YEARLY VARIATIONS IN RUNOFF AND FREQUENCY OF DRY YEARS FOR THE CONTERMINOUS UNITED STATES, 1911—79

By W.B. Langbein and J.R. Slack

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Yearly Variations in Runoff and Frequency of Dry Years for the Conterminous United States, 1911-79

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ABSTRACT

This report presents gaging station data on variations in annual runoff over the conterminous United States and nearby Canada during the period 1911-79 in tabular and graphic (map) form. These data bring up to date and extend backward in time previous reports on streamflow stations by Harbeck and Langbein in 1949 which covered the period 1921-45 and that by Busby in 1963 which covered the period 1931-60. As depicted by Langbein and Slack in 1980, these data show that, contained within a rather large seemingly random or sporadic pattern, there appears to be a previously unnoticed degree of similarity in the occurrence of subnormal flows across the country. In each of three regions, viz., West, Center, and East, dry years were concentrated in two sequences, one centered in the 1930's and the second in the decade from the mid-50's to the mid-60's.

INTRODUCTION

The computer-based maps shown in figures 1-69 give the annual runoff as a fraction of normal (defined below) for each water year from 1911 through 1979. Streamflow records at 211 stream-gaging stations (table 1) were used to provide the data on those maps. To compile the records for this purpose, we began by using the stations used by Busby (1963, table 1) for the 1931-60 period. It was found that few of these records extended back to 1911 and that many stations were either discontinued after 1960 or had become disqualified for the purposes of this report because of excessive regulation or diversions. It was necessary to look for other records. This search for usable records to cover the annual maps to the same degree as previously made necessary the inclusion of records of streamflow that are altered to some degree by regulation or diversion - giving preference to those least so affected. Station records were classified as follows in this regard.

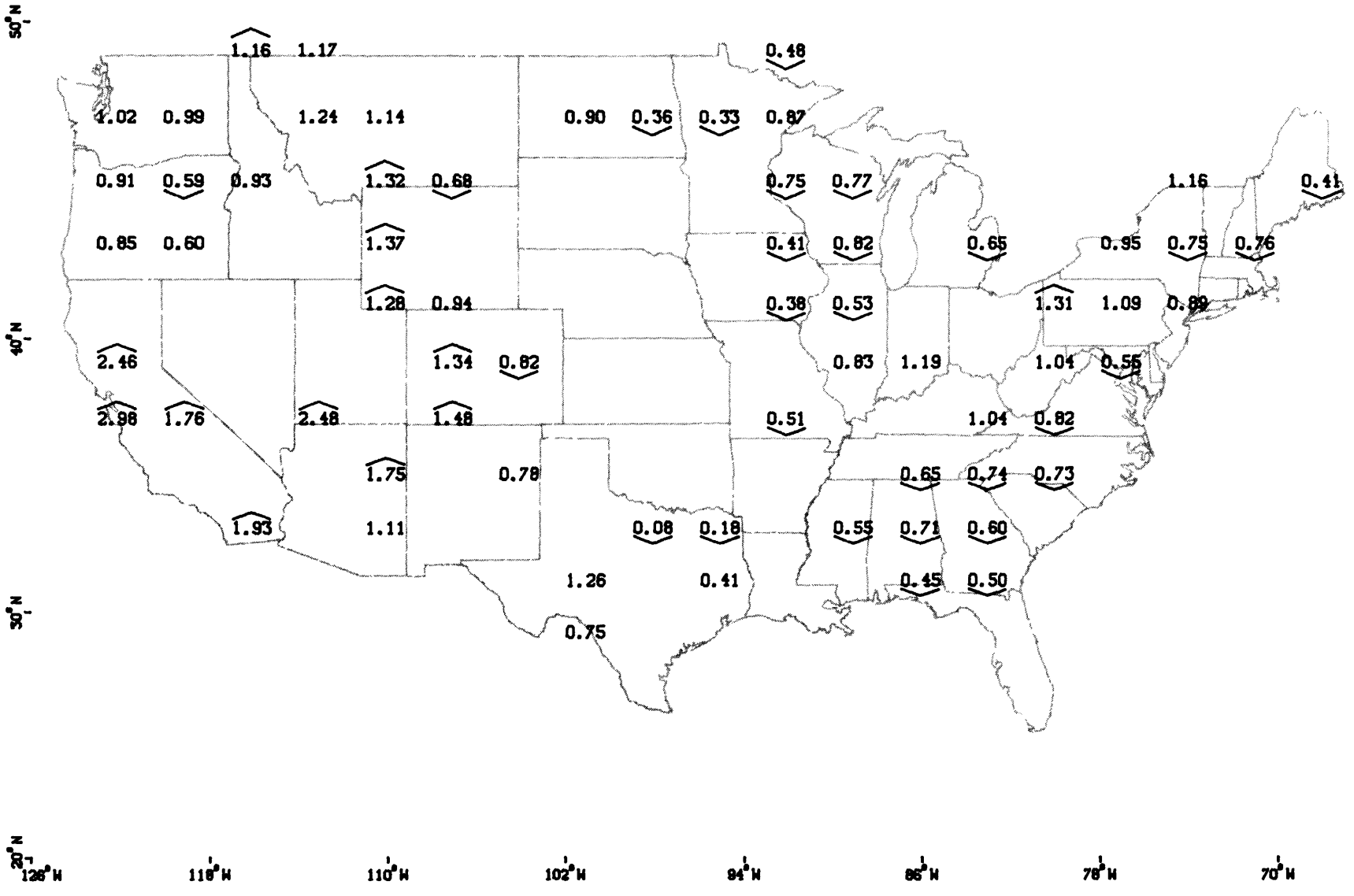
Class I - No reported regulation or diversion

Class II - Diversion less than ten percent of the mean flow and storage capacity less than ten percent of the mean annual runoff.

Class III - All others

Gaging-station records of Classes I and II were given priority; those of Class III were excluded except where needed to fill large areal gaps. Only 27 of such stations were included; all were in the central or western regions of the country. There was no drainage area criterion except that, where there was a multiple choice among stations otherwise acceptable, preference was given to those streams having drainage areas between 100 and 10,000 square

WATER YEAR 1911



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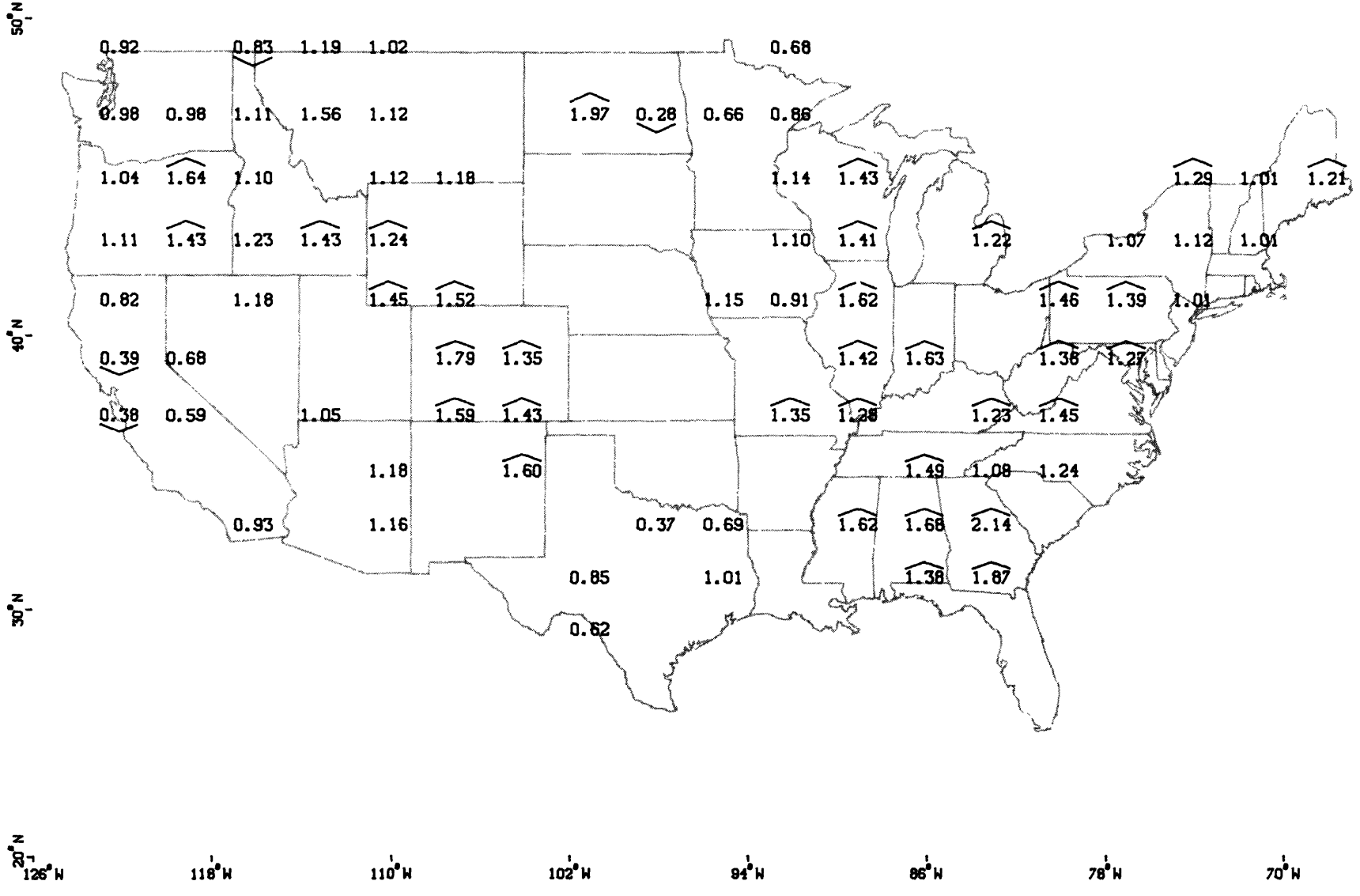

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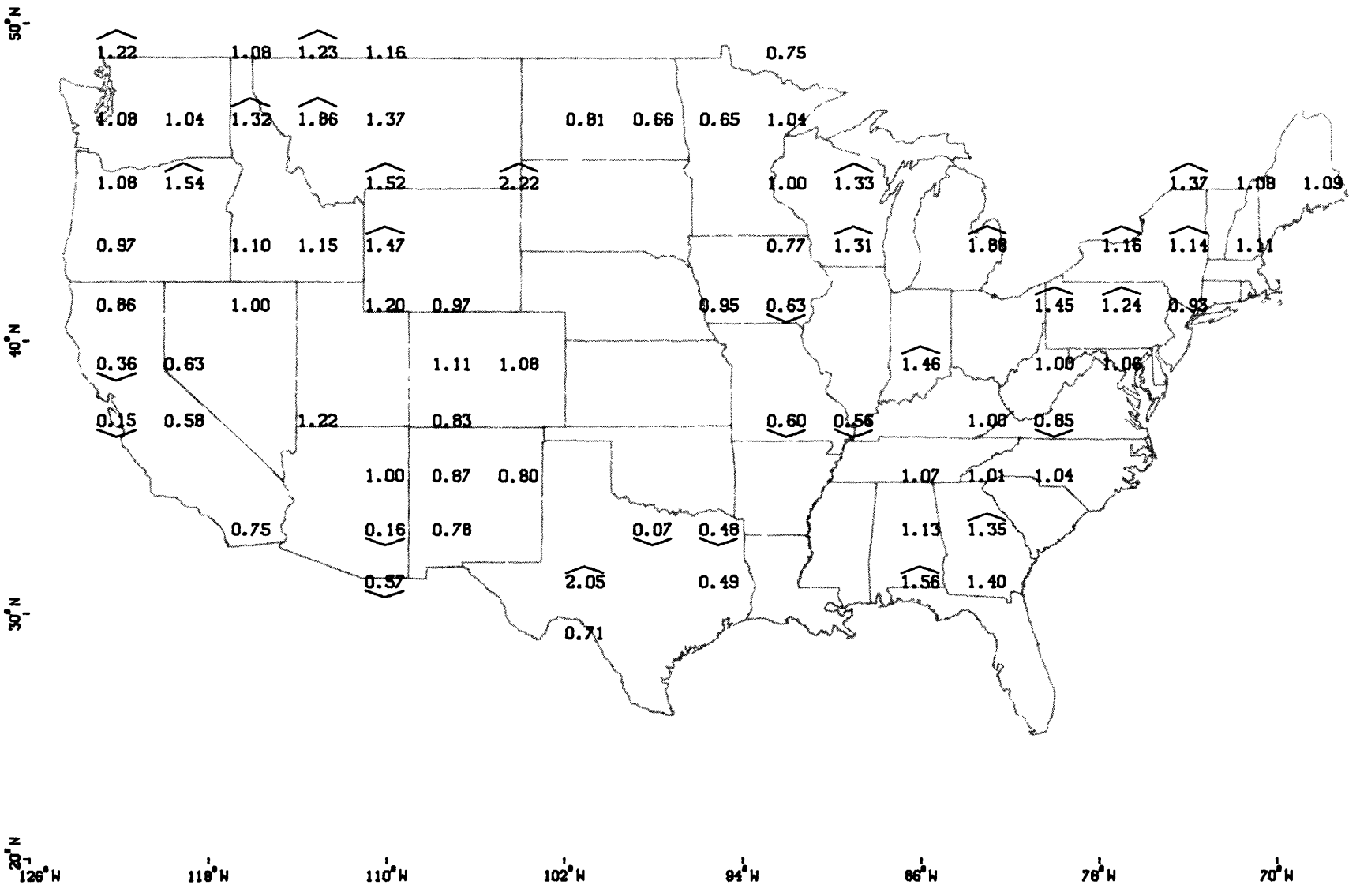

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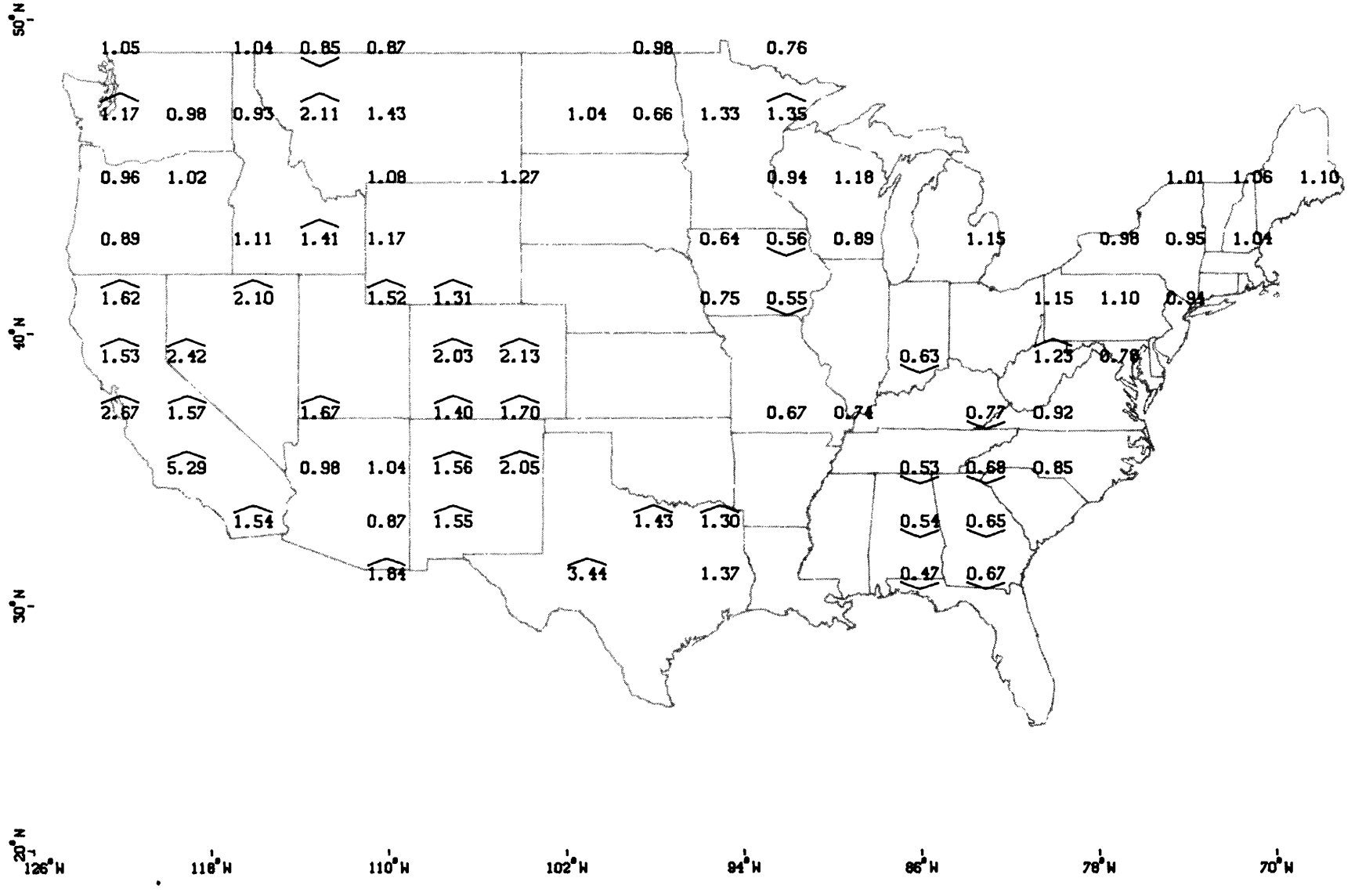

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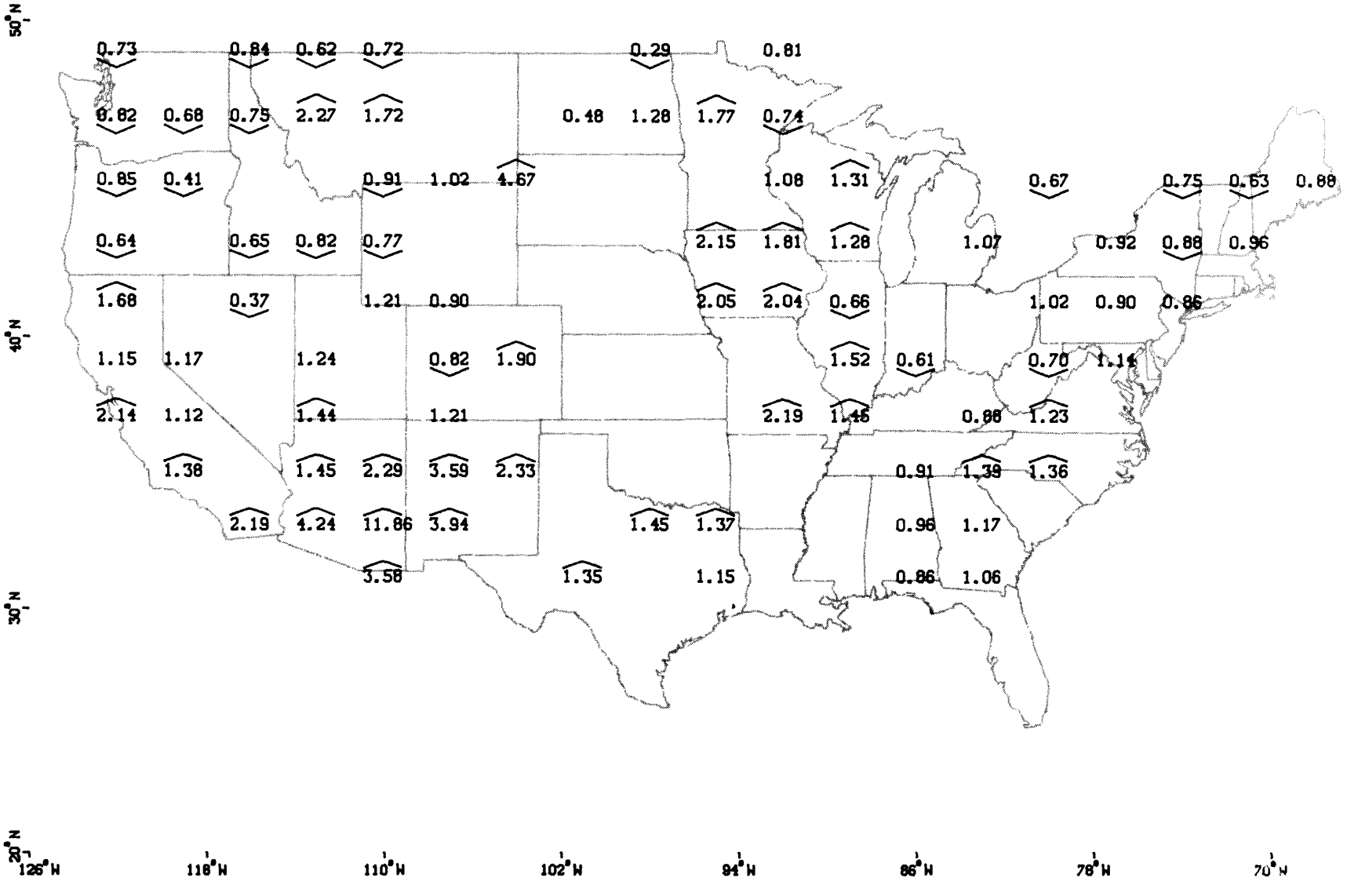

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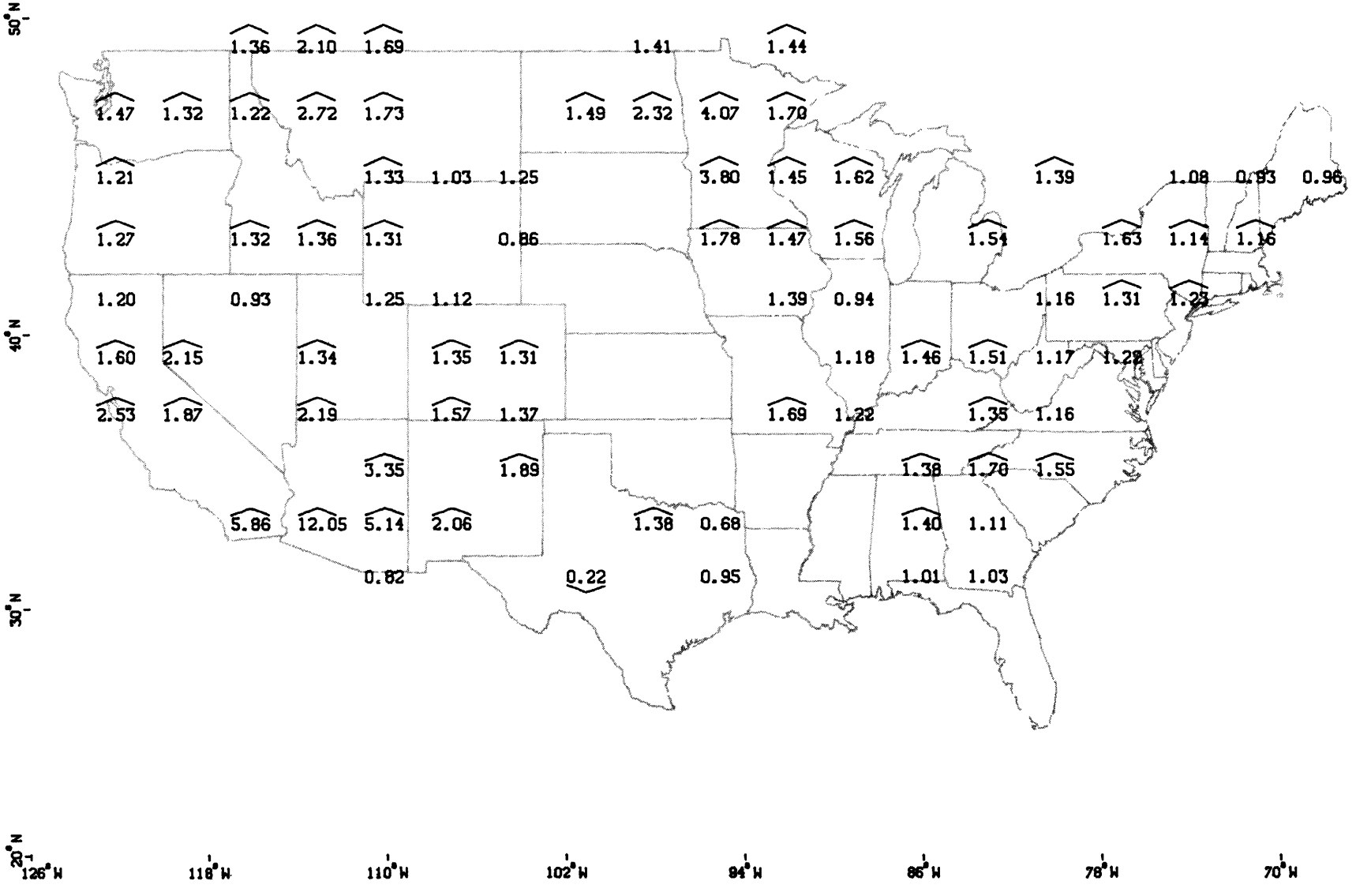

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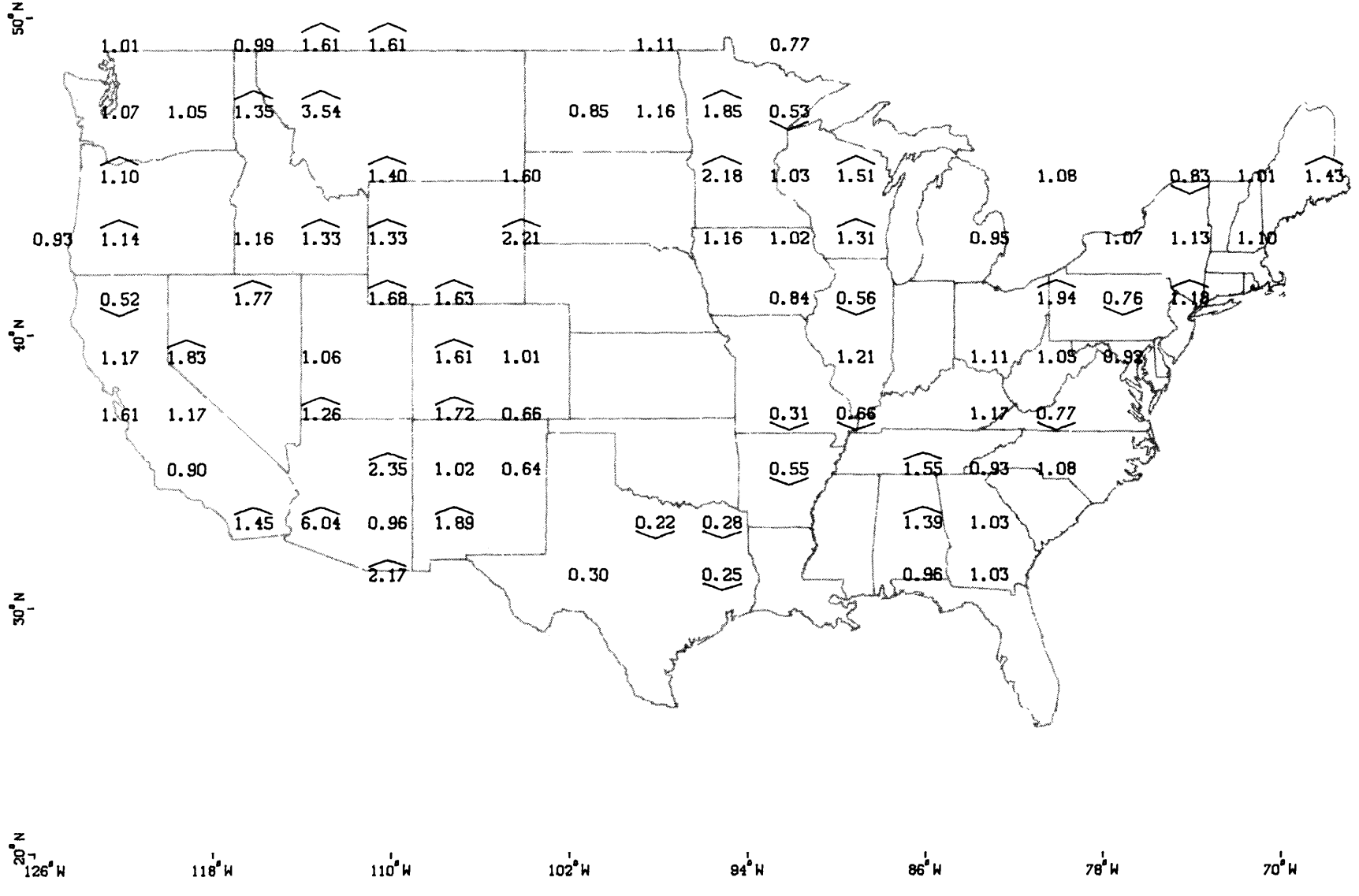

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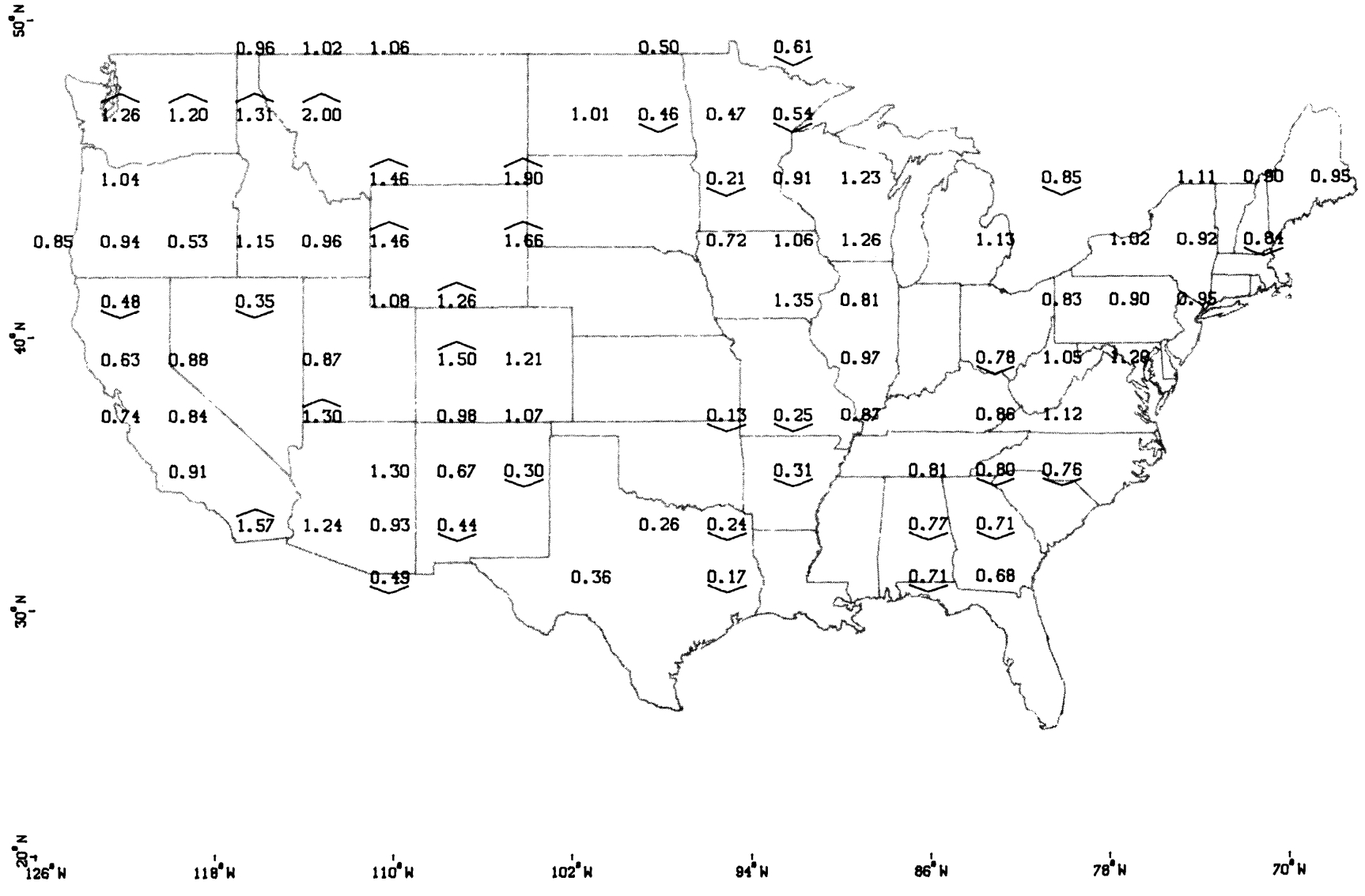

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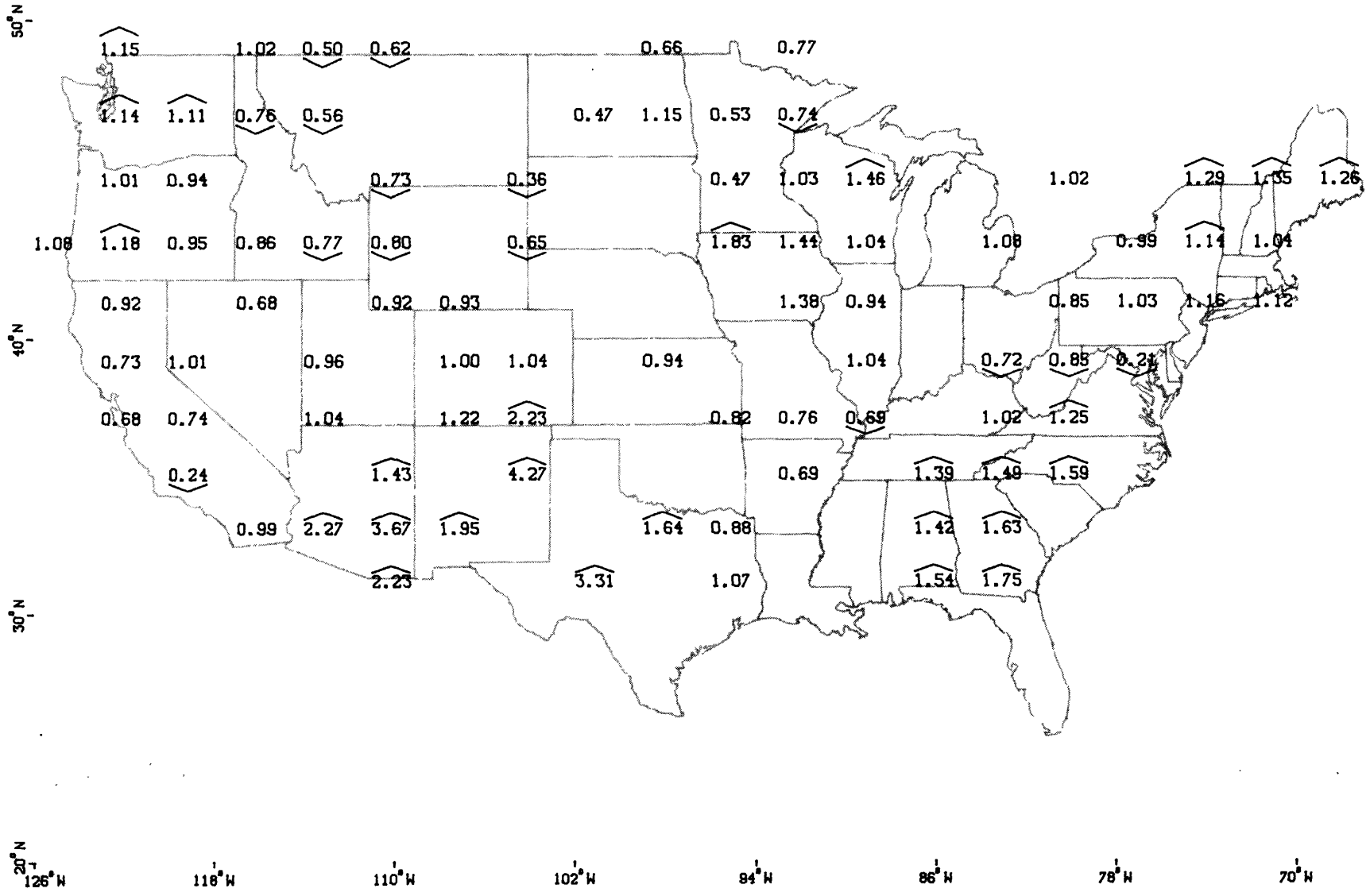

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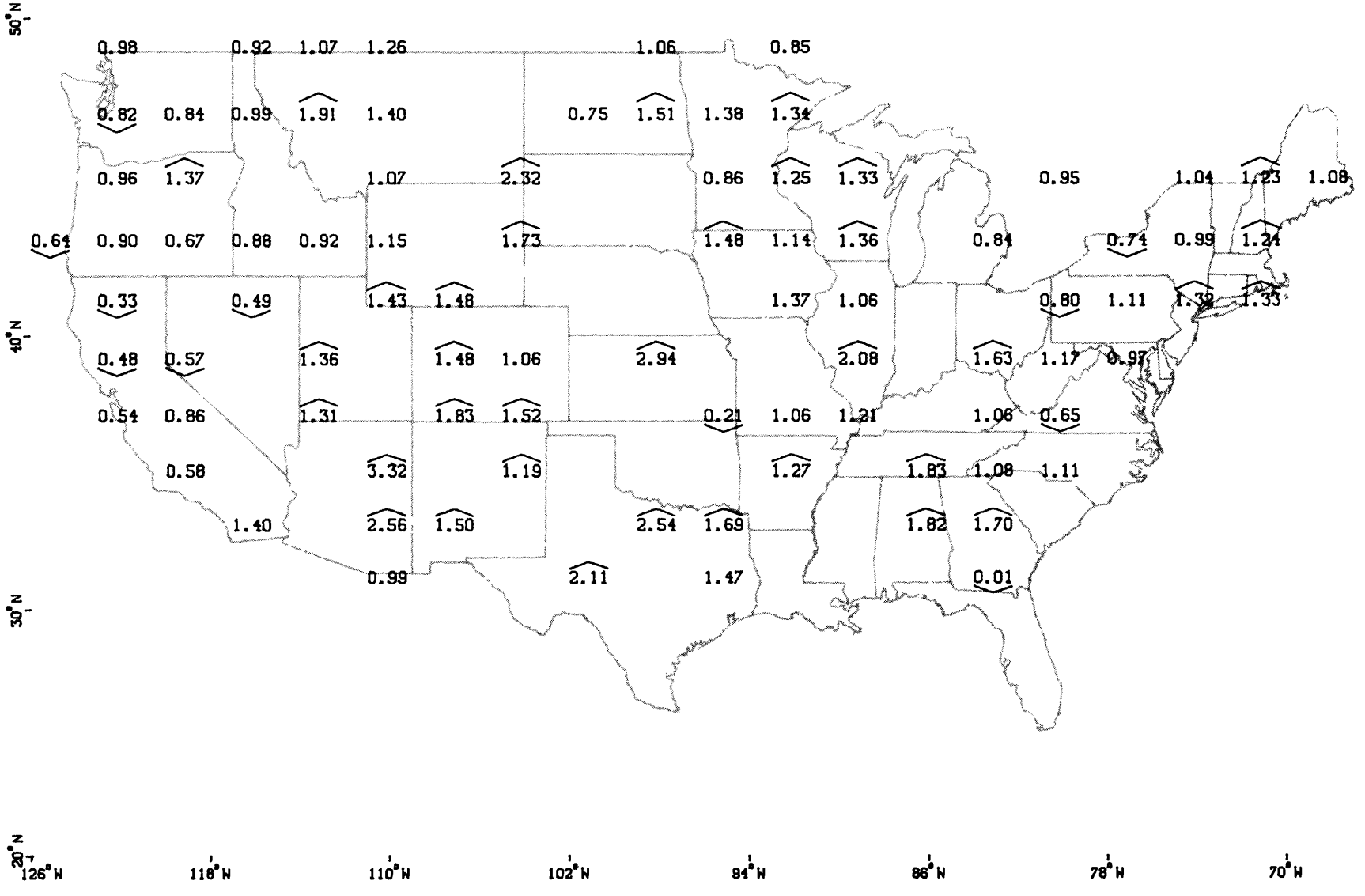

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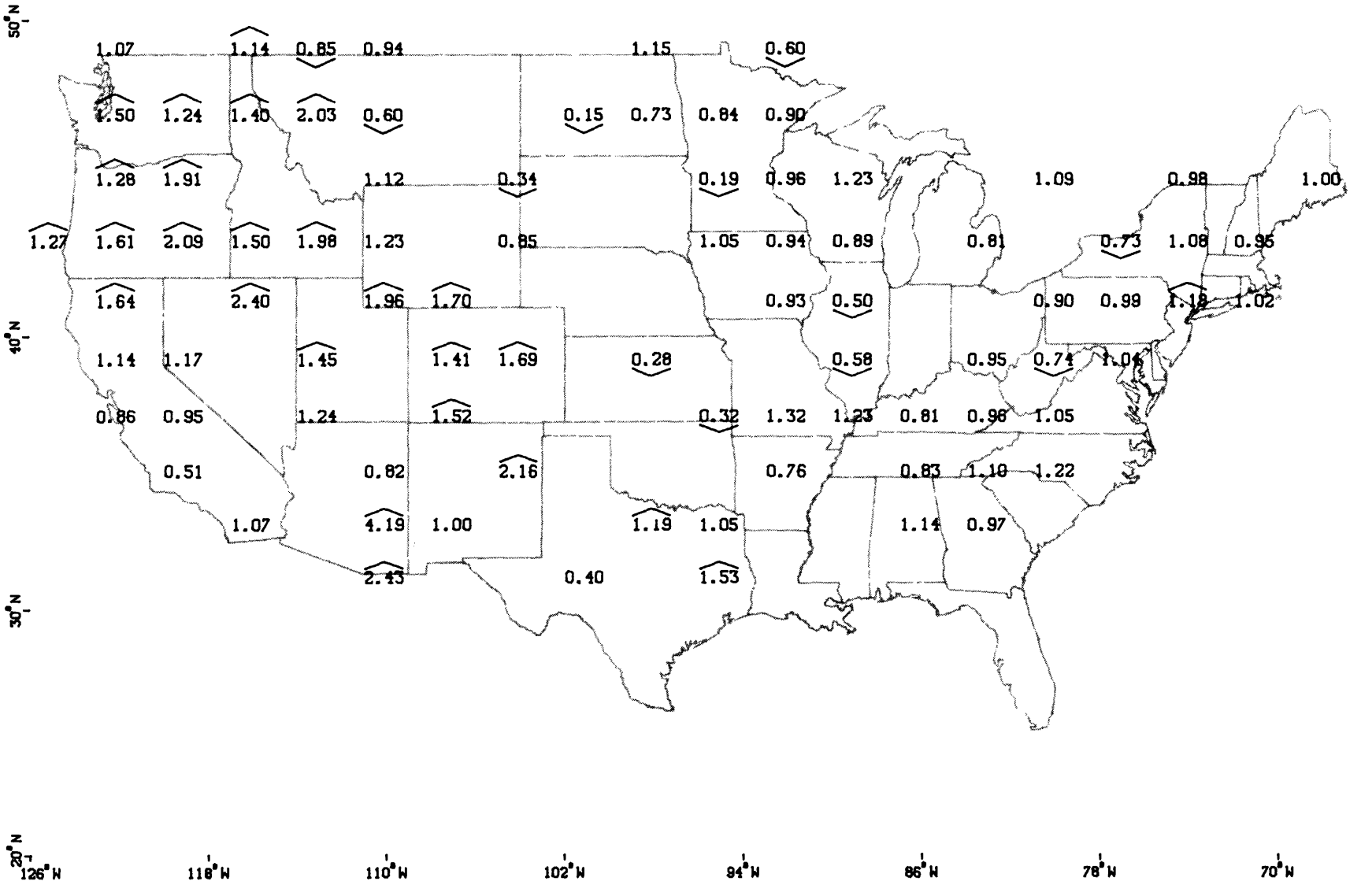

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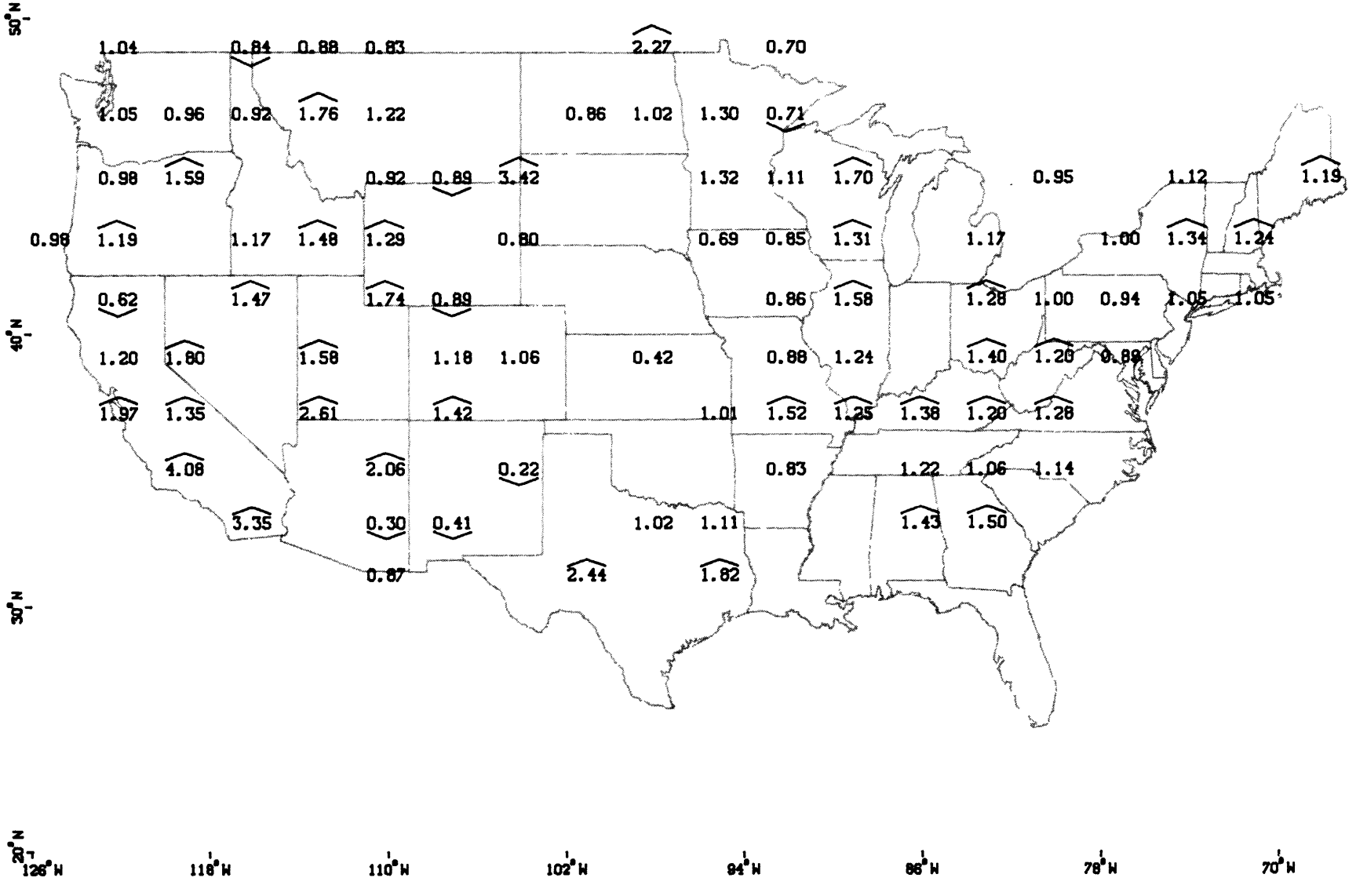

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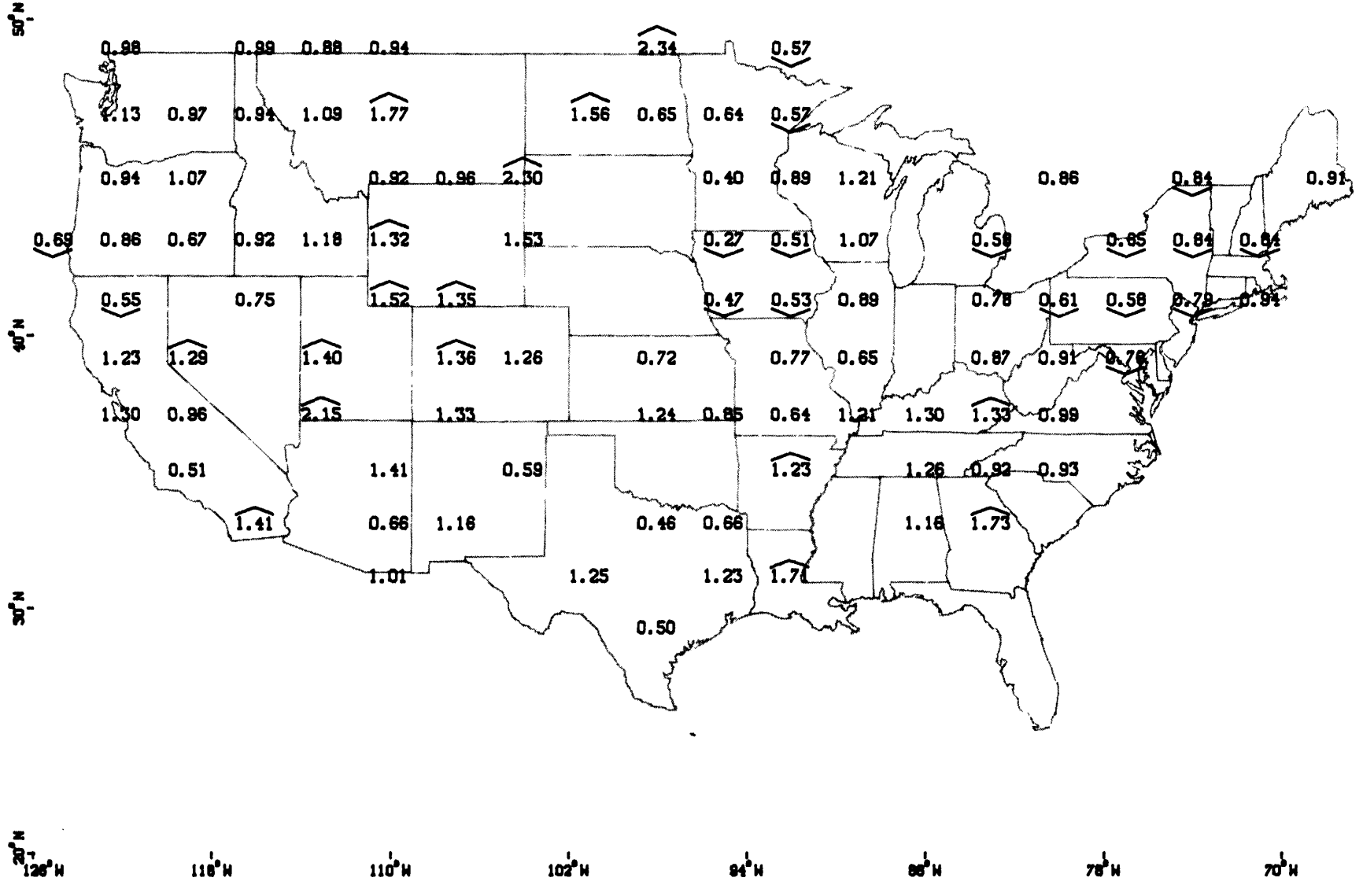

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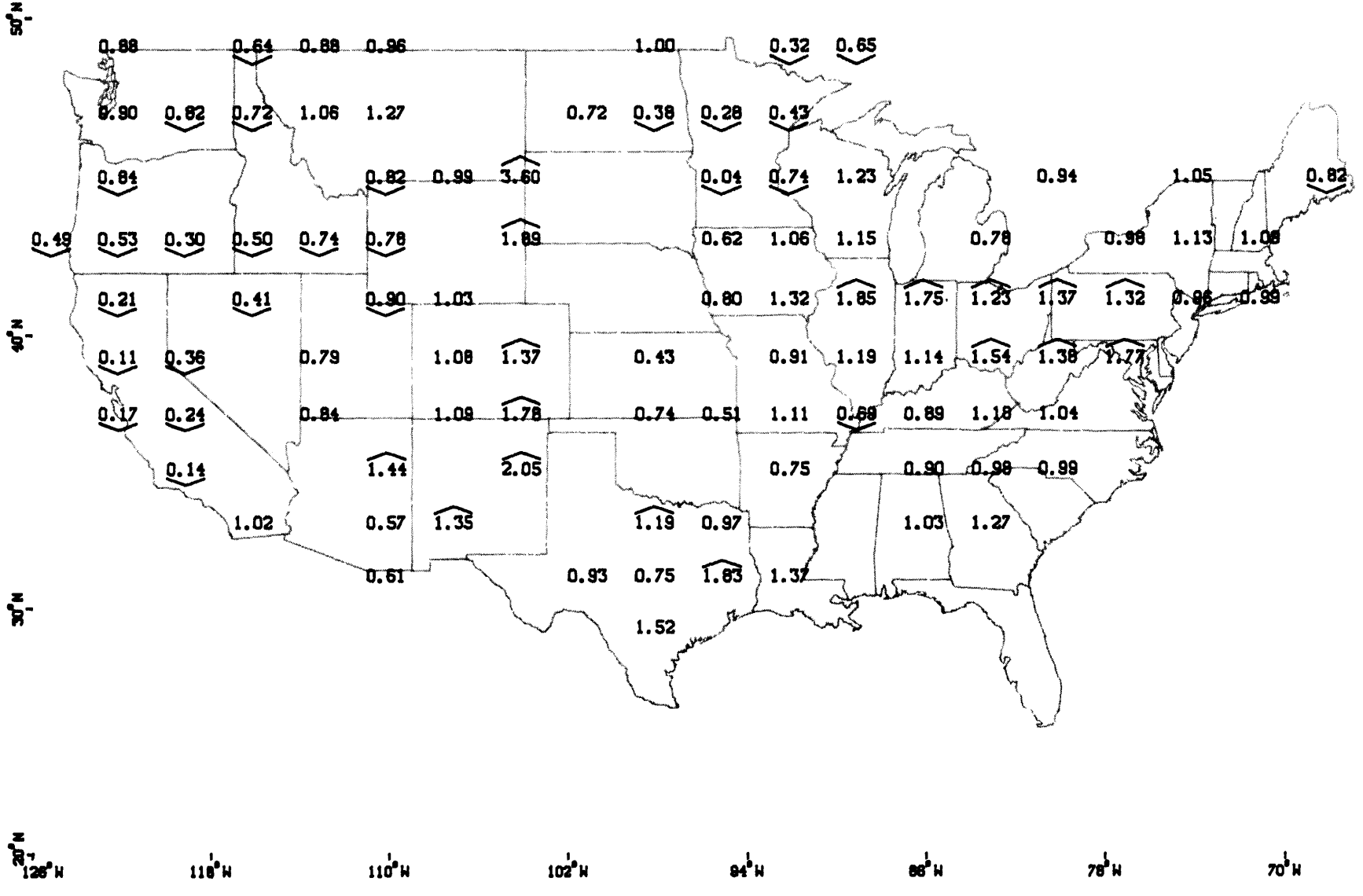

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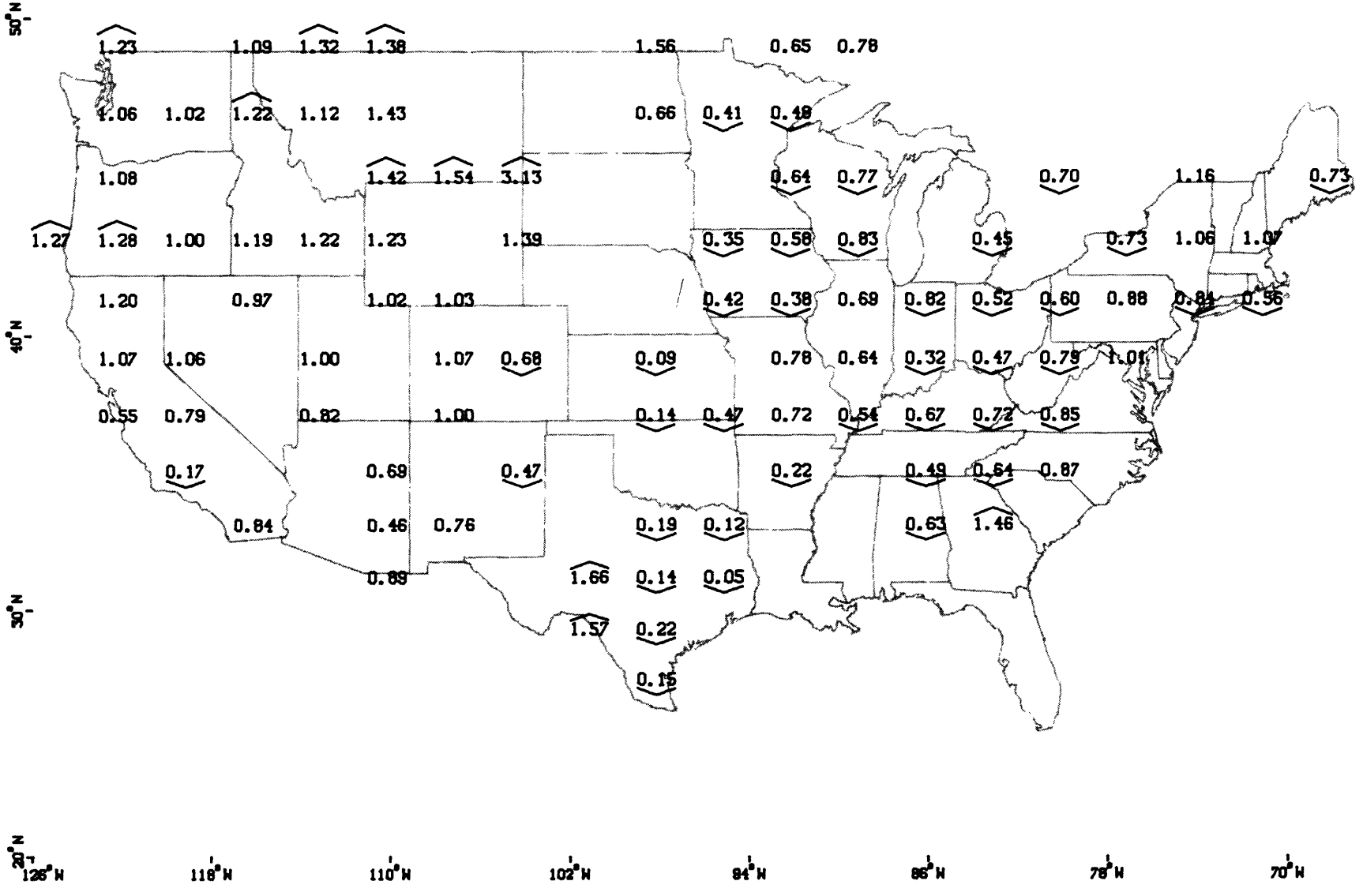

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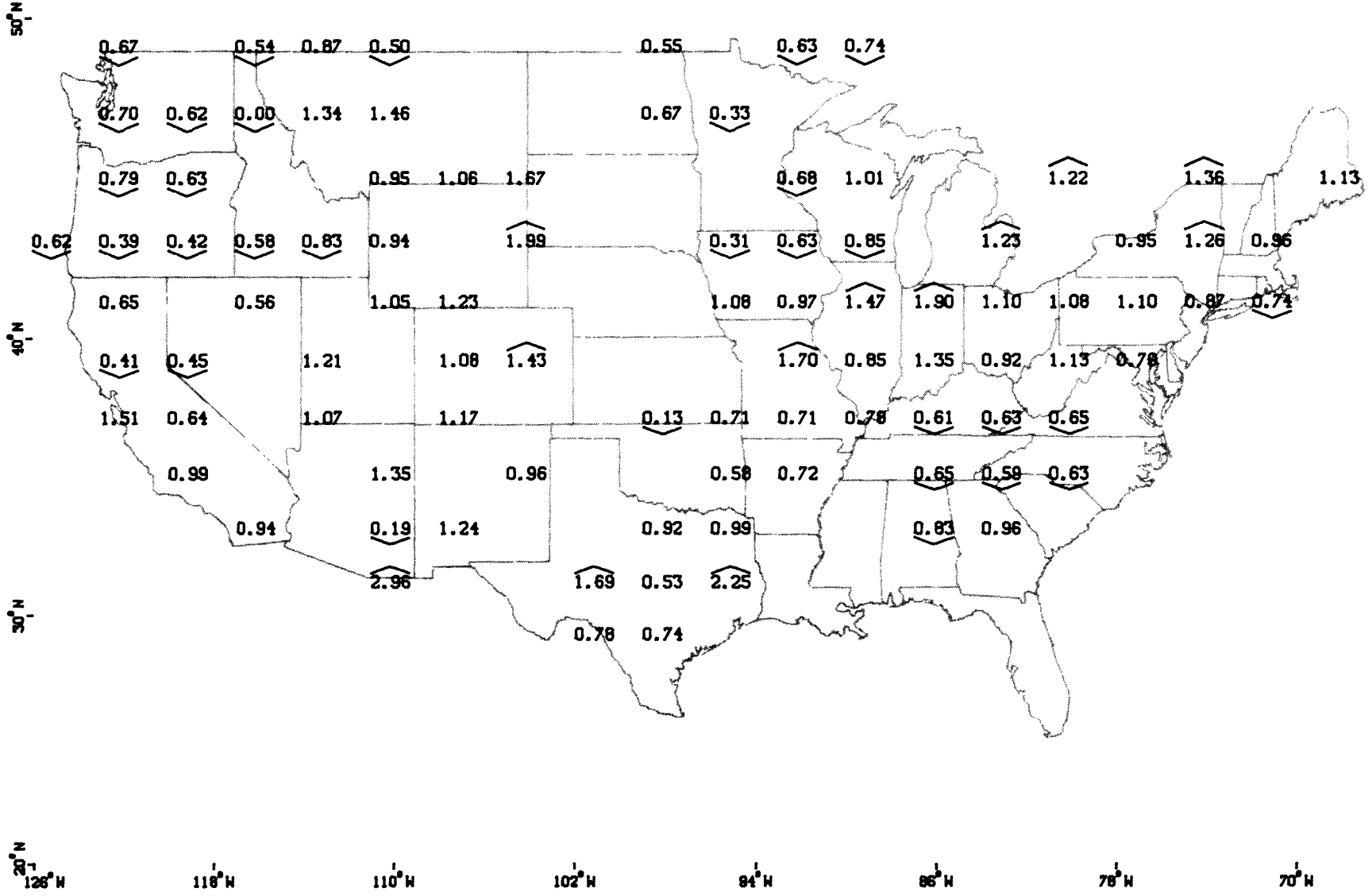

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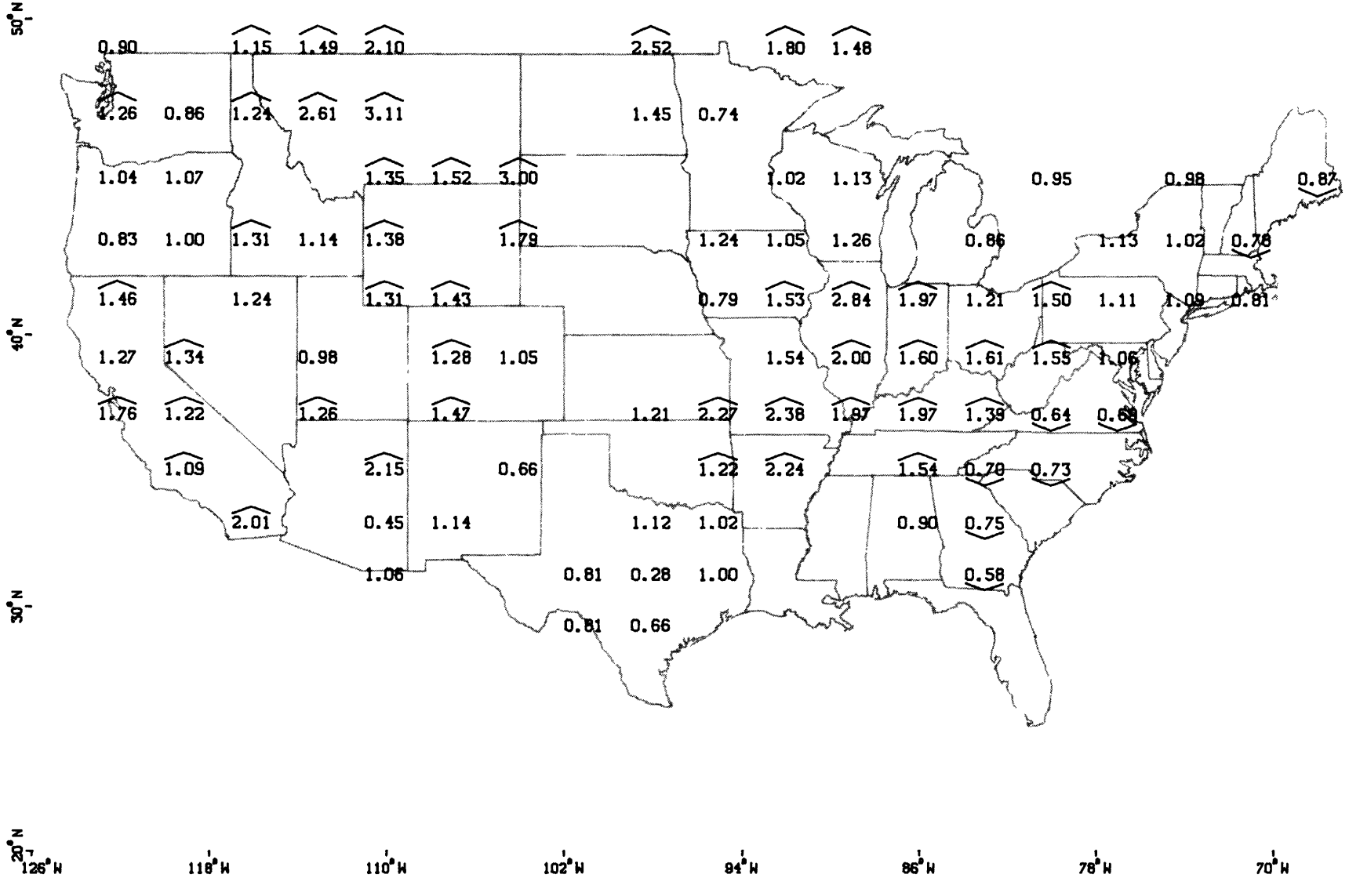

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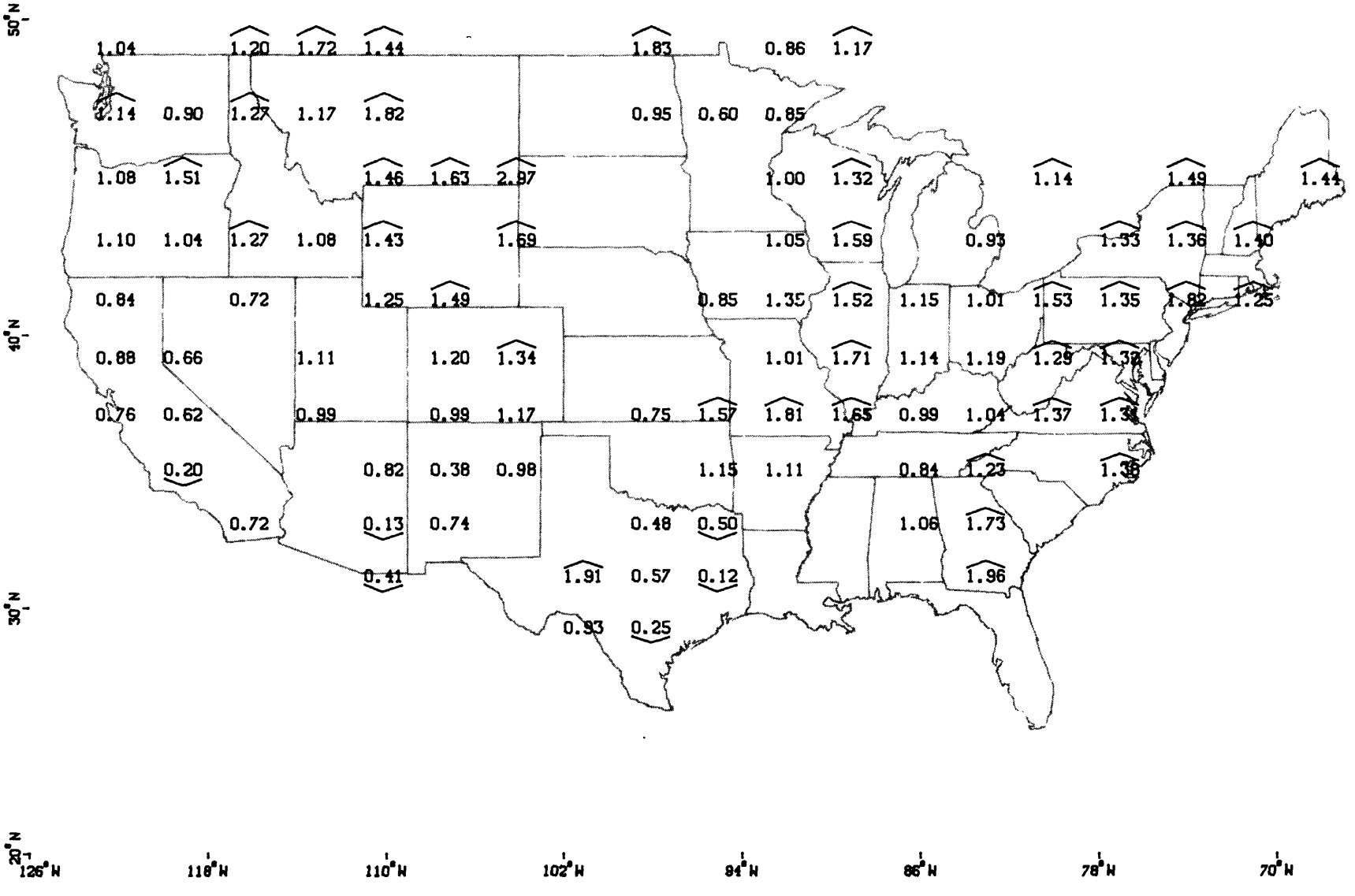

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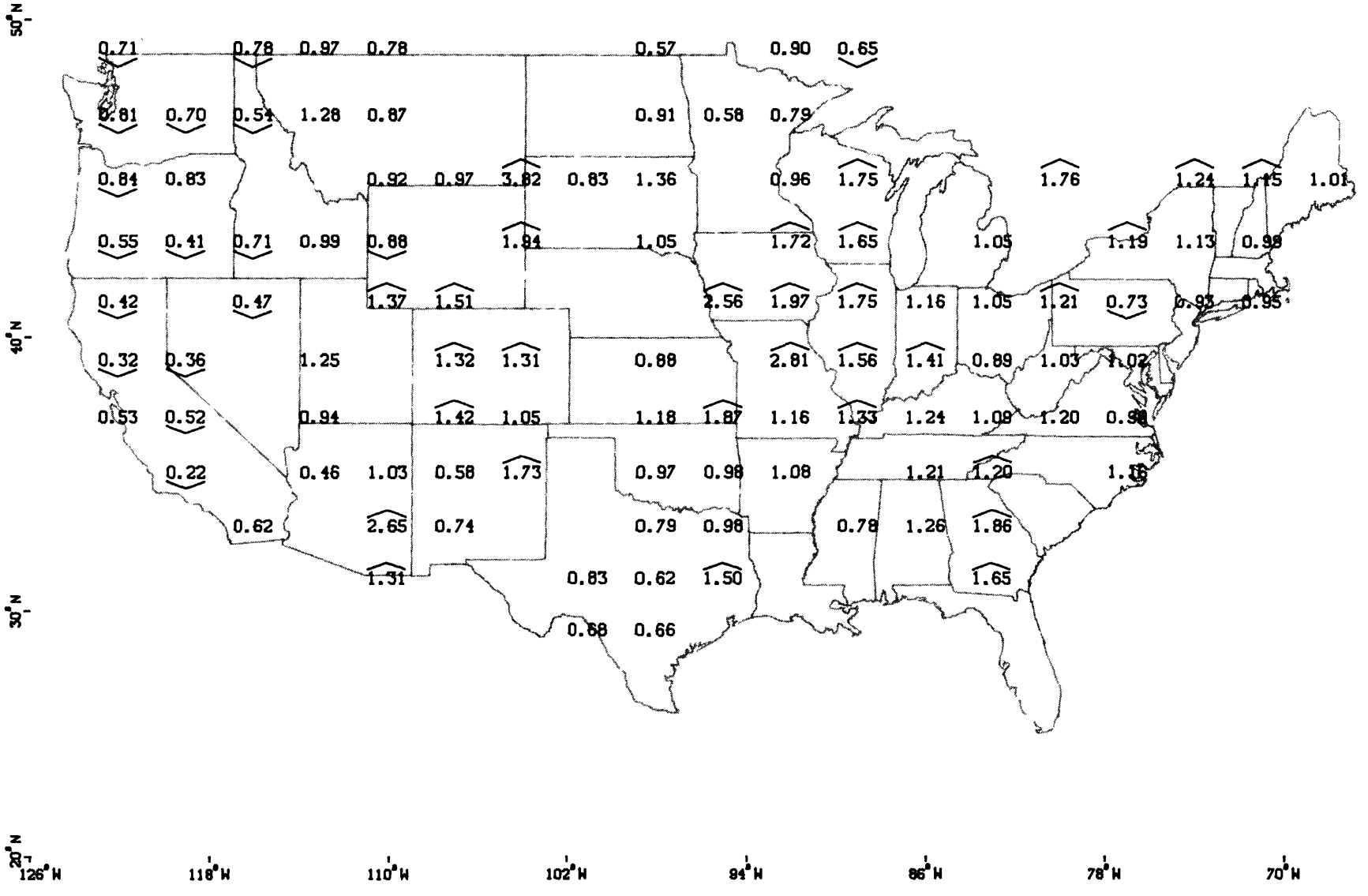

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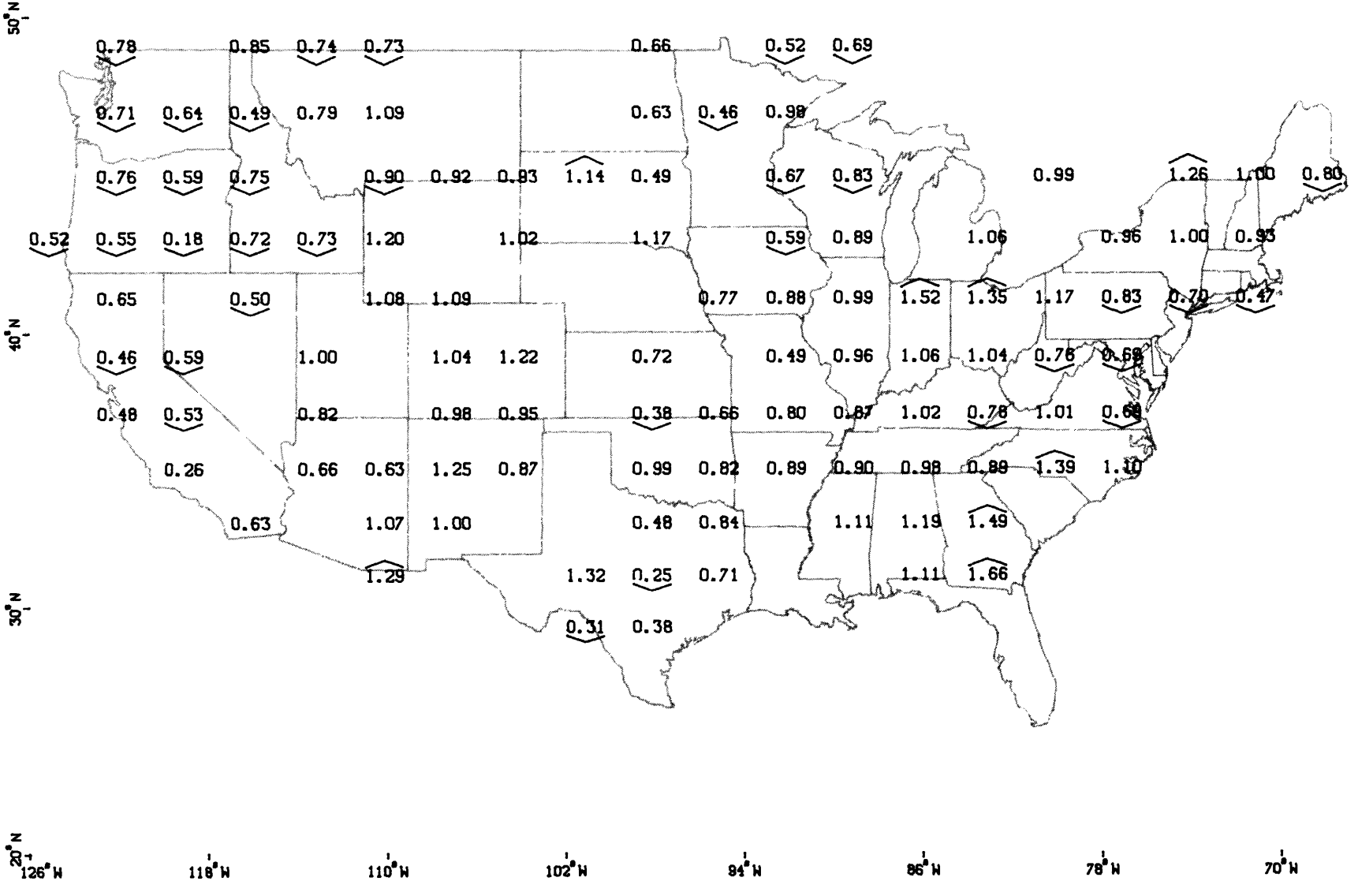

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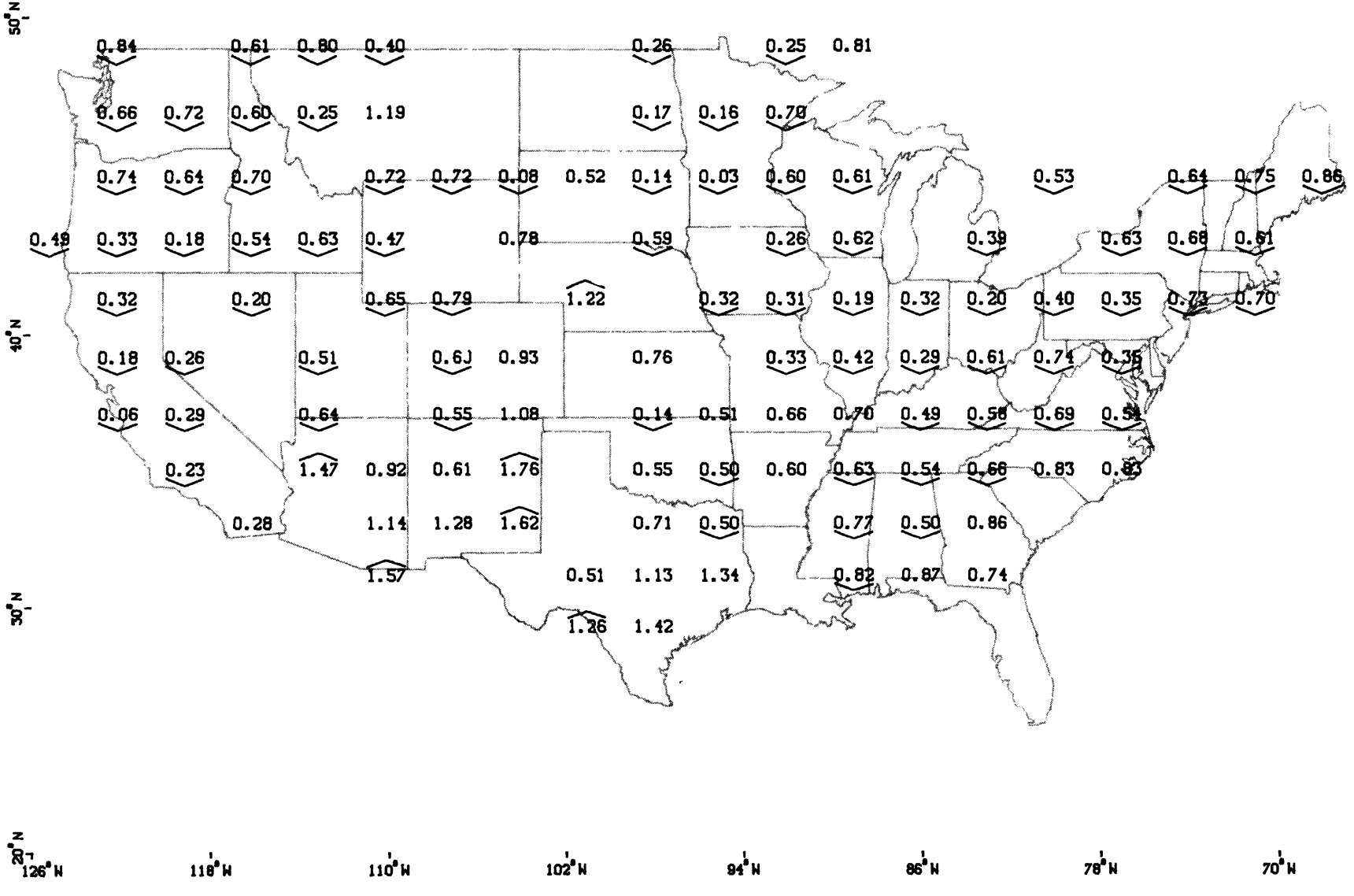

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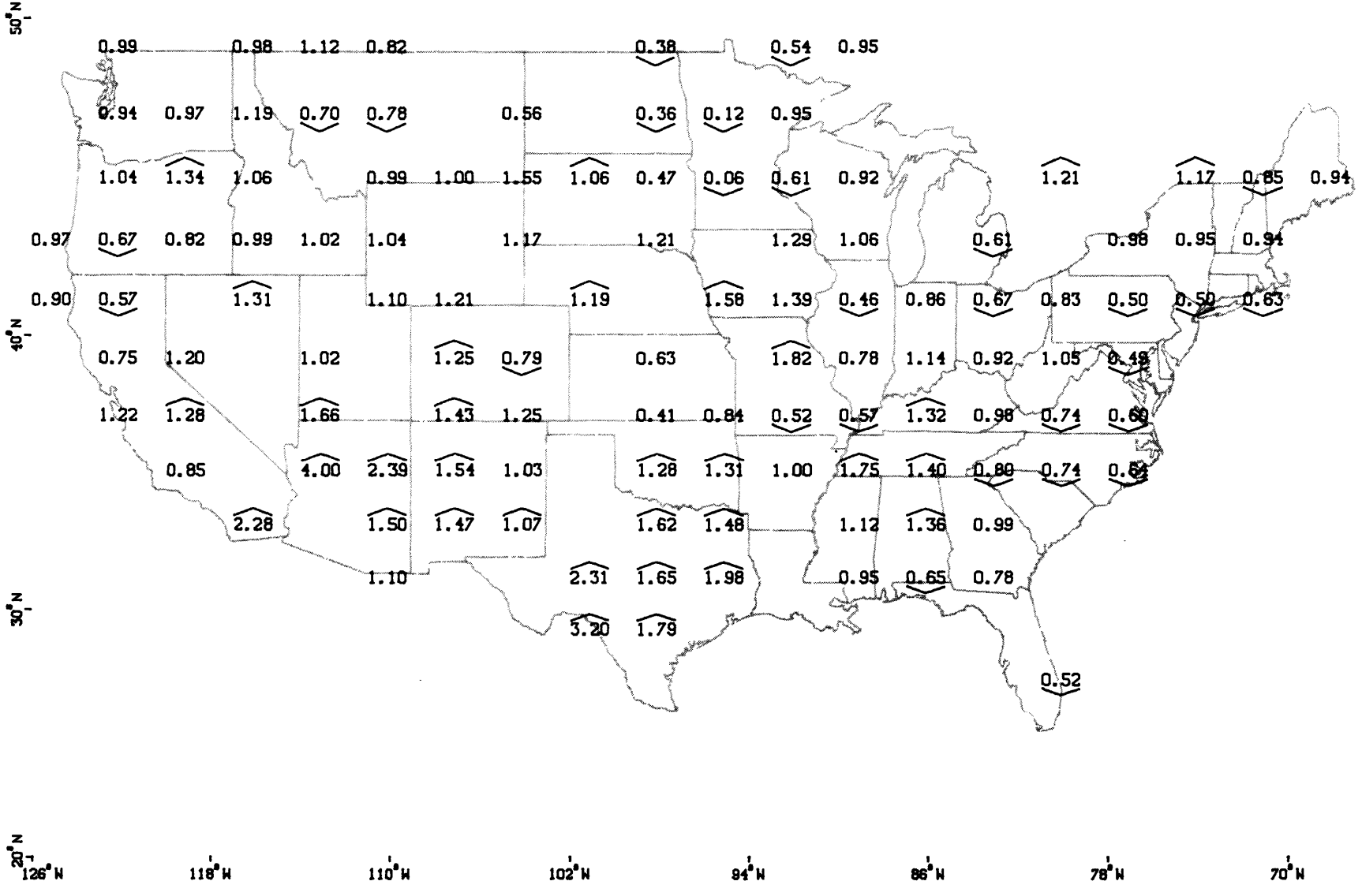

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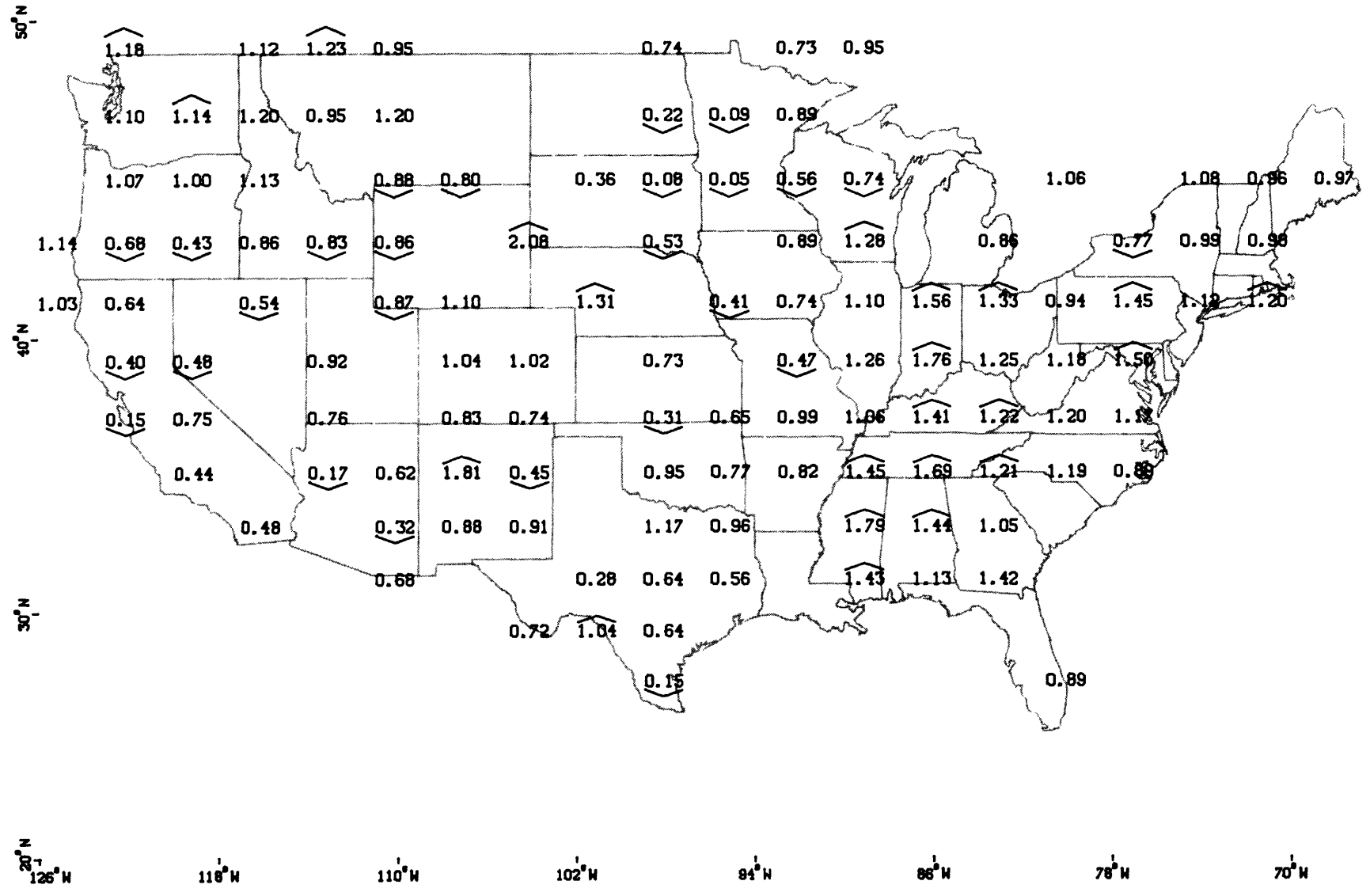

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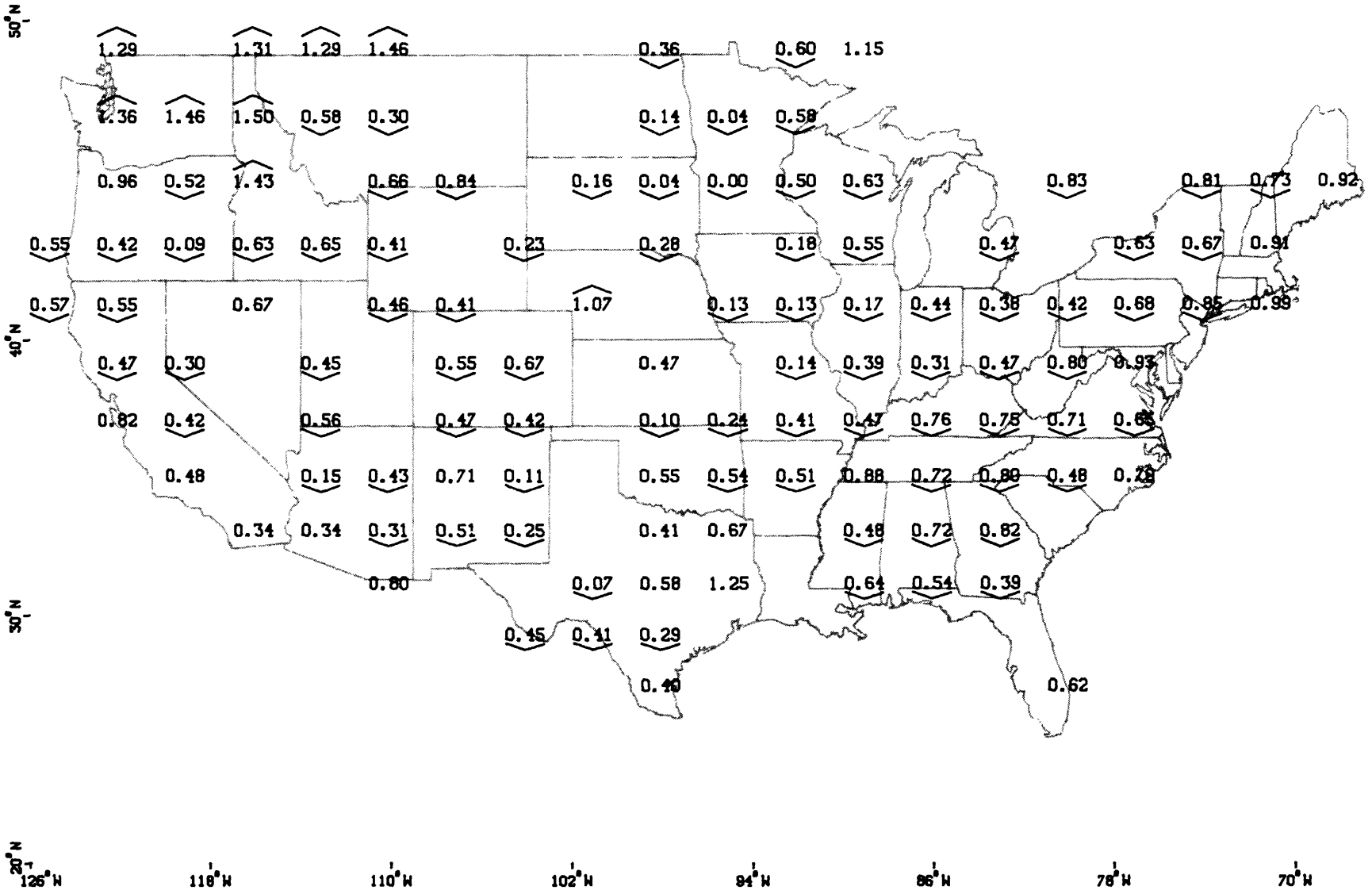

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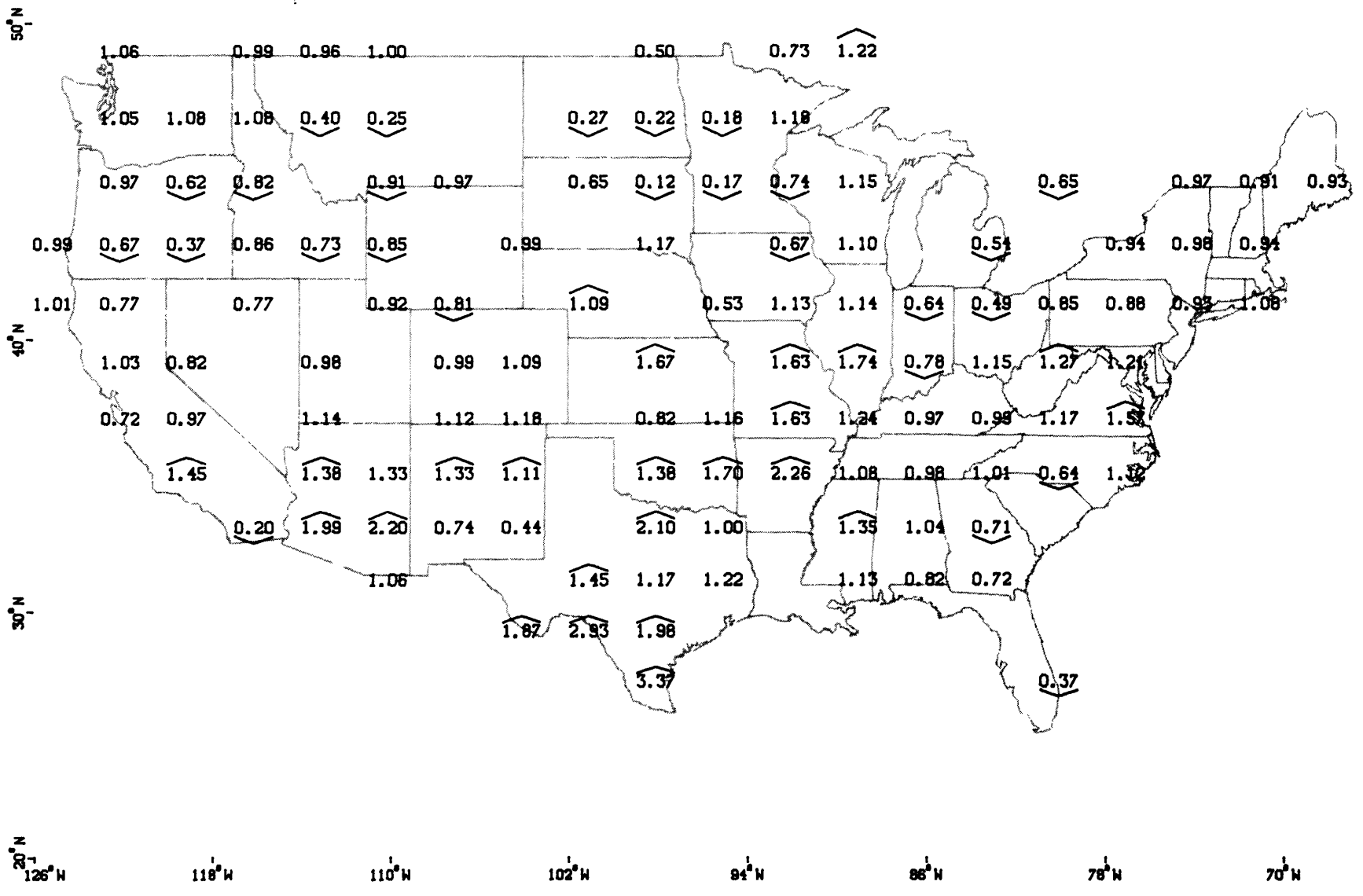

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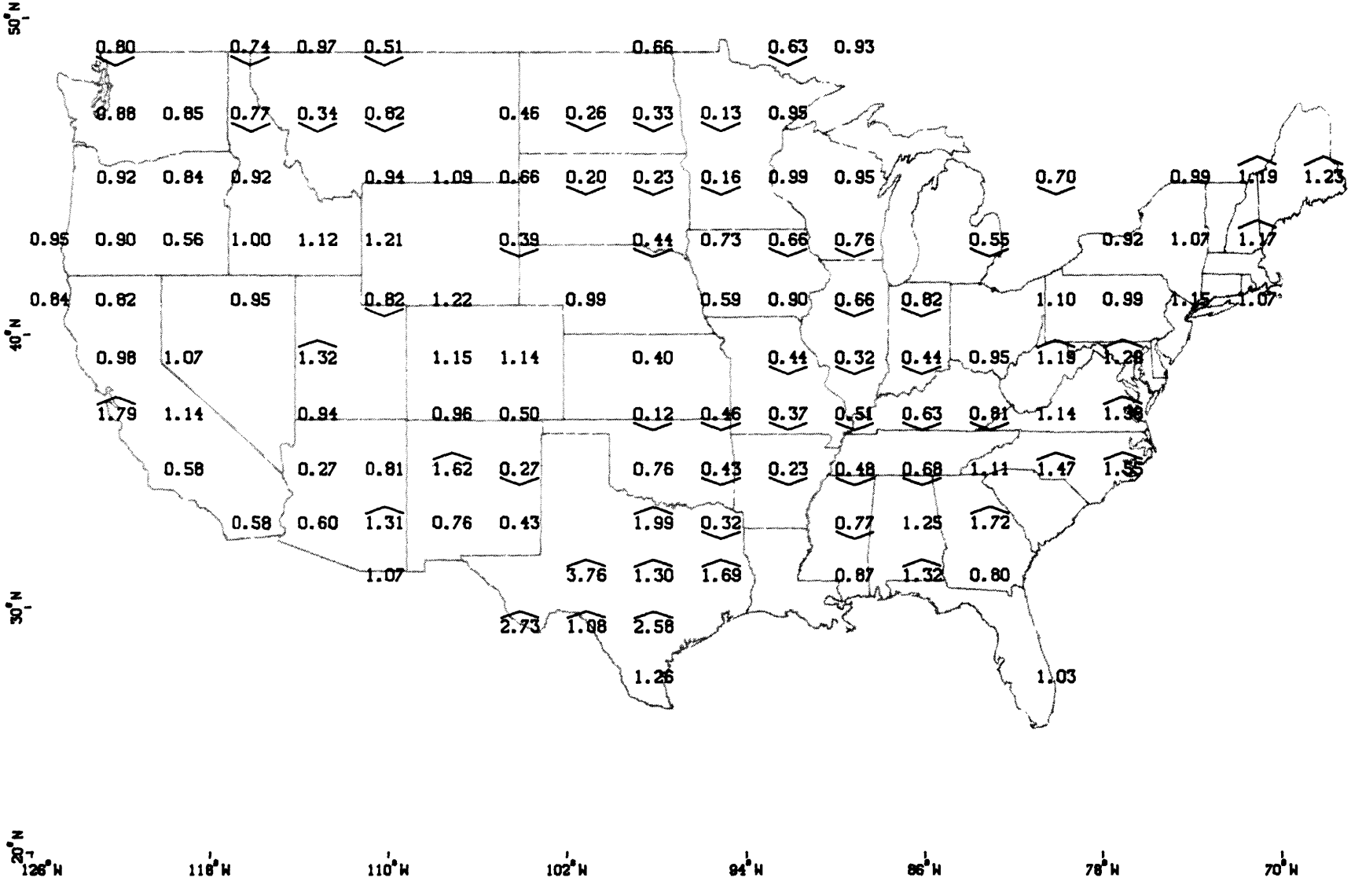

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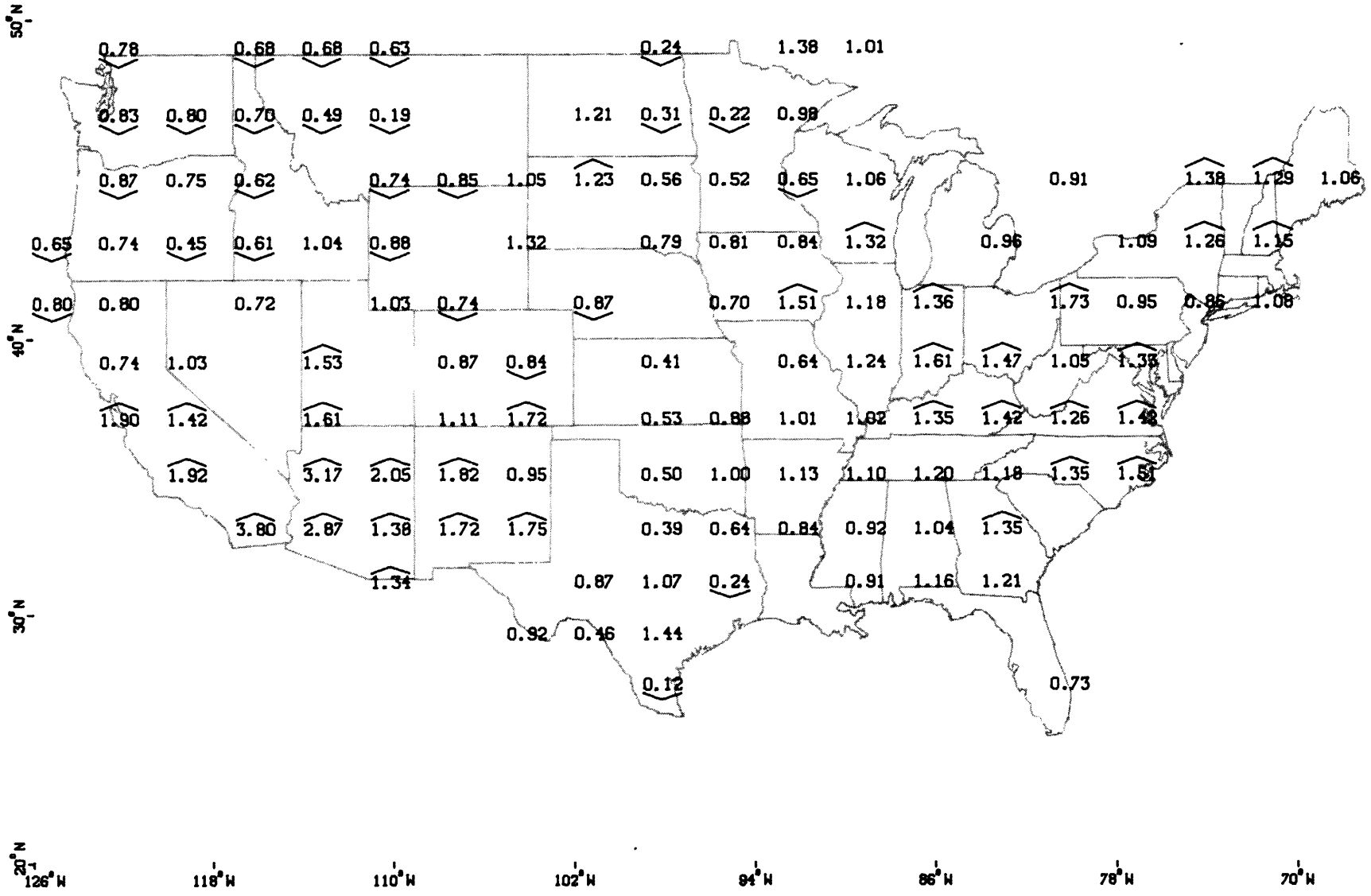

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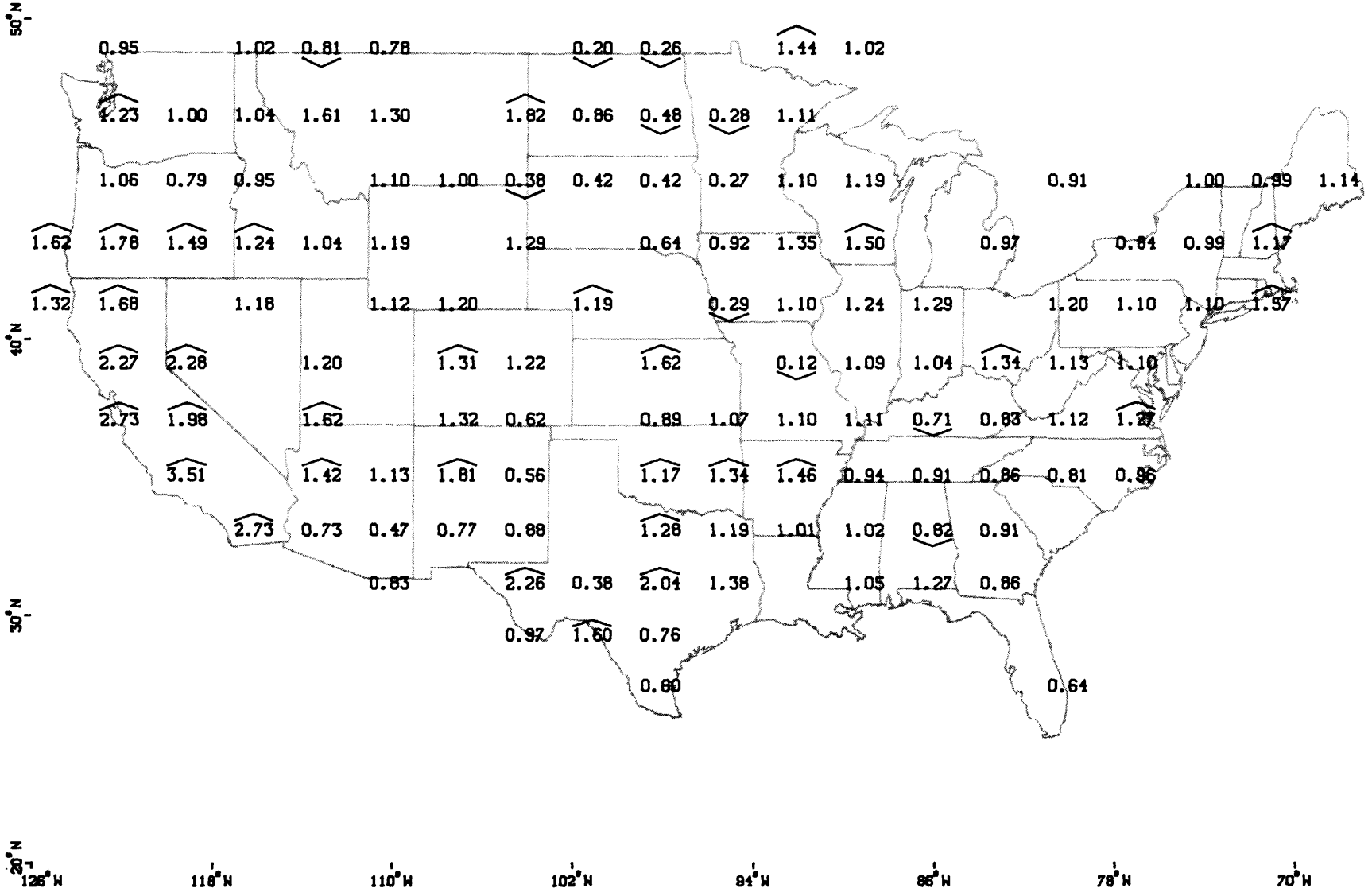

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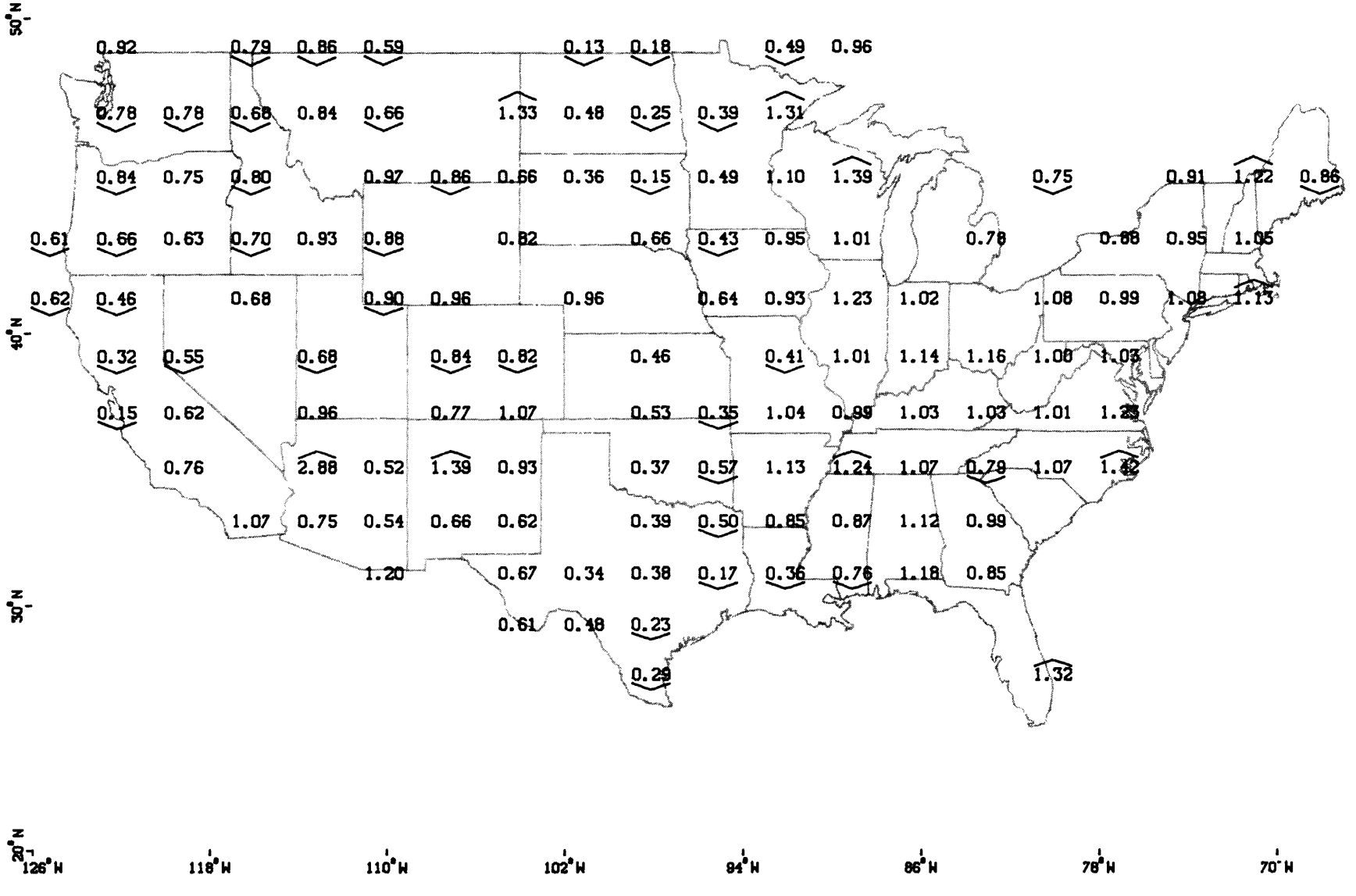

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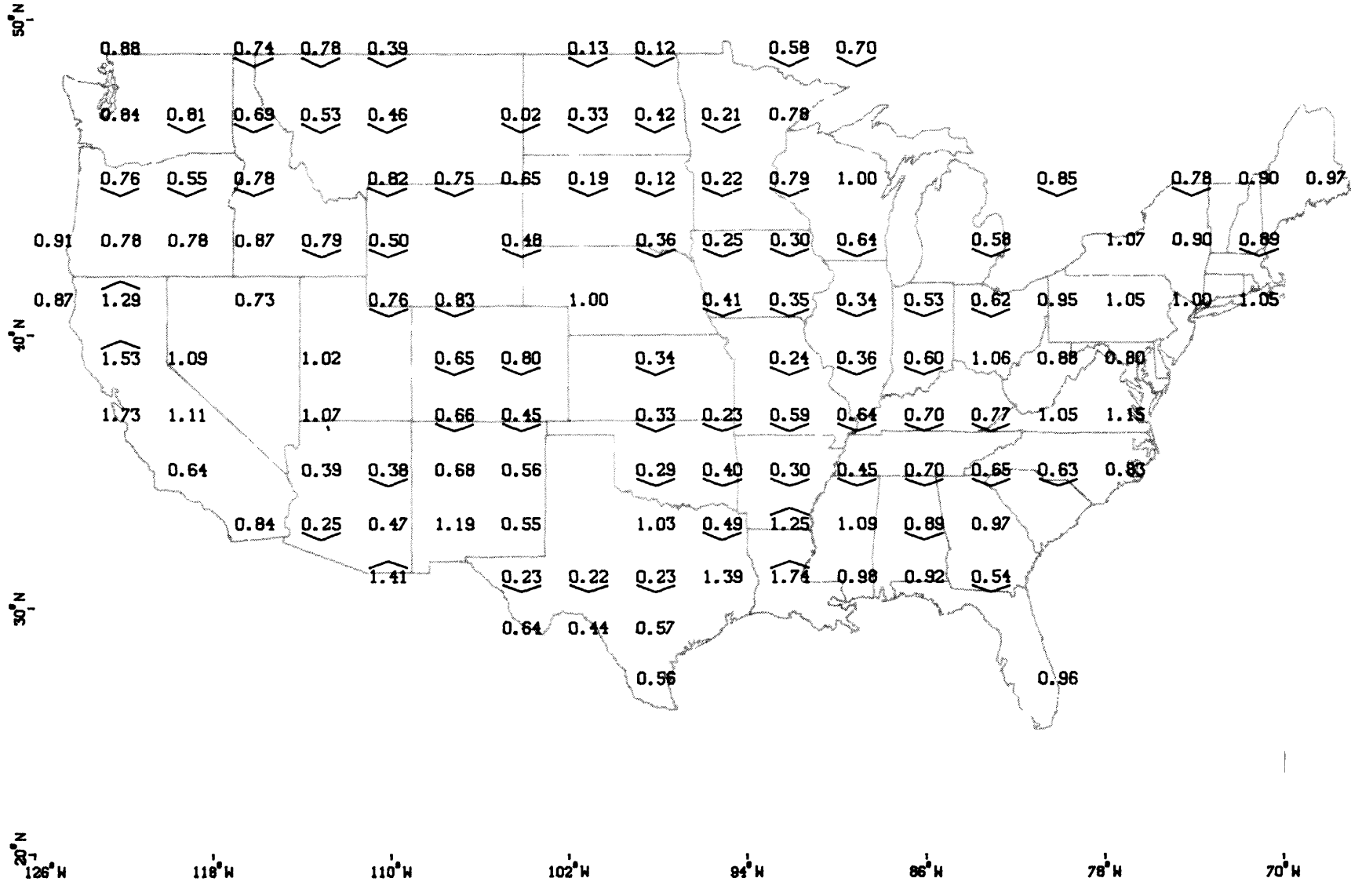

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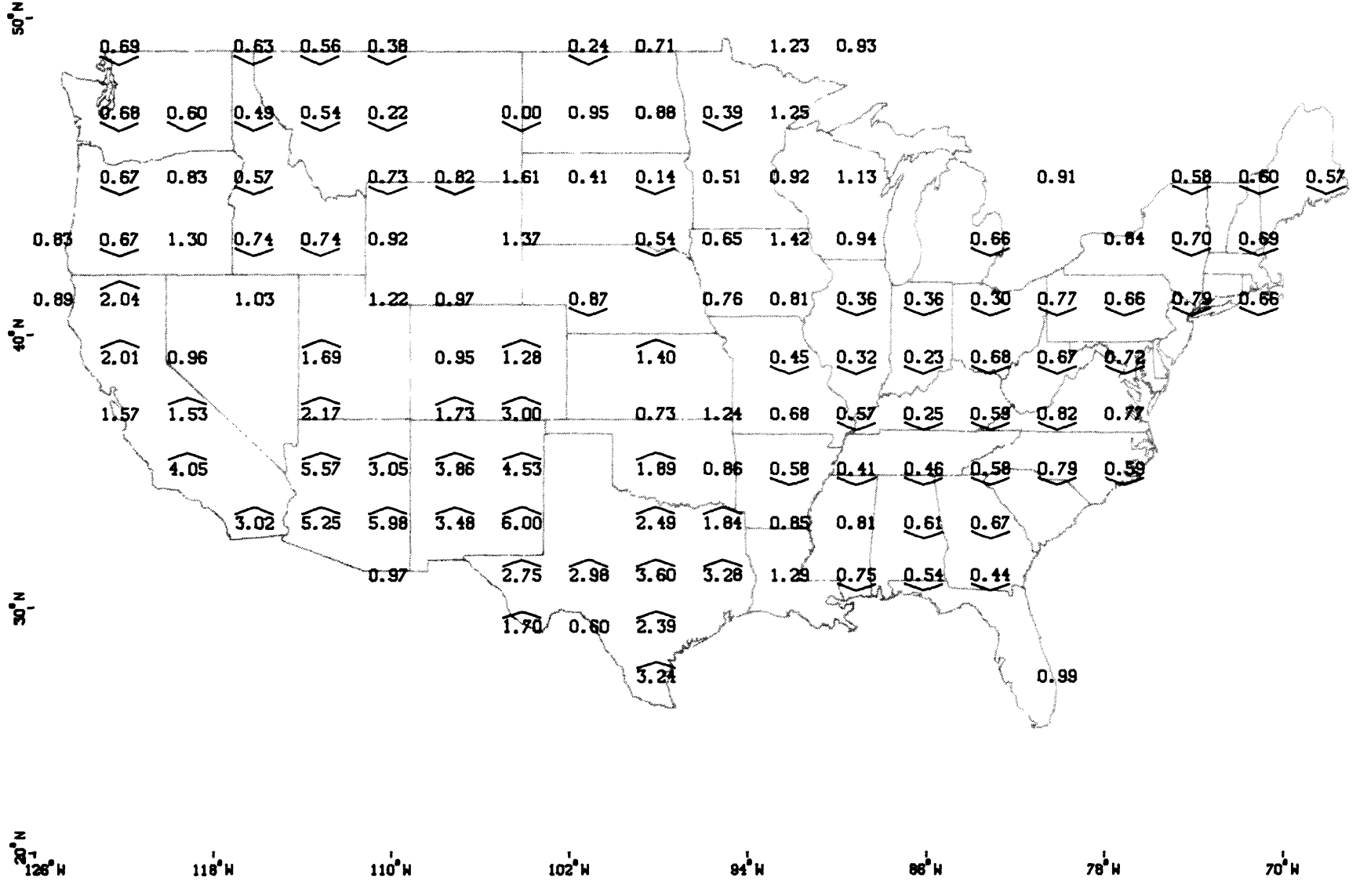

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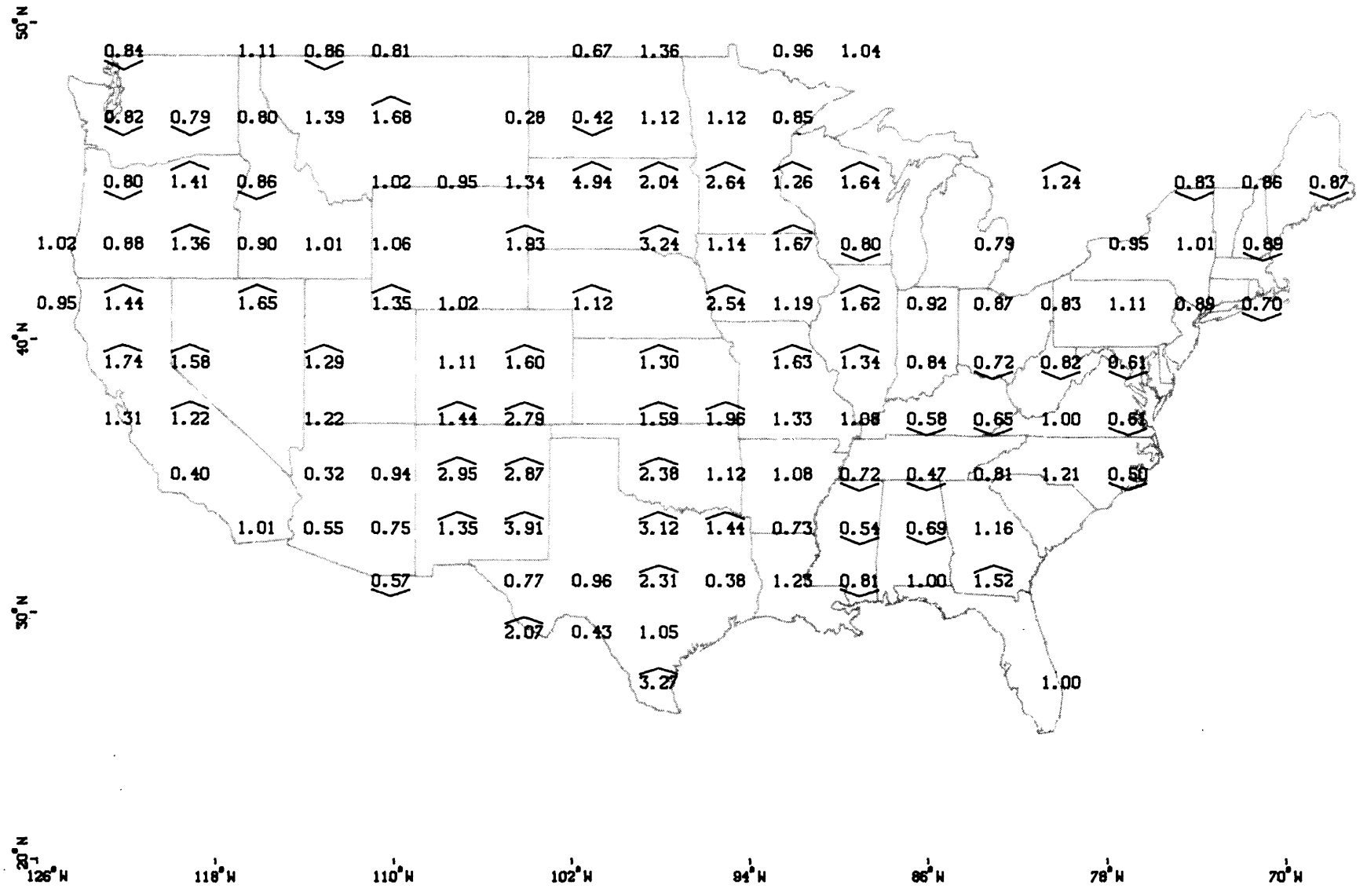

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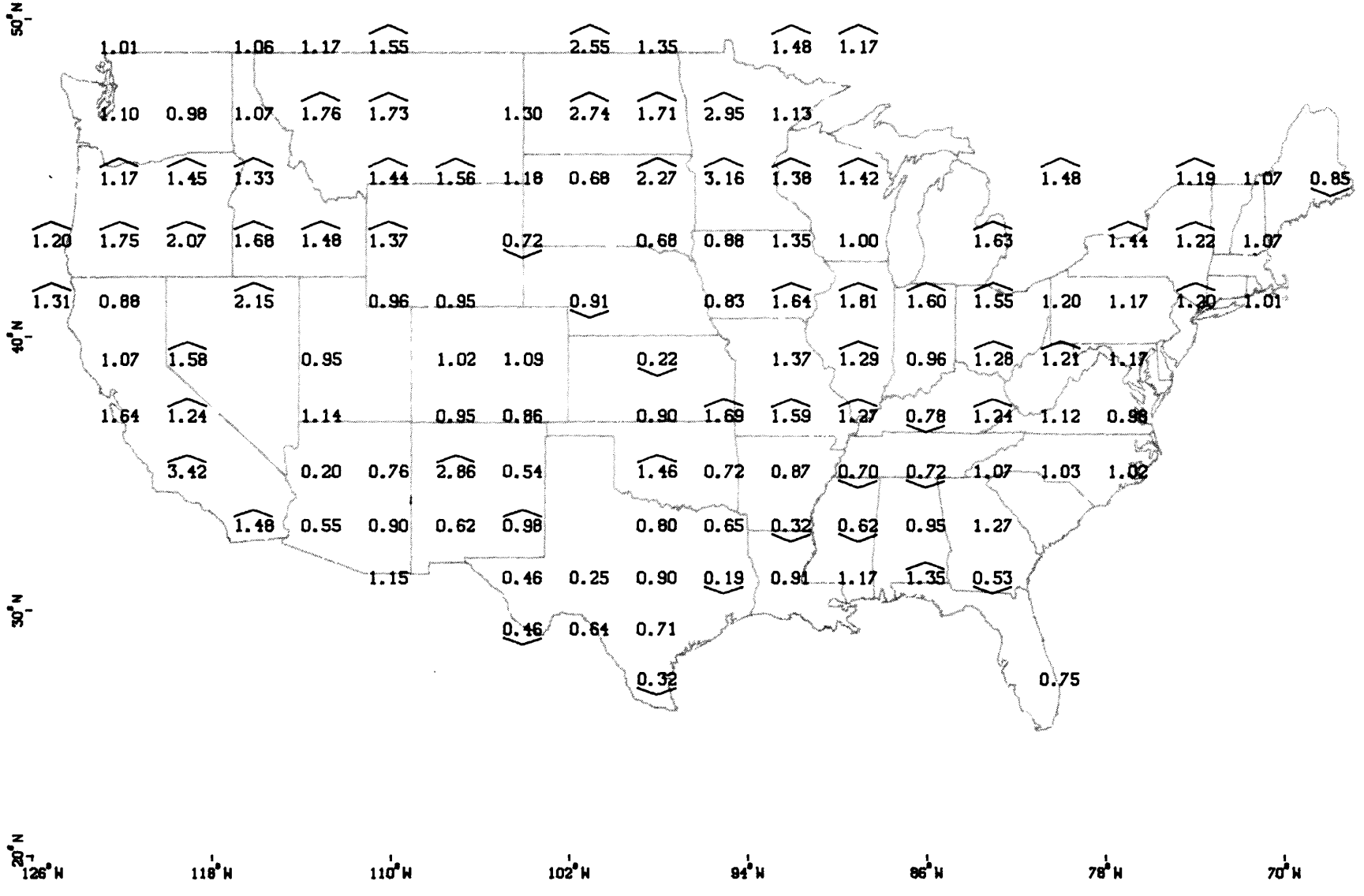

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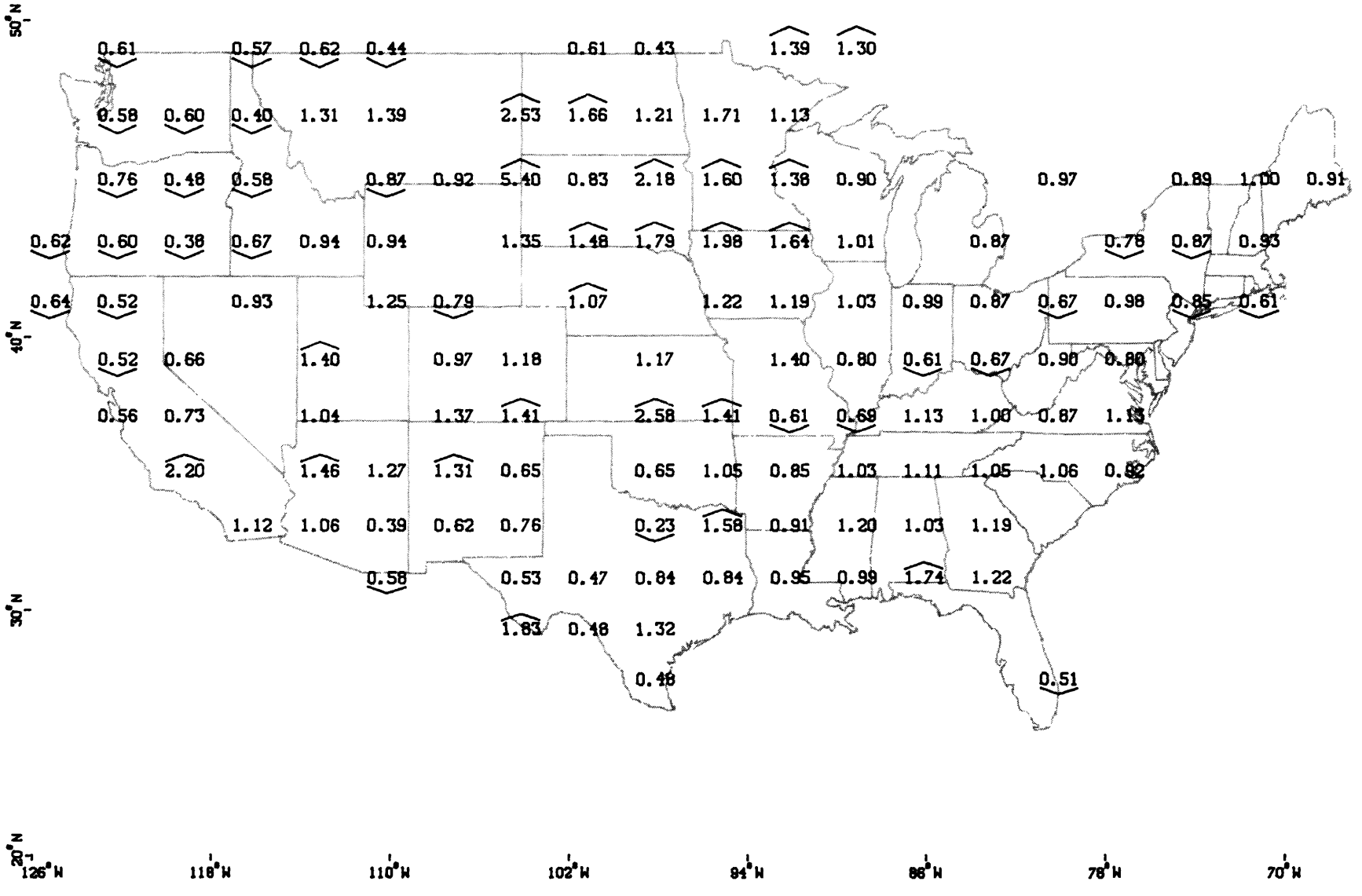

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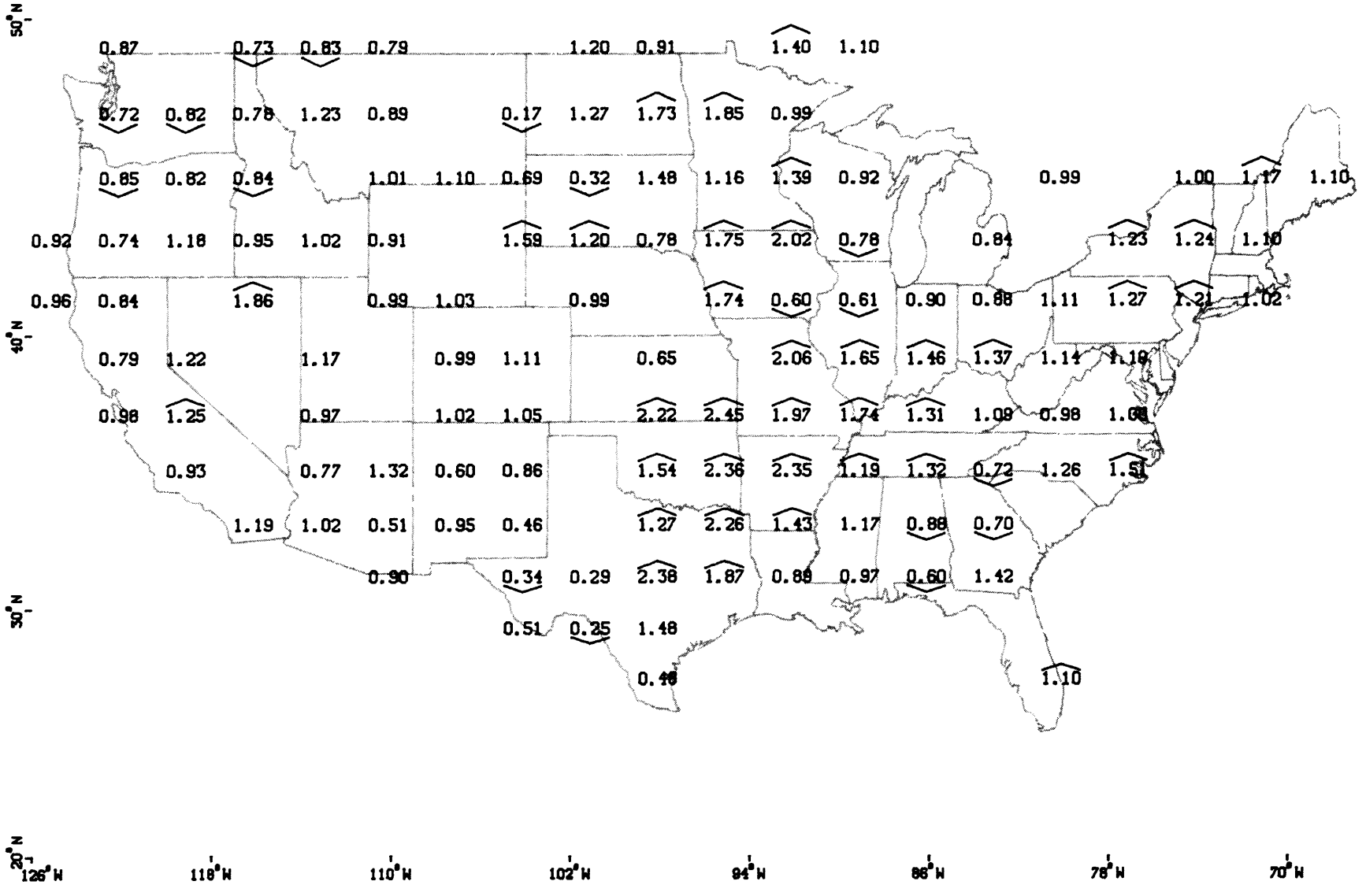

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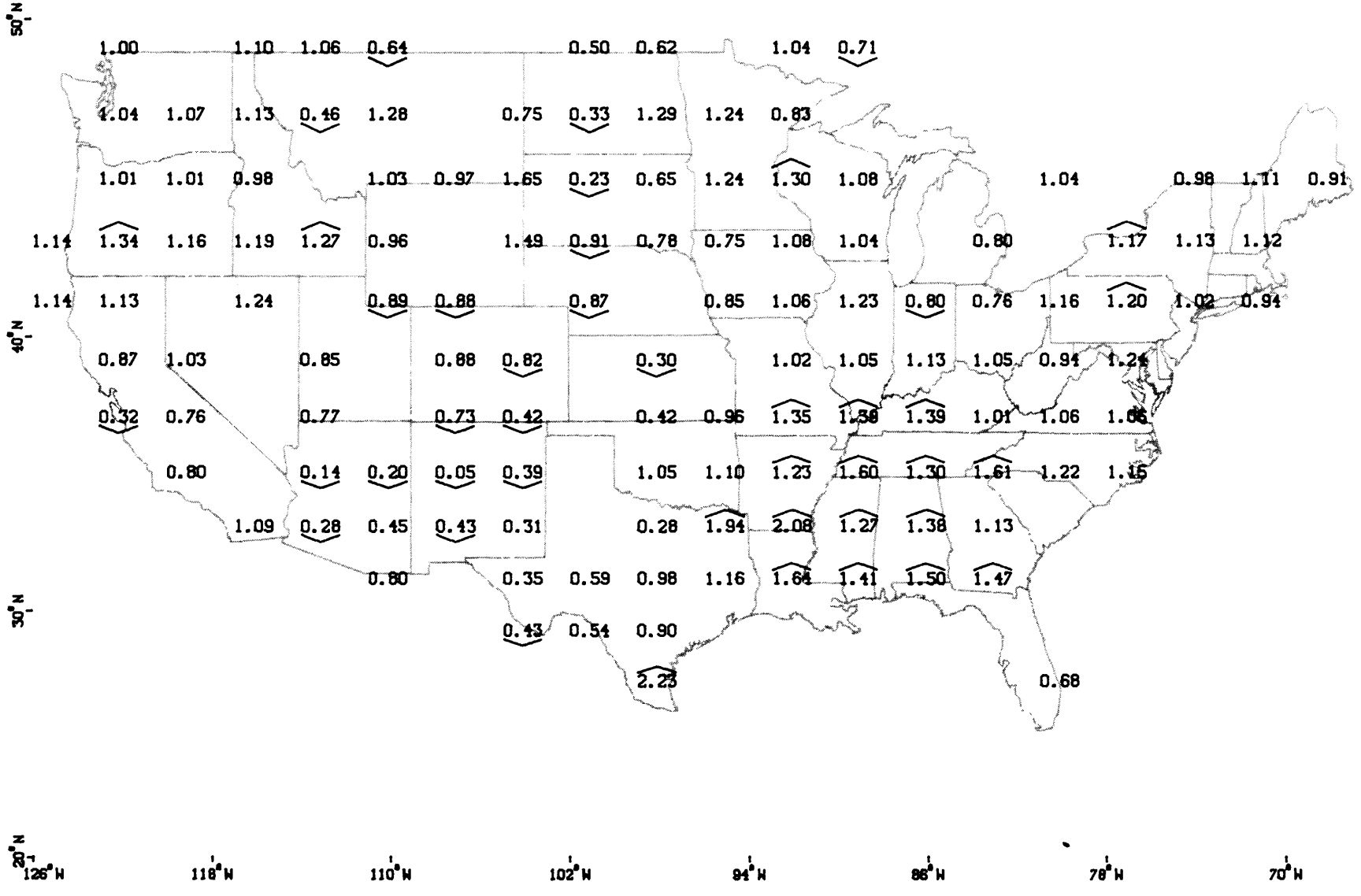

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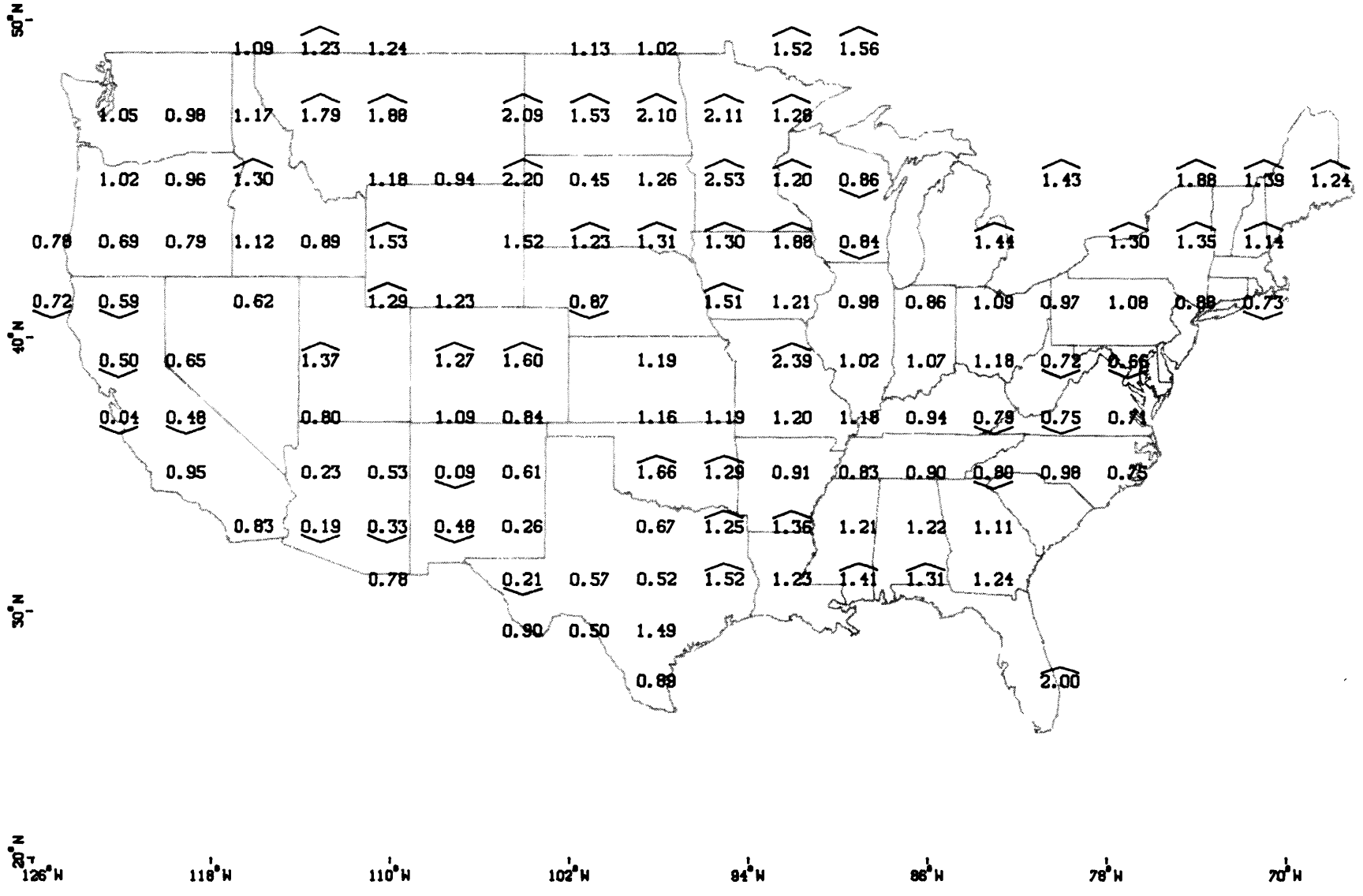

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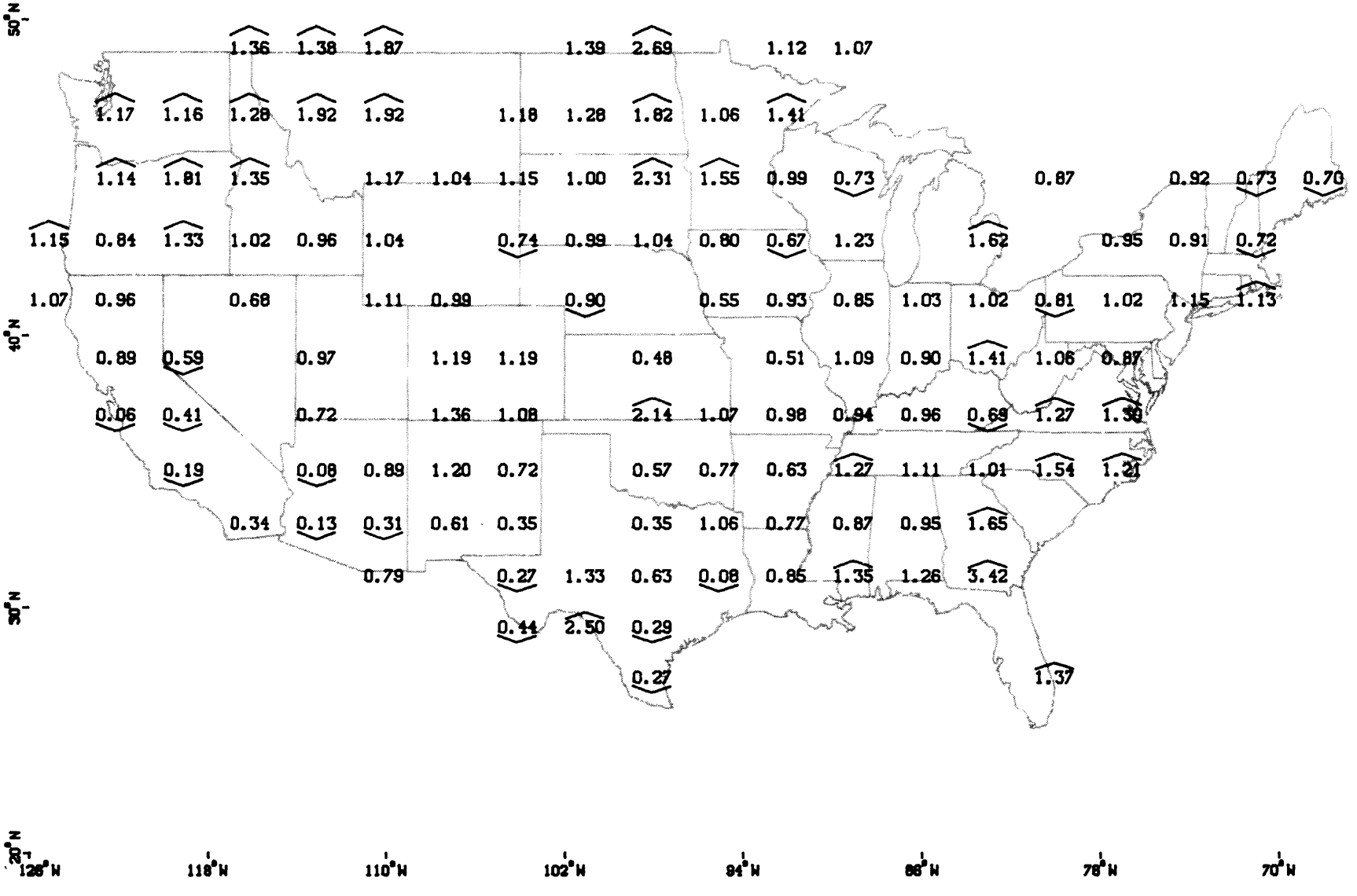

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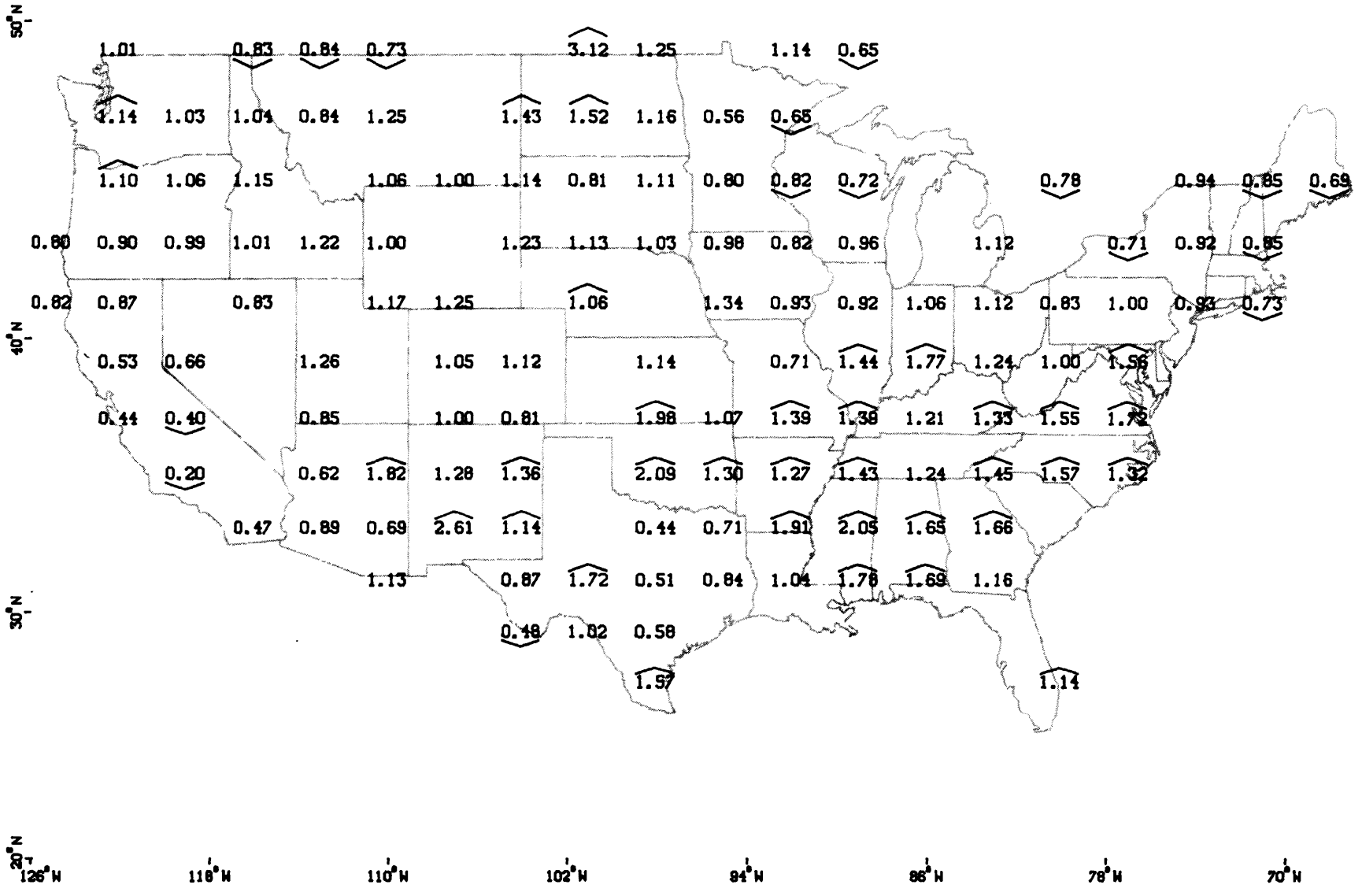

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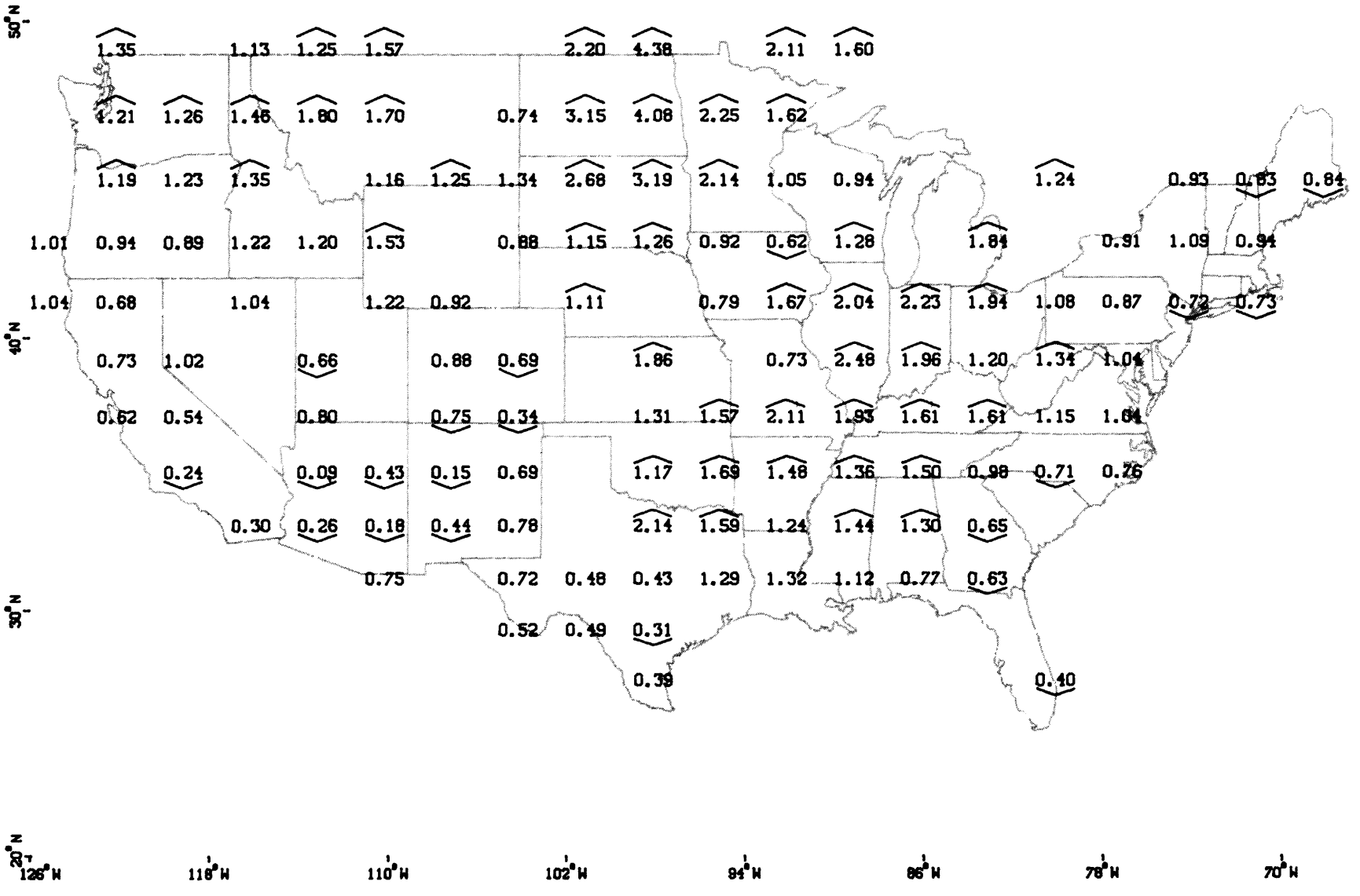

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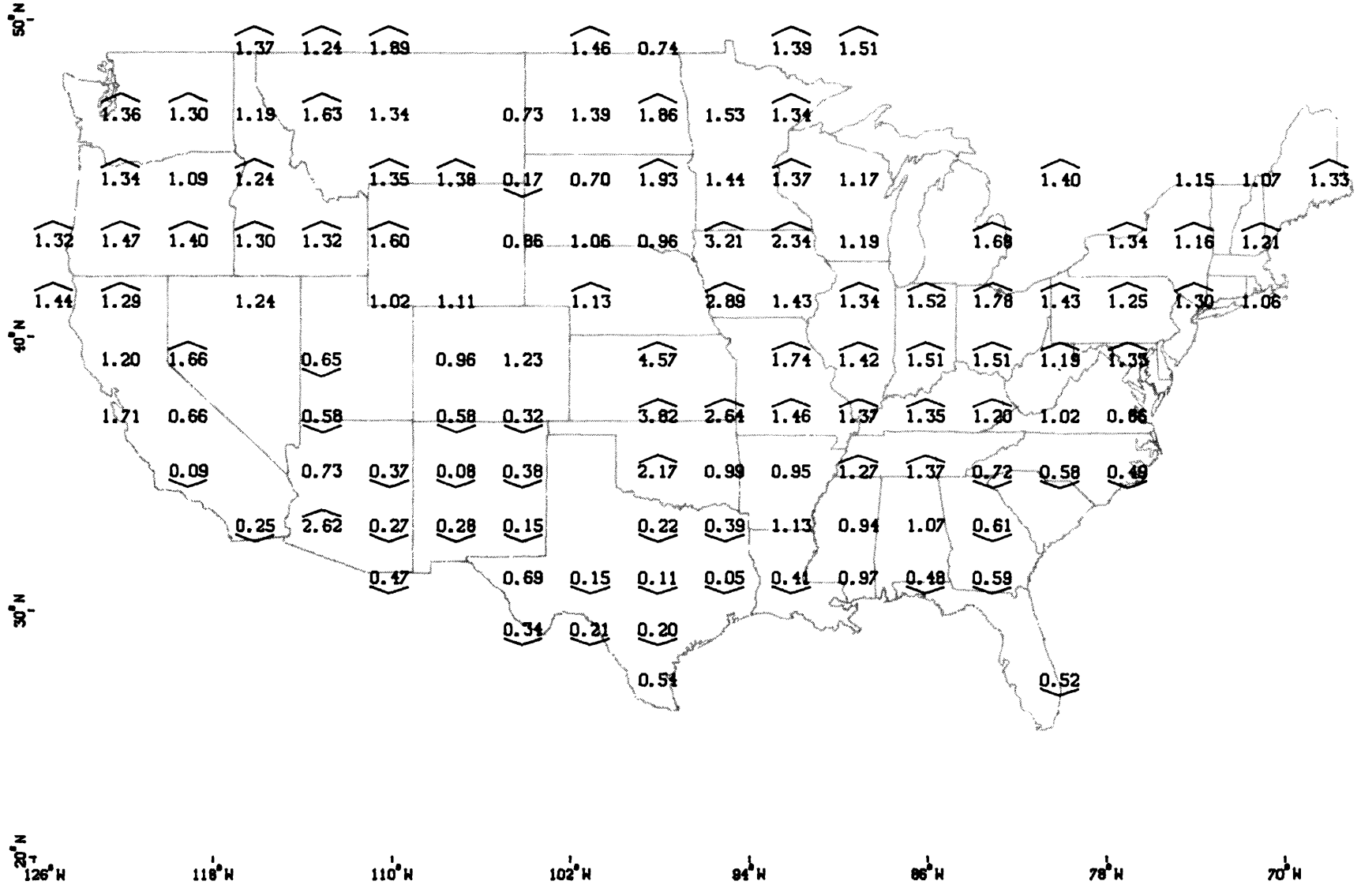

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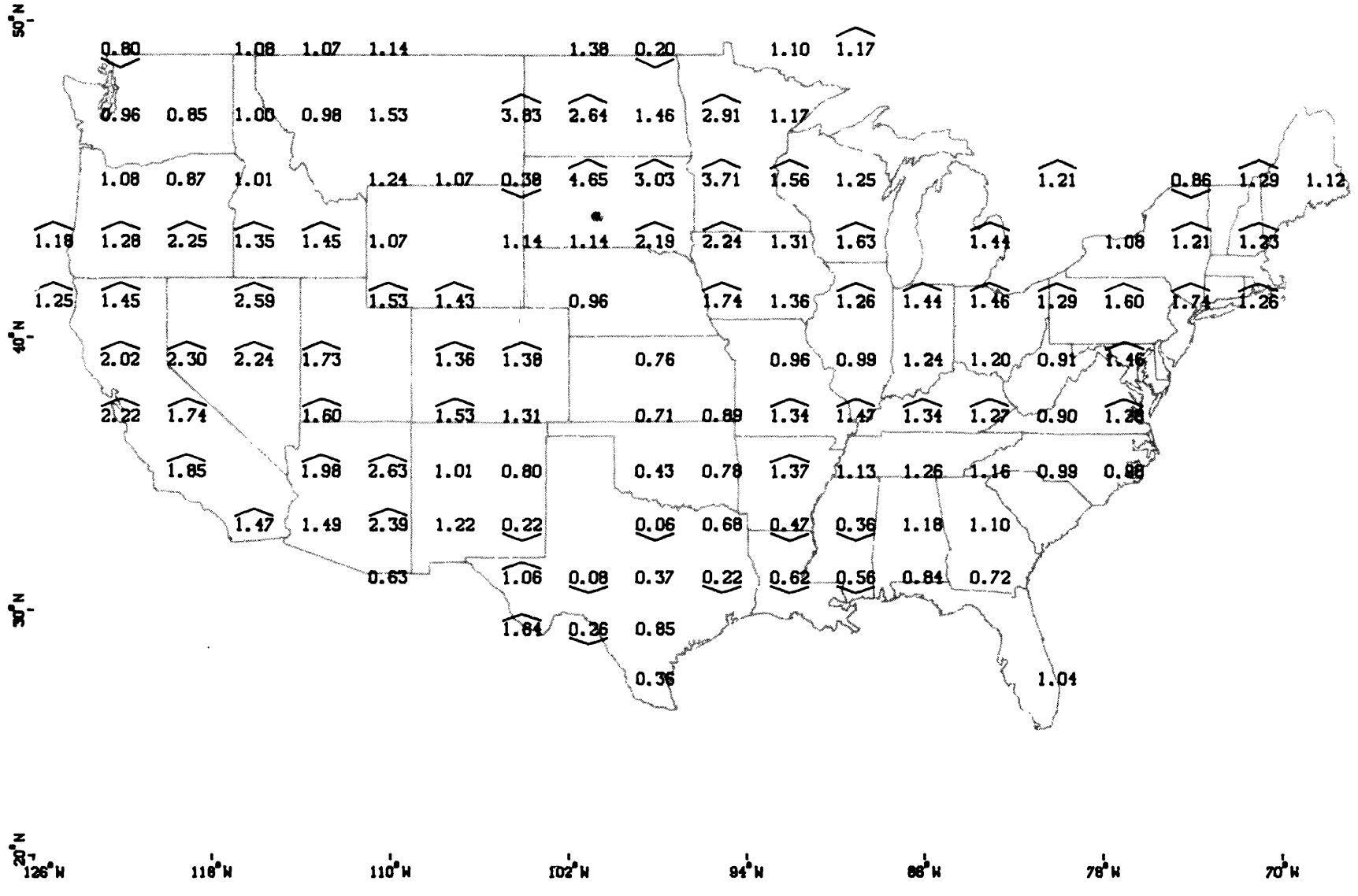

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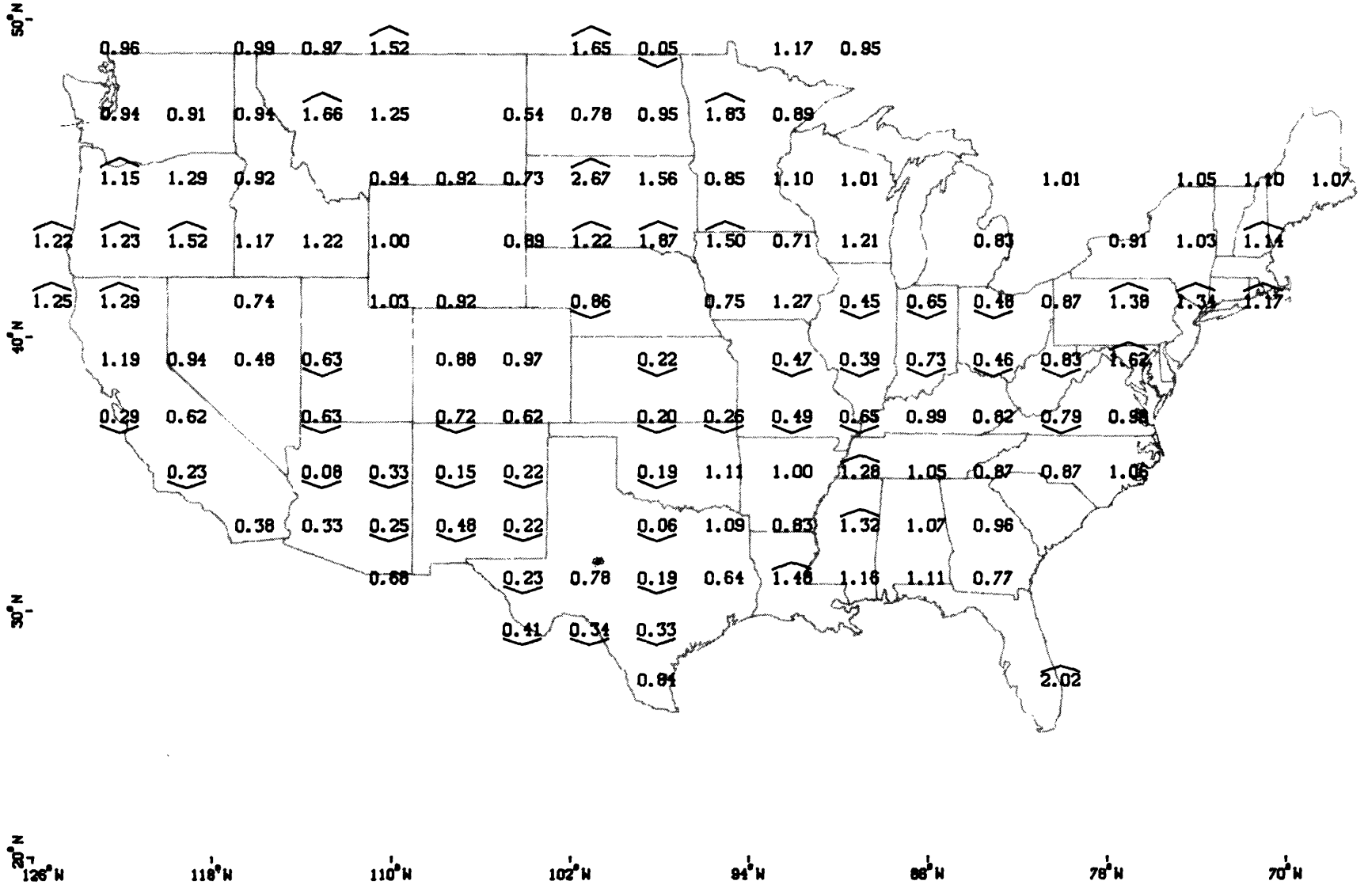

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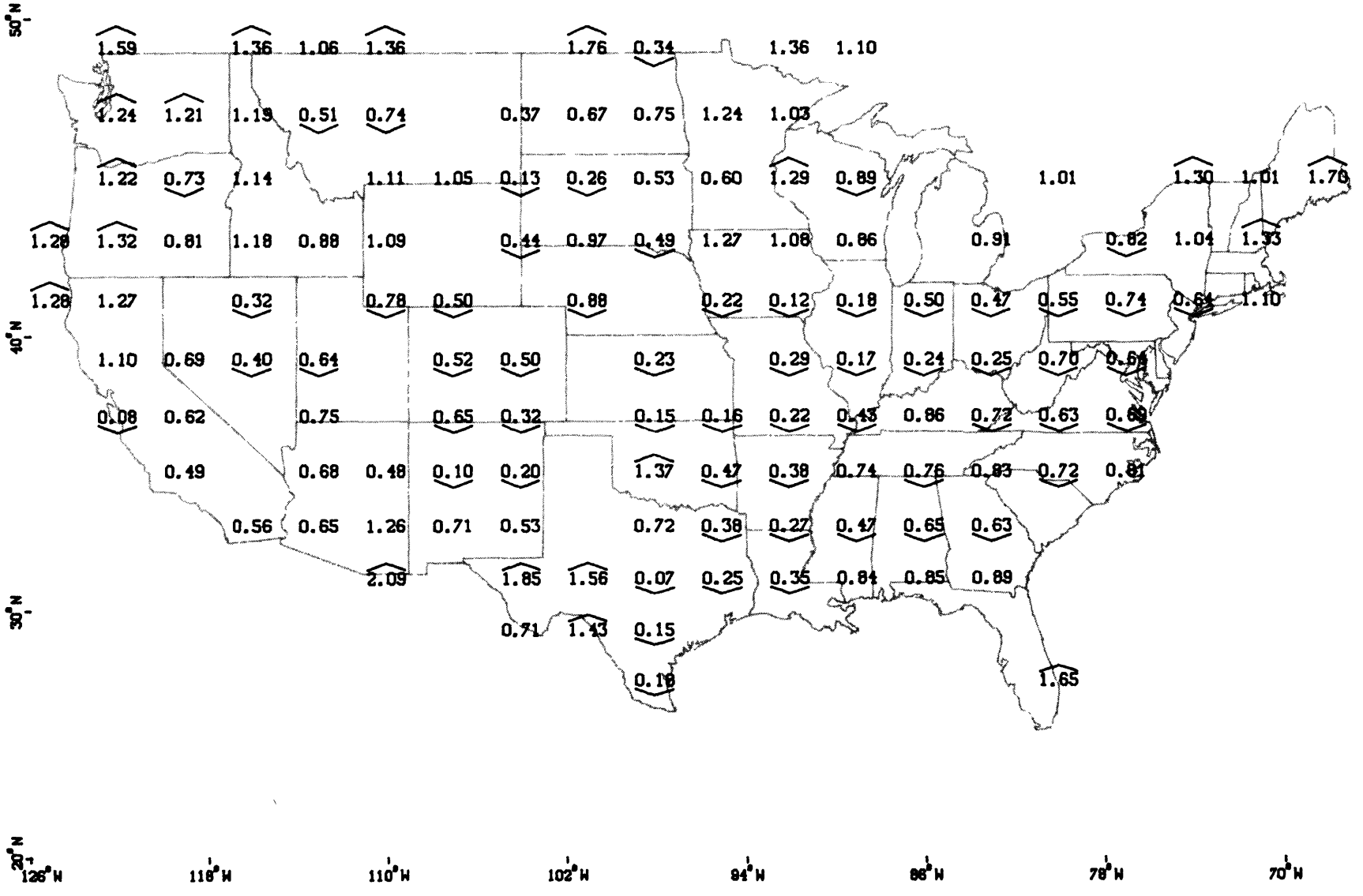

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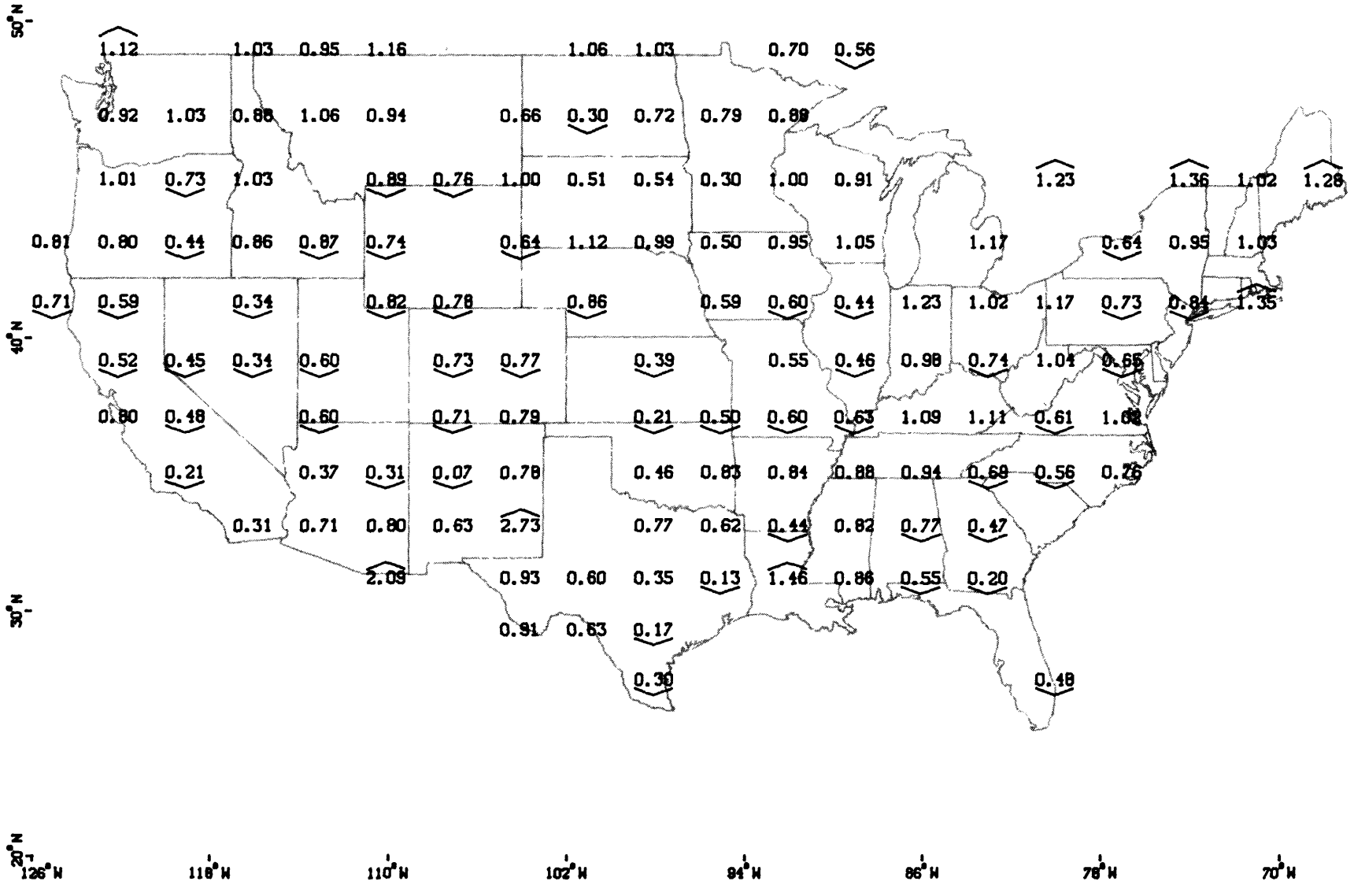

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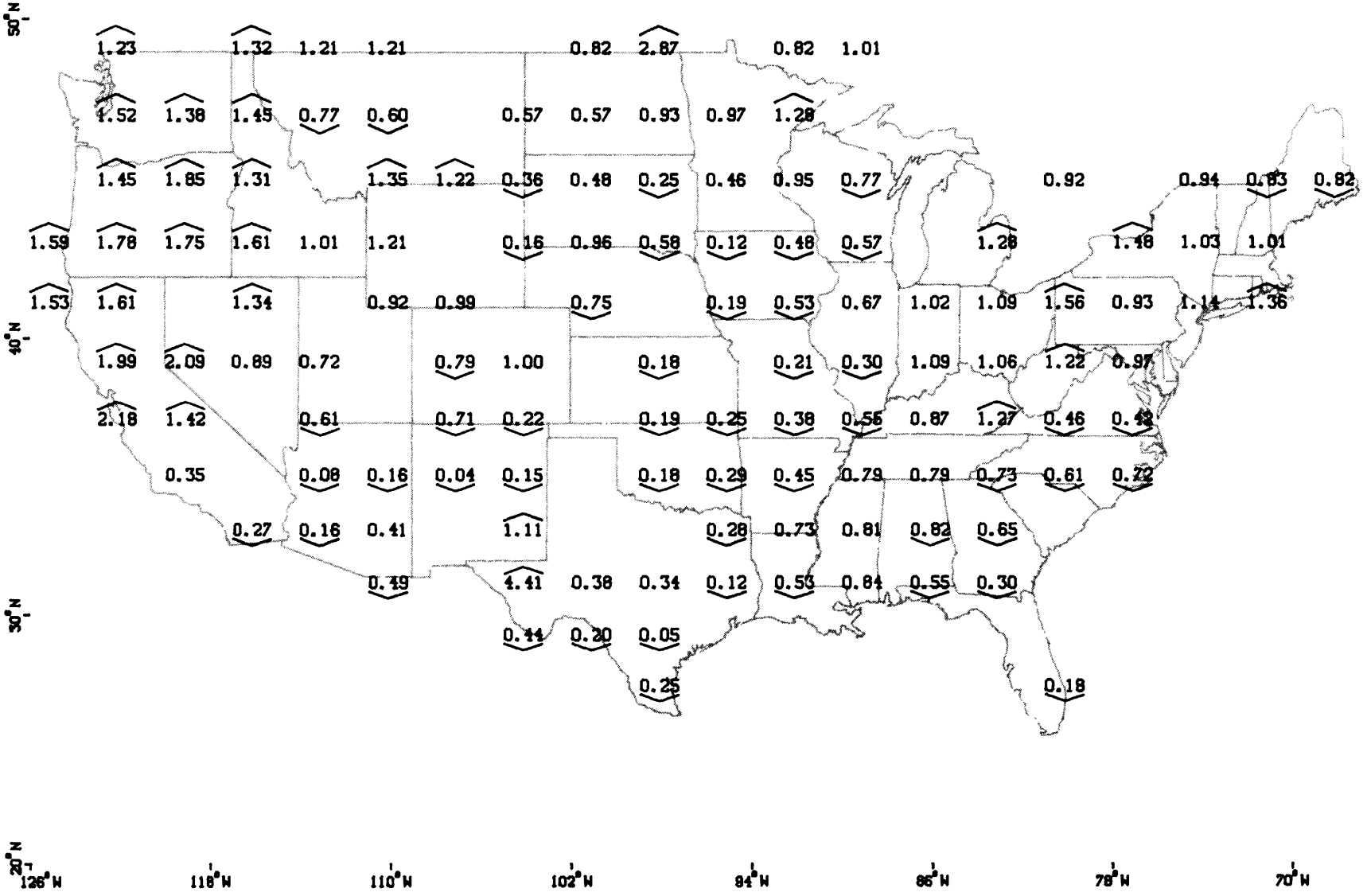

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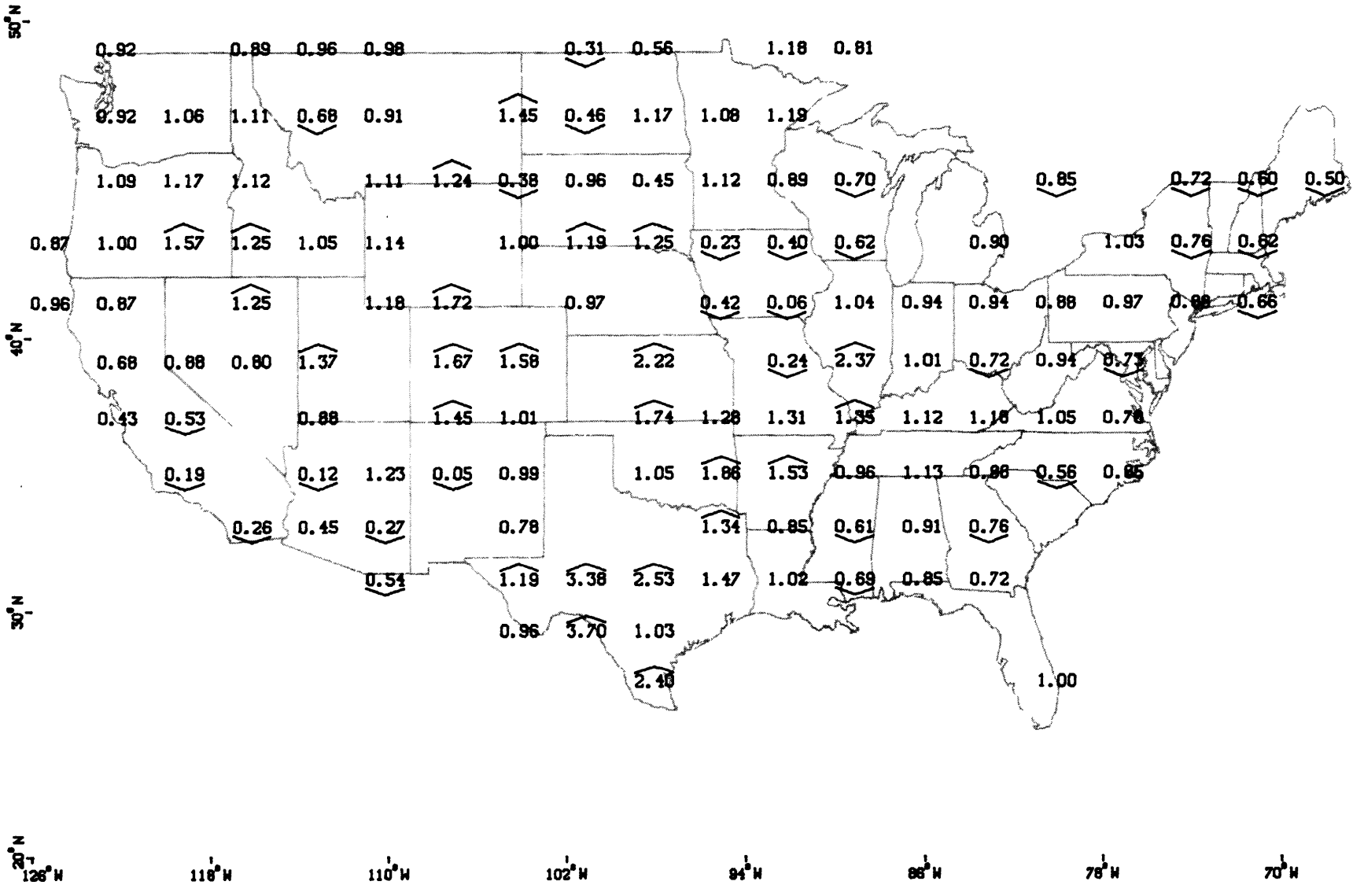

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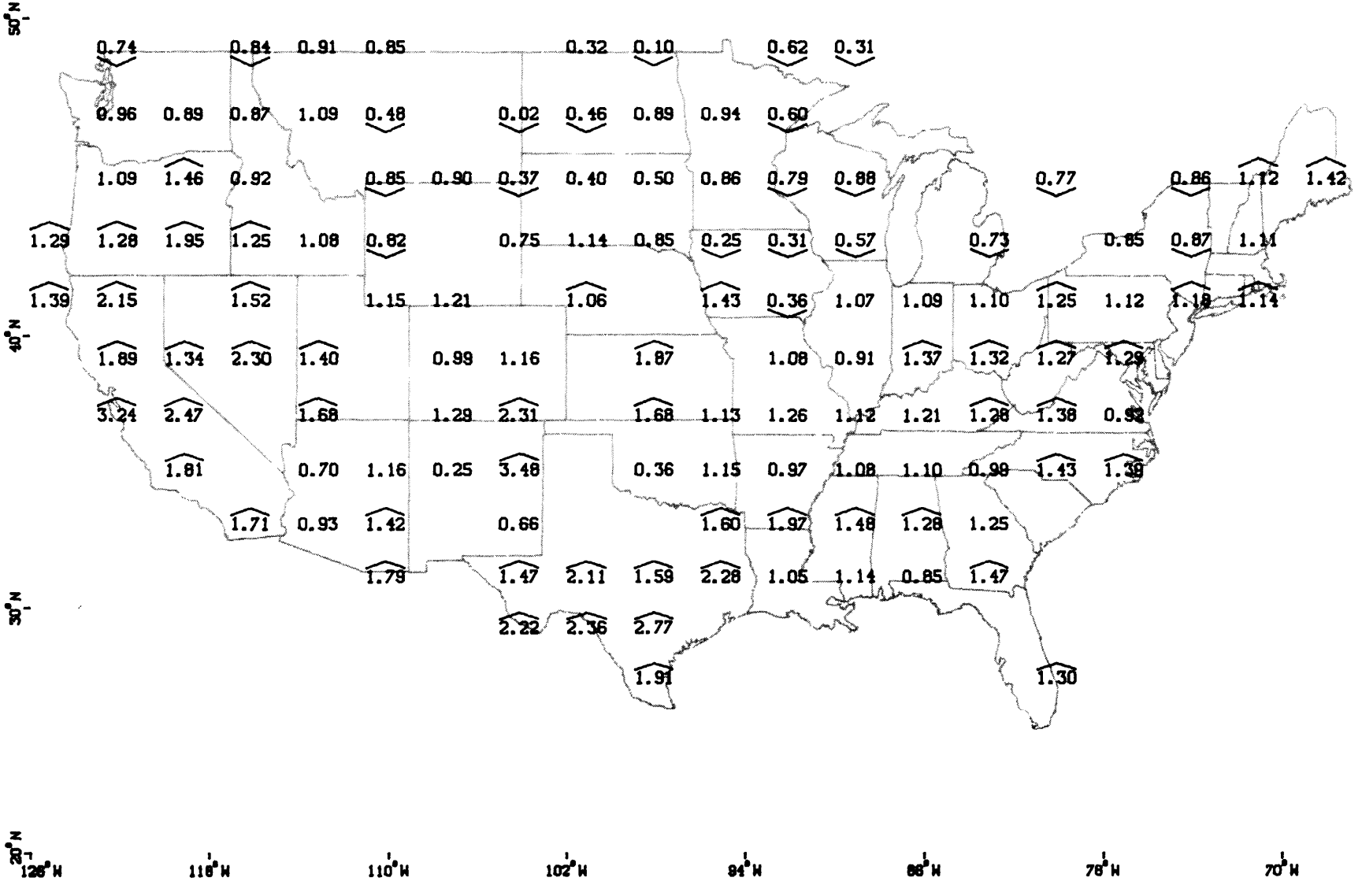

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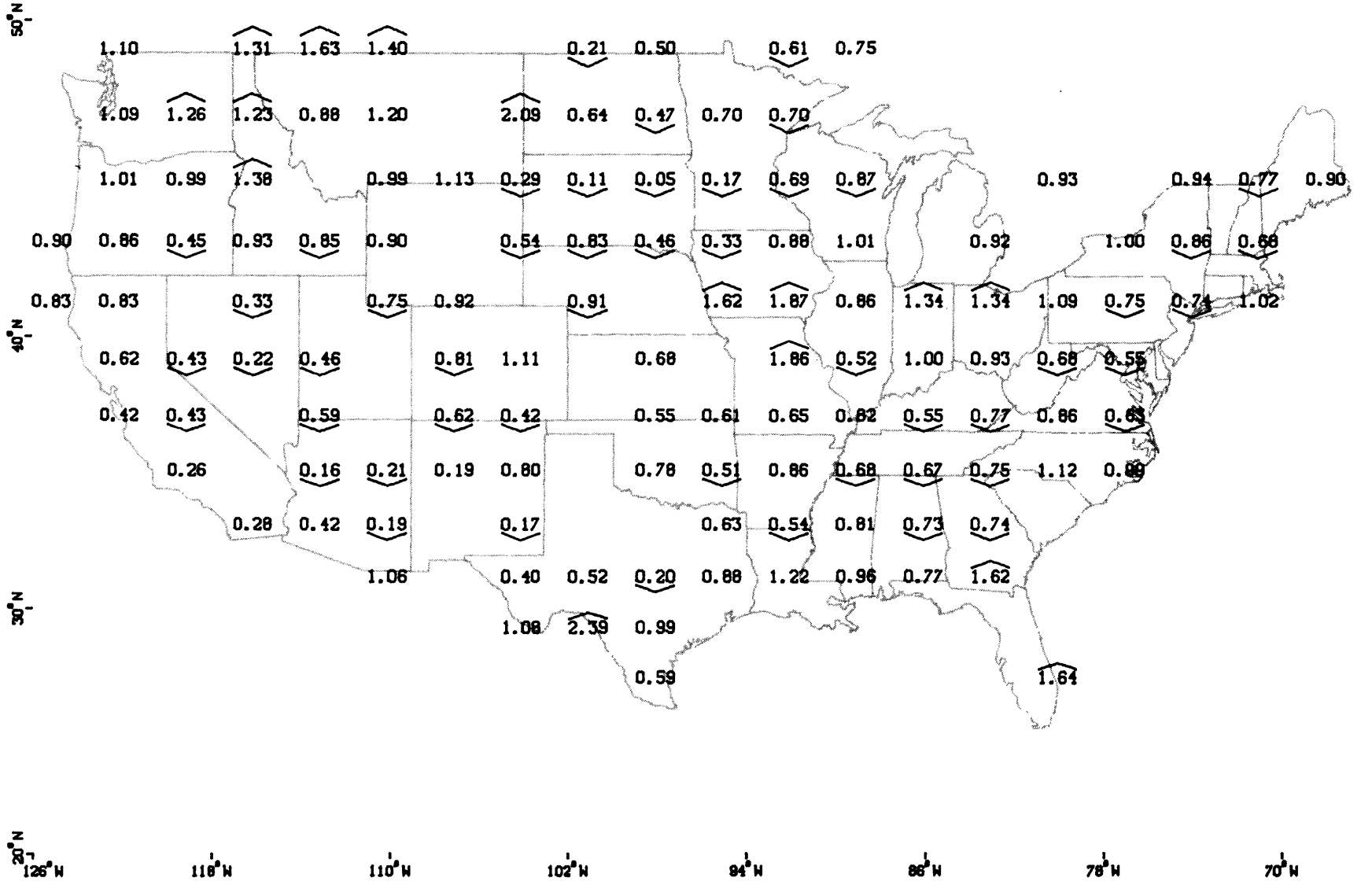

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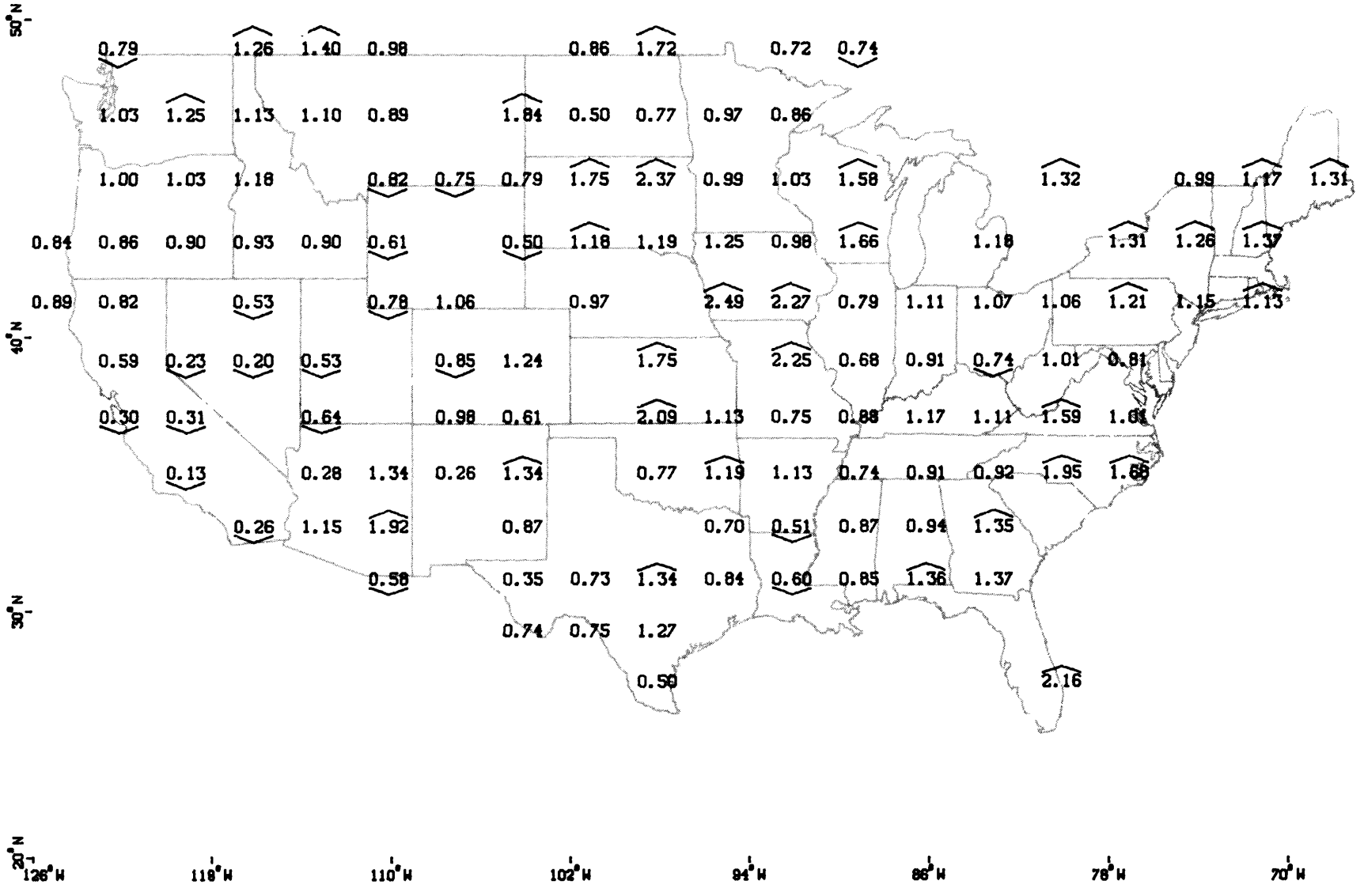

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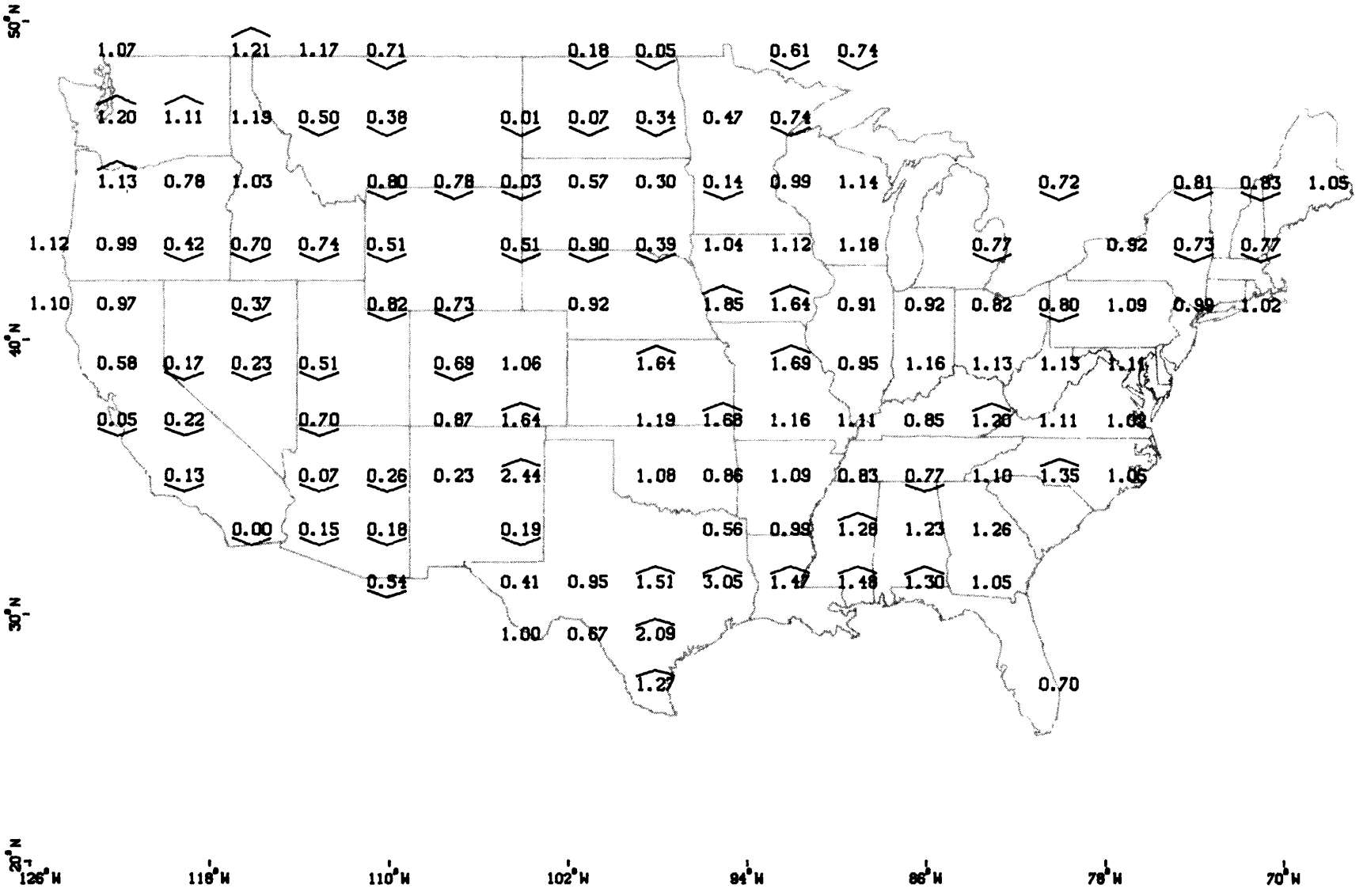

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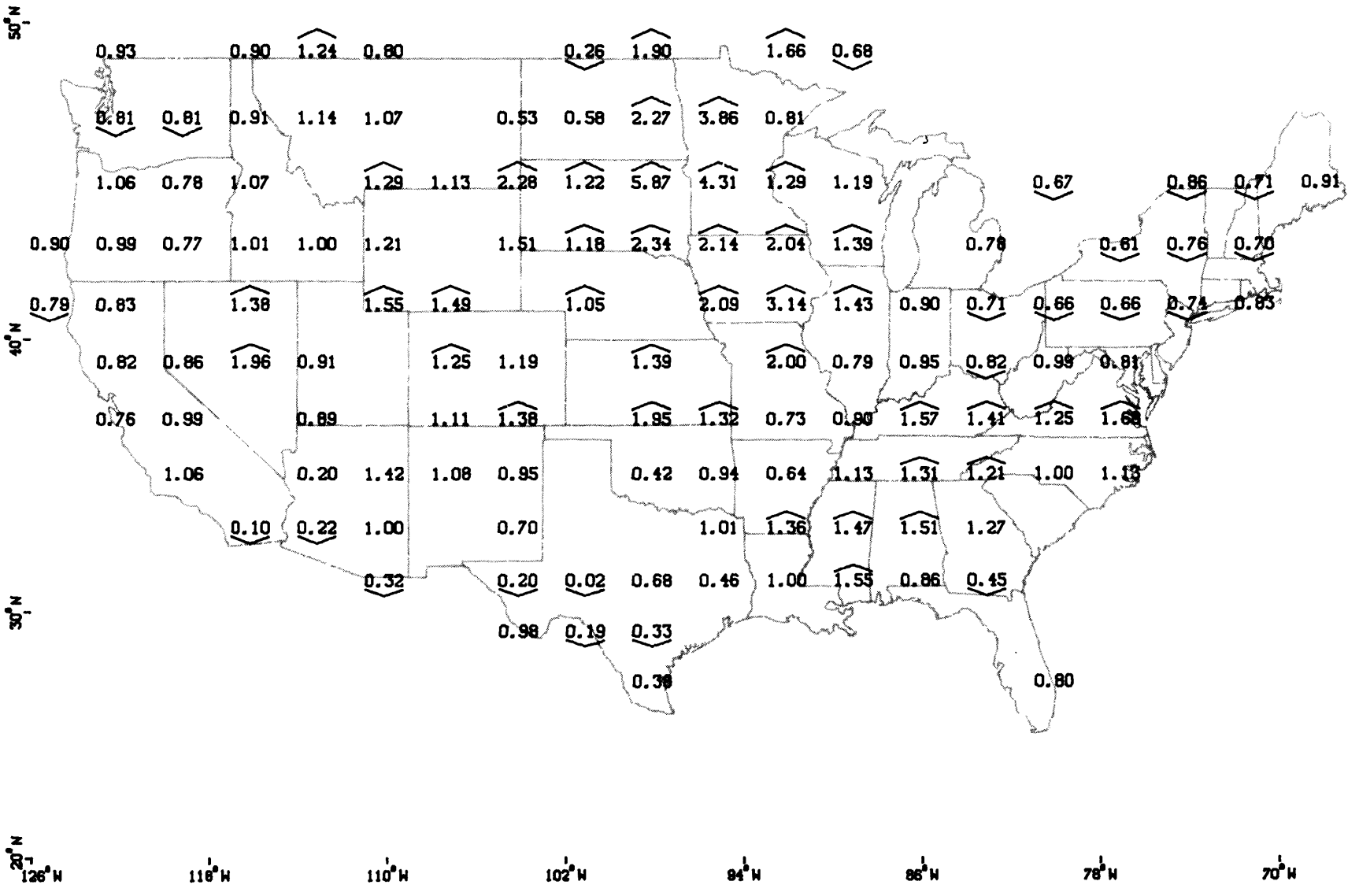

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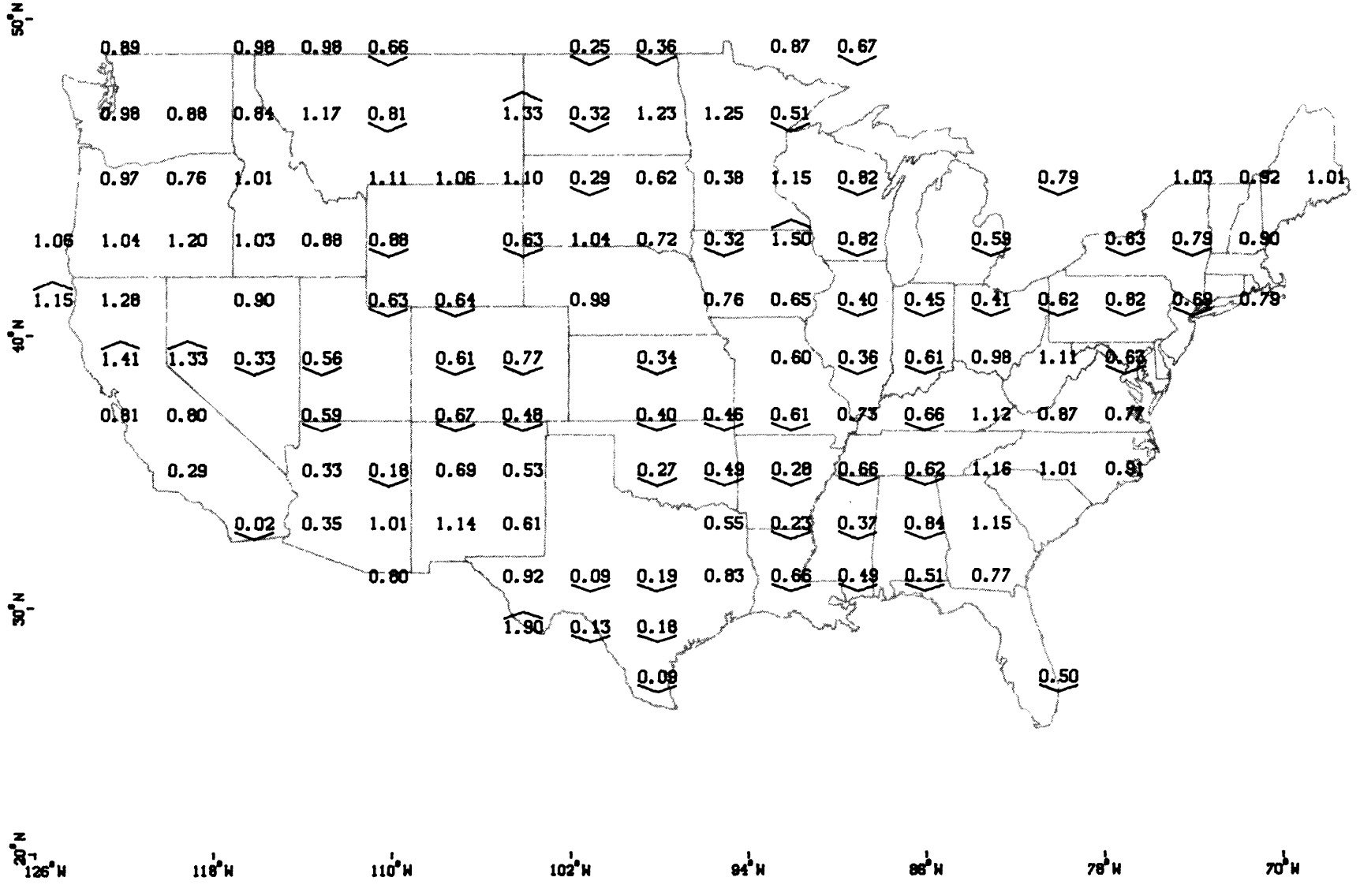

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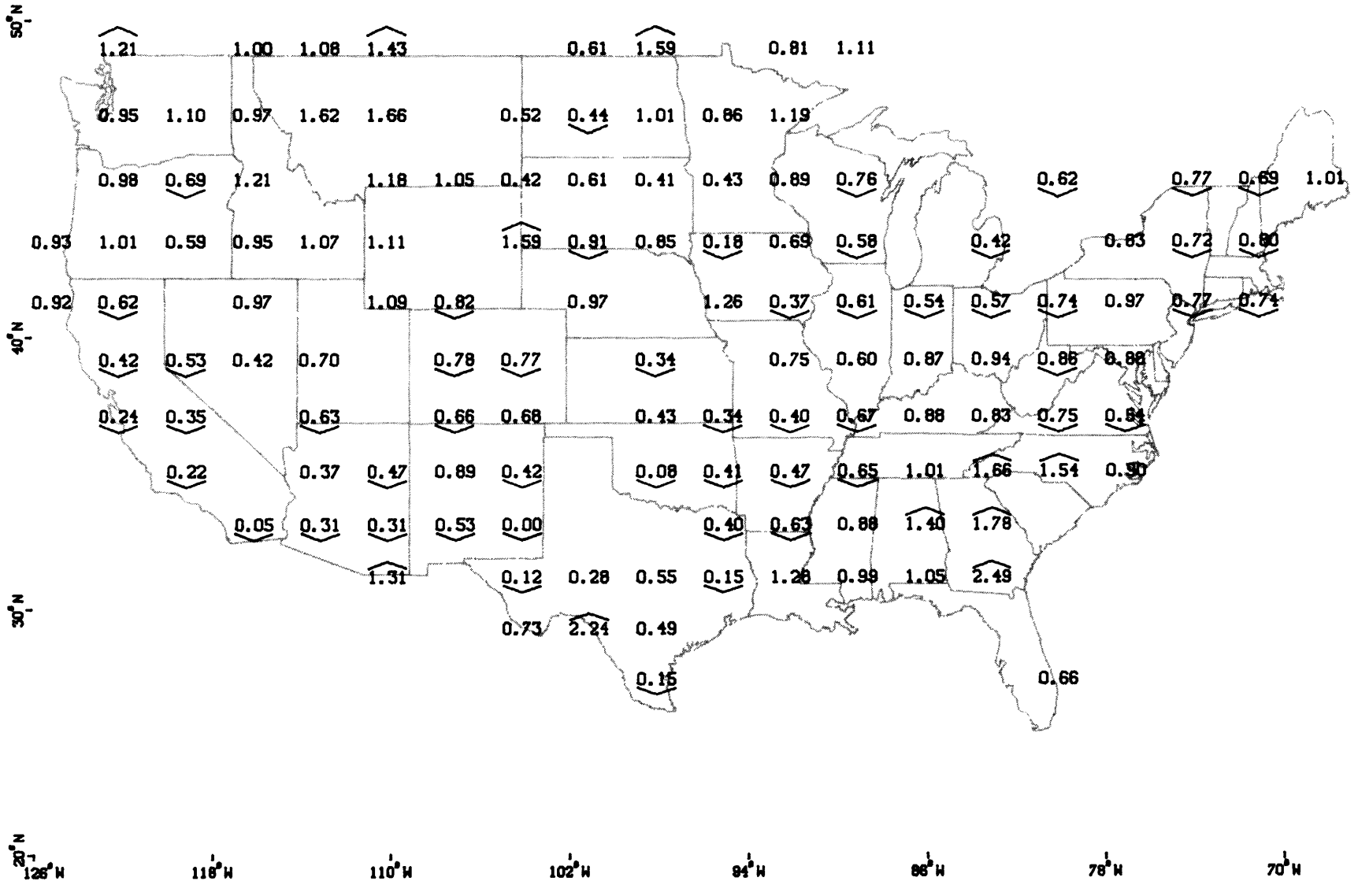

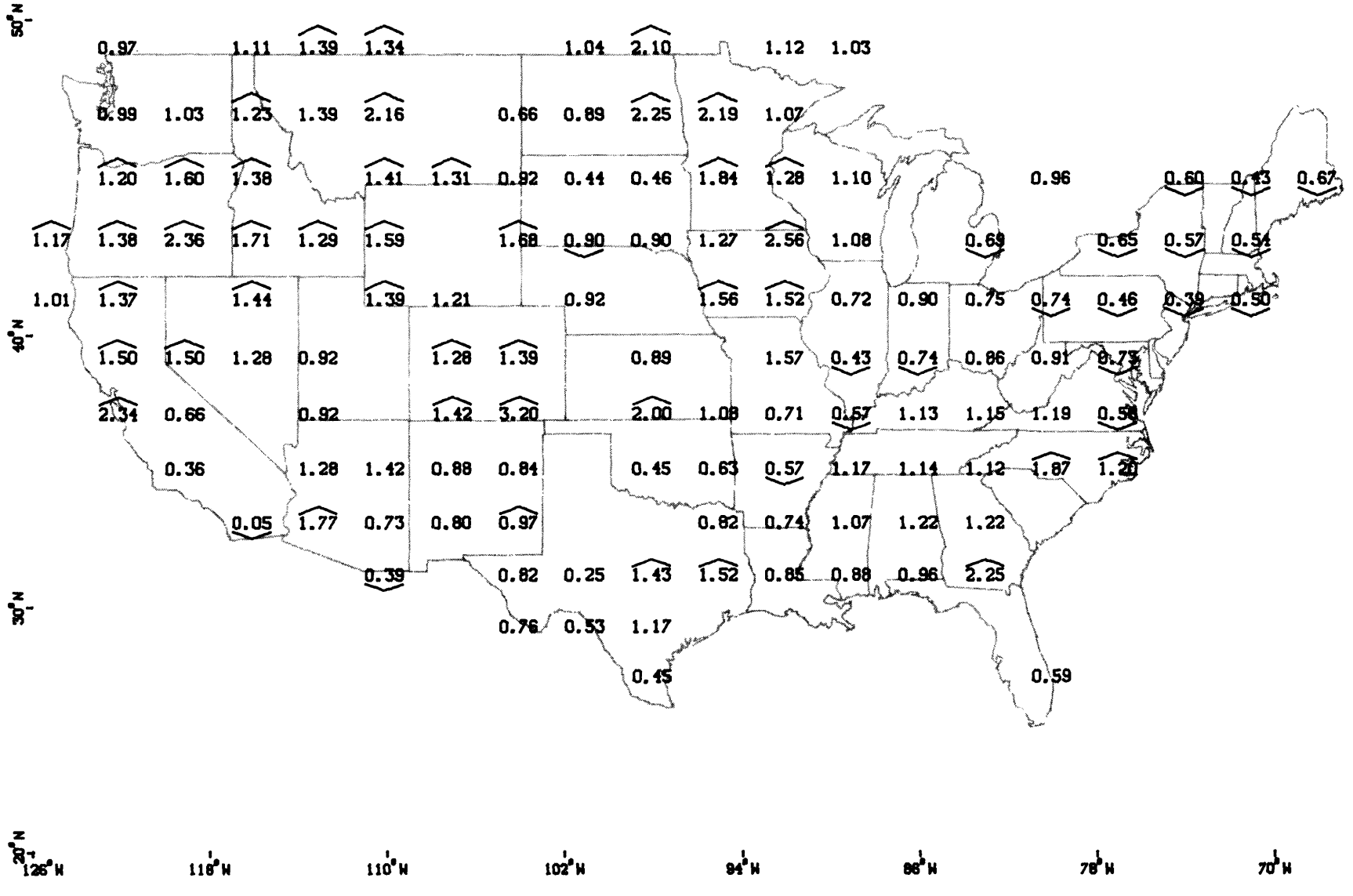
WATER YEAR 1965
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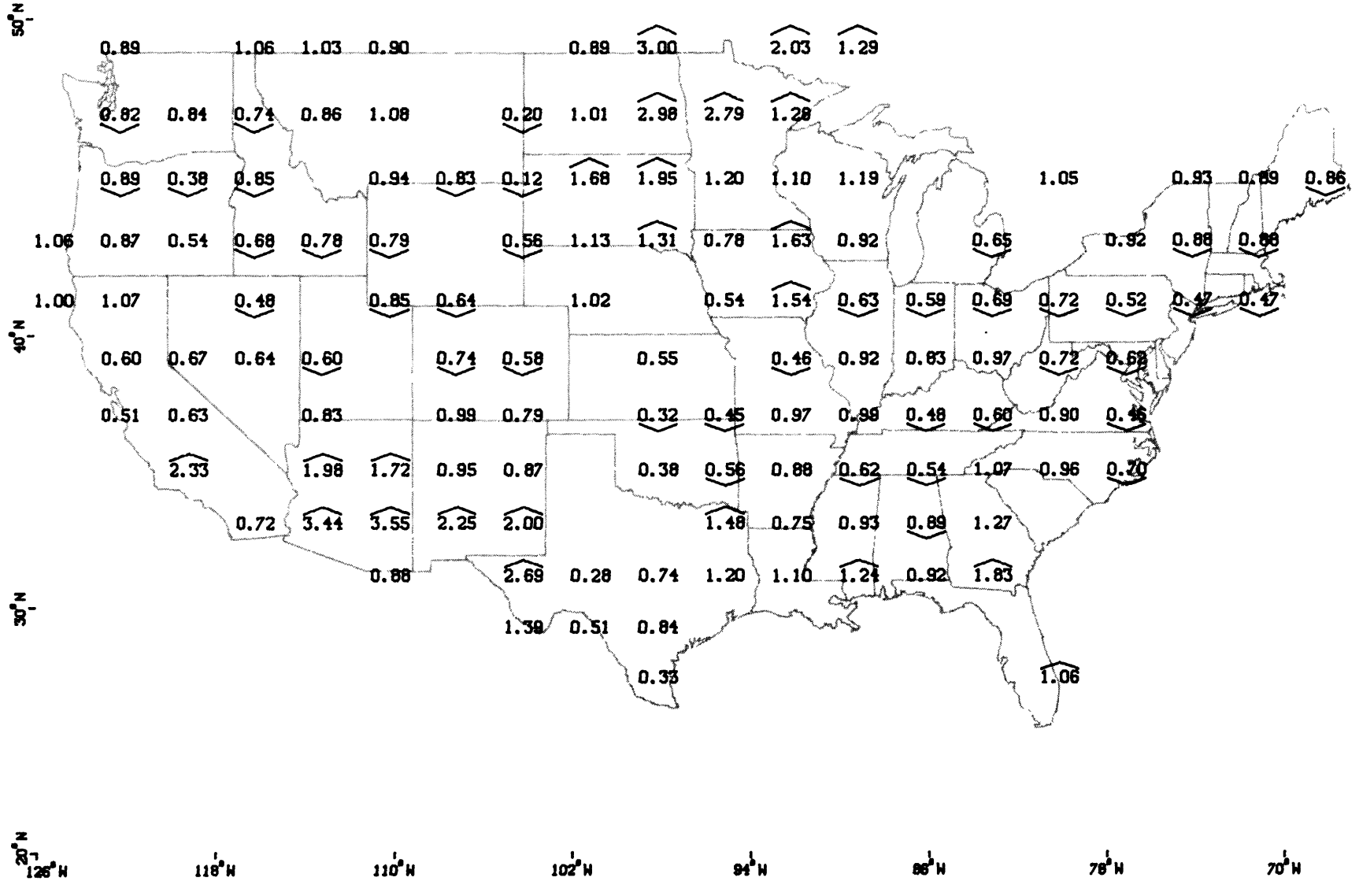
1.20 1.60 1.38 1.41 1.31 0.82 0.44 0.46 1.84 1.28 1.10 0.96 0.60 0.43 0.67
1.17 1.38 2.36 1.71 1.29 1.59 1.68 0.90 0.90 1.27 2.56 1.08 0.69 0.65 0.57 0.54
1.01 1.37 1.44 1.39 1.21 0.92 1.56 1.52 0.72 0.90 0.75 0.74 0.46 0.39 0.50
1.50 1.50 1.28 0.92 1.28 1.39 0.89 1.57 0.43 0.74 0.86 0.91 0.73
2.34 0.66 0.92 1.42 3.20 2.00 1.08 0.71 0.57 1.13 1.15 1.19 0.58
0.36 1.28 1.42 0.88 0.84 0.45 0.63 0.57 1.17 1.14 1.12 1.87 1.20
0.05 1.77 0.73 0.80 0.97 0.82 0.74 1.07 1.22 1.22
0.39 0.82 0.25 1.43 1.52 0.85 0.88 0.96 2.25
0.76 0.53 1.17
0.45 0.59
50°N
40°N
30°N
20°N
125°W
118°W
110°W
102°W
94°W
86°W
78°W
70°W

WATER YEAR 1966



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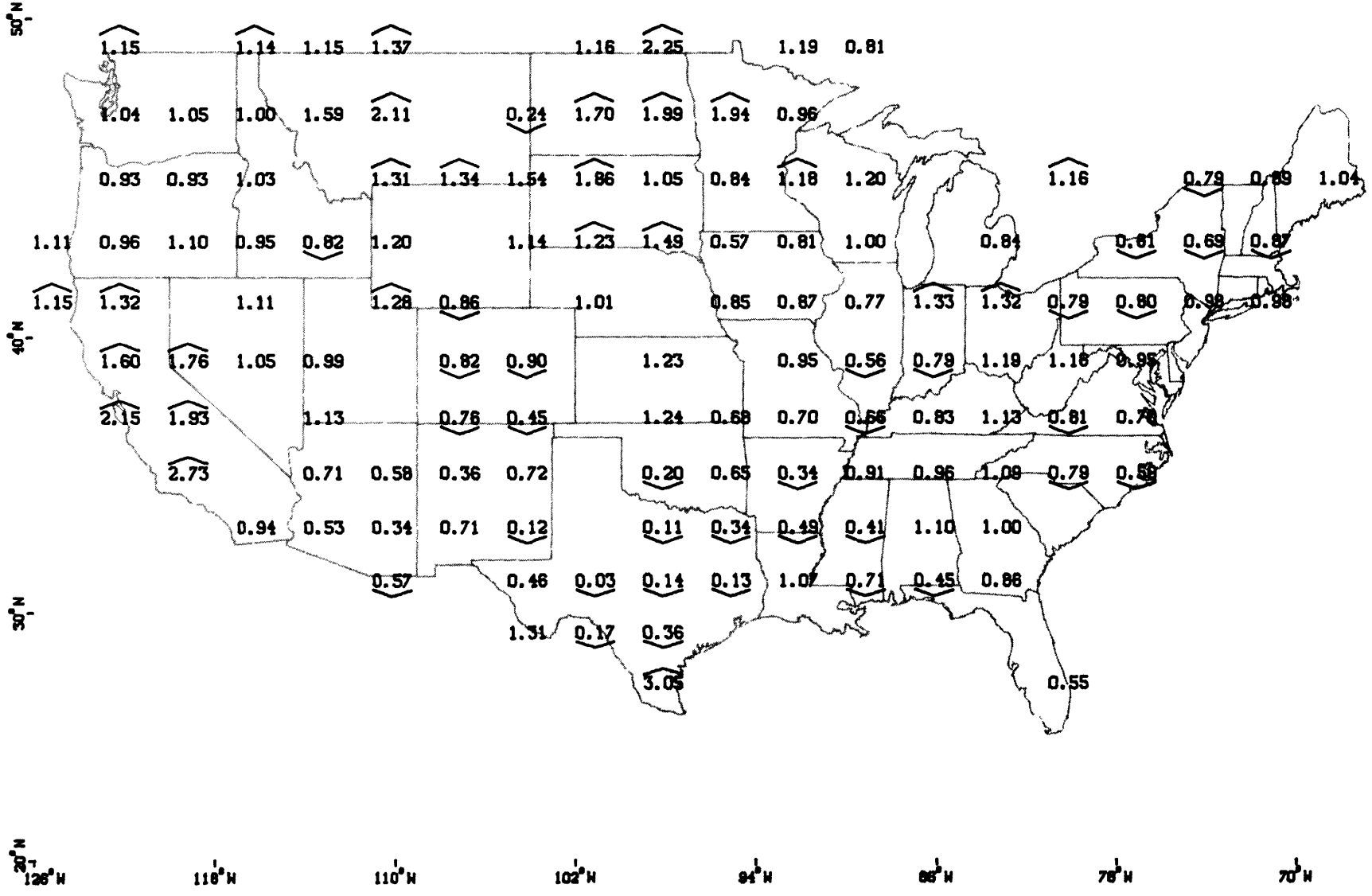
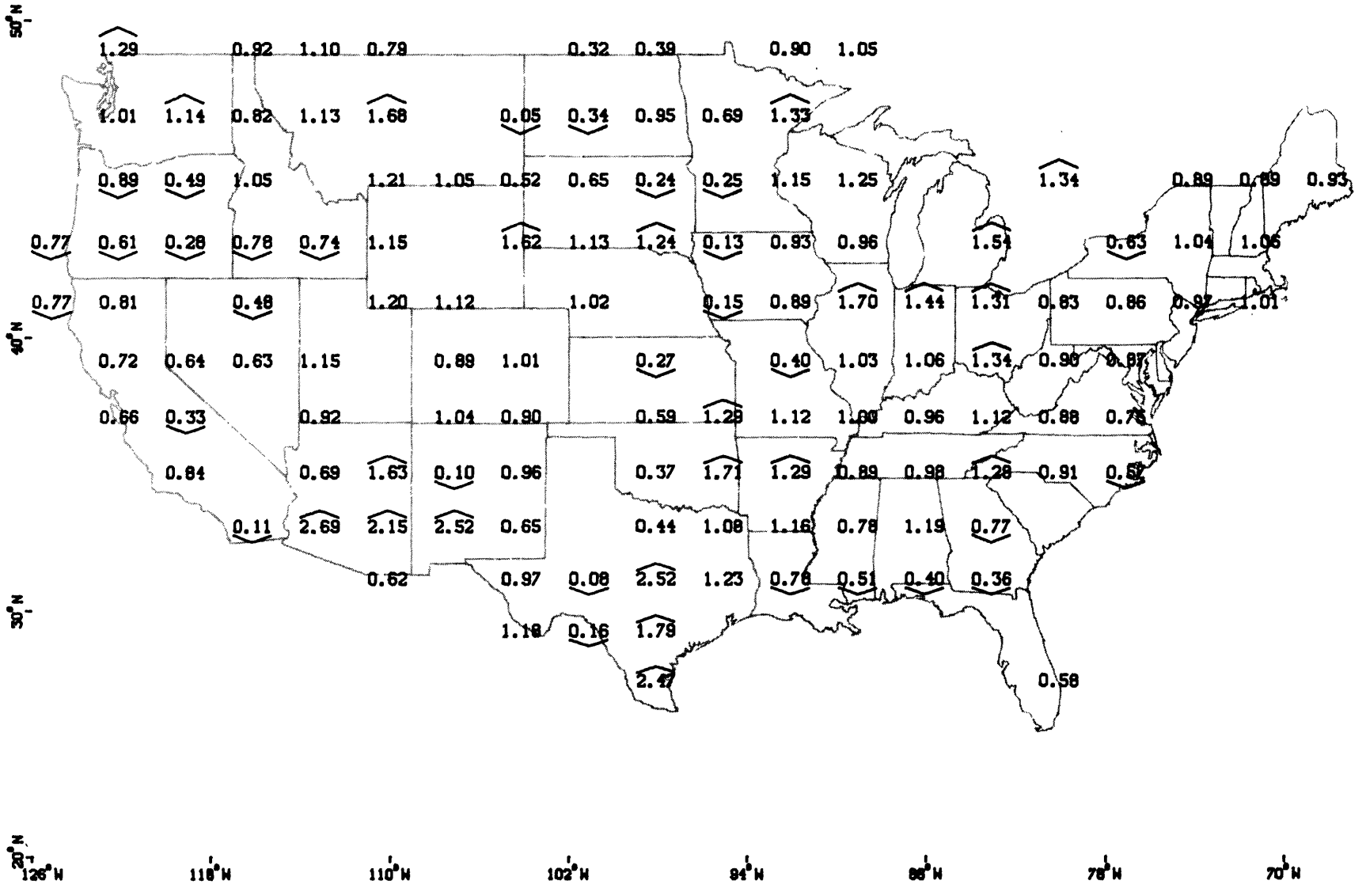


WATER YEAR 1968



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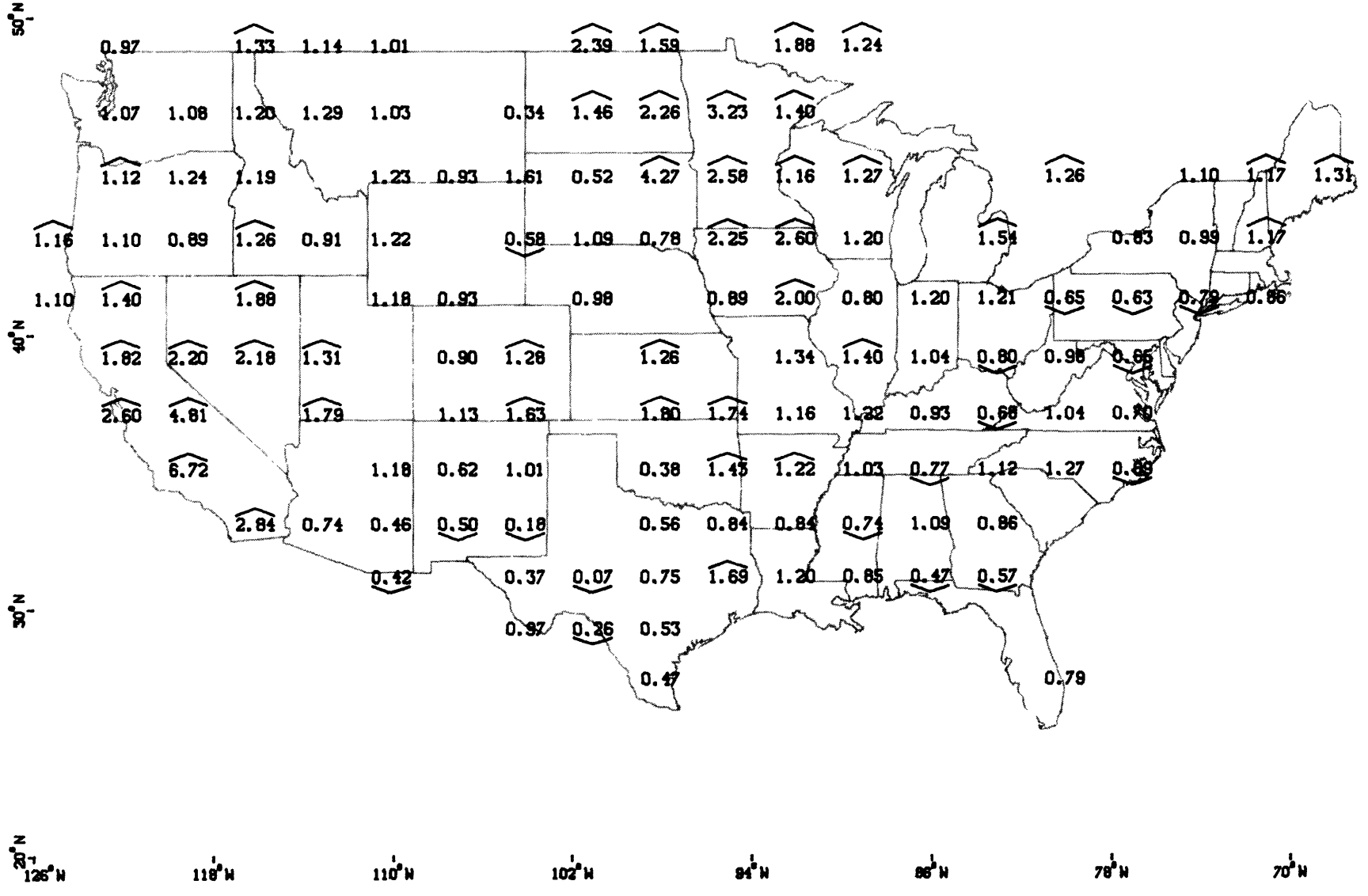

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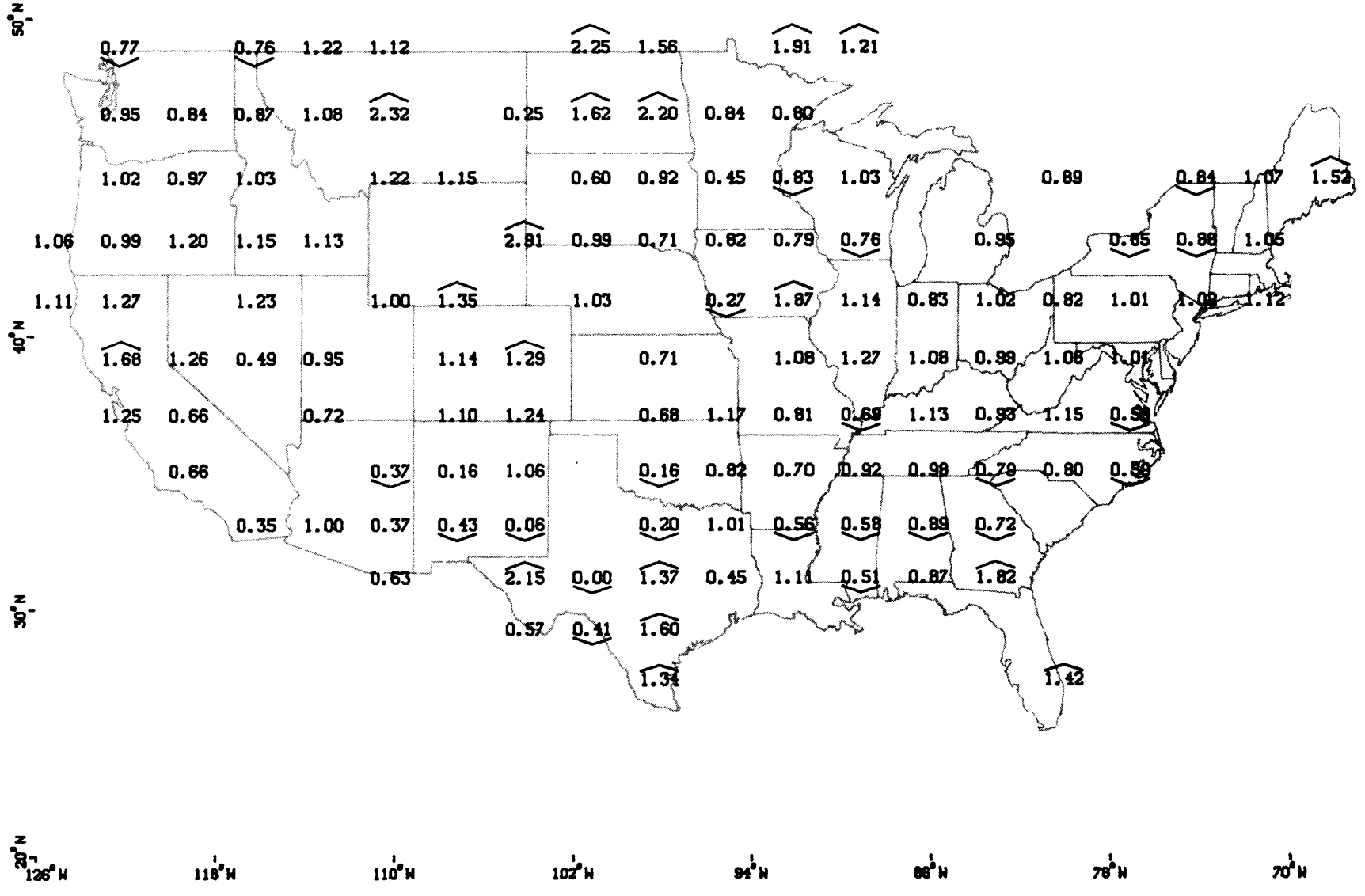

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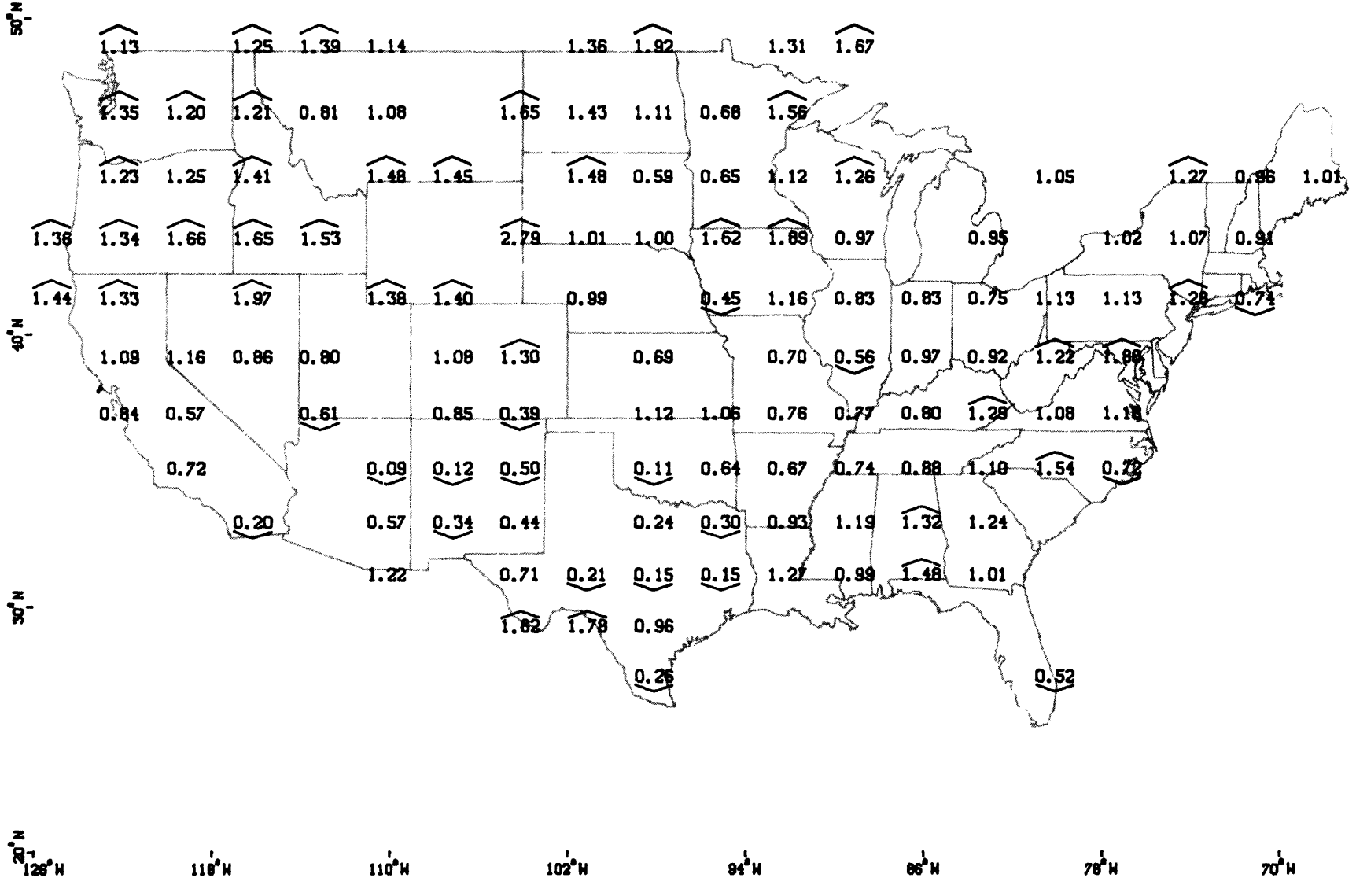

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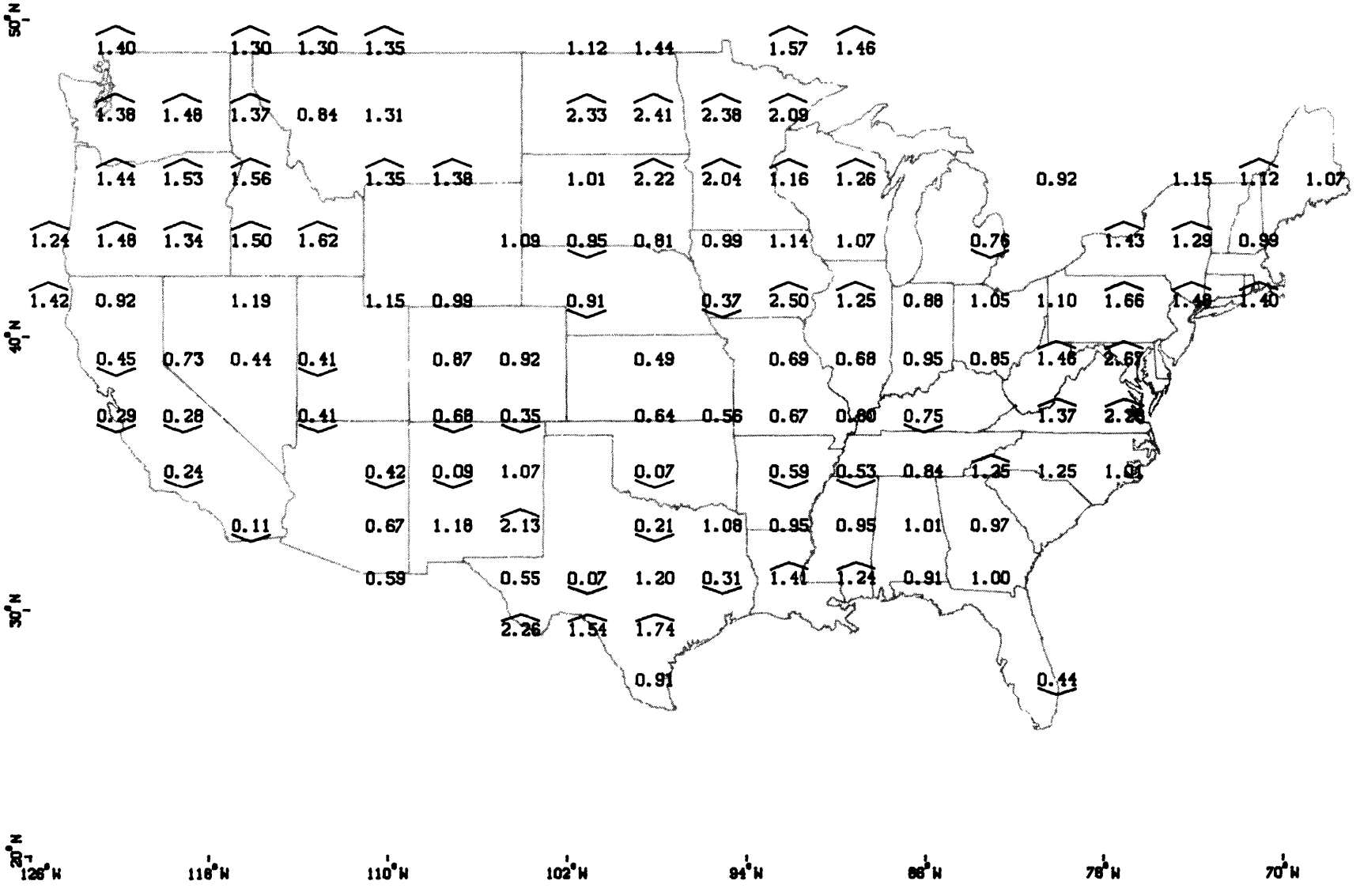

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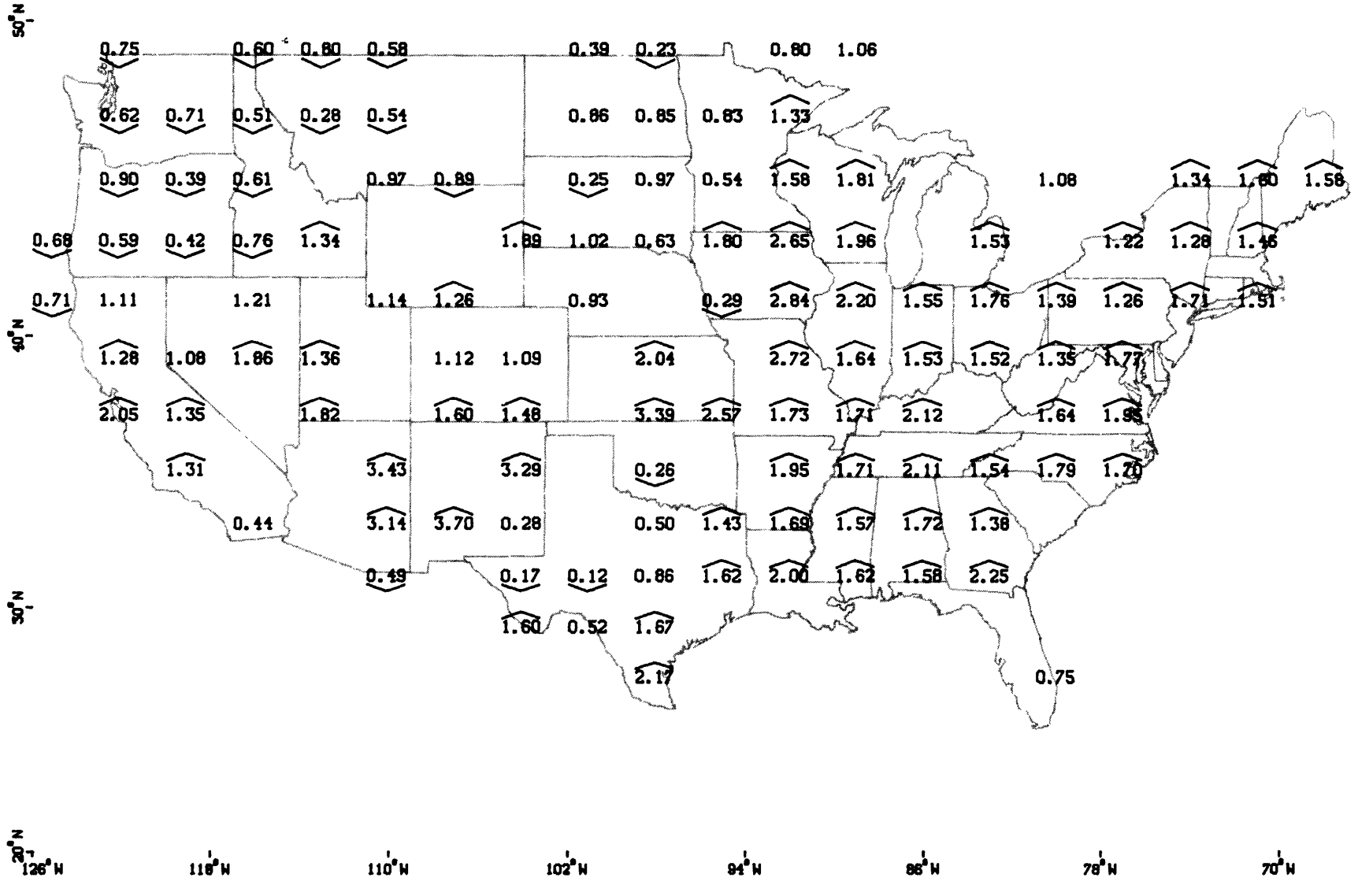

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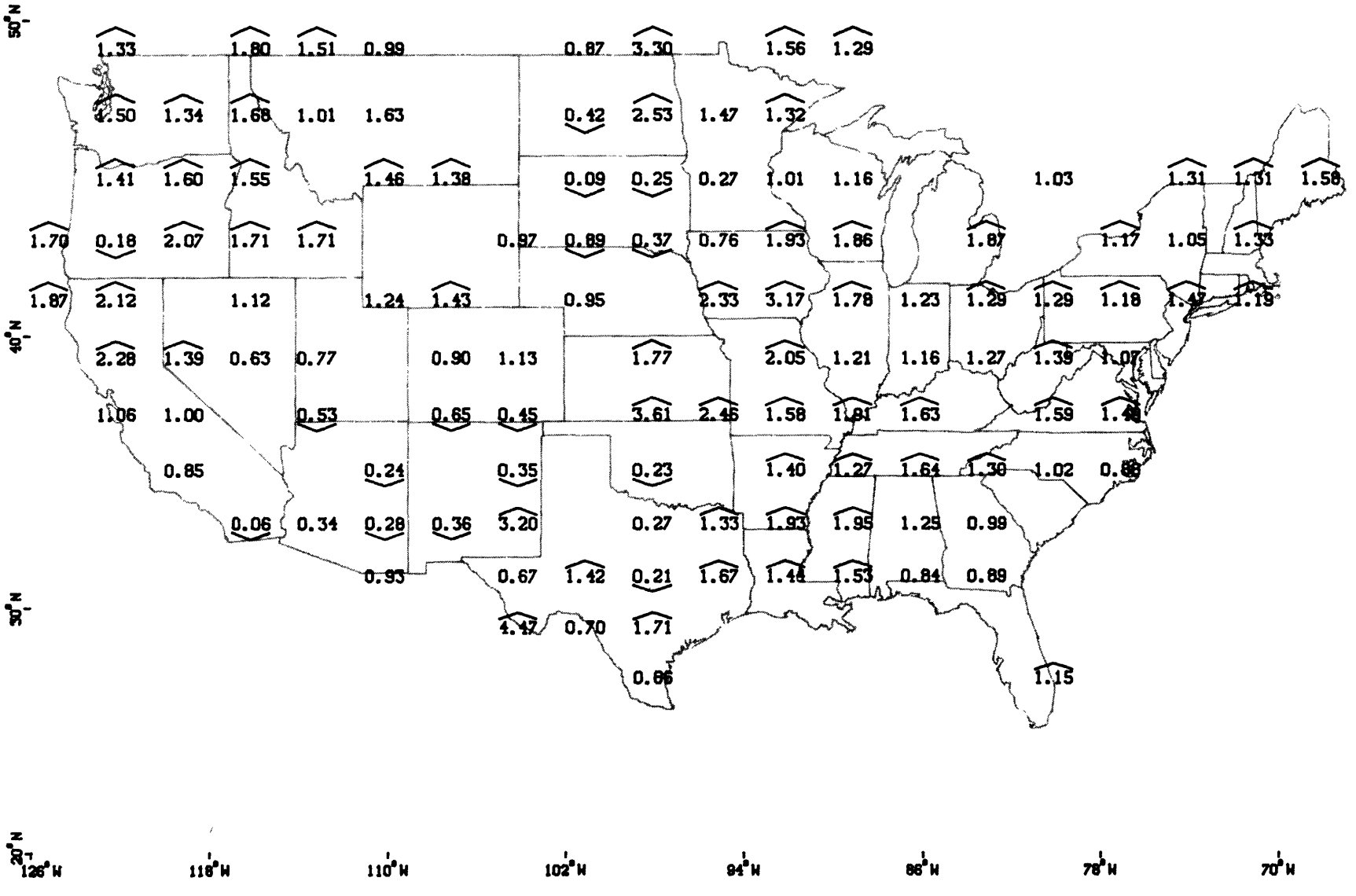

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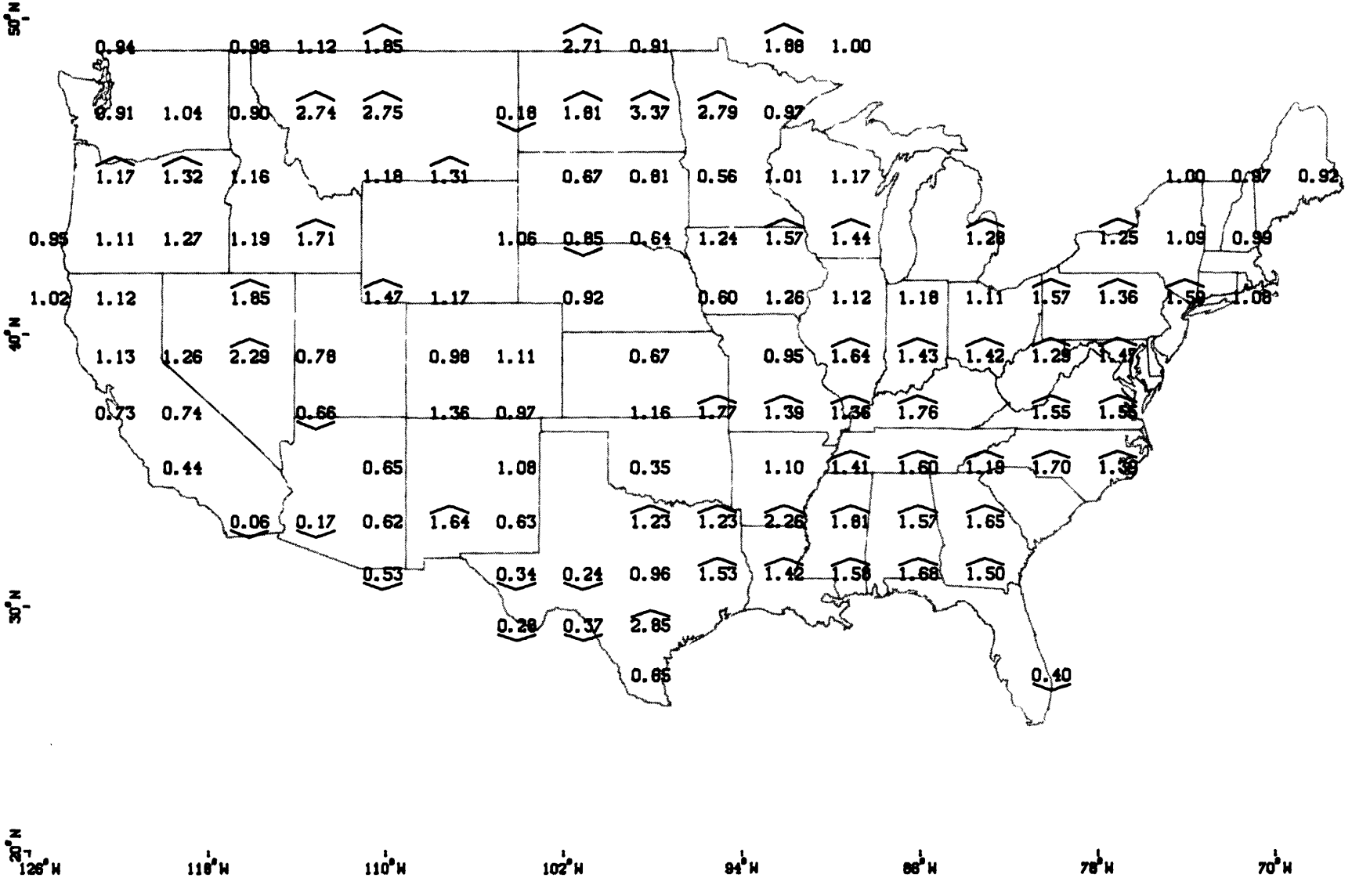

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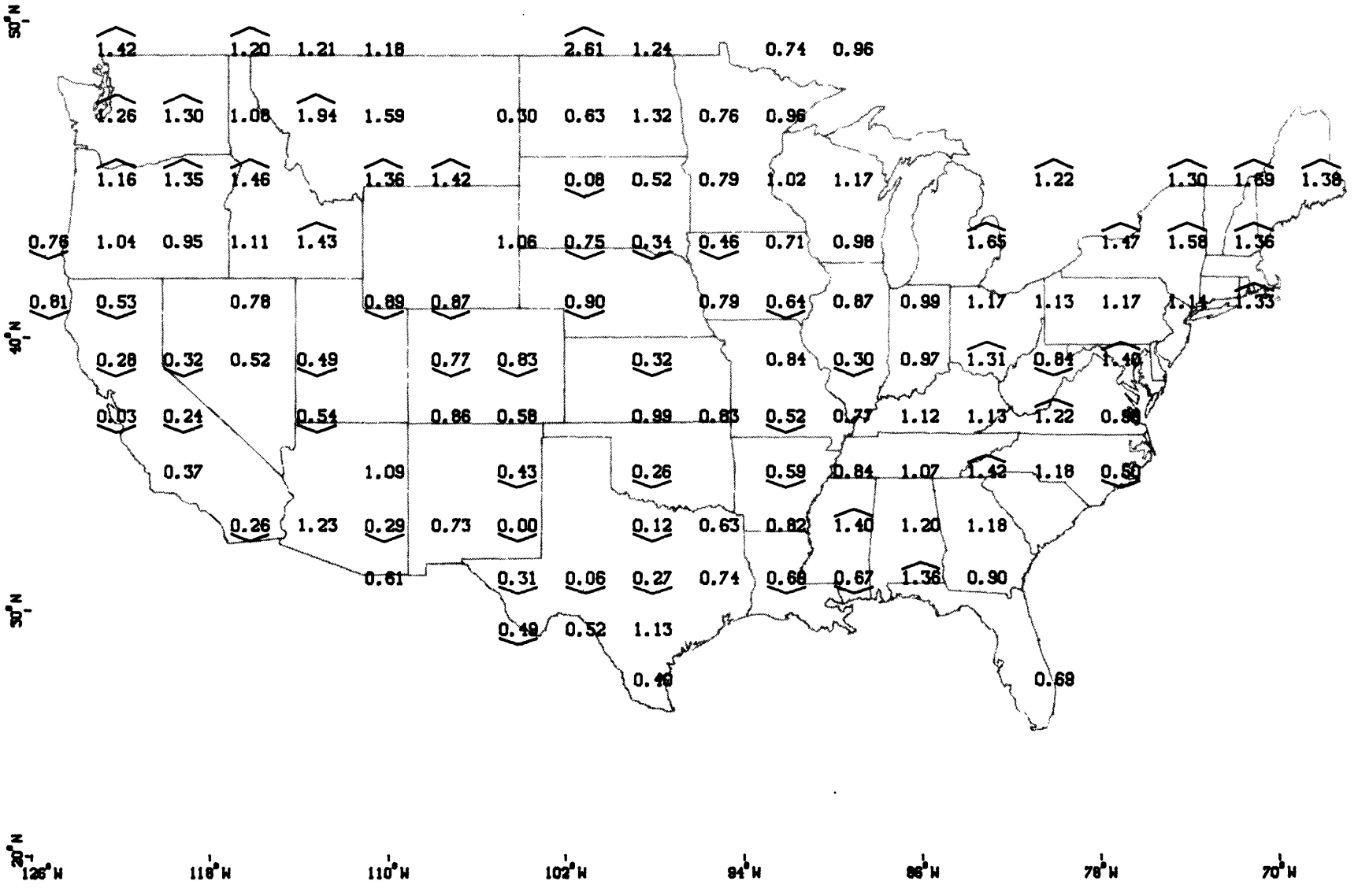
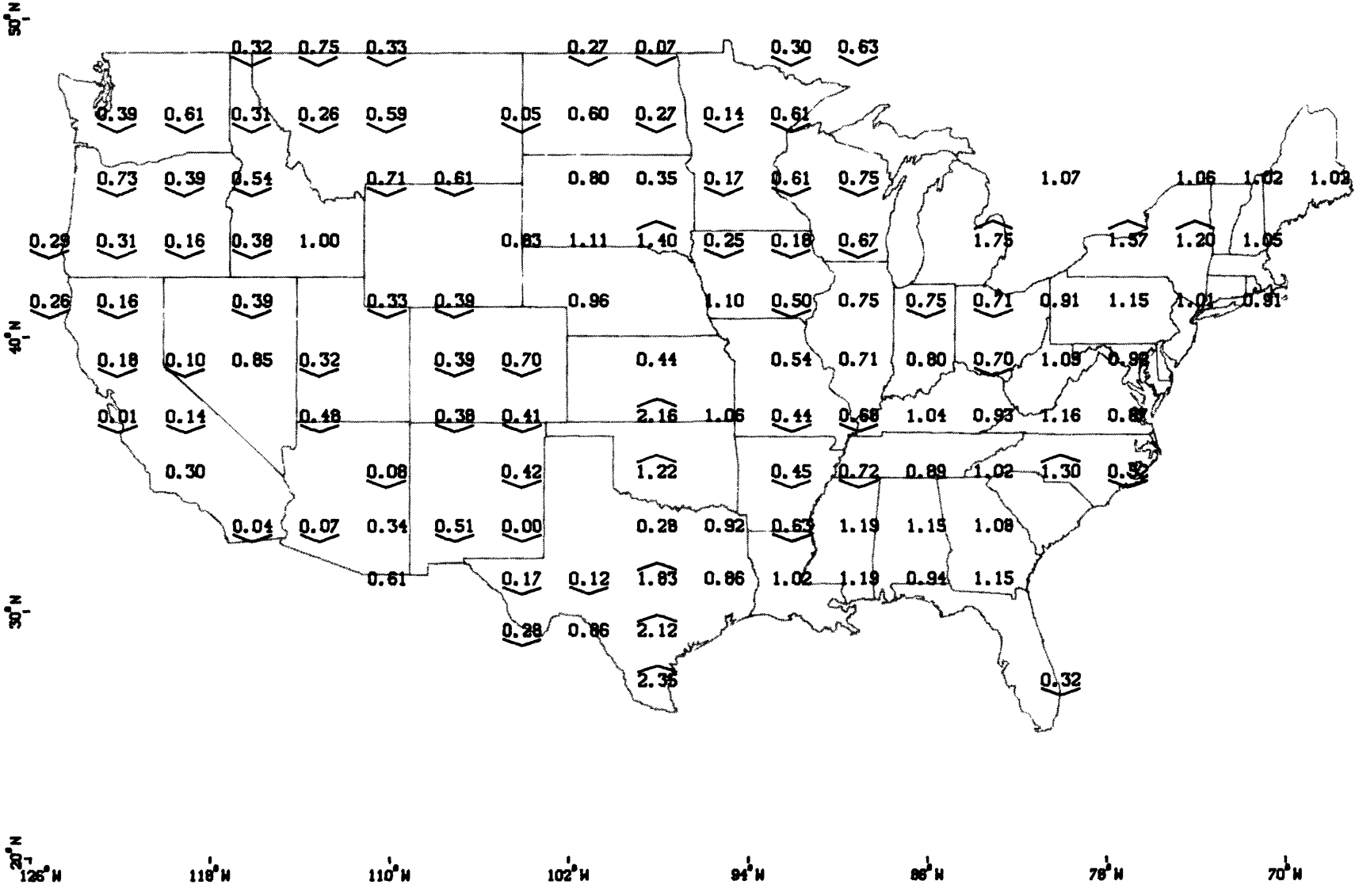
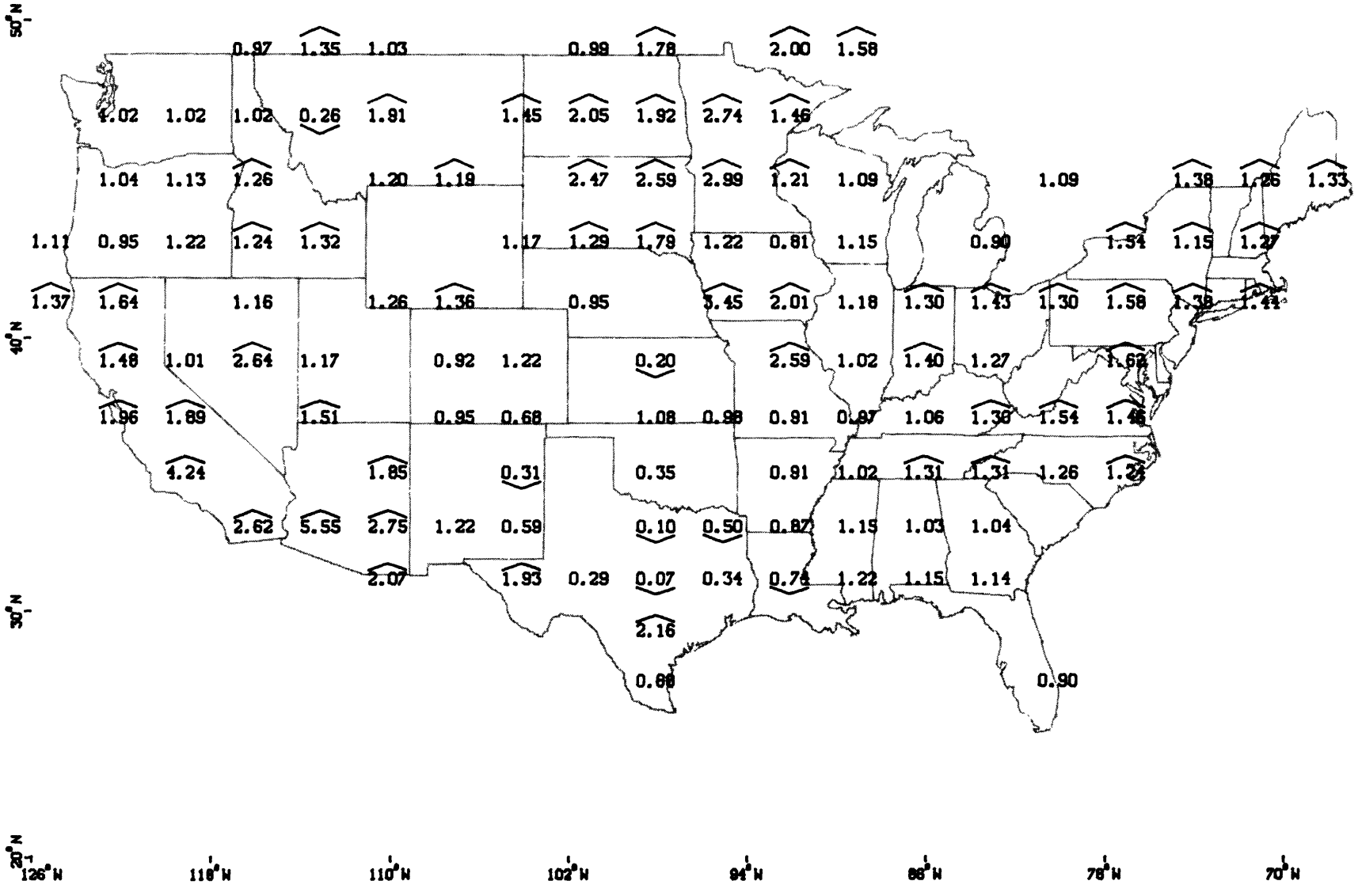


WATER YEAR 1977



WATER YEAR 1978



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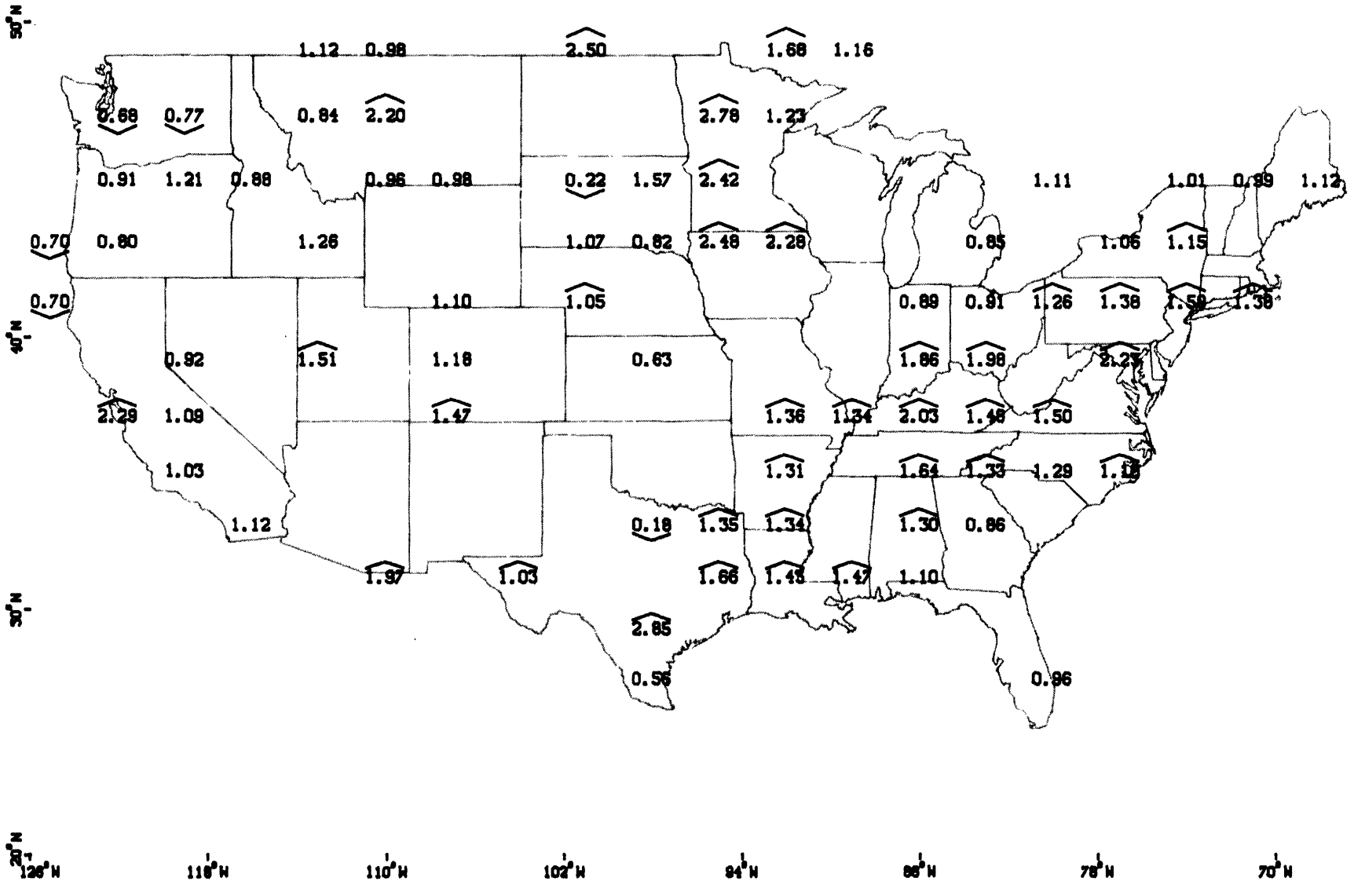

Table 1.--Gaging Station Records Used

Cell	Number	River	Dr.Area (mi^2)	Class	Ref. Normal ($ft^{3/s}$)	Period of Record used (water years)
2E	02256500	Fisheating Cr.	311	I	281	1932-
2E	02296750	Peace R	1367	I	1326	1932-
2K	08208000	Atascosa R	1171	II	140	1925,1933-
3K	08167500	Guadalupe R	1315	II	285	1923-
3L	08449500	Devils R	4185	I	580	1911-14,1925-56
3L	08455000	Pinto Cr.	236	I	27.6	1957-
3L	08449000	Devils R	2730	II	190	1964-
3M	08374000	Alamito Cr.	1504	II	21.5	1933-
4F	02231000	St. Marys R	700	I	608	1927-
4F	02352500	Flint R	5310	II	5830	1911-1920
4F	02329000	Ochlocknee R	1140	I	928	1927-
4G	02372500	Conecuh R	1344	II	1900	1911-19,1930-37
4G	02371500	Conecuh R	492	I	684	1938-
4H	02479000	Pascagoula R	6600	I	9450	1931-38
4H	07375500	Tangiphoa R	646	I	1078	1939-
4I	08013500	Calcasieu R	753	II	1150	1923-1924
4I	08010000	Bayou des Cannes	131	II	250	1939-
4J	08033500	Neches R	3637	II	2290	1911-24,1966-
4J	08110000	Yegua Cr.	1008	II	283	1925-65
4K	08095000	N. Bosque R	968	II	221	1924-
4L	08126500	Colorado R	16840	II	318	1911-30
4L	08128500	Middle Concho R	1280	II	42	1931-60
4L	08134000	N. Concho R	1249	II	46	1961-
4M	08408500	Delaware R	689	I	15	1913,1938-
4O	09471000	San Pedro R	1219	II	57.5	1913-
5F	02223500	Oconee R	4400	II	4440	1911-
5G	02416000	Tallapoosa R	2460	I	3500	1911-13
5G	02407000	Coosa R	8390	I,II	12950	1914-28
5G	02450000	Mulberry Fk.	368	I	618	1929-
5H	02486000	Pearl R	3100	II	3786	1911-12,1971-
5H	02487500	Strong R	429	I	550	1929-1970
5I	07369500	Tensas R	309	II	334	1937-
5J	08022500	Sabine R	4858	II	3660	1911-59
5J	08061700	Duck Cr.	31.6	II	32	1960-
5K	08055500	Elm Fk. Trinity R	2534	II	839	1911-32
5K	07314500	Little Wichita R	481	II	83	1933-55,1967
5M	08388000	Rio Ruidoso	290	II	19	1931-55
5M	08394500	Rio Felix	932	II	15	1951-
5N	09431500	Gila R	2860	II	170	1913-
5O	09486000	Rillito Cr.	918	III	14	1911-29
5O	09468500	San Carlos R	1027	II	46.5	1930-
5P	09513000	Aqua Fria R	1459	II	55	1915-19,1934-
5Q	11051500	Santa Ana R	202	III	69	1911-30,1942-47
5Q	10258500	Palm Canyon Cr.	93.3	I	4.87	1931-41,1948-

Table 1.--Gaging Station Records Used (continued)

Cell	Number	River	Dr.Area (mi^2)	Class	Ref. Normal ($ft^{3/s}$)	Period of Record used (water years)
6E	02121000	Yadkin R	3470	I	4300	1911-27
6E	02132000	Lynches R	1030	I	934	1930-
6F	03451500	French Broad R	945	I	2058	1911-36
6F	02392000	Etowah R	605	I	1160	1937-
6G	02396000	Etowah R	1810	I	2900	1911-20
6G	03602000	Duck R	2048	II	3150	1920-27
6G	03604500	Buffalo R	707	I	1140	1928-
6H	07030500	Wolf R	503	I	676	1930-71
6H	07031650	Wolf R	699	I	950	1971-
6I	07260500	Petit Jean R	764	I	874	1917-45
6I	07056000	Buffalo R	829	I	1110	1946-
6J	07336500	Kiamichi R	1423	II	1783	1926-71
6K	07331000	Washita R	7202	II	1540	1929-37
6K	07316500	Washita R	794	II	40	1938-
6M	08380500	Gallinas Cr.	84	II	16.6	1911-
6N	08342000	Bluewater Cr.	235	III	9.7	1912-15,1916-18,1927
6O	09509500	Verde R	6180	II	525	1911-29
6O	09399000	Clear Cr.	607	II	79	1930-
6P	09426500	Bill Williams R	5140	II	110	1914-15,1929-46
6P	09426000	Bill Williams R	4730	II	129	1940-68
6R	11098000	Arroyo Seco	16.4	II	8.6	1914-15,1917-
7D	02030500	Slate R	226	I	224	1927-
7E	02112000	Yadkin R	493	III	746	1921-
7E	02550000	Roanoke R	388	I	383	1911-1920
7F	03477000	So. Fk. Holston R	813	I	1175	1911-1930
7F	03409500	Clear Fk.	272	I	460	1931-71,1976-
7G	03433500	Horpeth R	408	I	545	1921-
7H	05597000	Big Muddy R	794	I	710	1912 only
7H	07067000	Current R	1667	I	1850	1913-
7I	06926000	Osage R	14000	I	9345	1911-25
7I	06933500	Gasconade R	2840	I	2466	1924-
7J	07183000	Neosho R	3818	I	1640	1918-24
7J	07187500	Shoal Cr.	439	I	380	1925-41
7J	07187000	Shoal Cr.	427	I	371	1942-
7K	07144200	Little Arkansas R	1327	III	255	1923-
7M	07208500	Rayado R	65	I	13	Broken
fN	09361500	Animas R	692	II	757	1911-
7N	08246500	Conejos R	282	II	312	1912-
7P	09406000	Virgin R	934	II	178	1911-23
7P	09403000	Bright Angel Cr.	98.4	II	36.8	1924-73
7P	09415000	Virgin R	5090	III	235	1974-
7R	11222000	Kings R	1694	II	2240	1911-50
7R	11213500	Kings R	952	I	1410	1927-28,1932-
7R	11224500	Los Gatos Cr.	95.5	II	5.35	1946-
7R	11210500	Kaweah R	520	II	571	1951-61
7S	11152000	Arroyo Seco	241	I	135	1911-40
7S	11312000	Bear Cr.	47.6	I	11.5	1931-

Table 1.--Gaging Station Records Used (continued)

Cell	Number	River	Dr. Area (mi^2)	Class	Ref. Normal ($ft^{3/s}$)	Period of Record used (water years)
8D	01668000	Rappahannock R	1596	I	1630	1911-30
8D	01645000	Seneca Cr.	101	II	94	1931-
8E	03051000	Tygart Valley R	408	I	773	1911-65
8E	03186500	Williams R	128	I	316	1966-
8F	03159500	Hocking R	944	I	945	1916-30
8F	03157500	Hocking R	459	I	434	1931-
8G	03373500	E. Fk. White R	4927	I	5260	1911-16,1924-30
8G	03303000	Blue R	461	I	611	1931-
8H	03380500	Skillet Fk.	464	I	380	1911-12,1915-21,1929
8H	07016500	Bourbeuse R	808	I	630	1922-
8I	06897500	Grand R	2250	I	1080	1922-
8K	06864500	Smoky Hill R	7580	II	301	1919-25,1929-
8M	07101000	Lion Cr.	2.0	I	0.83	1911-16
8M	06725500	Middle Boulder Cr.	36.2	I	52.5	1917-
8N	09085000	Roaring Fk.	1460	III	1258	1911-
8P	10234500	Beaver R	91	I	50.7	1915-
8Q	10325500	Reese R	53	I	12	1952-
8R	10312000	Carson R	1450	II	352	1912-
8S	11335000	Cosumnes R	537	II	492	1911-30
8S	11384000	Big Chico Cr.	67.9	I	141	1931-
9B	01127000	Quinebaug R	715	II	1282	1919-
9C	01439500	Bush Kill	117	I	235	1911-18
9C	01396500	So Br. Raritan R	65.3	I	117	1919-
9D	01548000	No. Bald Eagle Cr.	559	I	796	1911-20
9D	01573000	Swatara Cr.	337	I	572	1921-
9E	03021500	French Cr.	208	I	410	1911-15
9E	03109500	Little Beaver Cr.	496	I	520	1916-
9F	04193500	Maumee R	6330	II	4820	1922-35,1940-
9G	03326500	Mississinewa R	682	II	590	1924-29
9G	03328000	Eel R	417	I	351	1930-
9H	05572000	Sangaman R	550	I	391	1911-12,1915-
9I	05454500	Iowa R	3271	II	1500	1911-24
9I	05455000	Ralston Cr.	3.01	I	1.35	1925-
9J	06800500	Elkhorn R	6900	I	1065	1912-15
9J	06813000	Tarkio R	508	I	179	1923-
9L	06687000	Blue Cr.	-	II	70.3	1931-
9N	09239500	Yampa R	604	III	430.	1911-
9O	10168500	Big Cottonwood Cr.	48.5	II	63.8	1911-68
9O	09266500	Ashley Cr.	101	III	90.5	1914-
9O	10153800	N. Fk. Provo R	24.4	II	35	1969-
9Q	10322500	Humboldt R	5010	III	359	1912-21
9Q	10329500	Martin Cr.	172	II	31.9	1922-
9S	11525500	Trinity R	726	II,III	1729	1912-

Table 1.--Gaging Station Records Used (continued)

Cell	Number	River	Dr. Area (mi^2)	Class	Ref. Normal ($ft^{3/s}$)	Period of Record used (water years)
10B	01076500	Penngewasset R	622	I	1350	1911-
10C	01350000	Schoharie Cr.	236	I	462	1911-12
10C	01321000	Sacondaga R	491	I	1080	1912-
10D	04223000	Genesee R	981	II	1250	1911-
10F	04174500	Huron R	729	I,II	441	1911-
10H	04073500	Fox R	1430	II	1031	1911-14
10H	05436500	Sugar R	523	I	314	1915-
10I	05464500	Cedar R	6510	I	3021	1911-32
10I	05459500	Winnebago Cr.	526	I	199	1933-
10J	05480500	Des Moines R	4190	I	1332	1914-27
10J	06600500	Floyd R	882	I	166	1936-
10K	06452000	White R	10200	II	535	1929-
10L	06449500	So. Fk. (Little) White R	1020	II	104	1944-
10M	06646500	Deer Cr.	216	III	51.2	1916-60,(broken)
10M	06649000	La Prele Cr	135	III	34	1920-71
10M	06647500	Box Elder Cr.	63	II	35	1947-,(broken)
10O	13011000	Snake R	824	III	1354	1911-18
10O	06225000	Bull Lake Cr.	213	I	260	1919-37
10O	09201000	New Fork R	552	III	371	1938-69
10P	13083000	Trapper Cr.	53.7	II	13.6	1912-16,1920-
10P	13139000	Big Wood (and Slough)	640	II	426	1916-25
10Q	13185000	Boise R	830	I	1158	1912-
10R	10393500	Silvies R	934	I	166	1911-,(broken)
10S	14321000	Umpqua R	3683	II	7500	1911-
10S	11483500	Miller Cr.	220	III	71	1926-50
10T	14325000	So. Fk. Coquille R	169	II	810	1917-26,1930-
11A	01031500	Piscataquis R	297	I	584	1911-
11B	04286500	Dog R	52	II	80	1912-20,1929-34
11B	04287000	Dog R	76.1	II	121	1935-
11C	04269000	St. Regis	616	I	1004	1911-
11E	02FC001	Saugeen R (Ontario)	1570	I	1953	1915-
11H	04077000	Wolf R	812	II	757	1911-13
11H	04071000	Oconto R	678	I	515	1914-
11I	05341500	Apple R	555	II	287	1911-70
11I	05365500	Chippewa R	5600	II	4985	1971-
11J	05049000	Mustinka R	834	II	43.6	1916-24,1931-58
11J	05290000	Little Mustinka R	447	I	35.5	1959-
11K	06478500	James R	21550	II	335.	1929-
11L	06441500	Bad R	3107	I	162	1929-
11M	06334000	Little Missouri R	904	II	60	1913-32,1936-69
11N	06275500	Wood R	218	III	132	1911-12,1915-16
11N	06207500	Clarks Fork	1340	II	897	1922-
11O	06191500	Yellowstone R	2623	II	2865	1911-
11Q	13337000	Lochsa R	1180	I	2760	1911-12,1930-
11R	13319000	Grande Ronde R	678	II	370	1911-,(broken)
11S	14159000	McKenzie R	348	I,II	1650	1911-

able 1.--Gaging Station Records Used (continued)

ell	Number	River	Dr. Area (mi^2)	Class	Ref. Normal (ft^3/s)	Period of Record used (water years)
2I	04024000	St. Louis R	3430	III	2200	1911-25
2I	04014500	Baptism R	140	I	160	1928-
2J	05054000	Red R. of the N.	6800	III	455	1911-
2K	05082500	Red R.(Intervening area)	23300	III	1605	1911-
2L	06345500	Heart R	1240	I	103	1911-22
2L	06354000	Cannonball R	4100	I	233	1935-
2L	06339500	Knife R	1230	I	94	1911-,(broken)
2M	06177500	Redwater R	534	II	16.1	1932-71,(broken),1975-
2O	06061500	Prickly Pear Cr.	175	II	45	1911-16
2O	06110000	Judith R	331	I	45.3	1920-75
2O	06109800	So. Fk. Judith R	58.7	II	16.0	1976-
2P	06063000	Tenmile Cr.	102	II	21	1911-14
2P	06062500	Tenmile Cr.	32.7	III	14.5	1915-
2Q	13339000	Clearwater R	4850	I	7930	1911-20
2Q	12413500	Coeur d' Alene R	1220	I	2580	1912,1921-72
2Q	12413000	Coeur d' Alene R	895	I	1950	1966-
2R	12117500	Cedar R	125	III	680	1911-
2R	12452500	Chelan R	924	III	2081	1911-
2S	14110000	Klickitat R	360	II	818	1911-71
2S	12027500	Chehalis R	895	II	2850	1951-
3H	04010500	Pigeon R	600	I	503	1924-
3I	05129500	Rainy R	14900	III	9970	1911-28
3I	05132000	Big Fork	1460	I	644	1929-
3K	05MJ001	Assiniboine R	59100	II	1577	1914-
3K	05090000	Park R	695	II	48.5	1932-
3L	05120500	Wintering R	675	II	11.9	1938-
3O	06099500	Marais R	3242	III	920	1912-
3P	06095000	Birch Cr.	105	III	150	1911-22
3P	12370000	Swan R	671	II	1077	1923-
3Q	12303000	Kootenau R	10240	II	12100	1911-71
3Q	12304500	Yaak R	766	II	870	1972-
3S	08MH001	Chilliwack R (BC)	474	I	2400	1972-
3S	08MH016	Chilliwack R	127	I	680	1924-

miles. Table 1 shows the pertinent data for gaging stations used - drainage area, classification, normal flow, and period of record for which useful records were available and to which the indicated classification applies. Table 1 also shows the "cell" location based on the grid plan shown in figure 70. Each of the 165 cells has an area of about 23,000 square miles. The country (48 States) was divided into three regions as shown in figure 70, West, Center, and East, each region comprising about 55 cells.

The several stations were assigned to a cell depending on the latitude and longitude of the gage. Where, as was usually the case, records were not continuous over the whole 1911-79 period, different intervals may be represented by different stations. A cell may have more than one record for a given year and, in such cases, an average of the ratios to respective normal was calculated at each station.

The annual mean flows (by water years) at the several gaging stations are each reported following past practice (Busby, 1963) in ratio to a reference normal, based in this report on the mean flow during the 1931-60 period. Since much work had already been done on the 1931-60 period, that reference period was retained for this work. It is important to use a single reference period throughout a given data set and study; however, none of the results would be changed by the adoption of any other period.

Comparison of the means for the period 1931-1960 with that for the period 1911-1979 for the 15 stations that are continuous for that 69-year period show the following consistent results:

Region	Number of Stations	Ratio of means 1911-79 to 1931-60
West	6	1.06
Center	4	1.08
East	5	1.05

Figures 1-69 are computer plots of the annual ratios according to cell location. Annual ratios that are in the upper quartile of the ratios for each cell are noted by a superscript, and those that are in the lower quartile by a subscript. Unmarked ratios are deemed within the normal range; those marked by a superscript are termed "above normal" and those marked by a subscript are termed "below or subnormal." (In earlier reports the terms "excessive" and "deficient" were used.) Table 2 lists, by years, the percentage of measured cells in each region, and for the U.S. (48 States) as a whole, that are subnormal as defined.

1/ The water year is the 12-month period beginning October 1 through September 30 of the succeeding calendar year.

2/ A 30-year normal follows international convention (WMO, 1956), and that for 1931-60 is nearly central within the period from 1911 to 1979.

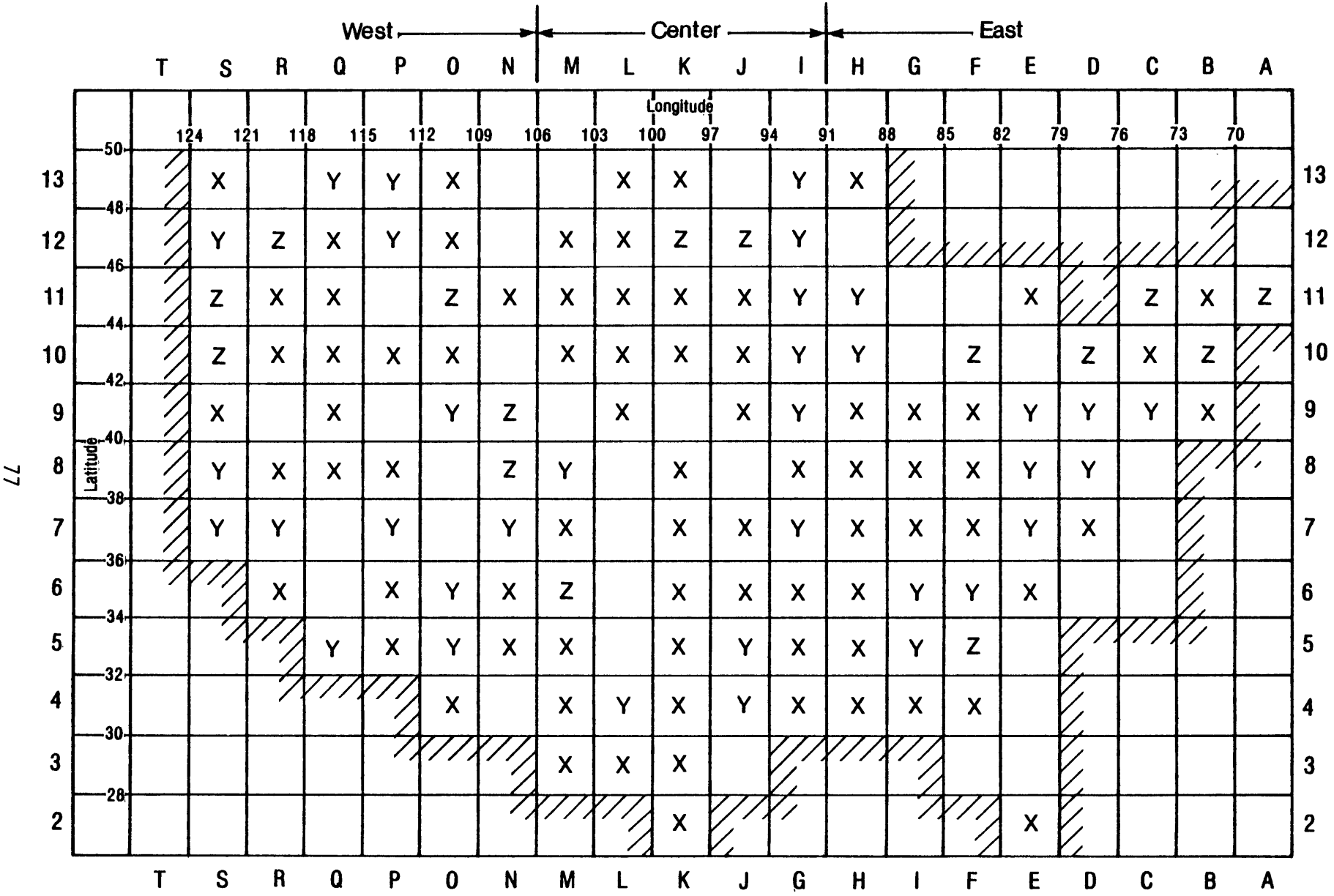

Figure 70. Grid plan superposed on conterminous United States.

Table 3.--Number of dry years by decades and for each region and for the conterminous United States as a whole

Decade	W	C	E	U.S.
1911-20	1	3	3	3
1916-25	1	4	3	3
1921-30	4	2	4	4
1926-35	7	3	5	4
1931-40	7	6	5	5
1936-45	5	3	4	4
1941-50	3	0	2	1
1946-55	3	4	2	3
1951-60	5	6	5	5
1956-65	6	5	7	5
1961-70	5	4	8	5
1966-75	3	1	4	2
1971-79	3	2	0	2

large areal coverage of subnormal flows than are indicated on an assumption of independence. The reason for this difference seems to rest upon the coherence among ratios at the several cells within the regions, particularly in dry years. For example, 87 percent of cells in a region had subnormal runoff at least once in the 69-year period, whereas, if the distribution were random, only 42 percent of the cells would be subnormal, as a maximum, in the 69-year period.

Regional totals such as reported in table 3 can mask large local variations. For example, dividing the West region into north and south sections (divided at 42° N. latitude) shows that each displays different variations. (See fig. 73.) The Northwest shows a peak in the number of dry years centering about the 1930's, whereas the Southwest shows its peak during the 1950's. Taken together, the West as a whole shows the two peaks common to the other regions. (See fig. 71.) However, the North-South contrast is more muted in the Center and East regions. The rough "cycle" suggested by the bar graphs in fig. 71 has often been noted in the precipitation in the United States, especially in the Great Plains, with

Even casual inspection of the data in table 2 will suggest that there is a similar pattern of variation among the years in each of the regions. There are 26 years in which the areal percentages are on the same side of the U.S. median (20 percent) in each of the three regions, as against an expected frequency of about 17 (= 69/4). There is less than one chance in a hundred that this conformance among the regions would occur in random trials.

The data compiled by Beall (1978) for the upper Ohio River basin provide a test of the similarity in regimen among the annual flows in a cell. The upper Ohio River basin examined by Beall has an area of 27,300 square miles, about the same order of magnitude as a 2° by 3° cell used in this study and contains 98 long-term gaging stations. About 85 percent of the standard deviation of the individual records is accounted for by the annual basin means. The intra-class correlation coefficient (Fisher 1936, p. 216) is 0.72. Although as Beall noted (p. 26) there is a remarkable consistency in the annual ratios over a considerable part of that basin, particularly in the drier years, the cell is not monolithic in its behavior.

Figure 71 shows, by regions, bar graphs of the frequency of "dry" years by decades - a "dry" year being defined as one in which the extent of subnormal runoff exceeded the average. By definition, the average areal extent of subnormal runoff equals 25 percent, which is confirmed by averaging the data in the columns of table 2. To illustrate, the 1911-20 decade had one dry year in the West, 3 in the Center, and 3 in the East region. Table 3 lists the counts by decades and regions. In each region dry years as shown in figure 71 seem to be concentrated in two epochs at about a 25-year separation. The frequency of dry years during these peak periods is about 2 to 3 times that during intervening years. With reference to the data in table 3, the variance among the decades (within the columns) is several times that among the regions (within the rows).

Busby (1963, table 5) shows data similar to that in table 2 for the conterminous U.S. as a whole. His figures for subnormal (= deficient) runoff are consistently less than those shown in table 2 of this report. His average of 0.18 (the same as obtained by Harbeck and Langbein, 1949, for the period 1921-45) seems significantly less than the 0.25 required by the definition of subnormal runoff. The difference may be due to the methods. In this report, the percent of subnormal runoff is the ratio of cells in the subnormal range for a given year to the number of cells for which data are available for that year. This procedure assumes that subnormal runoff among the ungaged cells occurs in the same ratio. In the earlier reports the subnormal area was defined from the areas shaded to designate the estimated areal extent, and as these areas were drawn more tightly about the known data, the percentages are lower. In the senior author's experience, the tendency was to view the ungaged area as being in the normal range.

The statistical distribution of the areal percentages for the regions given in table 2 is shown in figure 72 together with the theoretical ("random") distribution on the basis that subnormal flows occur 25 percent of the years at any cell by definition, and the assumption that the occurrence or non-occurrence of subnormal flows in any cell is independent of the experience at any other. The actual distributions show a far greater number of large

Table 2.--Percent of cells in each region with subnormal runoff by water years

Water Year	West	Center	East	U.S.	Water Year	West	Center	East	U.S.
1911	8.	63.	65.	43.	1946	26.	20.	5.	17.
1912	9.	6.	0.	5.	1947	22.	4.	20.	15.
1913	12.	22.	8.	13.	1948	17.	18.	15.	17.
1914	3.	10.	32.	14.	1949	12.	7.	20.	13.
1915	42.	11.	25.	29.	1950	21.	9.	20.	17.
1916	0.	5.	0.	1.	1951	24.	29.	18.	24.
1917	3.	27.	18.	14.	1952	2.	20.	8.	10.
1918	11.	43.	29.	26.	1953	23.	36.	23.	27.
1919	22.	13.	14.	17.	1954	28.	56.	55.	46.
1920	17.	4.	14.	13.	1955	51.	29.	43.	41.
1921	6.	26.	15.	14.	1956	26.	59.	40.	42.
1922	17.	8.	0.	9.	1957	19.	18.	38.	25.
1923	5.	21.	32.	18.	1958	12.	23.	18.	17.
1924	53.	20.	10.	29.	1959	33.	43.	43.	40.
1925	3.	68.	68.	43.	1960	38.	7.	5.	17.
1926	43.	23.	32.	34.	1961	62.	30.	23.	38.
1927	0.	0.	24.	8.	1962	14.	11.	33.	19.
1928	8.	11.	0.	6.	1963	28.	52.	60.	46.
1929	42.	0.	6.	17.	1964	37.	41.	48.	42.
1930	48.	22.	26.	33.	1965	5.	5.	40.	16.
1931	80.	49.	82.	71.	1966	33.	18.	50.	33.
1932	10.	22.	40.	24.	1967	12.	31.	38.	27.
1933	32.	31.	5.	22.	1968	28.	24.	15.	23.
1934	62.	78.	80.	73.	1969	5.	9.	28.	13.
1935	26.	19.	20.	22.	1970	10.	18.	30.	19.
1936	17.	45.	33.	31.	1971	13.	20.	10.	15.
1937	45.	20.	0.	22.	1972	25.	21.	10.	19.
1938	2.	16.	5.	8.	1973	49.	14.	0.	21.
1939	52.	36.	10.	34.	1974	18.	21.	0.	13.
1940	48.	70.	50.	56.	1975	10.	14.	3.	9.
1941	38.	18.	80.	44.	1976	35.	44.	10.	30.
1942	17.	2.	43.	20.	1977	87.	51.	25.	54.
1943	0.	16.	15.	10.	1978	3.	15.	0.	6.
1944	48.	4.	23.	24.	1979	16.	9.	0.	8.
1945	14.	11.	15.	13.					

	West	Center	East	U.S.
Median	19.	20.	20.	20.
Ave.	24.	24.	25.	24.
Std. dev.	19.	18.	21.	15.

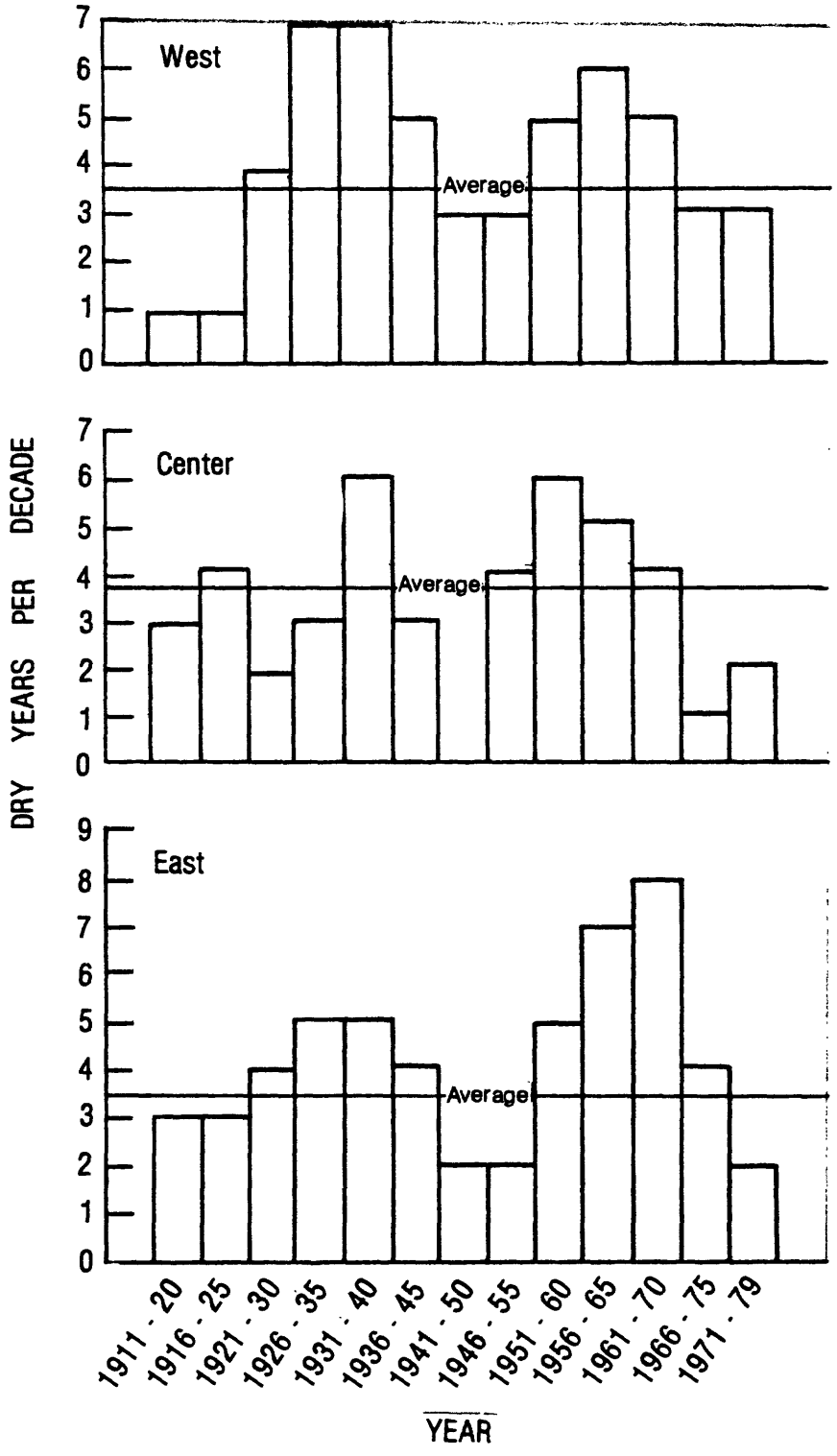

Figure 71. Frequency of dry years per decade, West, Center, and East regions.

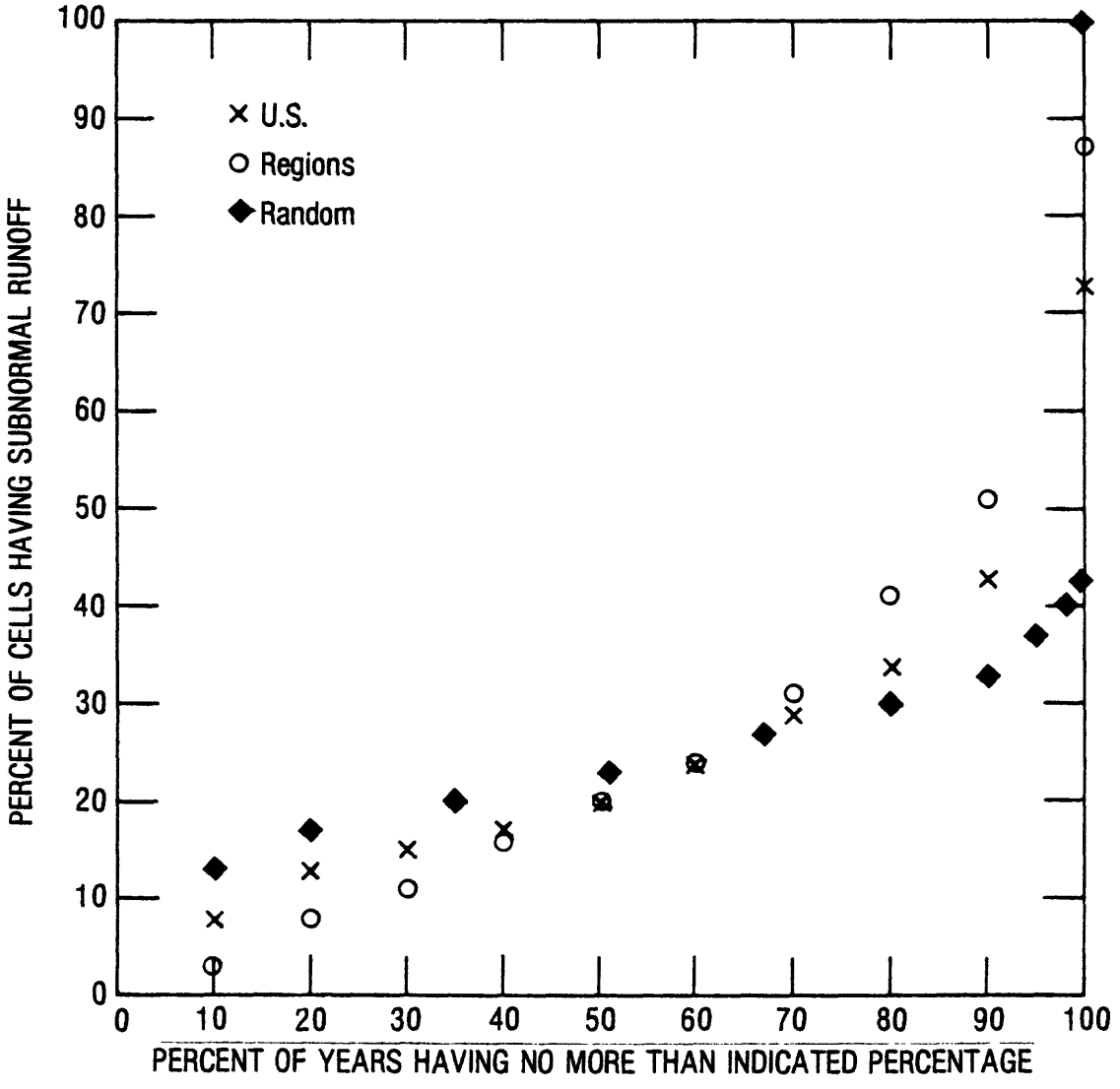

Figure 72. Distribution of years having indicated areal extent of subnormal runoff.

"dry" periods occurring in 1895, 1915, 1935, and 1955. Borchert (1971) viewed this sequence to constitute sufficient grounds to warn that possible drought might follow that of the 1950's in the 1970's, and citing Thomas (1963, p. A40), who had observed that, "Nevertheless some climatic fluctuations appear to have recurrence intervals sufficiently regular, and amplitudes sufficiently great, that they may be important considerations in long-range planning for water-resources development and utilization." This study shows that similar fluctuations are present in the runoff throughout the country when aggregated regionally. The probability of dry years is not uniformly distributed through time.

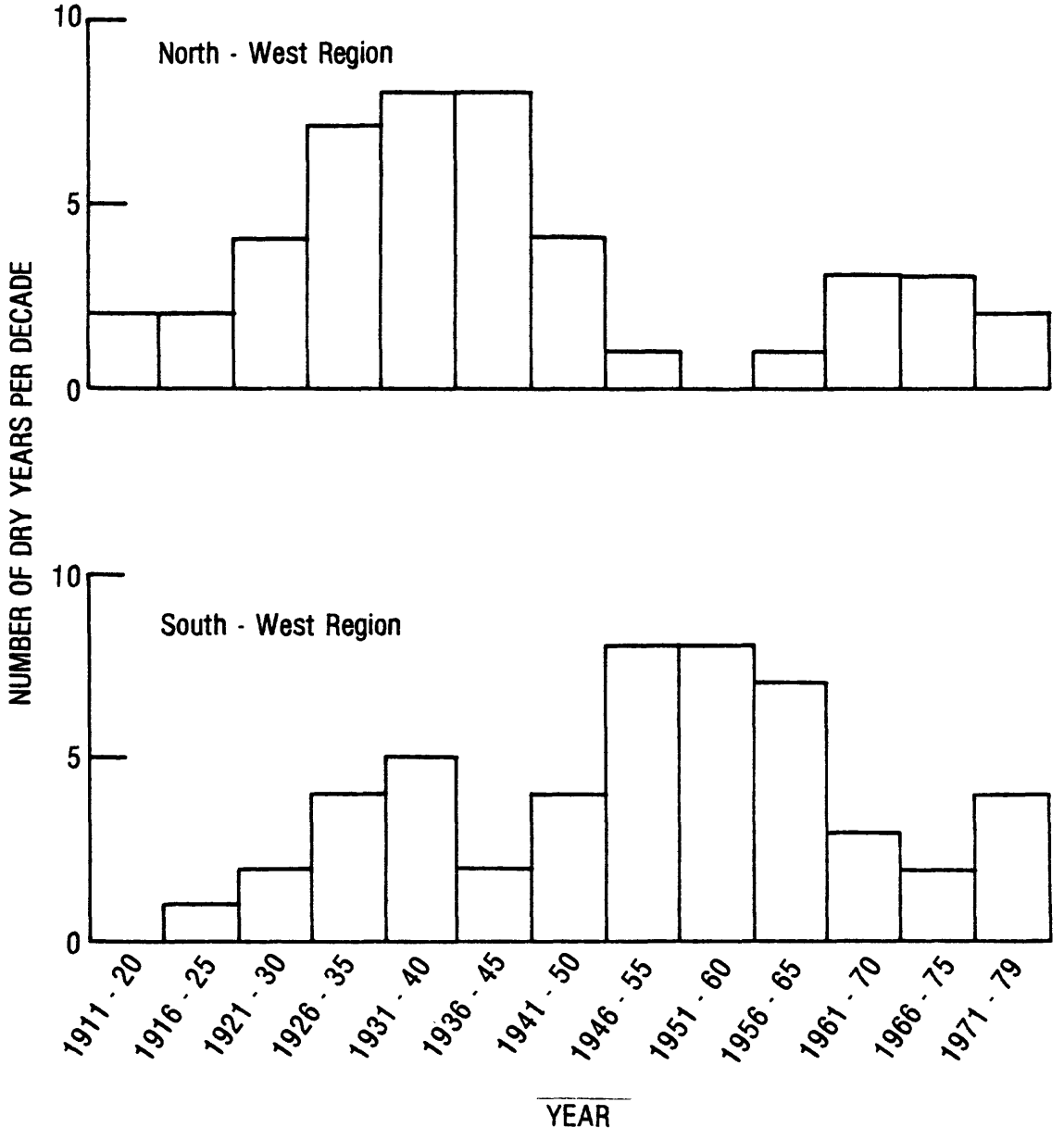

Figure 73. Frequency of dry years per decade in North and South parts of West region.

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