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ON THE UTILITY OF A GEOGRAPHIC INFORMATION SYSTEM IN MODELLING CLIMATIC SUITABILITY

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ABSTRACT. A long-term climatological data base for the eastern United States was developed as input into a Geographical Information System (GIS) to test its ability to determine the most suitable climate for human existence using a simple, generic, cartographic model which considered physiological and psychological factors as well as climatic hazards and cost. Results indicate the model is objective and sensitive to variations in climatic variables. Portions of South Carolina and Texas were found to be most suitable, but the model was not biased toward southern states in general. Mountainous areas and large bodies of water showed a distinct influence on the climatic ratings.

1. Introduction

The goal of this project was to attempt to define and locate the most suitable climate for human existence in the eastern half of the United States using a Geographical Information System (GIS). Briefly, a GIS is a set of software/hardware "tools" for collecting, storing, retrieving, transferring, and displaying spatial data from the real world to assist in a particular decision making process (Burrough, 1985). A schematic of a GIS is shown in Figure 1. Locating the most suitable climate implies that first a method of rating climate must be developed. This was accomplished using a climatological data base and a simple cartographic model.

Subjective climate ratings of major American cities abound (for example Boyer and Savageau, 1985), and the popular consensus is that residents of the western and southern cities enjoy the best climate. A GIS offers the ability to develop an objective climate rating with continuous coverage over a large area. The eastern half of the United States, which contains great geological, geographical, and climatological diversity will be used to test the ability of a GIS to respond to obvious as well as subtle changes in environmental variables.

2. Background

If a survey were given to a group of people on what they considered to be the ideal climate, a wide variety of responses would likely be returned. Aside from a rigorous treatment of the heat budget of the human body under controlled conditions (where a balance must exist between metabolic heat production and heat gained or lost by convection, conduction, radiation, and evaporation) the various effects of climate on humans can't be explicitly quantified. Climate affects human physiology as well as psychology (the two are interrelated), and the mitigation of detrimental climatic affects must exact a cost.

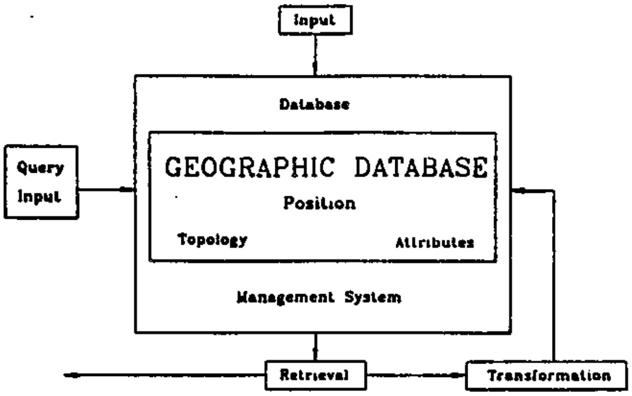


Fig. 1.7 The components of the geographical database.

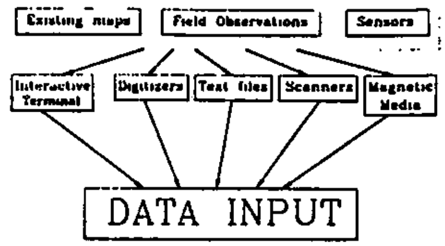


Fig. 1.6 Data input.

8 *Geographical Information Systems*

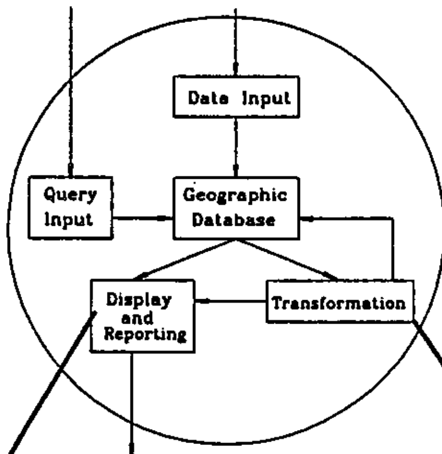


Fig. 1.5 The main software components of a geographical information system.

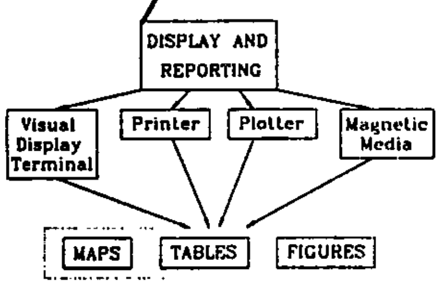


Fig. 1.8 Data output.

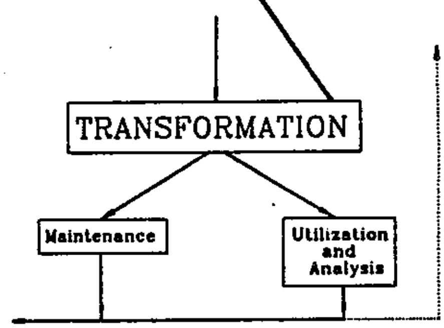


Fig. 1.9 Data transformation.

(from Burrough, 1985)

Fig. 1. The components of a Geographical Information System (Burrough, 1985).

The ideal climate model discussed here is an attempt to develop a simple universal model that does not consider human preference for any particular climatic factor. The model also does not consider external factors such as esthetic value, economy, food supply or recreation. It does, however, consider four general categories of climatic variables affecting human existence. These categories include: physiological, psychological, hazards, and cost. Clearly, these climatological variables are interrelated in varying degrees.

Physiologically, by considering the heat budget of the human body one can make the obvious assumption that the least stressful climate is one that does not contain extremes of heat or cold, or have extreme seasonal ranges of temperature. Of course, wind and relative humidity can either mitigate or increase stress due to extreme temperatures.

Psychological effects of climate are documented in a qualitative sense in virtually all modern texts on climatology and biometeorology (see, for example, Rosenberg et al., 1983 and Critchfield, 1983). In this sense, variables such as cloudiness, storminess, and sunshine are important. Psychological affects can range from severe depression through boredom to elation. These factors are nearly impossible to quantify, but variables that are related to them can be ranked from best to worst.

Climatic hazards are obviously critical in determining ideal climate. Hazards such as tornadoes, thunderstorms and lightning, hurricanes, and winter storms, can result either physiologically or psychologically in determining climatic stress. Earthquake hazards have also been included here on an experimental basis. While clearly not a climatic variable, it is an environmental variable that is of concern and can be ranked. Certainly, some geographic areas are statistically more prone to climatic dangers than others. Human perception of danger may not agree with statistics, and it is in this area that cartographic modelling can produce the most objective results.

In addition to the effects on the human body, climate must also have certain external effects that can best be described as cost effects. In this respect, the amount of heating, cooling, and protection from the elements that is needed to maintain human comfort is important. The cost can be monetary in the sense that one must build energy efficient shelters (passive solar, for example) and heat and cool them, modify existing shelters to conserve energy, or simply pay high utility bills. One could also attempt to build hazard-proof shelter. The cost can also be in physical expenditure, or lack thereof, in the sense that one must adjust ones heat balance in order to remain healthy in the absence of proper shelter. Note that the model presented here does not consider cost of utilities, which can vary greatly from area to area.

The universal model of the most suitable climate developed here attempts to incorporate the four categories mentioned above. A data base of long term averages of relevant climatic variables is utilized to develop the results. The source of most of the data was isoline maps of climatological variables contained in Climates of the United States (Baldwin, 1973). The intervals on the individual maps can be ranked from best to worst, input into a GIS, and modelled to rank climate suitability (McHarg, 1969).

3. GIS Methodology

The Professional Map Analysis Package (PMAP), a raster (or cell) based system, produced by Spatial Information System, Inc. (copyright 1985), was the GIS software used in this project. The climatological data base was developed from 16 isoline maps of relevant variables. Figure 2 shows the base map used and the project area. It is a grid of 41 rows and 40 columns comprising 1,640 grid cells 32.2 miles to a side. The left margin of the grid corresponds to the 100°W longitude line south from the Canadian border for 1,320 miles. The study area covered roughly 1.7 million square miles, of which some 17.5 percent consisted of large bodies of water. For a study area of this size the 32.2 mile resolution was considered to be adequate.

Geocoding, or data input, was accomplished by laying a clear plastic overlay of the 40 x 41 grid over a source map, and lining up the left margin as mentioned above. The source maps were already contoured and labelled by ranges. Access to the original data was not possible. Values from best to worst were assigned to the intervals on each source map with one being the least suitable for human existence, and higher numbers being more suitable. The data was thus already classified and was, in effect, renumbered upon input. A value for each grid cell was then input into PMAP. Each map was assigned a unique name relating to the data it contained. Table 1 gives the 16 original map titles, their source, and their assigned names.

Figure 3 shows a schematic of how the model determined the most suitable climate using the 16 source maps. No attempt was made to weight the 16 source maps, or ensure the range of values were equal on each map. The values and the results of manipulations of values were basically defined by the constraints of the original data analysis and the objective manipulation by the model.

Figure 4 shows the raw model output. Climate ratings range from one (worst) to 13 (best). Figure 5 is a smoothed contour analysis of the final ratings transferred to the geographic base map. Ratings greater than ten are hatched and ratings less than two are shaded.

Figure 6 shows the grid cell values for the northwest sector of the grid. The largest contiguous area of lowest ratings on the whole grid is found in an organized pattern along an axis from near Fargo, North Dakota to near Minneapolis, through the Chicago area into northern Indiana. Ratings range from one to seven in this sector. The mid-Missouri Valley (Lincoln, Nebraska area) received the highest rating in this sector.

Further east in the northeast sector of the grid (Figure 7), the lowest ratings are concentrated in northern Indiana and western Michigan. The other area of lowest rating is along the west slopes of the Appalachians. Note the sharp rating gradient across the mountains. A small area of rating eight to ten is located southeast of Washington, D.C. Ratings ranged from one to ten in this sector.

The southwest section of the grid (Figure 8) received ratings ranging from four to 13. One of the two highest rated cells is located northwest of San

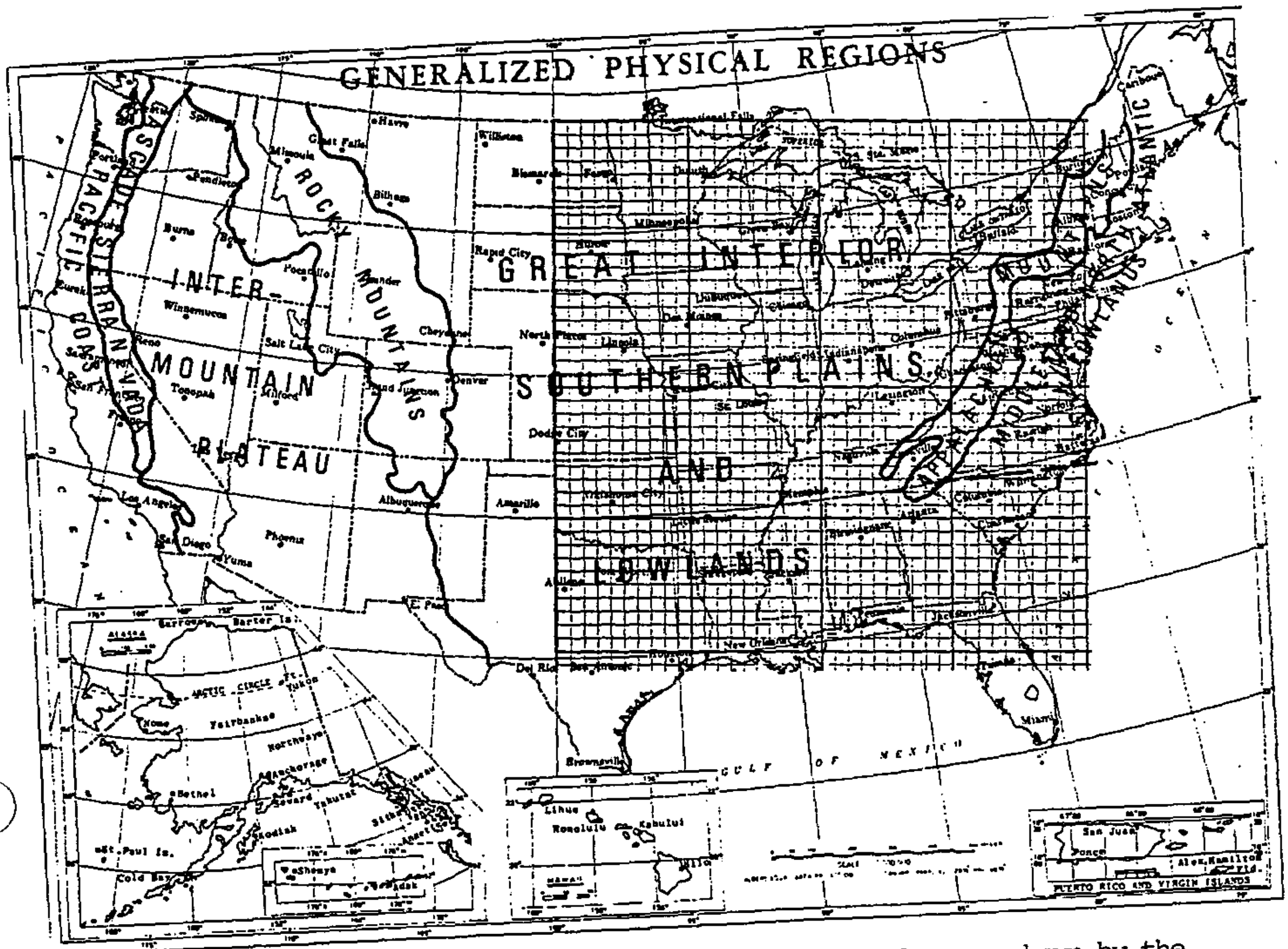


Fig. 2. Base map of climatological variables with the study area shown by the 40 x 41 grid.

TABLE 1
Sixteen data source maps, with sources, and
names used in the model.

1	Mean annual number of days minimum temperature 32°F and below	Baldwin		BELOW32
2	Mean annual number of days maximum temperature 90°F and above	"	"	OVER90
3	Mean annual temperature range (warmest - coldest month)	"	"	RANGE
4	Mean annual total heating degree days (Base 65°F)	"	"	HEATING
5	Mean annual total cooling degree days (Base 65°F)	"	"	COOLING
6	Mean annual number of days with 0.01 inches or more of precipitation	"	"	PRECIPDAYS
7	Mean annual total snowfall	"	"	SNOWFALL
8	Mean annual number of days with 1 inch or more snowfall	"	"	SNOWS
9	Mean annual number of days with thunderstorms	"	"	THUNDERSTORM
10	Mean daily relative humidity (%) July	"	"	HUMIDITY
11	Mean percentage of possible sunshine, annual	"	"	SUNSHINE
12	Mean daily solar radiation (langleys), annual	"	"	SOLAR
13	Mean daily sky cover, sunrise to sunset (in tenths), annual	"	"	CLOUDCOVER
14	Earthquake hazard zones	USGS		EARTHQUAKE
15	Hurricane risk areas	NOAA		HURRICANE
16	Average annual tornado incidence per 10,000 square miles	NOAA		TORNADO

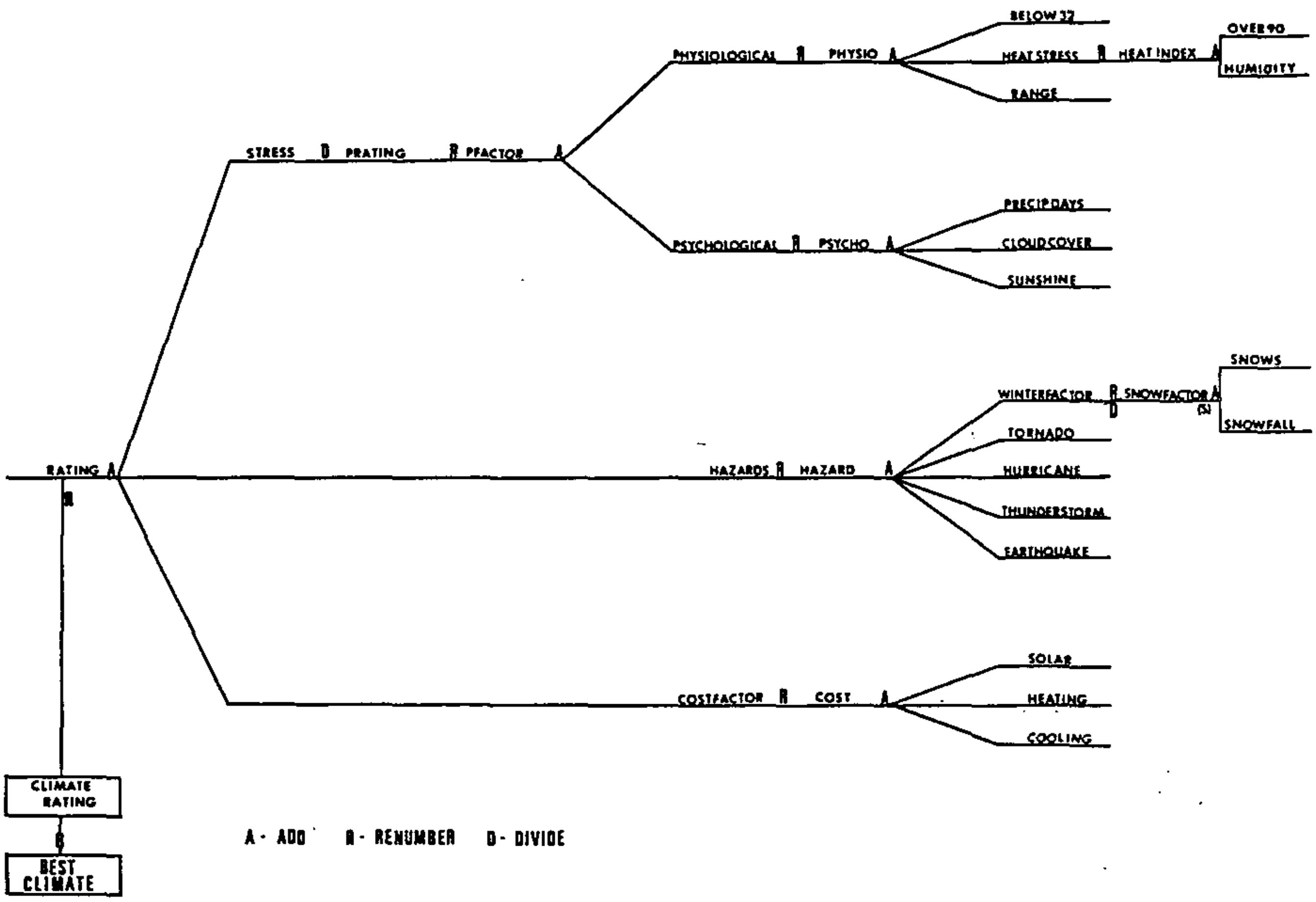
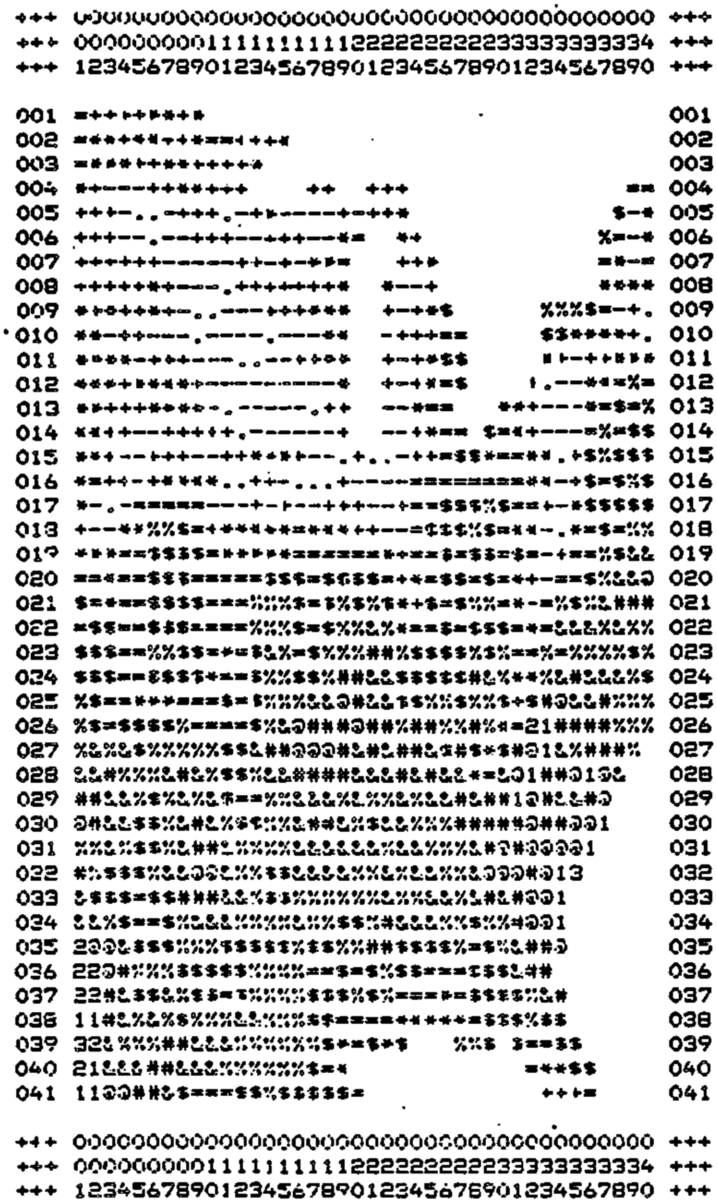


Fig. 3. Model schematic with operations indicated to combine all the data into one final rating map.



CLIMATERATING
SCALE: 32.2 MILES PER CELL

SYMBOL	VALUE	LABEL	NO.OF CELLS	PCT. OF MAP
	0		291	17.74
....	1	WORST CLIMATE RATING	28	1.71
----------	2		129	7.87
++++++++++	3		158	9.63
**********	4		154	9.39
==========	5		167	10.18
$$$$$$$$$$	6		225	13.72
%%%%%%%%%%	7		203	12.38
&&&&&&&&&&	8		129	7.87
##########	9		92	5.61
@@@@@@@@@@	10		39	2.38
1111111111	11		15	.91
2222222222	12		8	.49
3333333333	13	BEST RATING	2	.12

TOTAL NO. OF CELLS = 1640

Fig. 4. Final raw model output. Rankings range from one to 13.

Fig. 5. Smoothed contour analysis of final climate ratings at two unit intervals. Areas greater than ten are hatched and areas less than two are shaded.

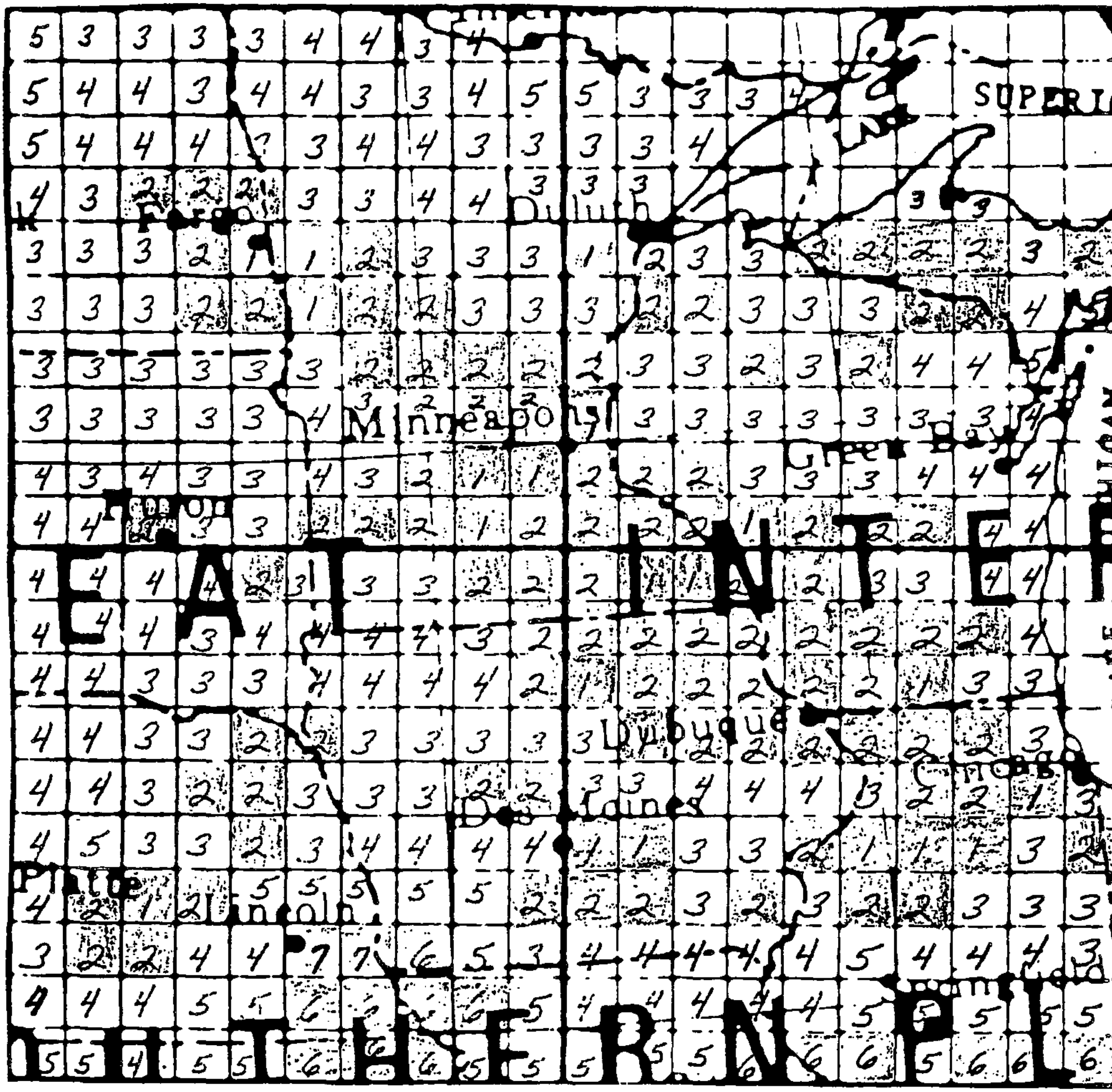


Fig. 6. Grid cell values of the northwest quarter of the grid.

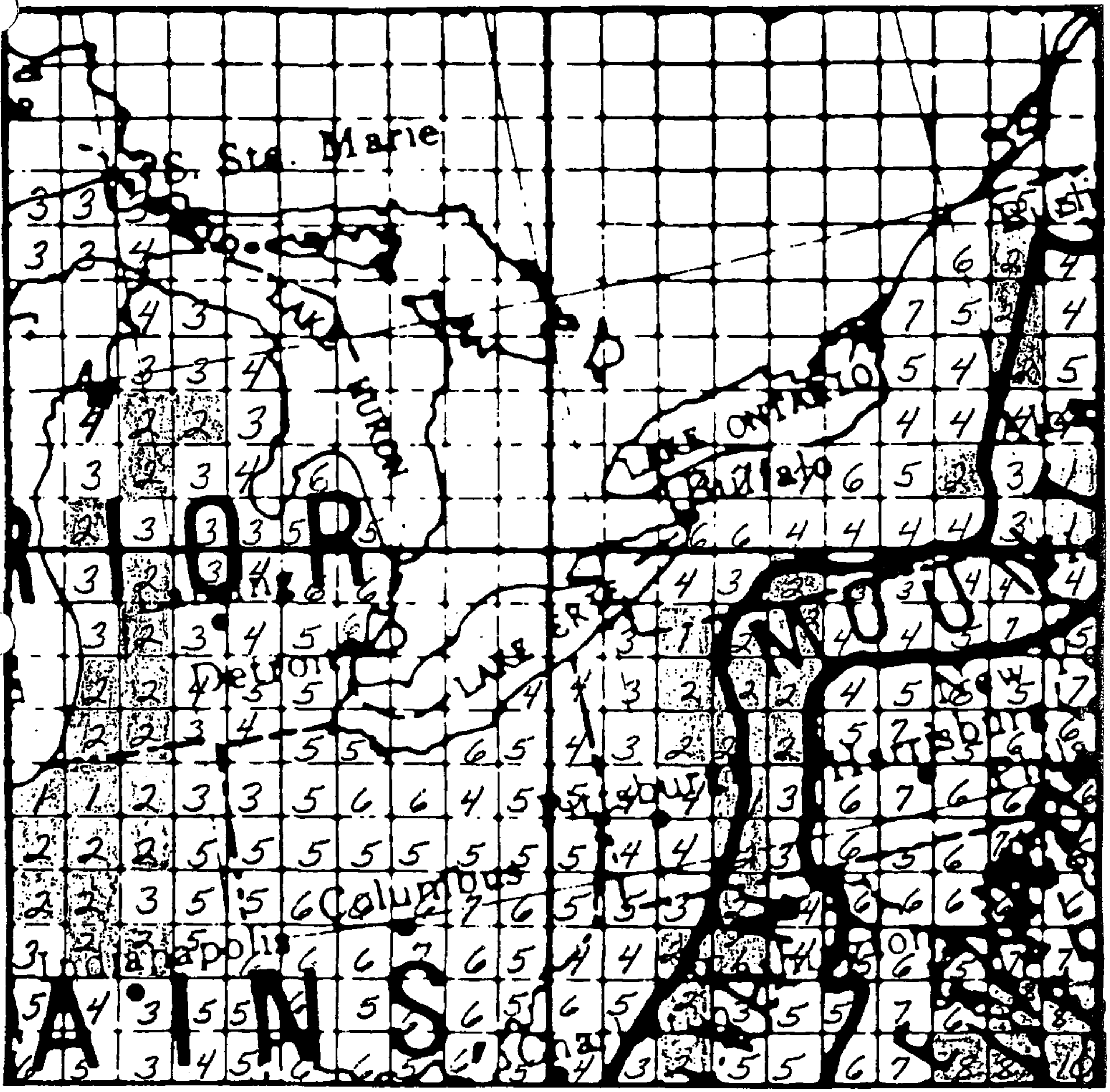


Fig. 7. Grid cell values of the northeast quarter of the grid.

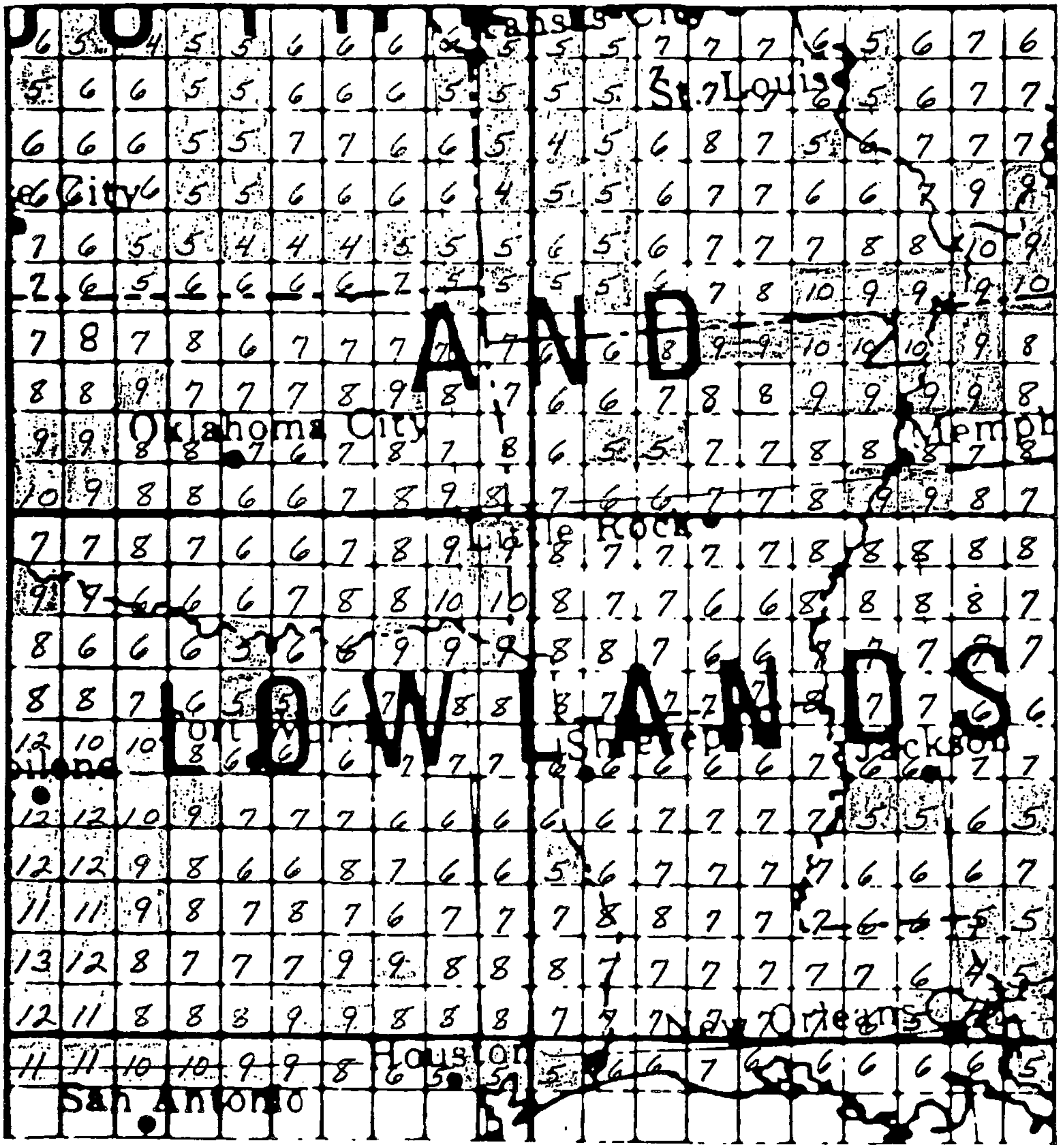


Fig. 8. Grid cell values of the southwest quarter of the grid.

Antonio, Texas, but note the large area of highly rated climate over the four-state area where the Ohio and Mississippi Rivers join. There is a general trend of higher rated climate running southwest to northeast from central Texas to western Kentucky. There is evidence that the model is not biased toward southern latitudes since Houston and New Orleans are rating lower than St. Louis and many other areas of the Midwest. The response of the model is surprisingly detailed. Note that ratings range from four along the Iowa-Missouri border to near ten in the Bootheel, and there appears to be a distinct climatic transition zone.

The southeast sector of the grid (Figure 9) clearly has the highest rating, but the distribution of the ratings is interesting, if not controversial. The ratings range from two to 13, the largest range of any sector. The lowest ratings are found along the Gulf Coast from around Mobile, Alabama to just north of Tampa, Florida (note the three "3" rated cells just north of Tampa Bay), and along the southern end of the Appalachians. The highest rated climates are found in a large contiguous area that covers nearly all of eastern Georgia, South Carolina, and parts of North Carolina. The second of the two highest rated cells is found just southwest of Charleston, South Carolina, while the second highest rated climate is found near Asheville, North Carolina. Note the sharp gradient from rating five to 12 on the east slope of the mountains.

4. Conclusion

Clearly, the model indicates that South Carolina, eastern Georgia, and parts of North Carolina enjoy the climate most suitable for human existence in the eastern half of the United States. The area averaged rating for the entire state of South Carolina was ten of a possible 13. A smaller area of most suitable climates was found in central Texas at the extreme southwest corner of the grid. The surprise was the third largest area of highly rated climate centered around the confluence of the Ohio and Mississippi Rivers.

Based on the results the model appears to be objective and sensitive to variations in climatic variables. The fact that much of the Gulf Coast was rated as low, or lower, than the upper Midwest indicates that the model does not contain a bias for southern states in general. Mountainous areas and large bodies of water showed a distinct influence on climate. It should be noted that due to the nature of the data, one can't say that a ten rating is twice as good as a five. Mathematical manipulation is not possible on the final ratings, and the final ratings are simply relative to each other. Additionally, two equal five ratings could be based on entirely different circumstances.

It would be easy to argue for or against the final ratings based on personal preference. One could weight the input variables differently to find areas that are better suited to the individual and construct a personalized model, for example, multiplying the tornado map by 100 could result in new climate ratings with the areas of high tornado incidence excluded from consideration. However, it must be stressed that the suitability ratings are based on long term averages, thus the fact that a lesser probability of occurrence of some phenomena exists for certain areas does not preclude the occurrence of the phenomena in those areas. This is especially true when considering climatic

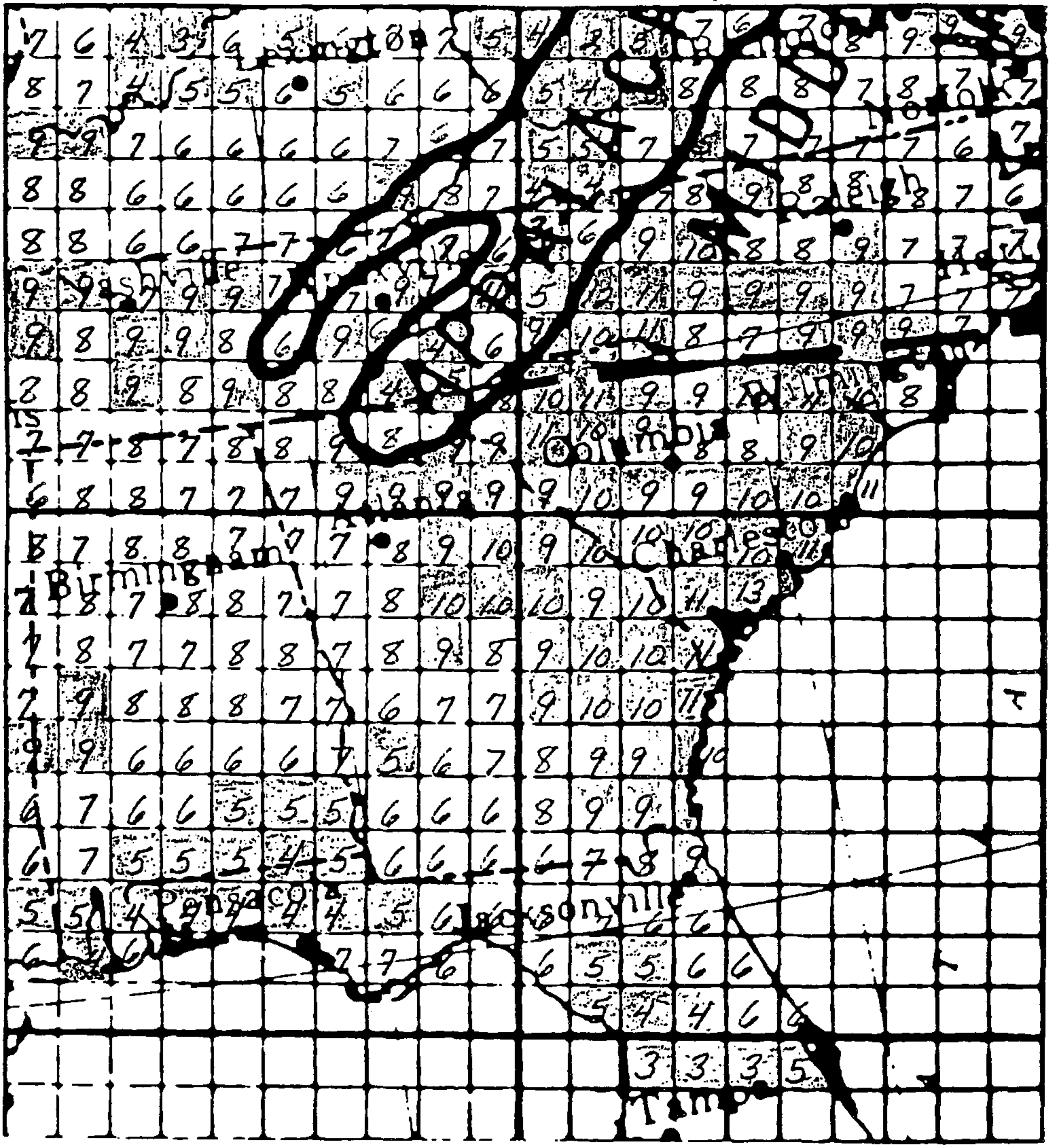


Fig. 9. Grid cell values of the southeast quarter of the grid.

hazards. One should not move to South Carolina expecting to avoid all hardships imposed by the environment. A major tornado outbreak occurred there as recently as March 1984 (Whitten, 1984).

The model could be more objective, and thus convincing, if the relationships between climatic variables and suitability were more explicit and quantitative, but this is a research problem unto itself. A rigorous model should be based on an isoline analysis of the latest point data of long term climatological normals. When building a model such as this, one must remember that the computer processed output is only as objective and valid as the original input.

5. References

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