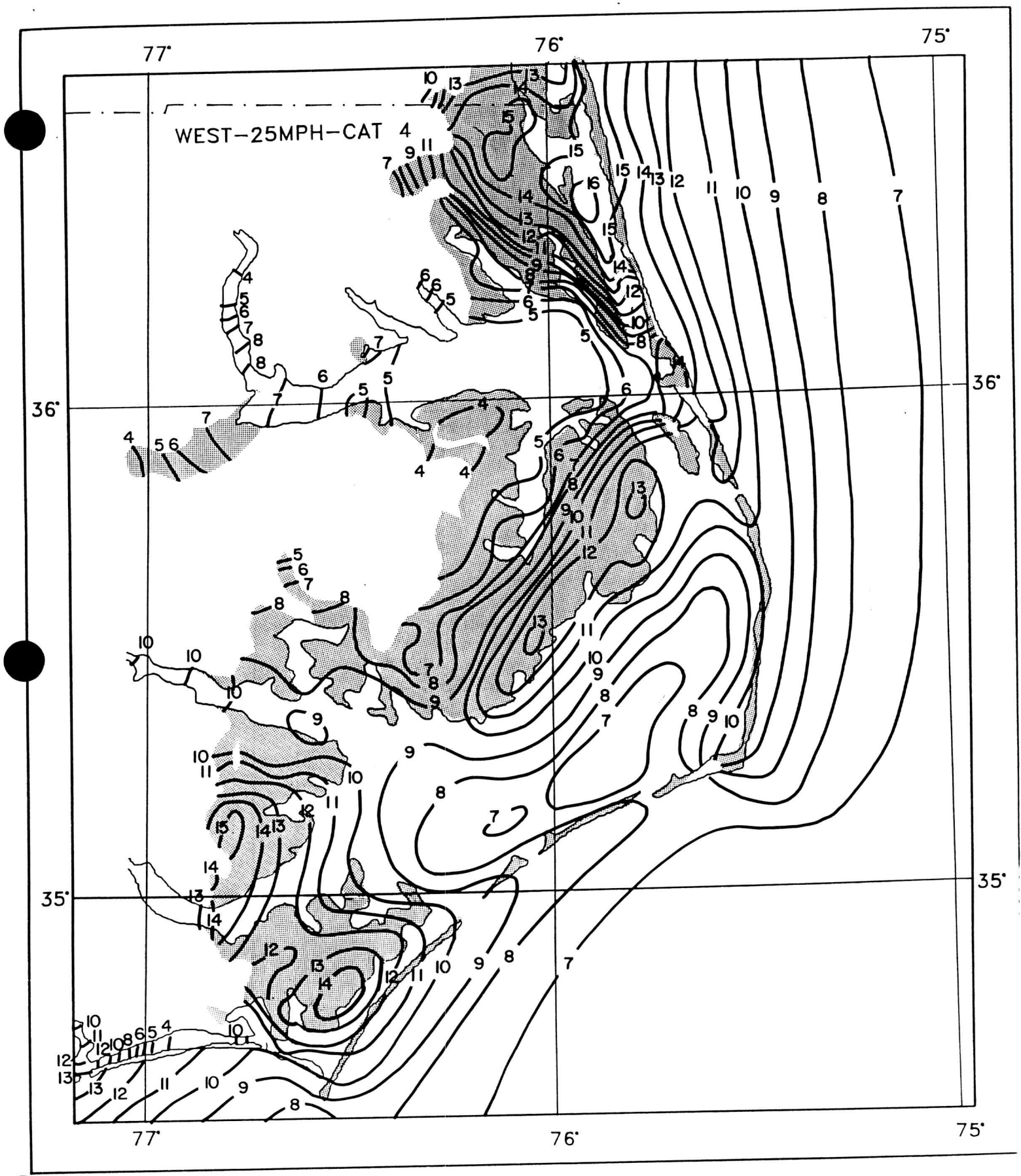

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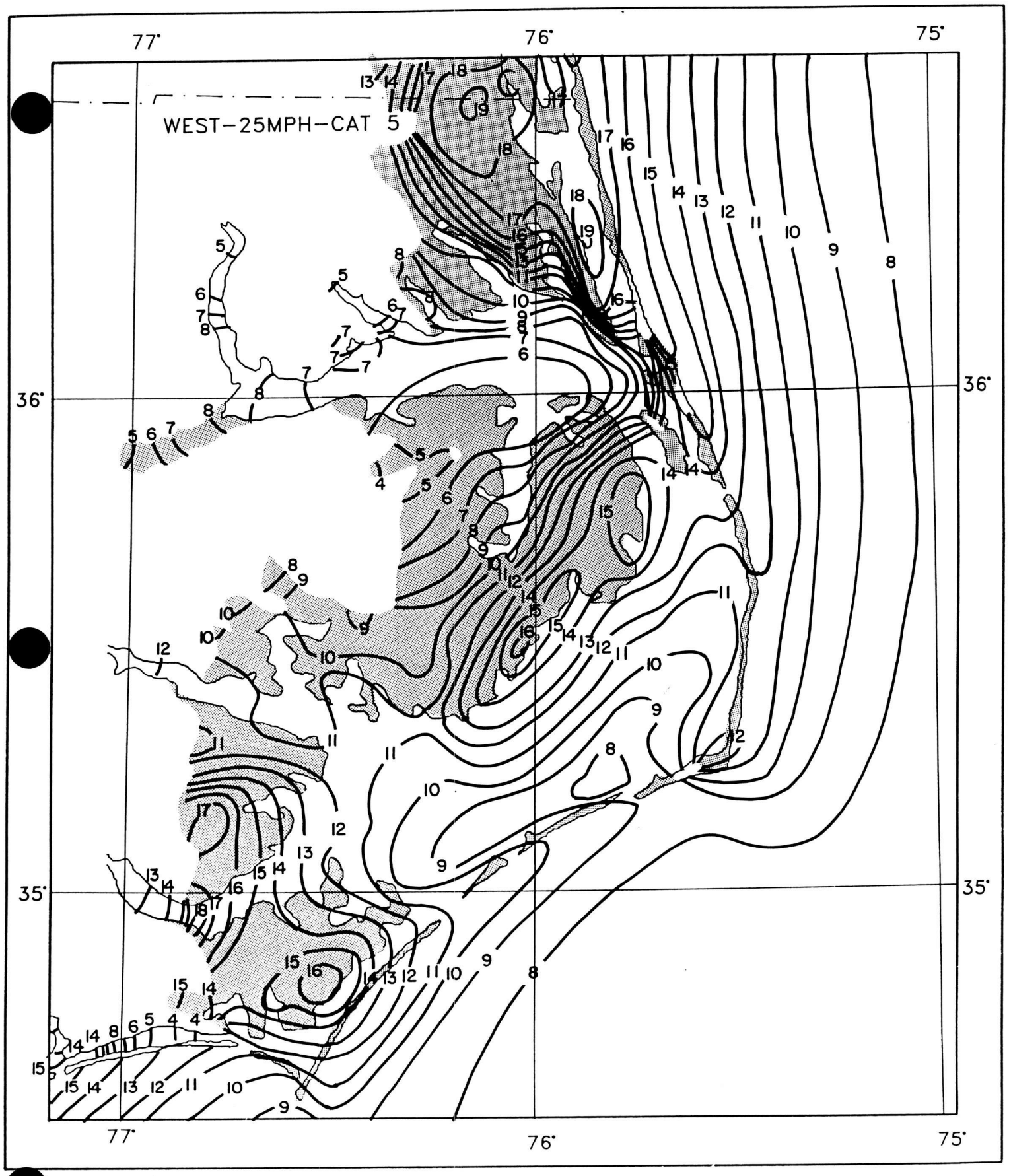

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WEST–15MPH–CAT 5
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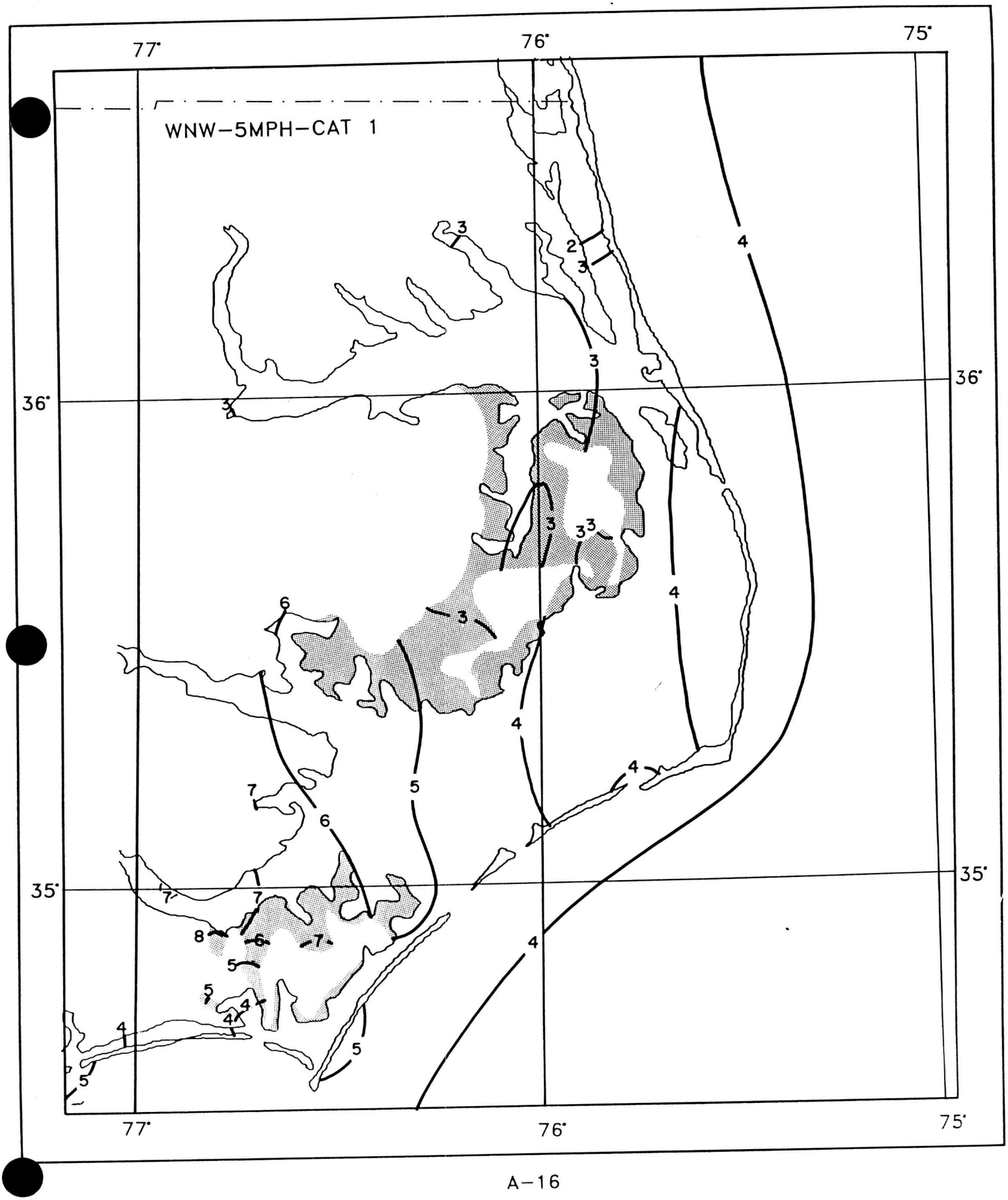

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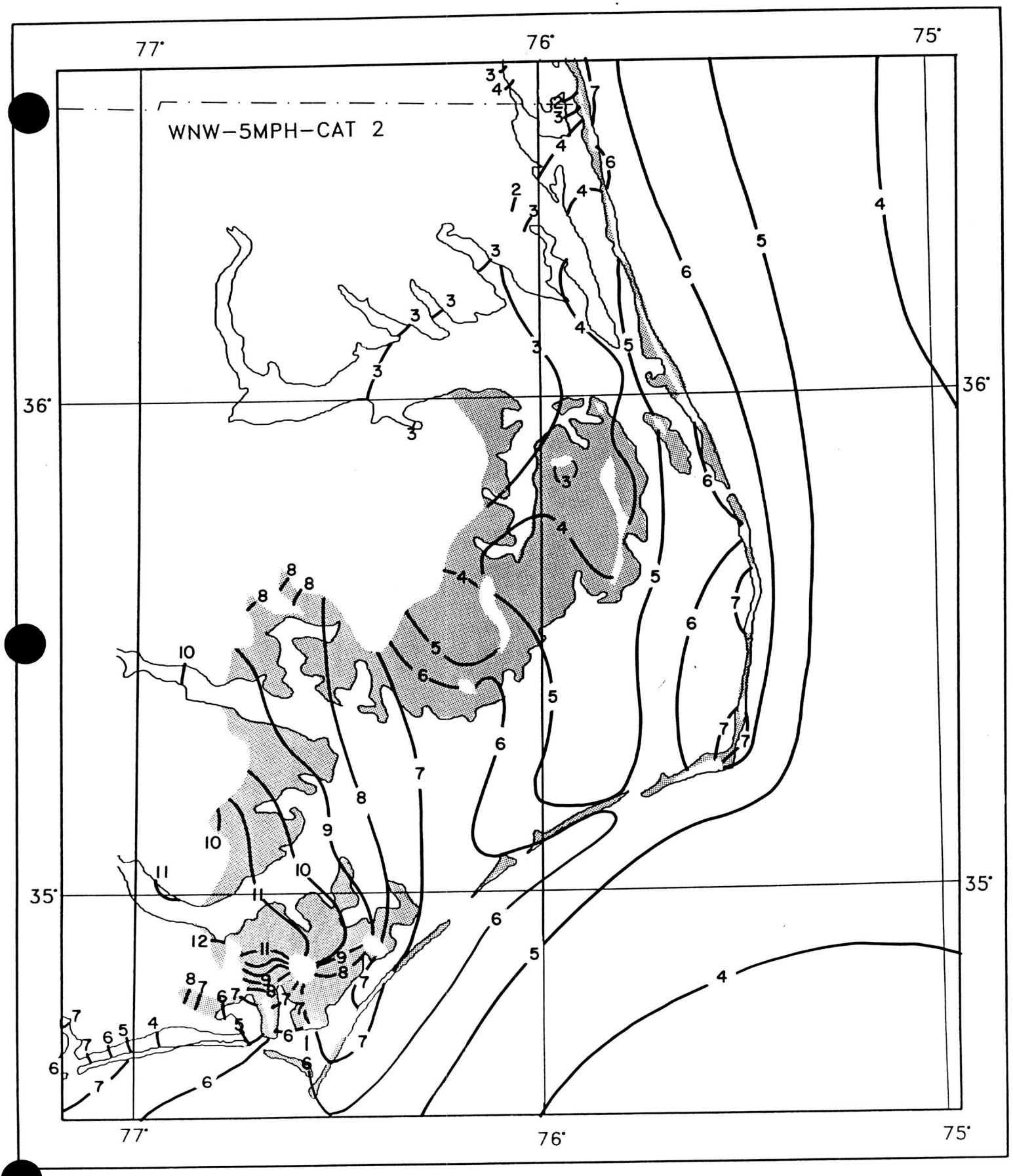

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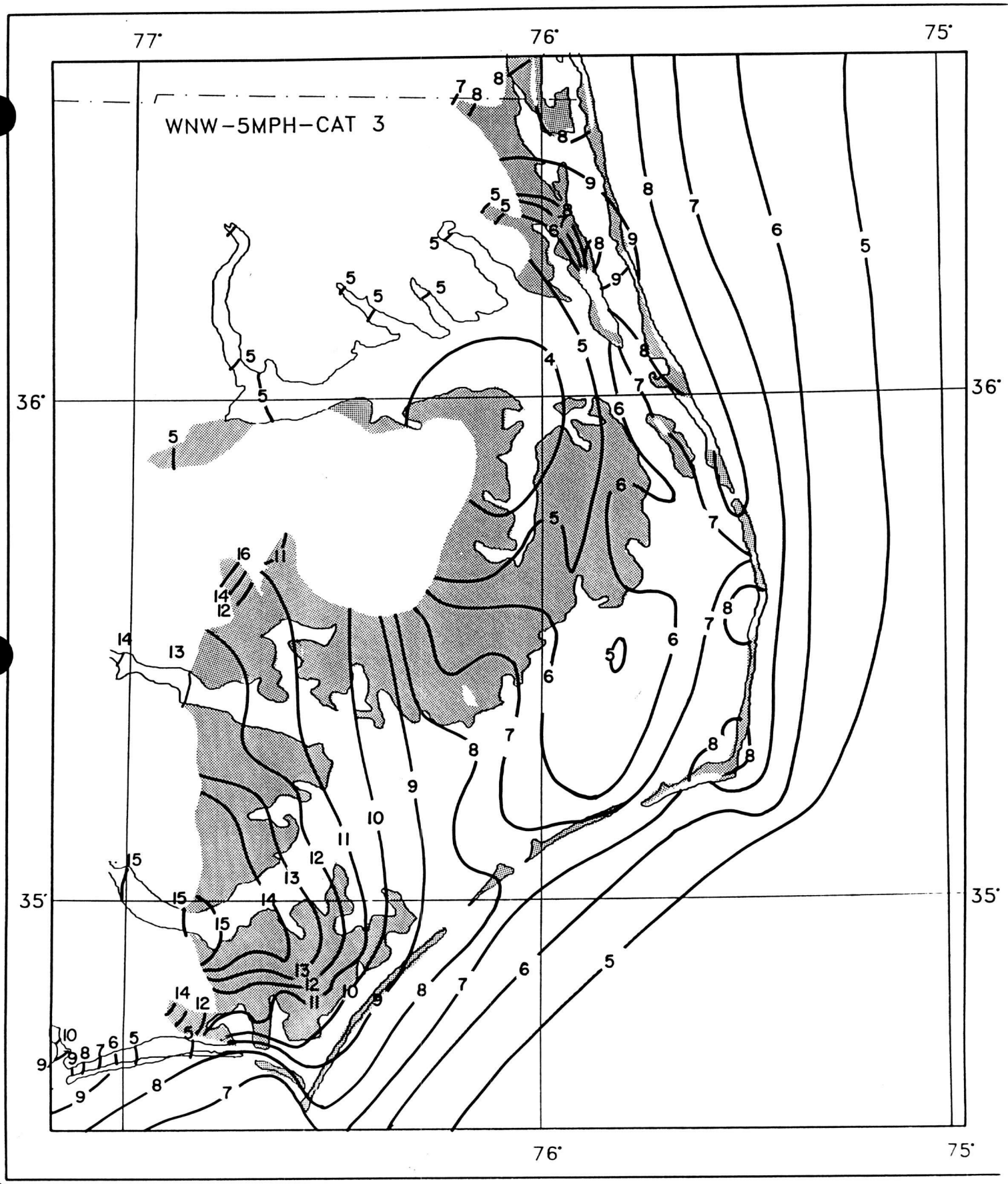

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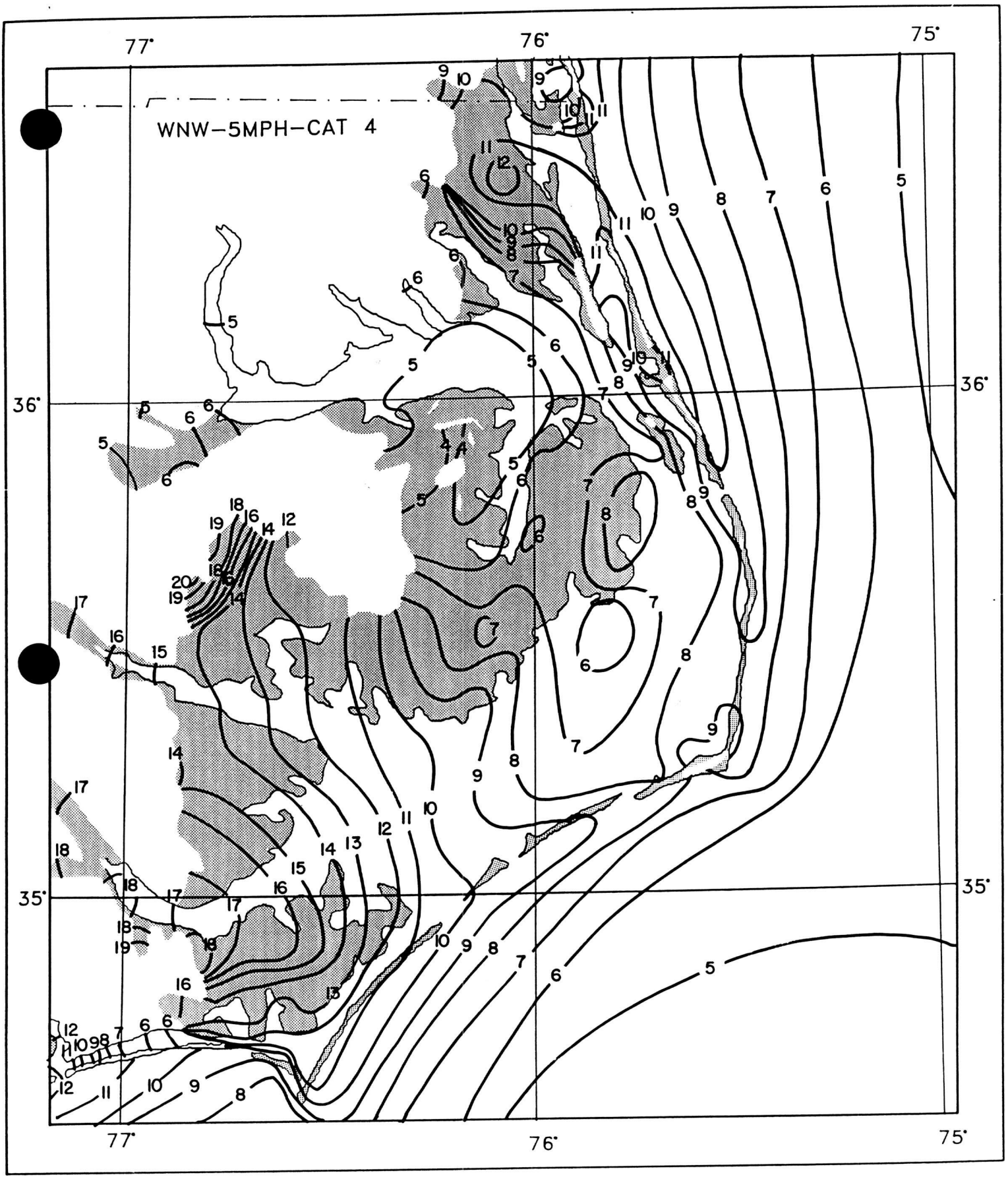

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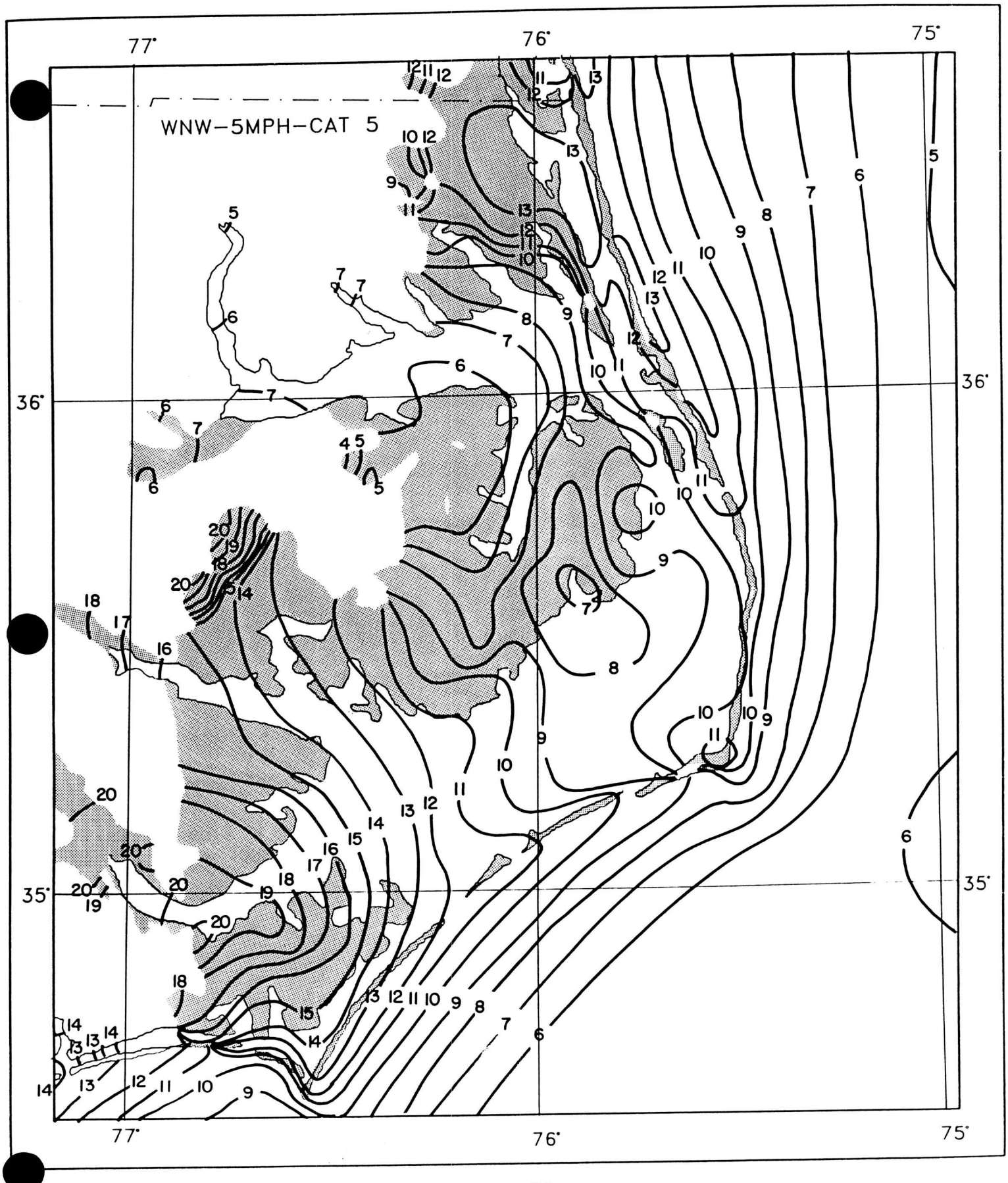

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WEST–25MPH–CAT 5
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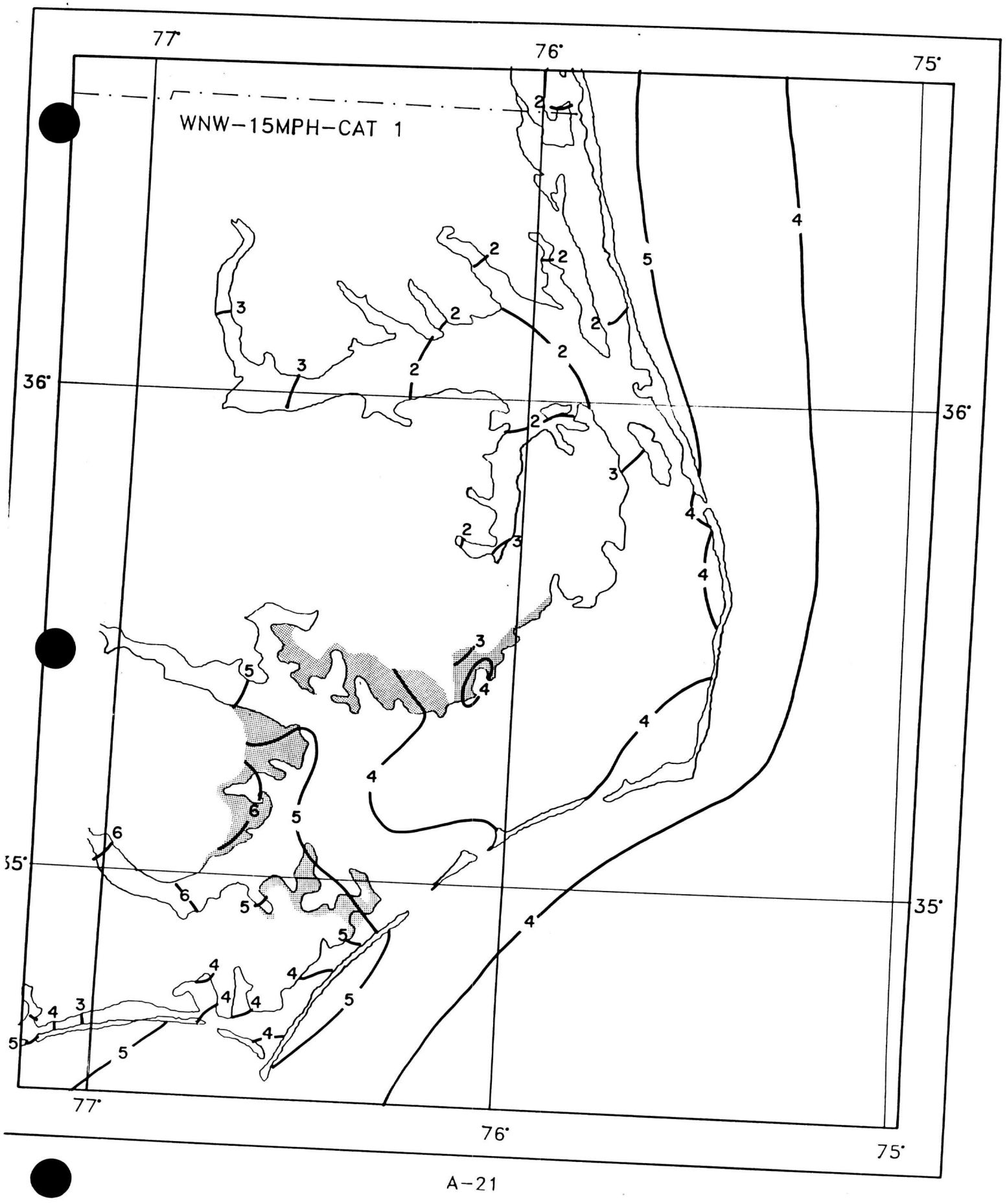

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WNW–5MPH–CAT 1
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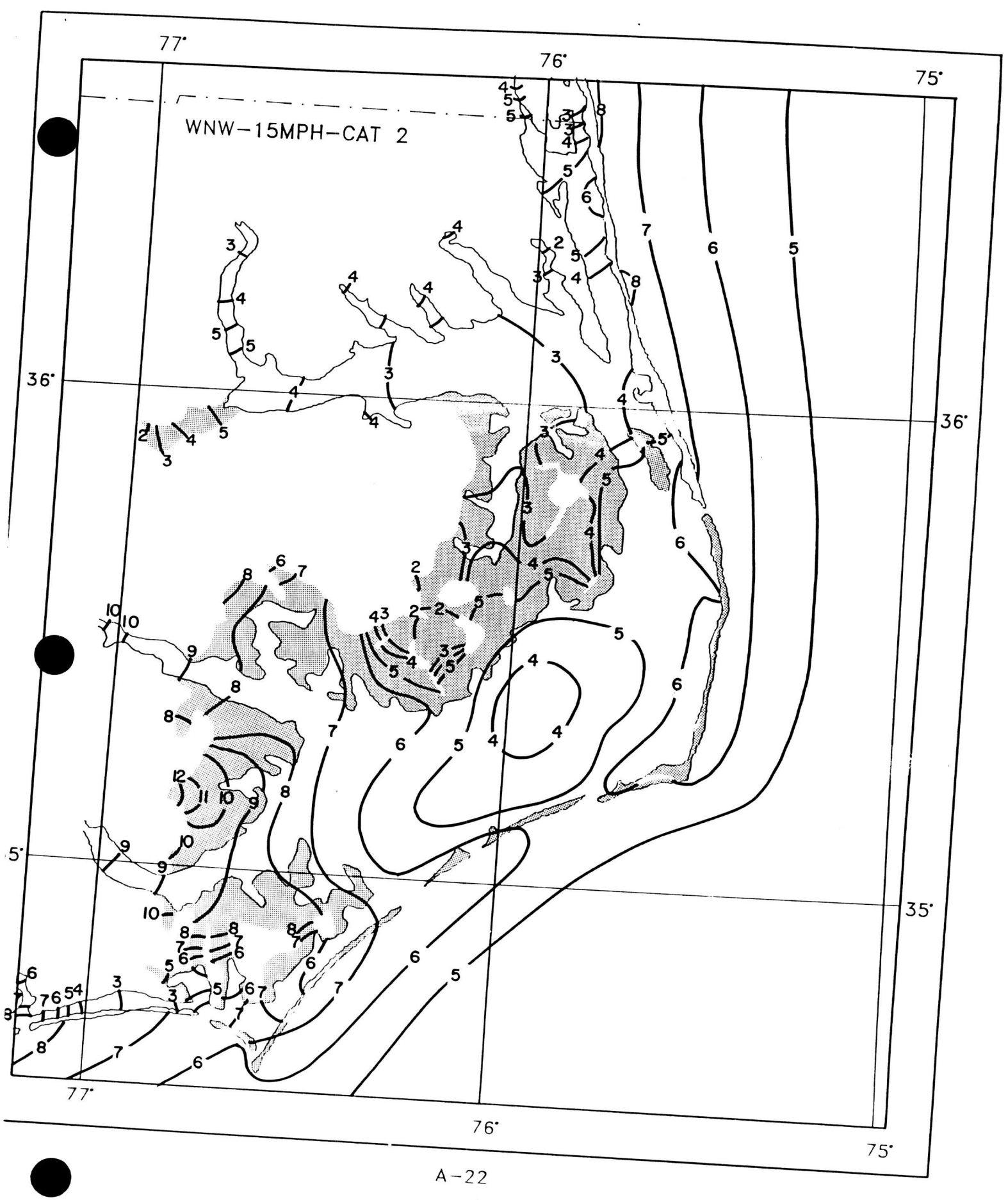

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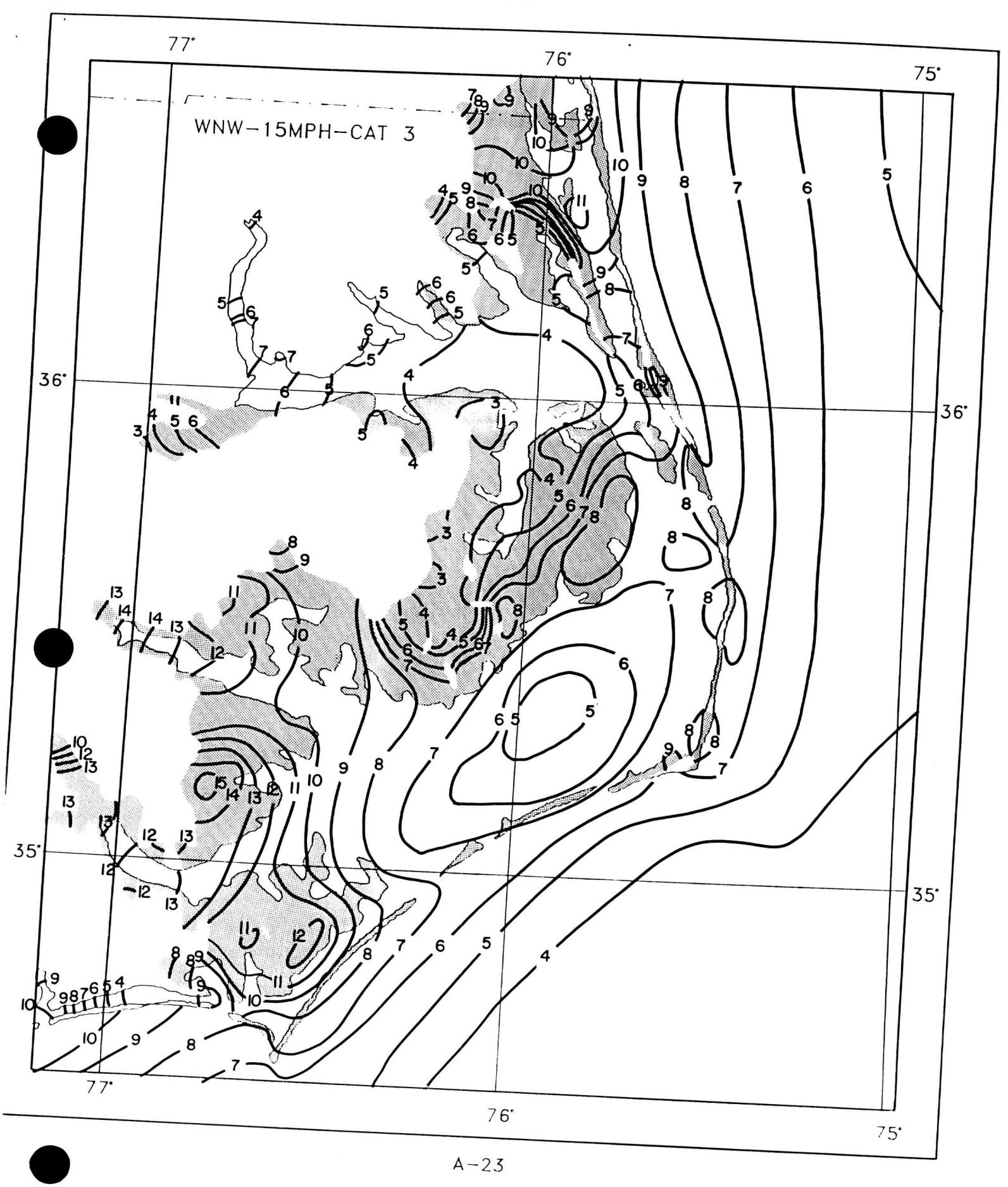

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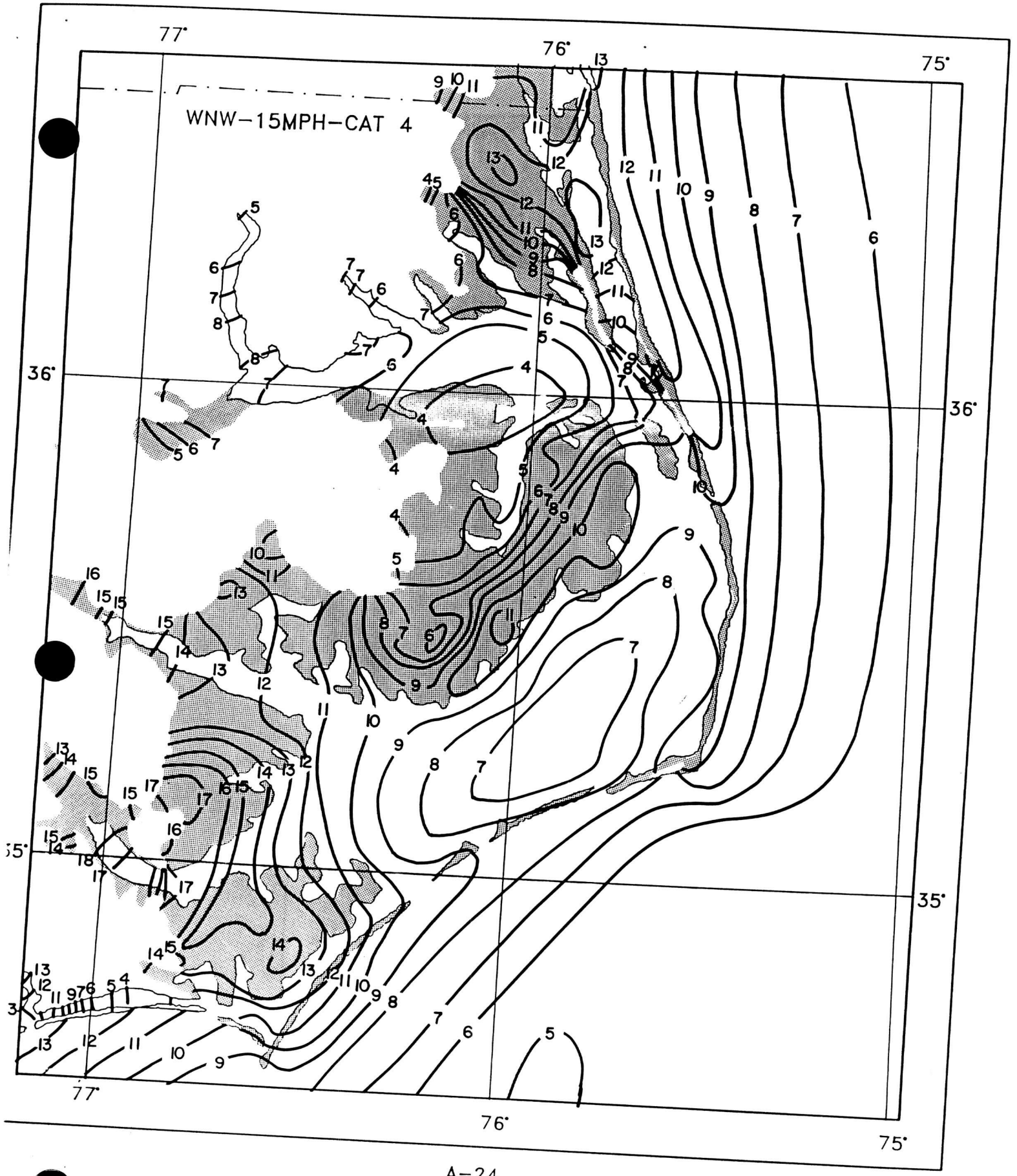

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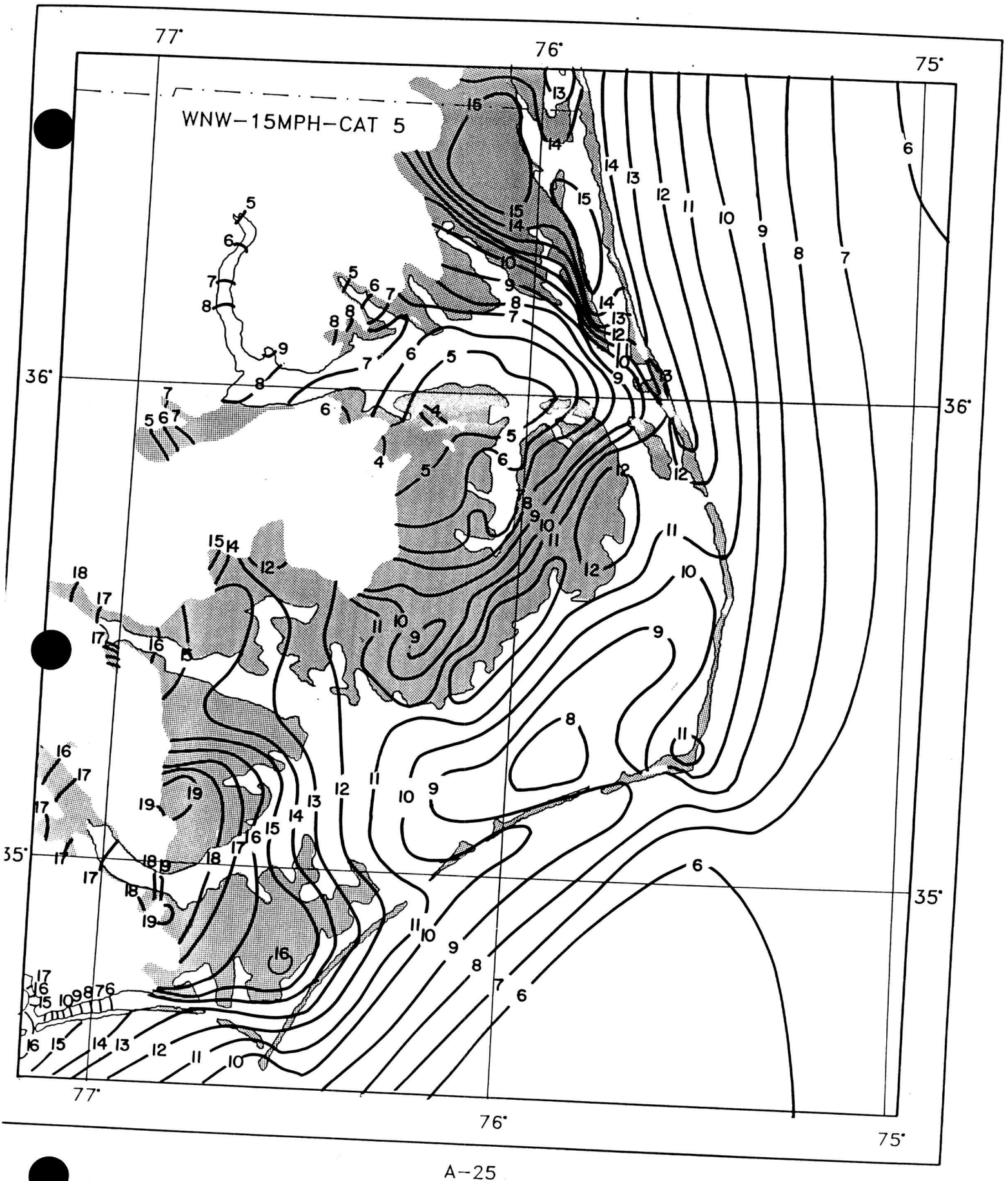

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WNW–5MPH–CAT 5
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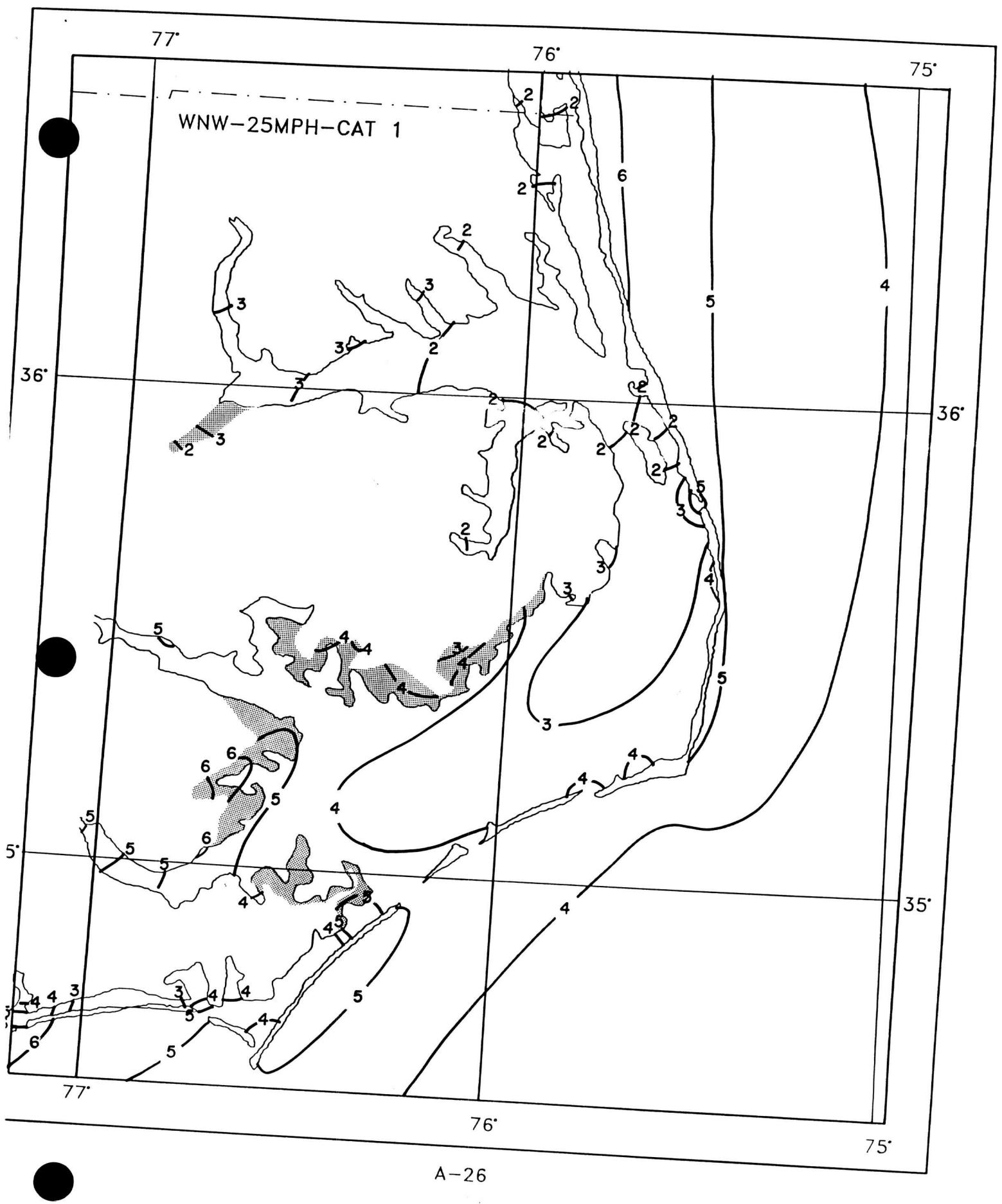

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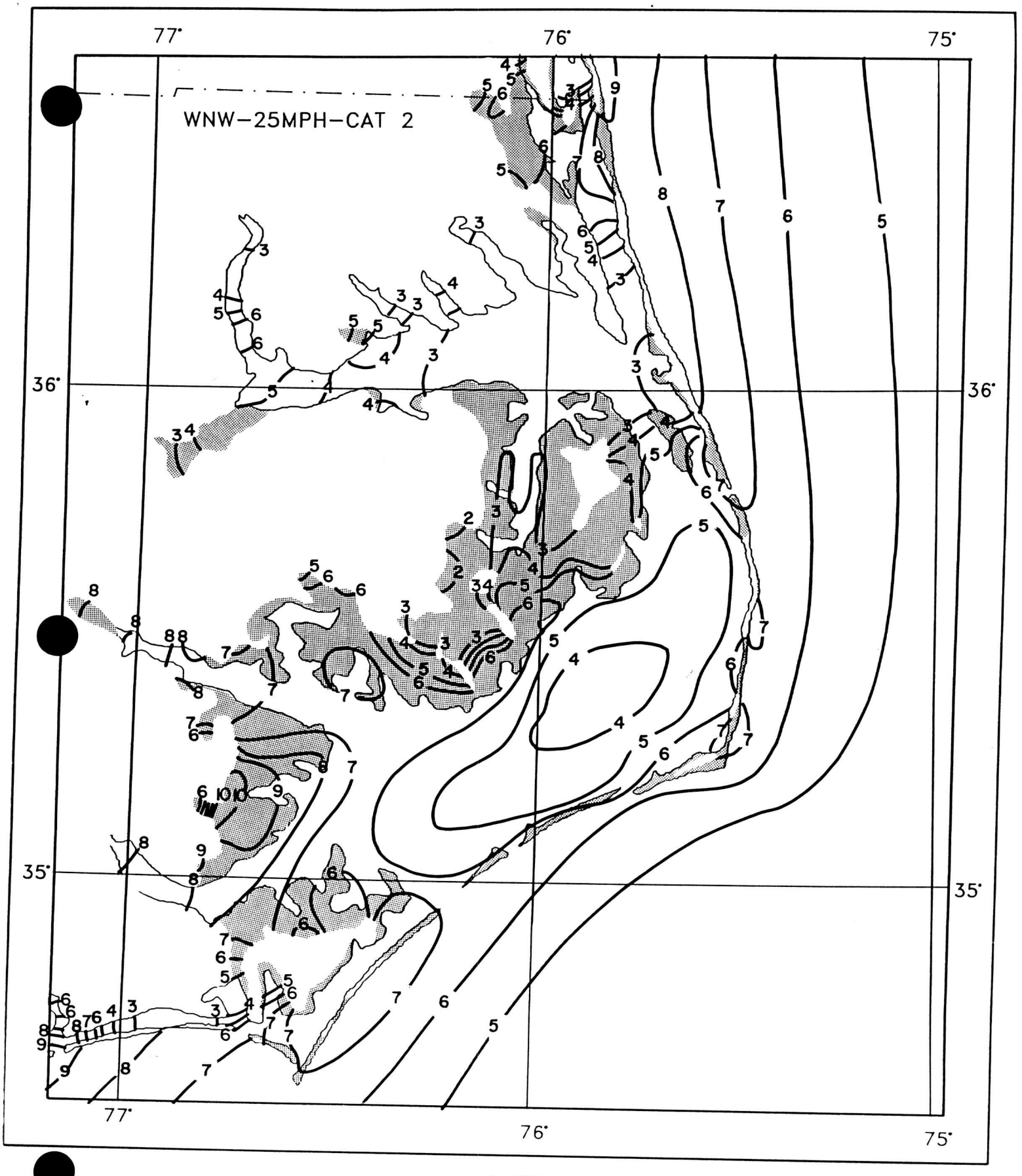

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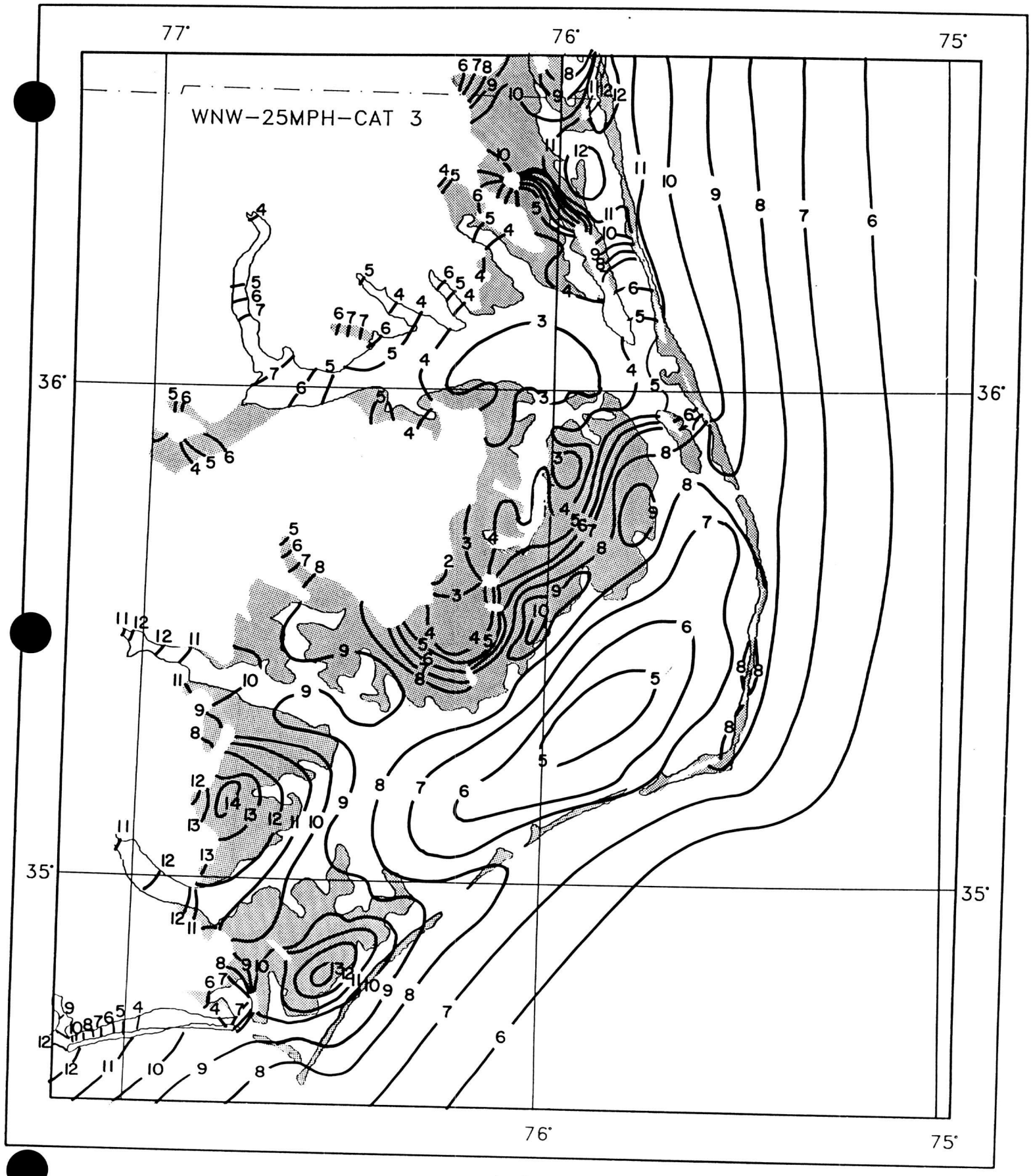

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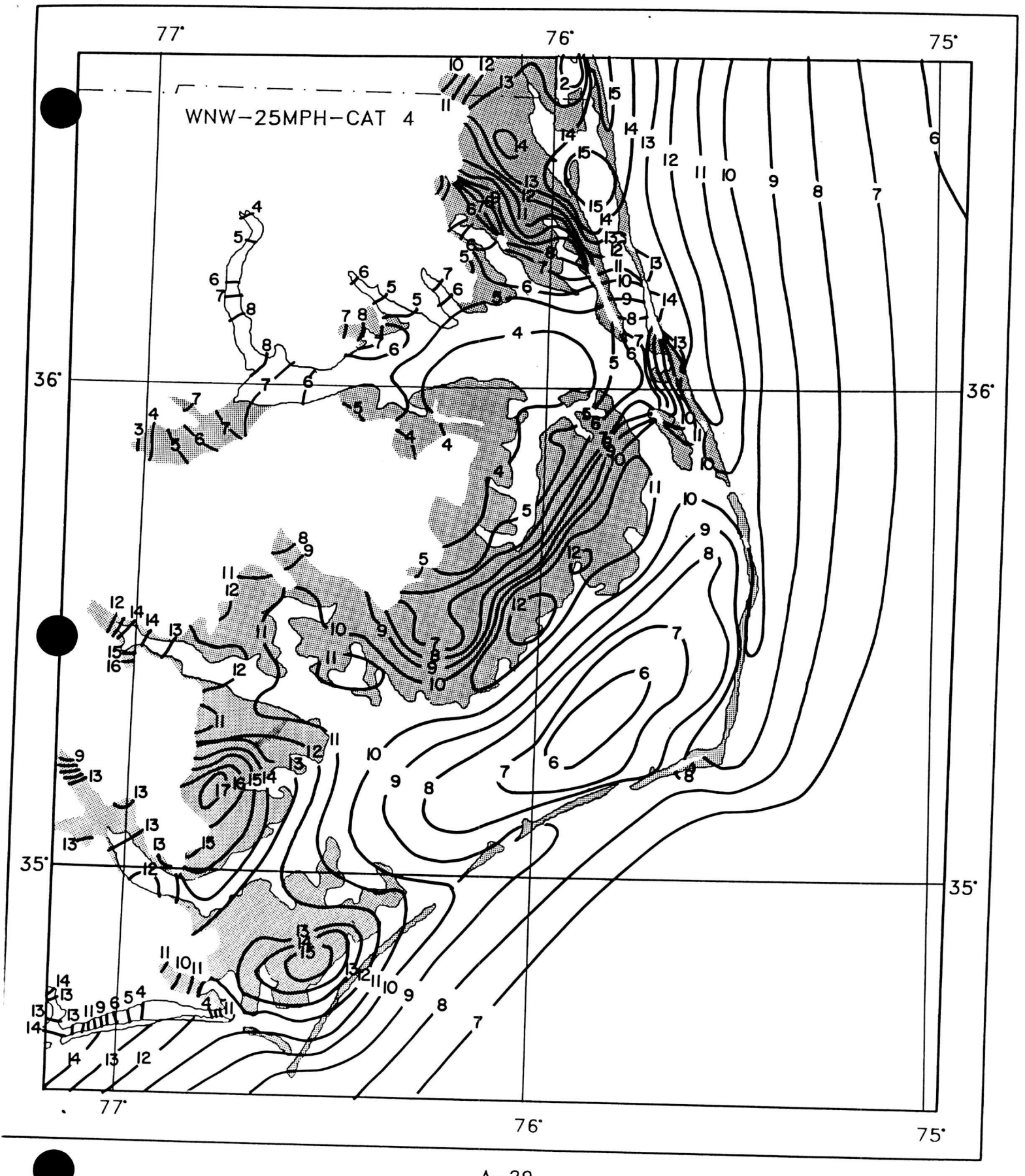

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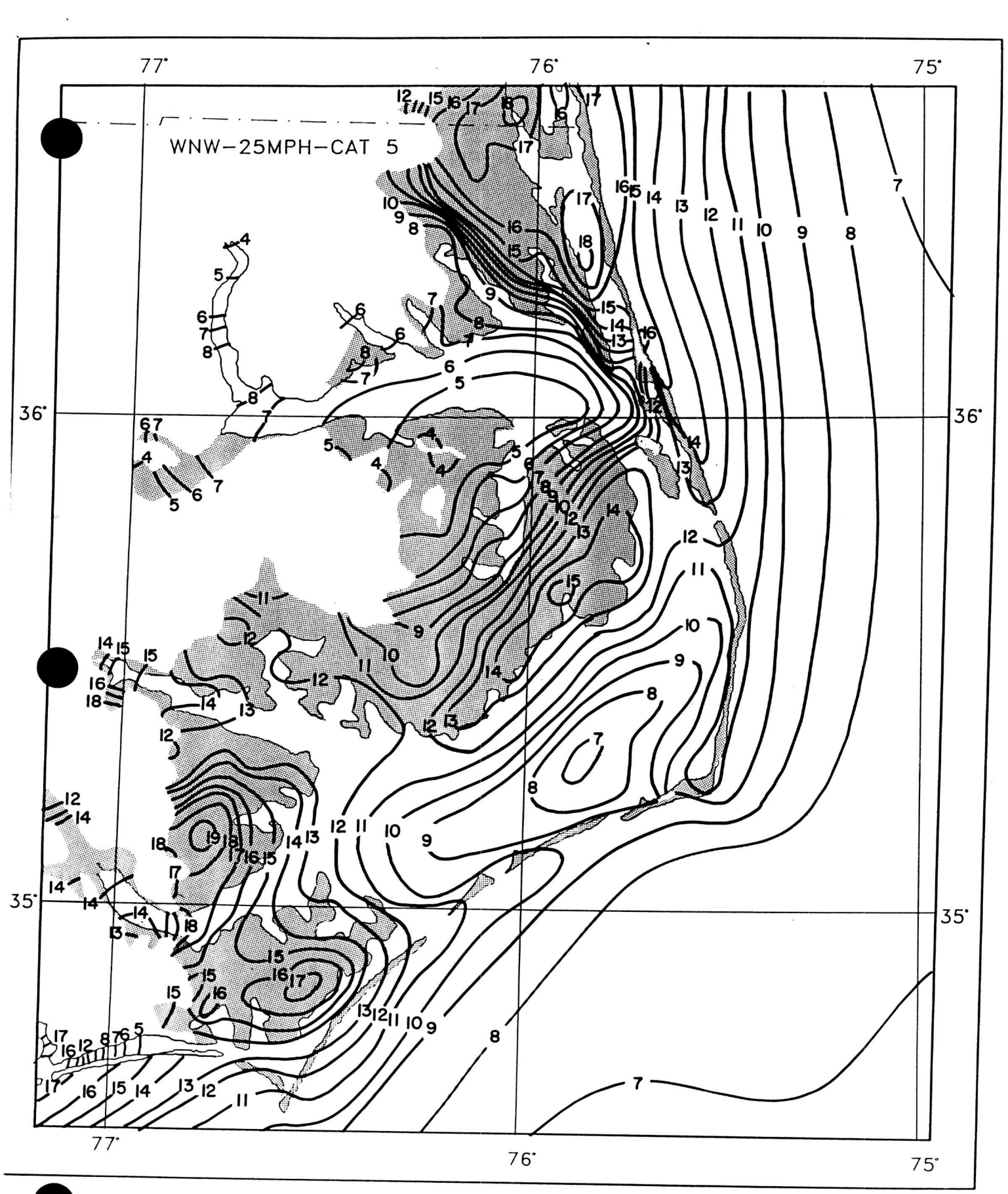

WNW–15MPH–CAT 5
77°
76°
75°
36°
35°

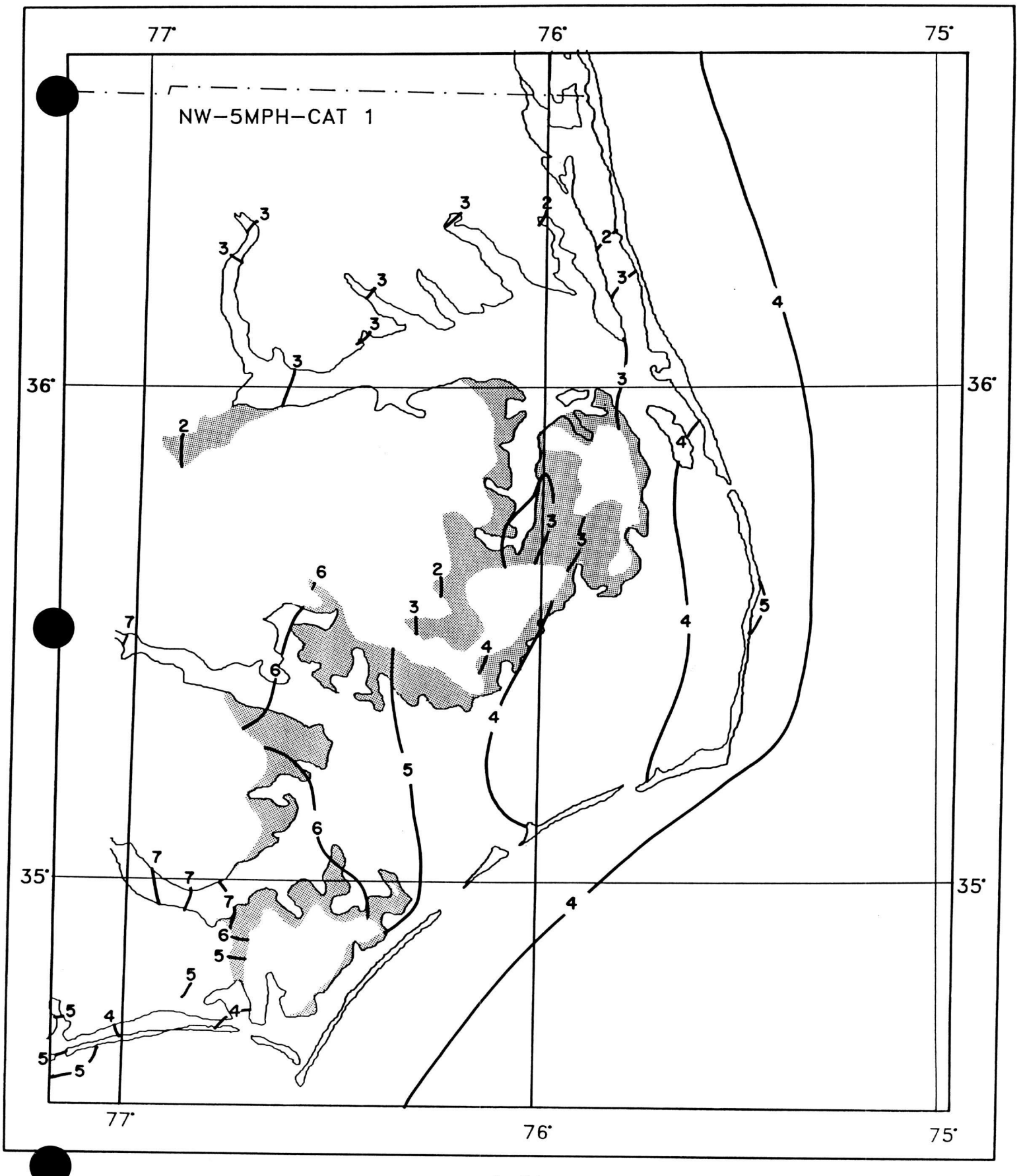

WNW–25MPH–CAT 1
77°
76°
75°
36°
35°

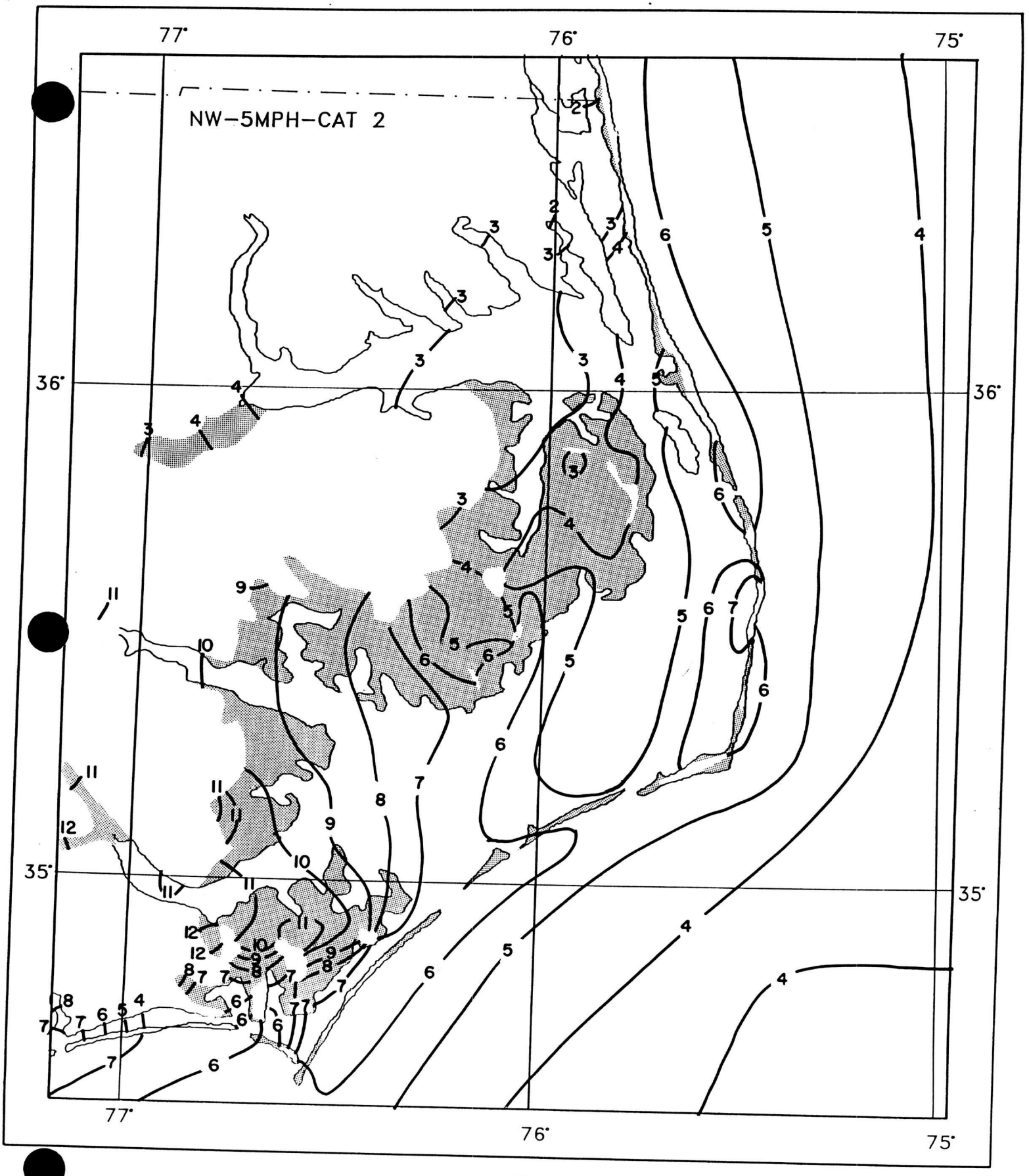

WNW–25MPH–CAT 2
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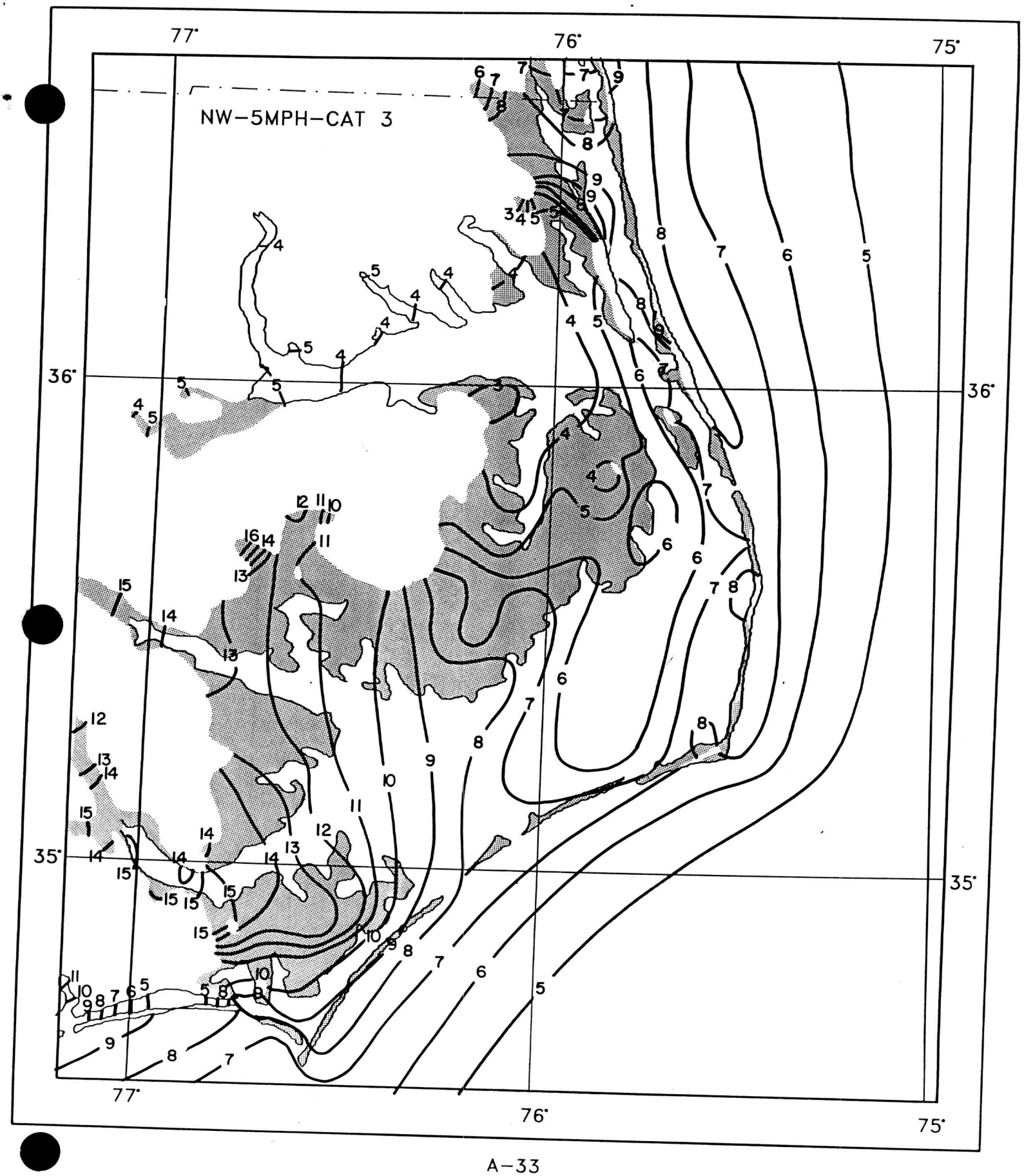

WNW–25MPH–CAT 3
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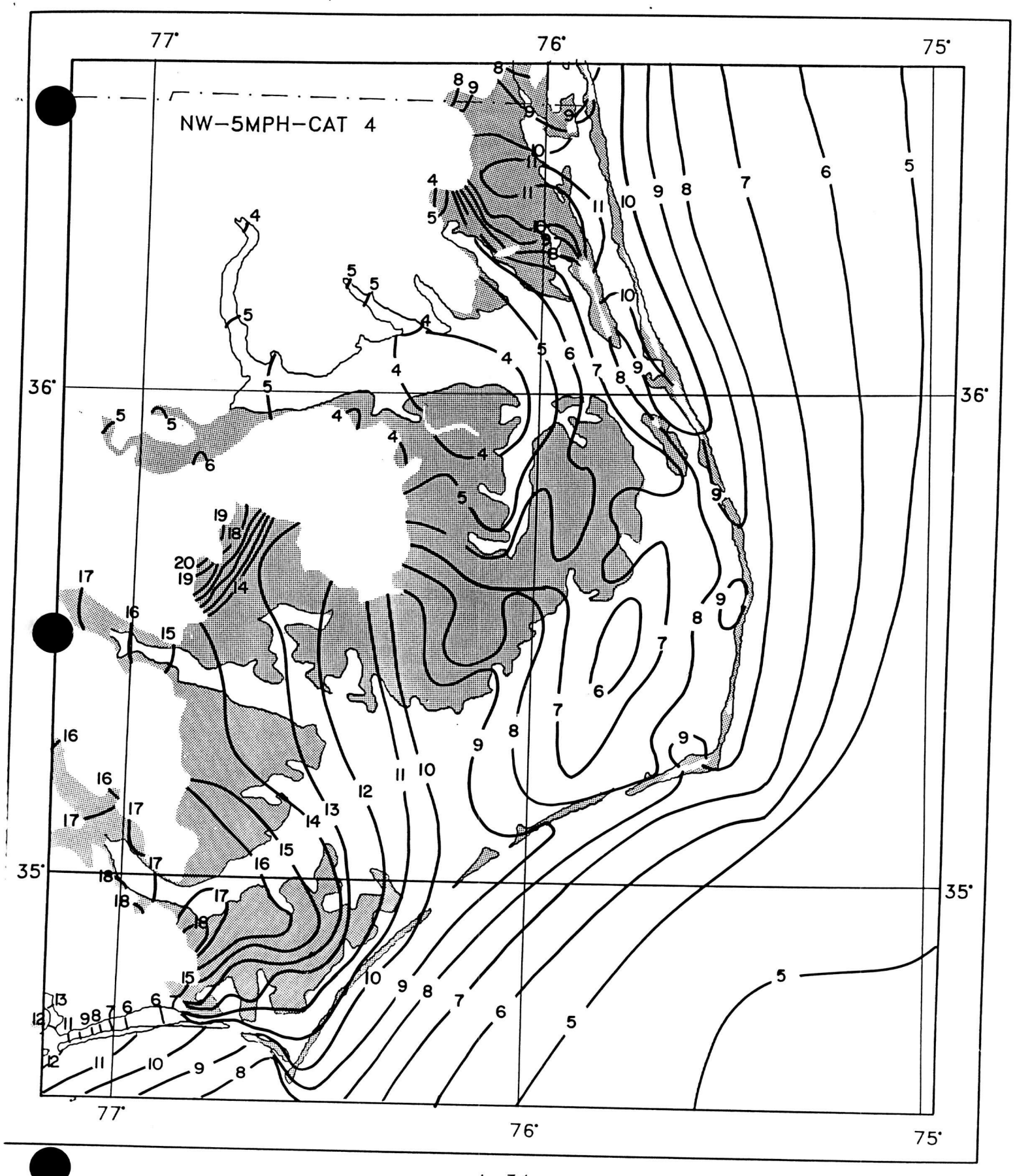

WNW–25MPH–CAT 4
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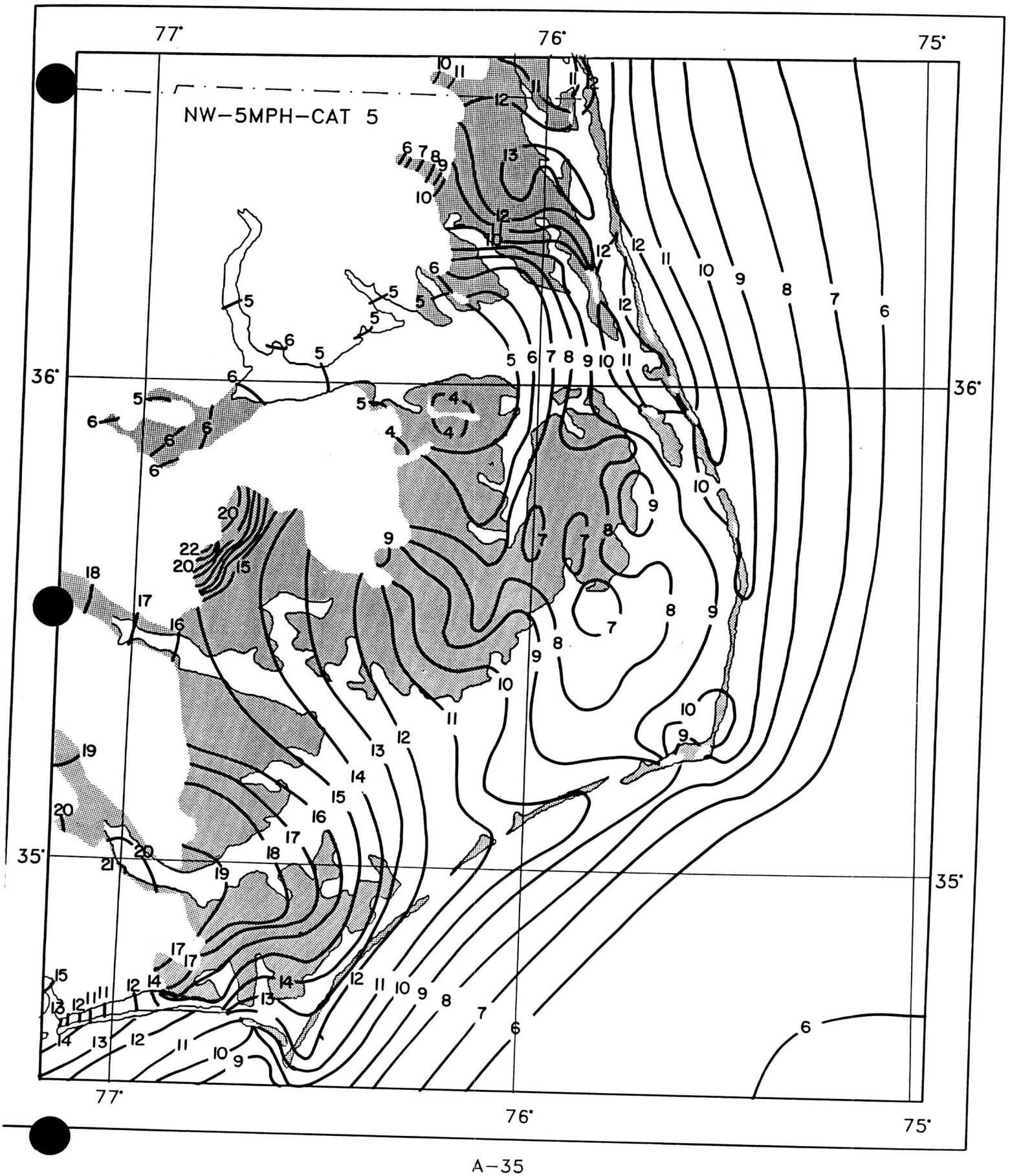

WNW–25MPH–CAT 5
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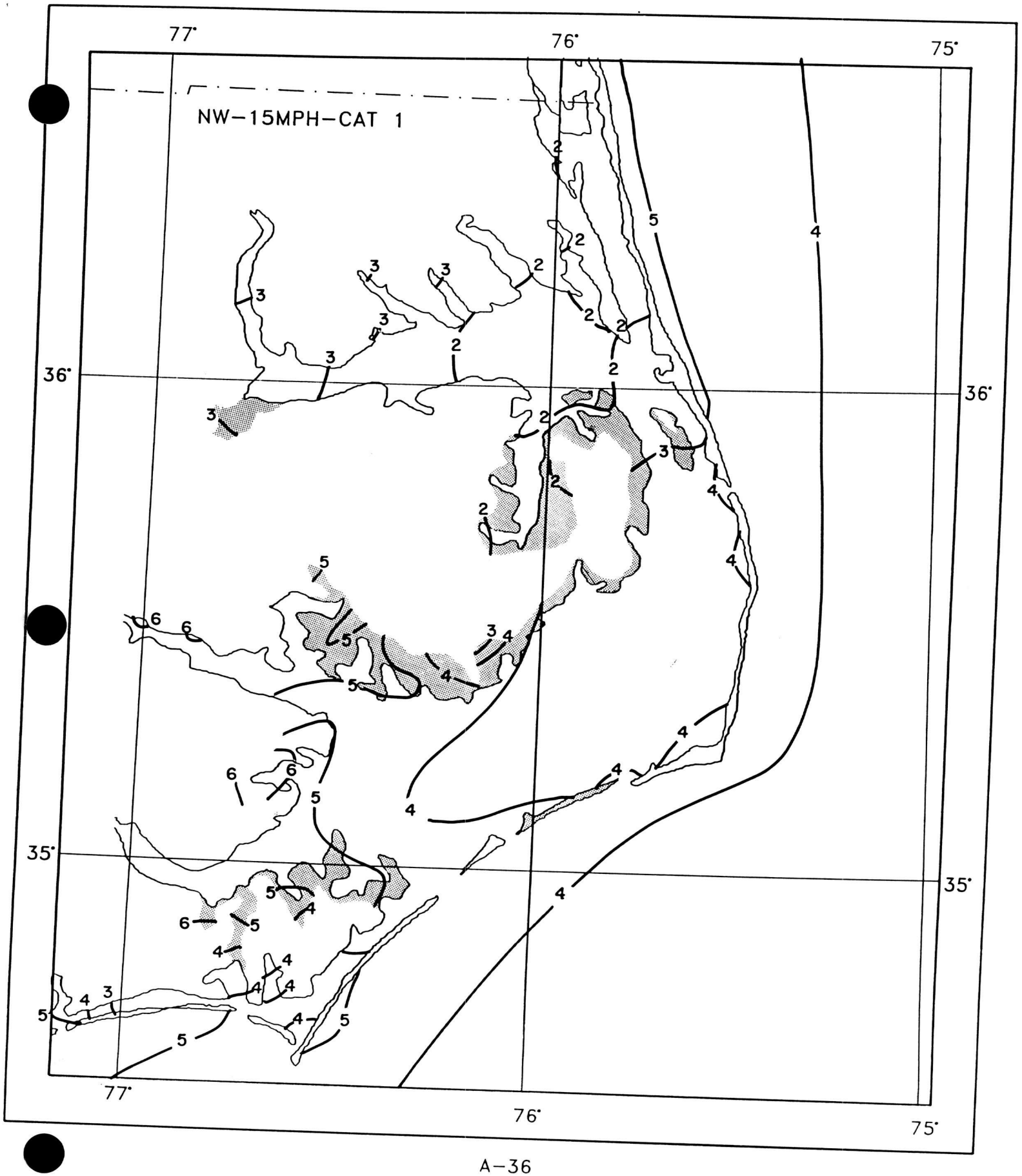

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NW–5MPH–CAT 1
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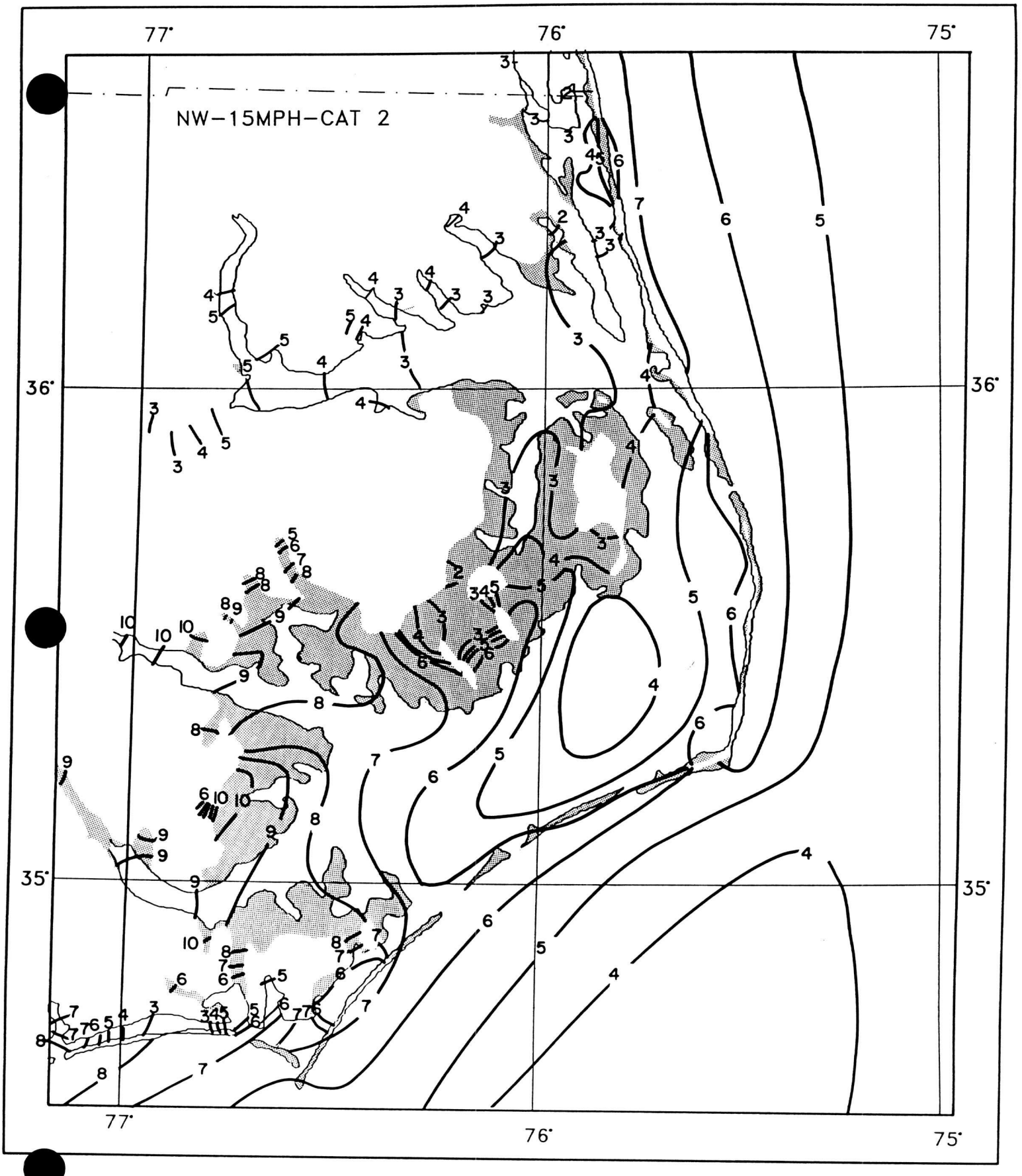

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NW–5MPH–CAT 2
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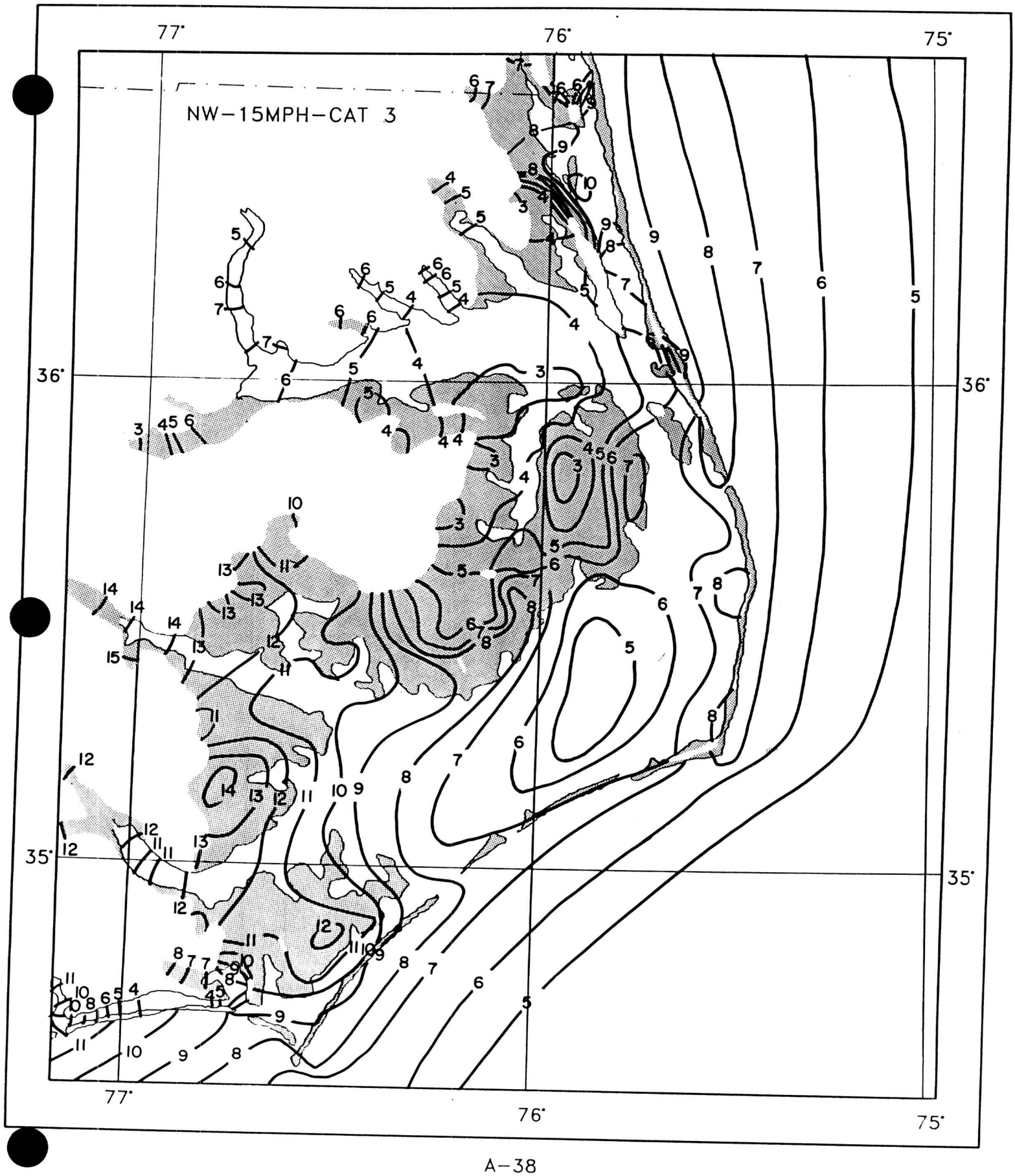

NW–5MPH–CAT 3
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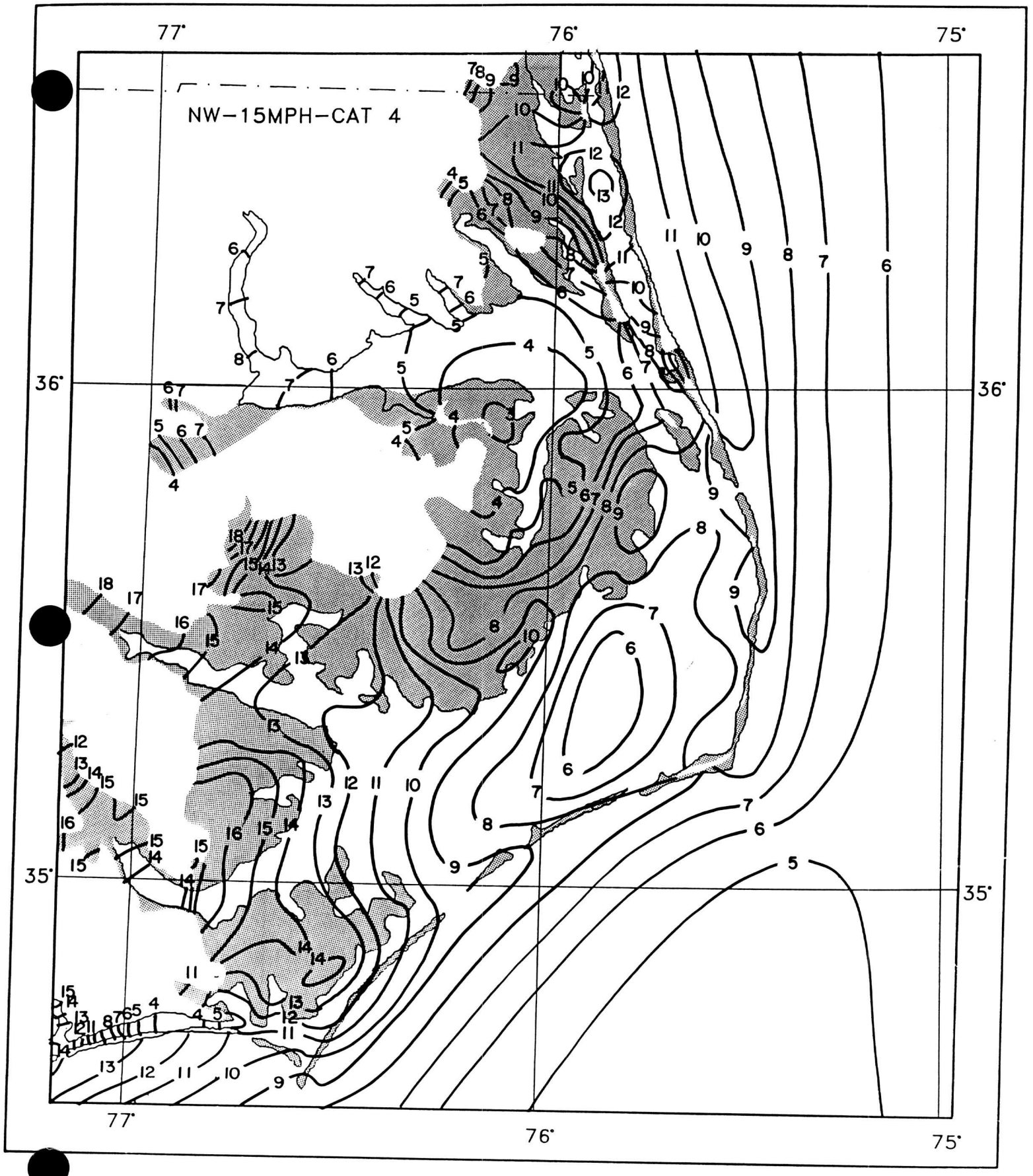

NW–5MPH–CAT 4
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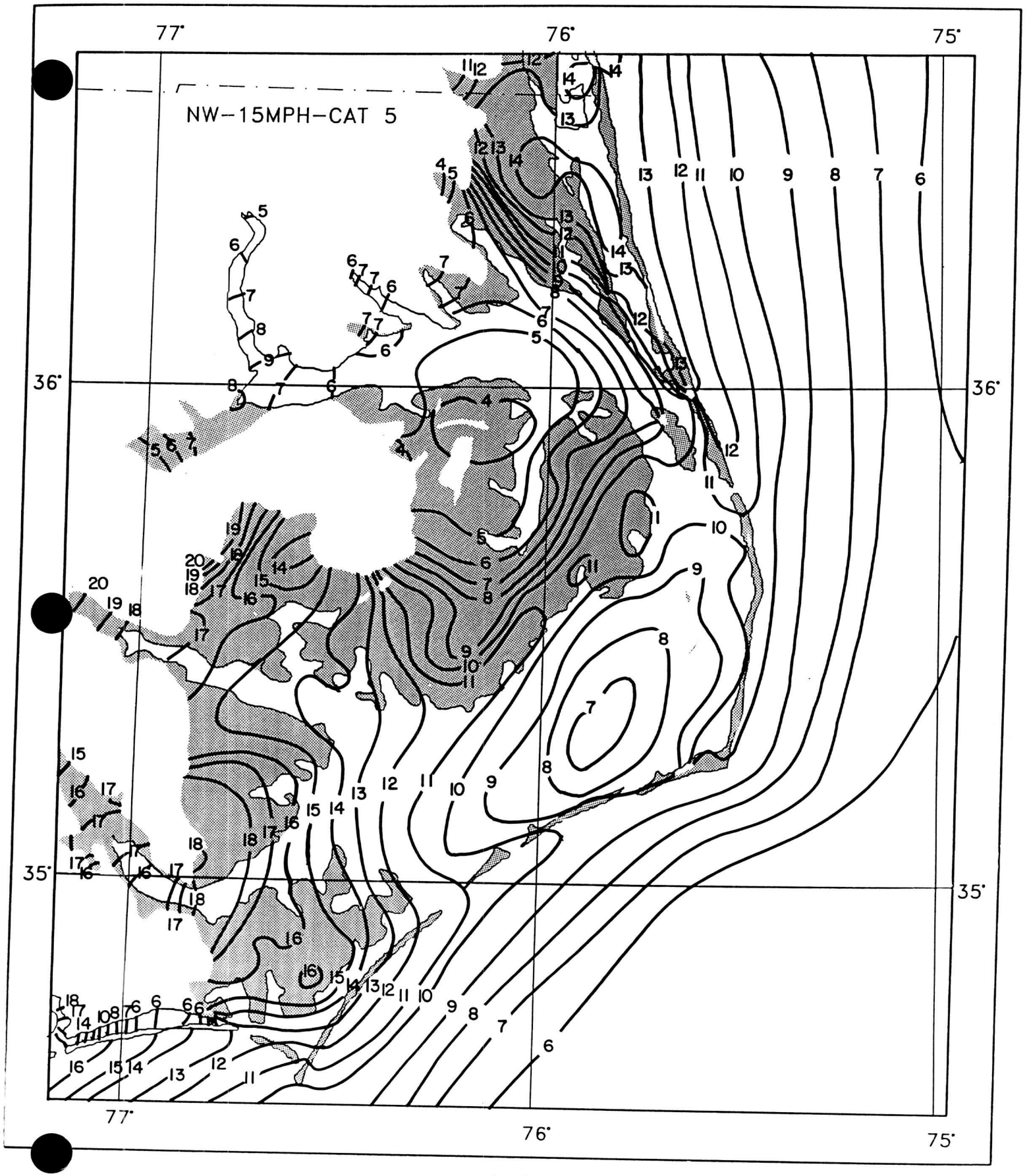

NW–5MPH–CAT 5
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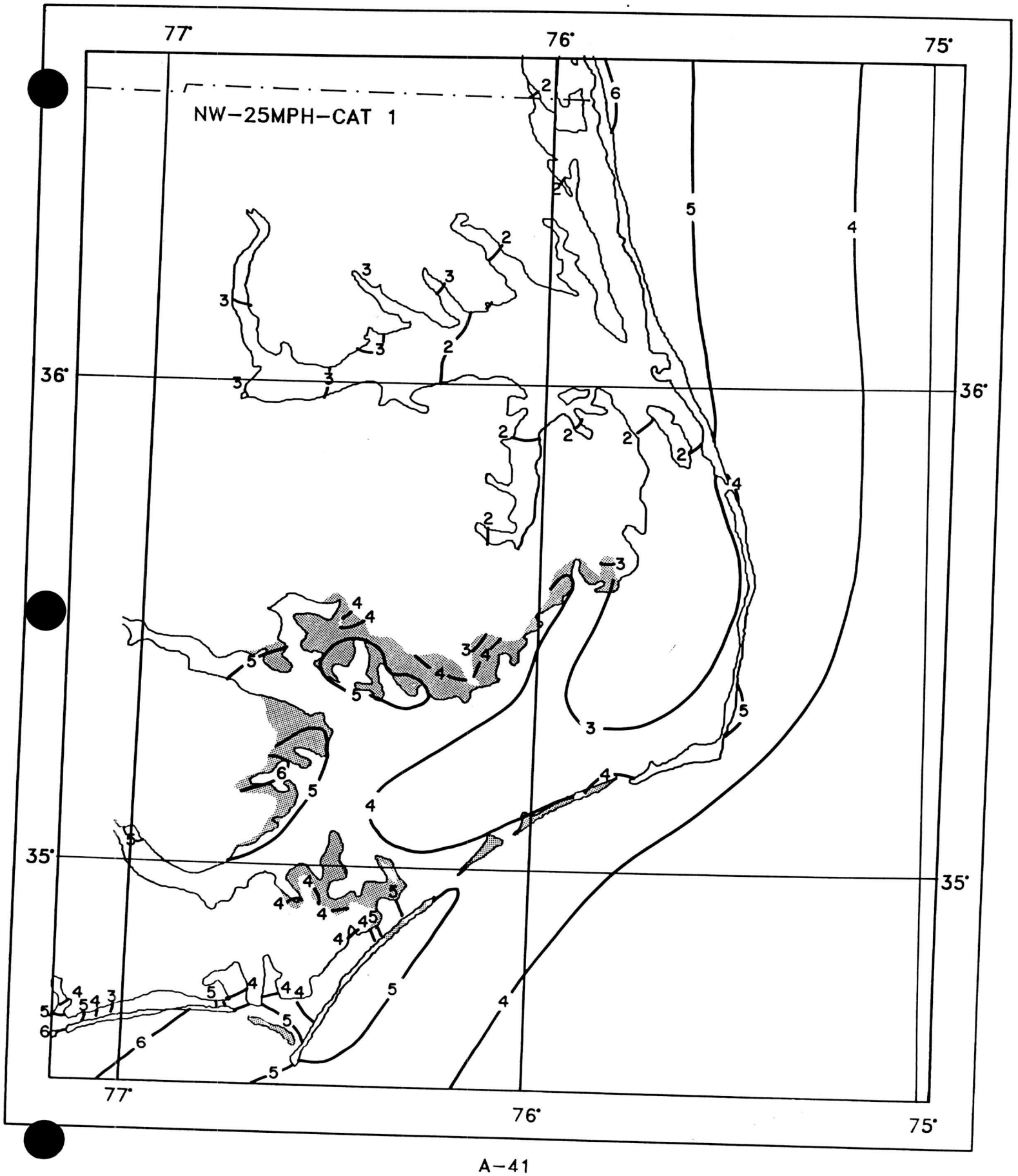

NW–15MPH–CAT 1
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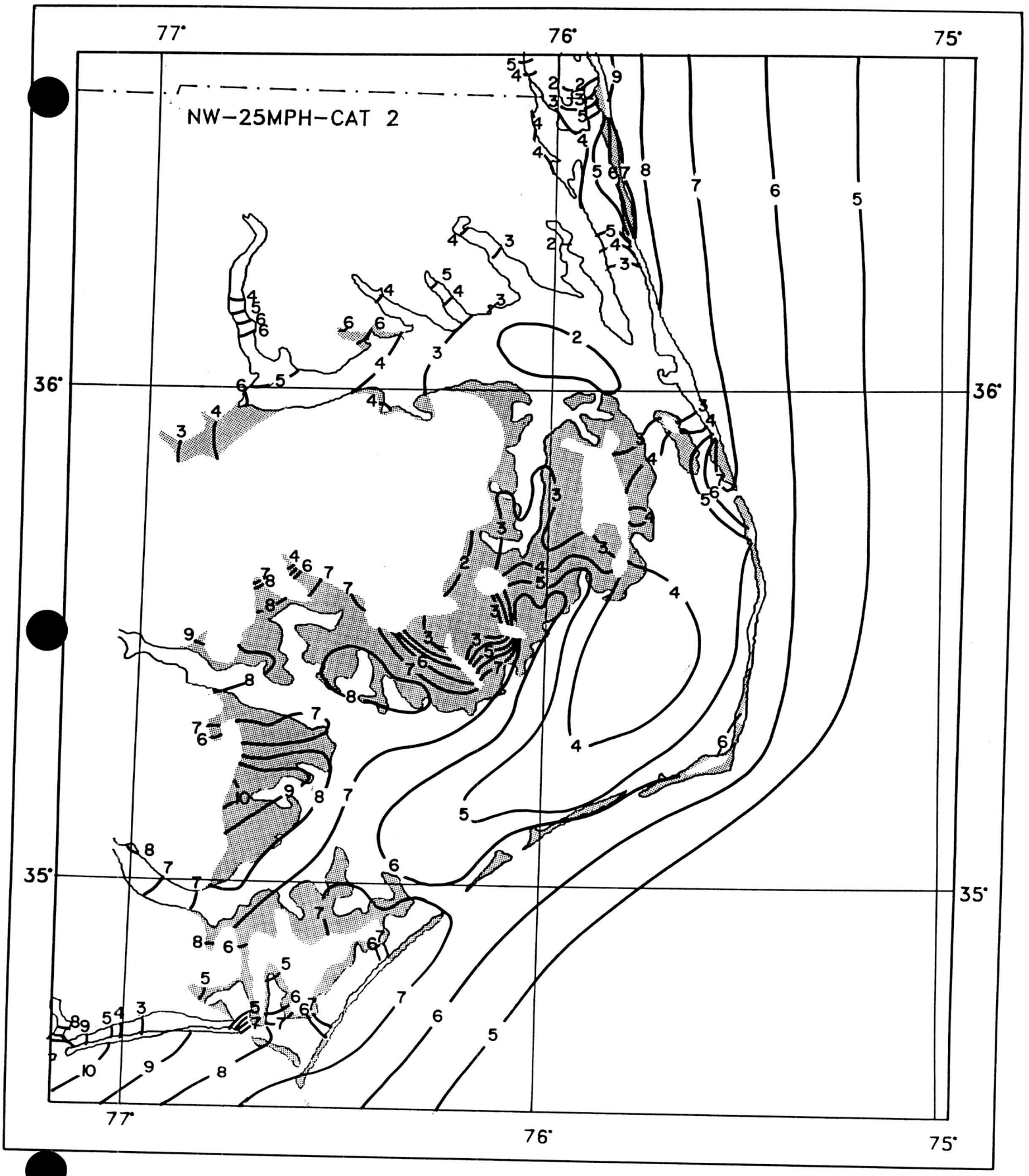

NW–15MPH–CAT 2
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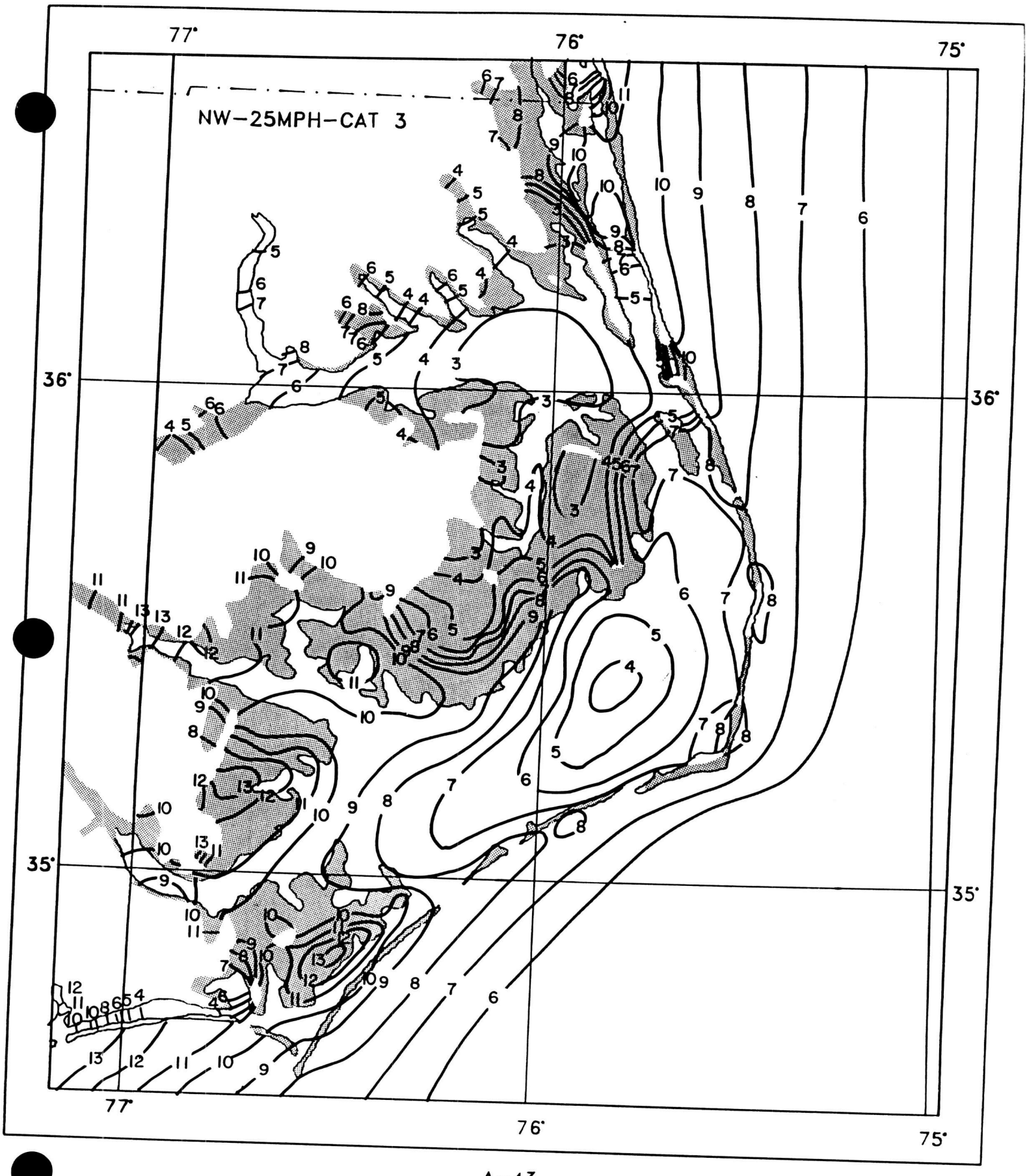

NW–15MPH–CAT 3
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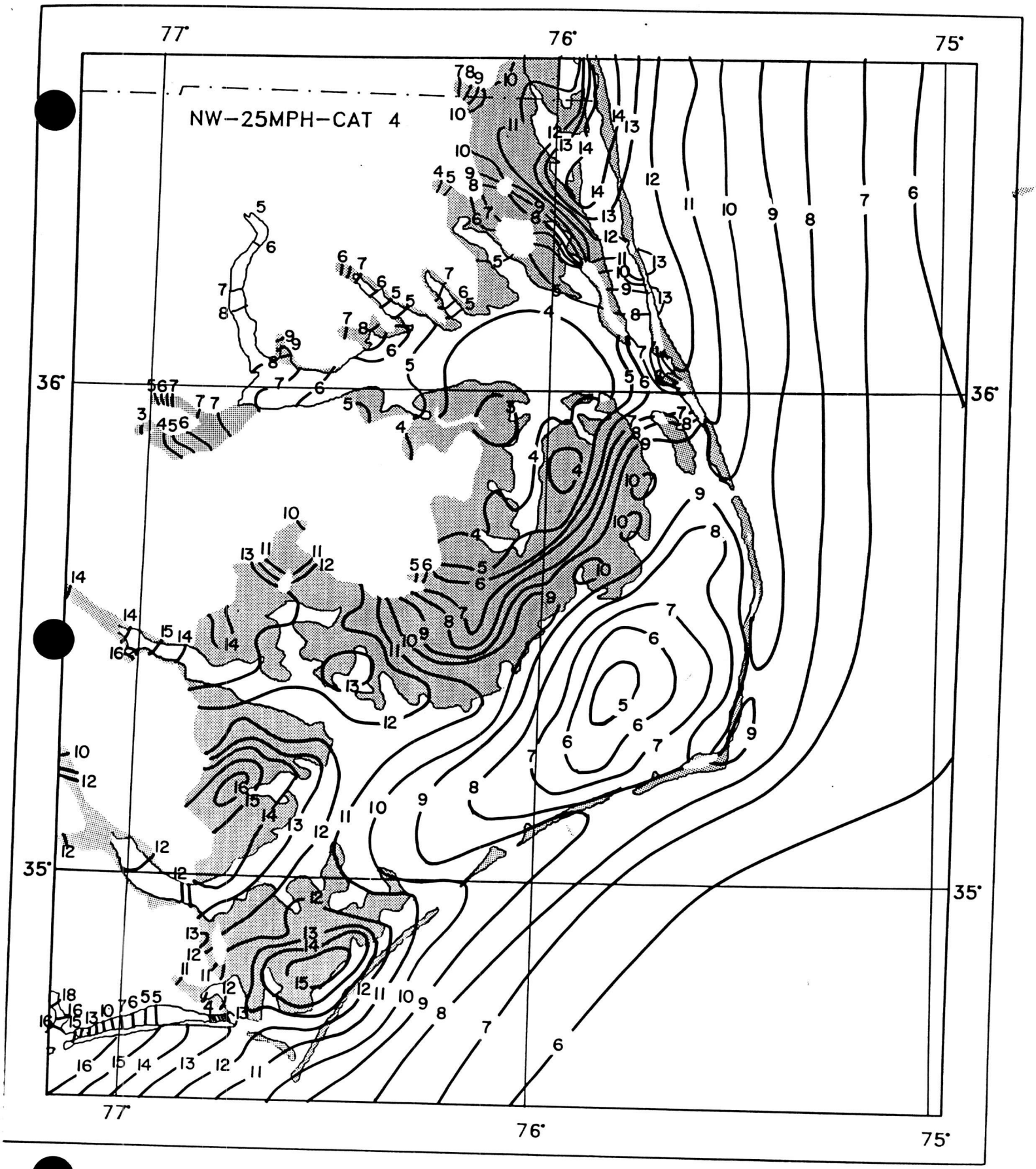

NW–15MPH–CAT 4
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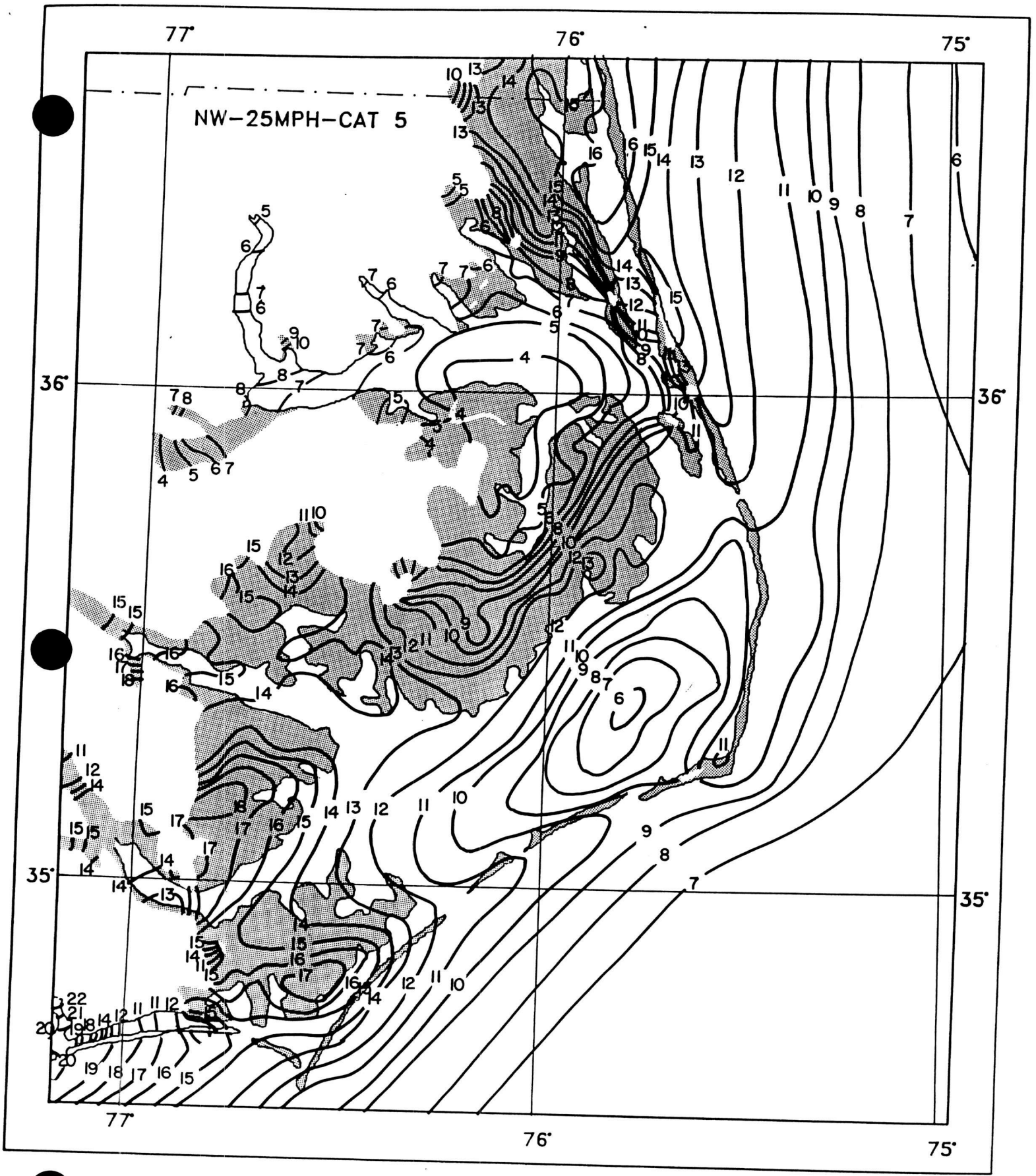

NW–15MPH–CAT 5
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36°
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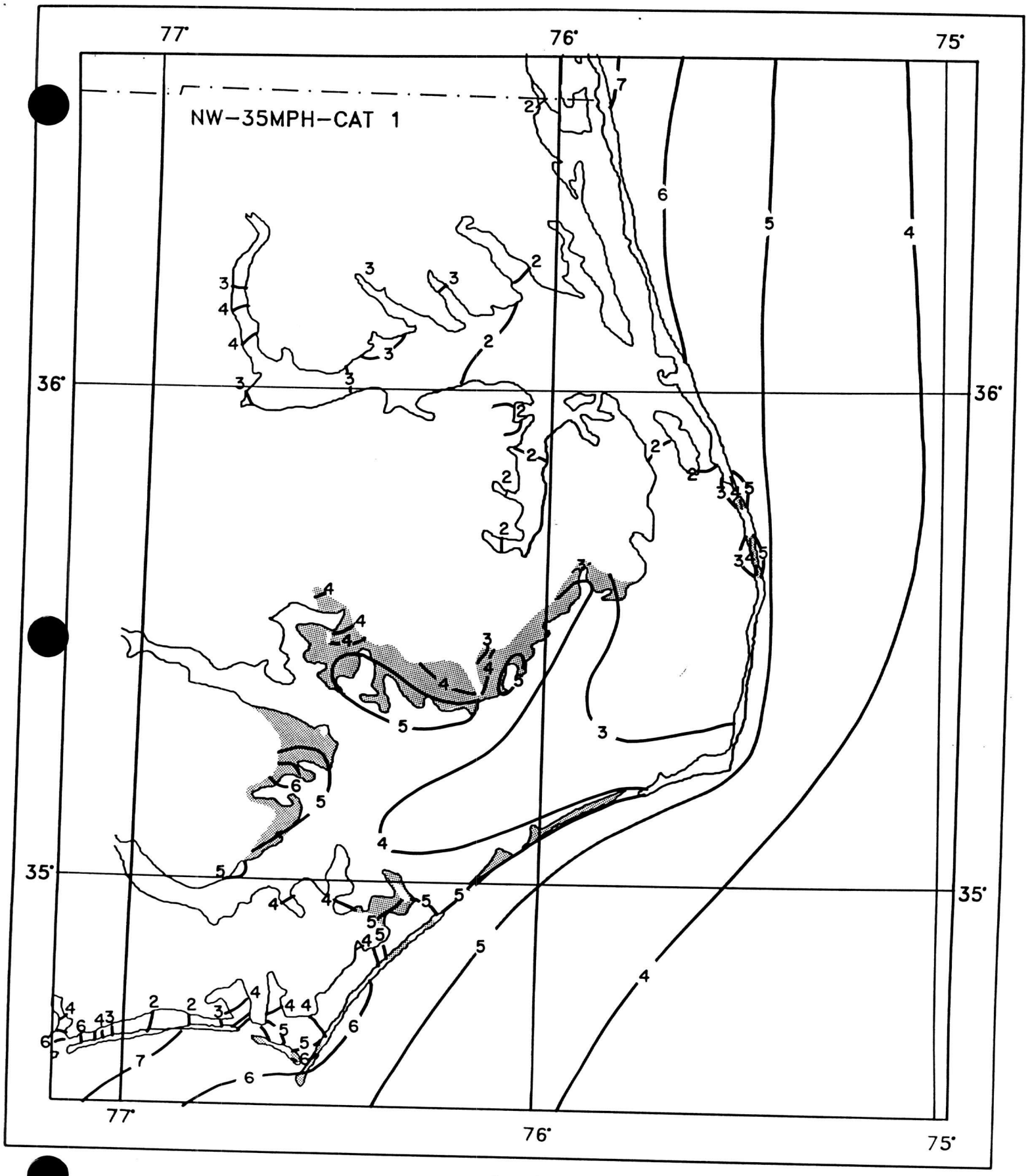

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NW–25MPH–CAT 1
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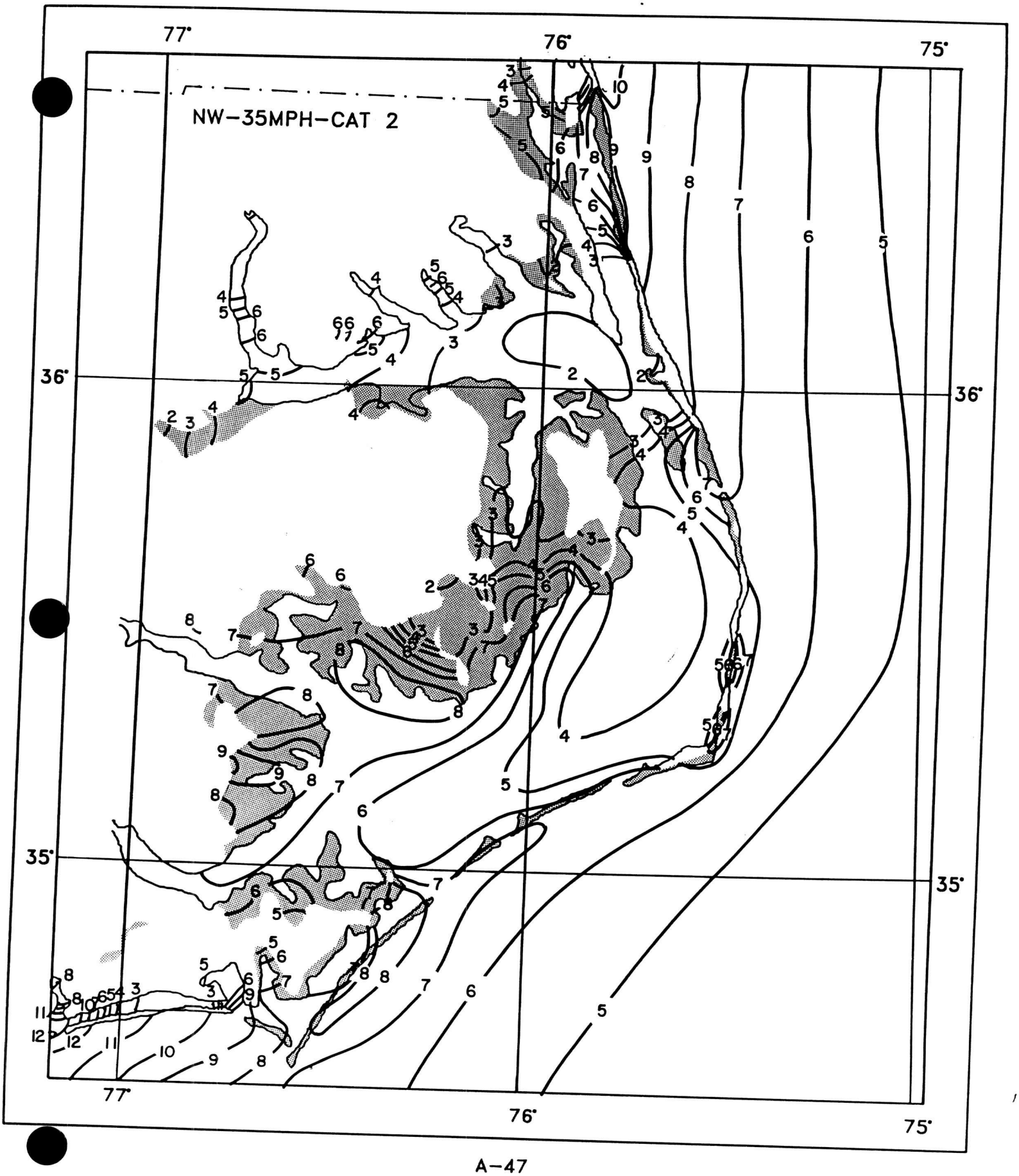

NW–25MPH–CAT 2
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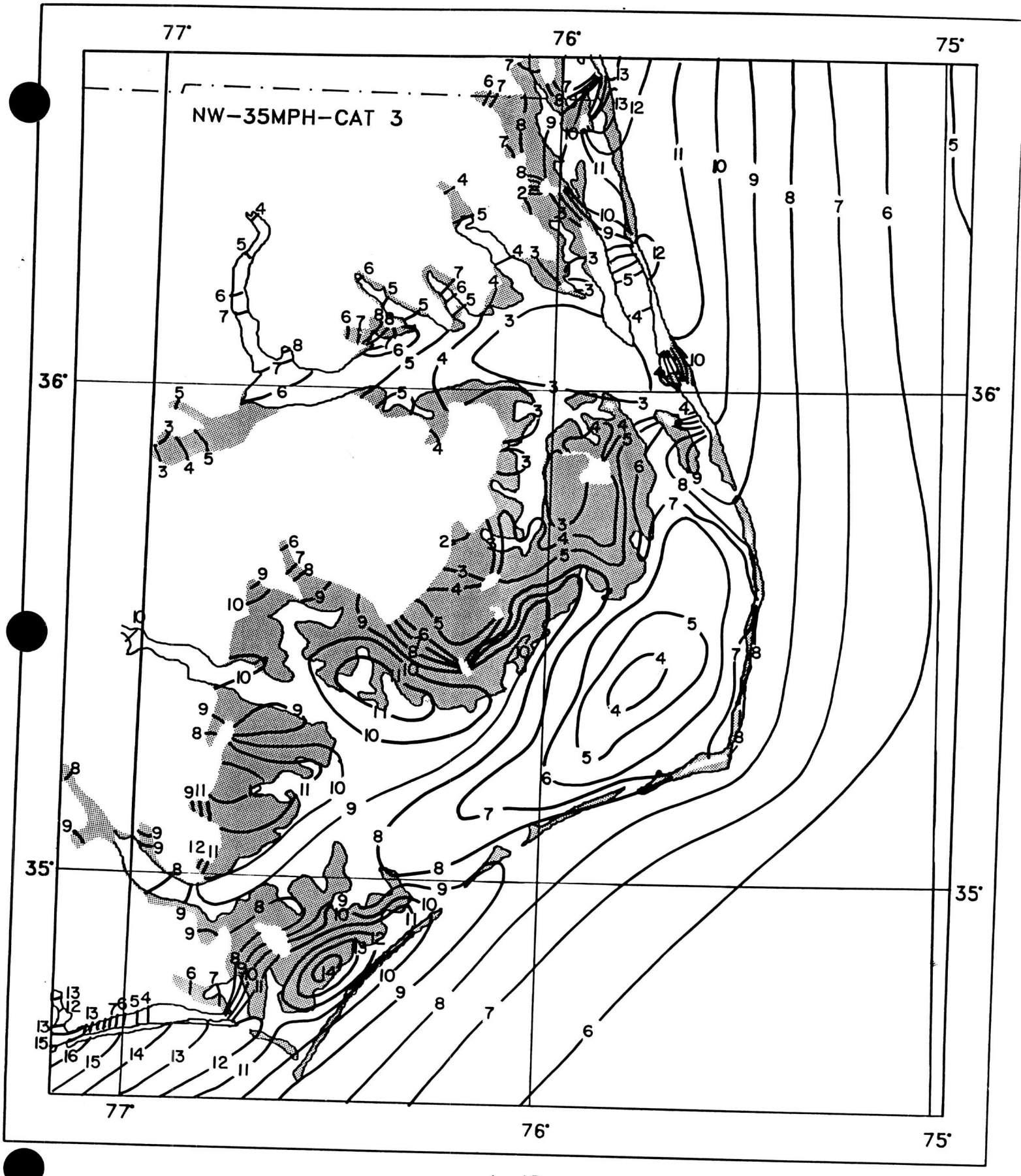

NW–25MPH–CAT 3
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36°
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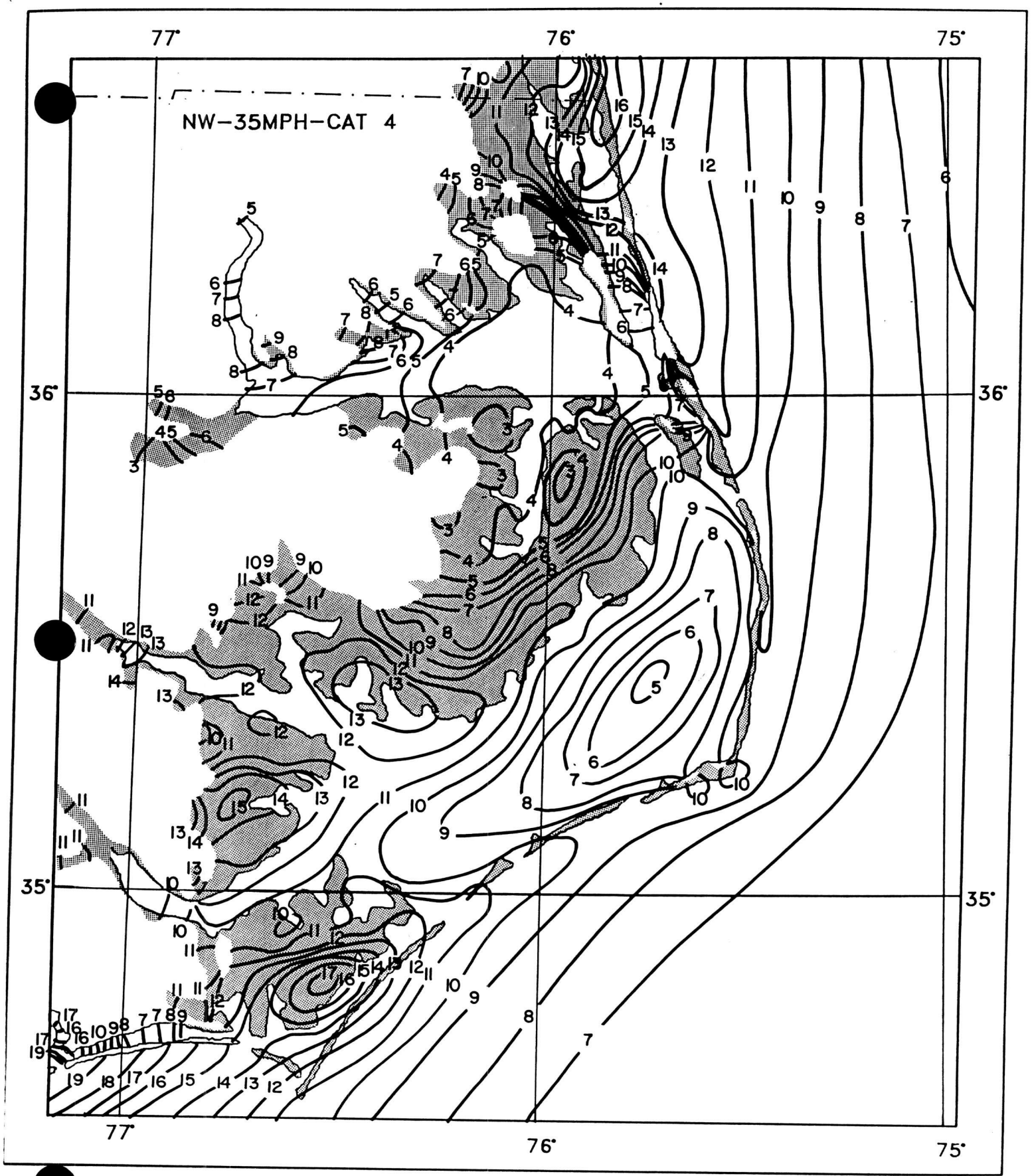

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NW–25MPH–CAT 4
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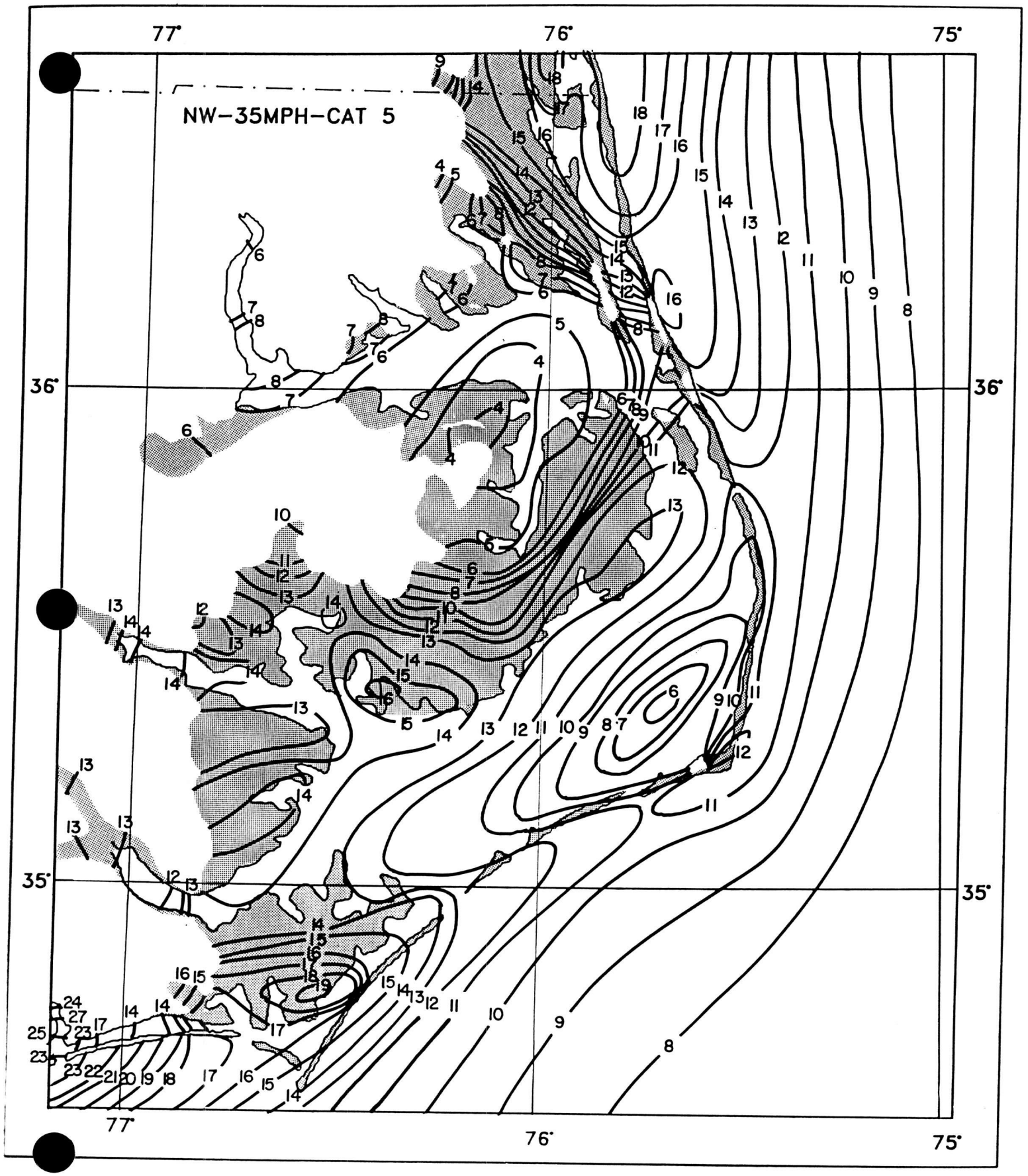

NW–25MPH–CAT 5
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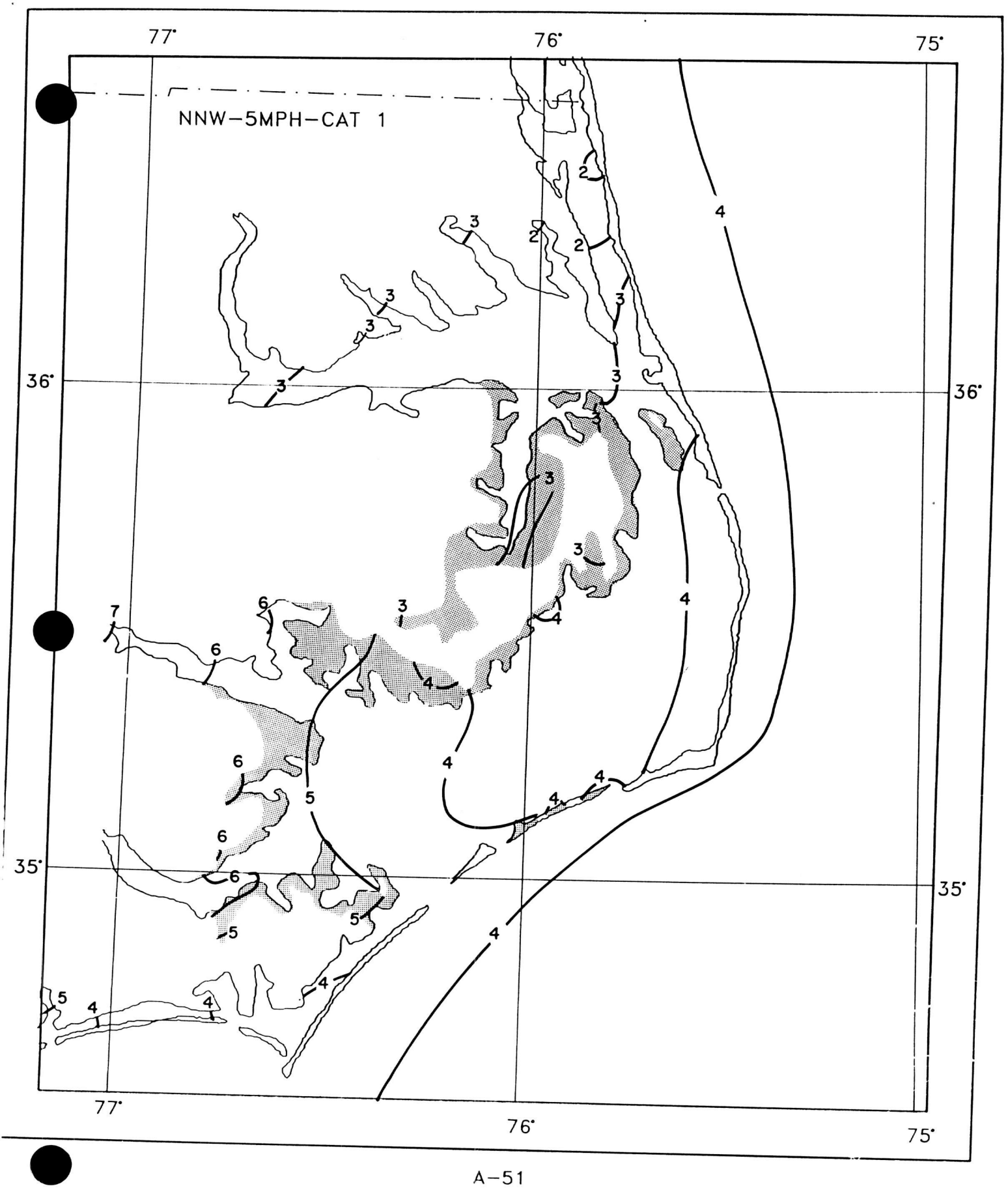

NW–35MPH–CAT 1
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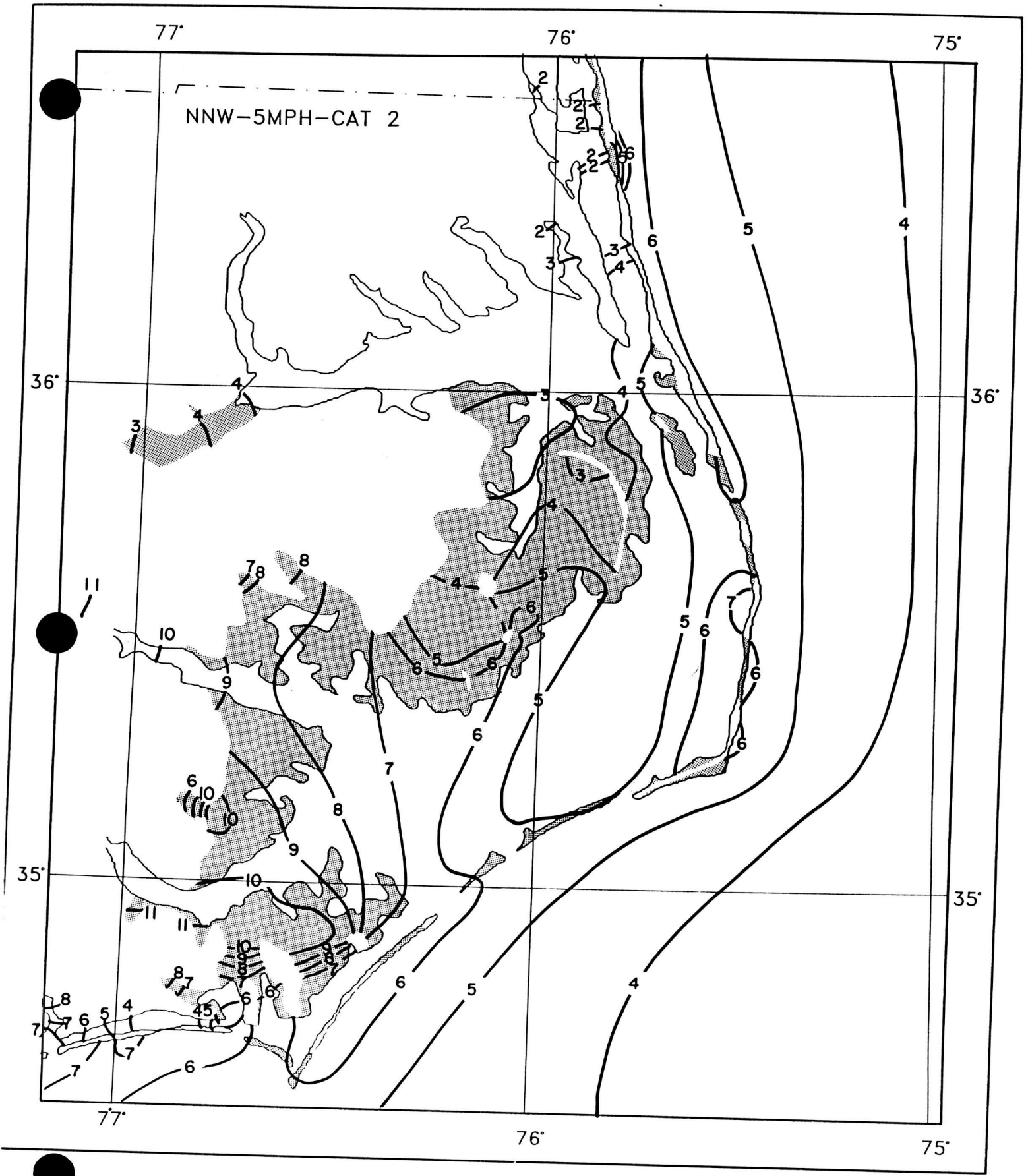

NW–35MPH–CAT 2
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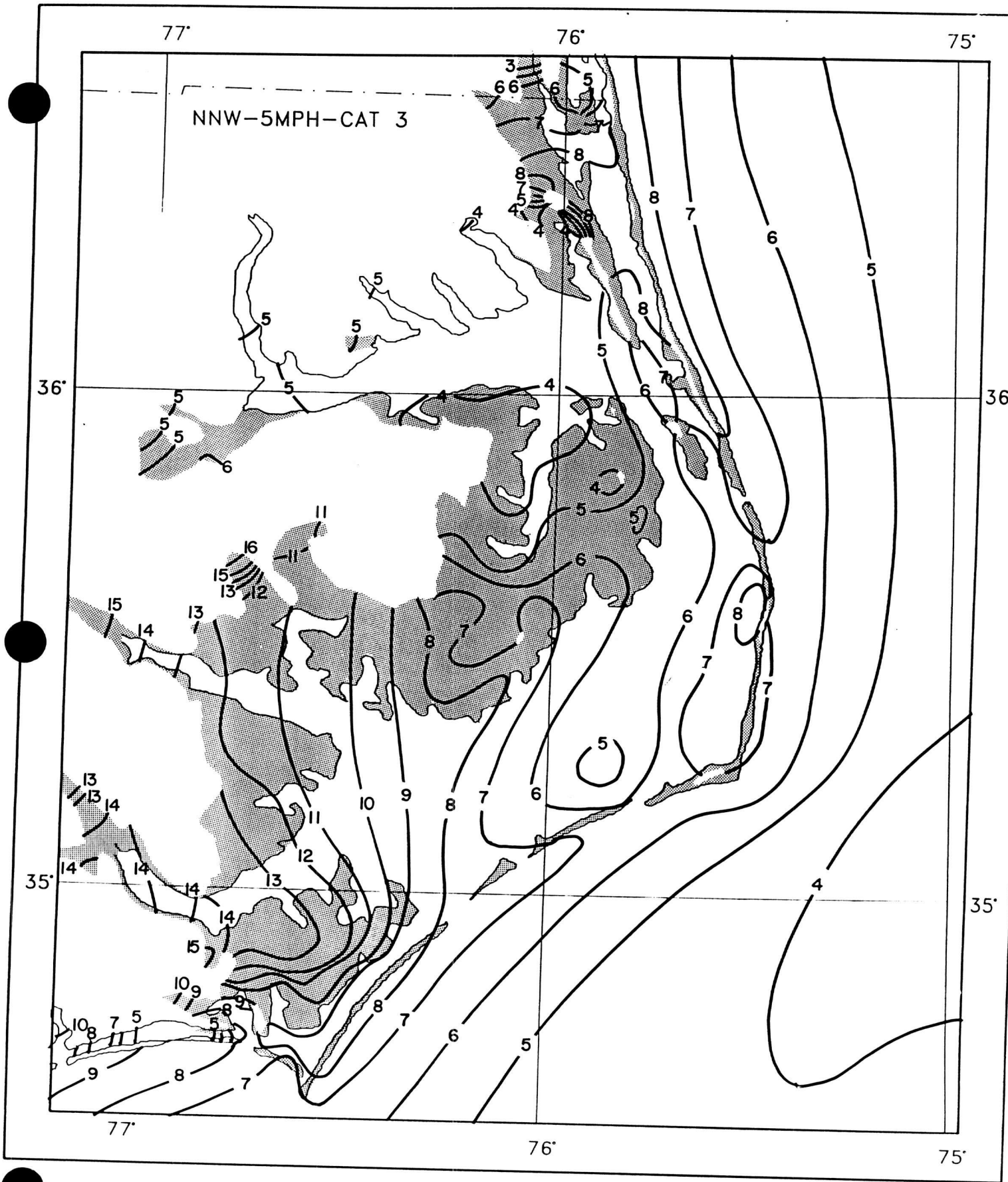

NW–35MPH–CAT 3
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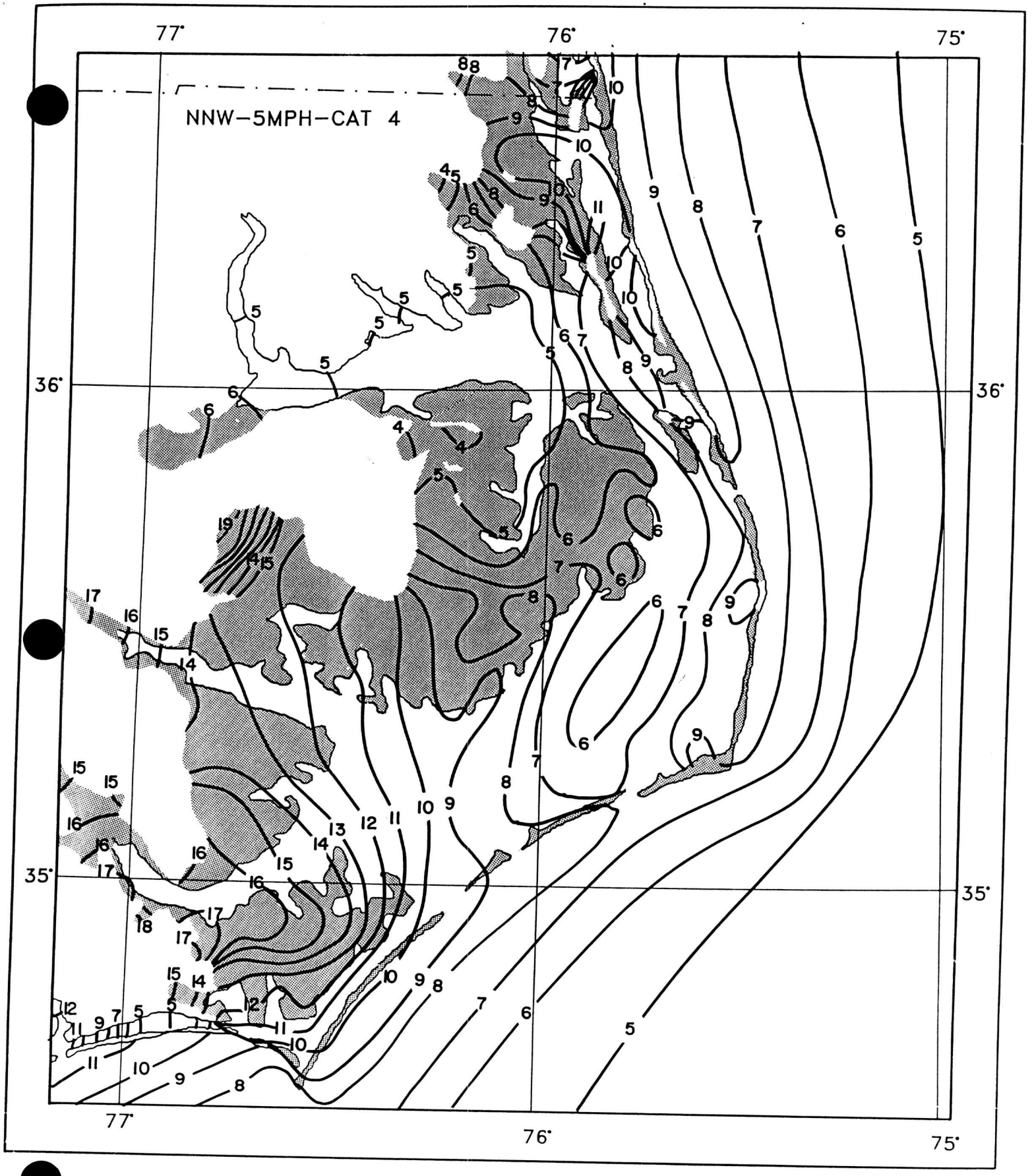

NW–35MPH–CAT 4
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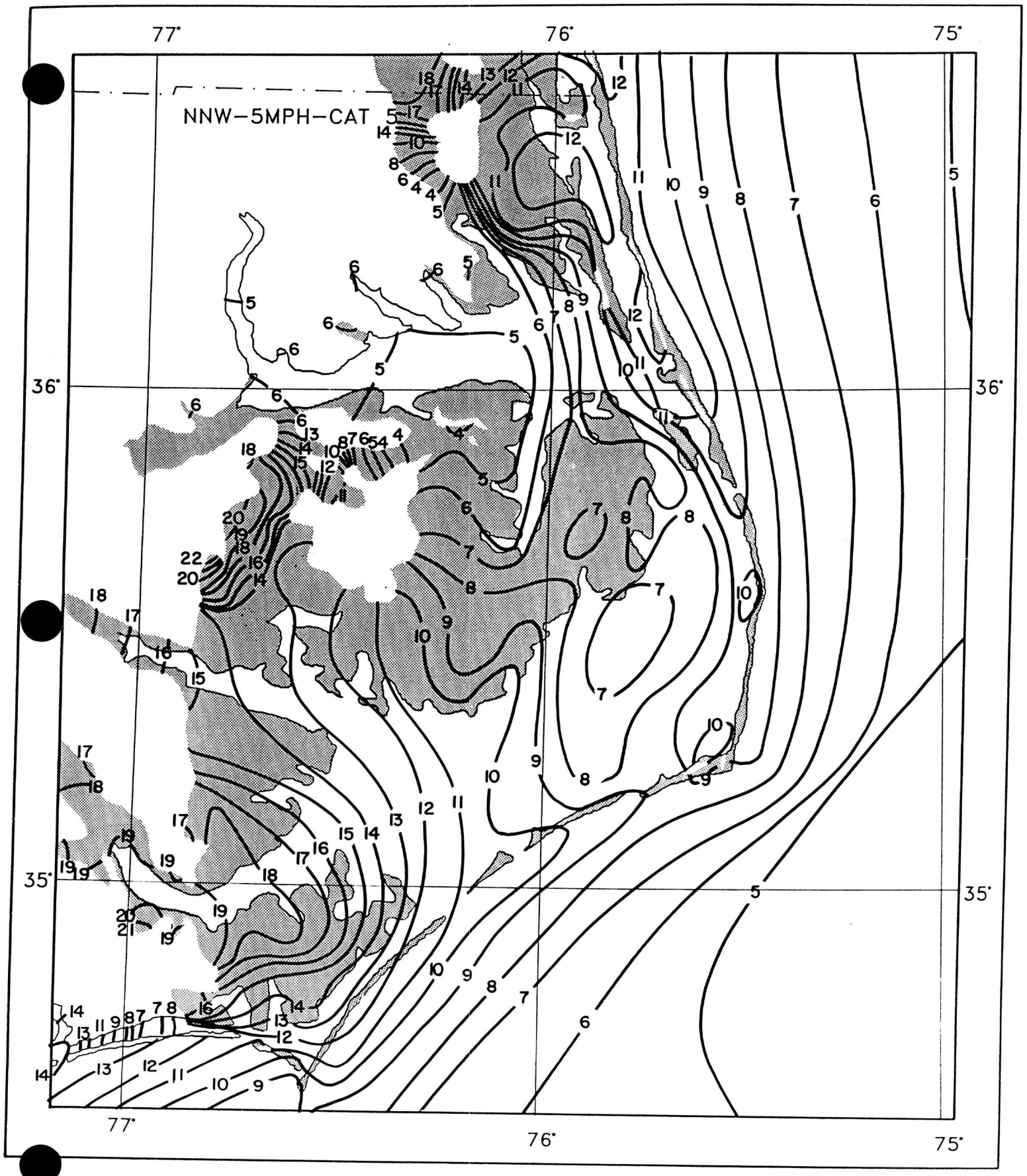

NW–35MPH–CAT 5
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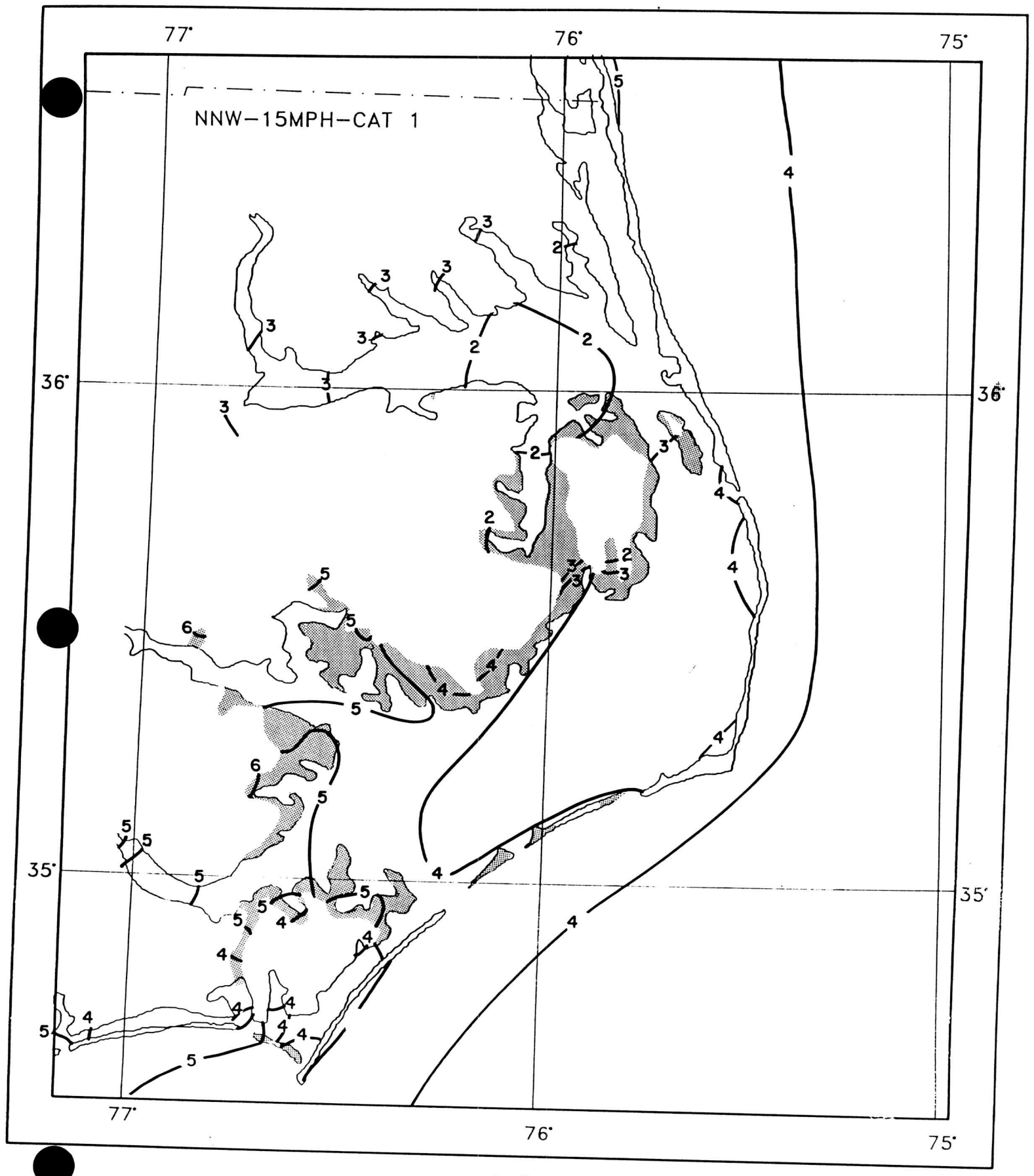

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NNW–5MPH–CAT 1
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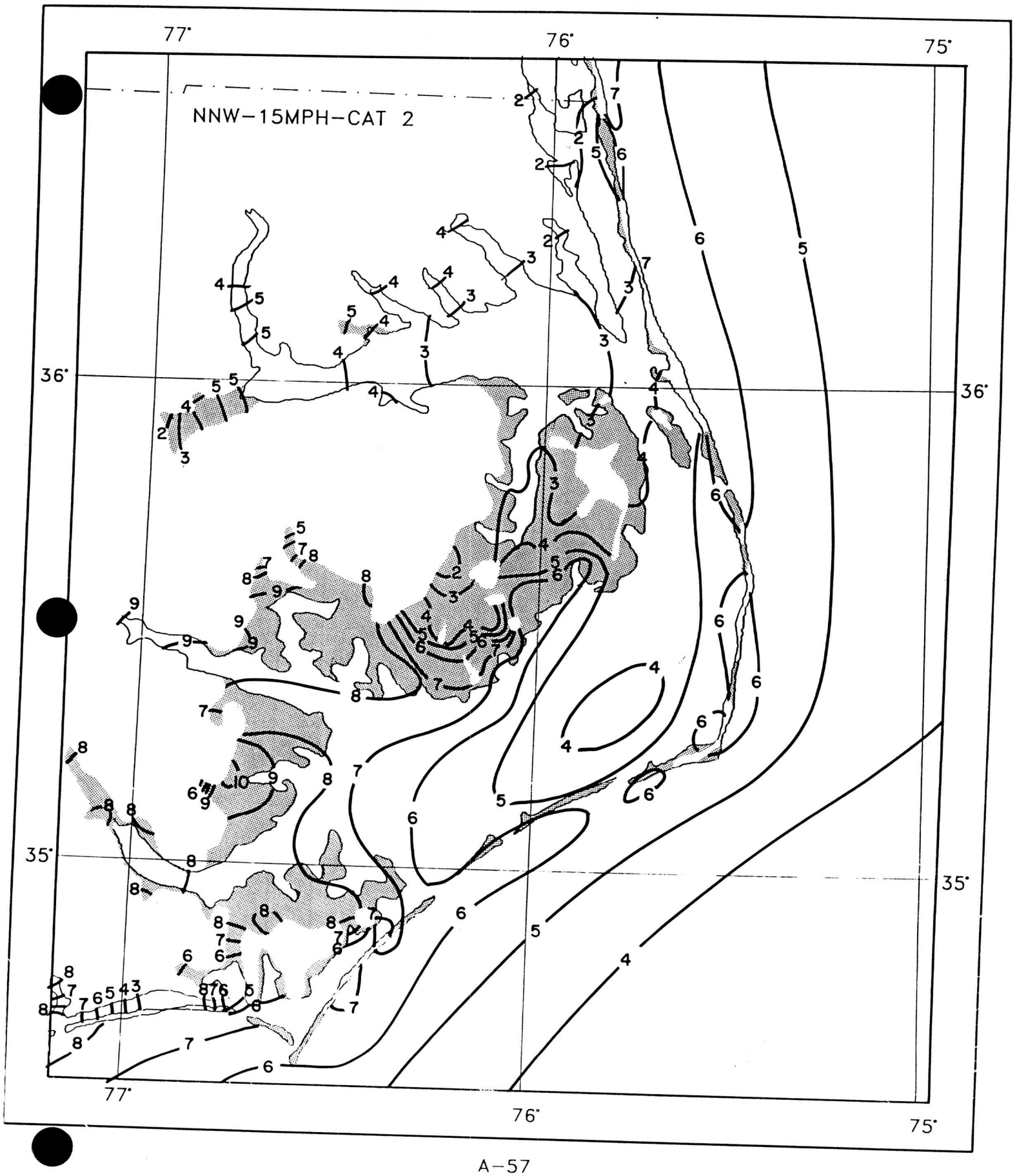

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NNW–5MPH–CAT 2
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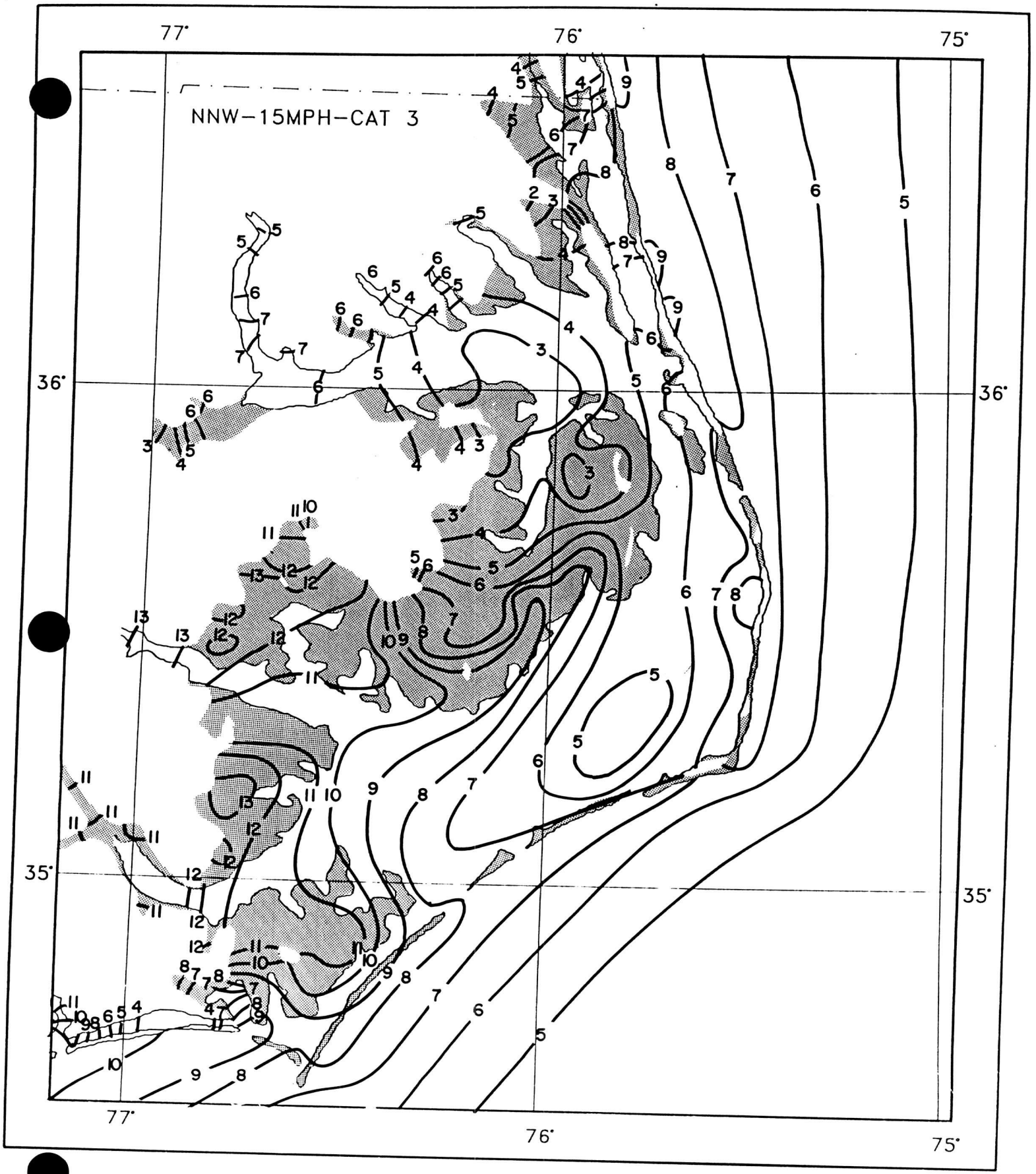

NNW–5MPH–CAT 3
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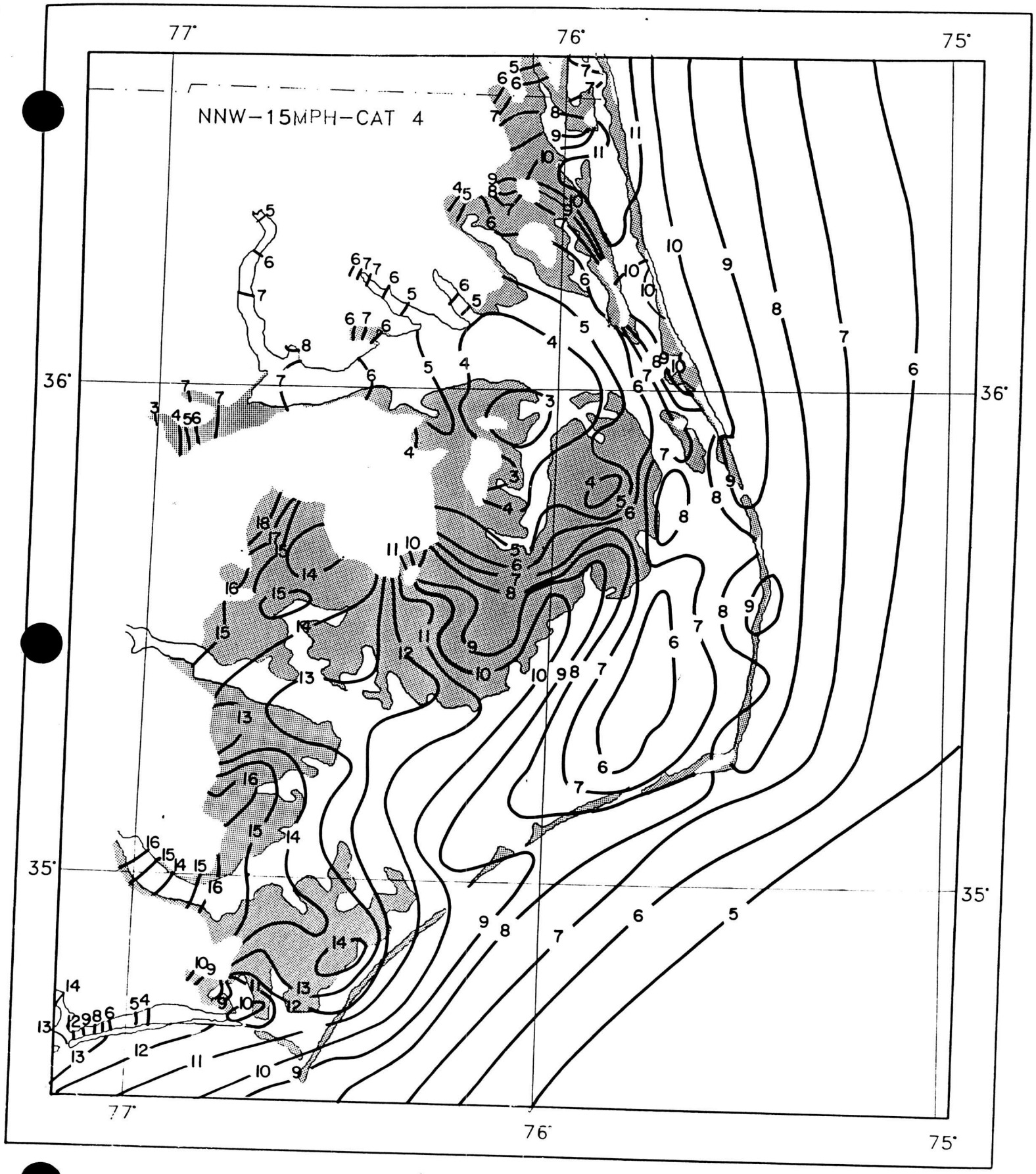

NNW–5MPH–CAT 4
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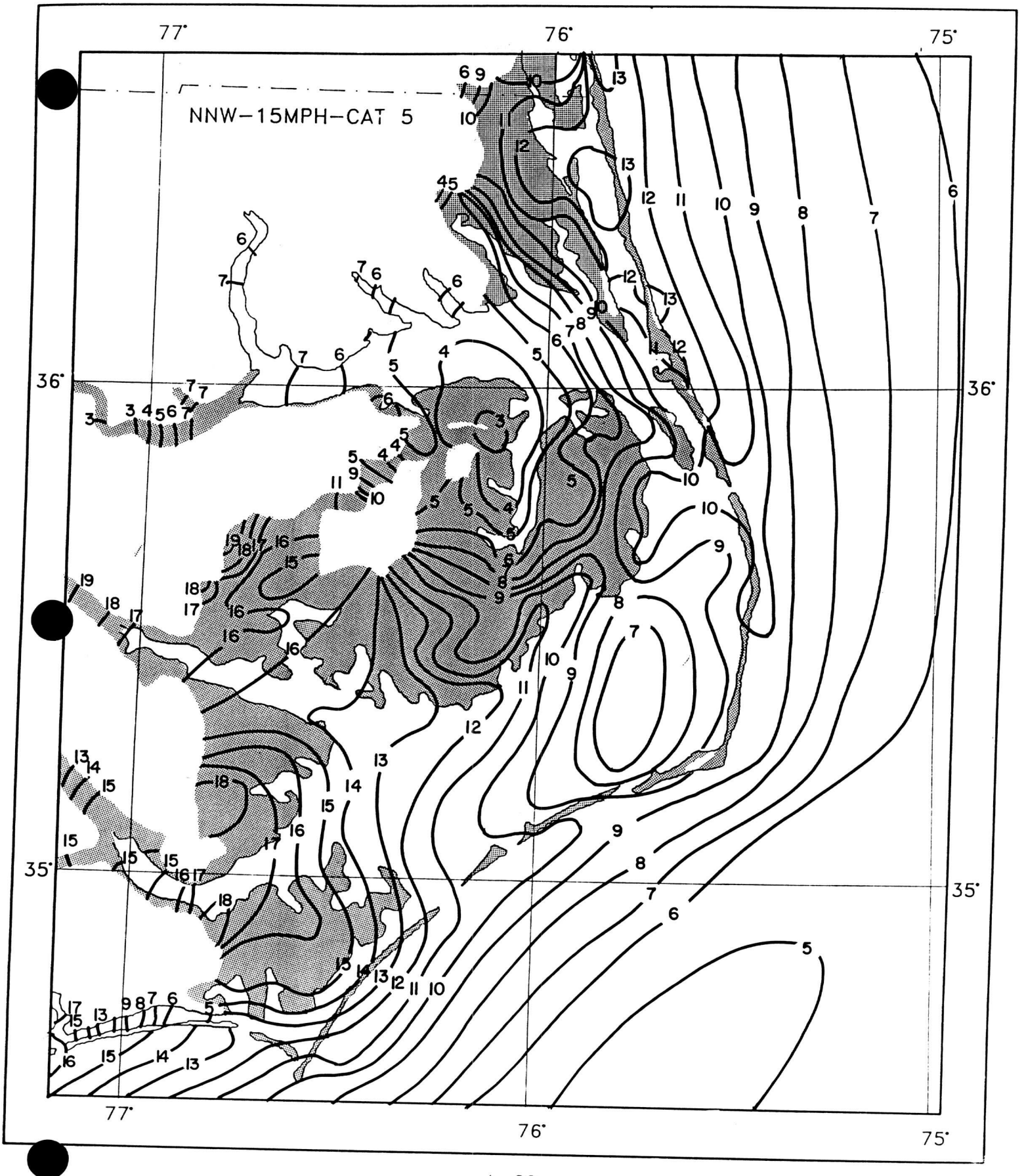

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NNW–5MPH–CAT
36°
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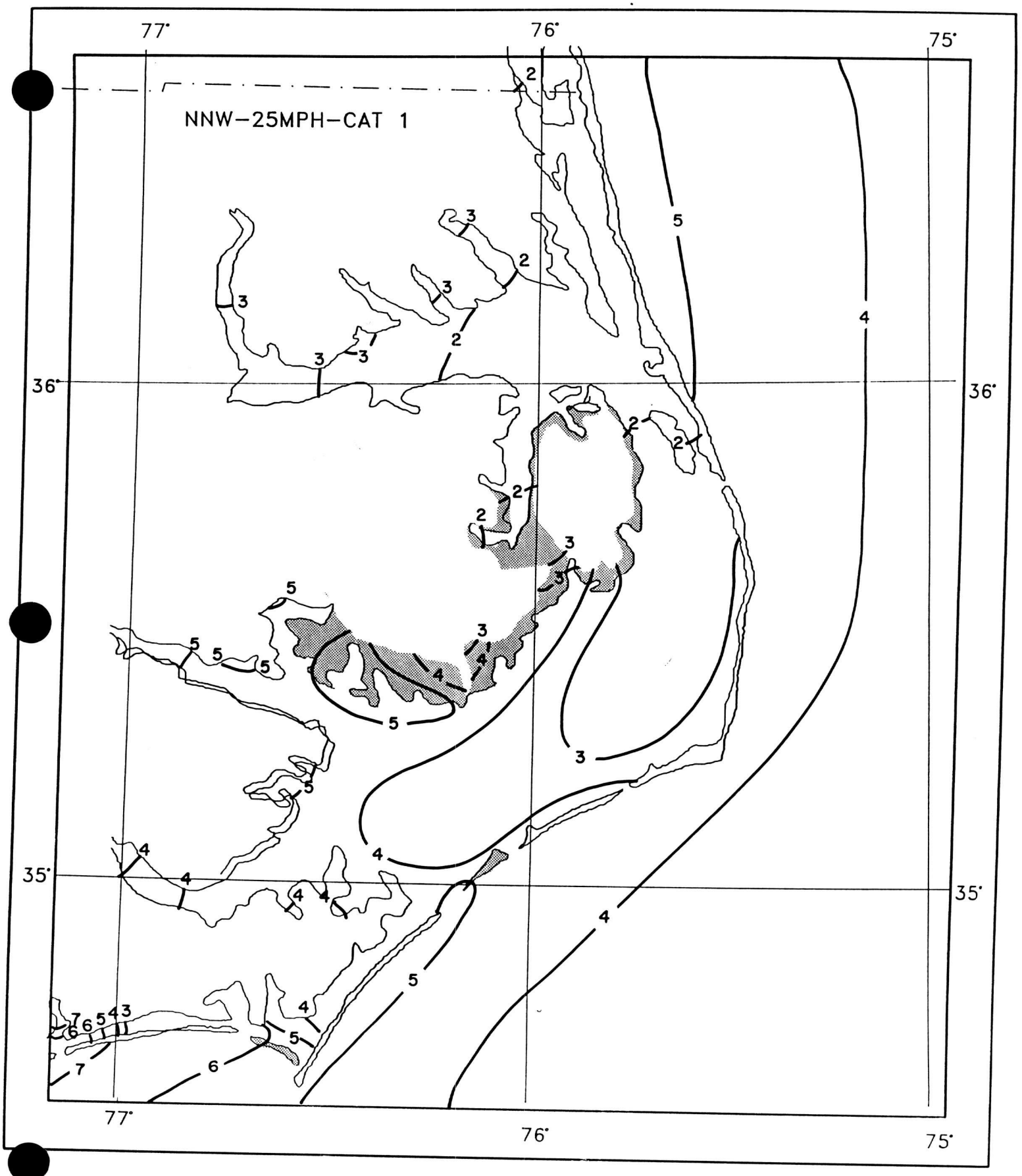

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NNW–15MPH–CAT 1
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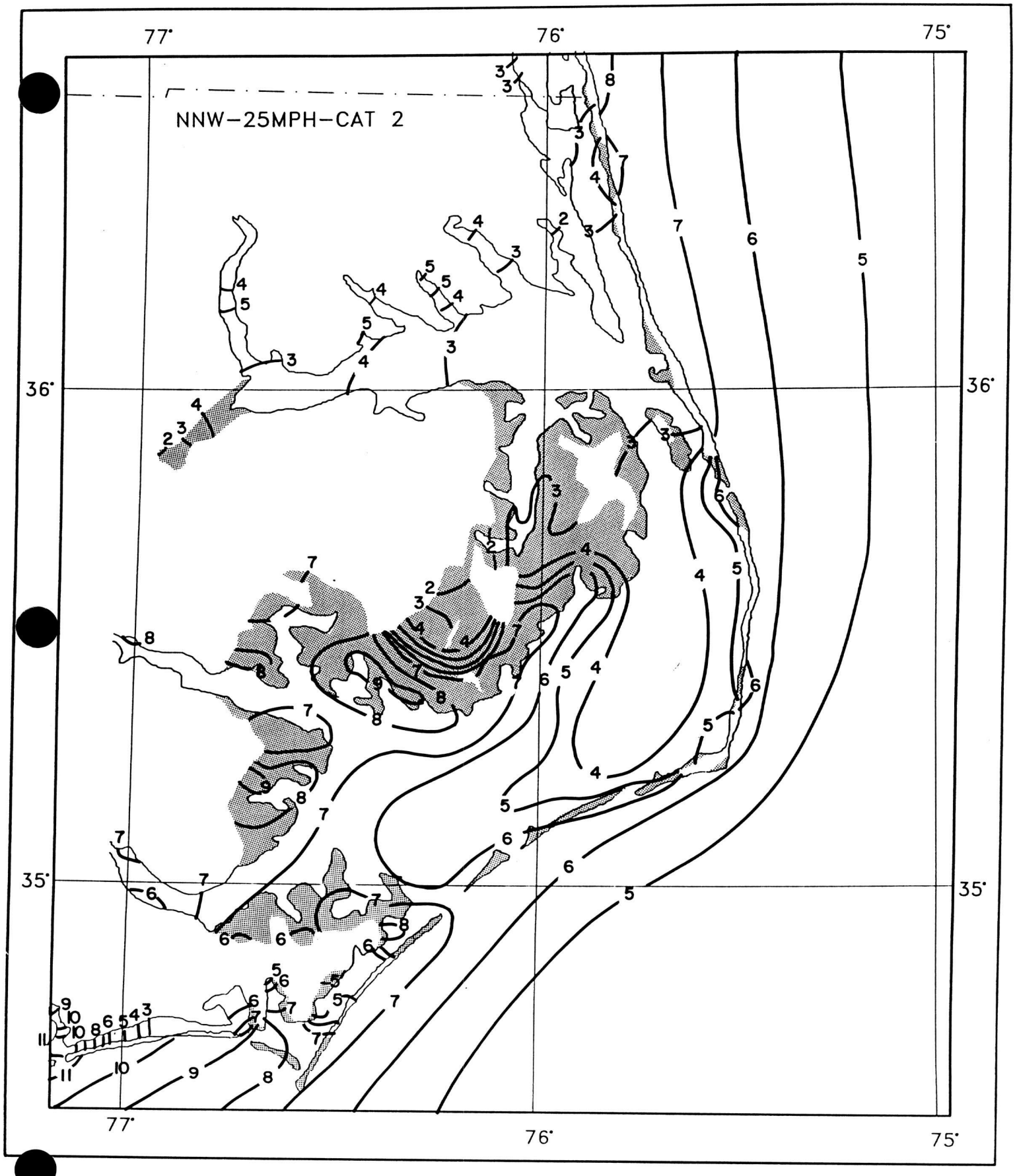

NNW–15MPH–CAT 2
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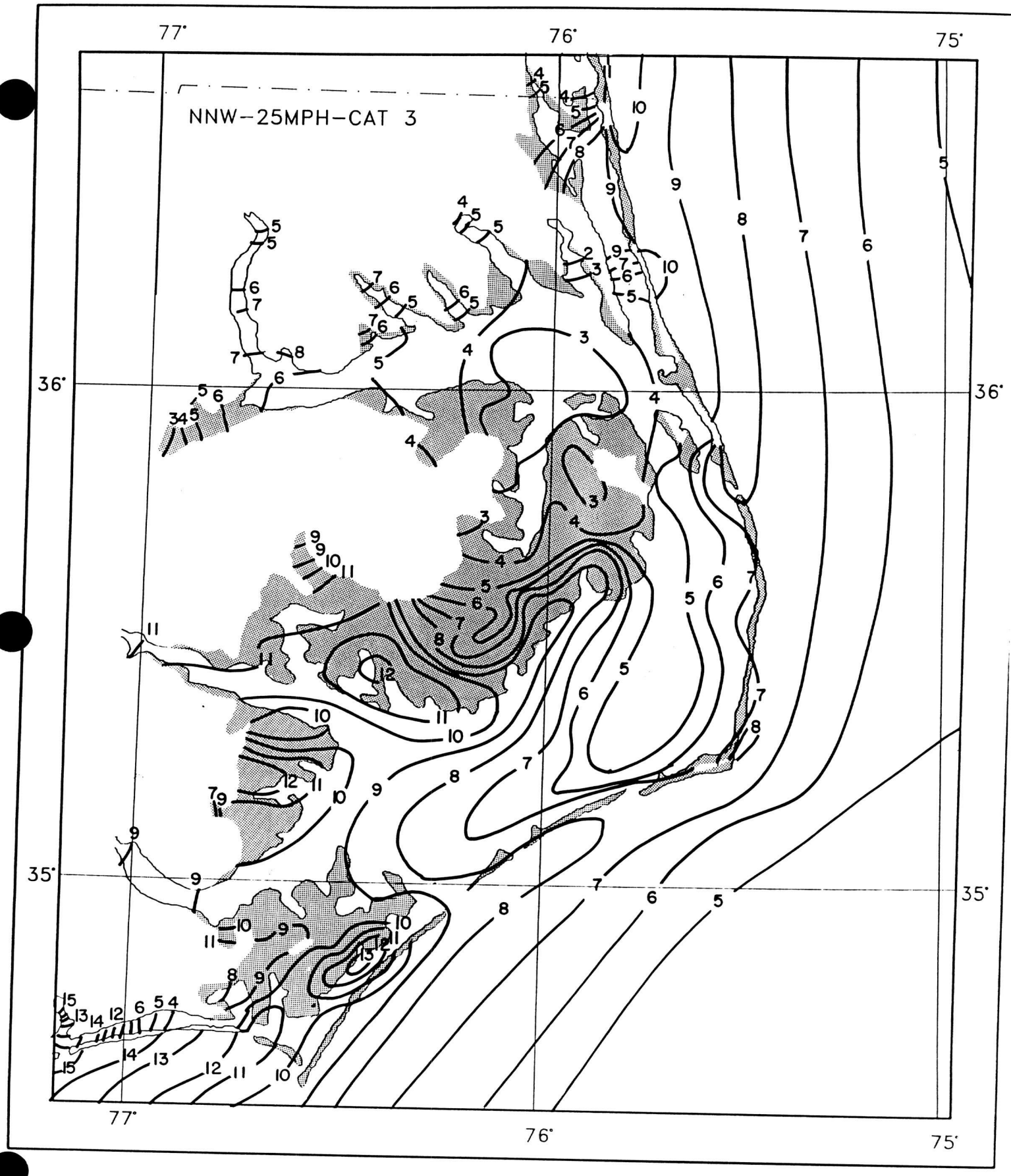

NNW–15MPH–CAT 3
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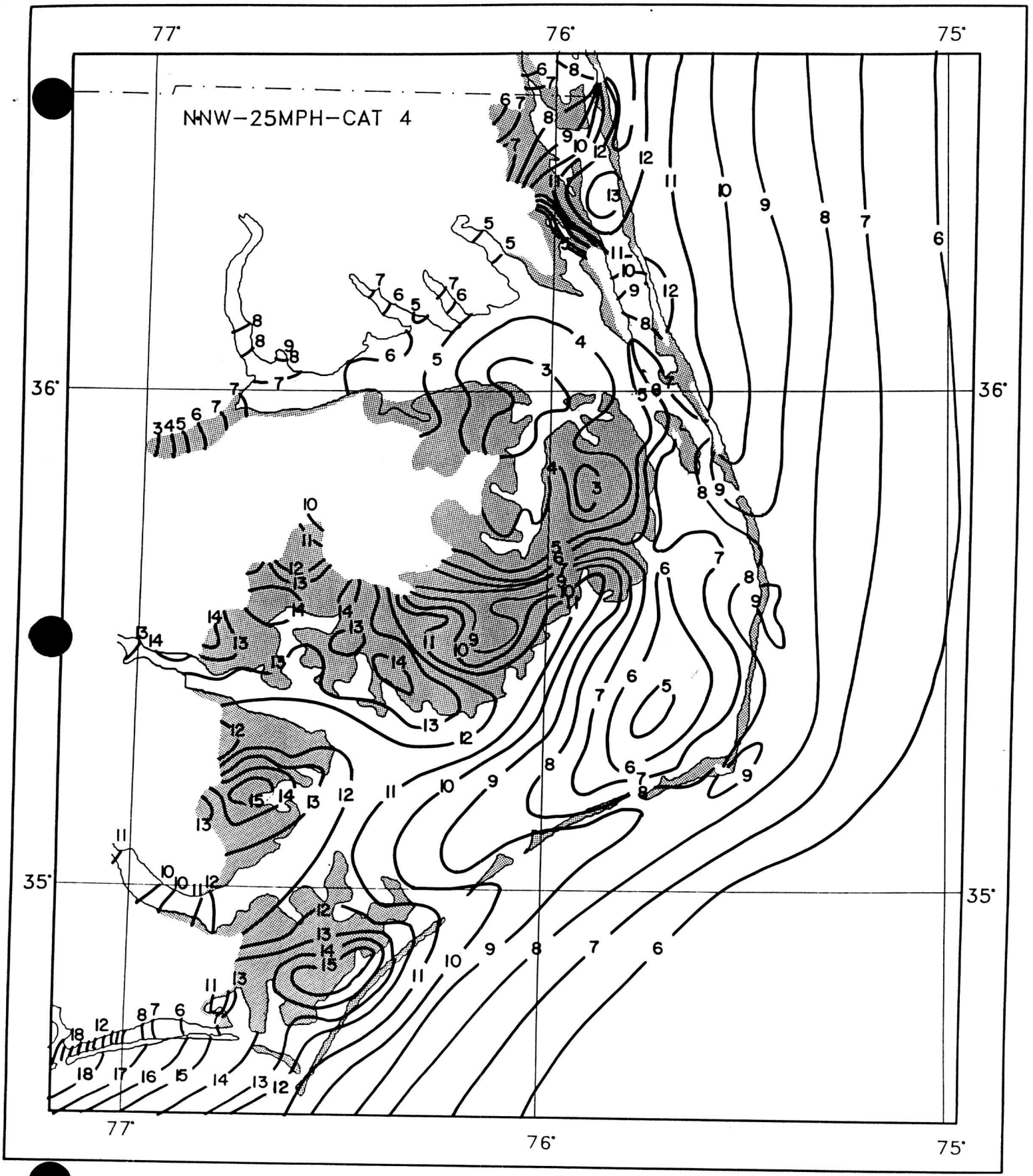

NNW–15MPH–CAT 4
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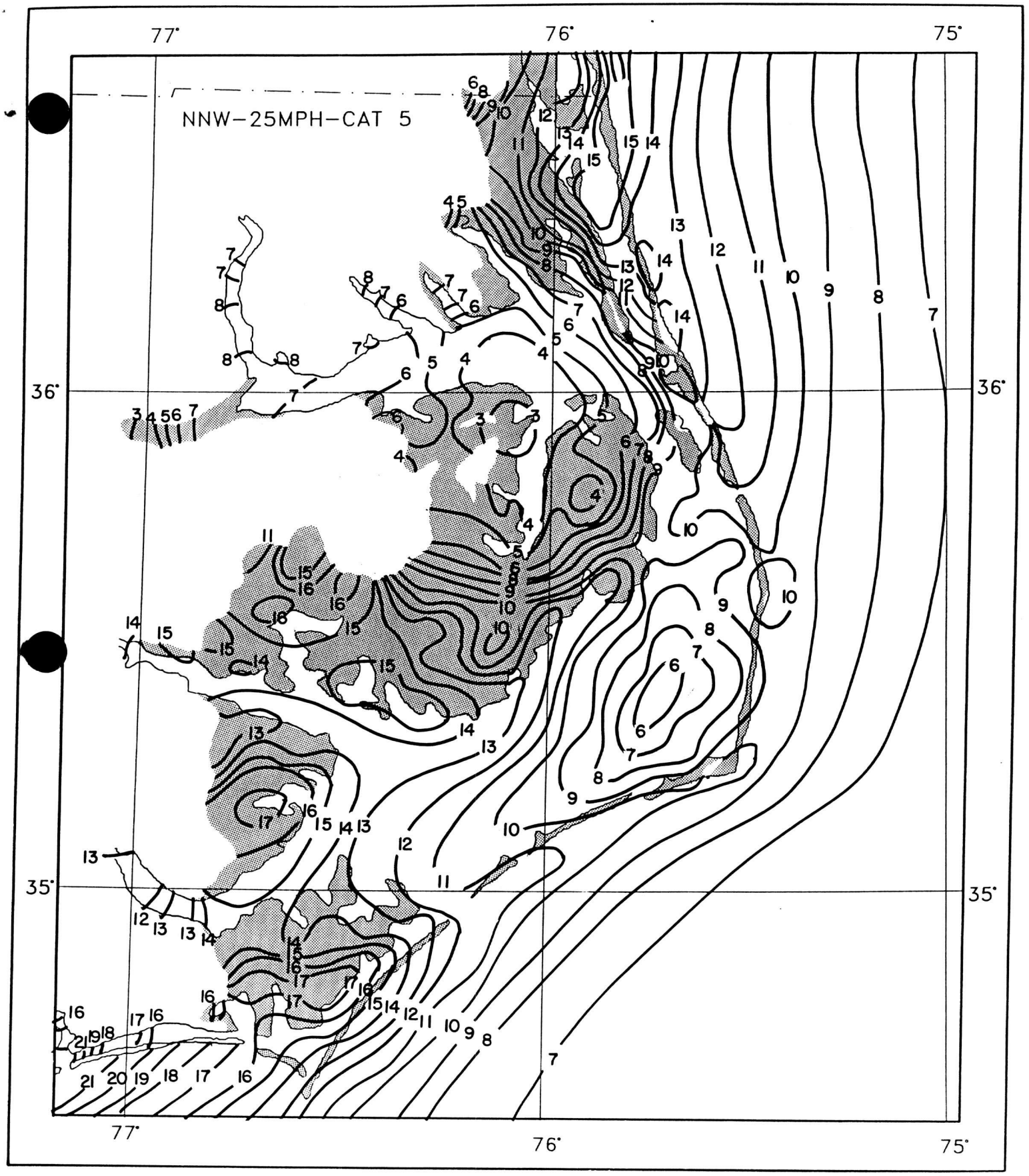

NNW–15MPH–CAT 5
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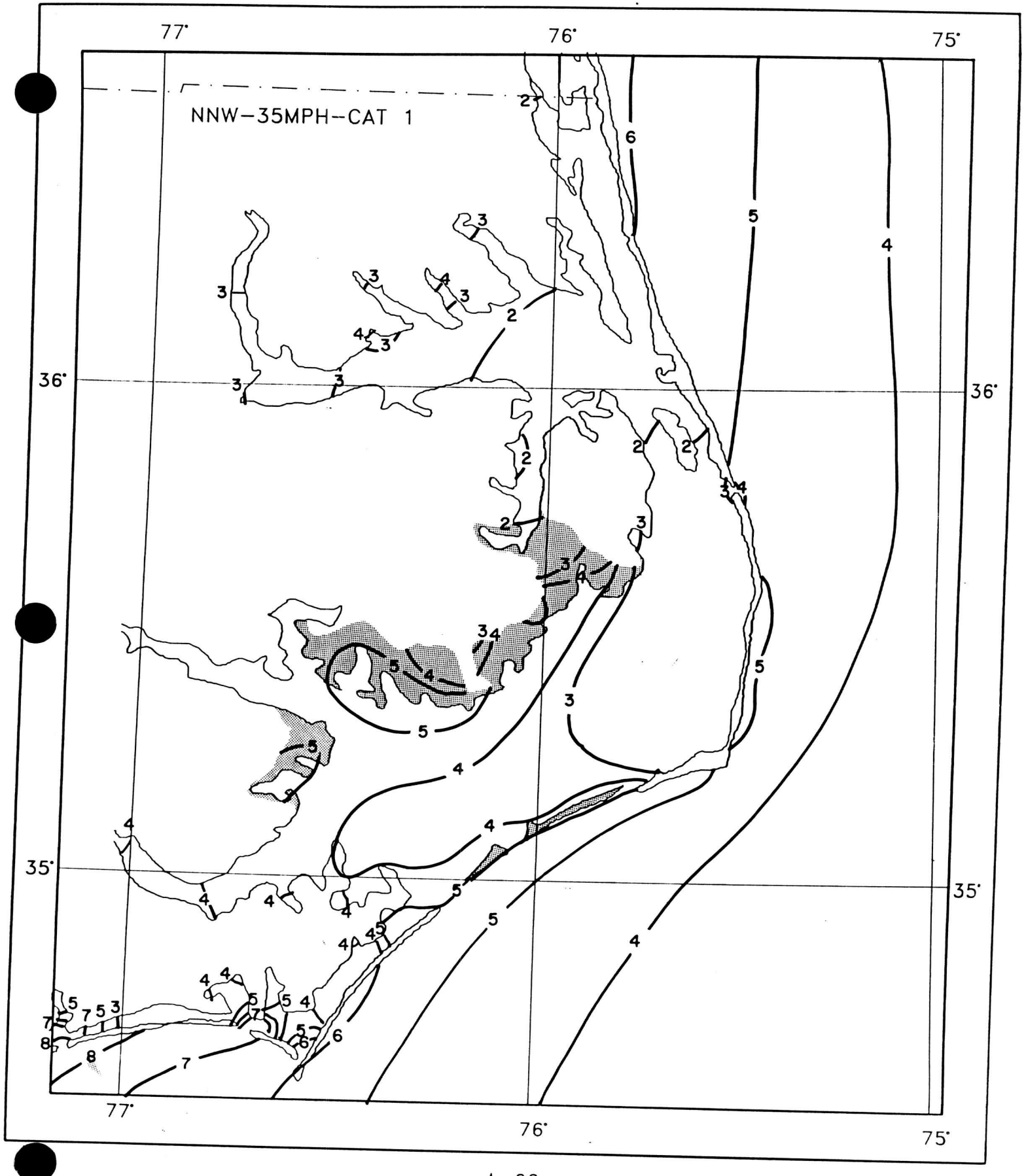

NNW–25MPH–CAT 1
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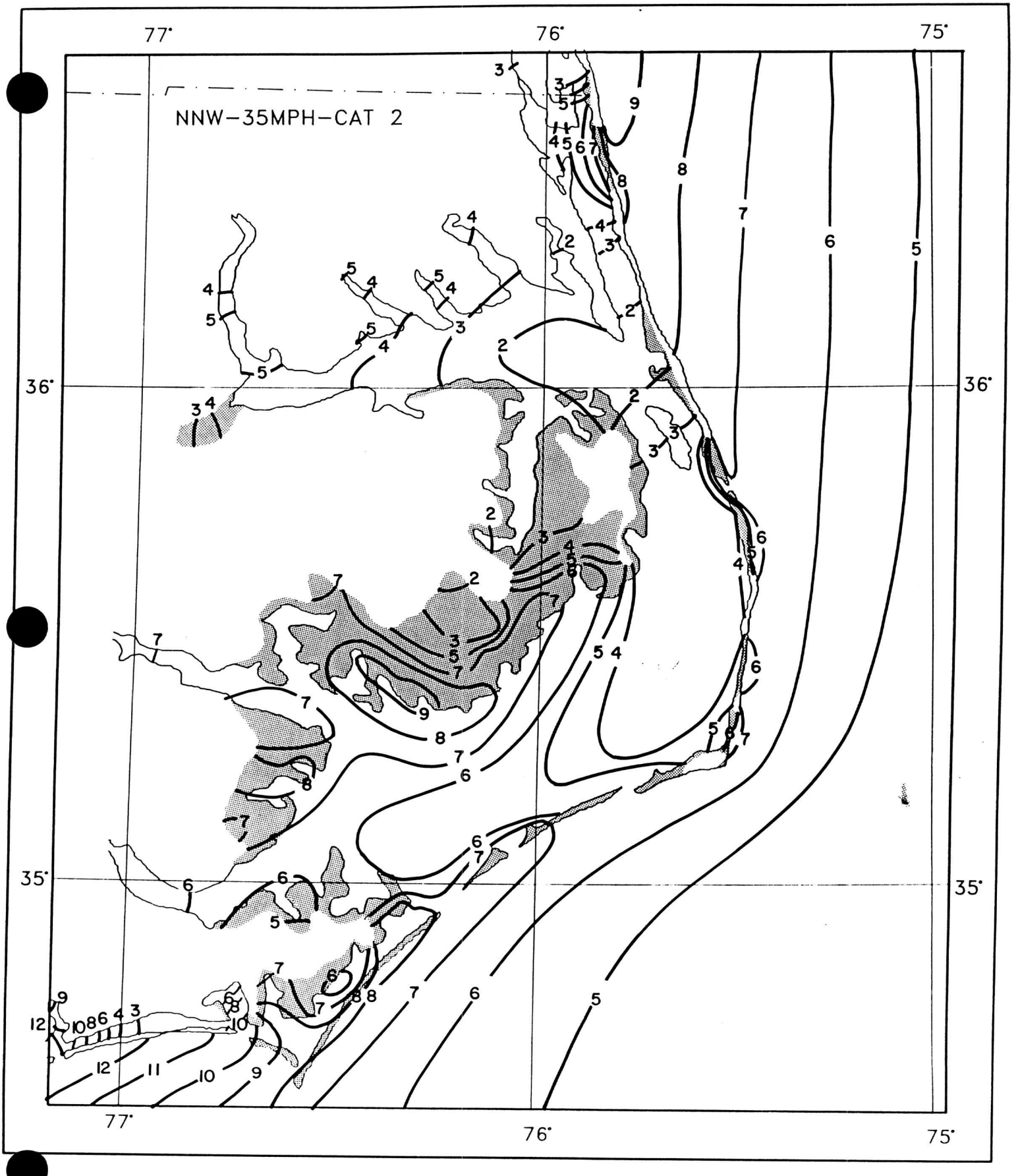

NNW–25MPH–CAT 2
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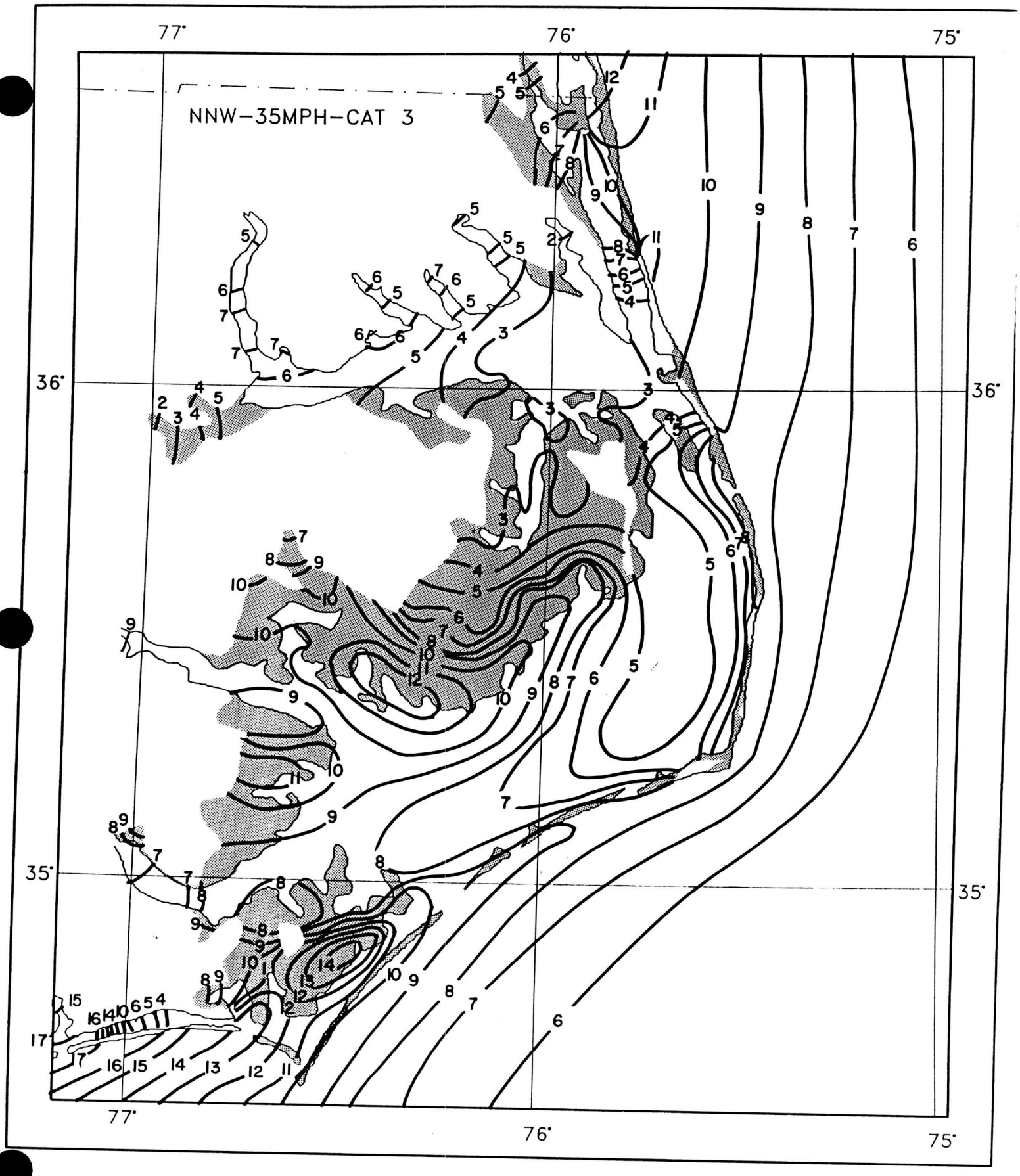

NNW–25MPH–CAT 3
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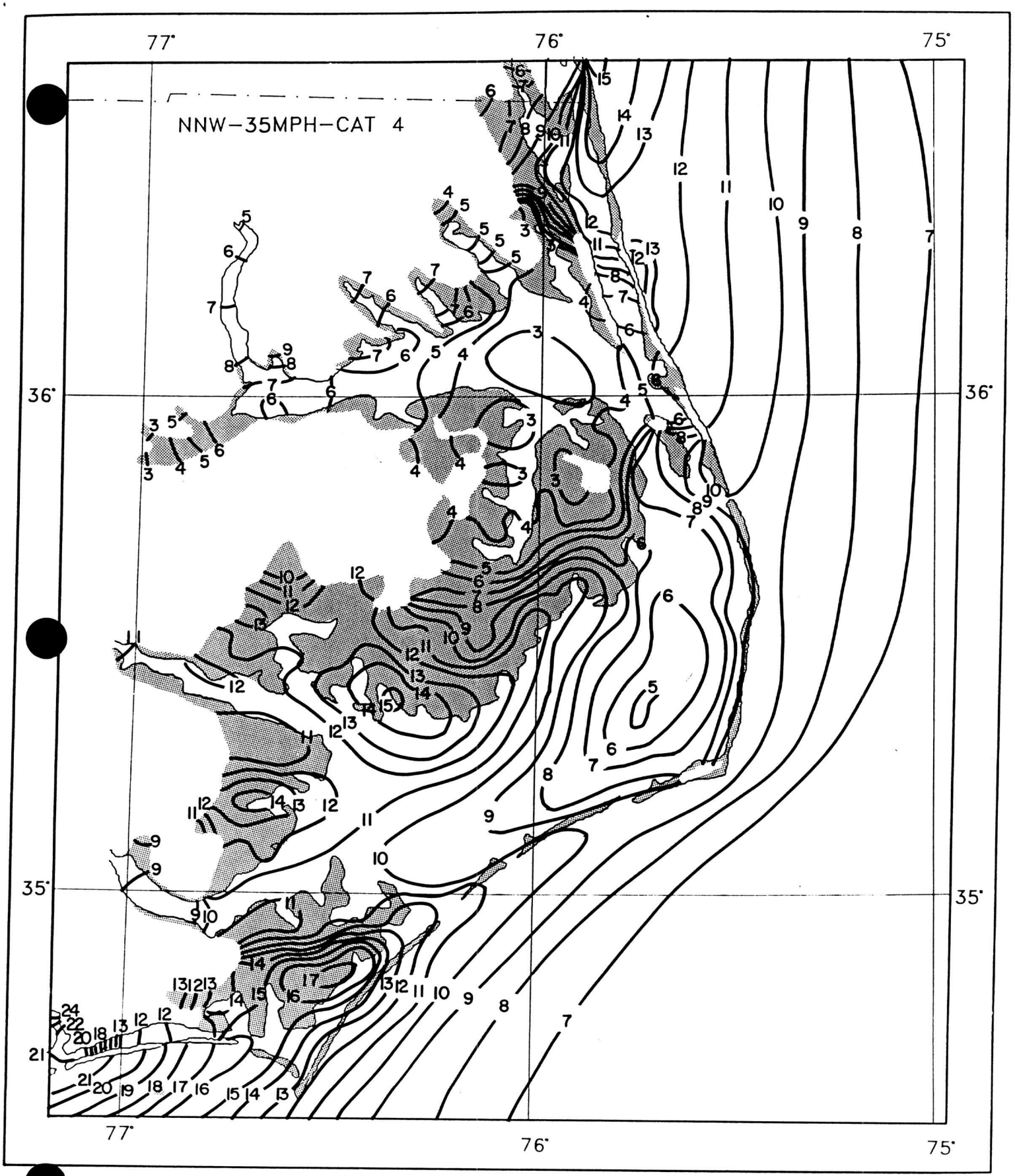

NNW–25MPH–CAT 4
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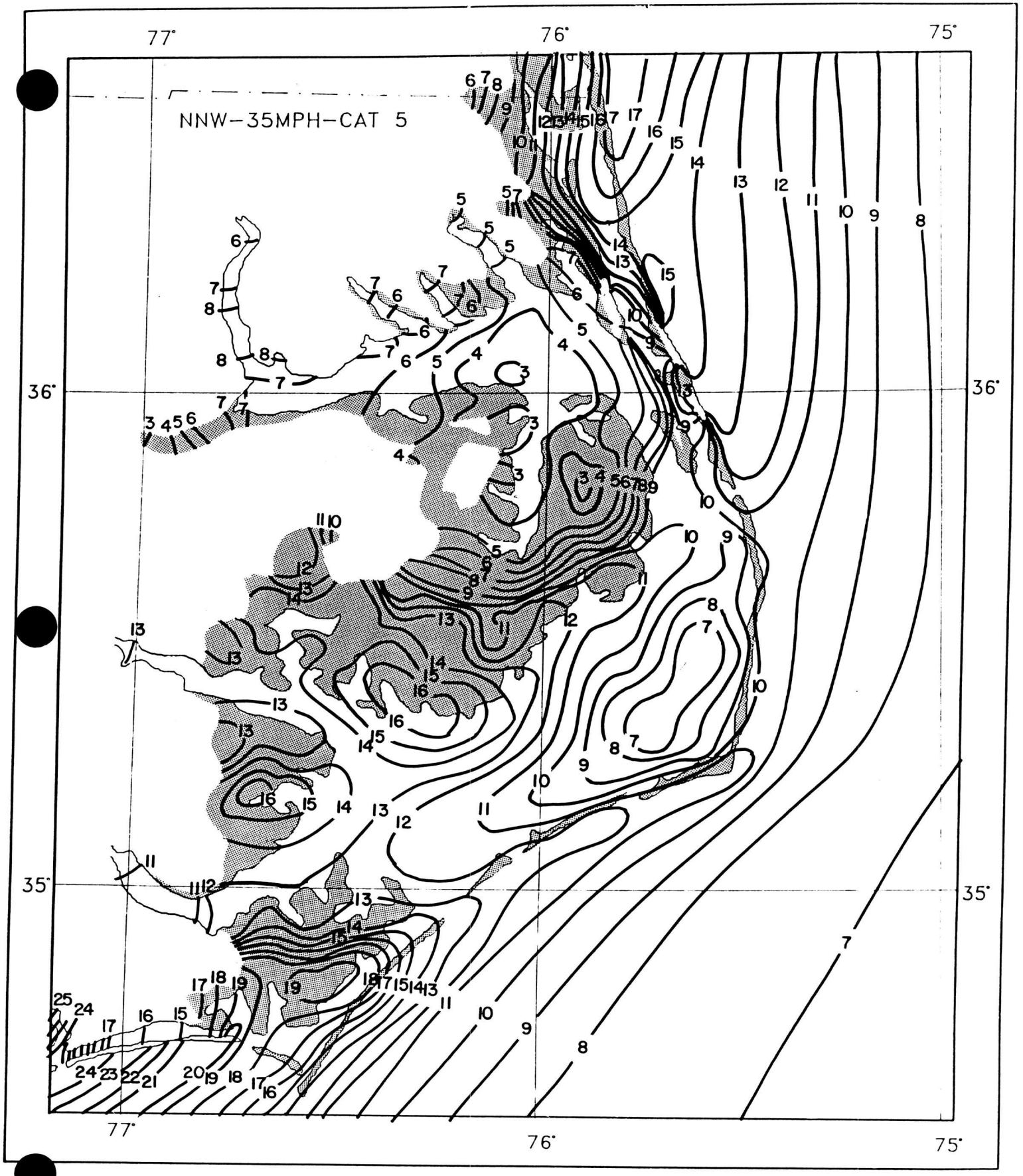

NNW–25MPH–CAT 5
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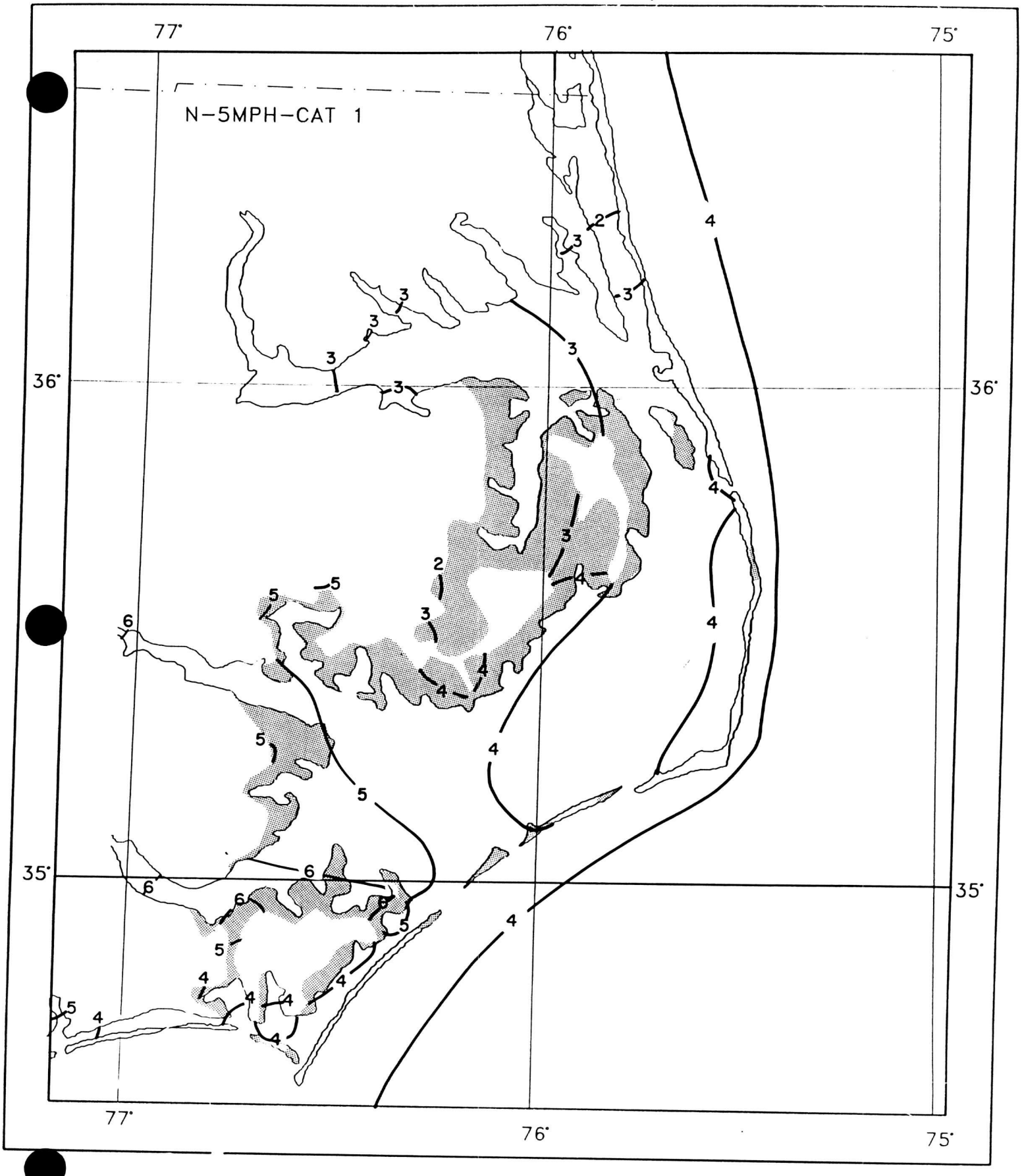

NNW–35MPH–CAT 1
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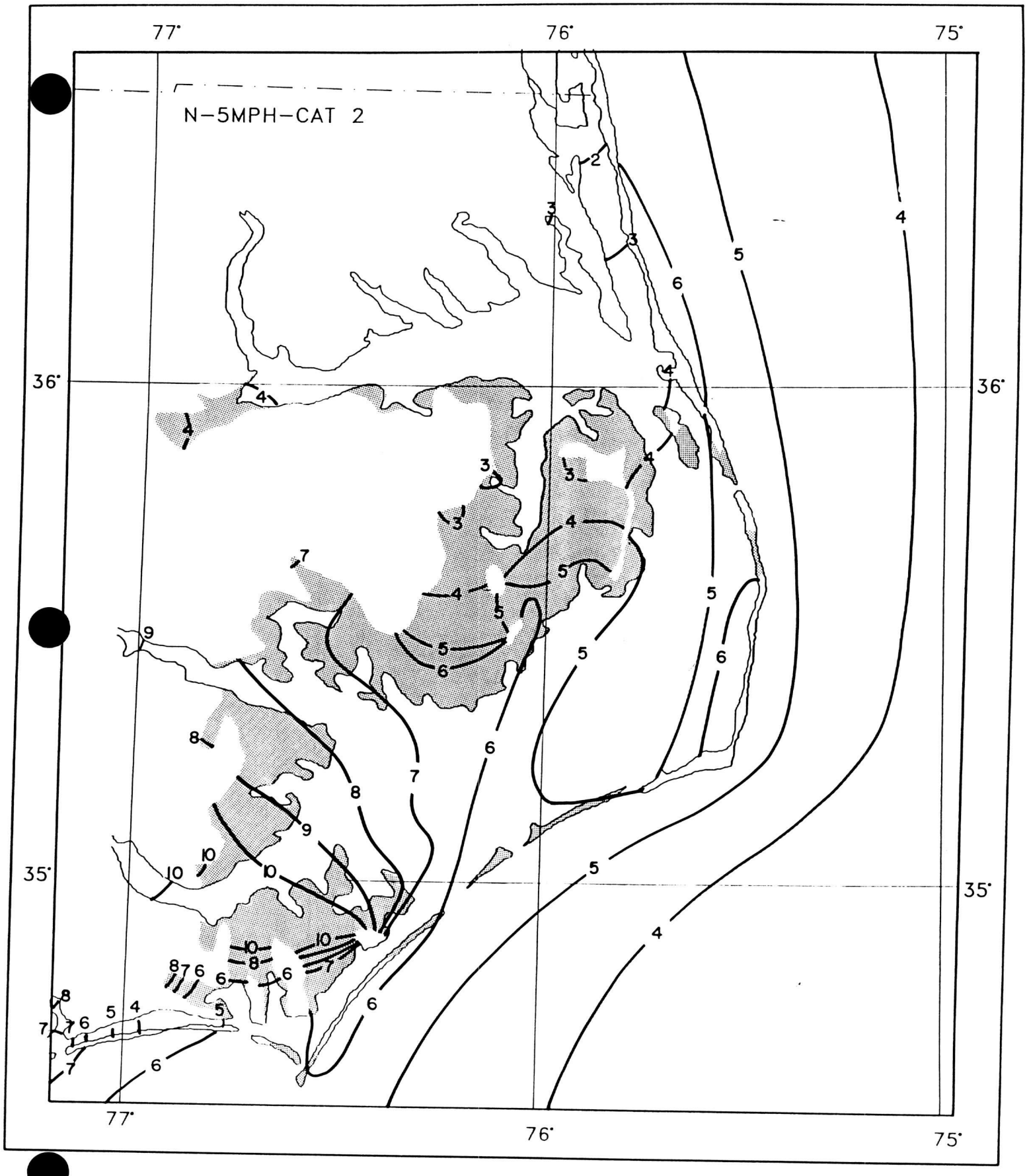

NNW–35MPH–CAT 2
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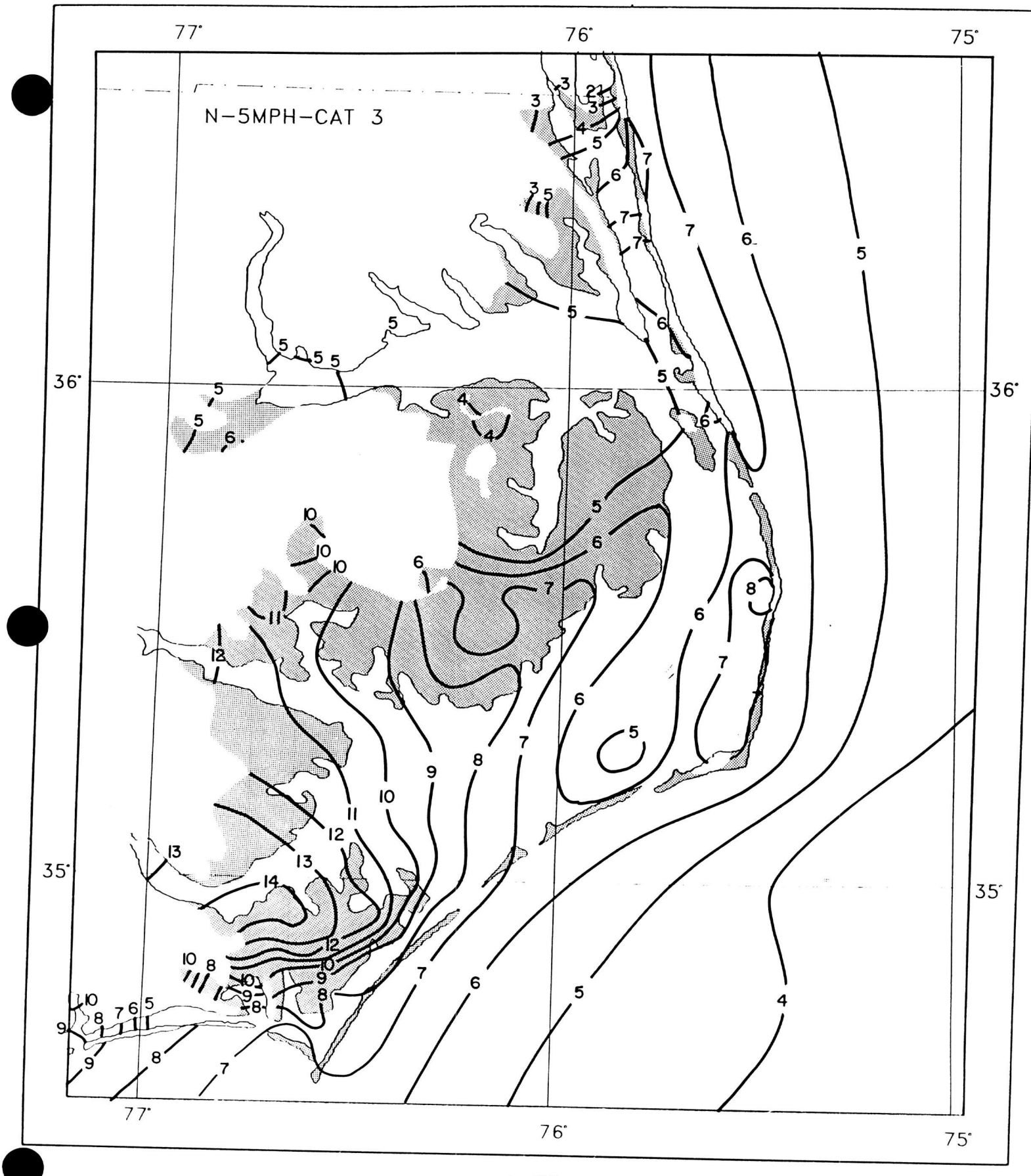

NNW–35MPH–CAT 3
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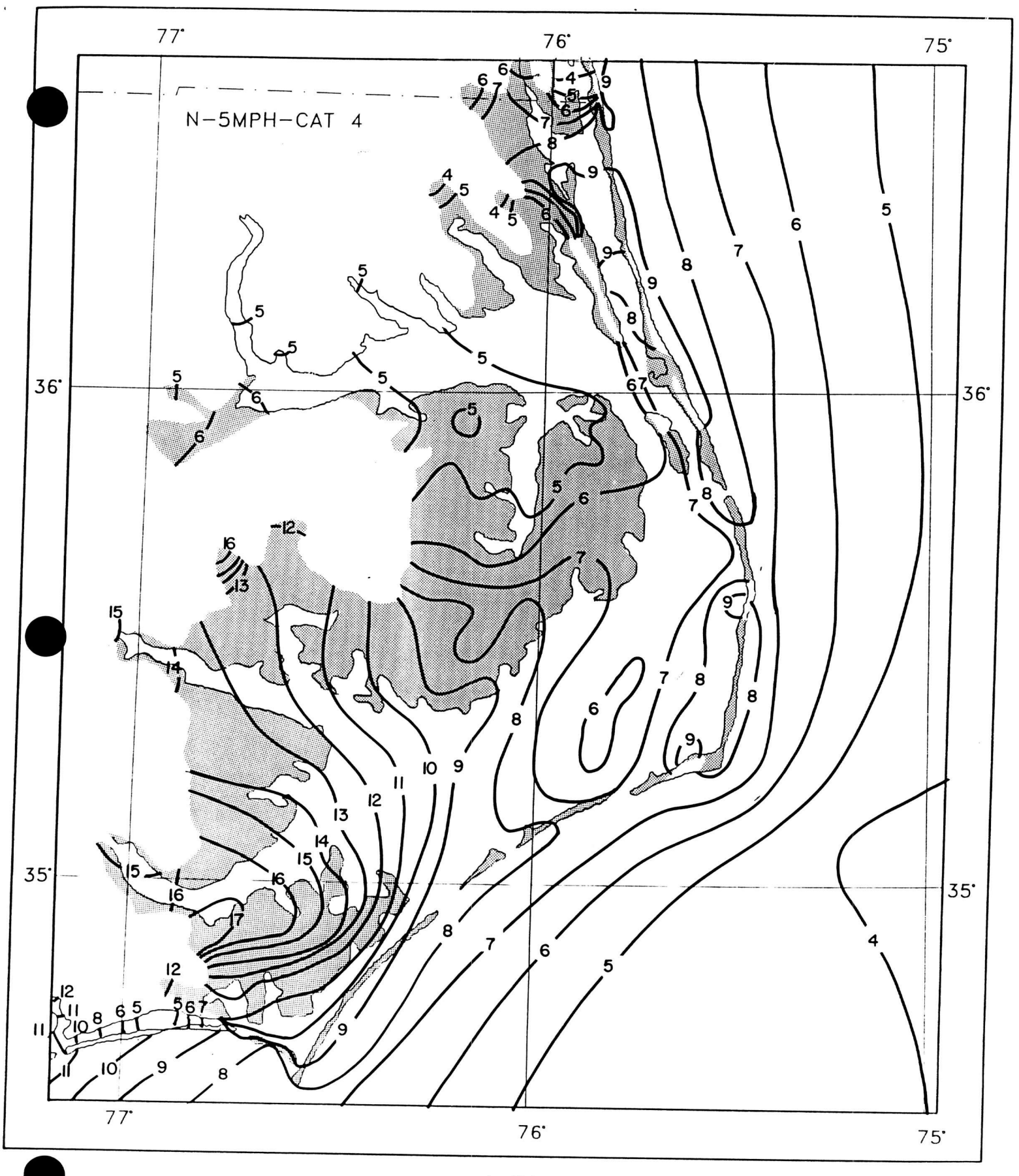

NNW–35MPH–CAT 4
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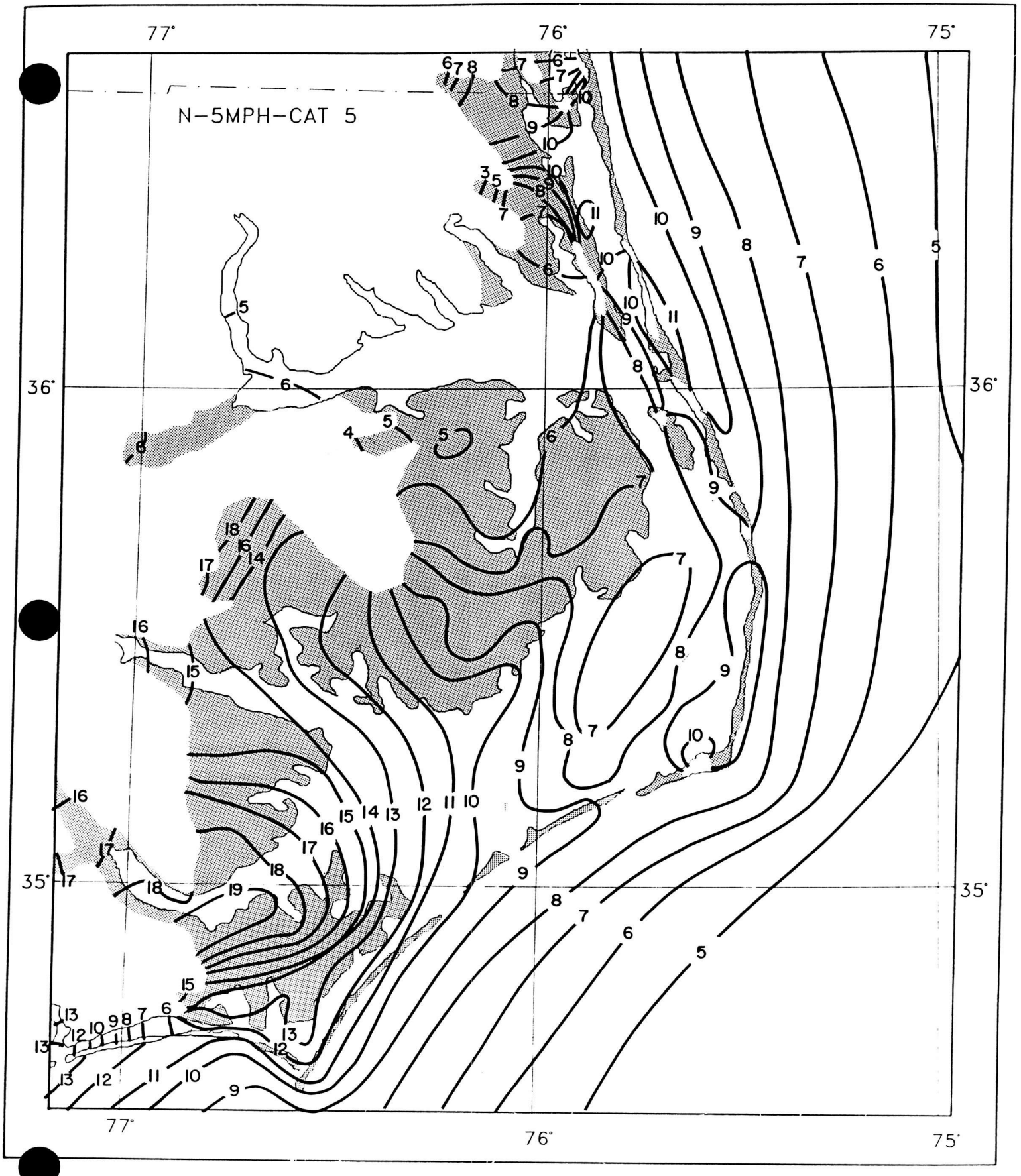

NNW–35MPH–CAT 5
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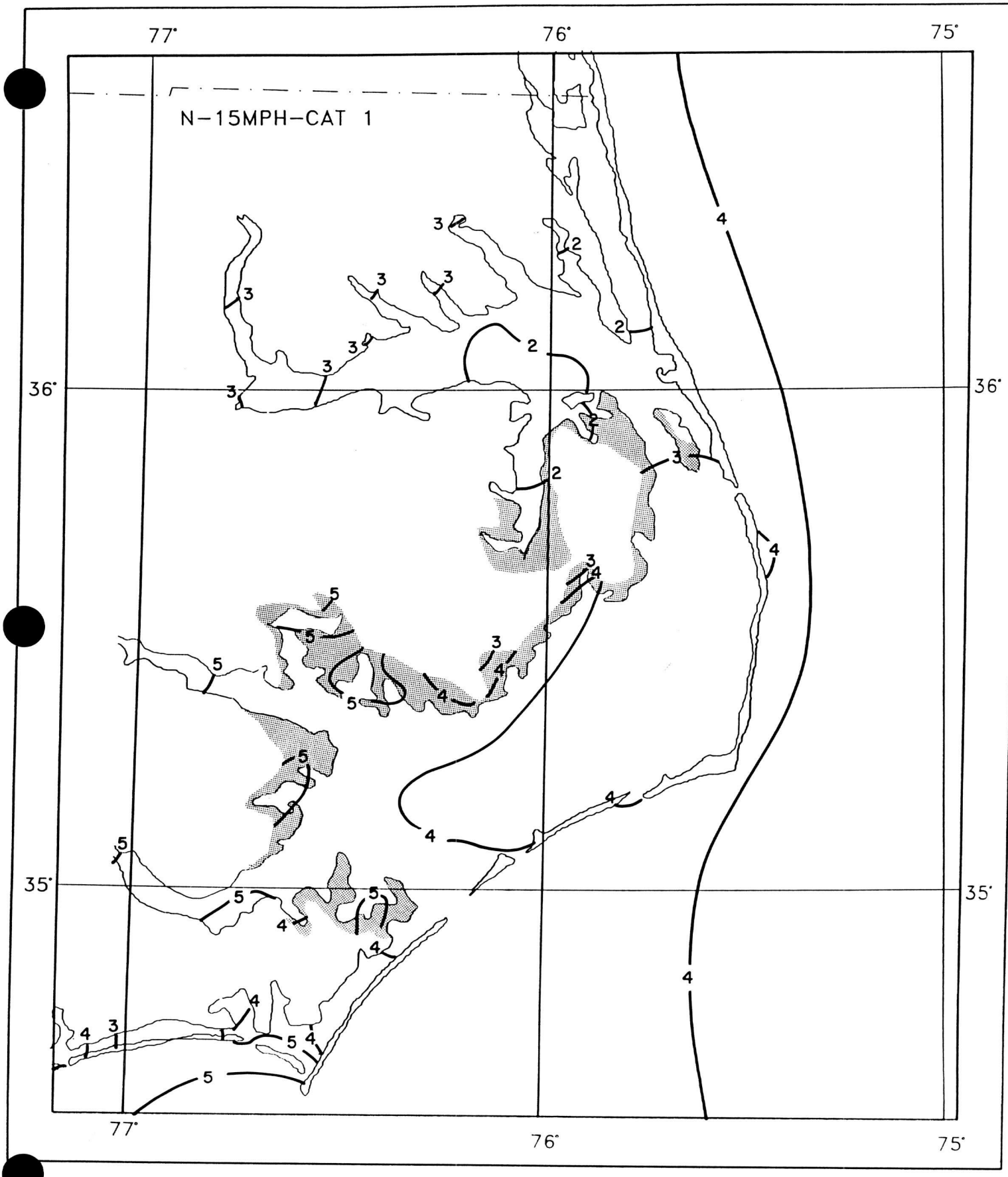

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N-5MPH-CAT 1
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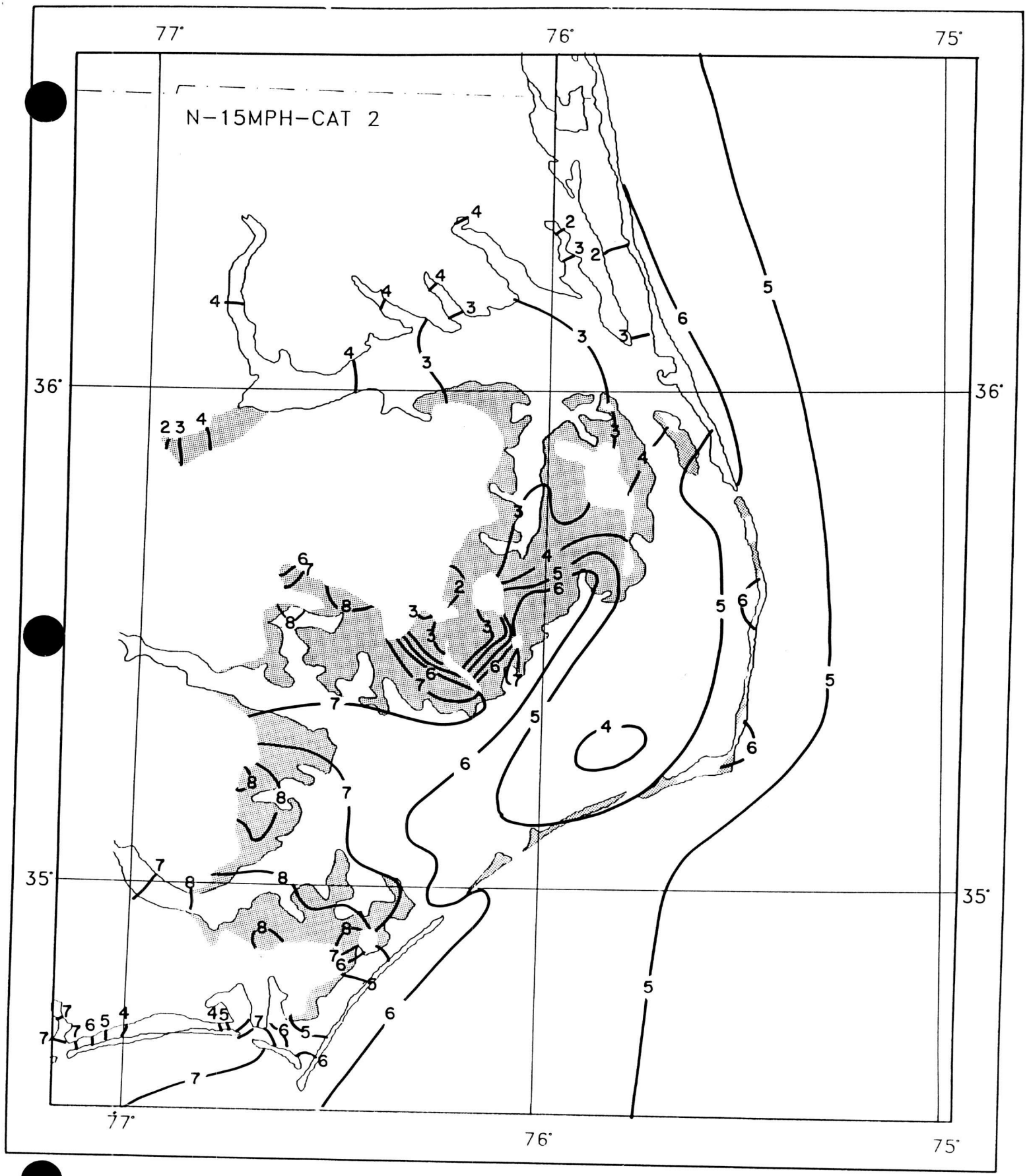

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N–5MPH–CAT 2
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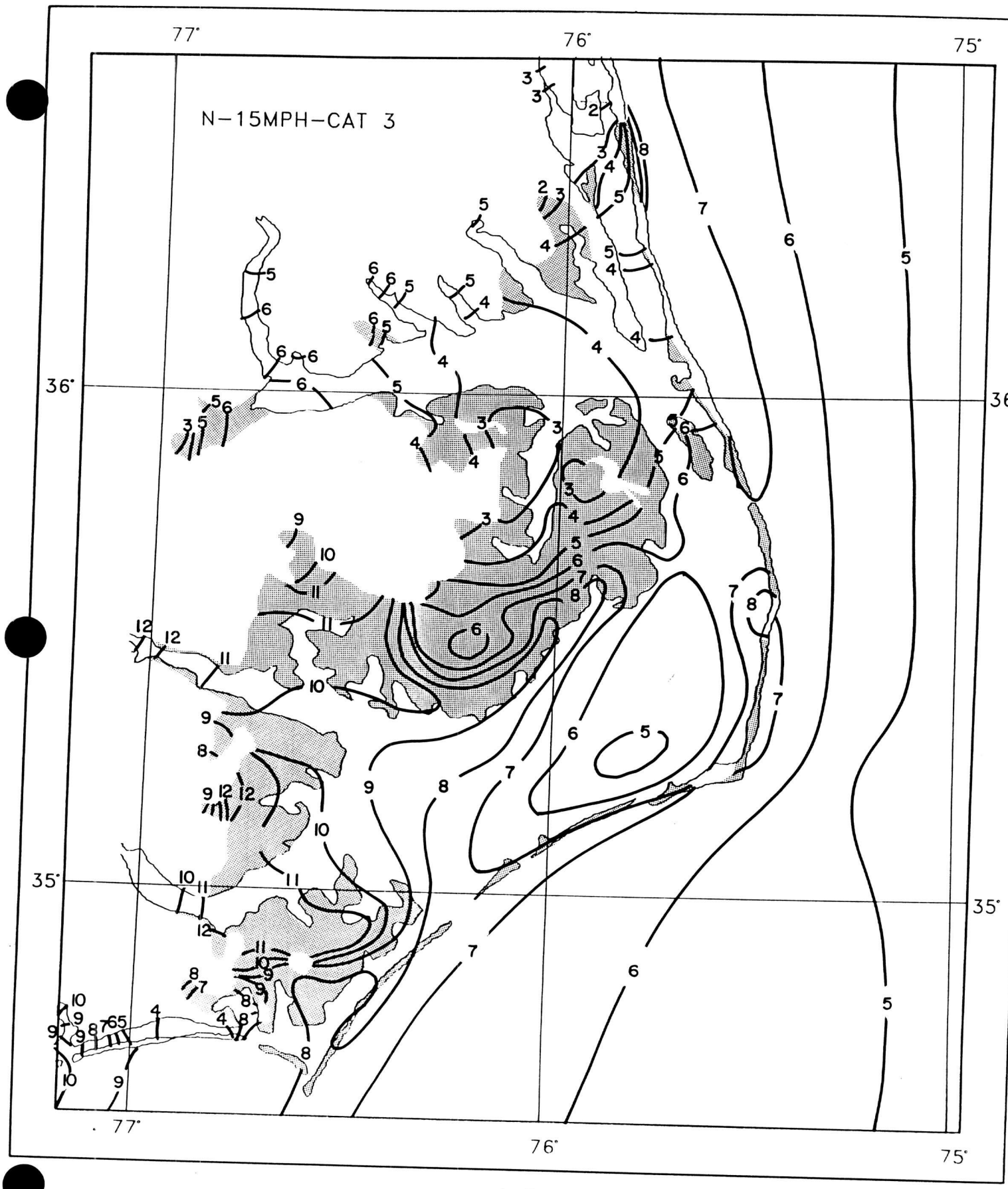

N-5MPH-CAT 3
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76°
75°
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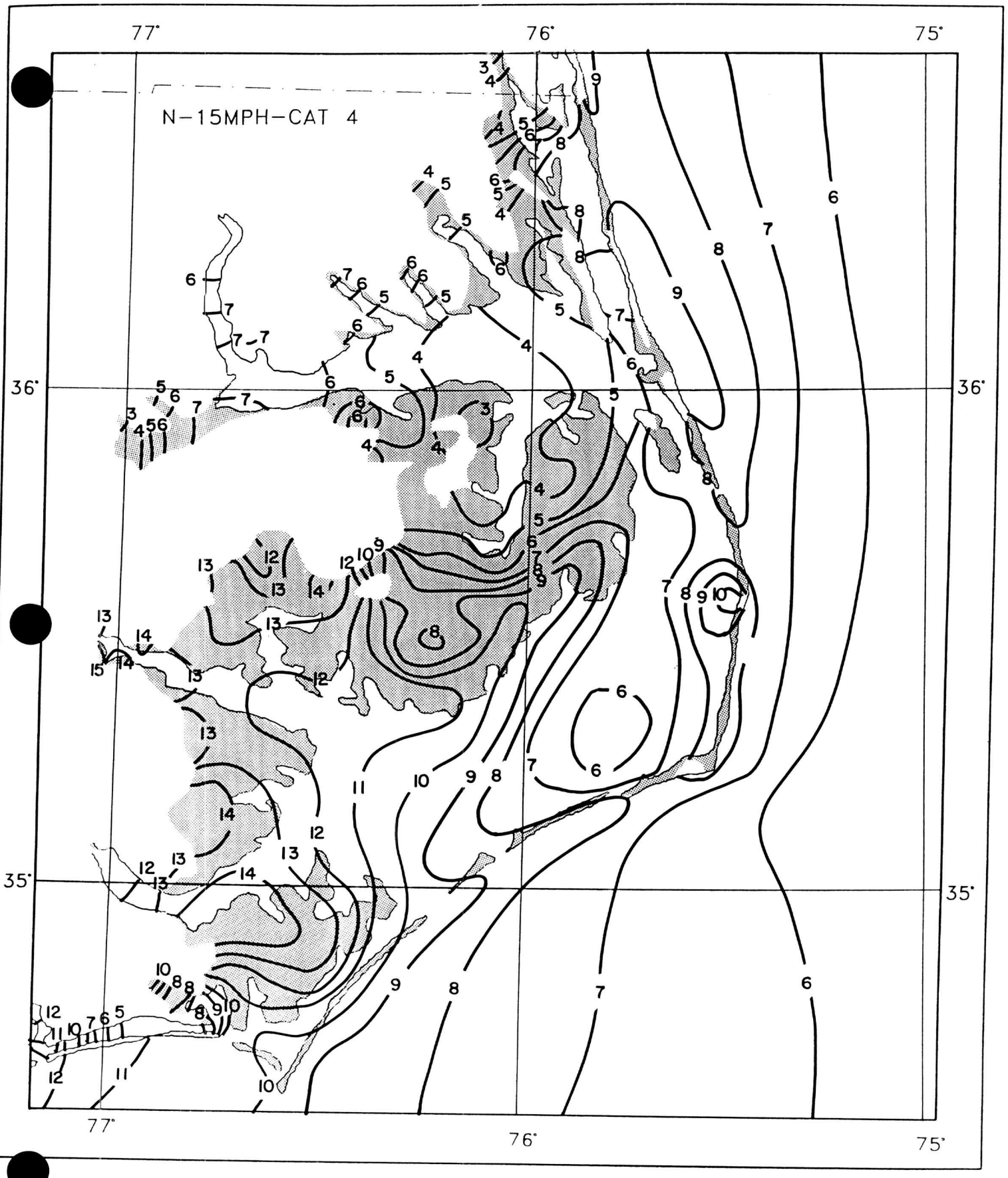

N-5MPH-CAT 4
77°
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75°
36°
35°

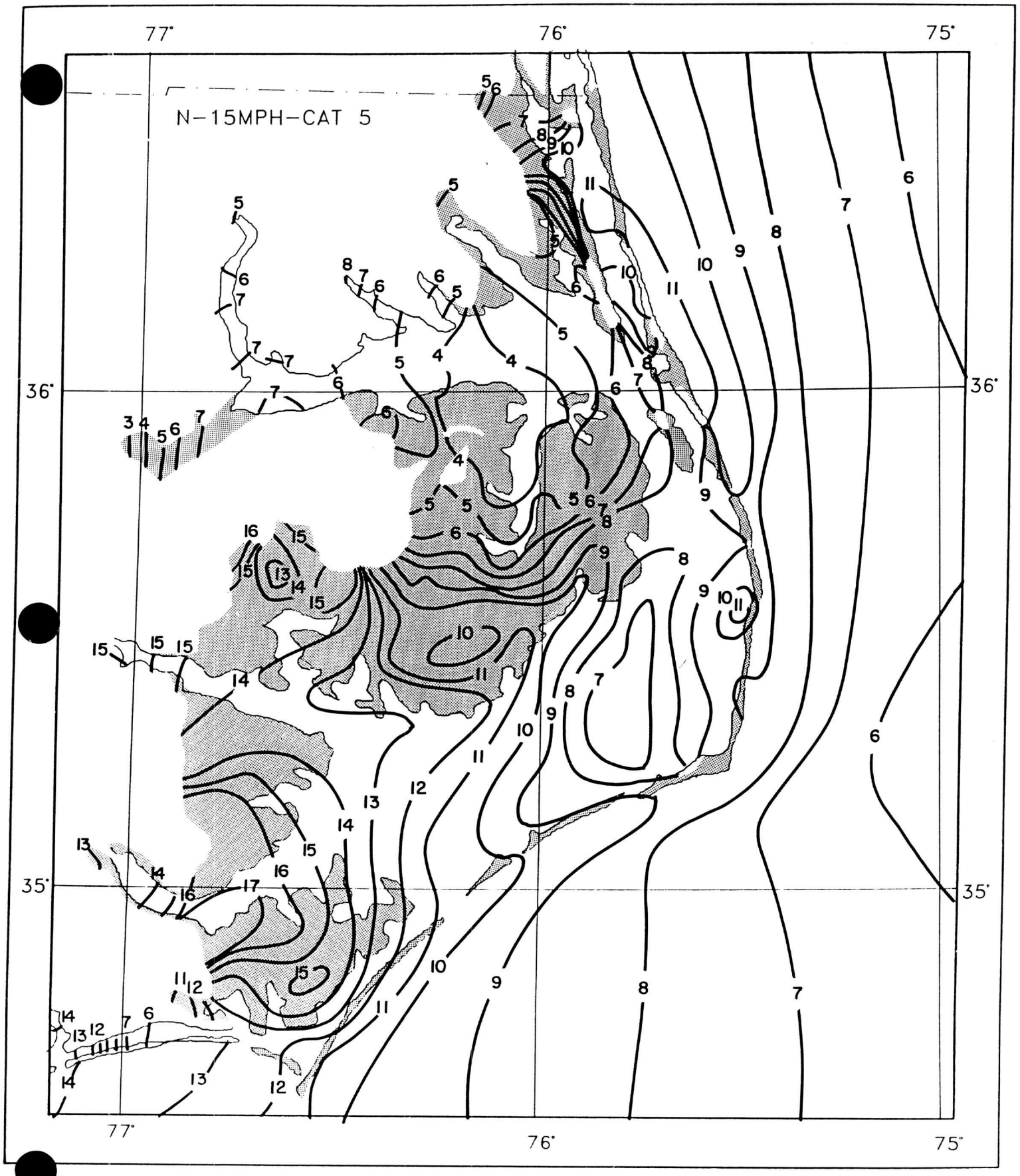

77°
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N-5MPH-CAT 5
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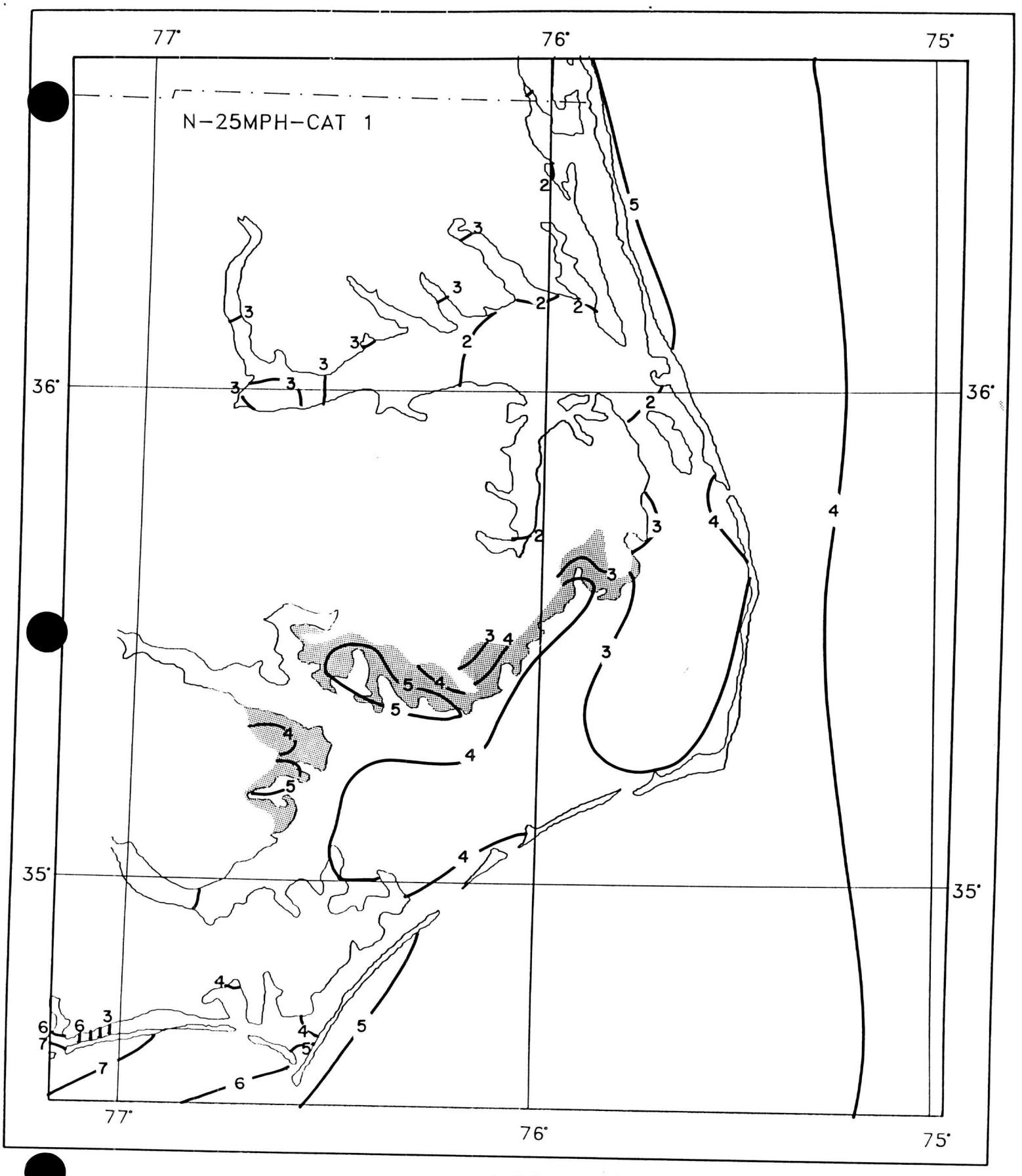

N-15MPH-CAT 1
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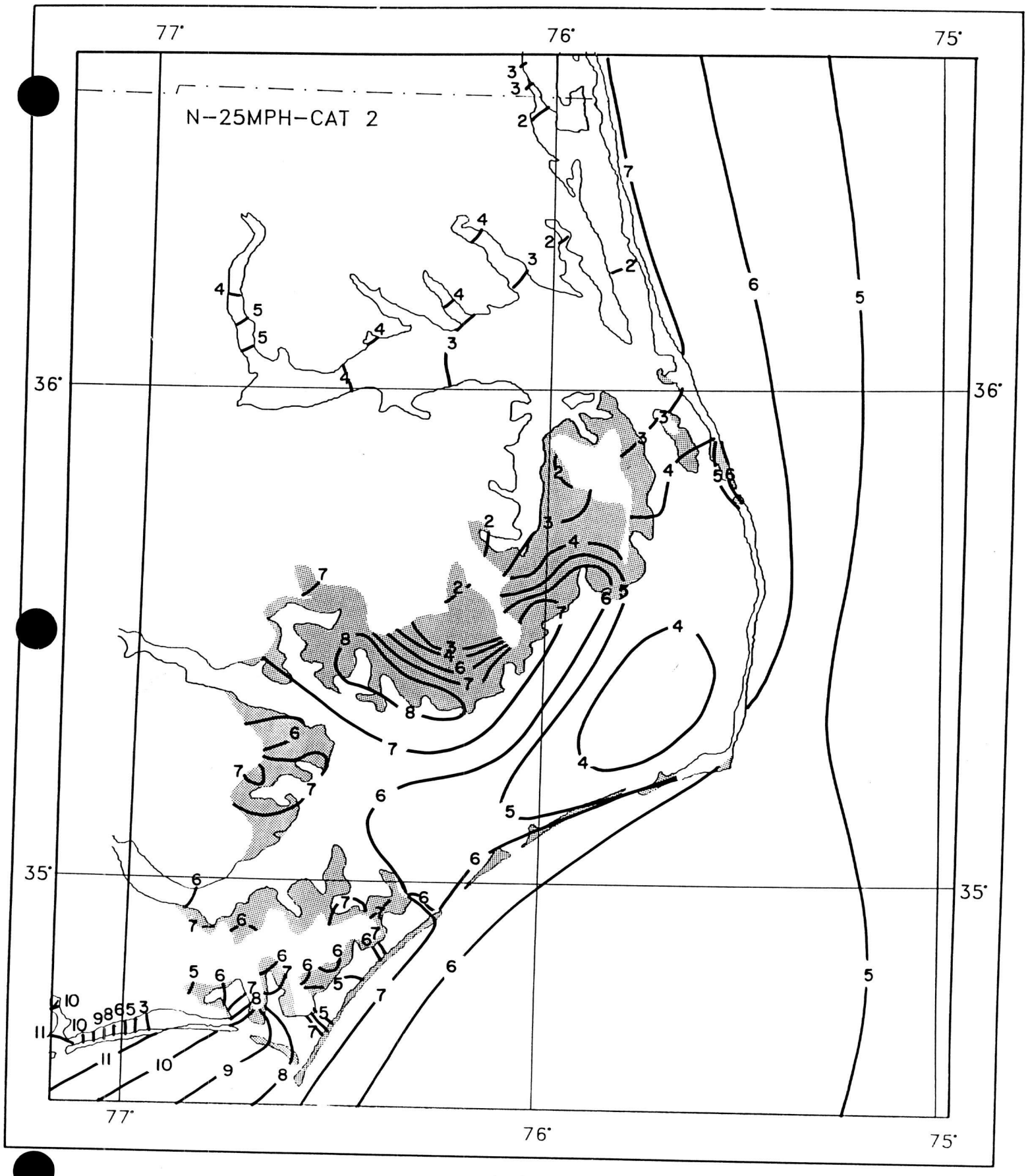

N-15MPH-CAT 2
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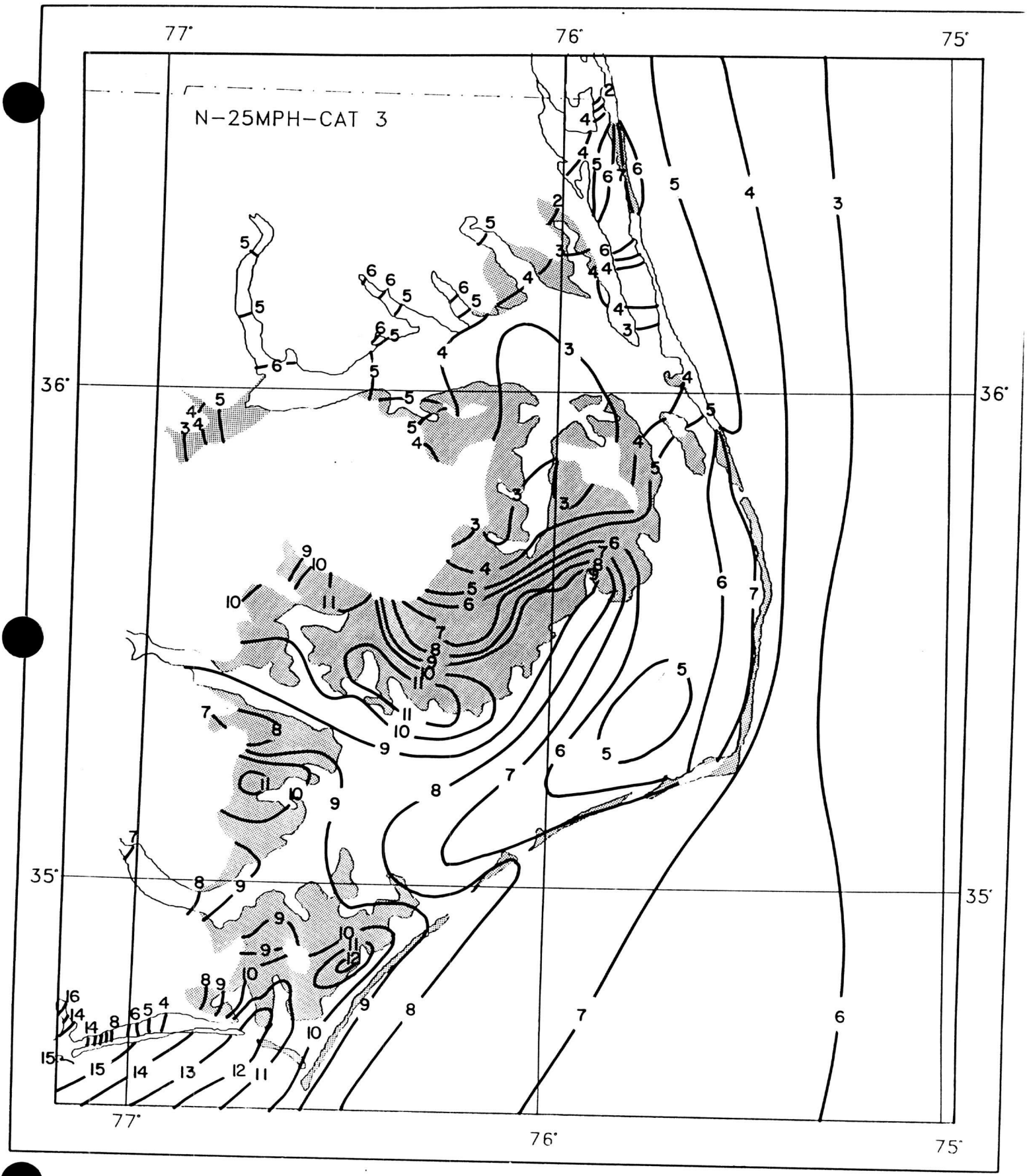

N-15MPH-CAT 3
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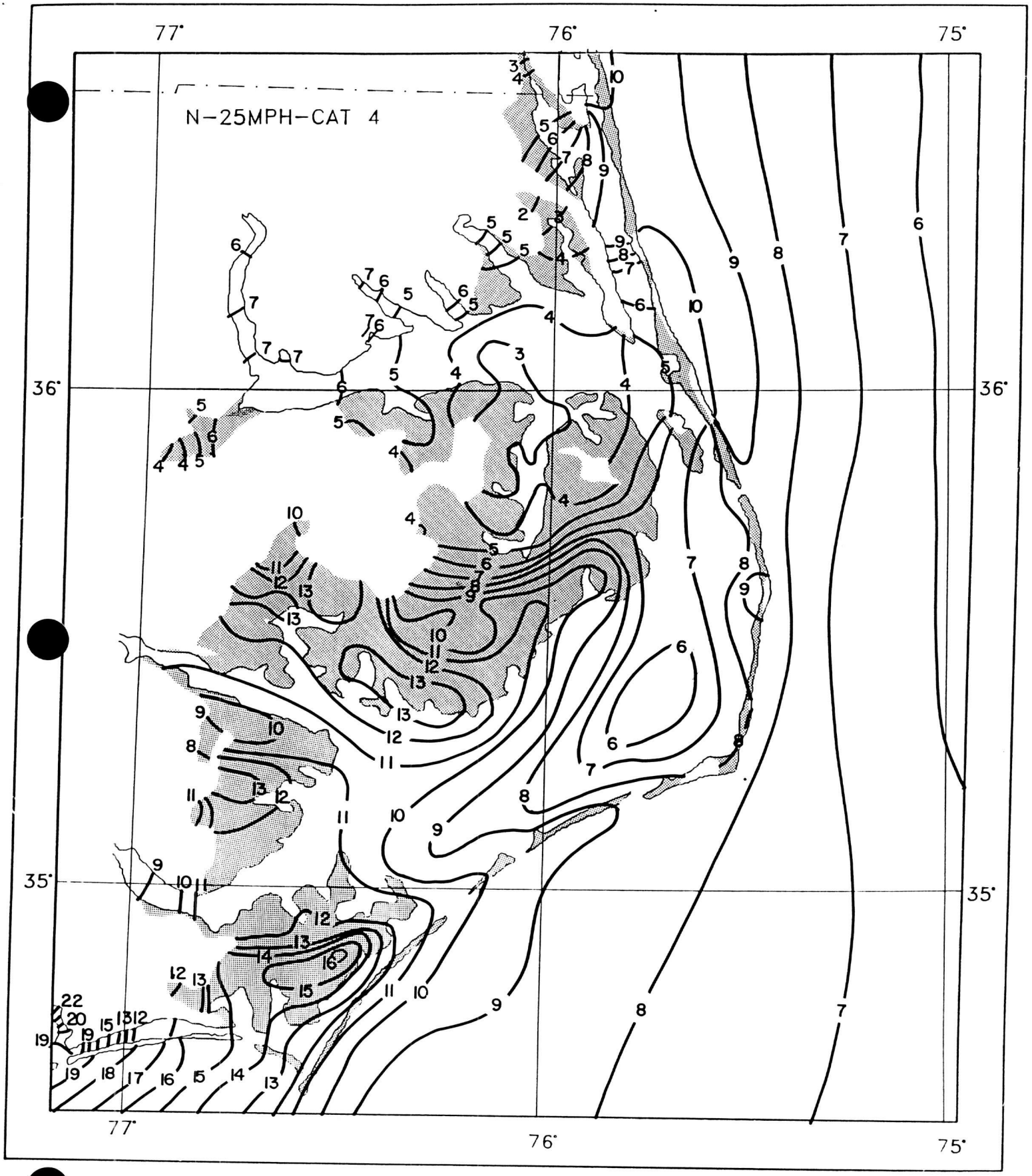

N-15MPH-CAT 4
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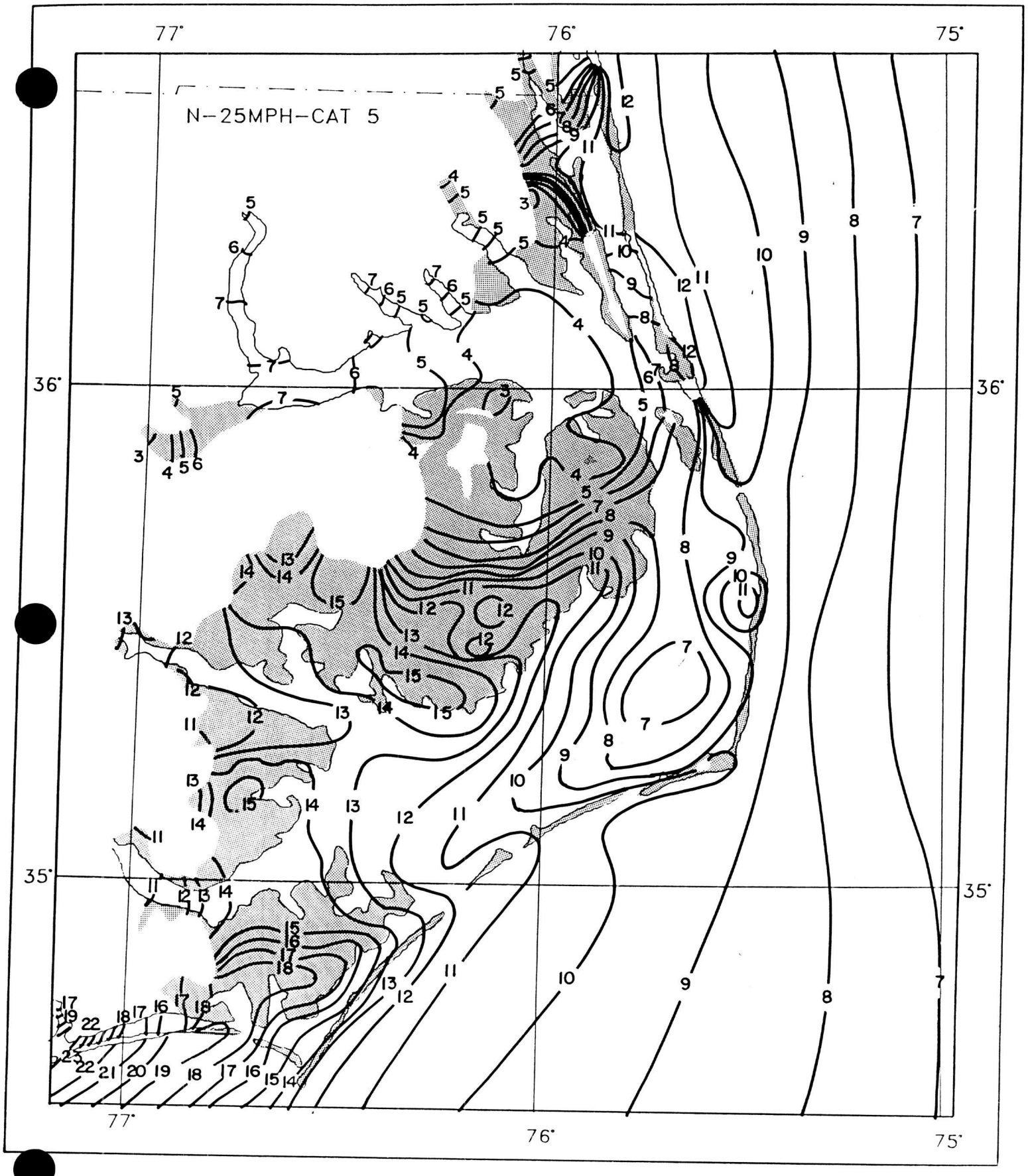

N-15MPH-CAT 5
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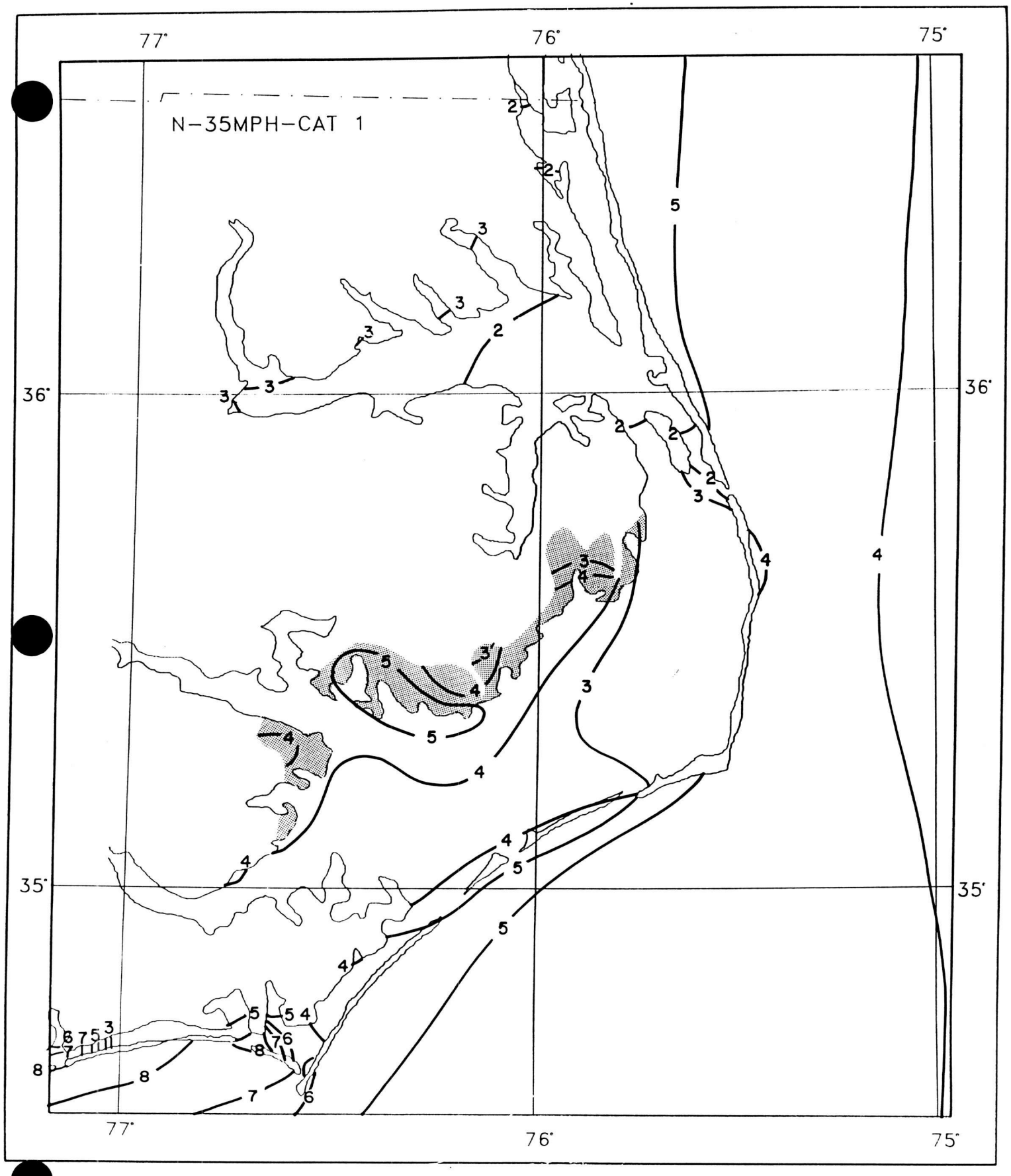

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N-25MPH-CAT 1
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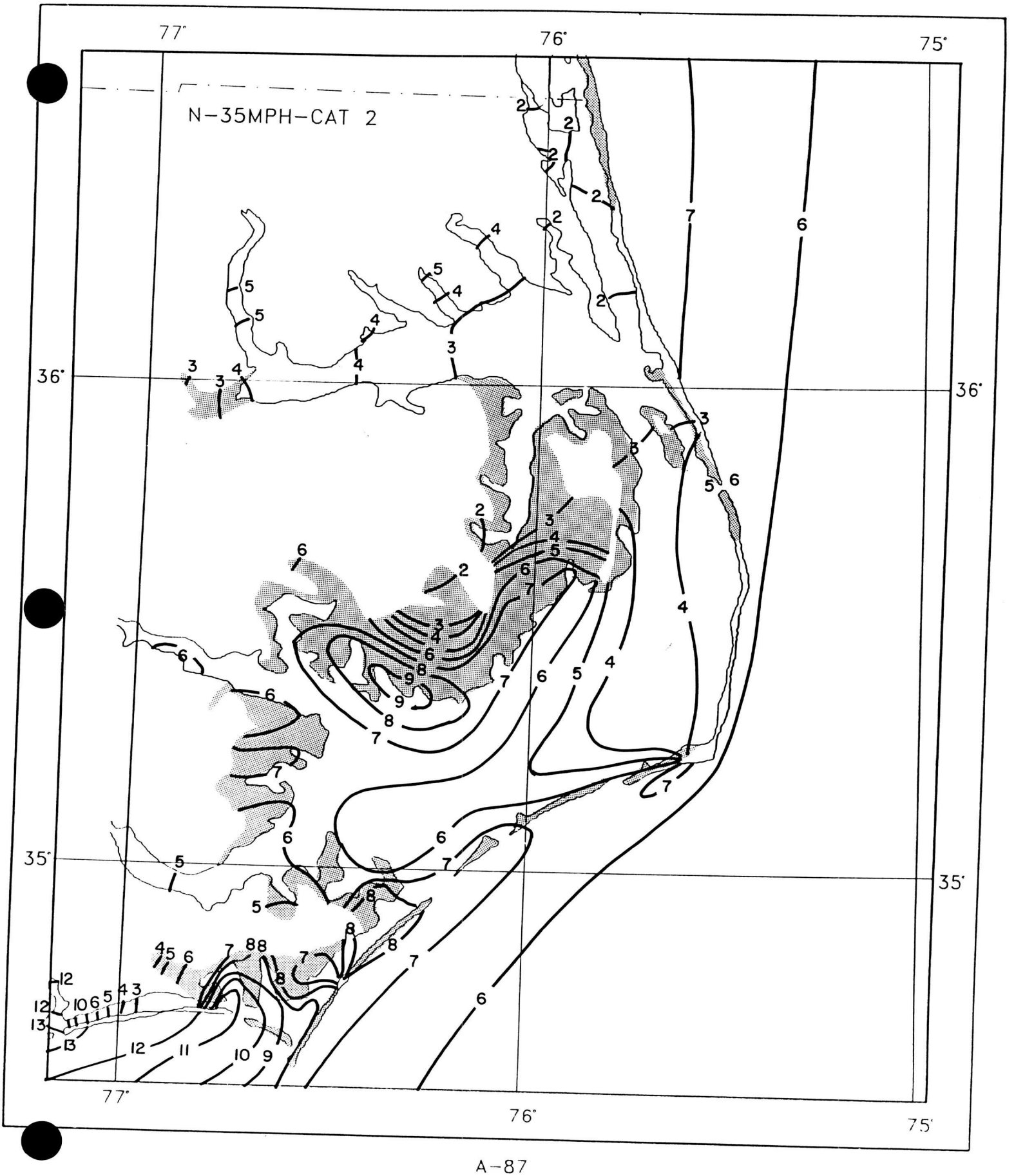

N-25MPH-CAT 2
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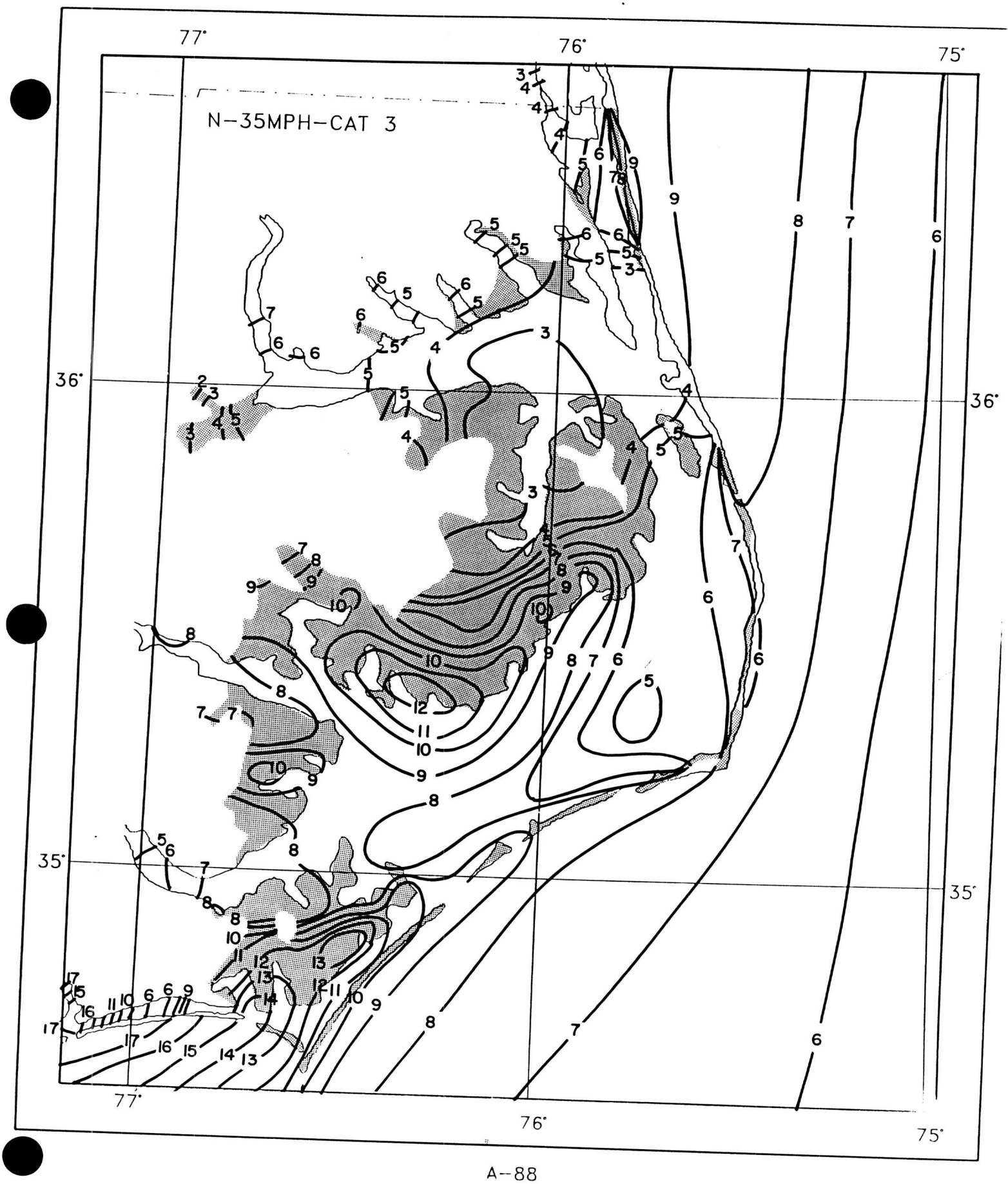

N-25MPH-CAT 3
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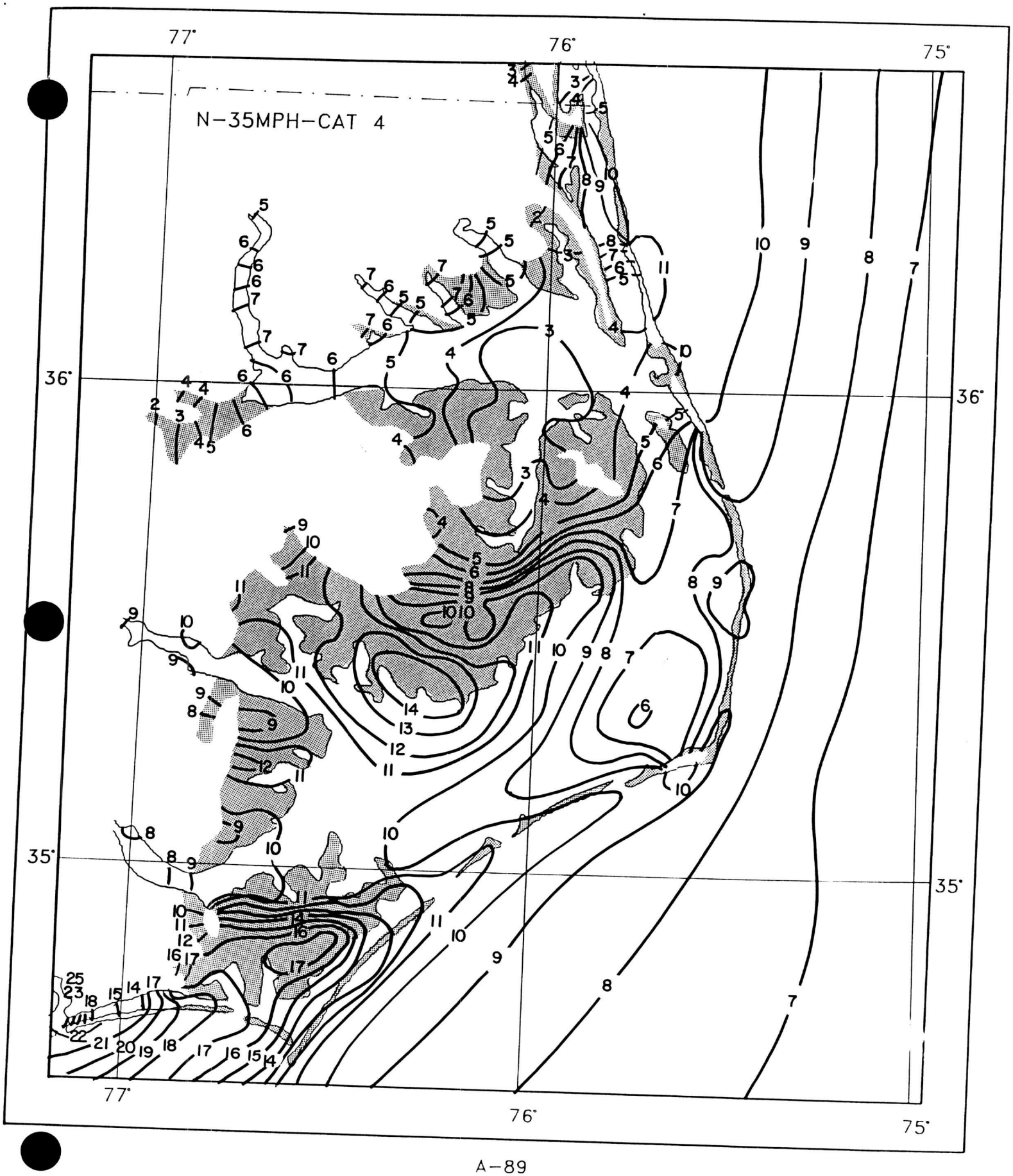

N-25MPH-CAT 4
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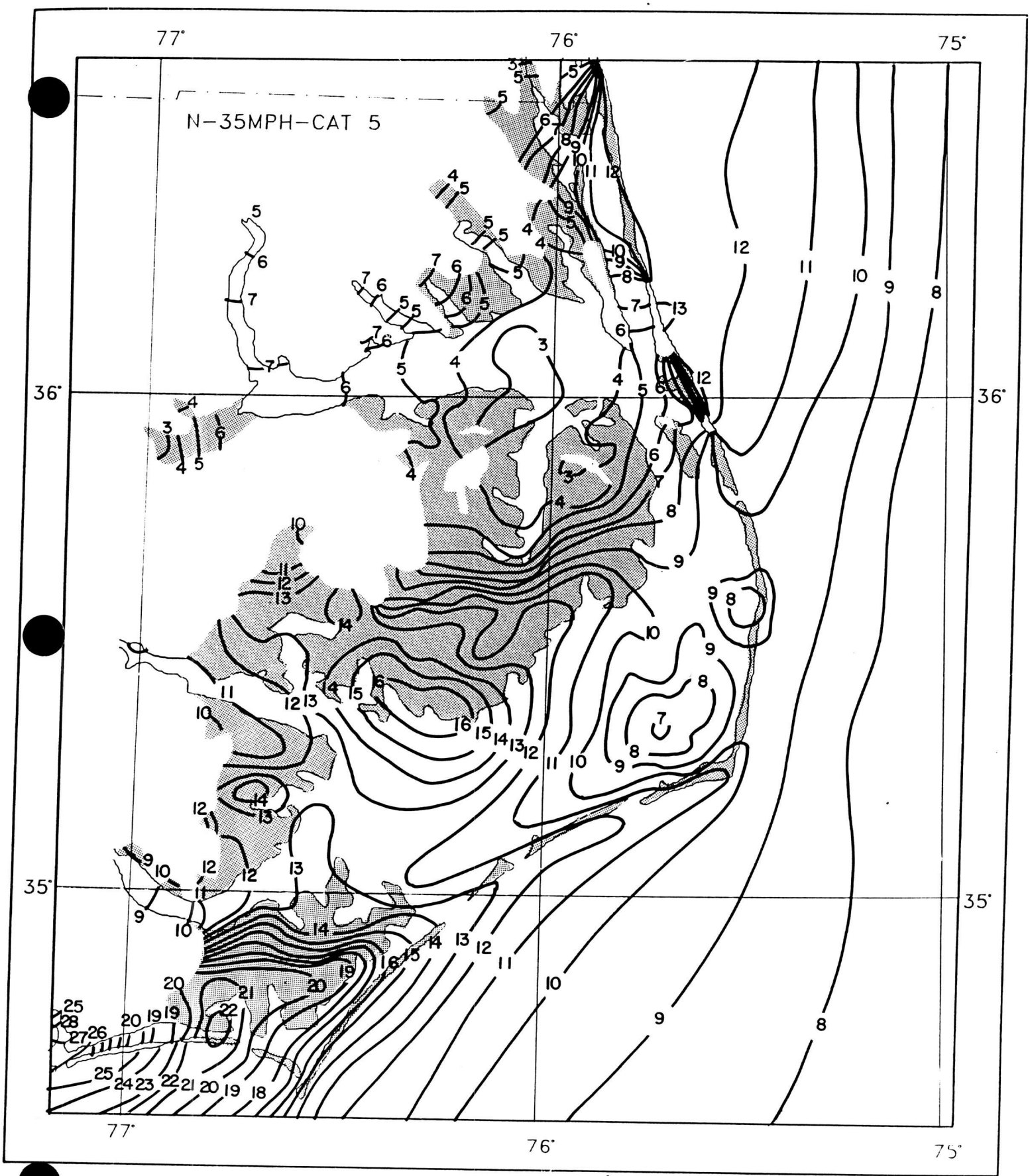

N-25MPH-CAT 5
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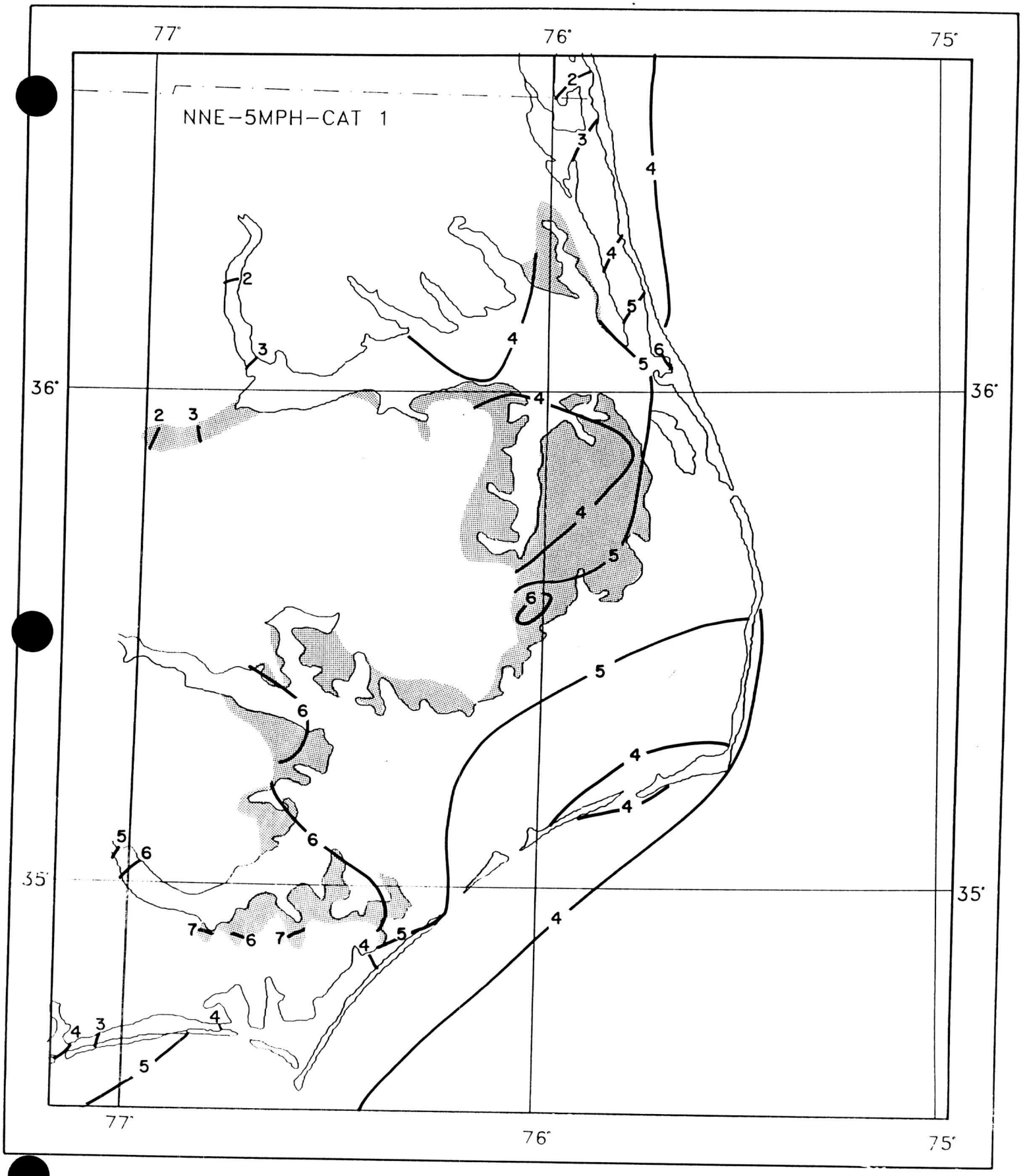

N-35MPH-CAT 1
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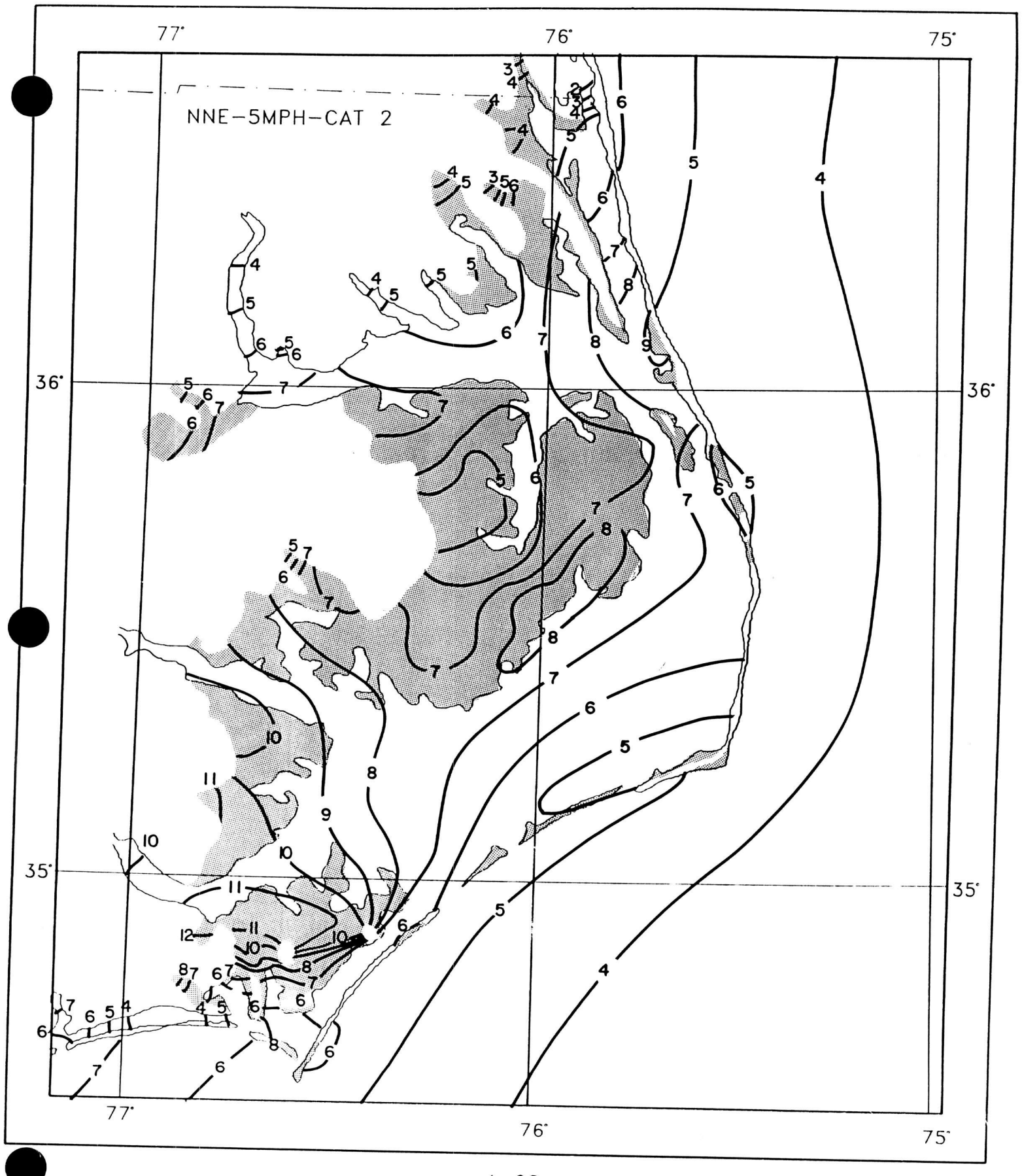

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N-35MPH-CAT 2
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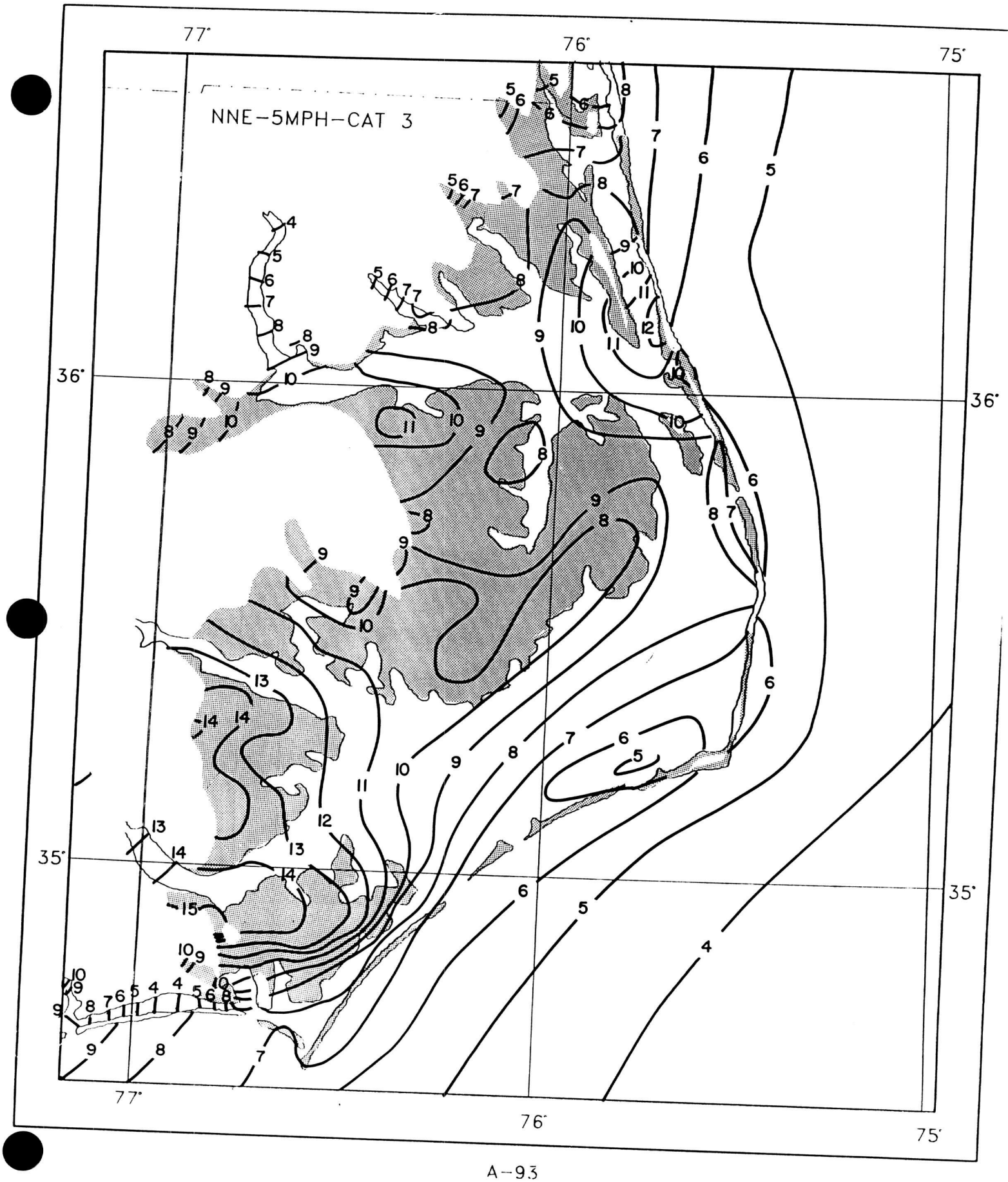

N-35MPH-CAT 3
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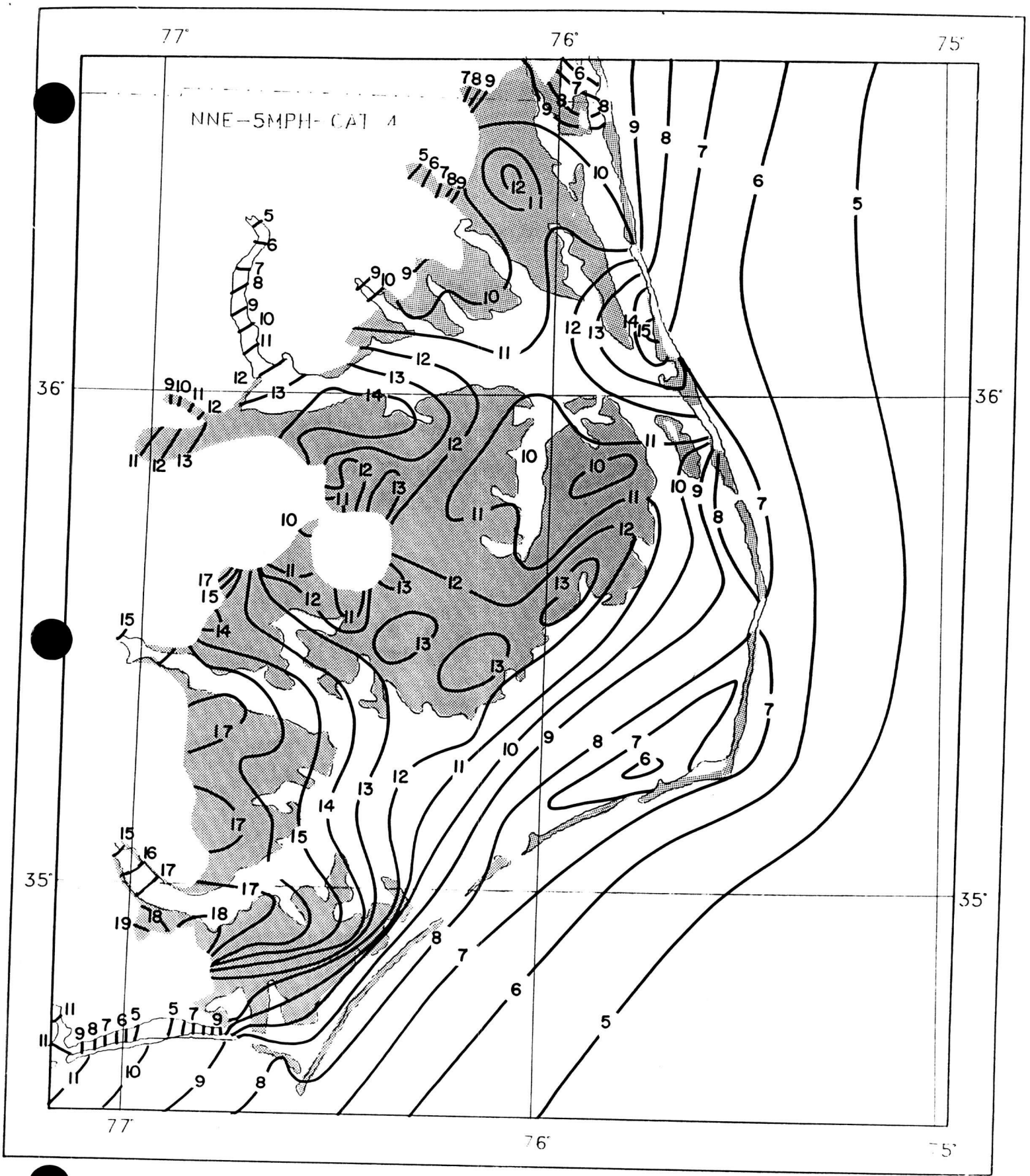

N-35MPH-CAT 4
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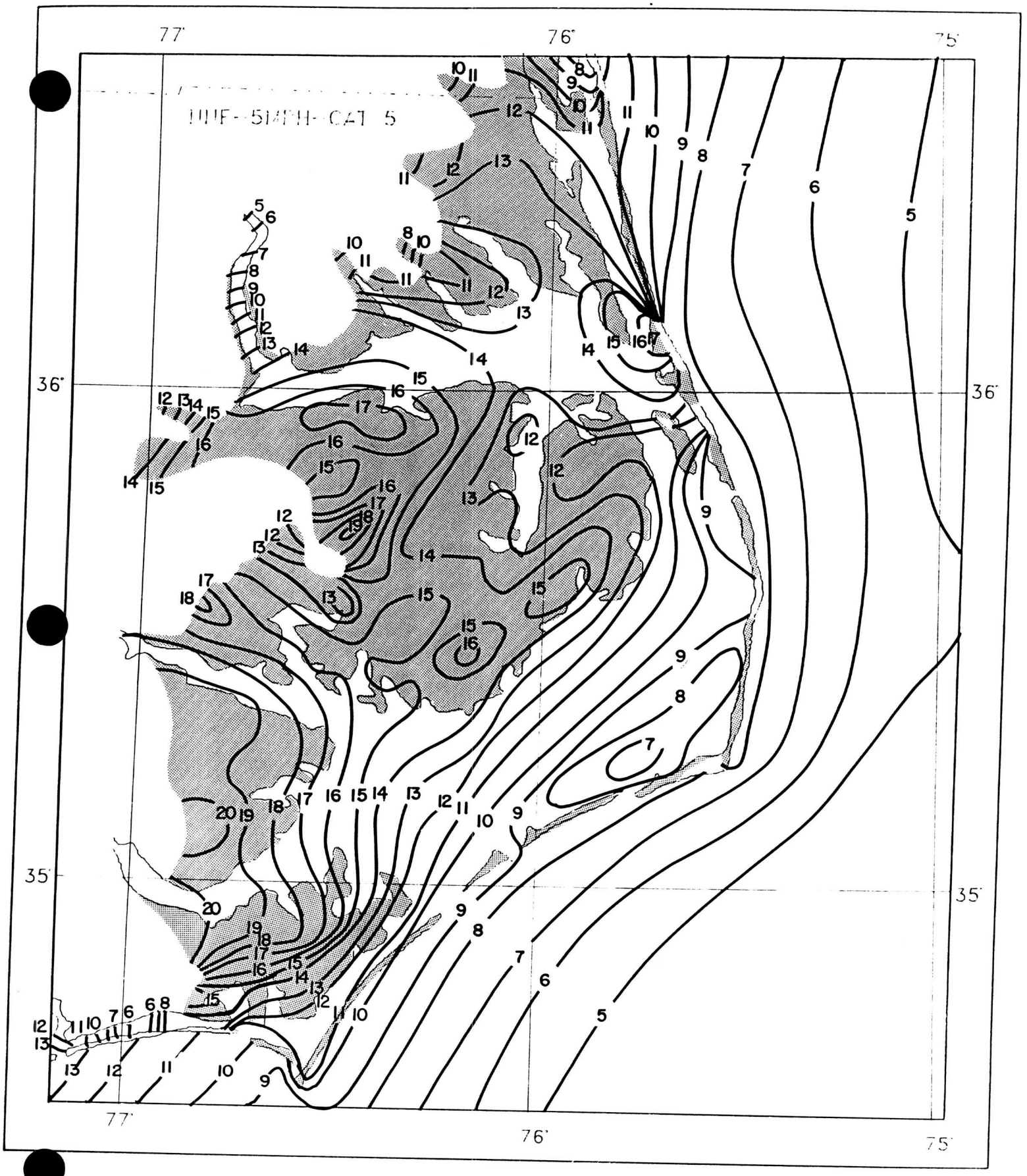

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N-35MPH-CAT 5
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35°

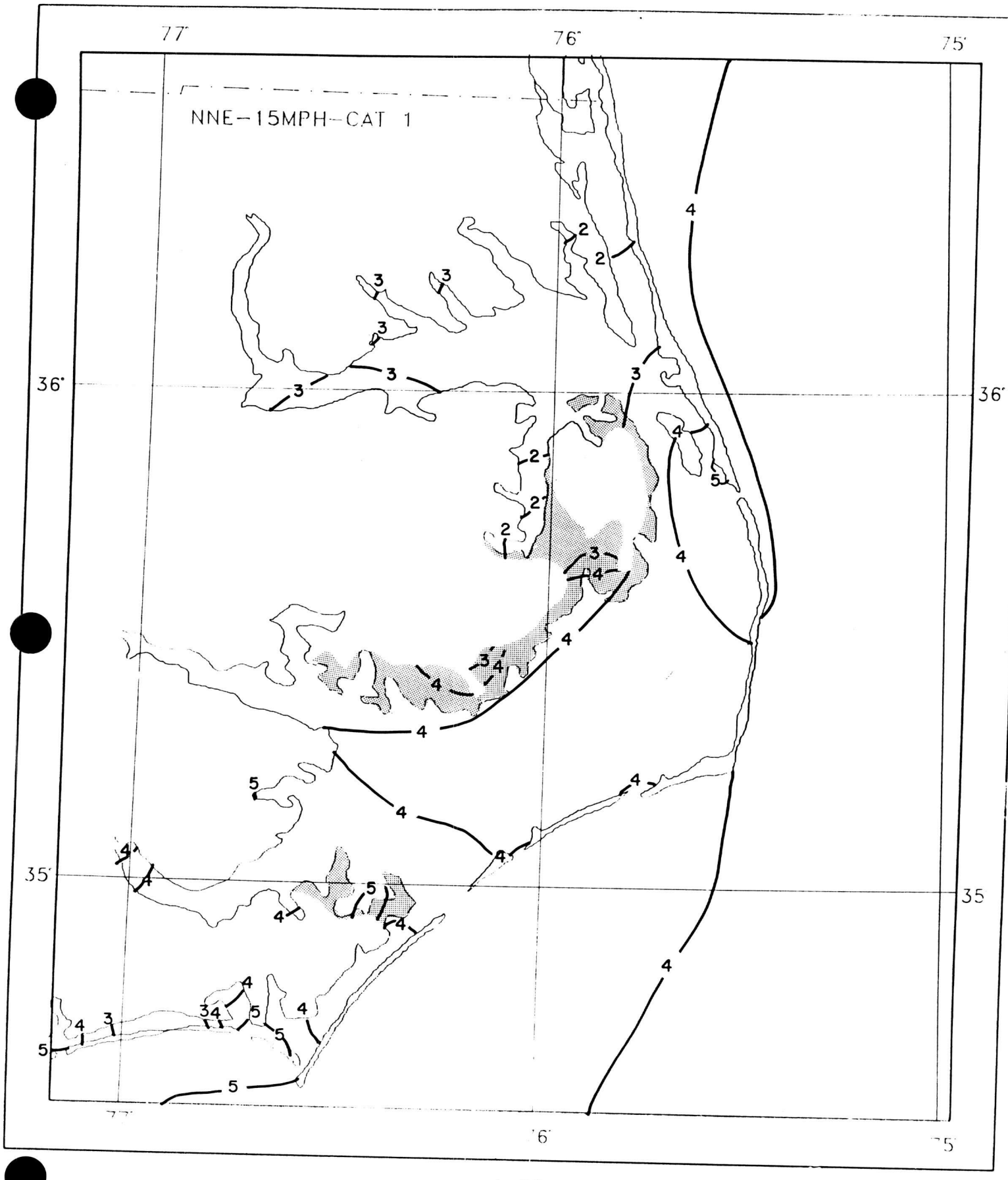

NNE–5MPH–CAT 1
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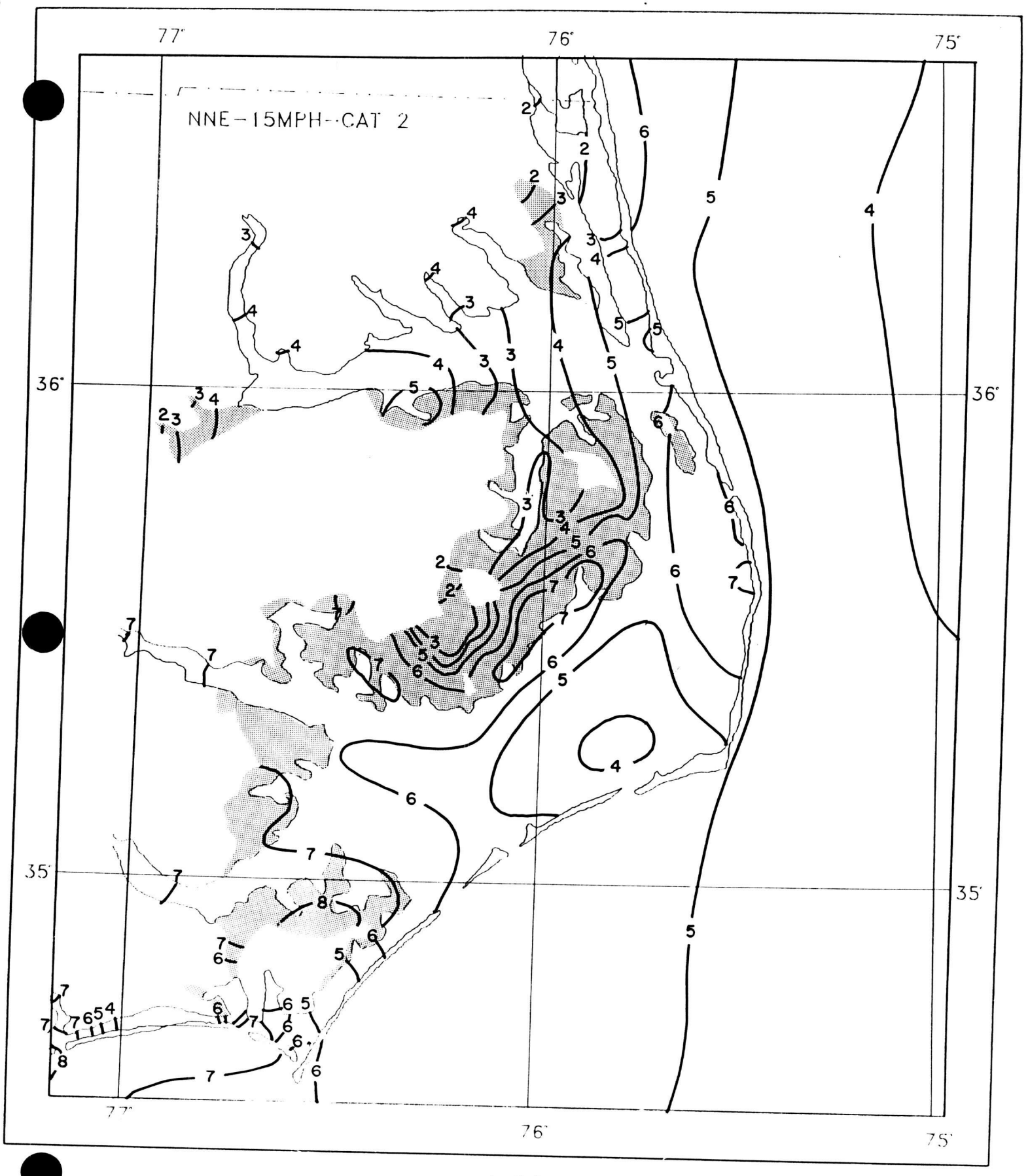

NNE–5MPH–CAT 2
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76°
75°
36°
35°


NNE–5MPH–CAT 3
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76°
75°
36°
35°

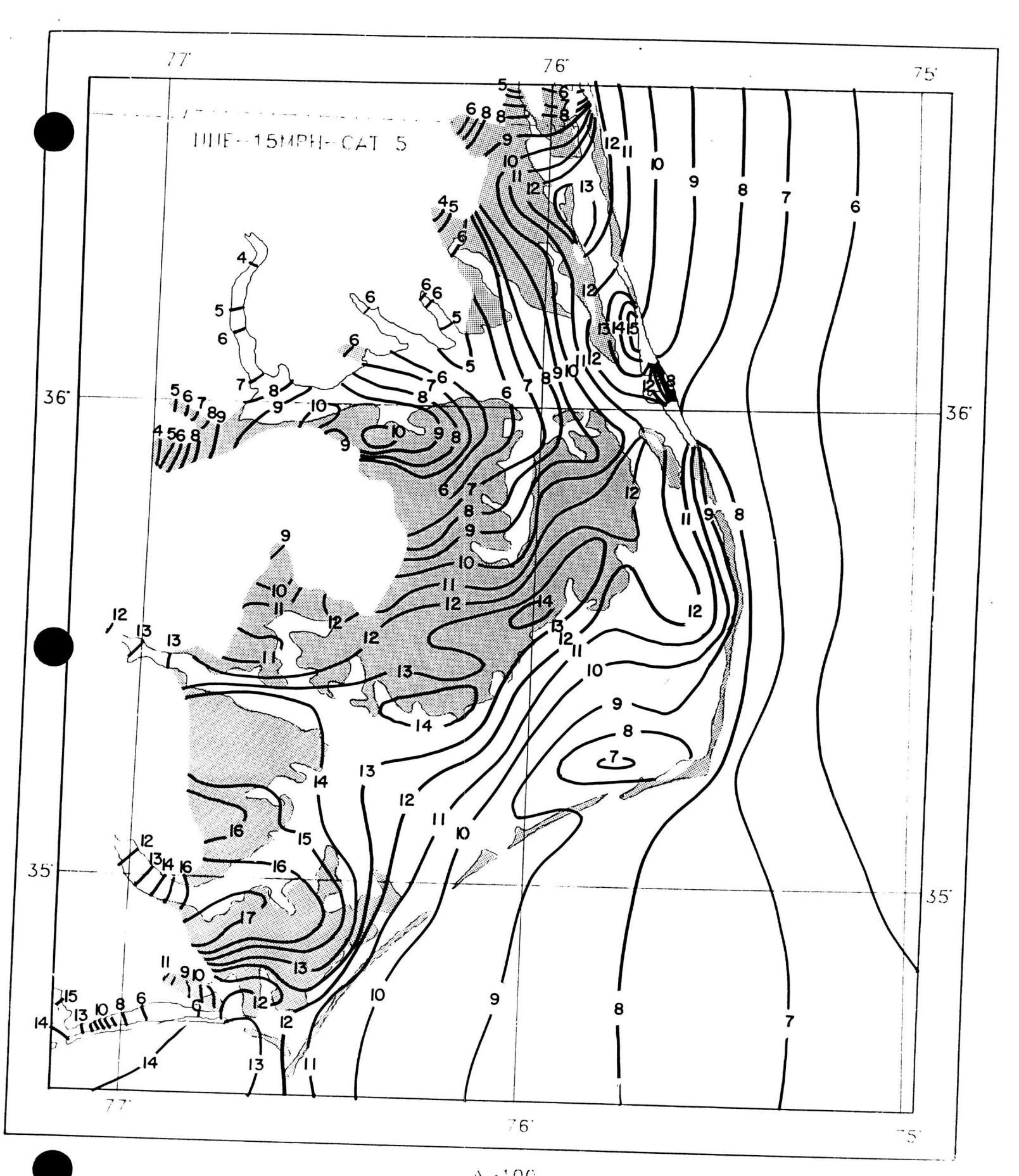

NNE—5MPH- CAT 1
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76°
75°
36°
35°

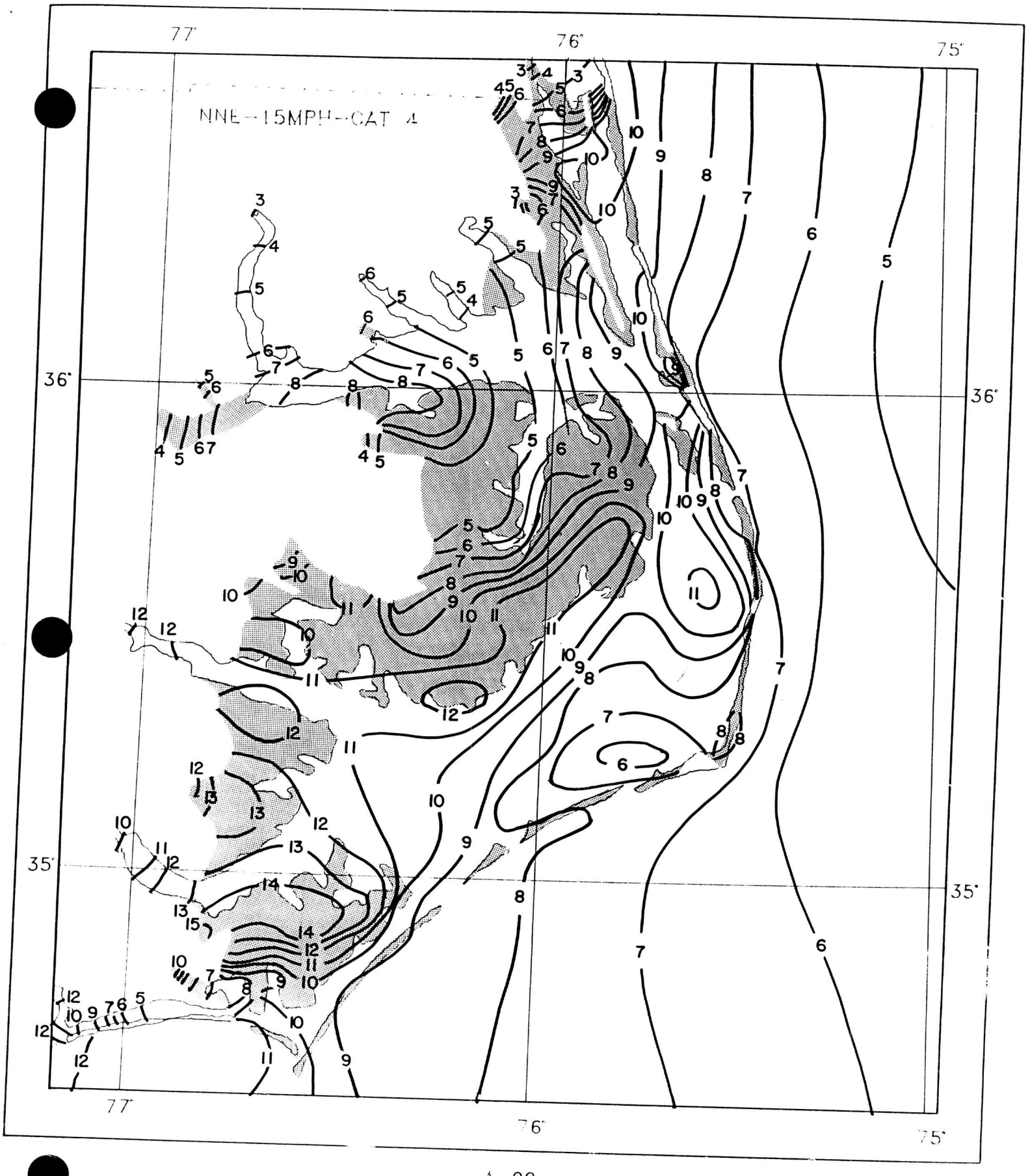

77°
76°
75°
36°
35°
LINE - SMITH - CAT 5

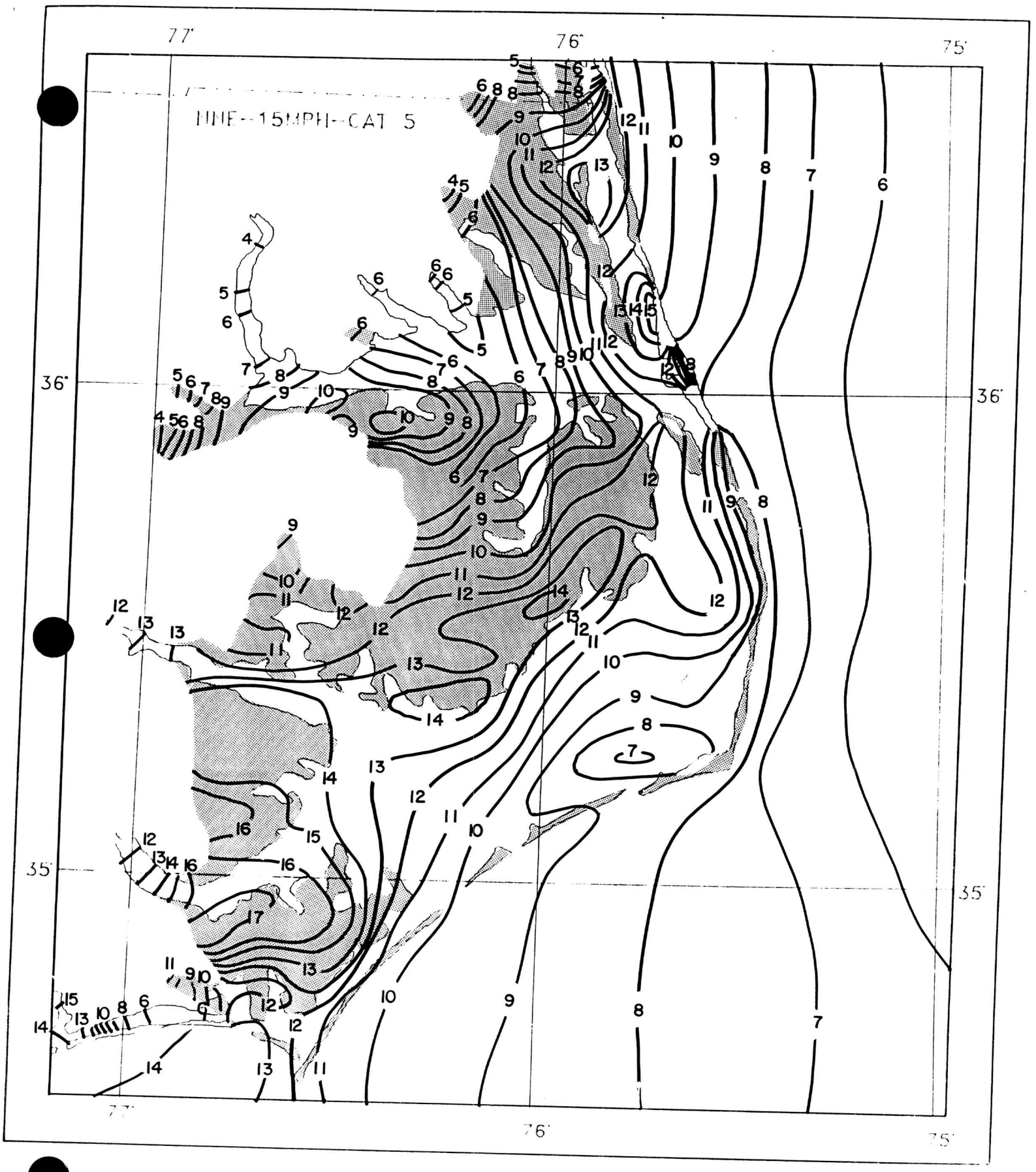

77°
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75°
NNE–15MPH–CAT 1
36°
35°

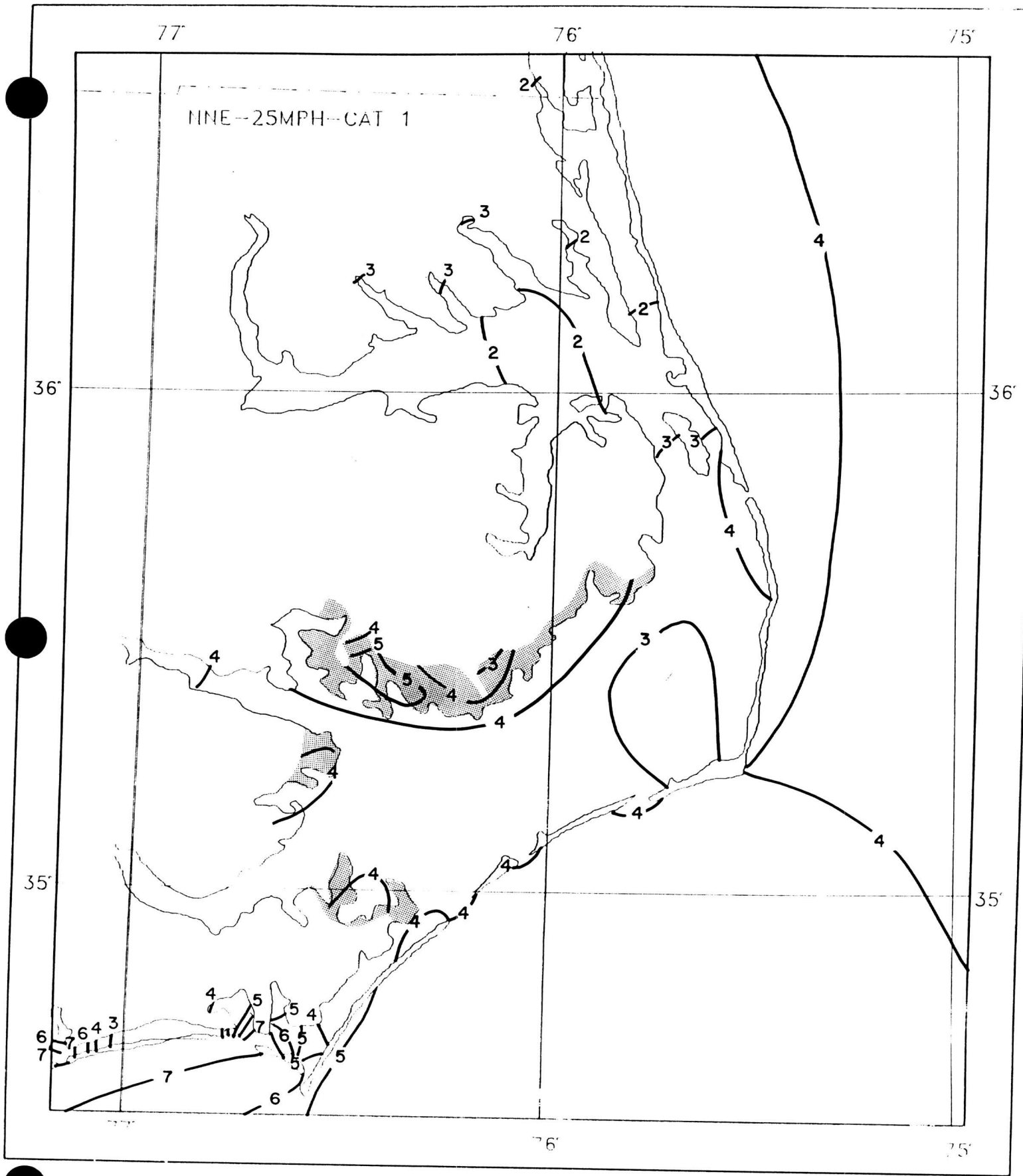

NNE-15MPH--CAT 2
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76°
75°
36°
35°

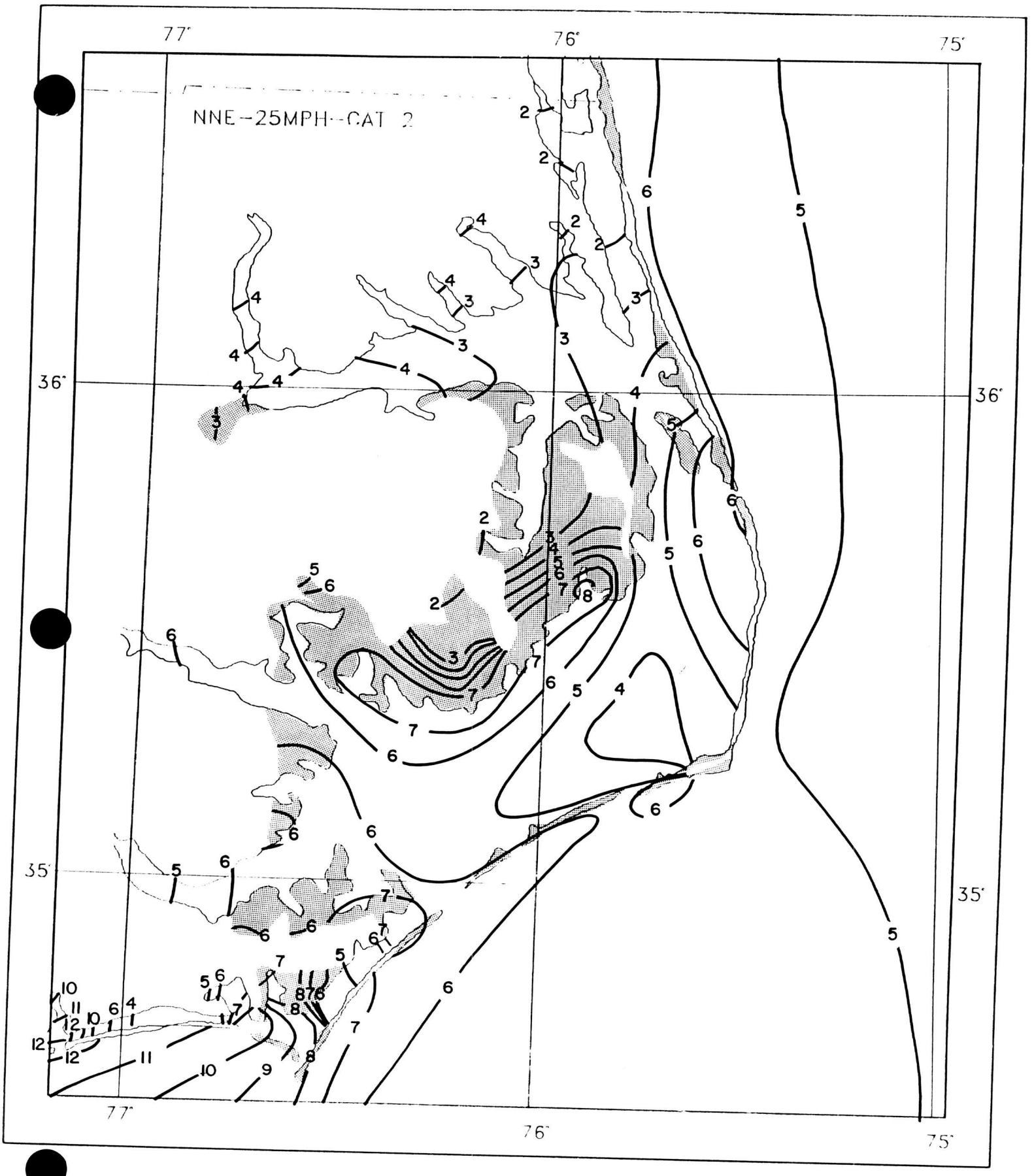

NNE - 15MPH--CAT 3
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75°
36°
35°

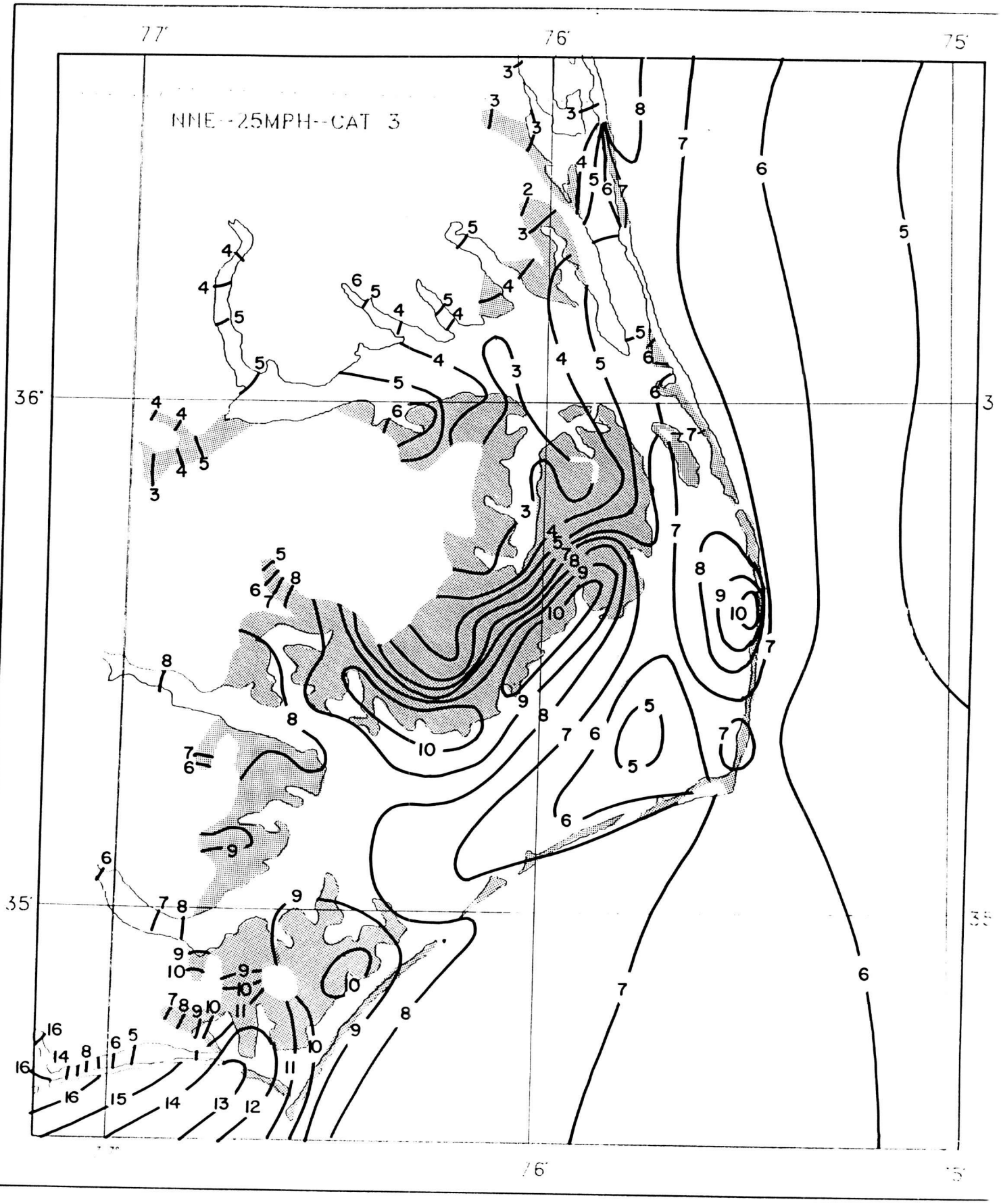

77°
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75°
36°
35°
TIME - 15MPH - CAT 5

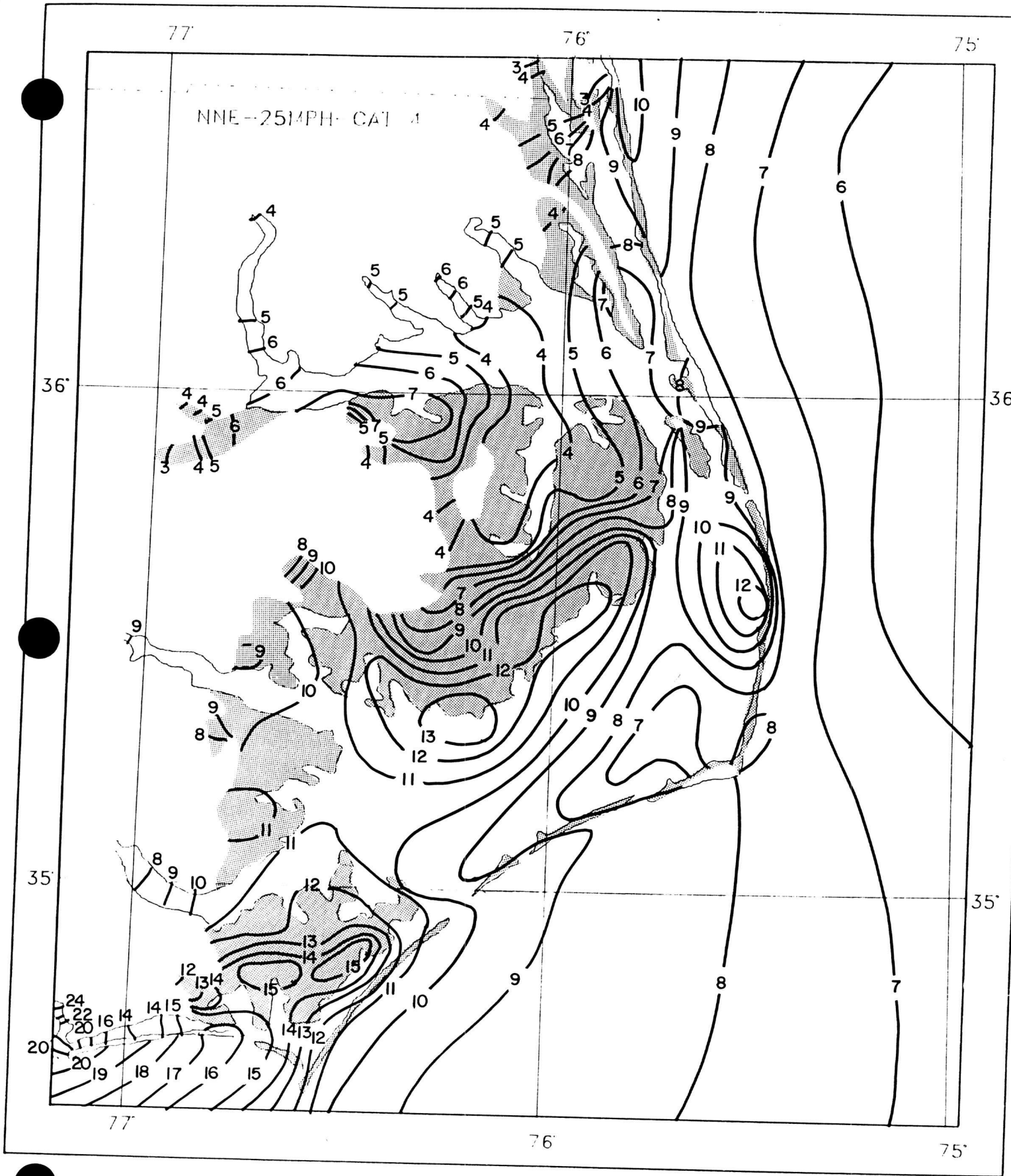

NNE–15MPH–CAT 4
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36°
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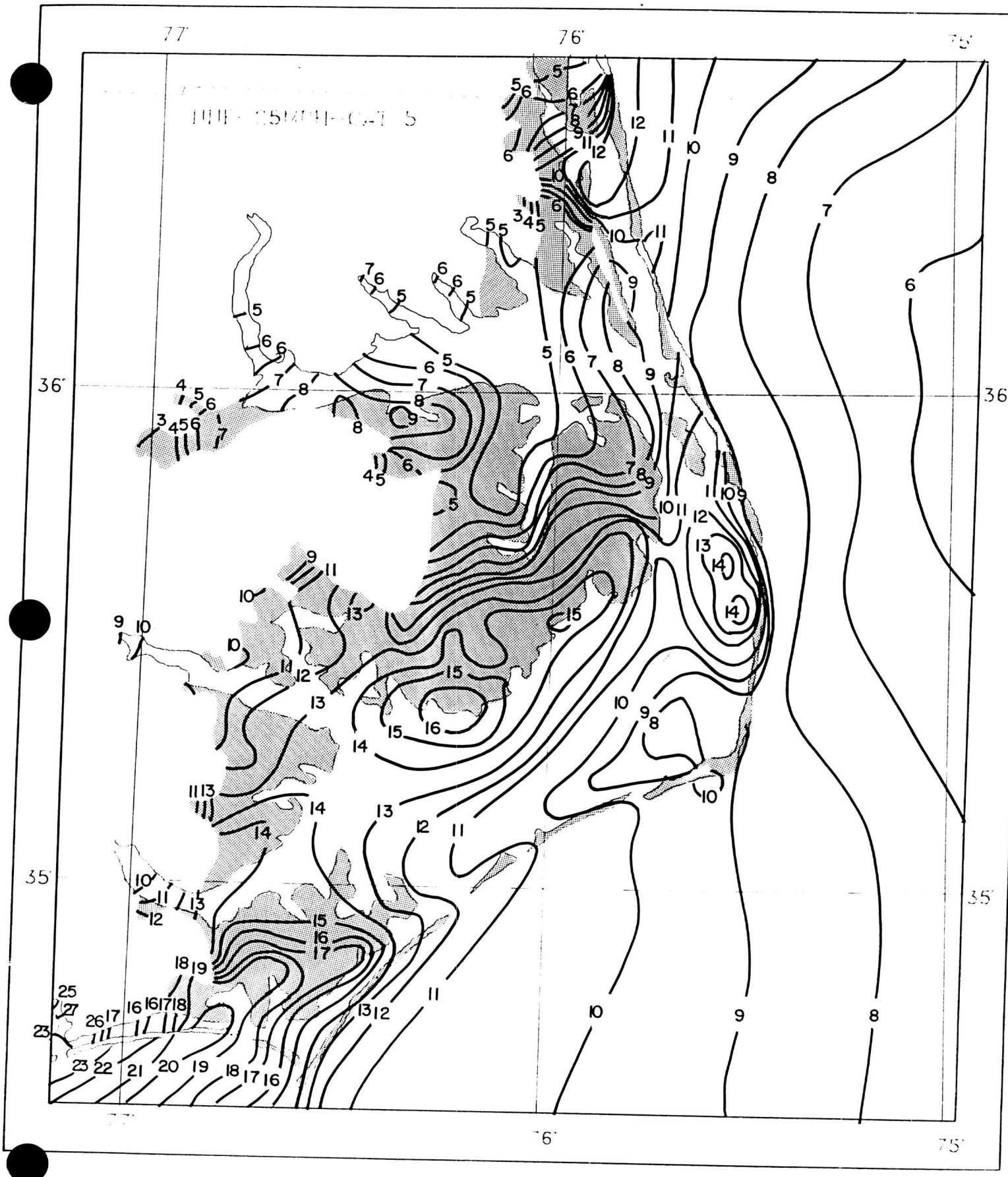

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36°
35°
NNE--15MPH--CAT 5

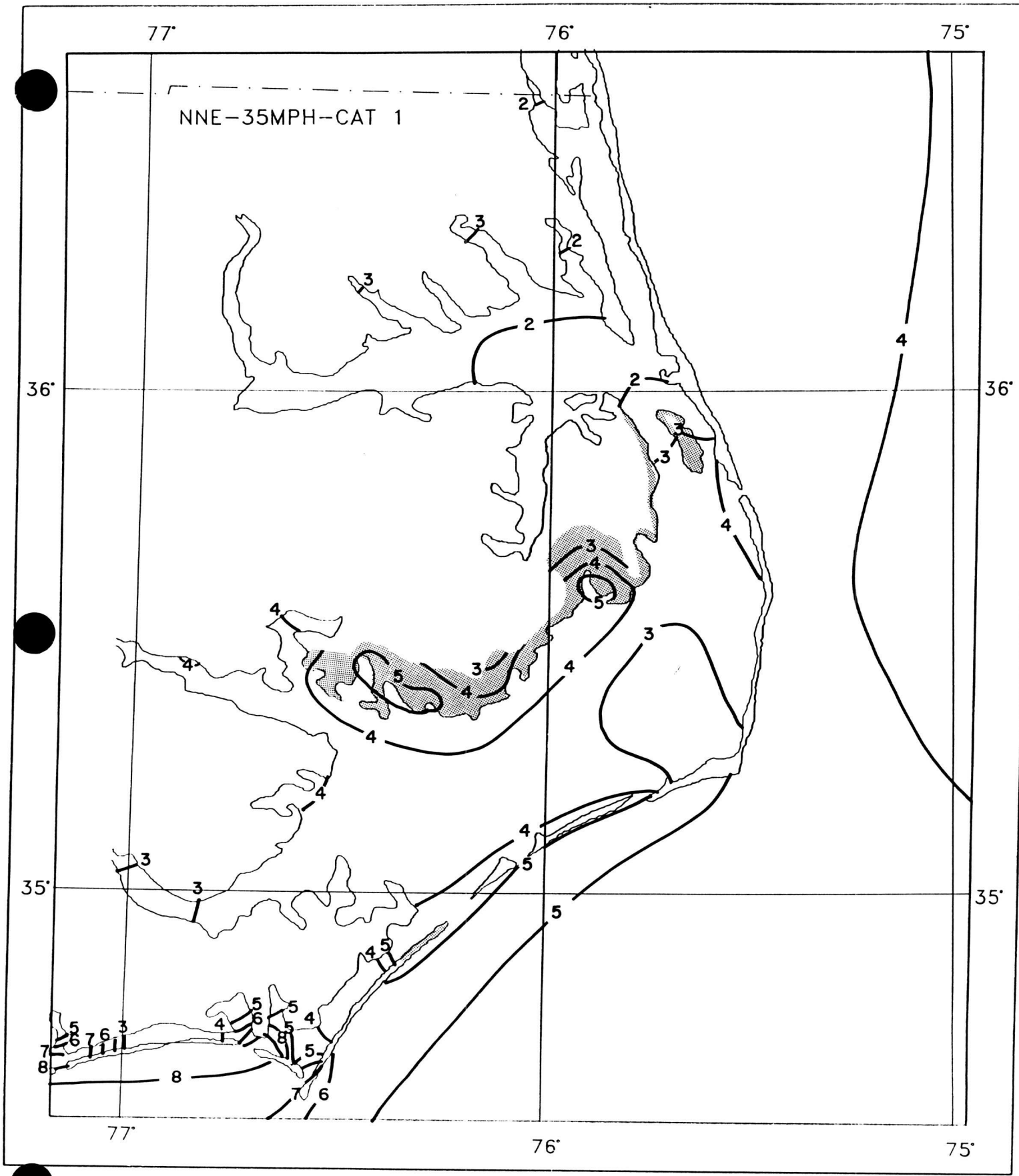

NNE--25MPH--CAT 1
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36°
35°

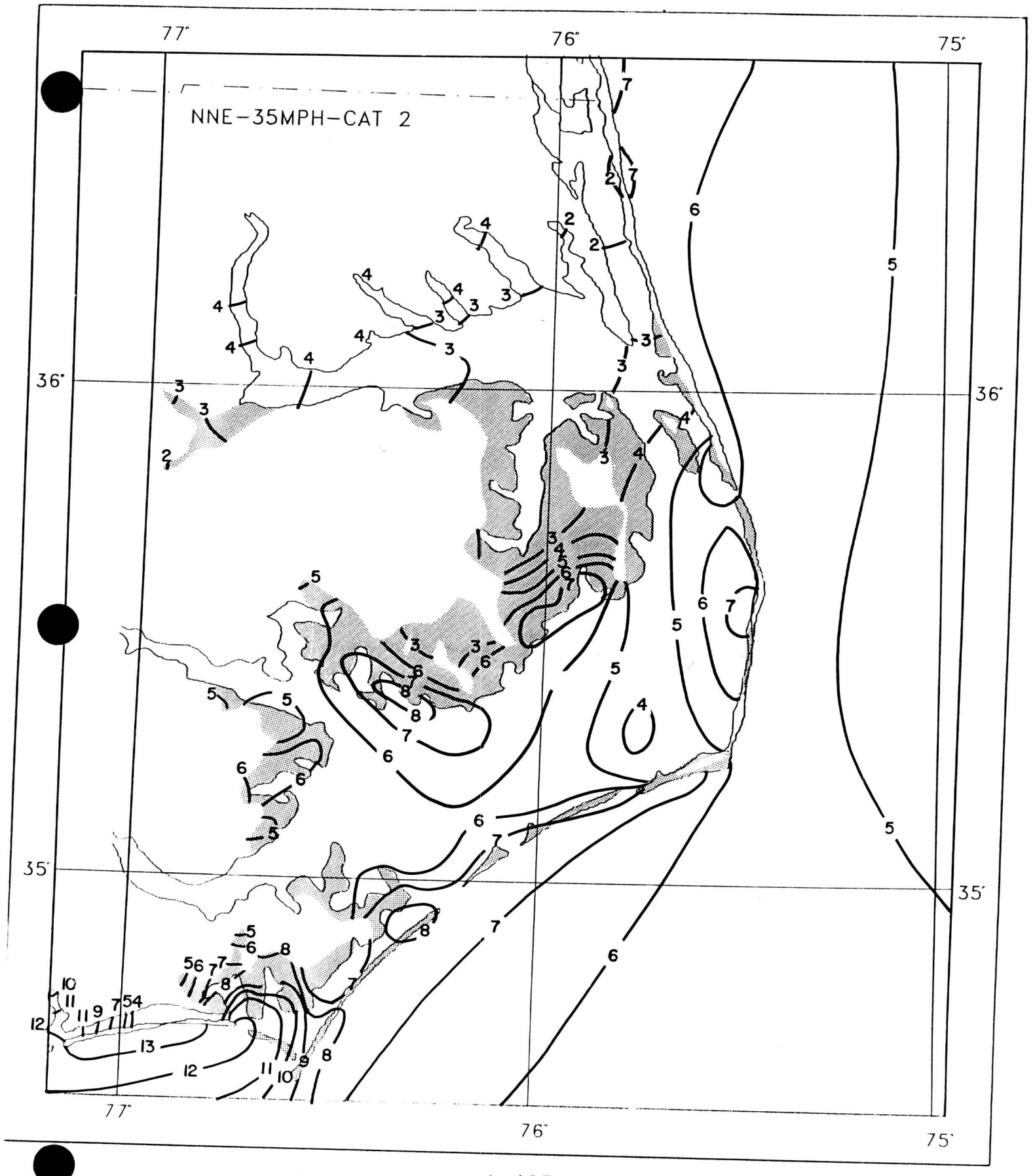

NNE–25MPH--CAT 2
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36°
35°

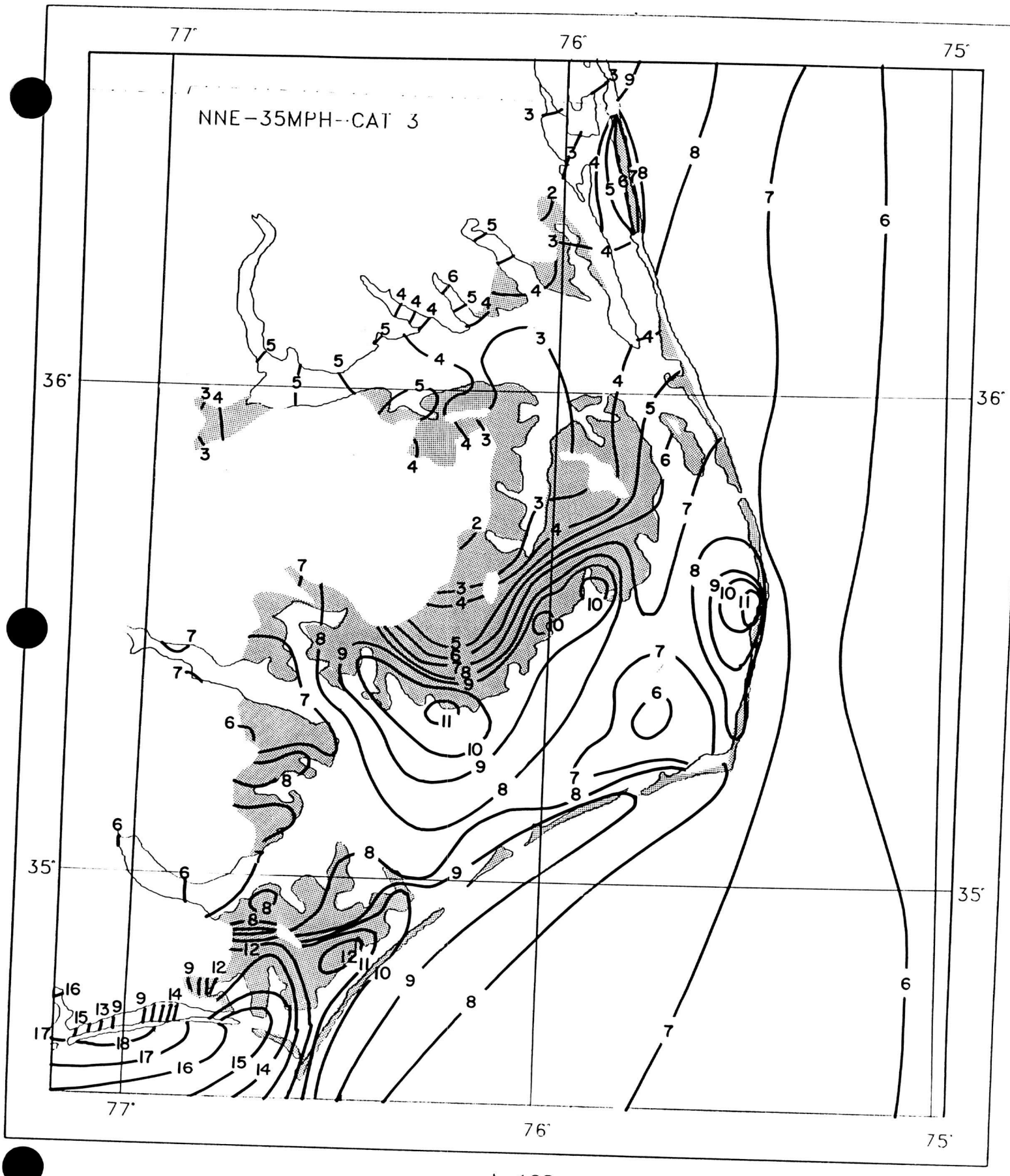

NNE--25MPH--CAT 3
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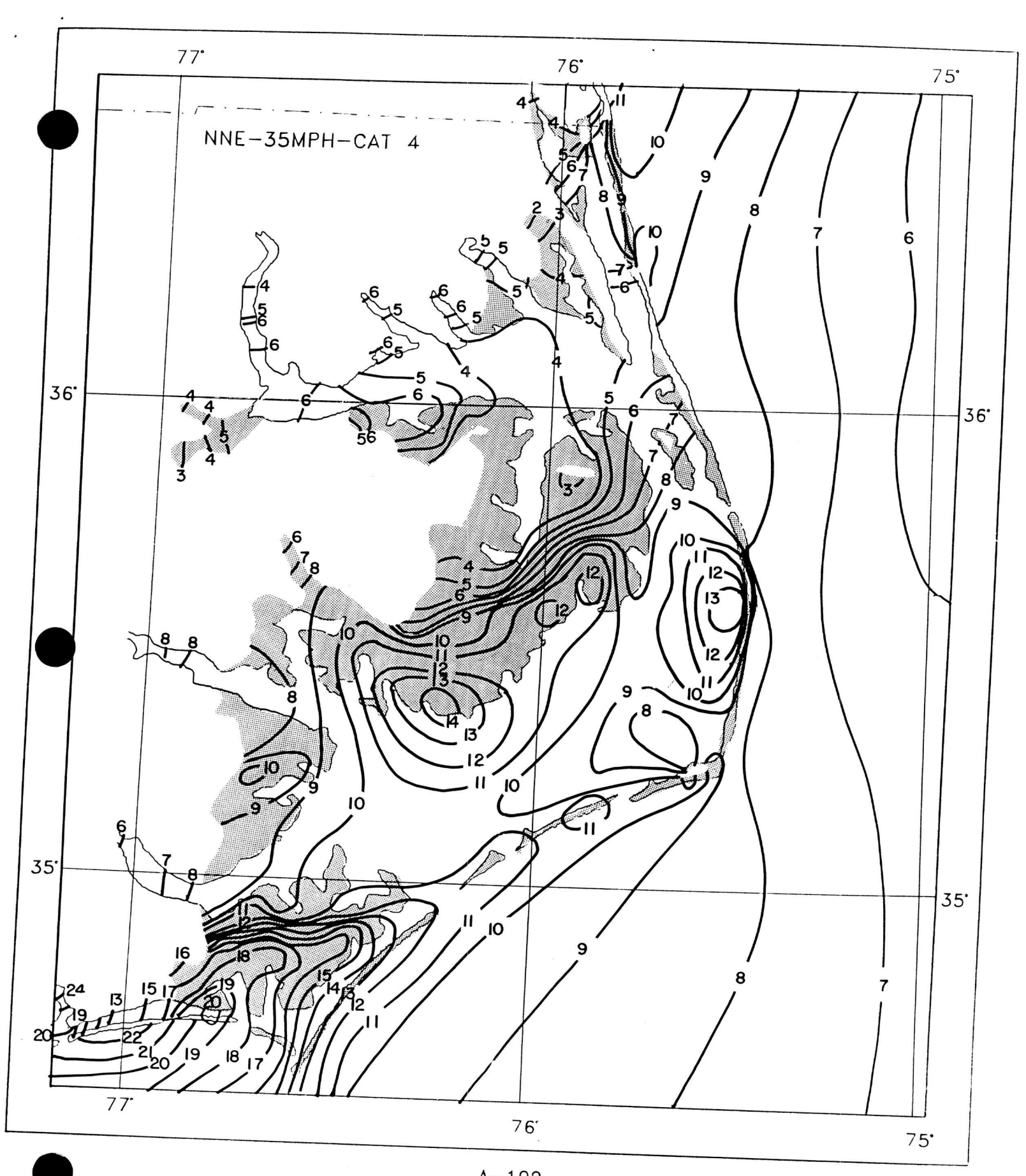

NNE–25MPH CAT 1
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76°
75°
36°
35°

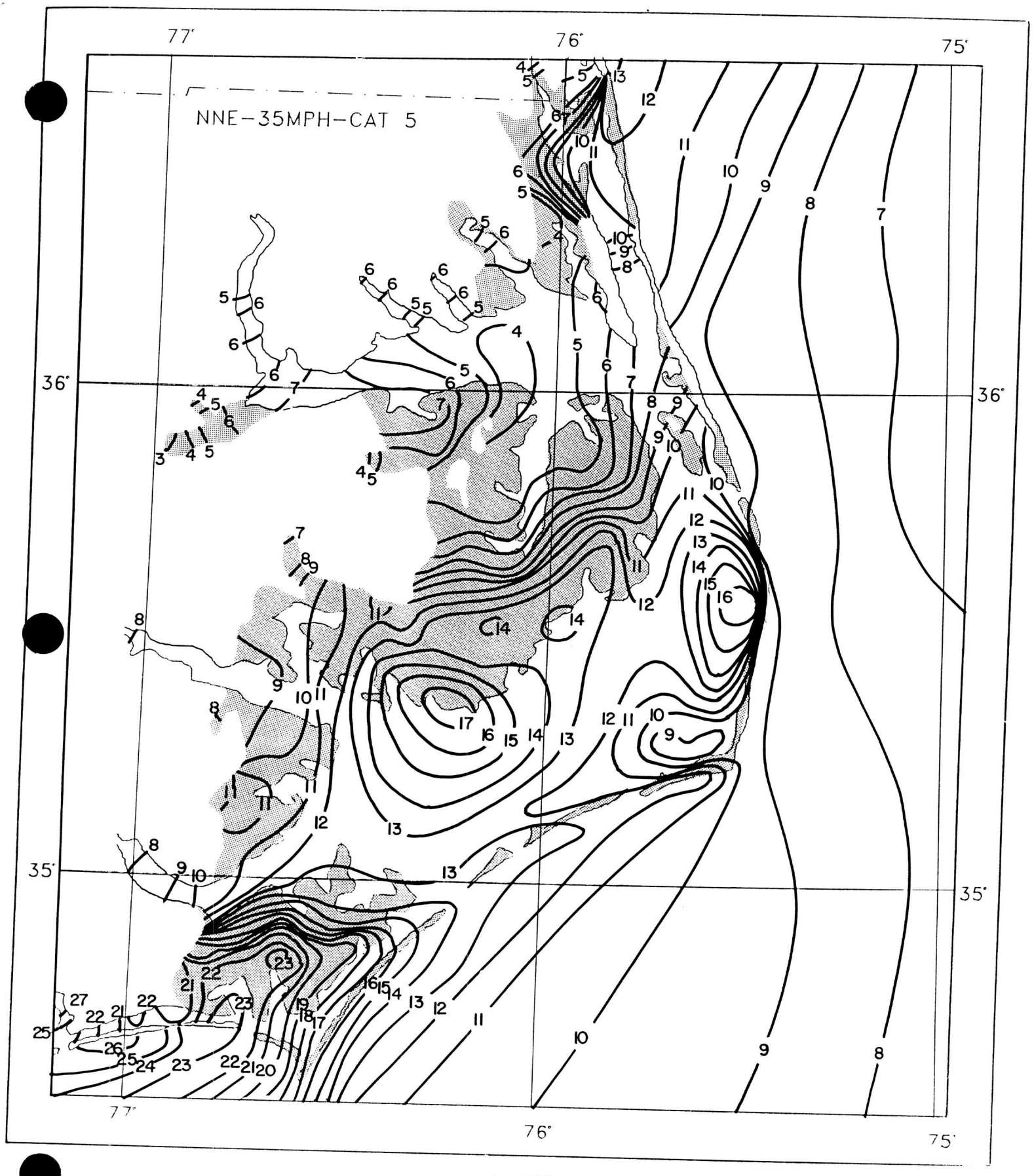

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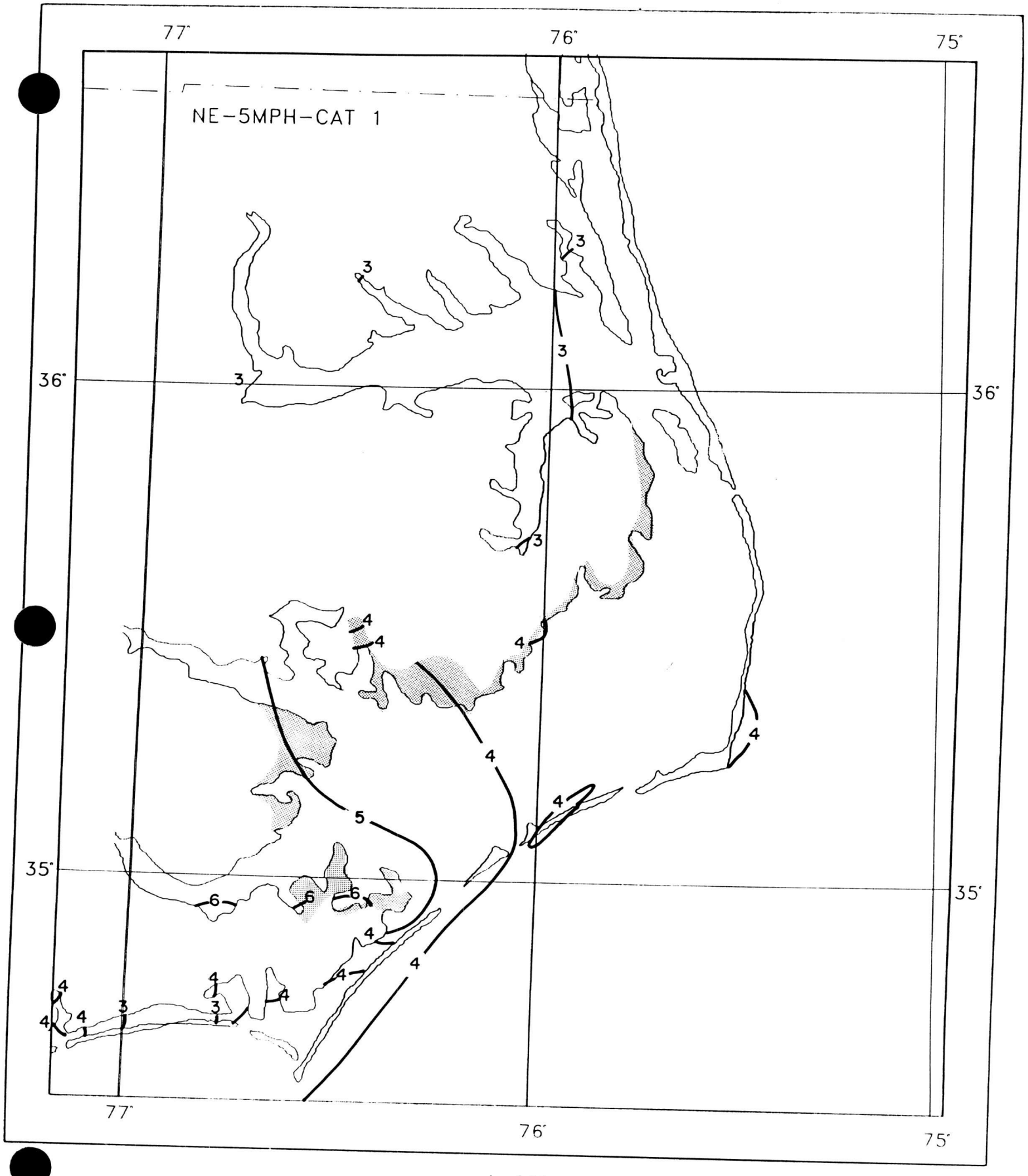

NNE–35MPH–CAT 1
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35°

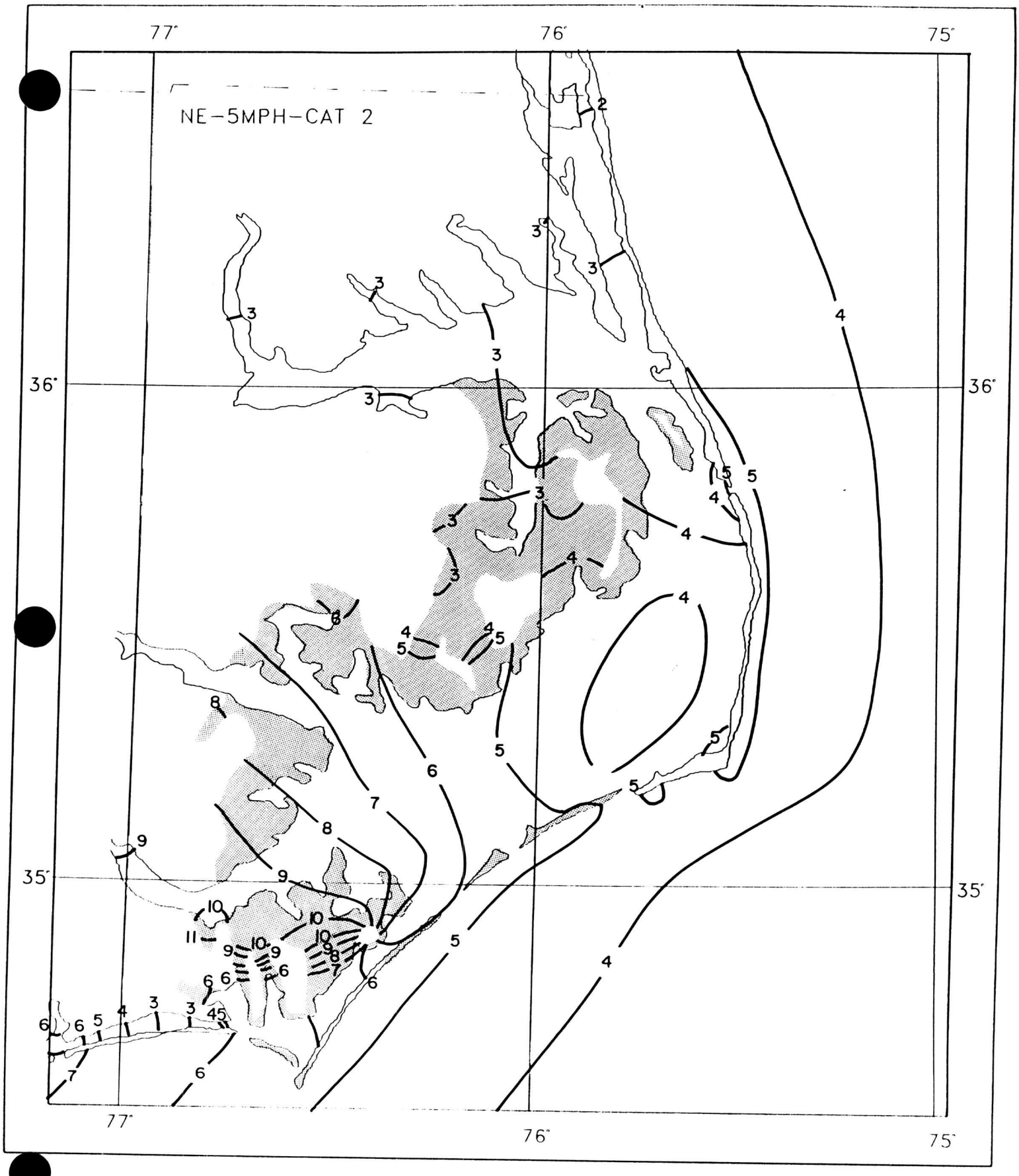

NNE-35MPH-CAT 2
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76°
75°
36°
35°

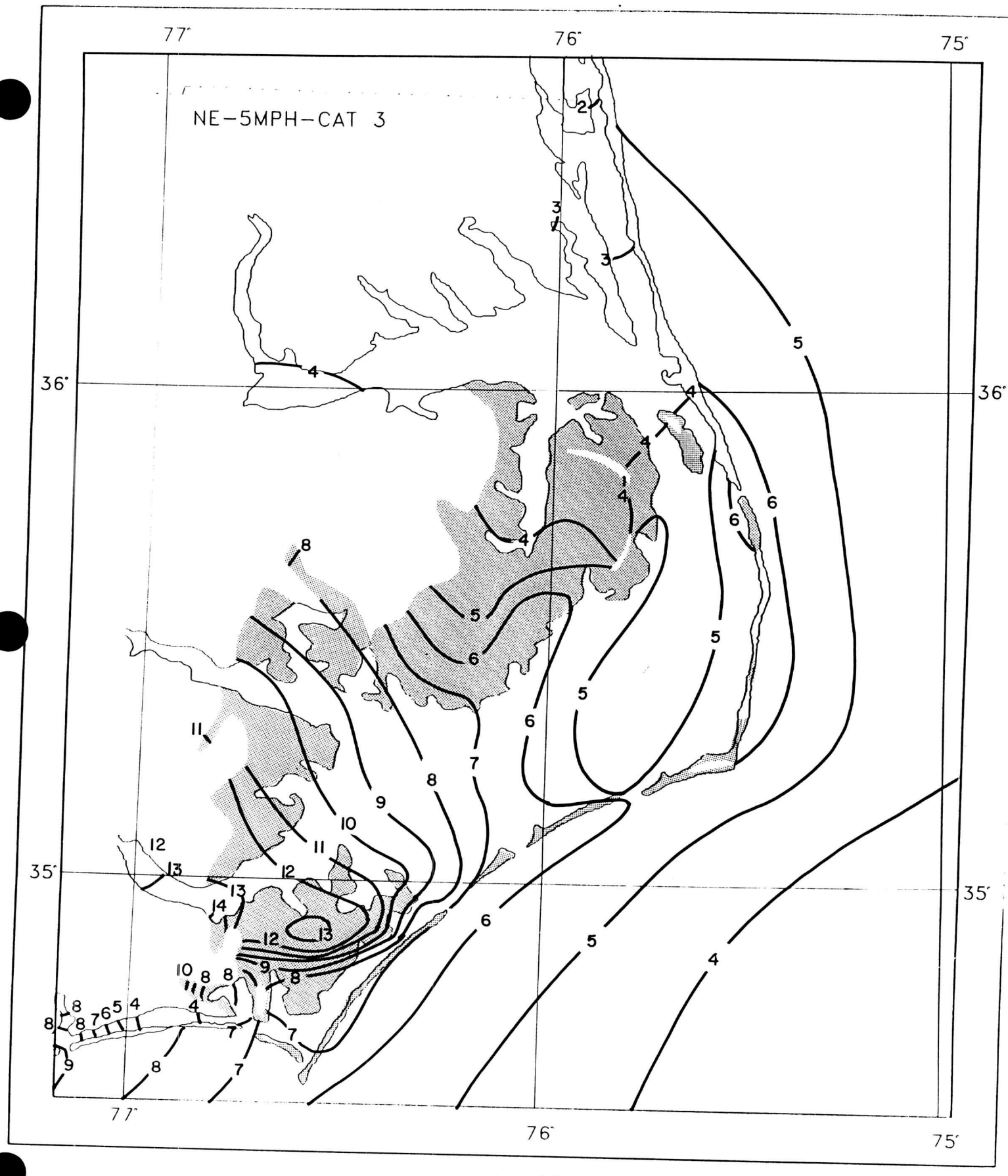

NNE–35MPH--CAT 3
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35°

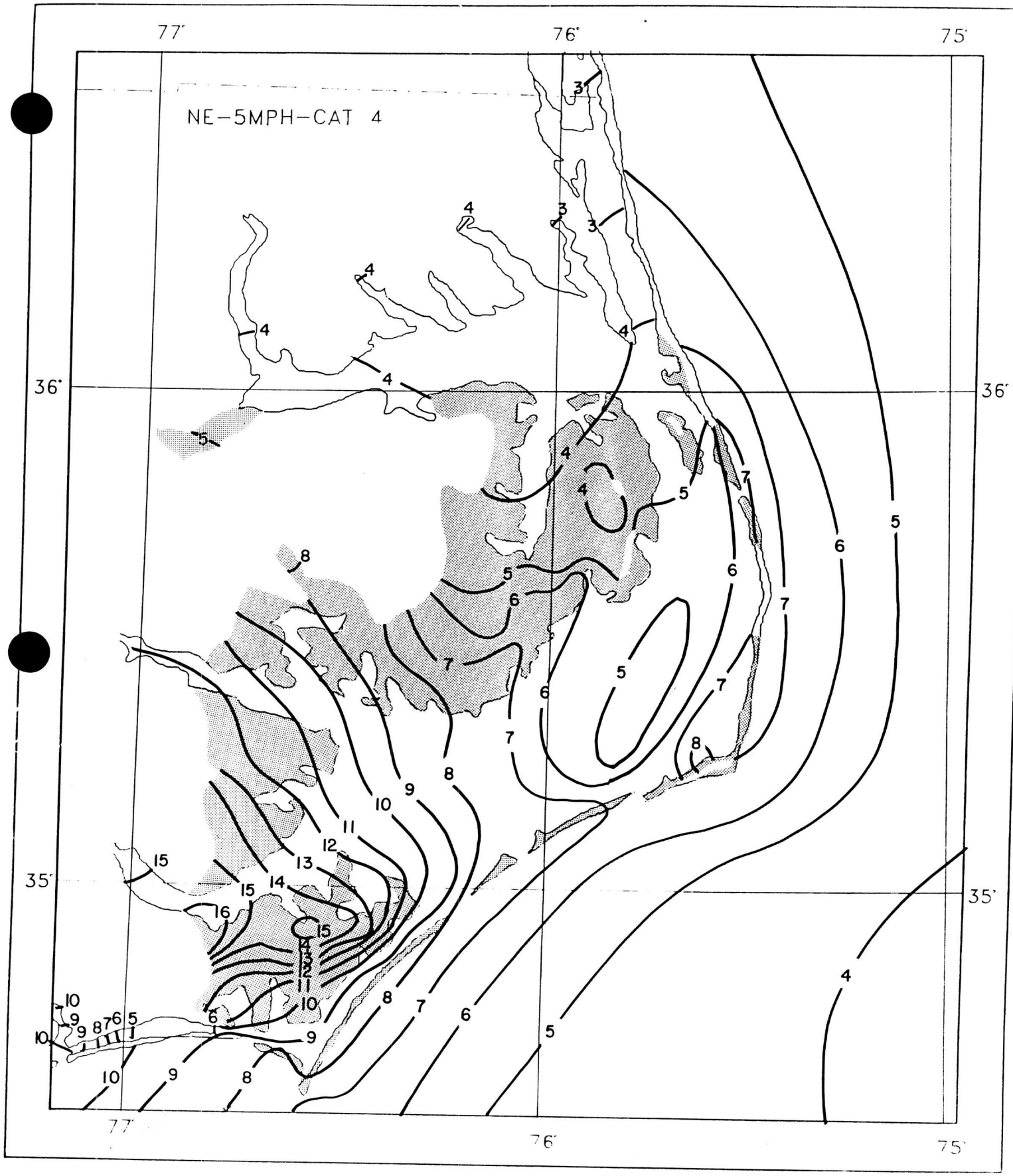

NNE–35MPH–CAT 4
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35°

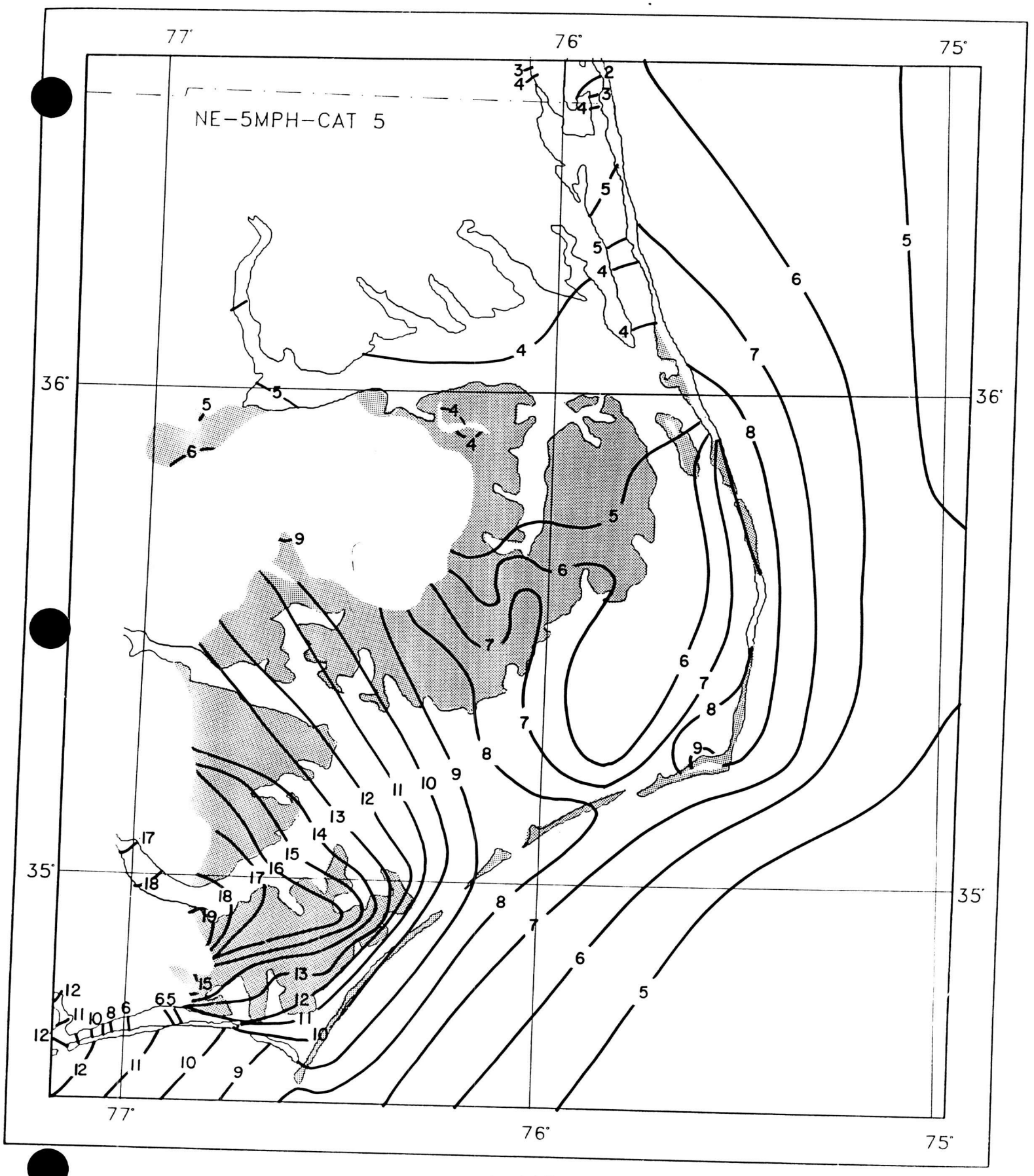

NNE–35MPH–CAT 5
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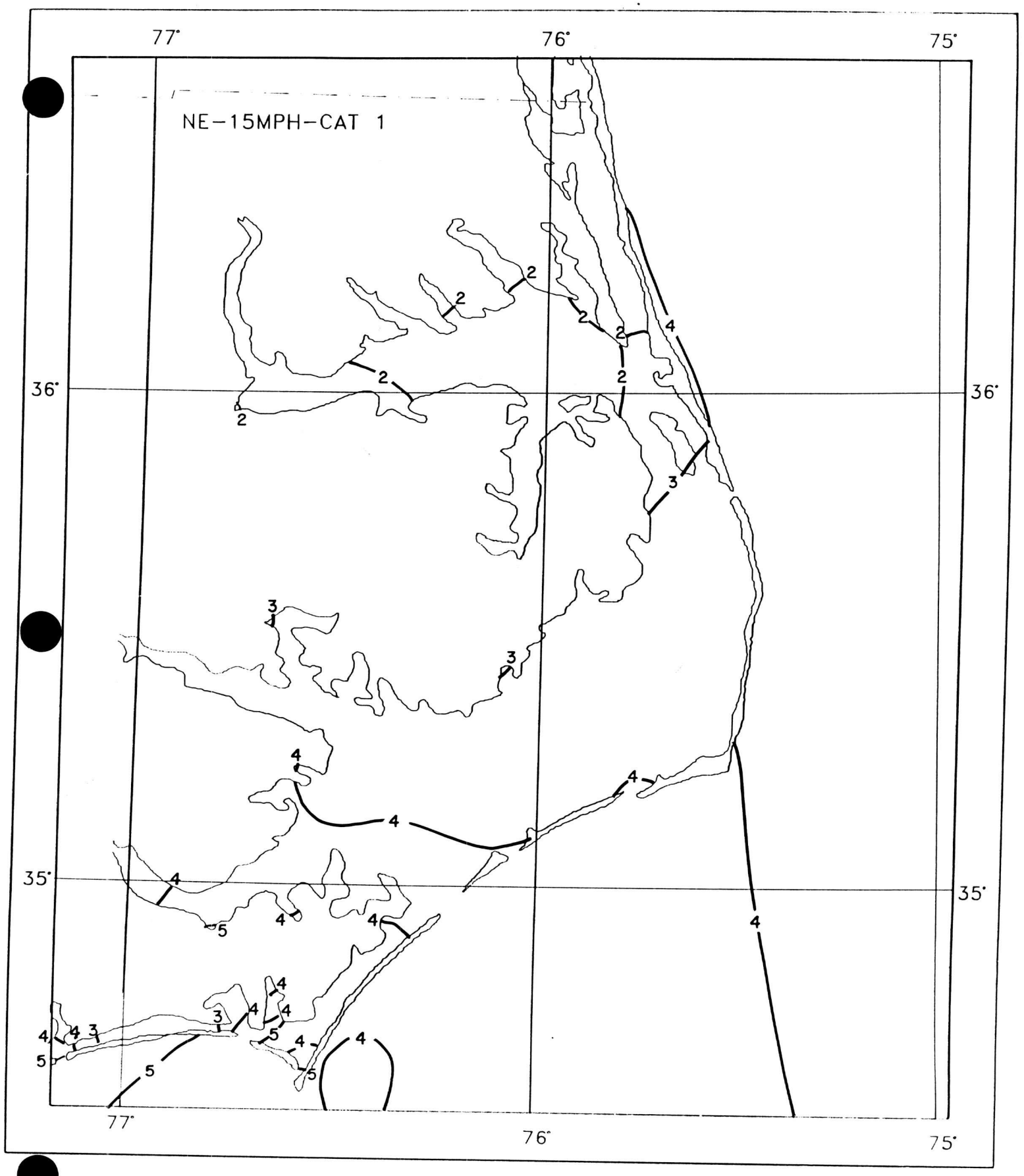

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NE-5MPH-CAT 1
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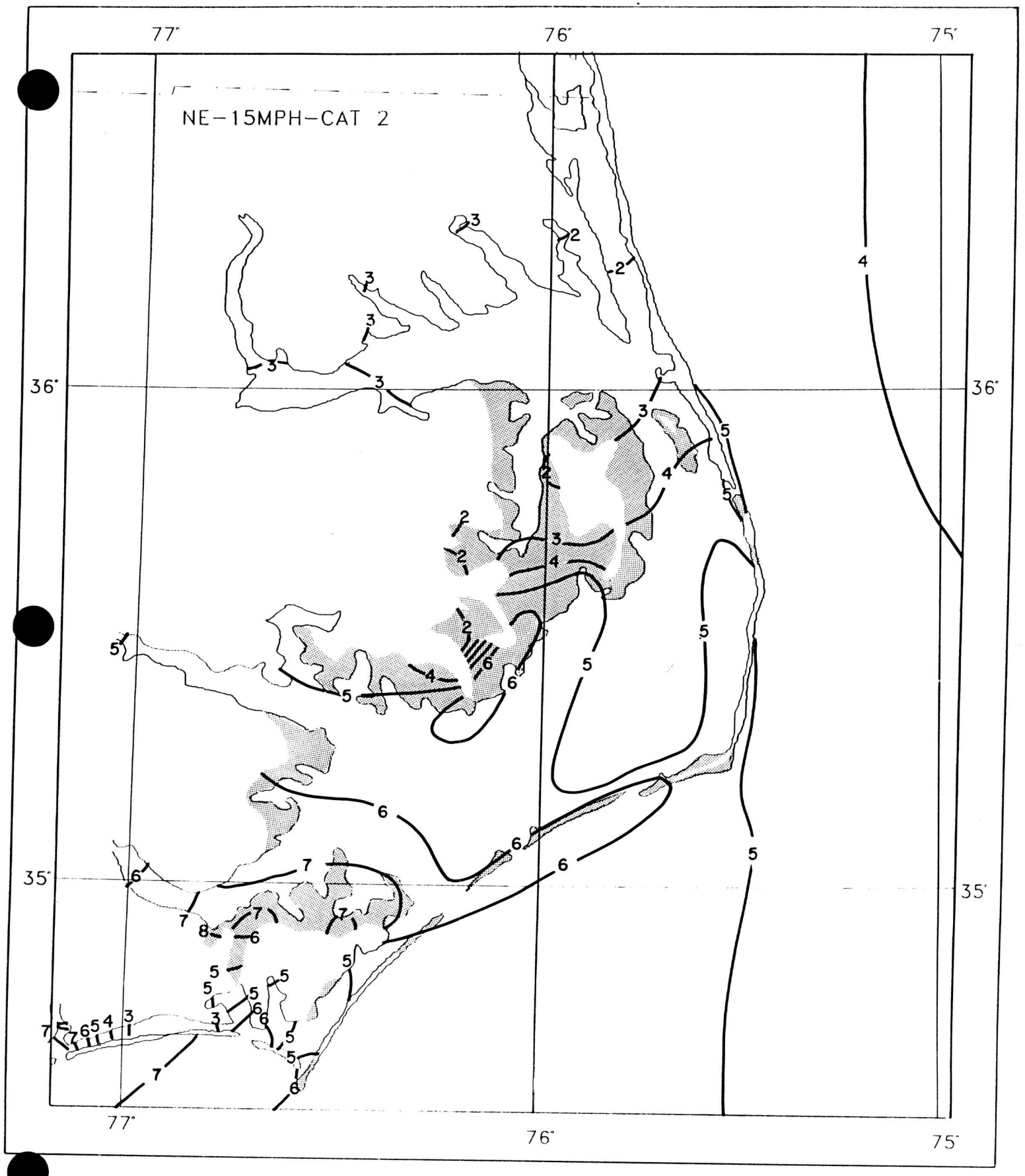

NE-5MPH-CAT 2
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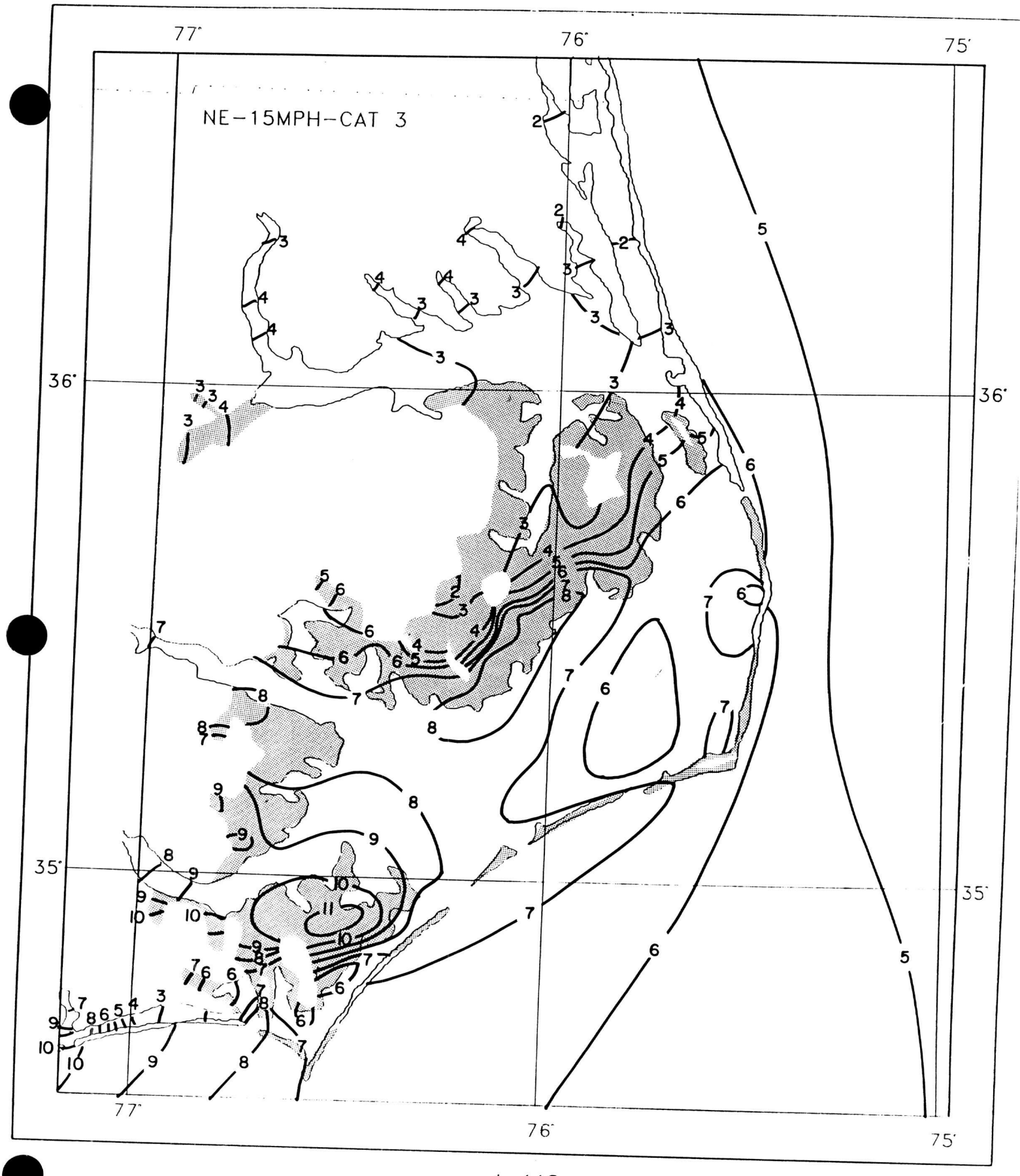

NE–5MPH–CAT 3
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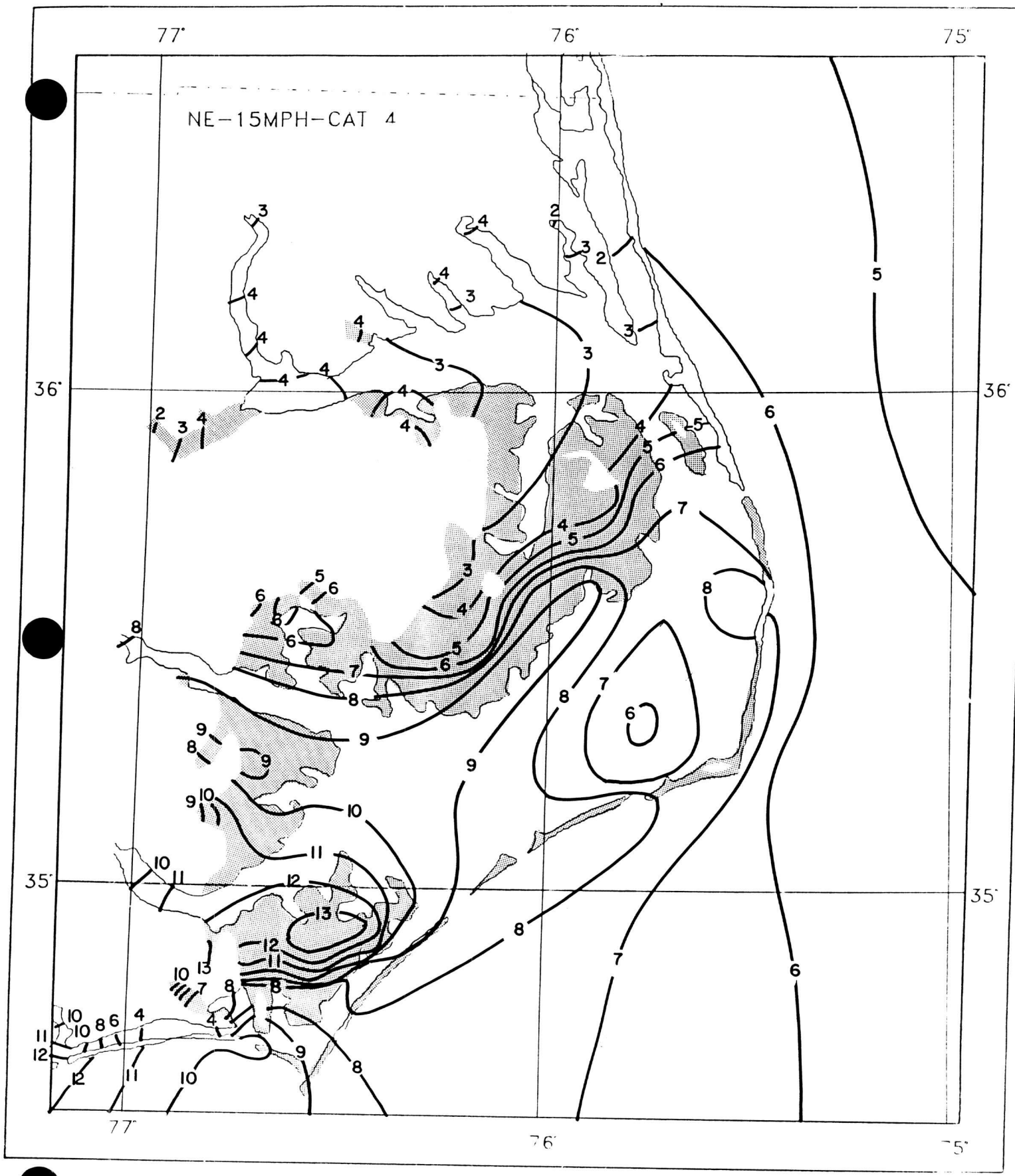

NE–5MPH–CAT 4
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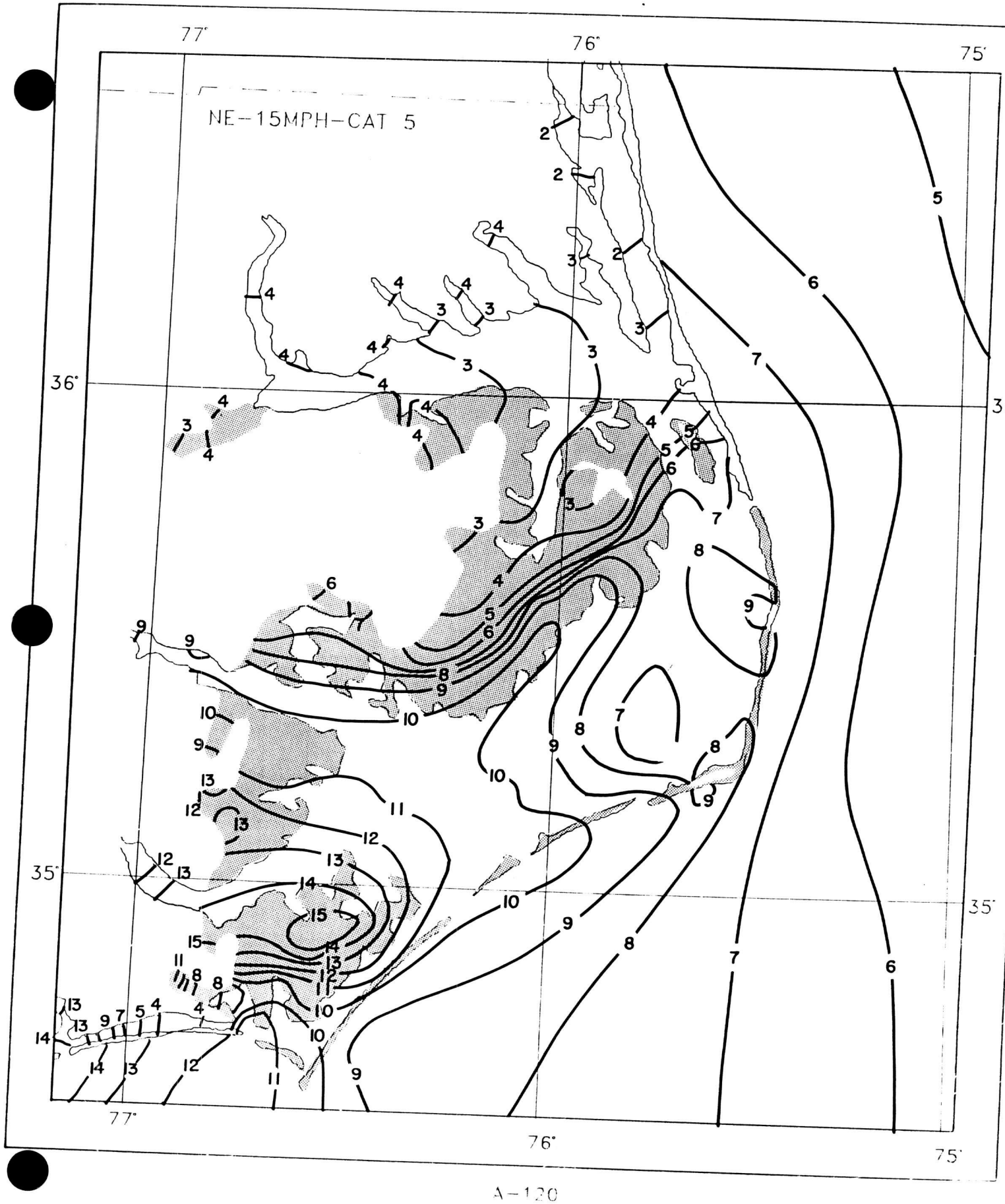

NE-5MPH-CAT 5
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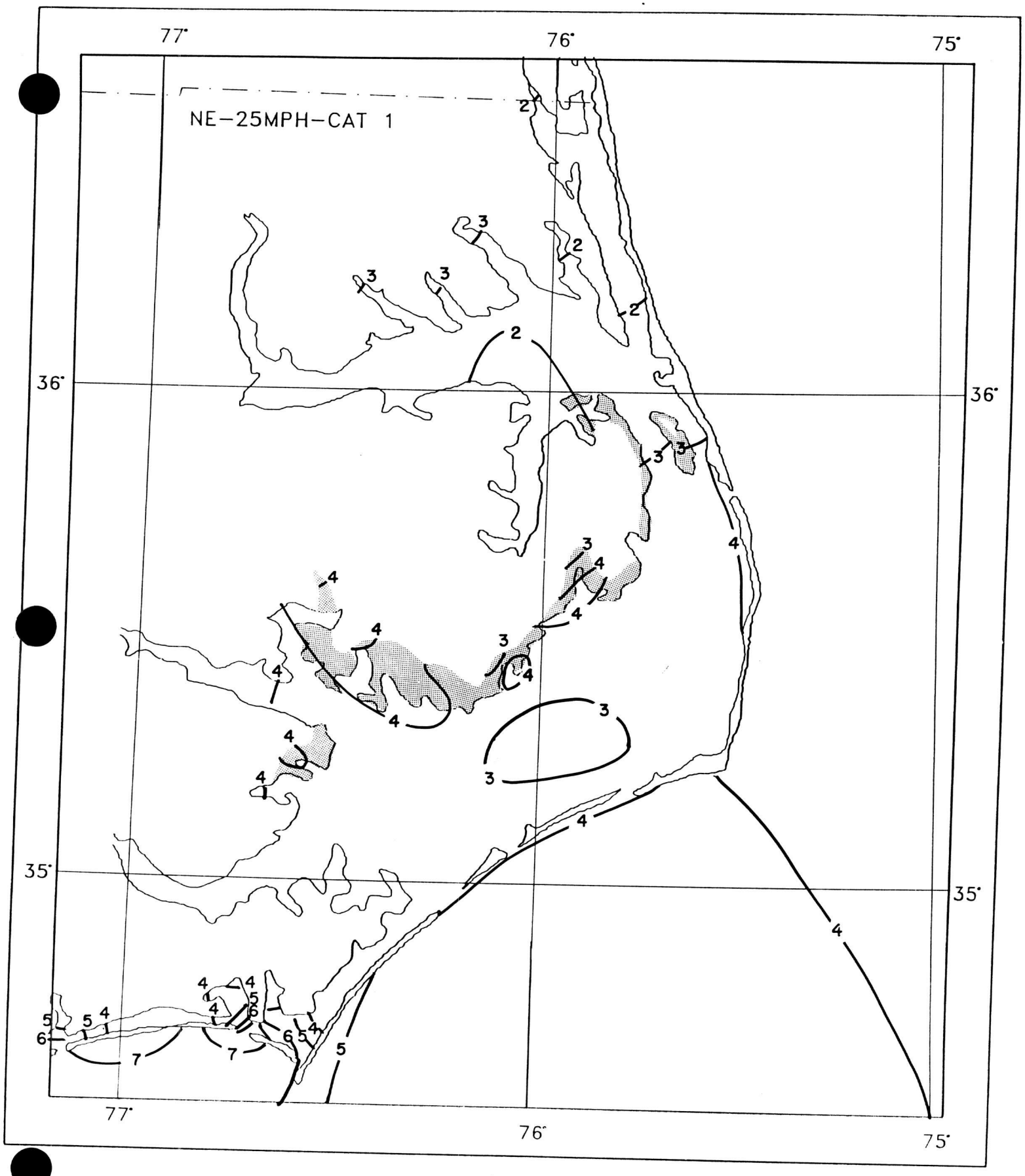

NE-15MPH-CAT 1
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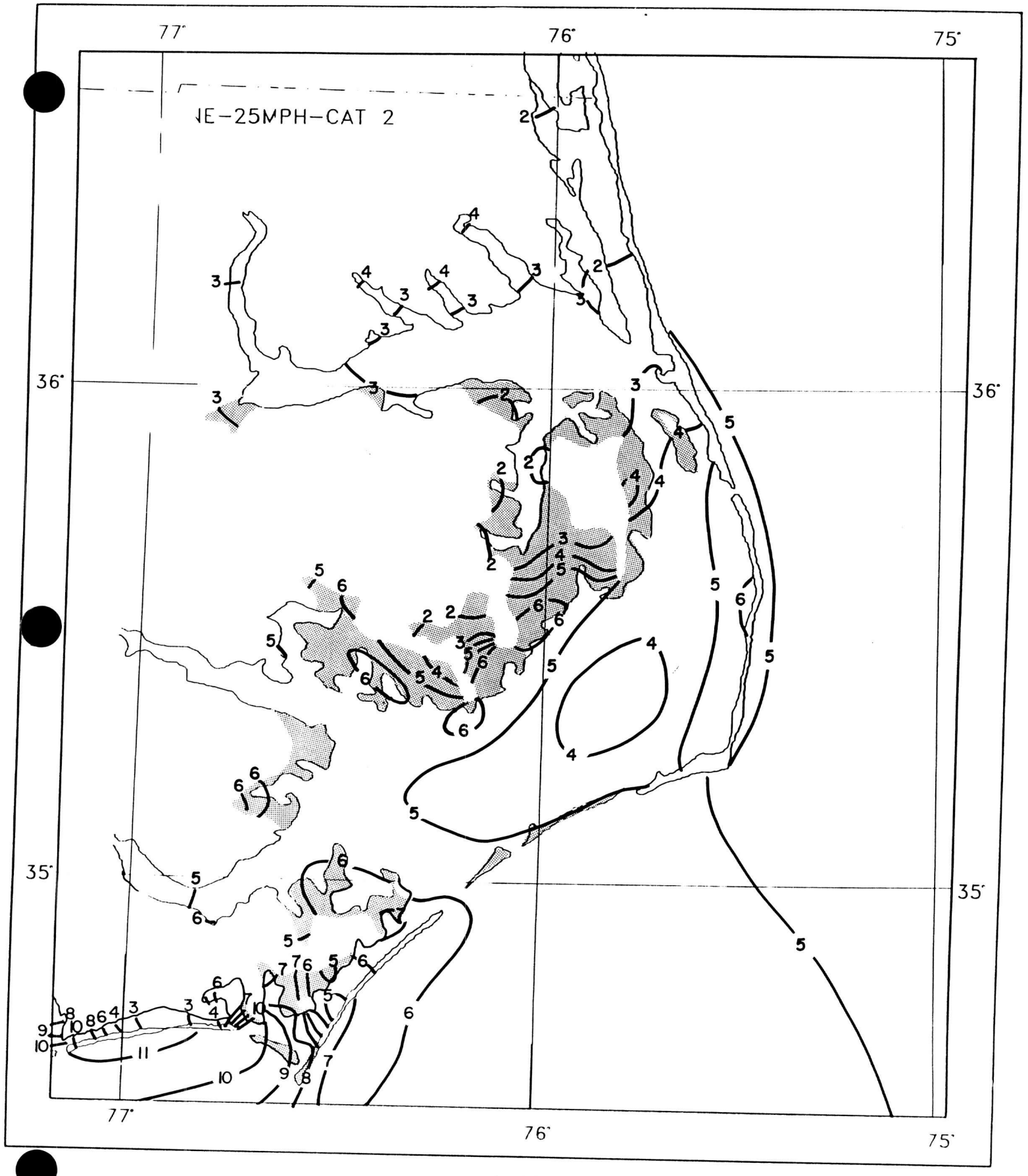

NE-15MPH-CAT 2
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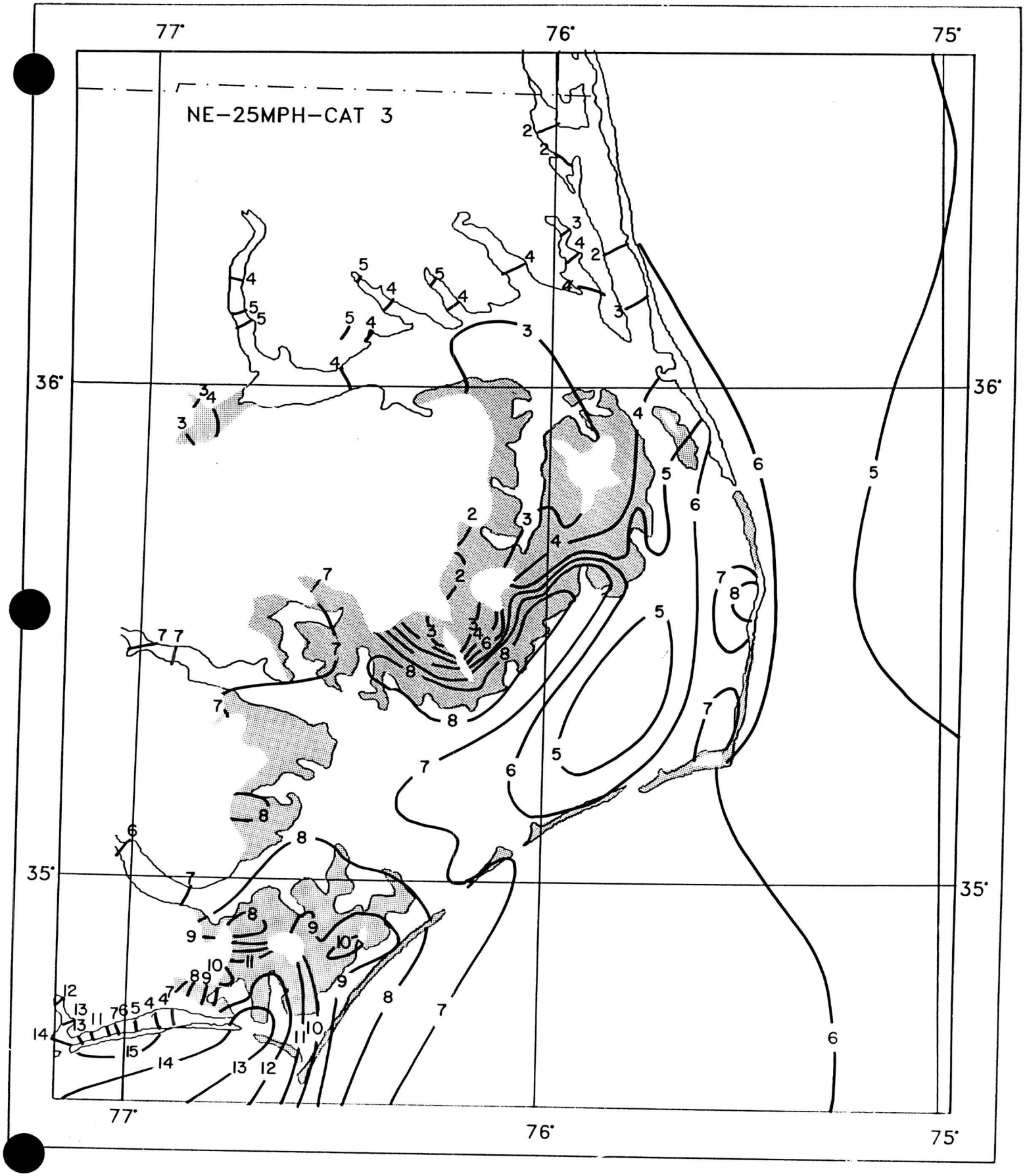

NE-15MPH-CAT 3
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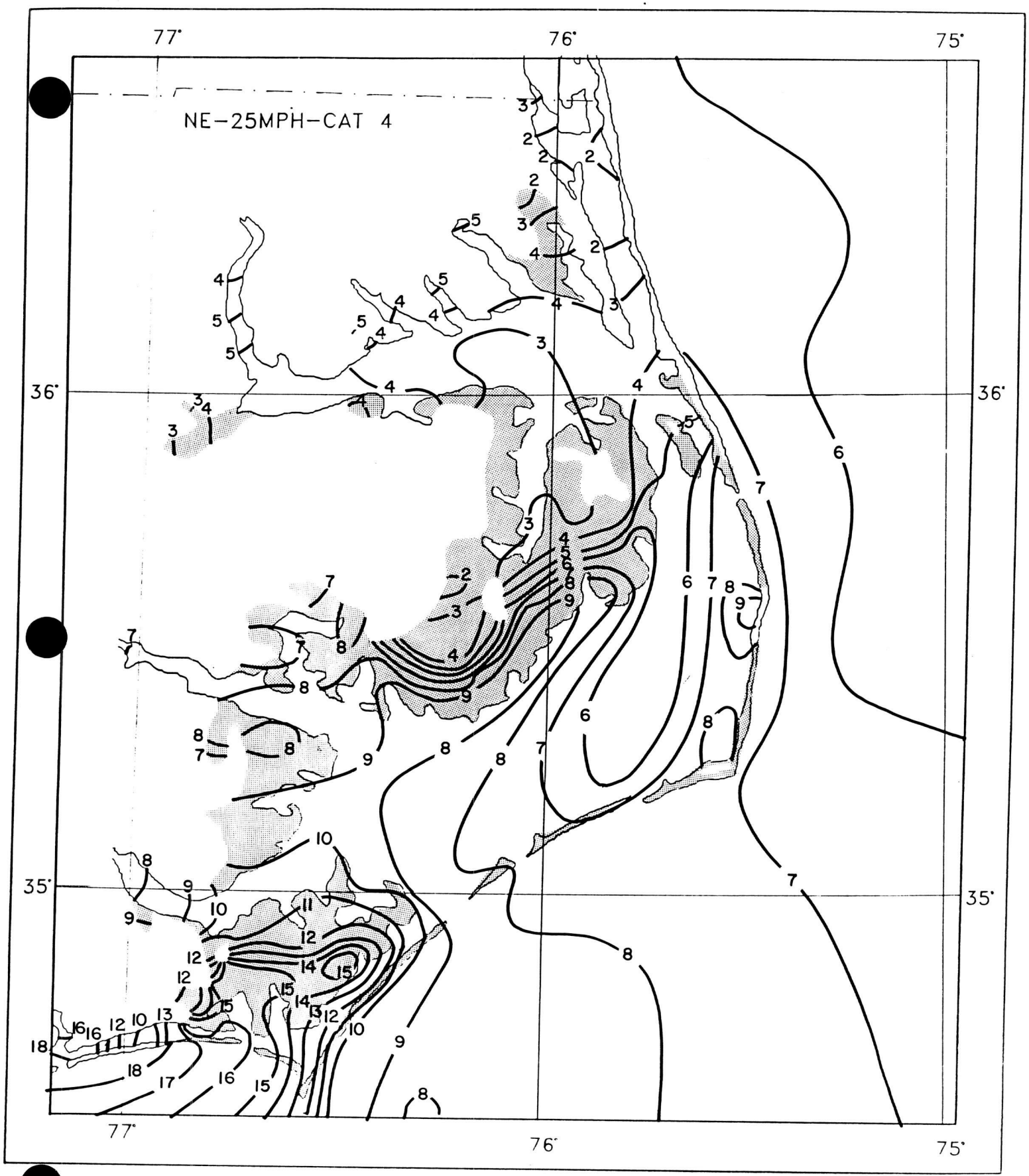

NE–15MPH–CAT 4
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36°
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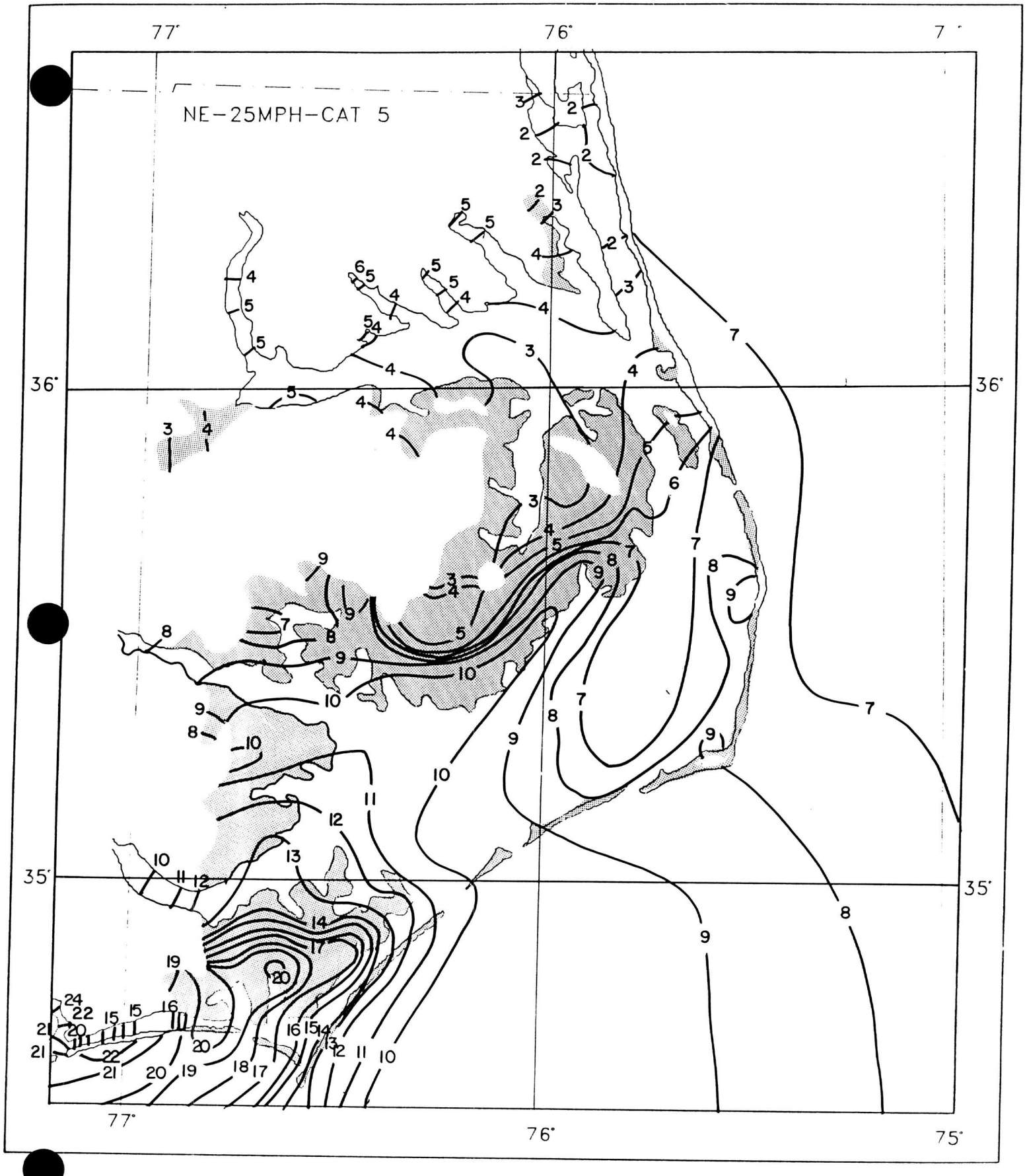

NE-15MPH-CAT 5
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35°

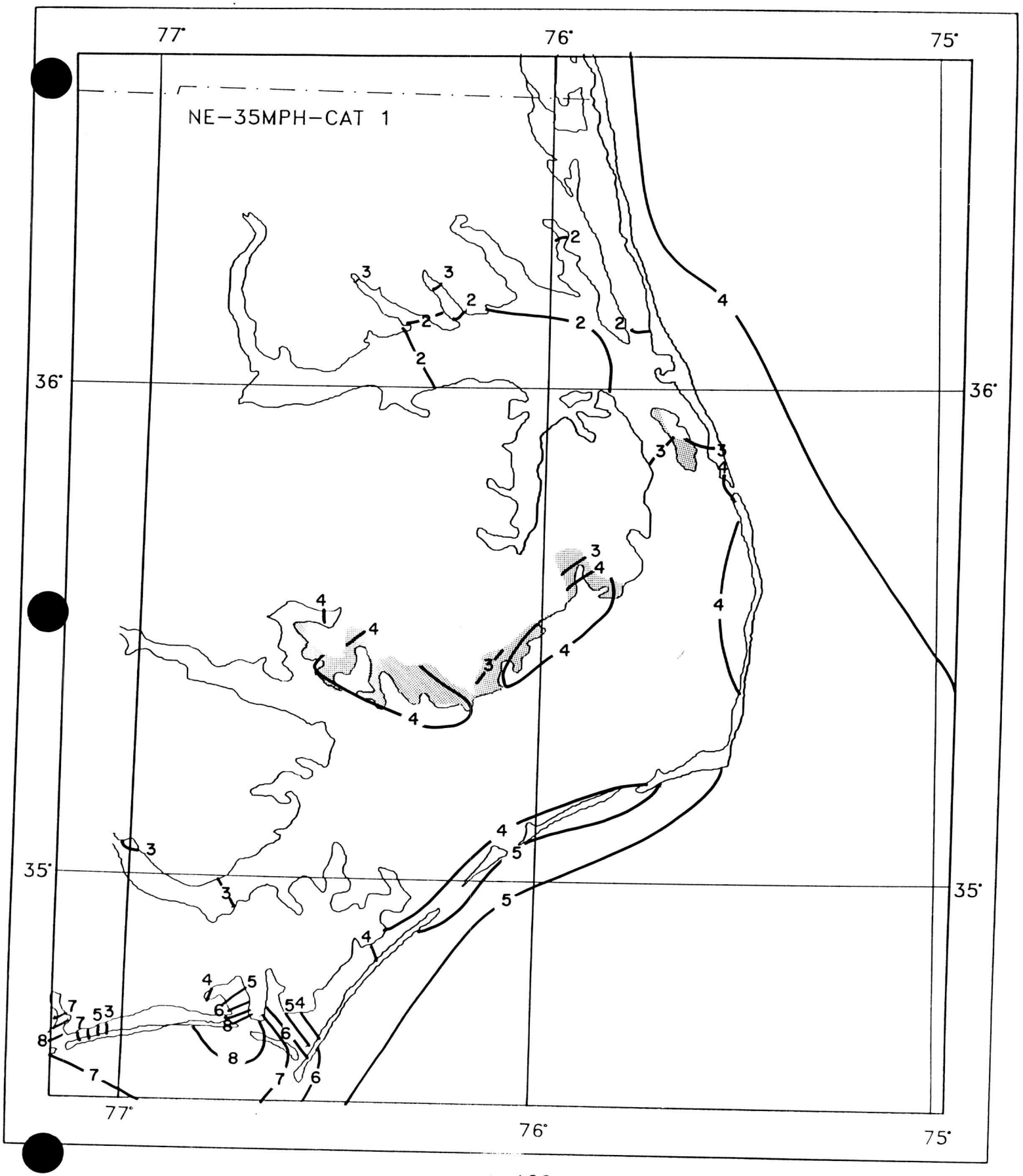

NE–25MPH–CAT 1
77°
76°
75°
36°
35°

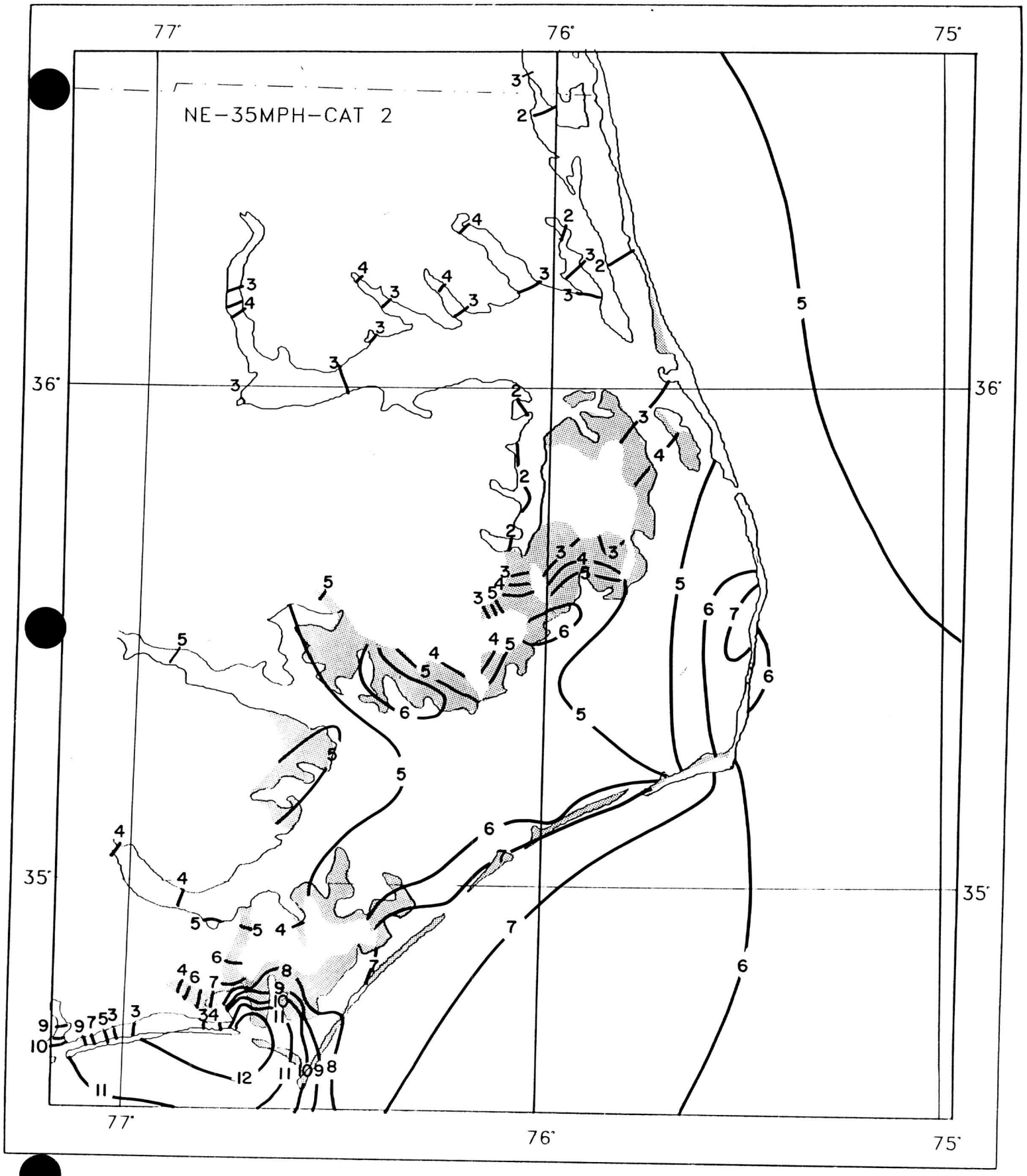

77°
76°
75°
NE-25MPH-CAT 2
36°
35°

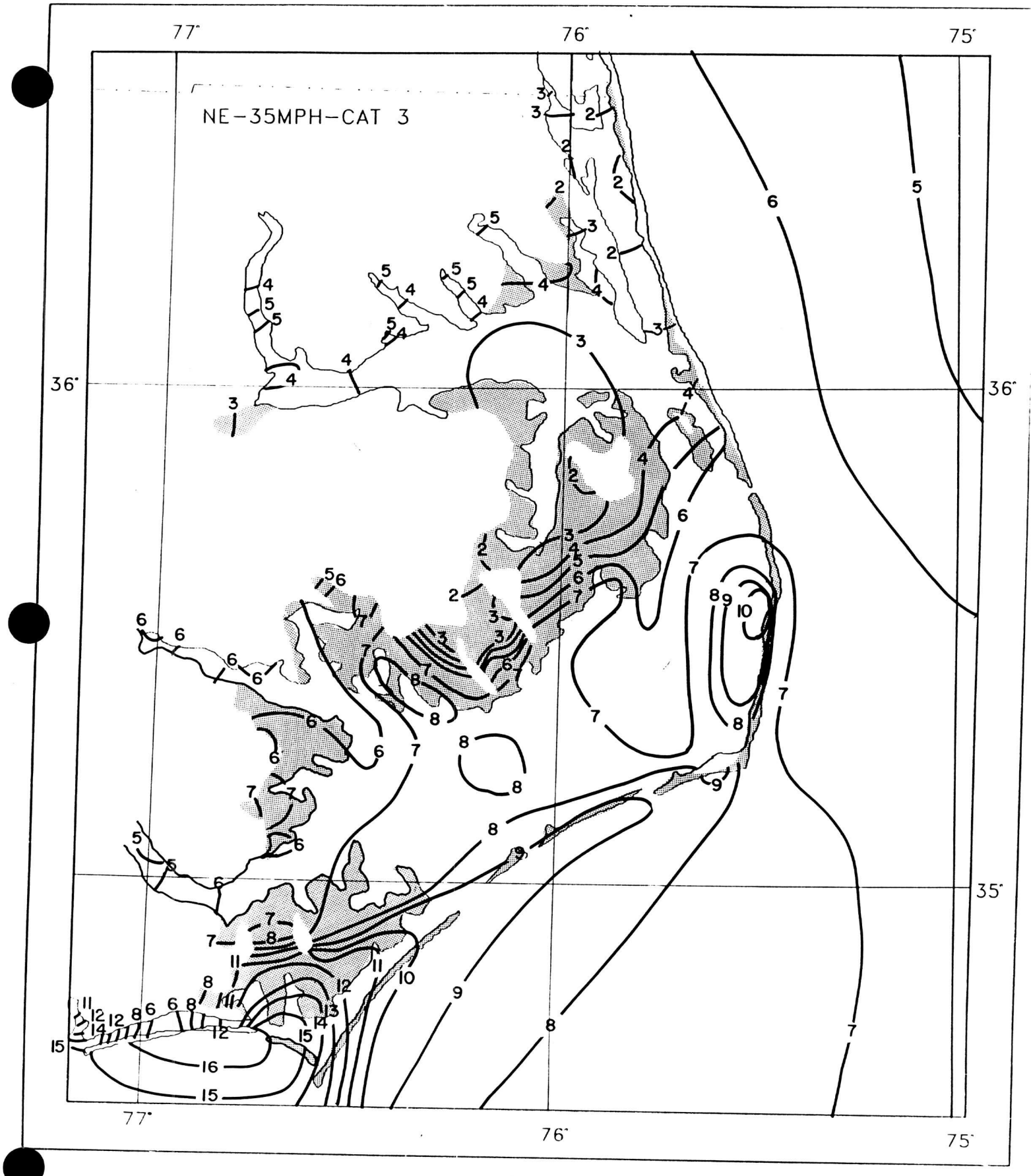

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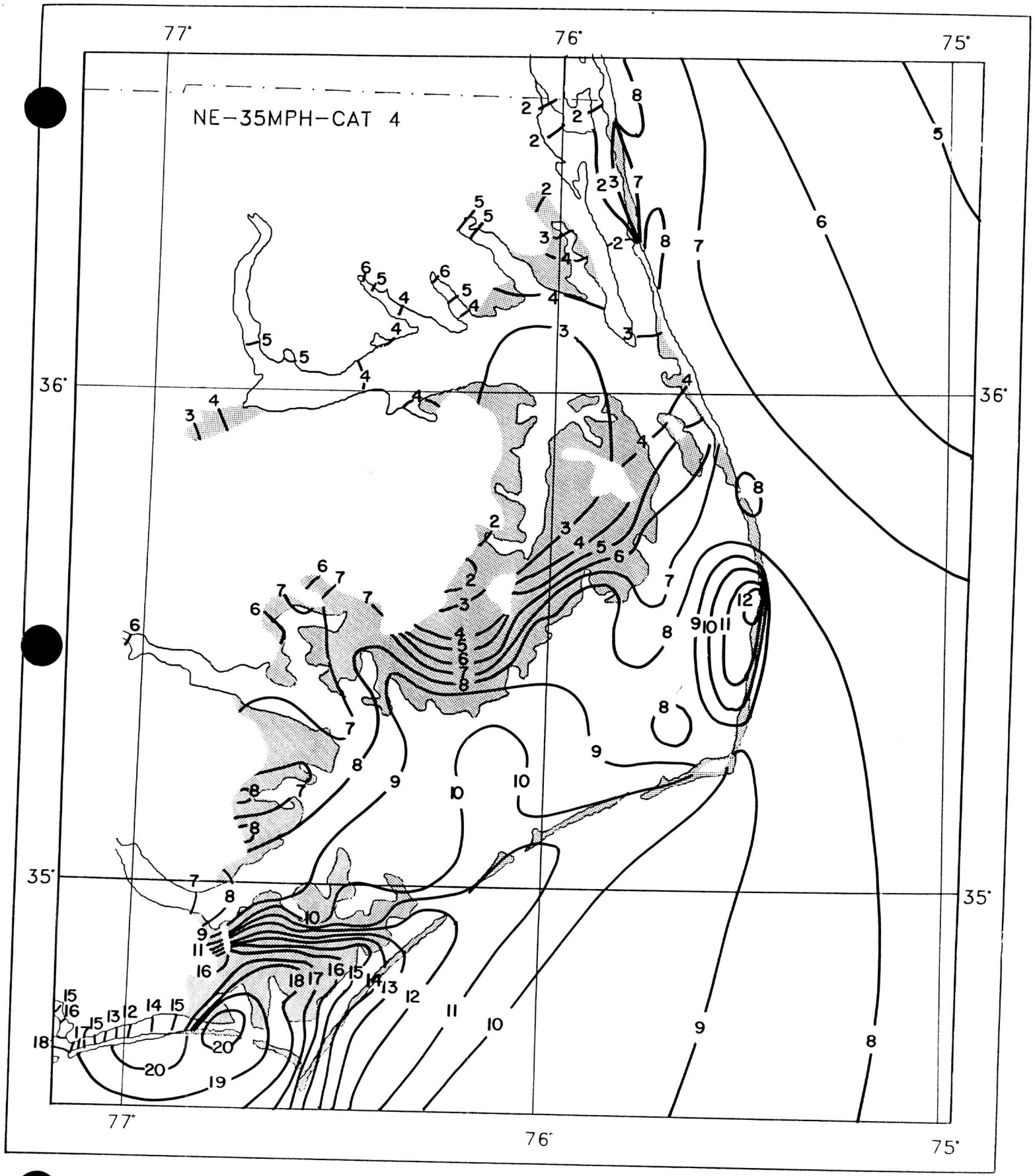

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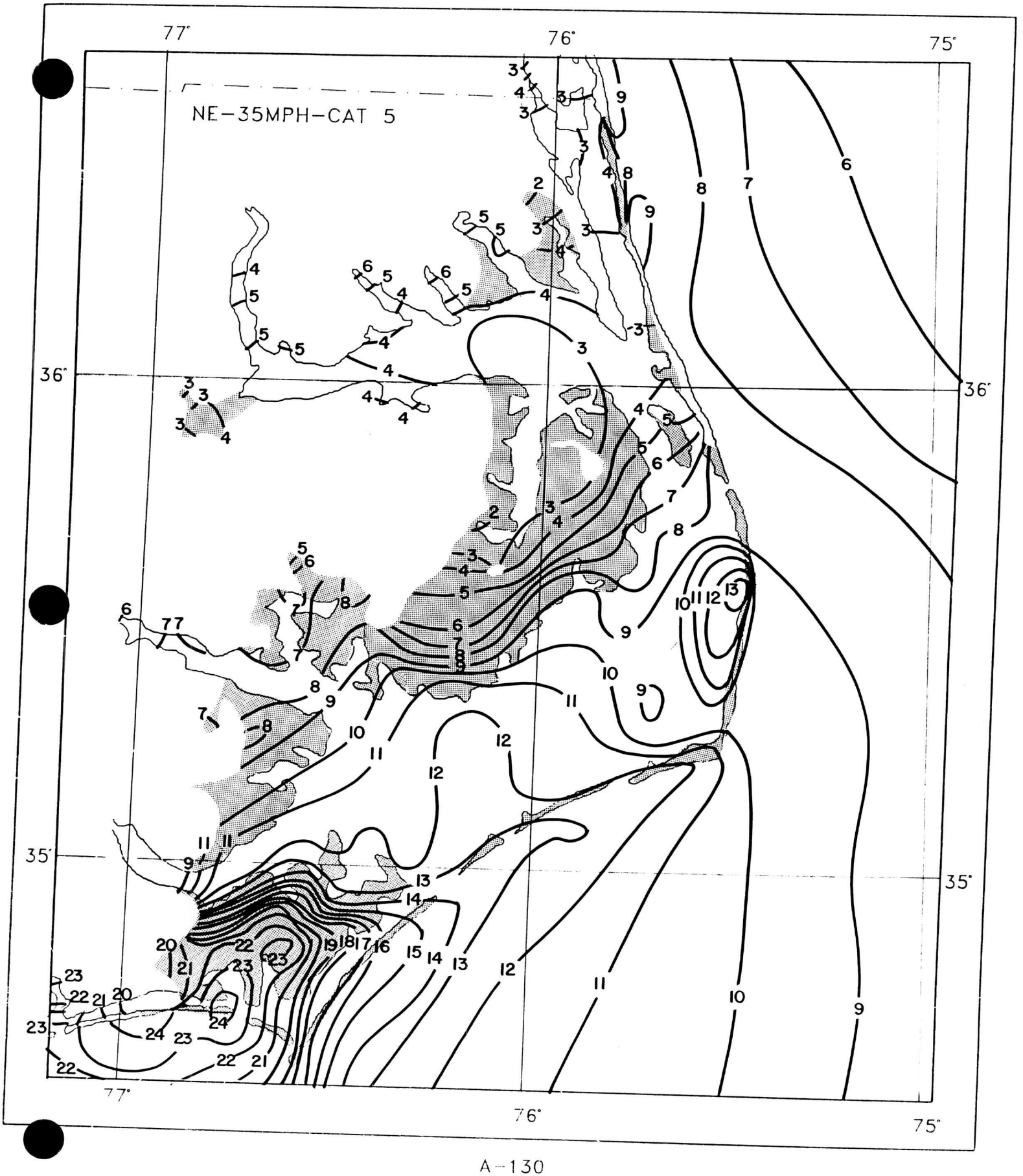

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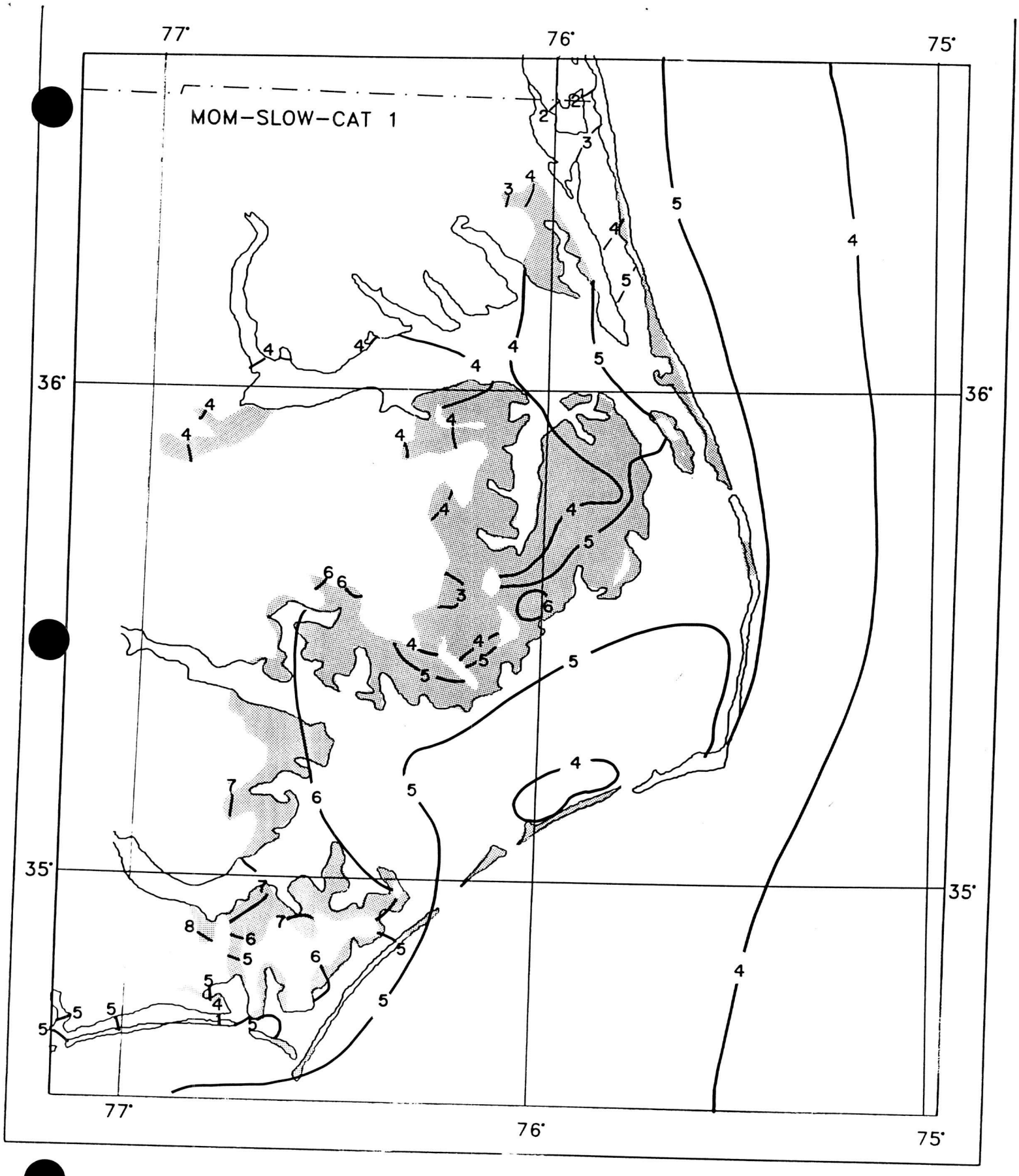

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35°

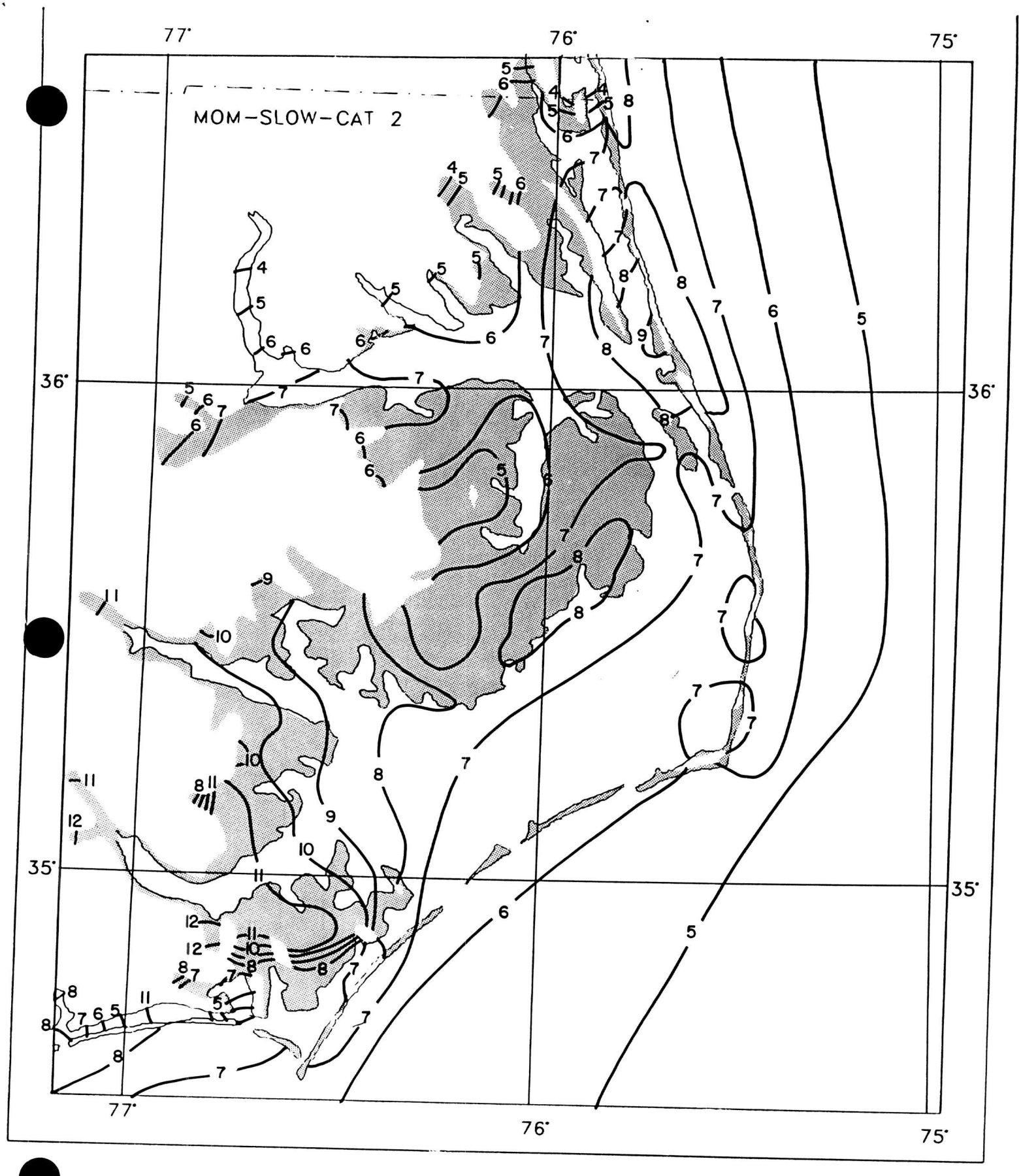

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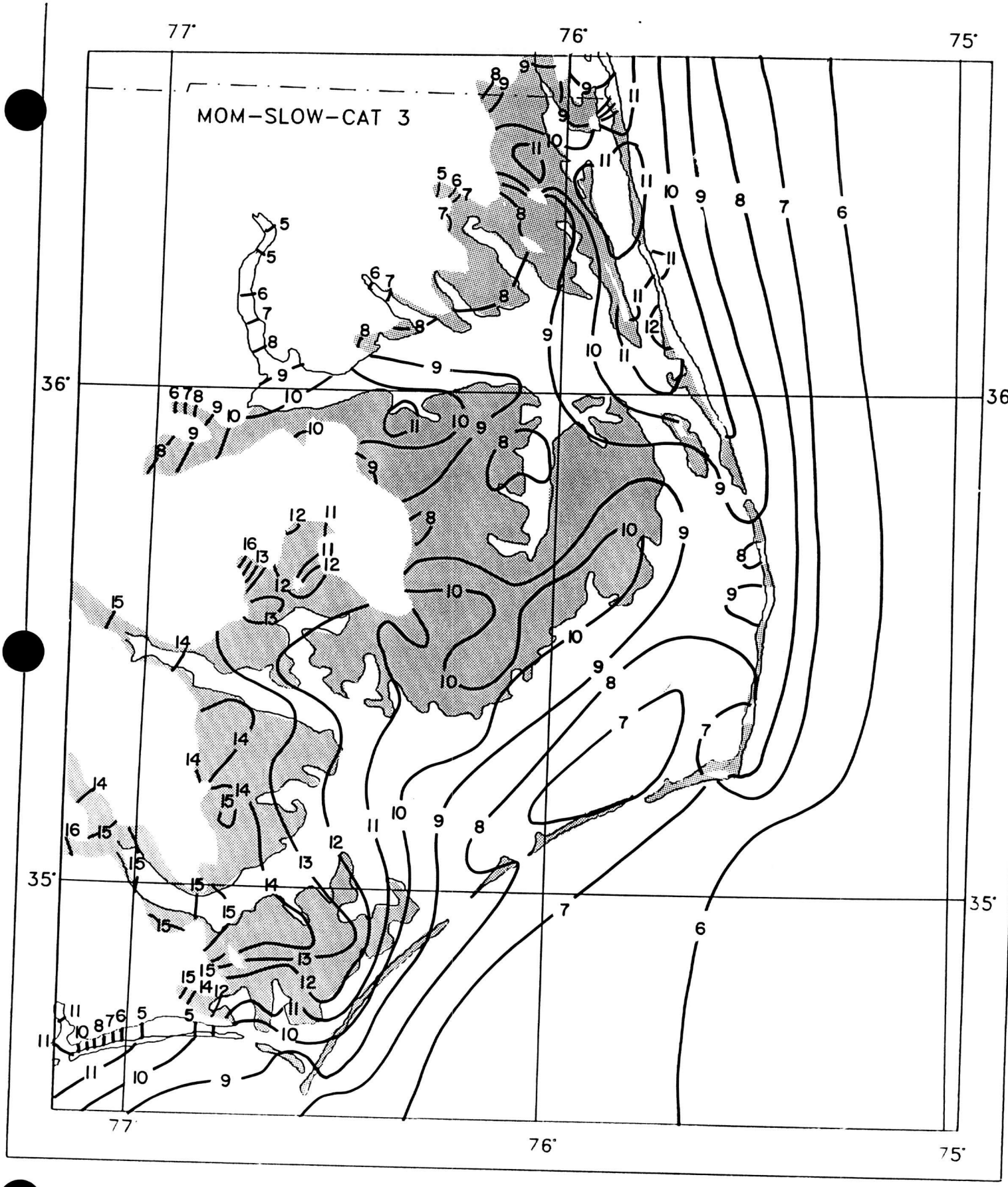

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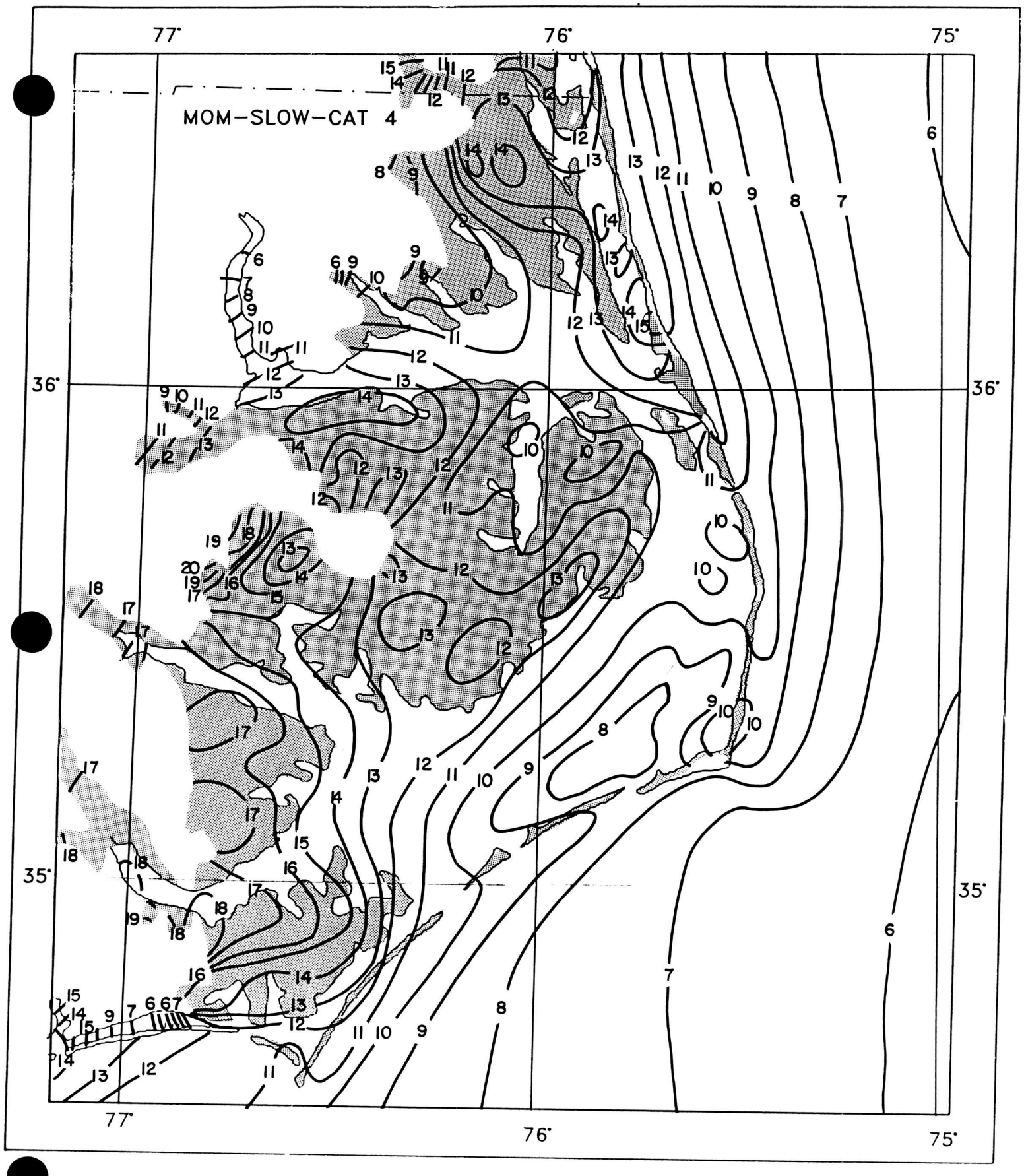

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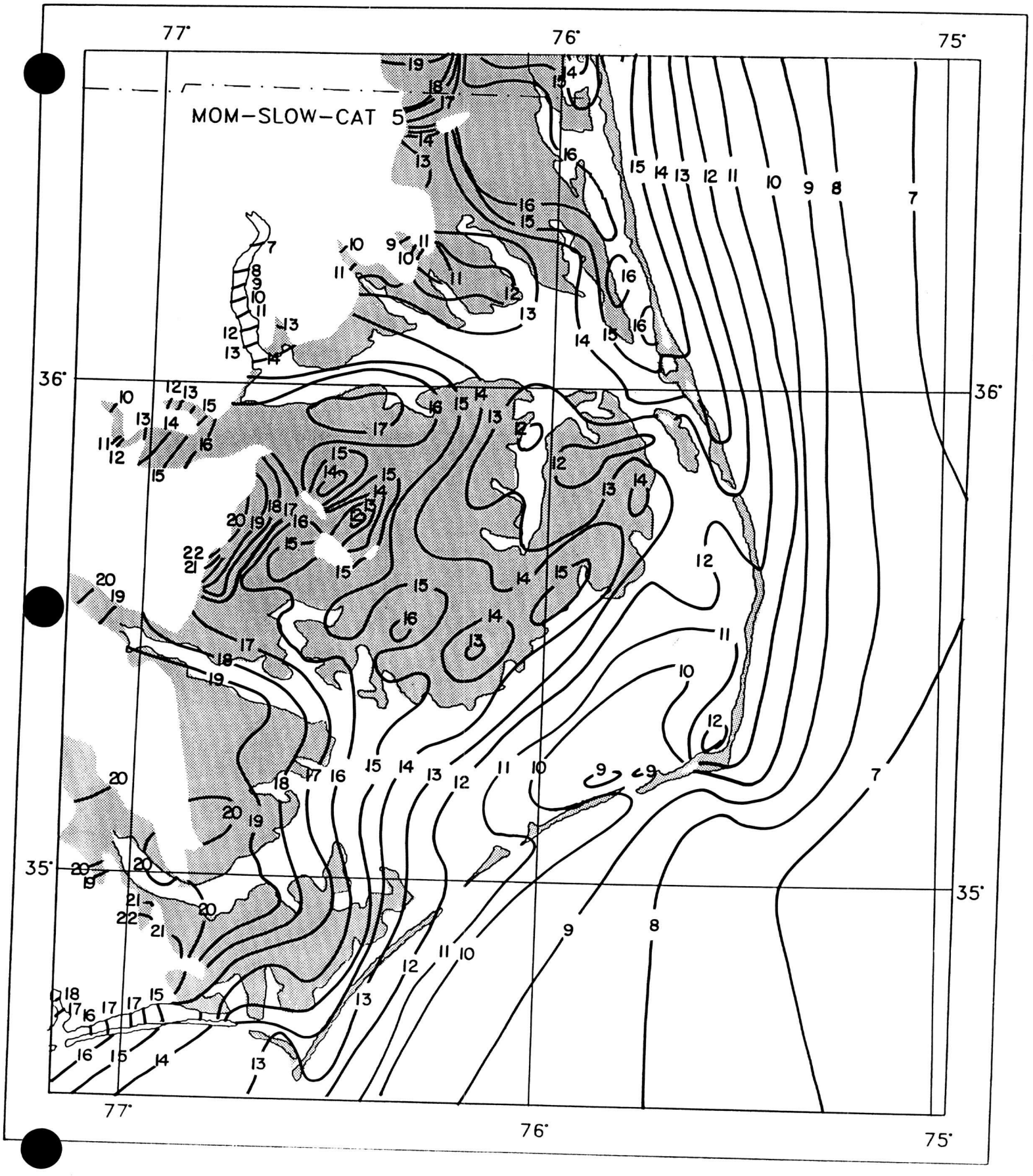

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35°

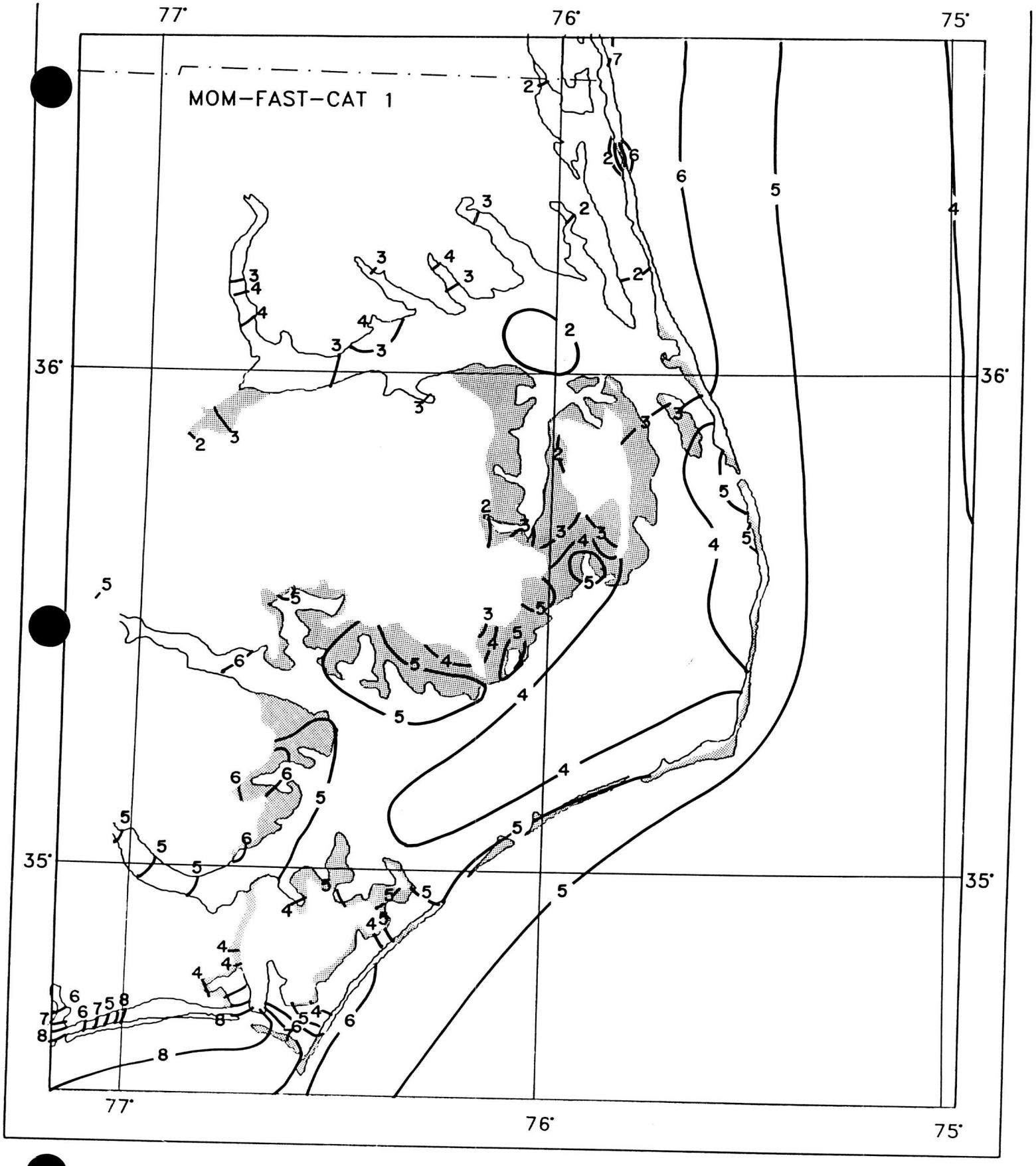

MOM-SLOW-CAT 1
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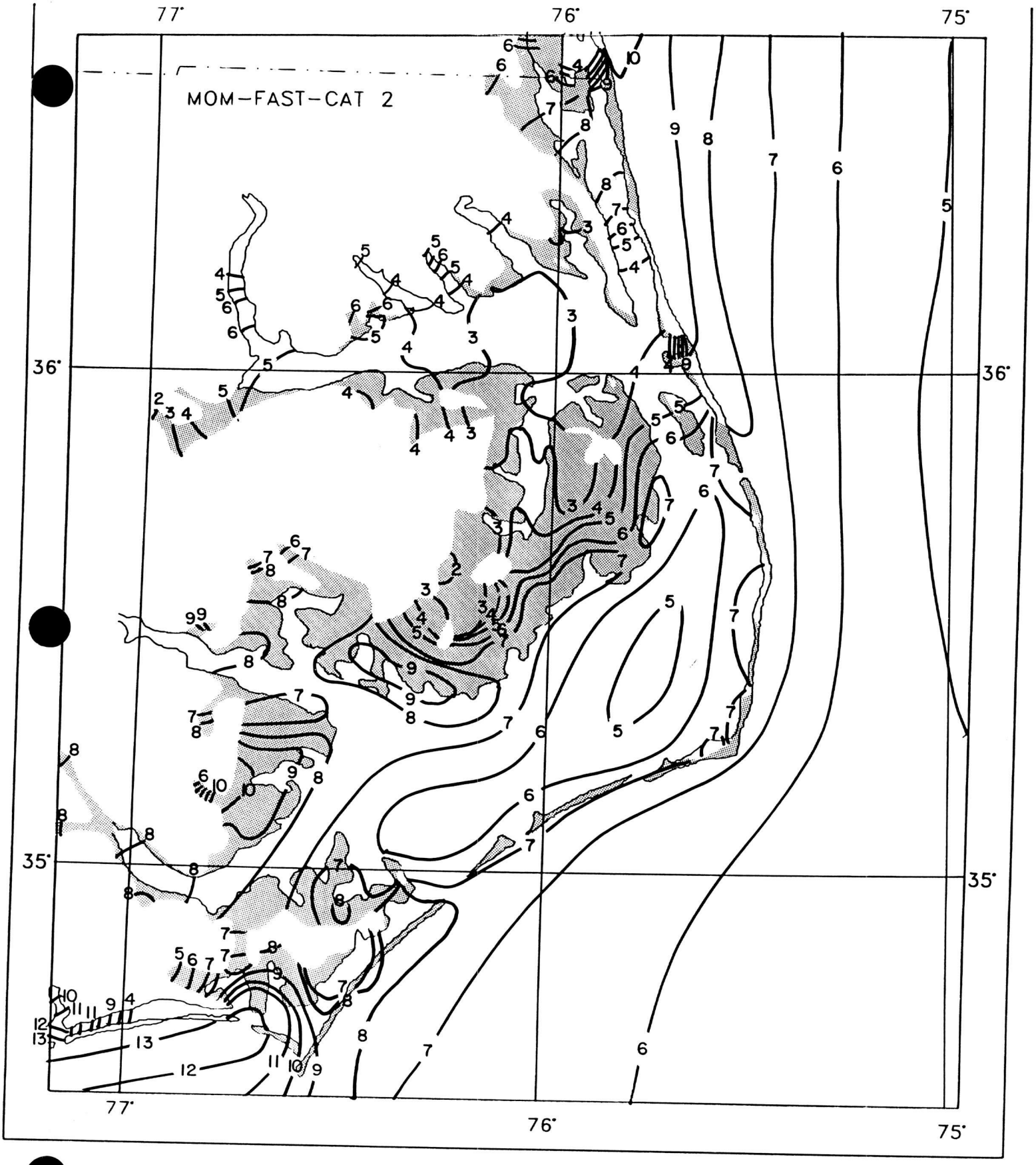

MOM-SLOW-CAT 2
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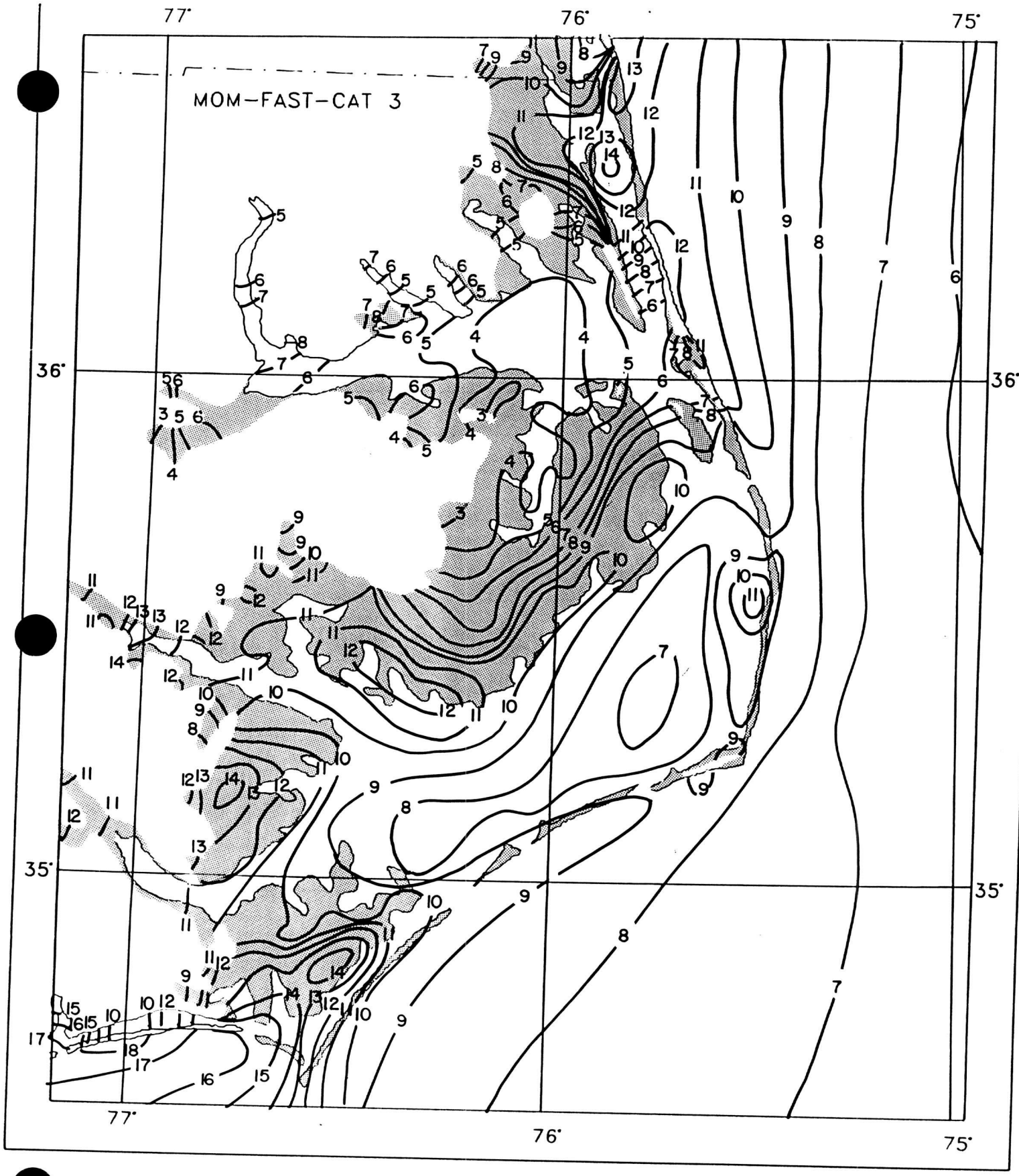

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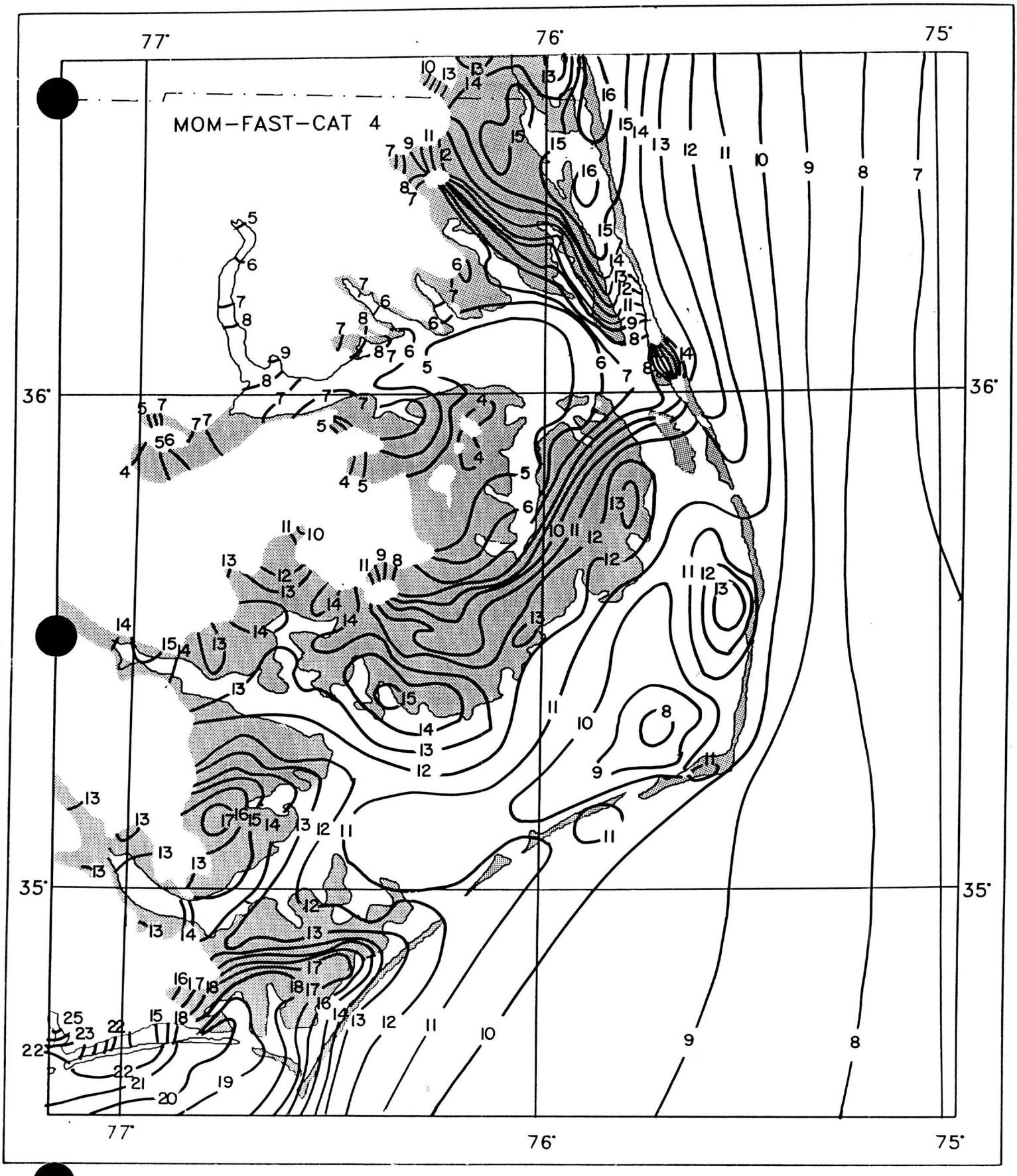

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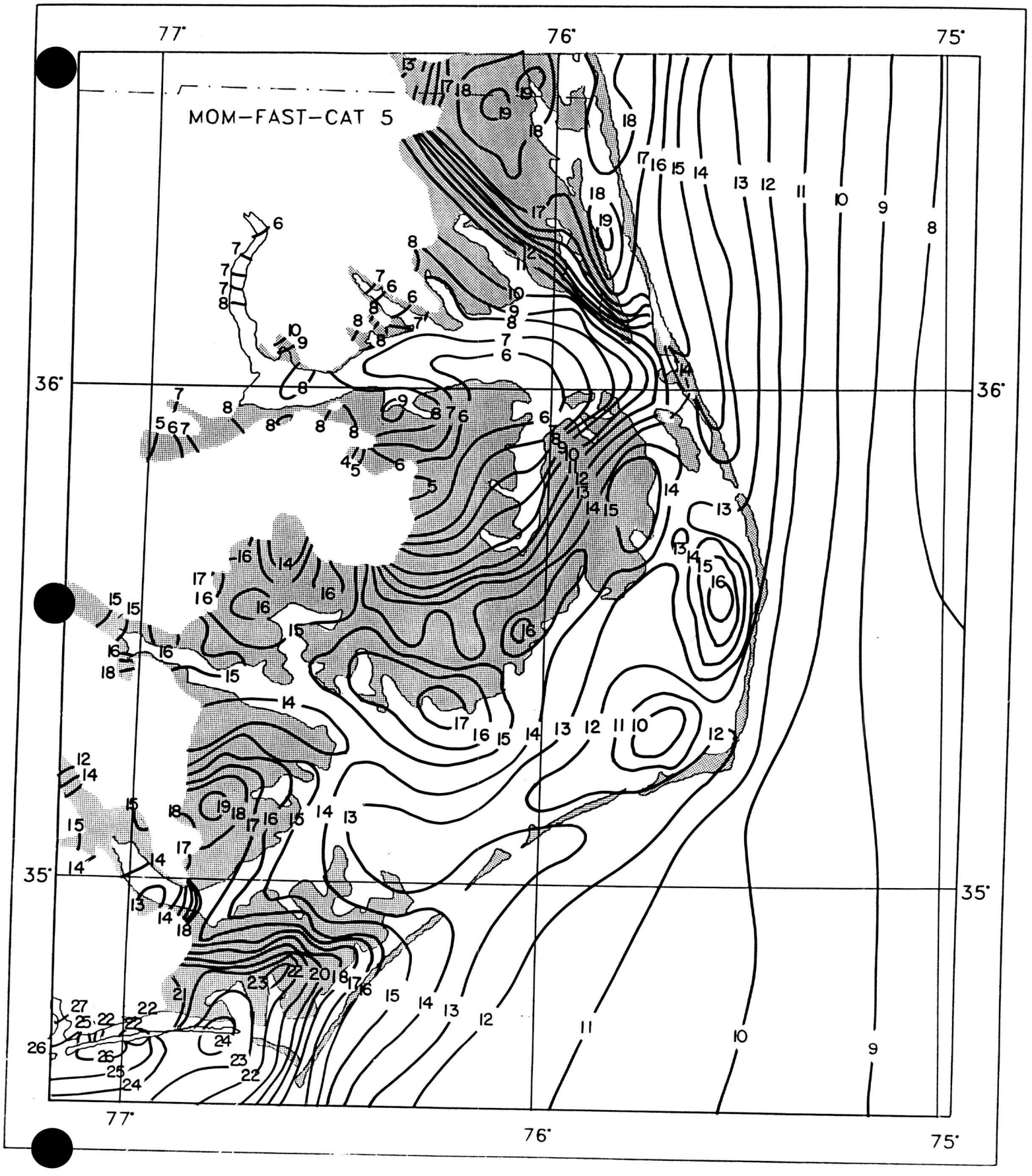

MOM-SLOW-CAT 5
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36°
35°


MOM–FAST–CAT 1
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76°
75°
36°
35°


MOM-FAST-CAT 2
77°
76°
75°
36°
35°


MOM-FAST-CAT 3
77°
76°
75°
36°
35°


MOM-FAST-CAT 4
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36°
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MOM-FAST-CAT 5
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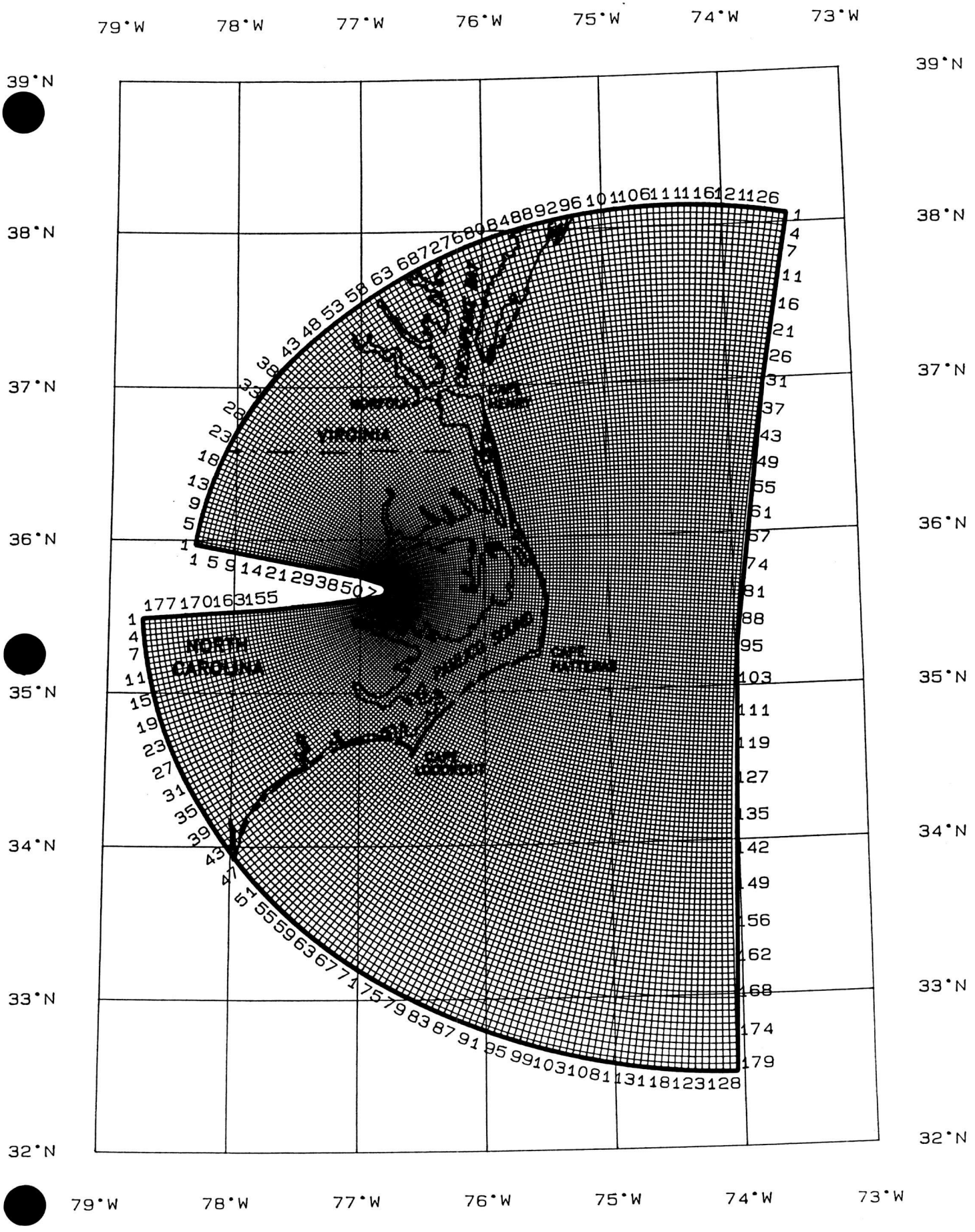

79°W
78°W
77°W
76°W
75°W
74°W
73°W
39°N
38°N
37°N
36°N
35°N
34°N
33°N
32°N
VIRGINIA
NORTH CAROLINA
CAPE HATTERAS
CAPE LOOKOUT

FIGURE 1.

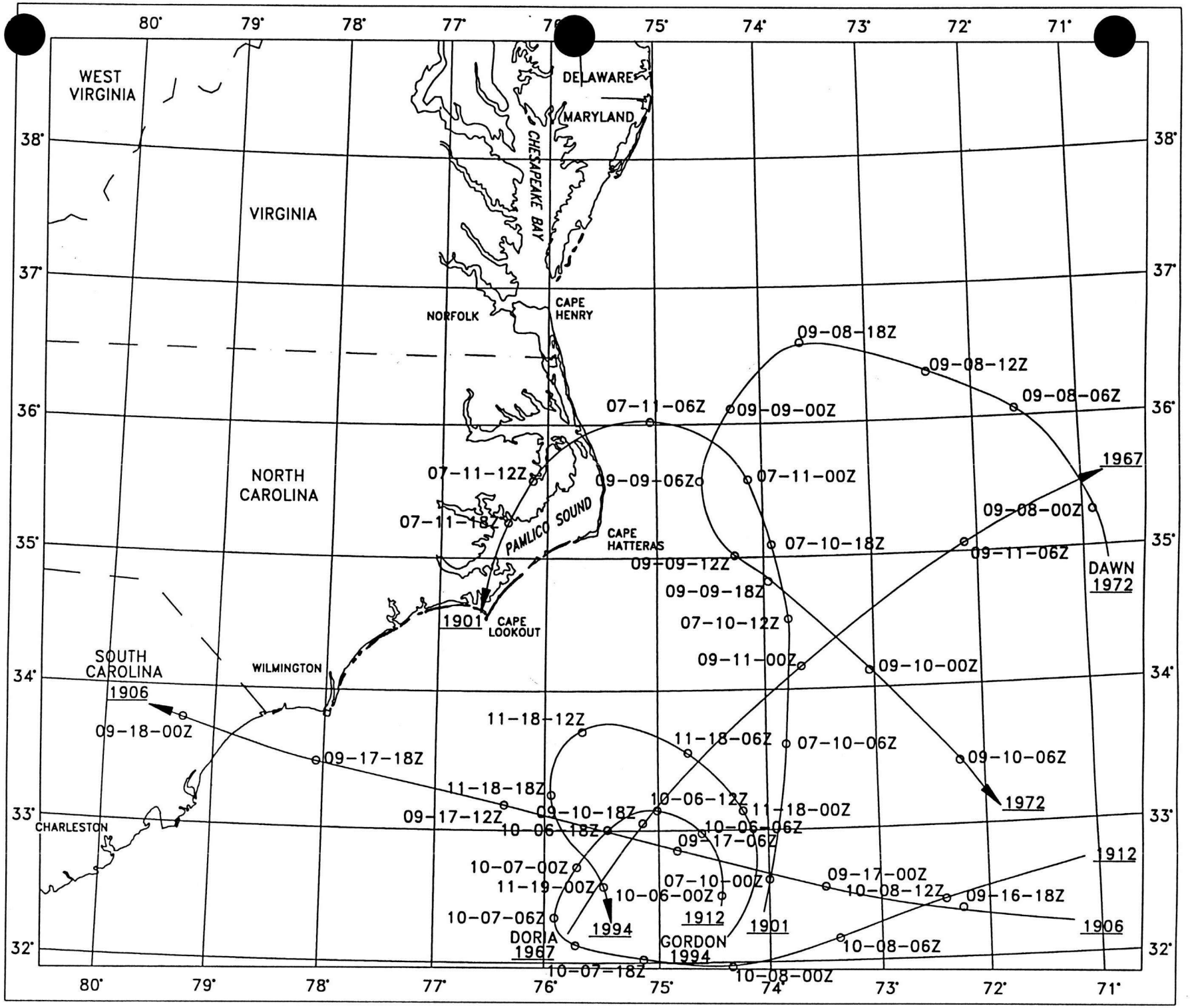

WEST VIRGINIA
DELAWARE
MARYLAND
CHESAPEAKE BAY
VIRGINIA
NORFOLK
CAPE HENRY
NORTH CAROLINA
PAMLICO SOUND
CAPE HATTERAS
CAPE LOOKOUT
SOUTH CAROLINA
WILMINGTON
CHARLESTON
80° 79° 78° 77° 76° 75° 74° 73° 72° 71°
38° 37° 36° 35° 34° 33° 32°
09-08-18Z
09-08-12Z
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1967
07-11-12Z
09-09-06Z
07-11-00Z
09-08-00Z
07-11-18Z
07-10-18Z
09-11-06Z
09-09-12Z
DAWN
1972
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1901
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1912
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09-17-00Z
11-19-00Z
07-10-00Z
10-08-12Z
10-06-00Z
09-16-18Z
10-07-06Z
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1912
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1906
DORIA
1967
GORDON
1994
10-08-06Z
10-07-18Z
10-08-00Z

FIGURE 2.

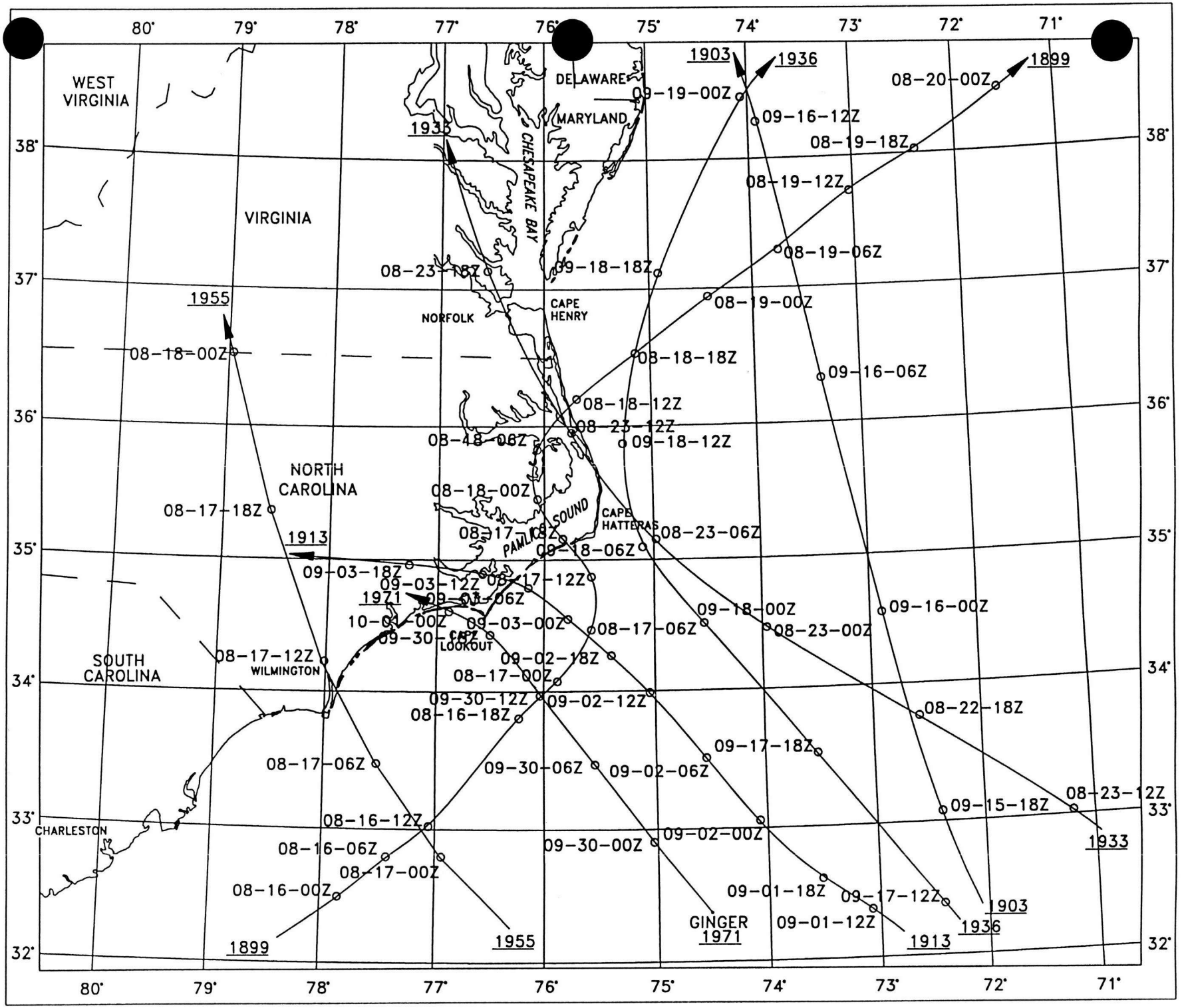

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NORTH CAROLINA
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DELAWARE
MARYLAND
CHESAPEAKE BAY
NORFOLK
CAPE HENRY
CAPE HATTERAS
PAMLICO SOUND
LOOKOUT
WILMINGTON
CHARLESTON
GINGER
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1935
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1971
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09-19-00Z
09-16-12Z
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FIGURE 3.

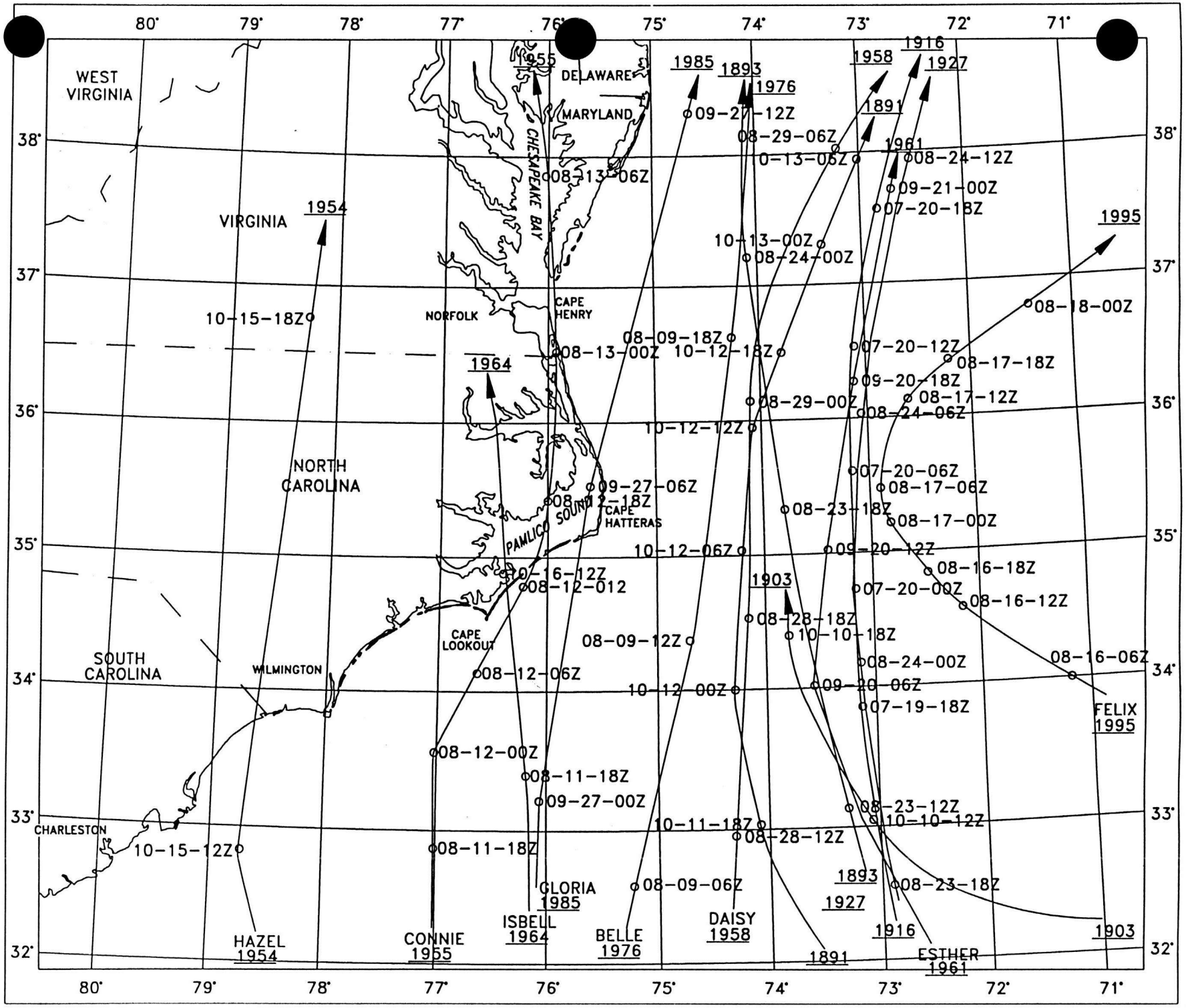

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CAPE HENRY
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PAMLICO SOUND
CAPE LOOKOUT
WILMINGTON
CHARLESTON
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HAZEL 1954
CONNIE 1955
ISBELL 1964
GLORIA 1985
BELLE 1976
DAISY 1958
ESTHER 1961
FELIX 1995
09-27-12Z
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FIGURE 4.

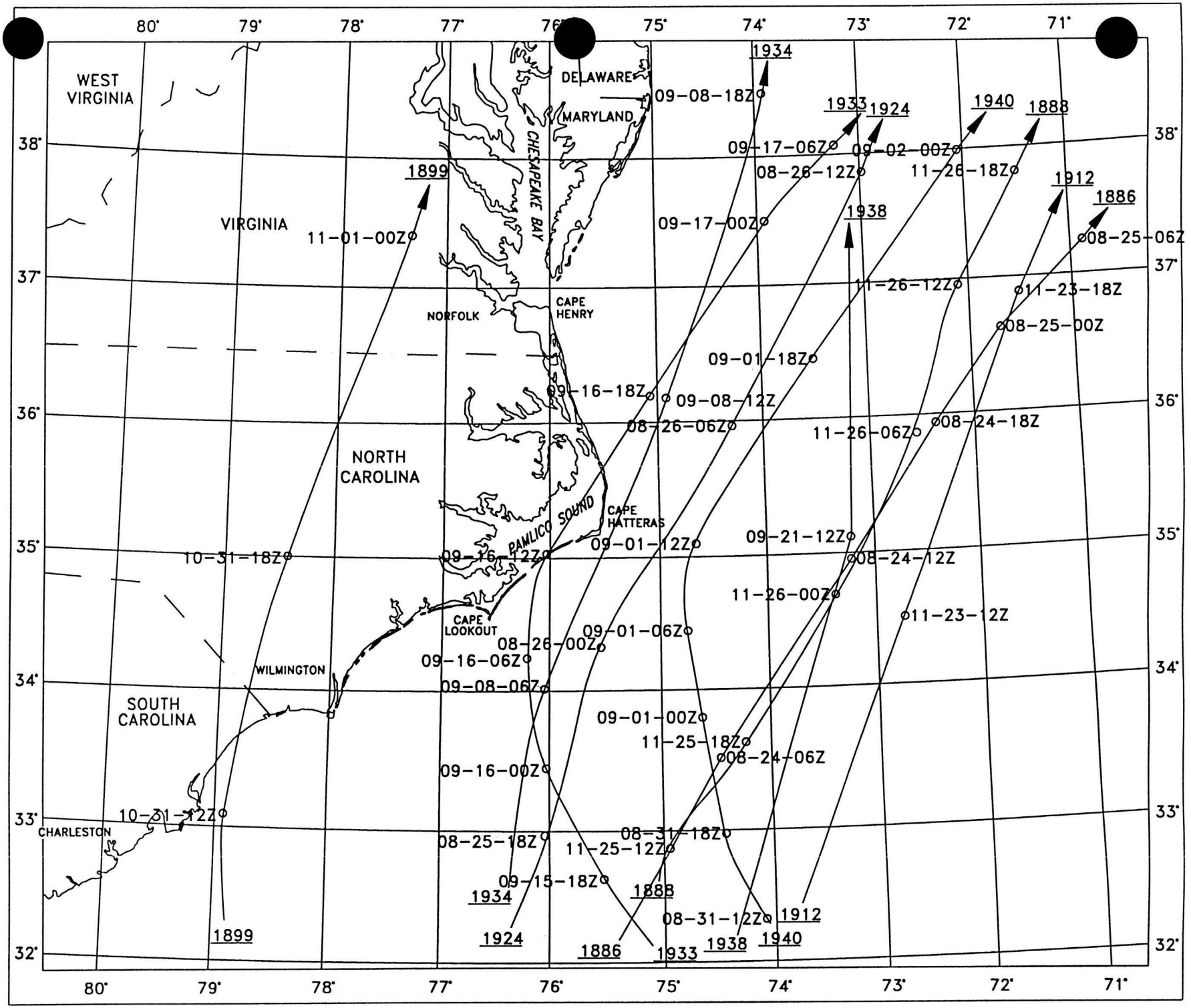

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CHARLESTON
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1940
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09-17-06Z
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1912
1886
1938
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FIGURE 5.

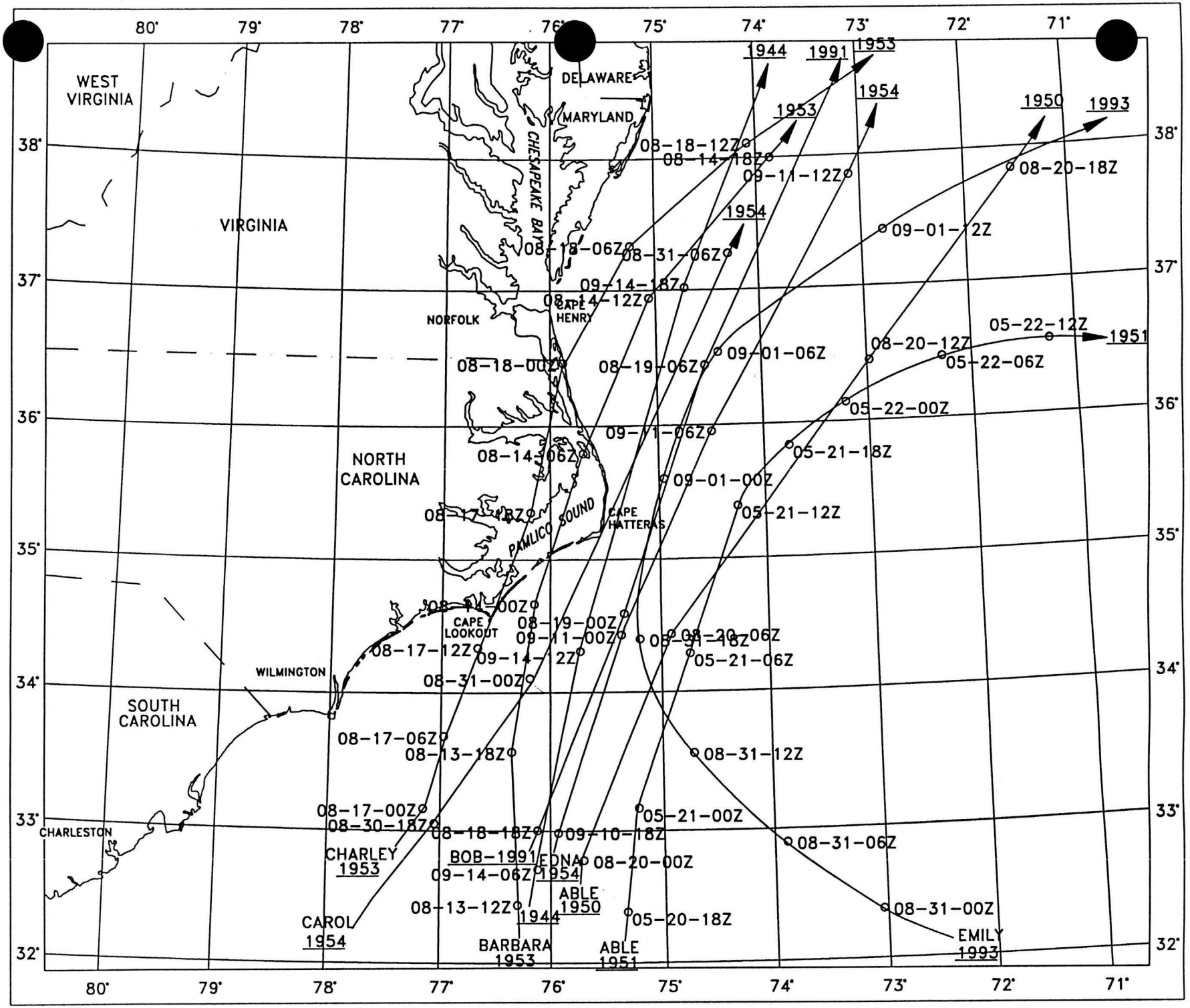

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CAPE HATTERAS
PAMLICO SOUND
CAPE LOOKOUT
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1993
1954
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CHARLEY 1953
BOB-1991
EDNA 1954
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BARBARA 1953
ABLE 1951
EMILY 1993

FIGURE 6.

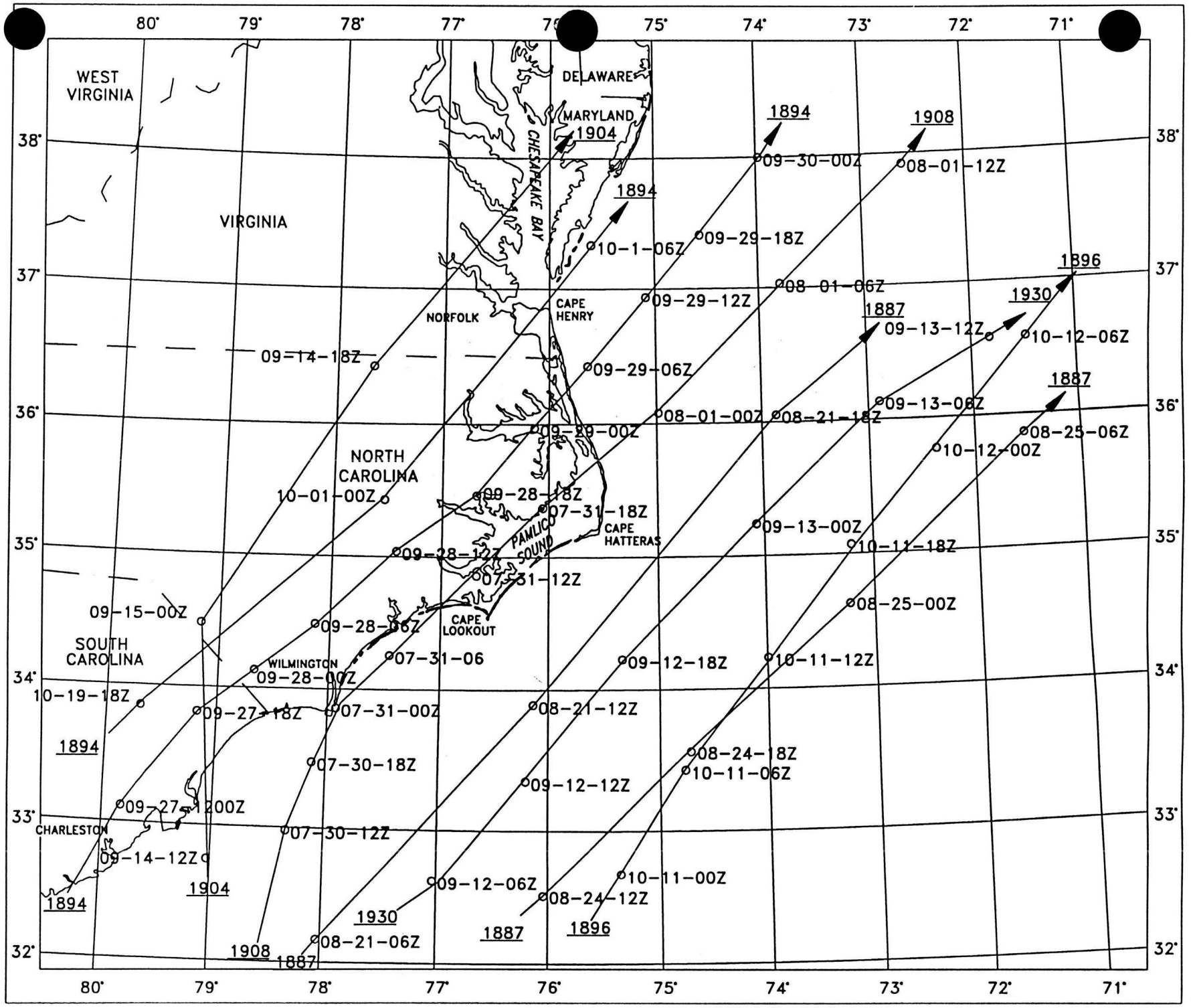

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1930
1887
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NORFOLK
CAPE HENRY
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CAPE HATTERAS
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CAPE LOOKOUT
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FIGURE 7.

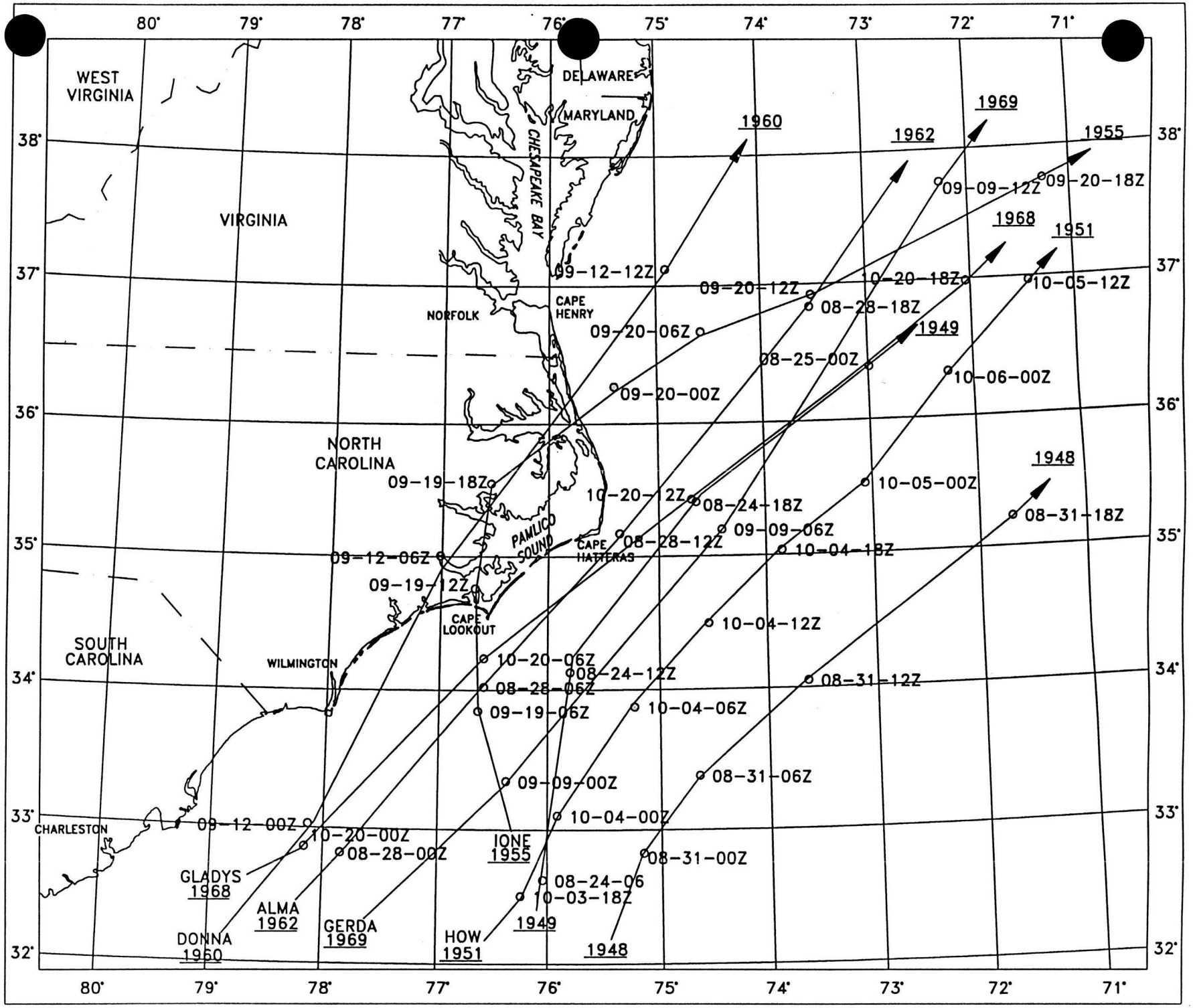

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NORFOLK
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PAMLICO SOUND
CAPE HATTERAS
CAPE LOOKOUT
WILMINGTON
CHARLESTON
1960
1962
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1968
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09-09-12Z
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10-03-18Z
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ALMA 1962
GERDA 1969
DONNA 1960
IONE 1955
HOW 1951

FIGURE 8.

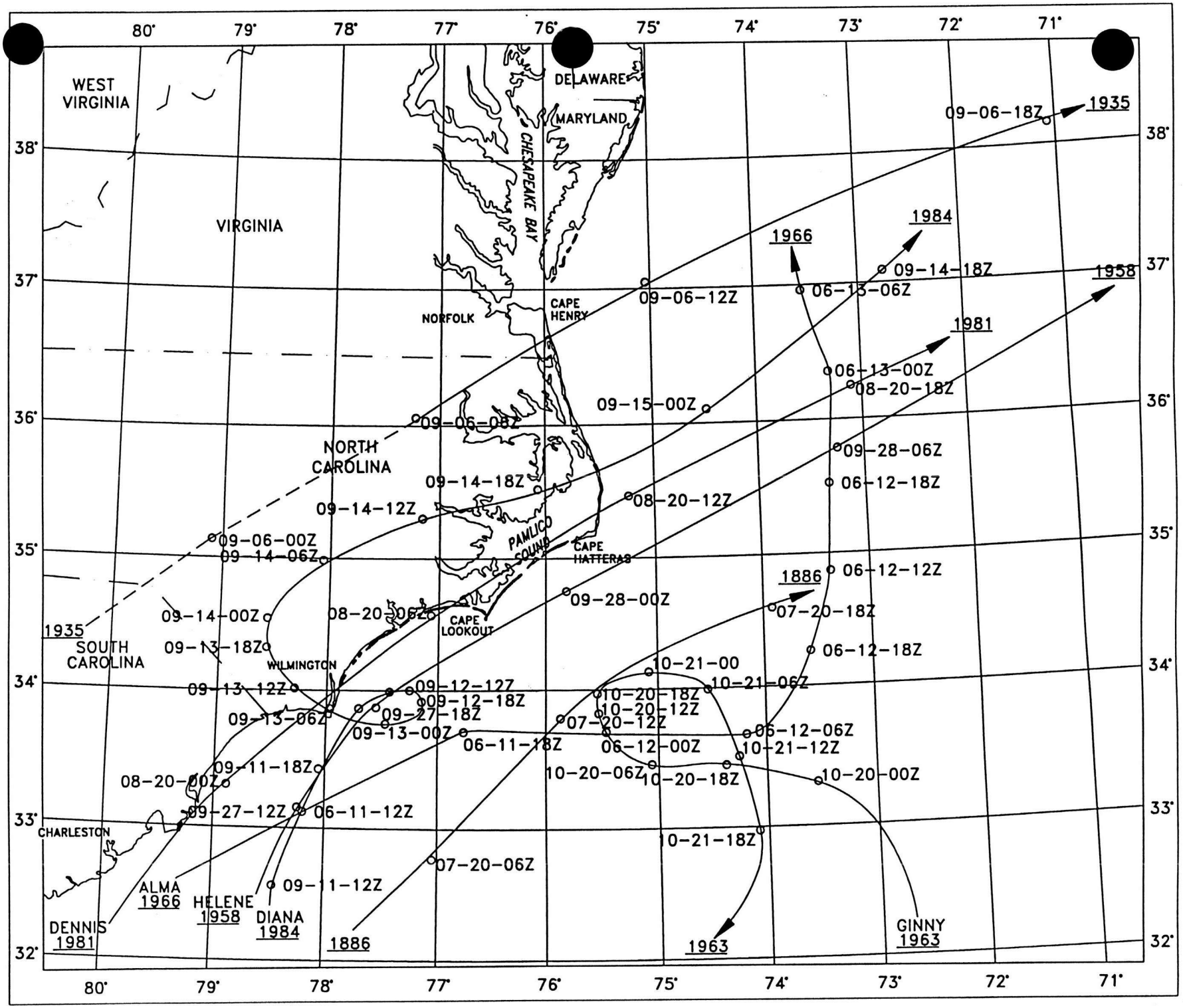

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PAMLICO SOUND
CAPE HATTERAS
CAPE LOOKOUT
SOUTH CAROLINA
WILMINGTON
CHARLESTON
1935
09-06-18Z
1984
1966
09-14-18Z
06-13-06Z
1958
09-06-12Z
1981
06-13-00Z
08-20-18Z
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09-06-06Z
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09-14-18Z
06-12-18Z
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08-20-12Z
09-06-00Z
09-14-06Z
1886
06-12-12Z
09-28-00Z
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09-14-00Z
08-20-06Z
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10-20-00Z
08-20-00Z
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ALMA 1966
HELENE 1958
DIANA 1984
DENNIS 1981
1886
1963
GINNY 1963

FIGURE 9.

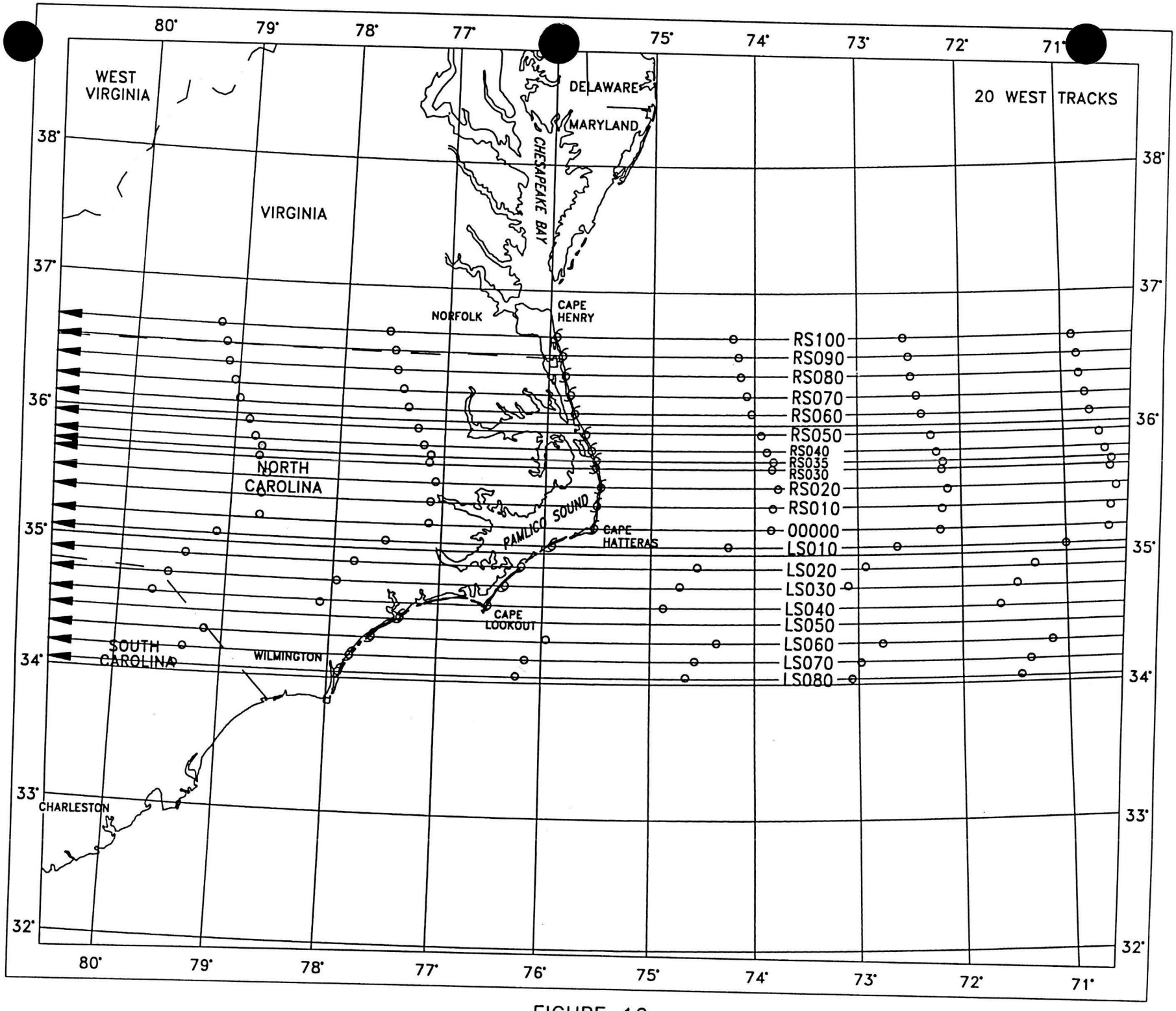

WEST VIRGINIA
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CHESAPEAKE BAY
NORFOLK
CAPE HENRY
CAPE HATTERAS
PAMLICO SOUND
CAPE LOOKOUT
WILMINGTON
CHARLESTON
20 WEST TRACKS
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FIGURE 10.

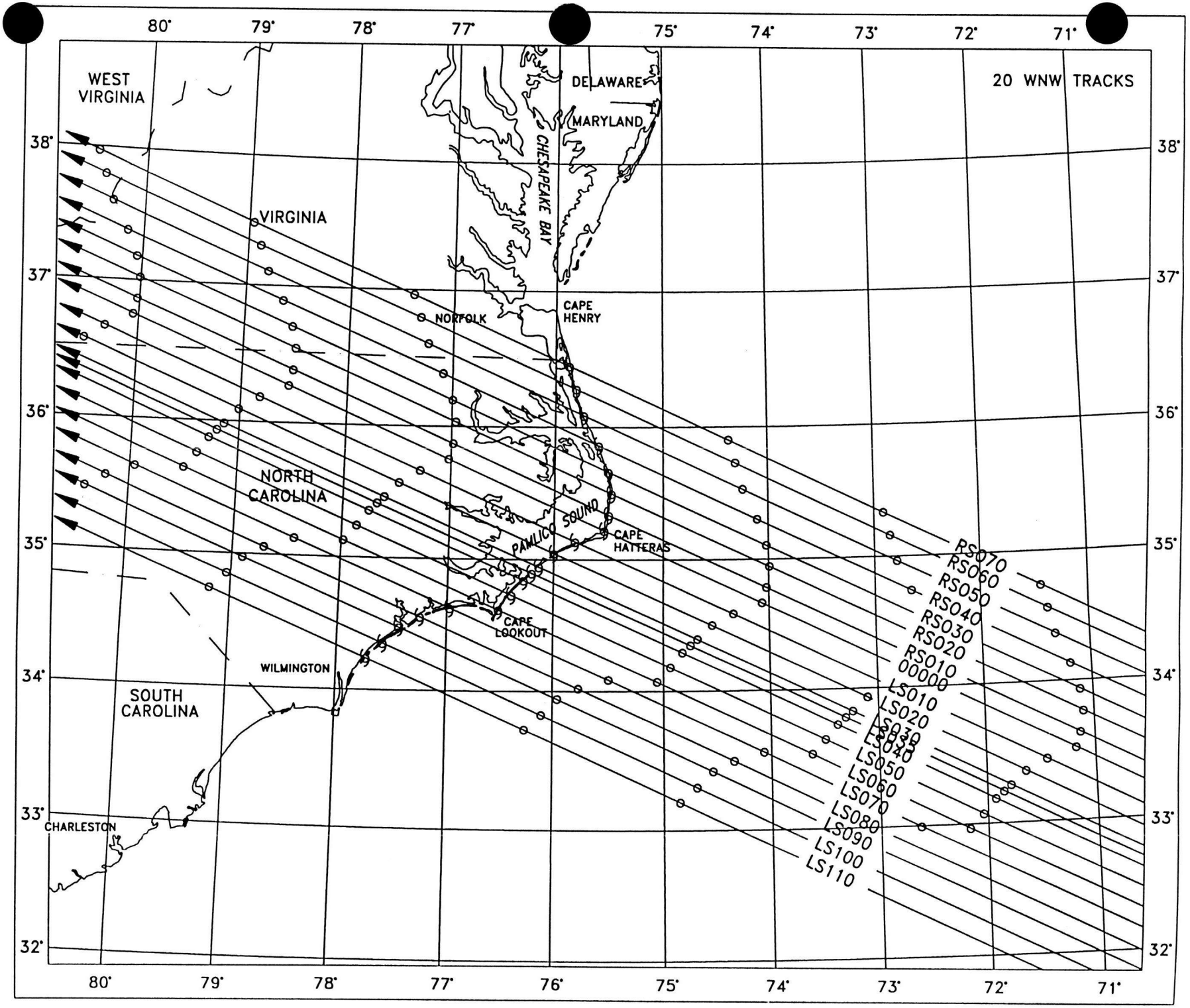

20 WNW TRACKS
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CAPE HATTERAS
CAPE LOOKOUT
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FIGURE 11

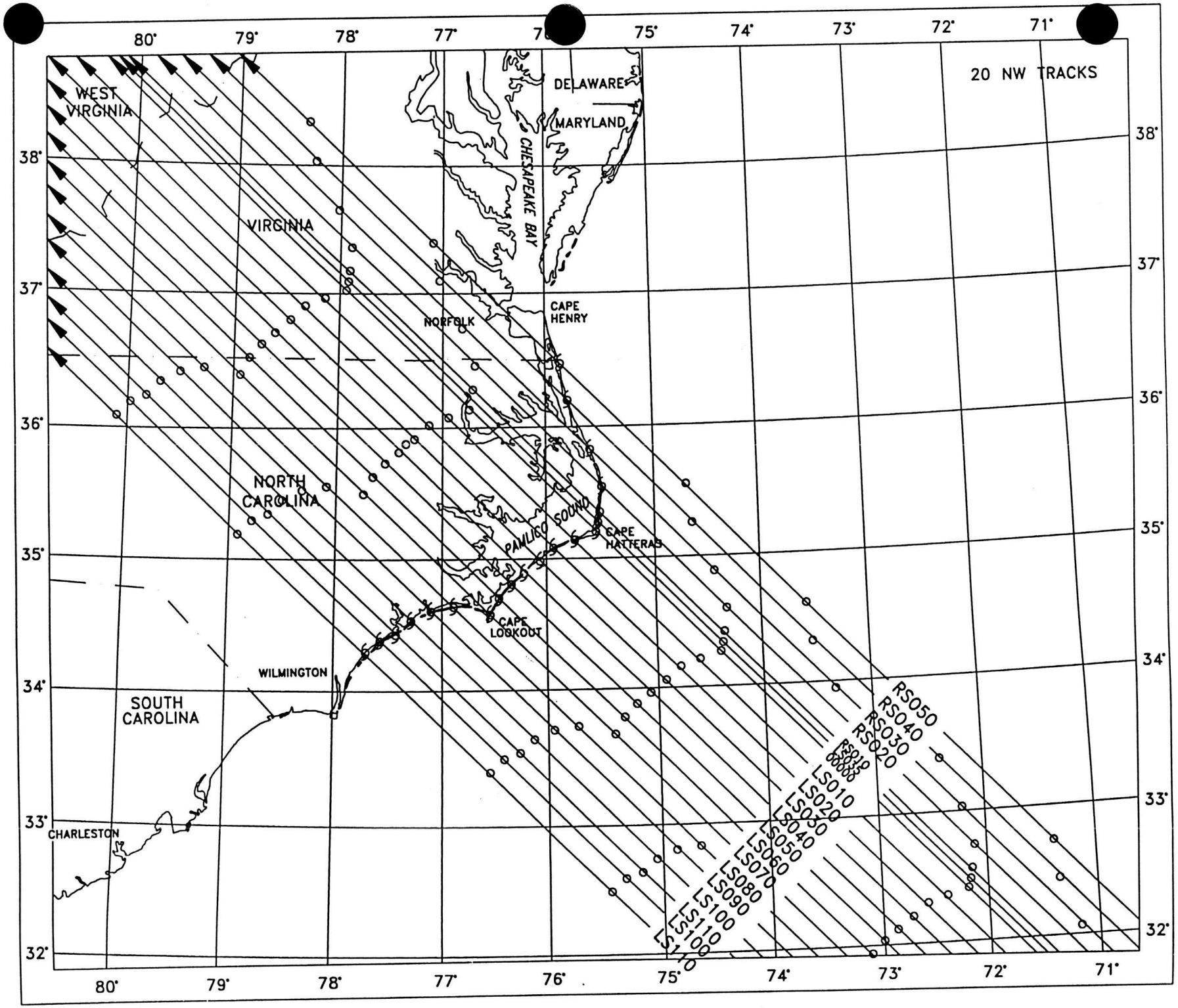

20 NW TRACKS
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SOUTH CAROLINA
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FIGURE 12

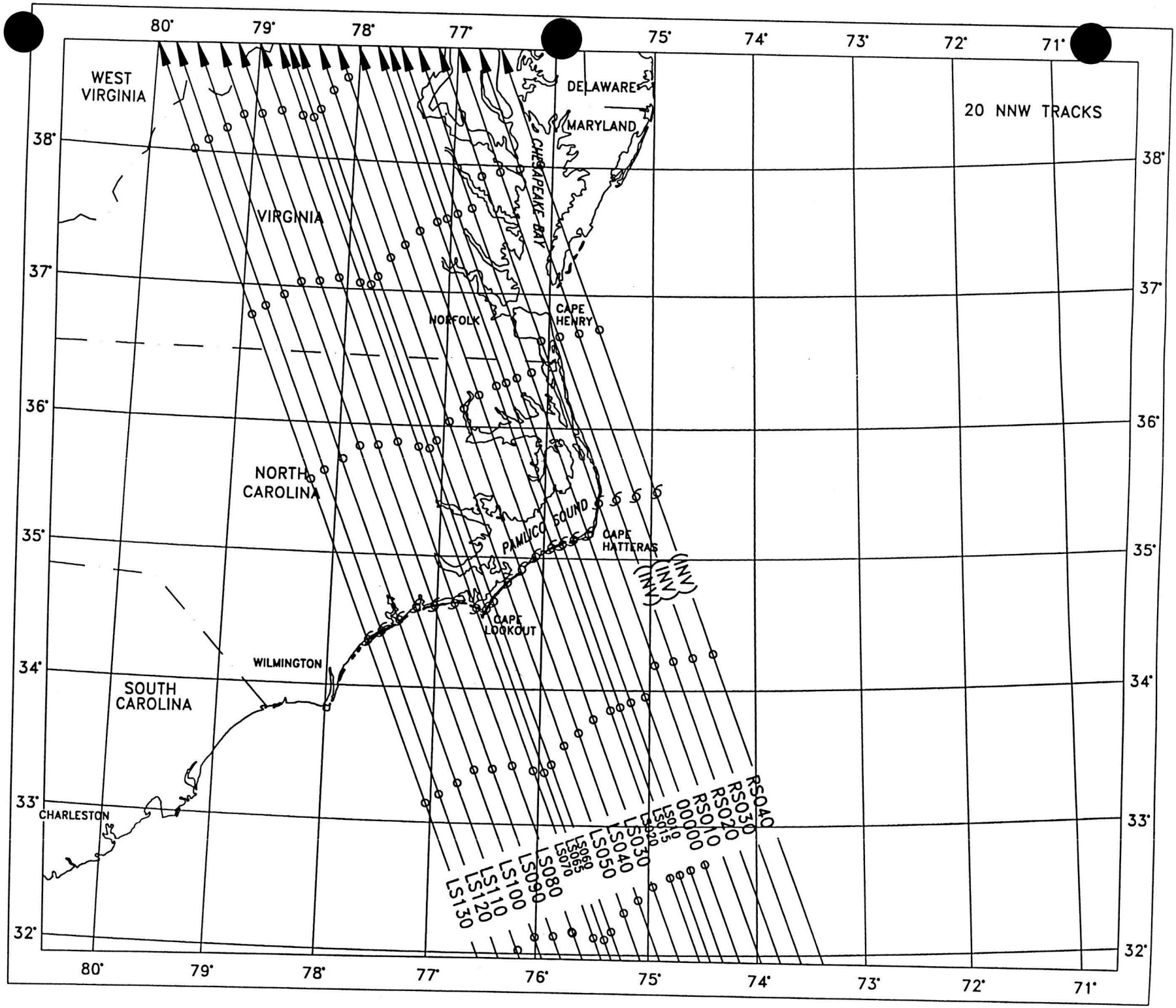

20 NNW TRACKS
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PAMLICO SOUND
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FIGURE 13.

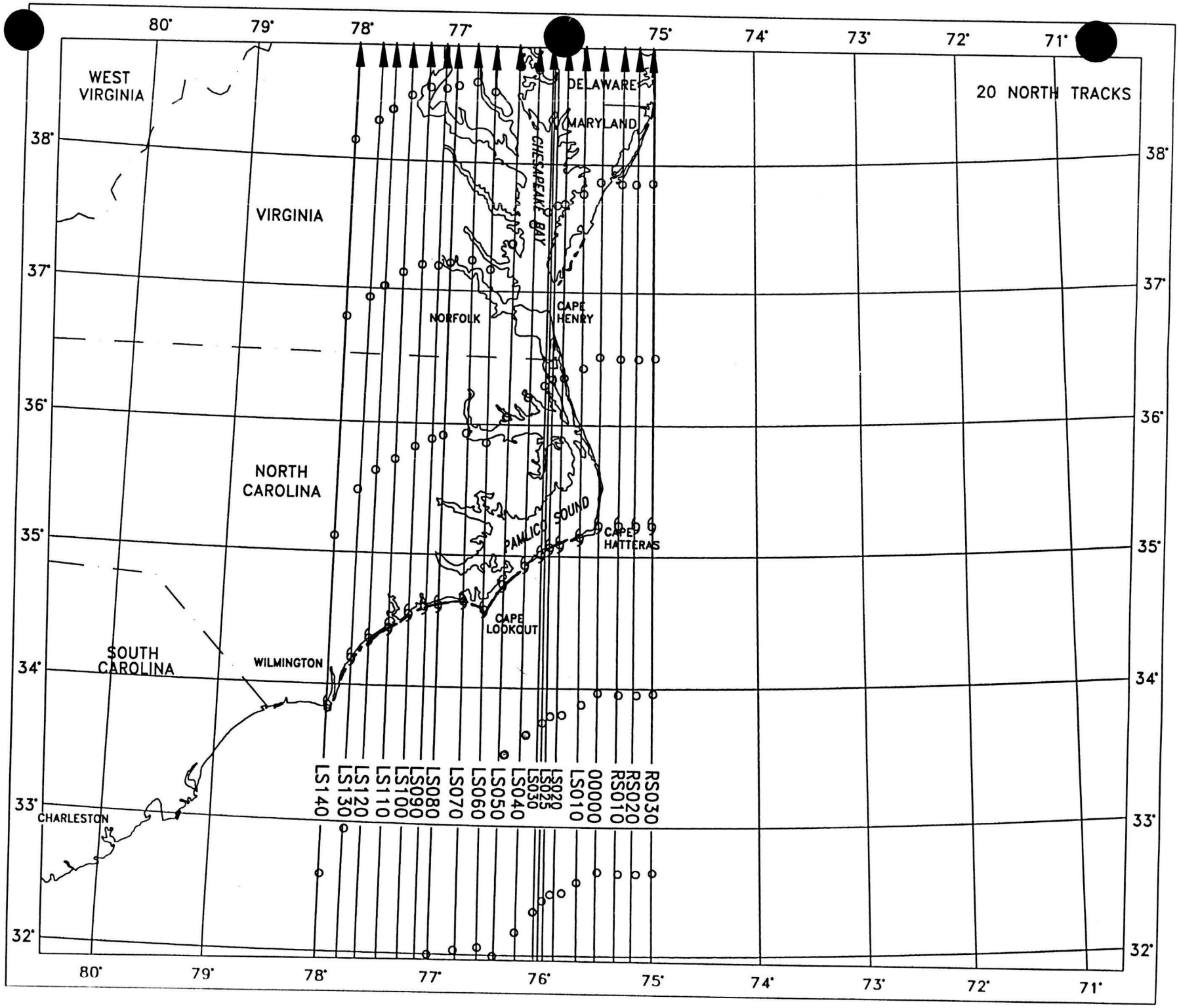

20 NORTH TRACKS
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CAPE HENRY
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CAPE LOOKOUT
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FIGURE 14.

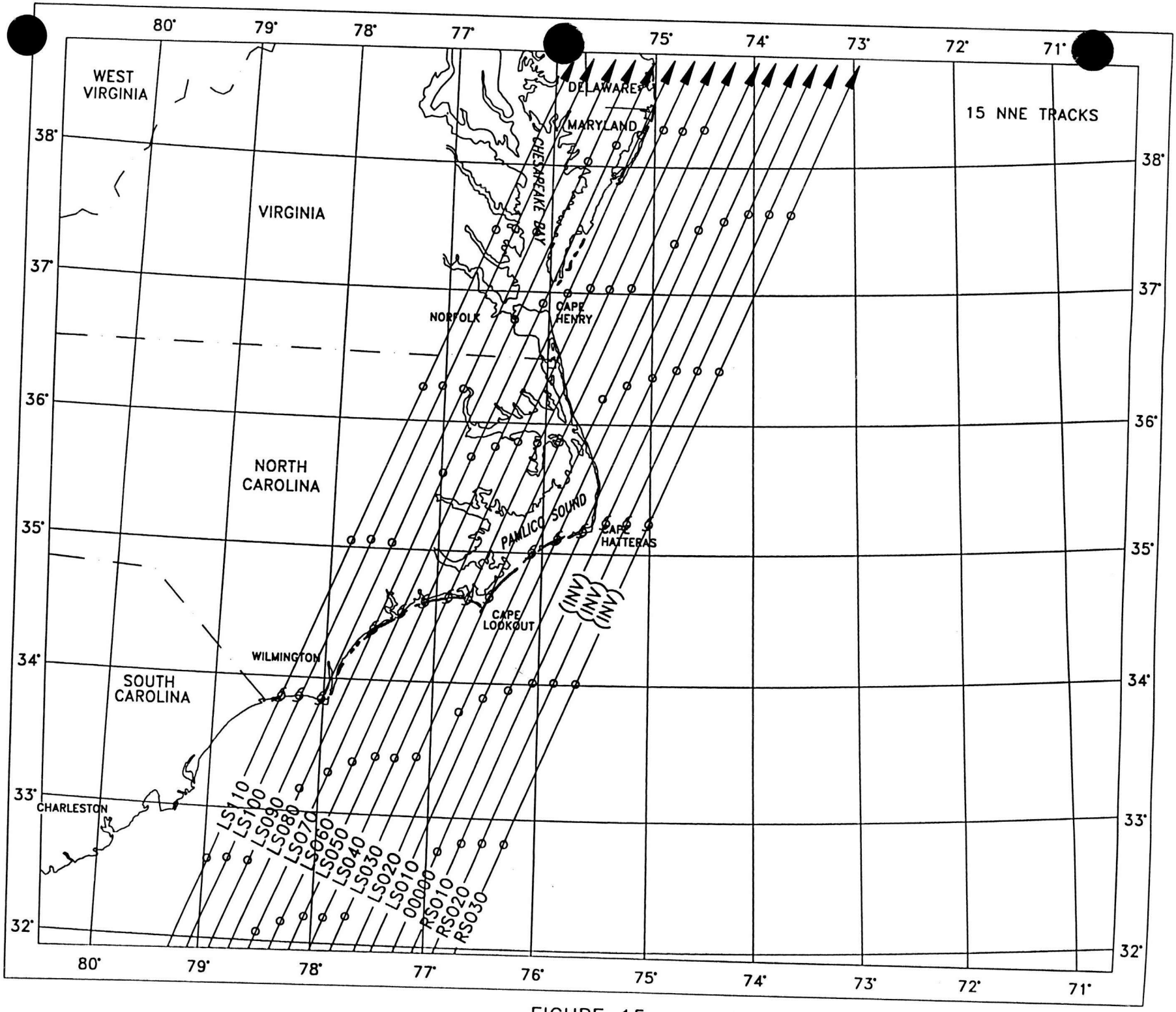

15 NNE TRACKS
WEST VIRGINIA
VIRGINIA
NORTH CAROLINA
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CHESAPEAKE BAY
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CAPE HENRY
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FIGURE 15.

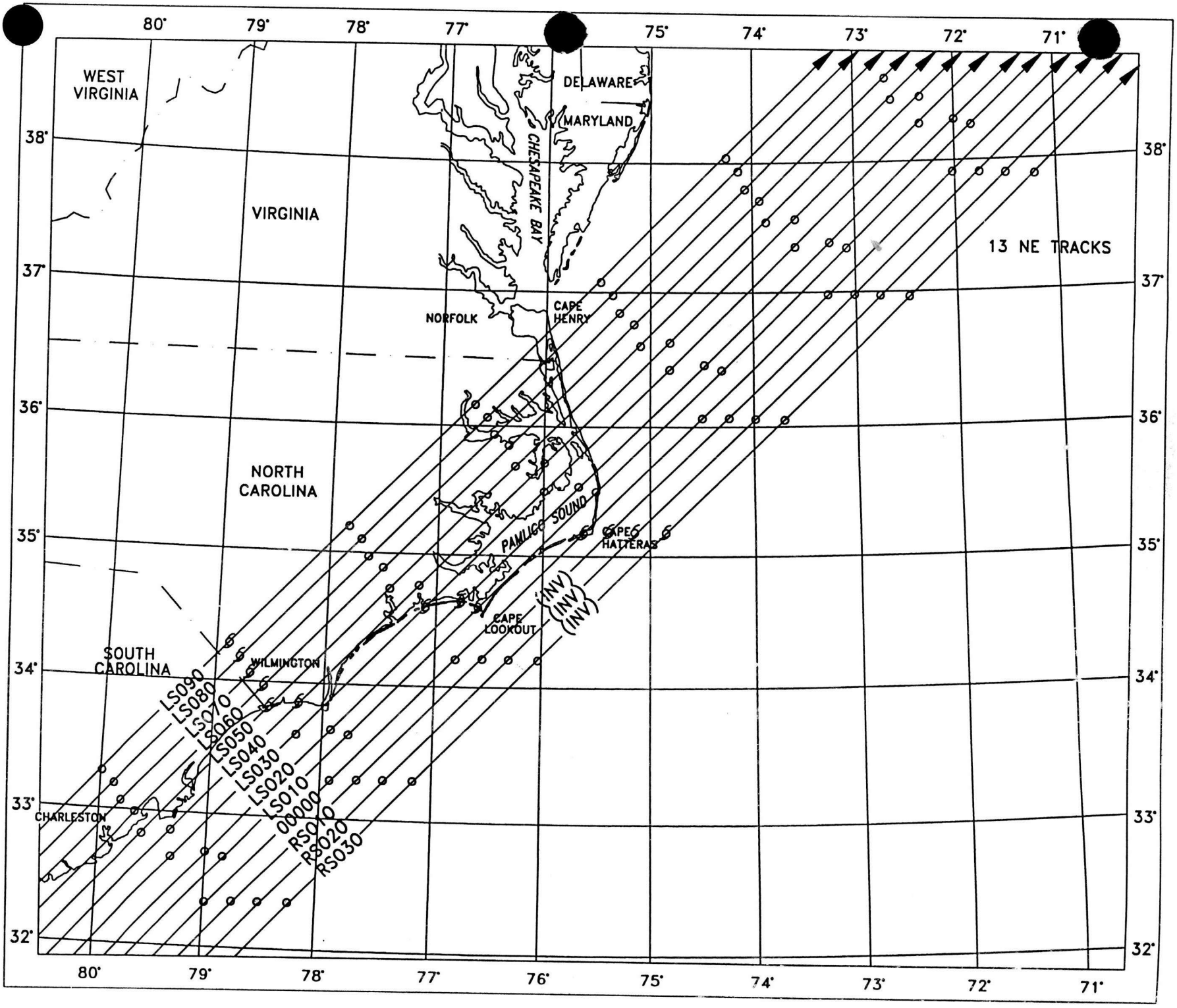

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CHESAPEAKE BAY
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FIGURE 16.