

I.O.S.

CONTOURED WAVE DATA OFF SOUTH UIST

by

B. C. H. FORTNUM, J. D. HUMPHERY and E. G. PITT

Report No. 71

1979



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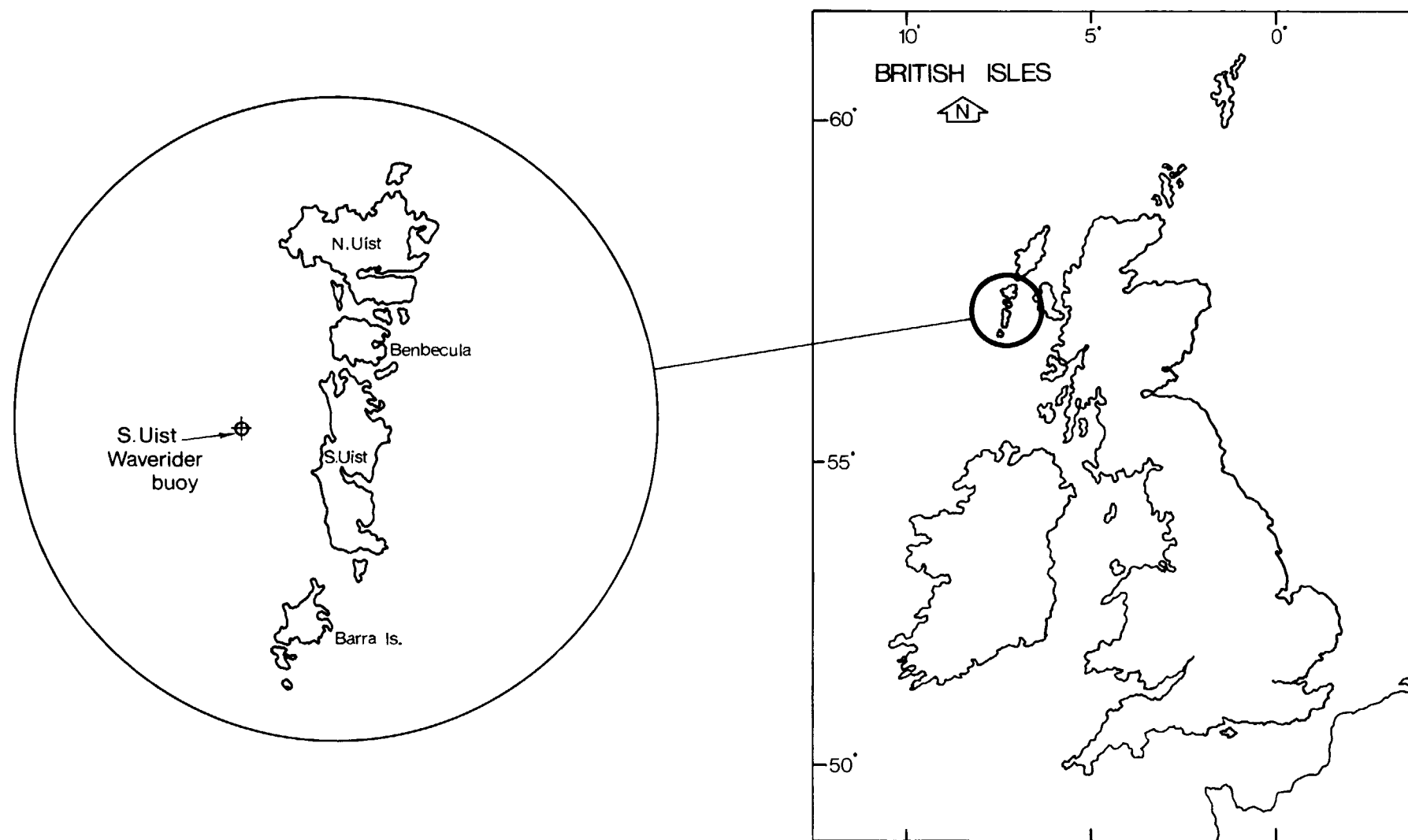
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The installation of the wave recording system and the analysis of the data referred to in this report were part of the long-term IOS wave climate study, and were financed by the Departments of Industry and of Energy.

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Location map of S.Uist Wave Recorder

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1. INTRODUCTION

1.1 SITE DESCRIPTION

The site at which the wave measurements were taken is shown on the figure at the front of this report. It is approximately ten miles west of the island of South Uist in the Outer Hebrides, where the water depth is about 42 metres; its position is 57°18'N, 07°38'W. As well as experiencing locally generated waves, the site is also exposed to swell from a great area of the Atlantic Ocean.

1.2 DESCRIPTION OF MEASURING AND RECORDING SYSTEMS

The wave measurements were made by a Waverider buoy (manufactured by Datawell, Haarlem) which measures the vertical acceleration of the water surface. This is integrated twice to give the elevation of the water surface above the mean water level, and transmits this information by a radio link to the receiving equipment on the island of South Uist. This information about the water surface elevation is sampled twice each second and recorded digitally on magnetic tape by a Rapco data logger. Each data record contains 2088 values of elevation (covering approximately 17½ minutes), and the time between starts of successive records is three hours. (In addition, data are recorded in analogue form by a chart recorder and as an fm signal on magnetic tape, purely for back-up purposes). Tape translation is carried out at the Taunton laboratory using a replay unit interfaced to a DEC PDP-11 computer. Data validation and analysis are described in Appendices II and III respectively.

1.3 DATA COVERAGE AND DATA RETURN

The period covered by the data is from 5 March 1976 to 28 February 1977. For this period 204 of the 2884 possible records were either missing or classified invalid (see Appendix II), resulting in a data return figure of 92.9 per cent.

2. PRESENTATION OF THE WAVE DATA

The data are presented in weekly sections, each week consisting of 56 three-hourly records (with the exception of the first and last weeks which have 52 and 32 records respectively). The data in each weekly section are presented in the following two ways:

(i) as a grid of spectral estimates,

(ii) as an overlay showing contours based on the spectral estimates.

The grid and overlay are paired together for each week, and 52 of these pairs are presented in this report, covering almost a full year's data. The grids and overlays are described more fully below.

(i) Information relating to the first record of the week appears at the top of the page and each succeeding record appears on the line below the previous record, so that the last record of each week is the penultimate line of each page. The information displayed for each record is arranged in the following order across each page:

date (ie day, month, and the last two digits of the year)

time of record start (in hours and minutes)

H_s (in metres)

T_z (in seconds)

spectral estimates (in m^2/Hz , 32 in number).

When no record was available, or the record was considered to be invalid (see Appendix II), only the date and time of the record appear. The last line on each page consists of the 32 values of frequency (in Hz) at which the spectral estimates were computed: details of the windowing function (a cosine taper) used in the derivation of these estimates are given in Appendix III.

(ii) The contours are calculated by computer program and plotted using a plotter of the Calcomp type. At the numerical approximation stage of the calculation a minimal amount of smoothing is performed. The intention of this is to bring out the general 'pattern' of each plot with as little reduction in the peak values as is possible. The contouring intervals used are 1, 2, 5, 10, 20, 30, 40, 50, 60, 70, 80, 90, 100, 150, 200 (m^2/Hz), and a knowledge of these will show what value a contour line has if, due to the closeness of the contours, the numbers are overwritten. Although no border appears on the contoured plot (this is one of the limitations of the program used) each plot extends over the same area as the grid of values which it represents (as far as the printing and binding processes will allow). Consequently the spectral estimates and the contoured representation of them, the latter on a transparent overlay, can be easily matched, week by week.

To ensure that the contours at the end of one week match as well as possible those at the beginning of the next week, the numerical approximation is carried out on data of two weeks' duration, consisting of the week to be contoured together with the previous half-week and the following half-week. The matching cannot be complete on the plots since there is a gap corresponding to three hours between the last record of one week and the first record of the next week.

Where gaps in the data are of only one or two records, the data are interpolated and the contour lines are uninterrupted. For the larger gaps, interpolation is not used, and the corresponding portion of the contour plot is left blank.

The data on which the contours are based assume a constant interval of three hours between consecutive records. There are several occasions when this interval has differed from three hours by up to 5 minutes; the errors resulting from this are too small to be discernible on the contoured plots. However, there are three instances of the interval being significantly different from three hours, two of them during the week beginning 25 March (4 hours 20 minutes, and 40 minutes), and the remaining one during the week beginning 3 June (3 hours 59 minutes). This is equivalent to introducing a different scale factor for the time-axis in these three regions, and will lead to local distortions which should be borne in mind when interpreting the plots.

The Bibliography gives two past publications in which this method of contouring has been used as an aid to data presentation.

3. DISCUSSION OF THE CONTOURED WAVE DATA

The contoured plots may be used to derive information about the storms which have generated waves arriving at the South Uist buoy, particularly the distance of a storm from the buoy and the time at which it occurred. The method used is explained in Appendix IV. The value of k which is referred to in that appendix is, for the data presentation in this report, 4.285×10^{-7} . When the distance, d , is required in kilometres, equation (3) of the appendix leads to the following formula for calculating the distance,

$$d = 1822 \tan \alpha$$

To find the time of the storm, the position of the time-axis must be determined. For the scales used on the contoured plots in this report, the zero frequency point lies a distance 5.74 centimetres to the left of the cross found on each of the plots.

The data show a number of the patterns (described in Appendix IV) which correspond to the arrival of waves from a distant storm. However the position and slope of the best line through each pattern is often open to quite large uncertainties, so that the distance, d , and the time, t_0 , calculated for the storm are very approximate.

Apart from their use in identifying wave generating centres, the contoured plots provide a good visual indication of the variation of wave activity at the South Uist site during 1976/77. The months of May, June, July, August and September seem to have experienced comparatively little wave activity, although during the two weeks beginning 6 May and 10 June there appears to be appreciably more wave energy at the site. These five

months include the four weeks with the very lowest values, those beginning 1 July, 12 August, 19 August and 23 September; during these four weeks the highest value of spectral intensity is $2.9 \text{ m}^2/\text{Hz}$. The highest levels of wave activity occurred during the months October, November, December and January (although the weeks beginning 18 November, 16 December and 23 December were comparatively quiet); especially noteworthy were the weeks beginning 30 September, 28 October, and 25 November. The latter gave the highest spectral estimate of the year: $198 \text{ m}^2/\text{Hz}$ (the maximum contour being $100 \text{ m}^2/\text{Hz}$).

4. AVAILABILITY OF THE WAVE DATA

The spectral estimates and derived statistical data from the South Uist site are available on magnetic tape from the Marine Information and Advisory Service (MIAS). Each spectral data file contains the following parameters:

H_s (significant wave height)

T_z (zero-crossing period)

Spectral moments (seven in number, from $n = -2$ to $+4$)

Spectral quality figure, low frequencies

Spectral quality figure, high frequencies

Taper adjustment factor (a cosine taper is used on the data, see Appendix III).

The latter three parameters are not actual data but are used in assessing the quality of the data.

Spectral peakedness factor

Spectral estimates (64 in number, from $f = 0.0249$ Hz to 0.6401 Hz).

In addition to these parameters, each file contains the date and time of the record, and validation flags (see Appendix II).

Also available from MIAS are index files, each of which contains only a part of the information contained in the corresponding spectral data file (the spectral estimates are omitted); the time series of digital data from which the spectral estimates were obtained may also be obtained.

Enquiries about these data should be made to the MIAS Enquiry Office at:

Institute of Oceanographic Sciences
 Brook Road
 Wormley
 Godalming
 Surrey GU3 5UB, England.

5. ACKNOWLEDGEMENTS

The authors would like to thank the many people whose efforts have made this report possible, in particular:

J.A.Crabb, of the Institute of Oceanographic Sciences for translation and validation of the digital data, and for writing Appendix II;

M.G.Turner, of the Institute of Oceanographic Sciences for mastering and operating the computer program SACM which was used to produce the contoured plots;

Datawell, inventors and manufacturers of the Waverider buoy, for permission to use their data about the response of various parts of the system as shown in Appendix III.

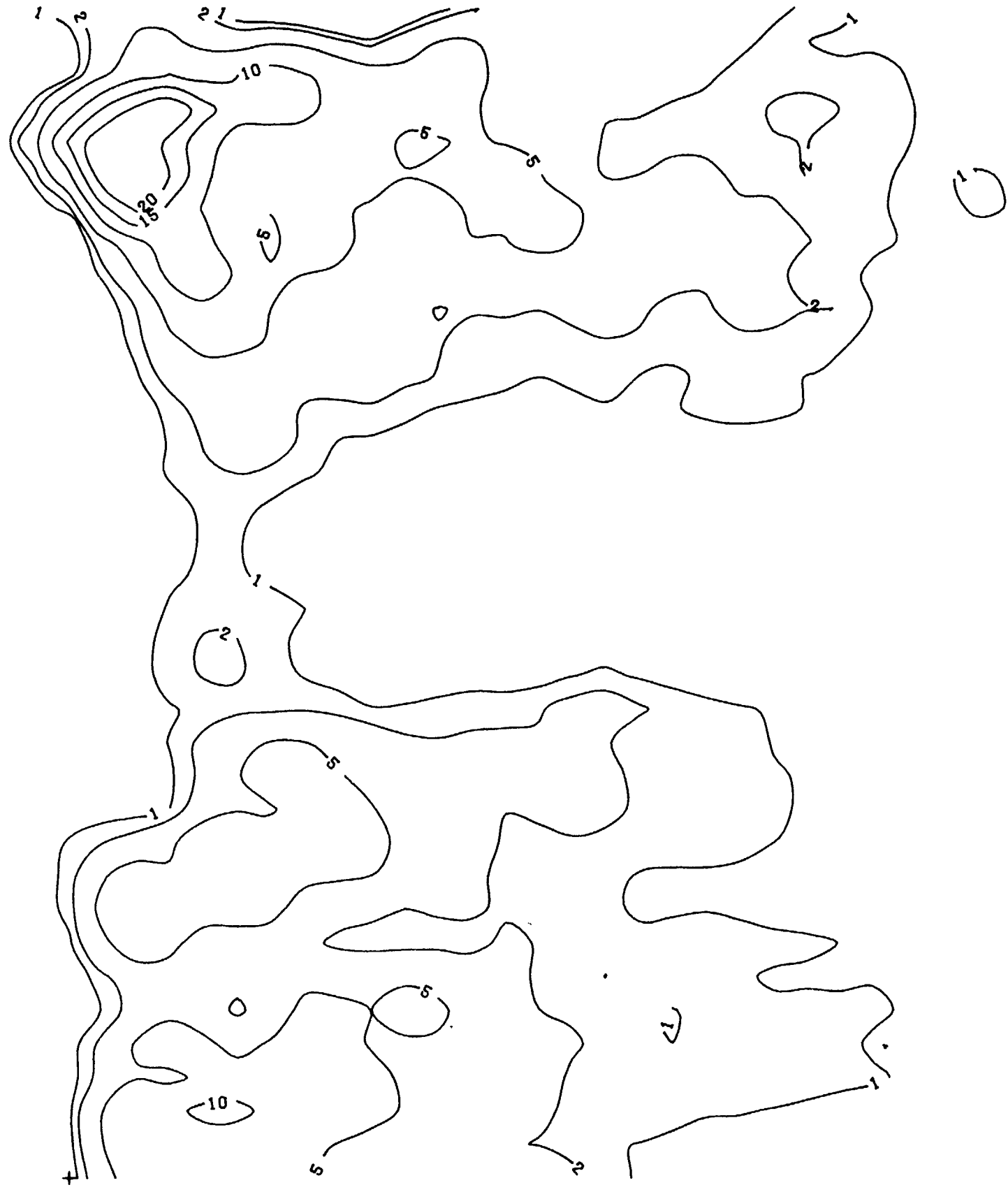
6. BIBLIOGRAPHY .

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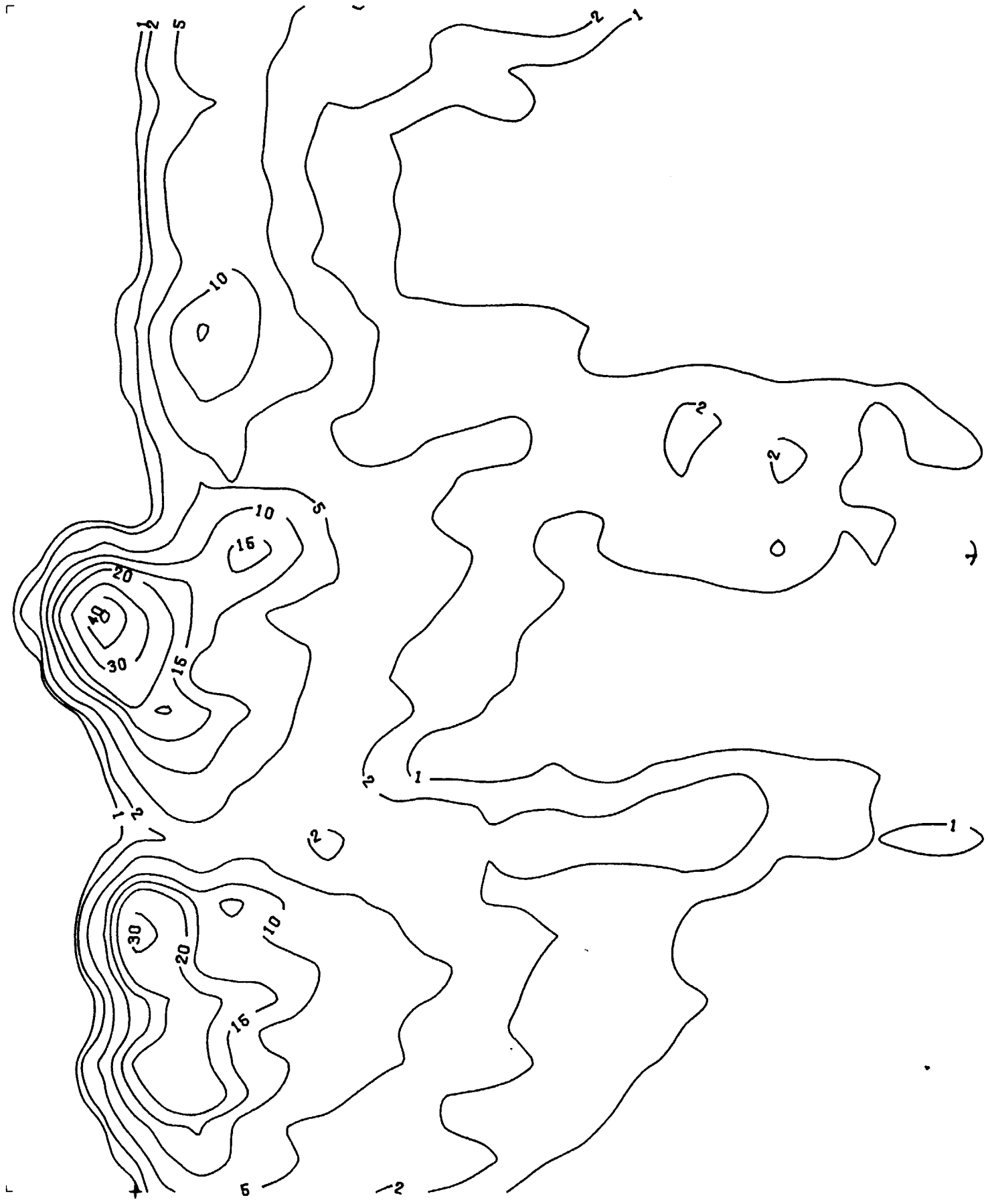
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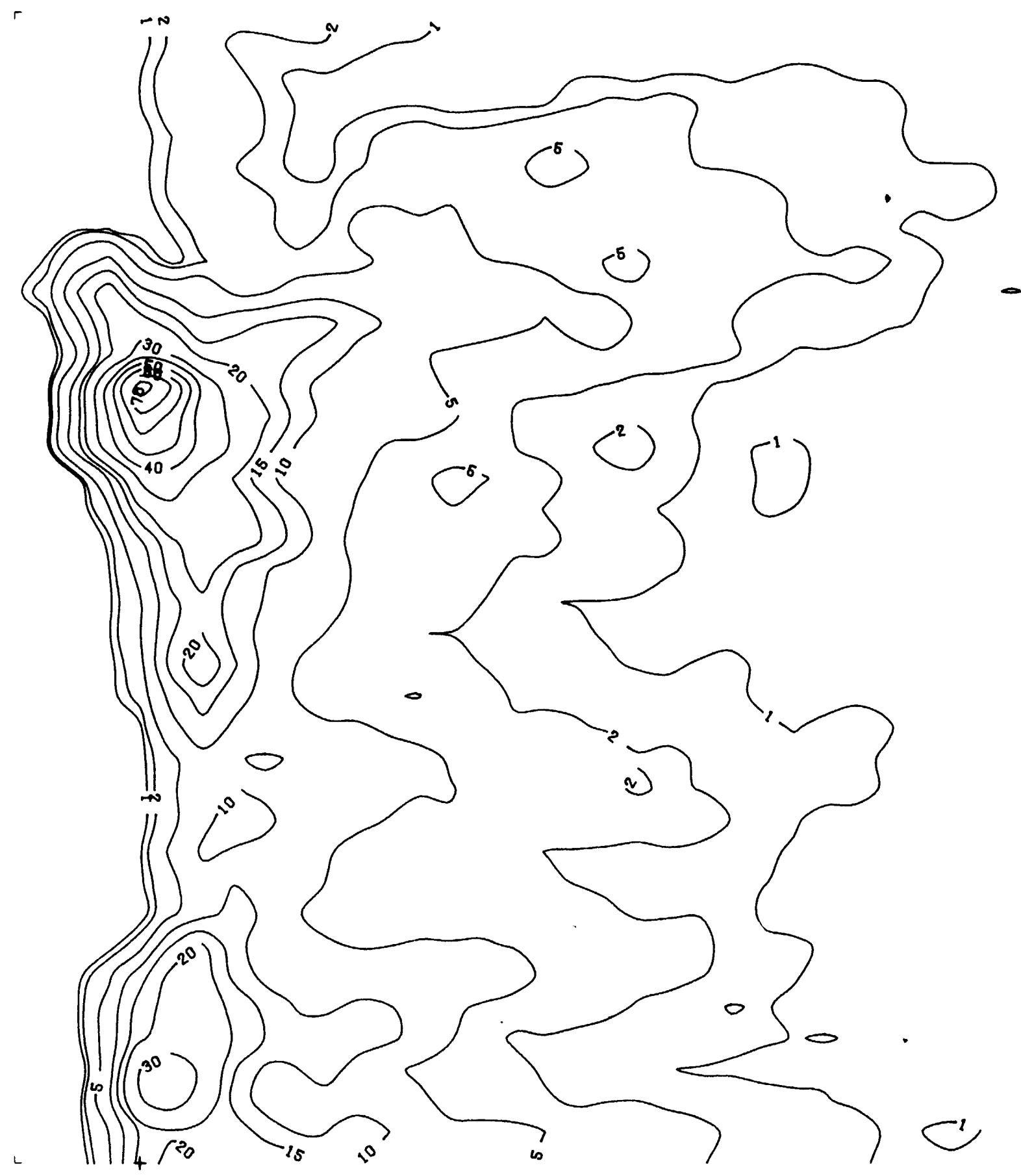
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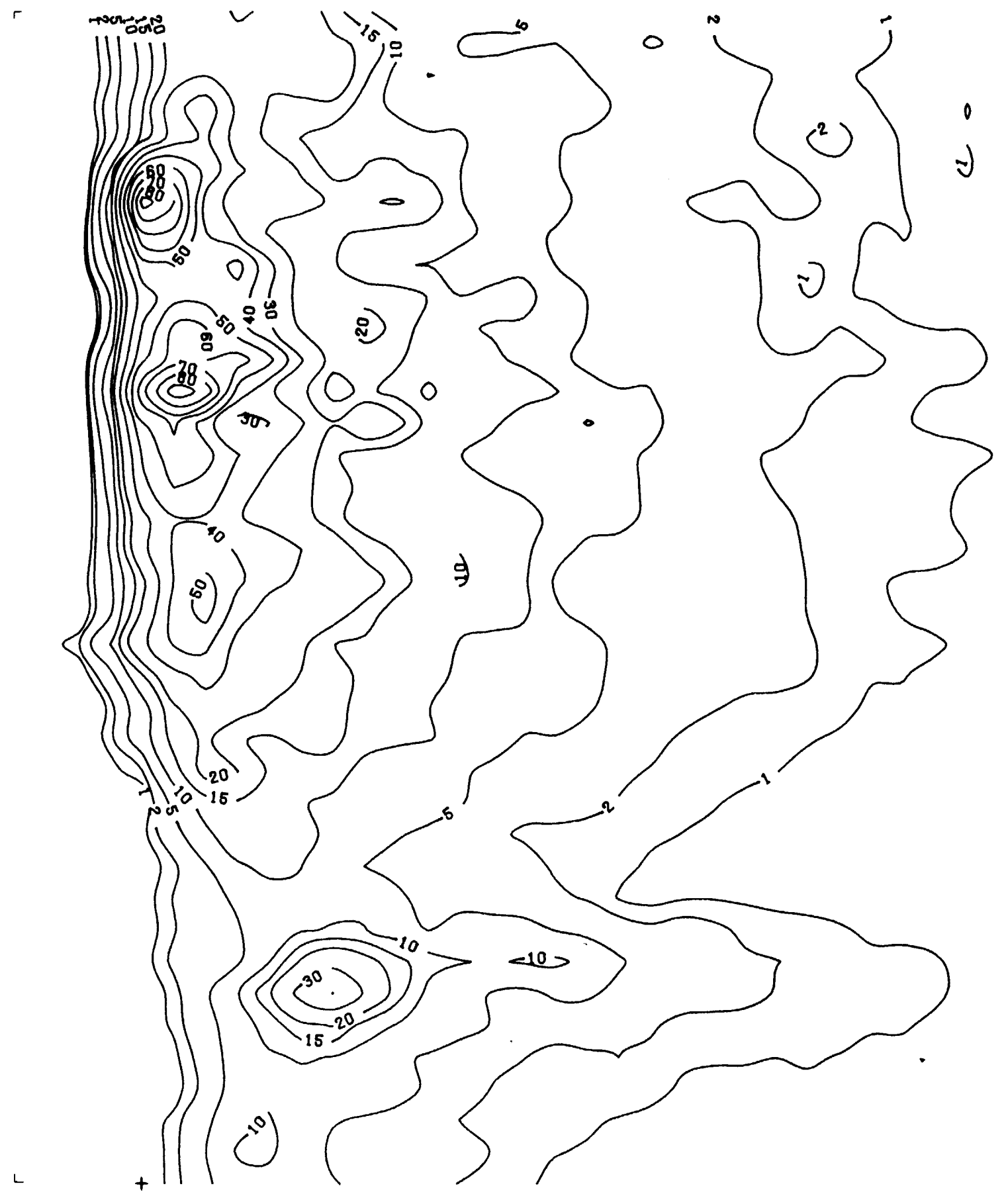
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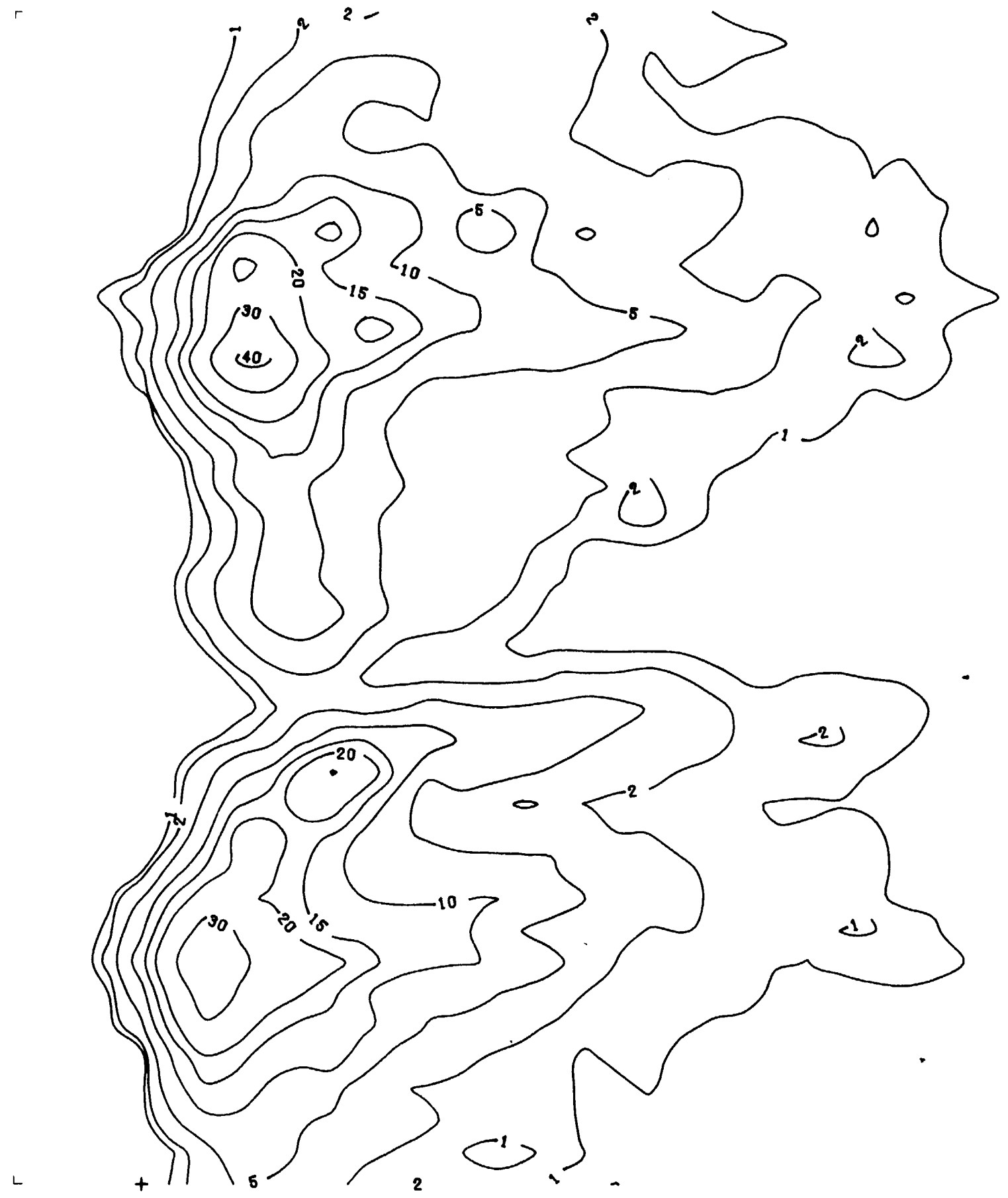


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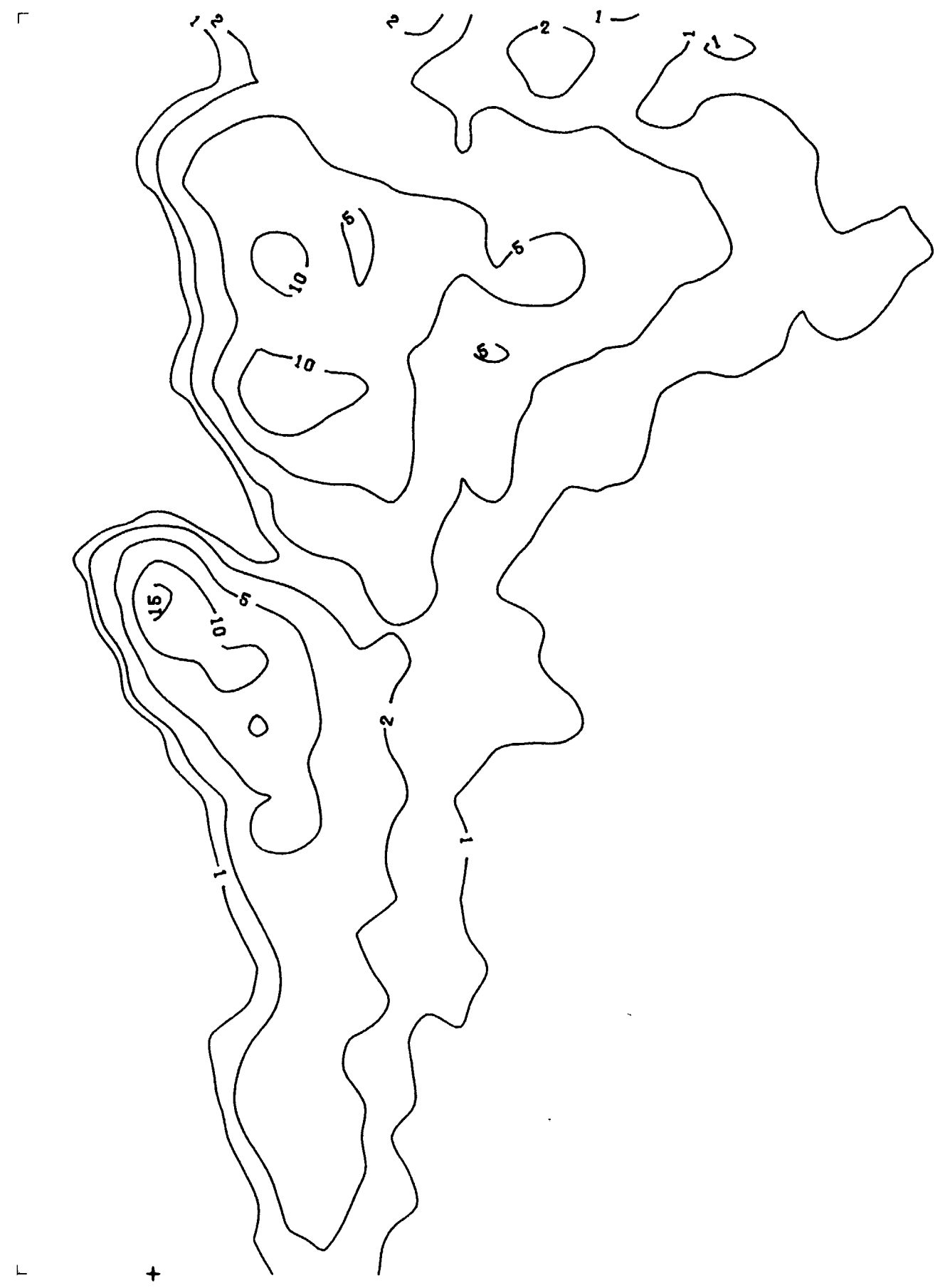
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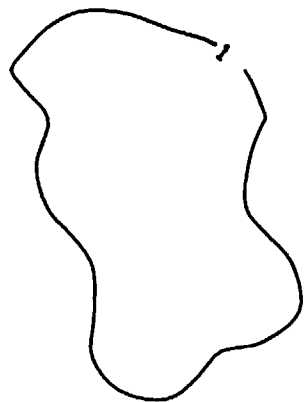
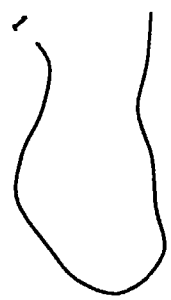


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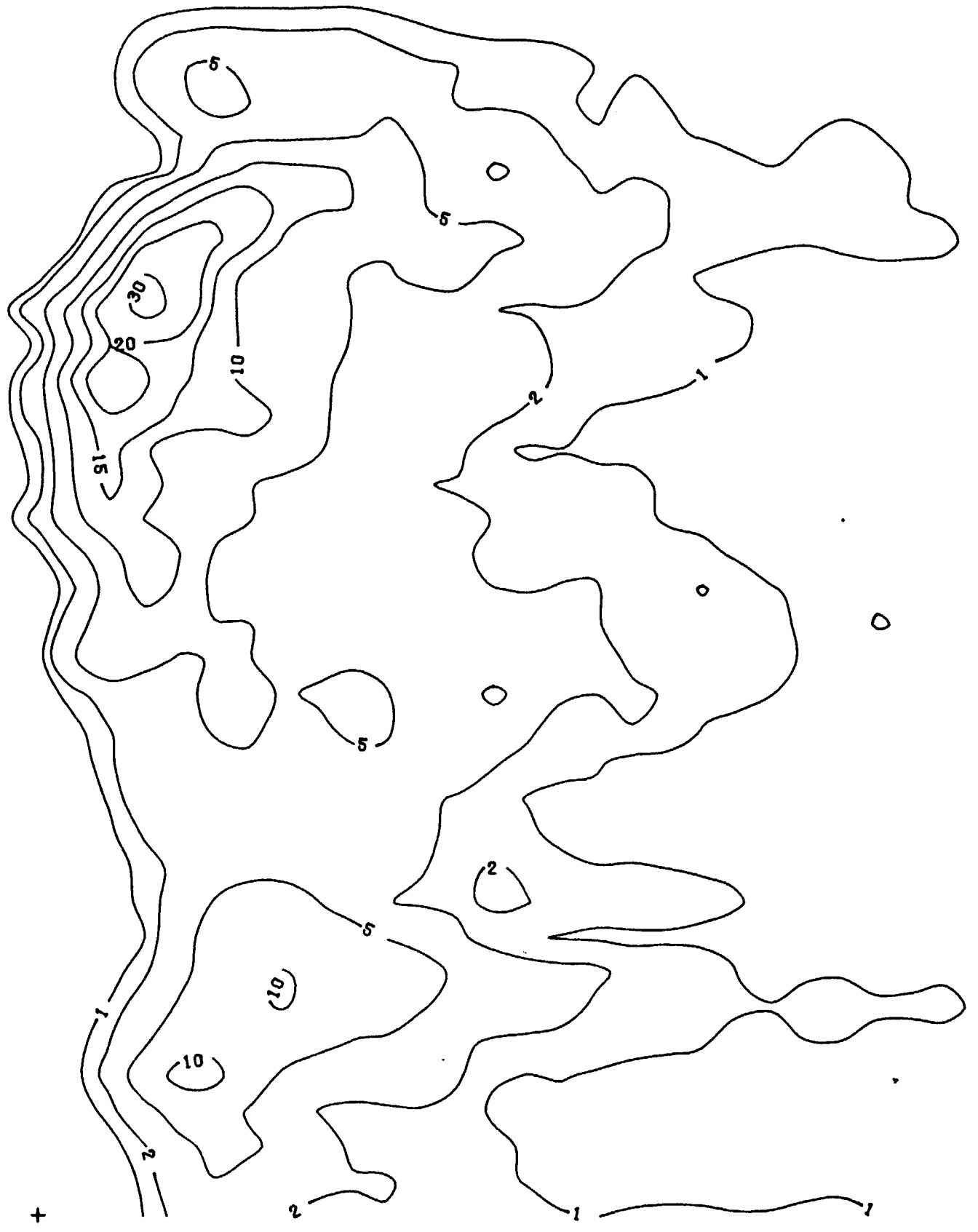
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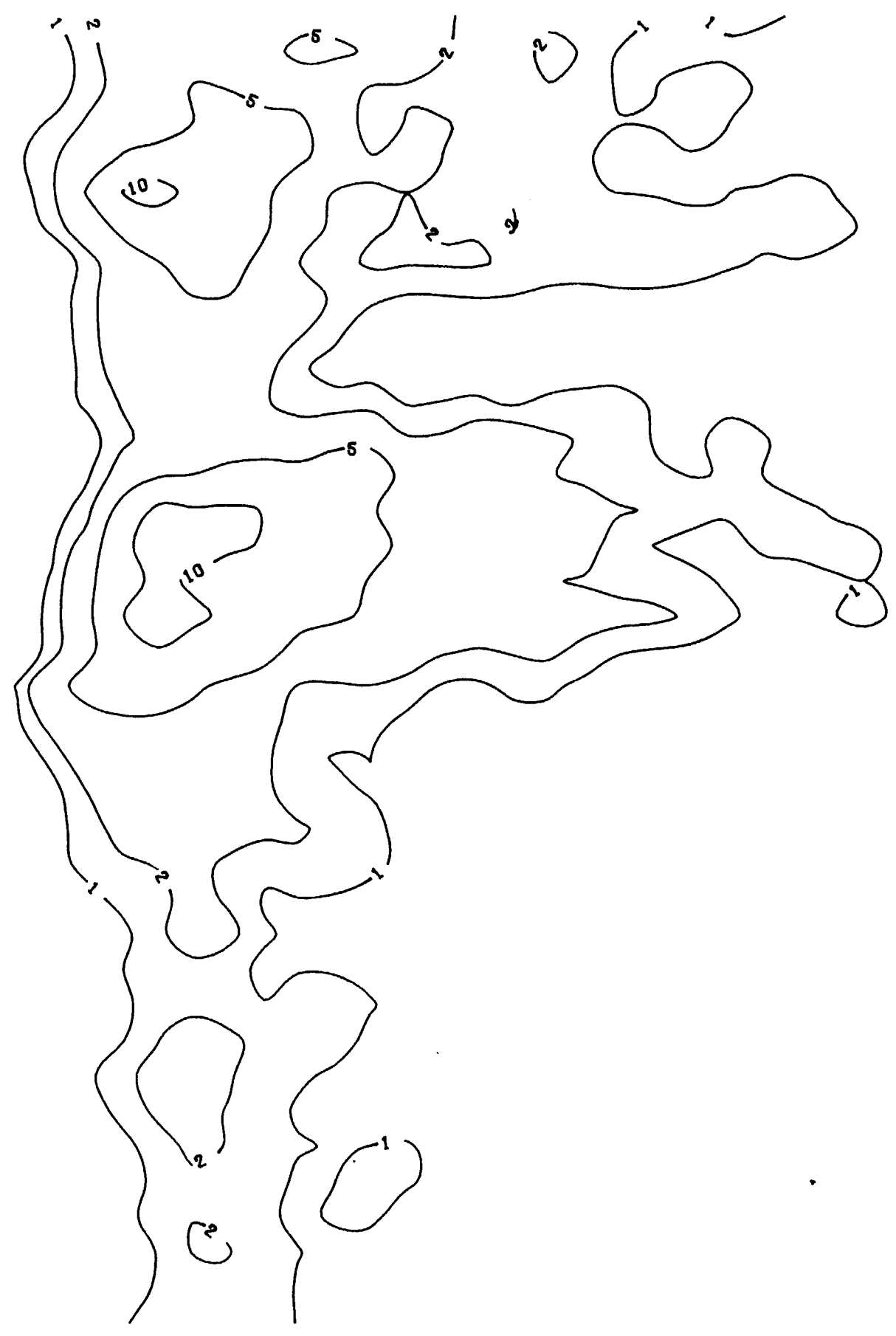


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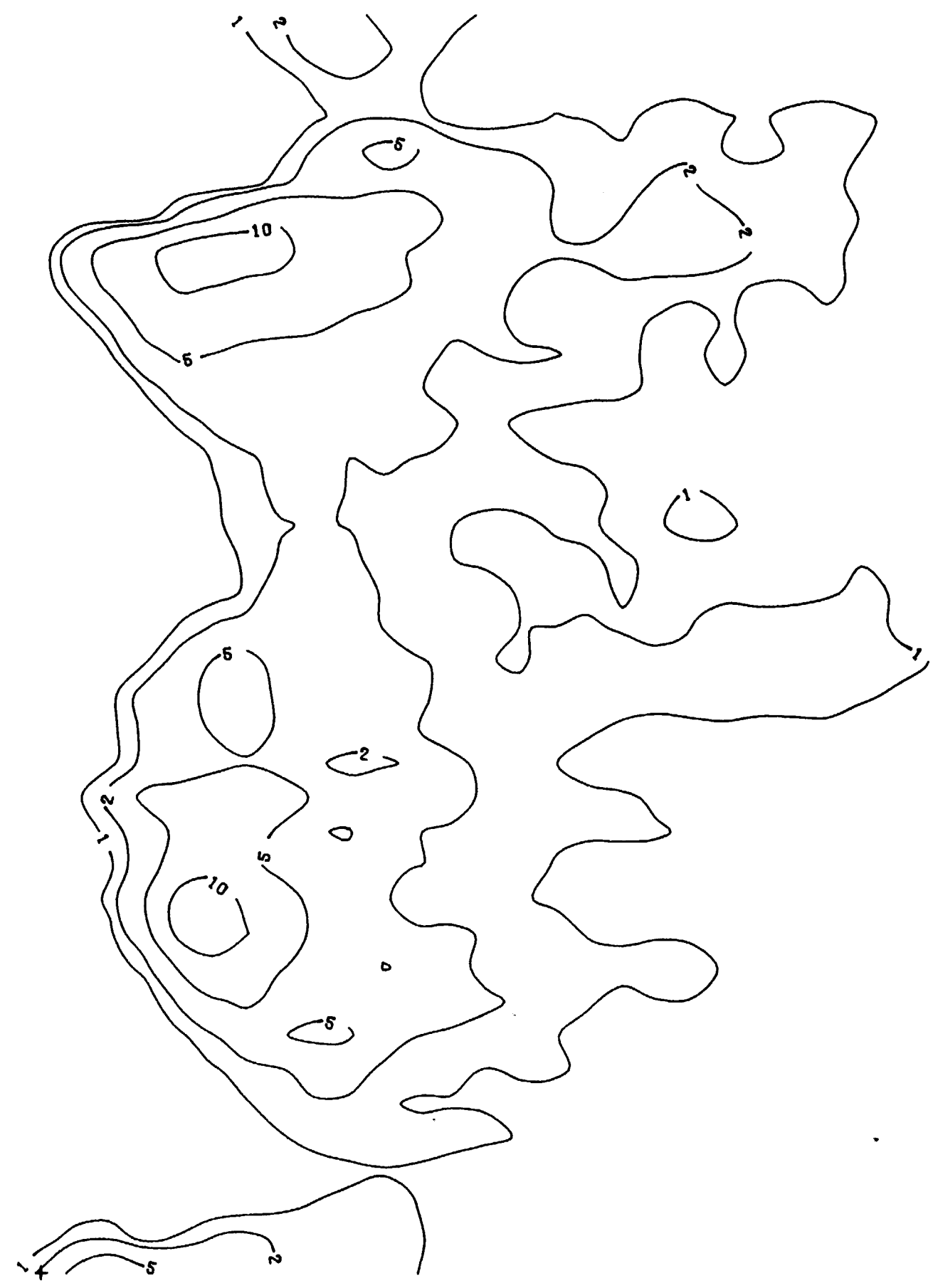
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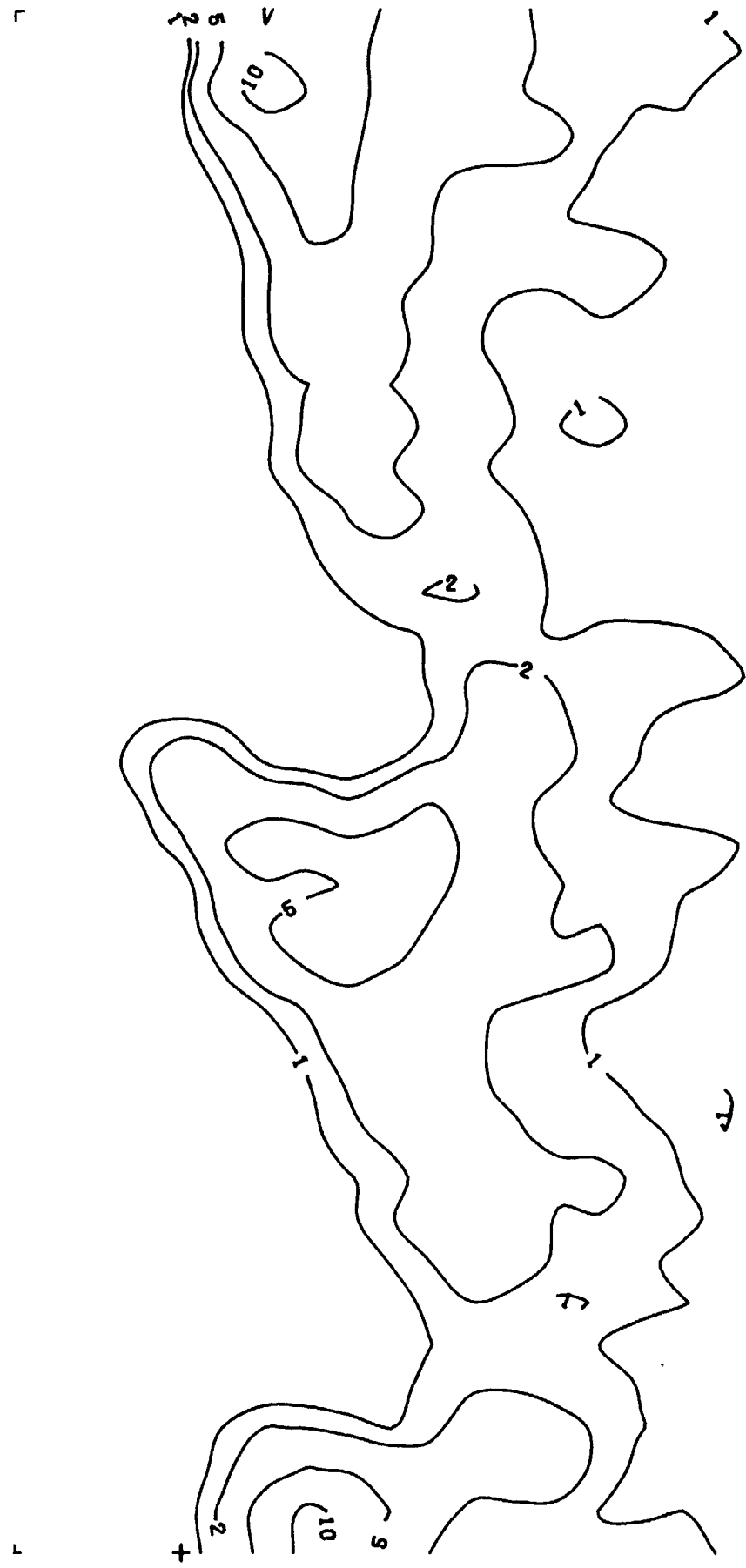


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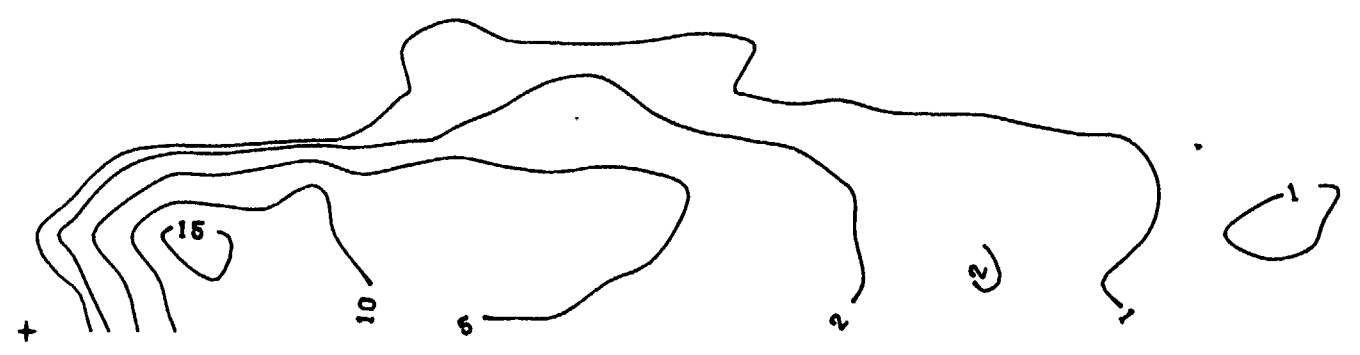


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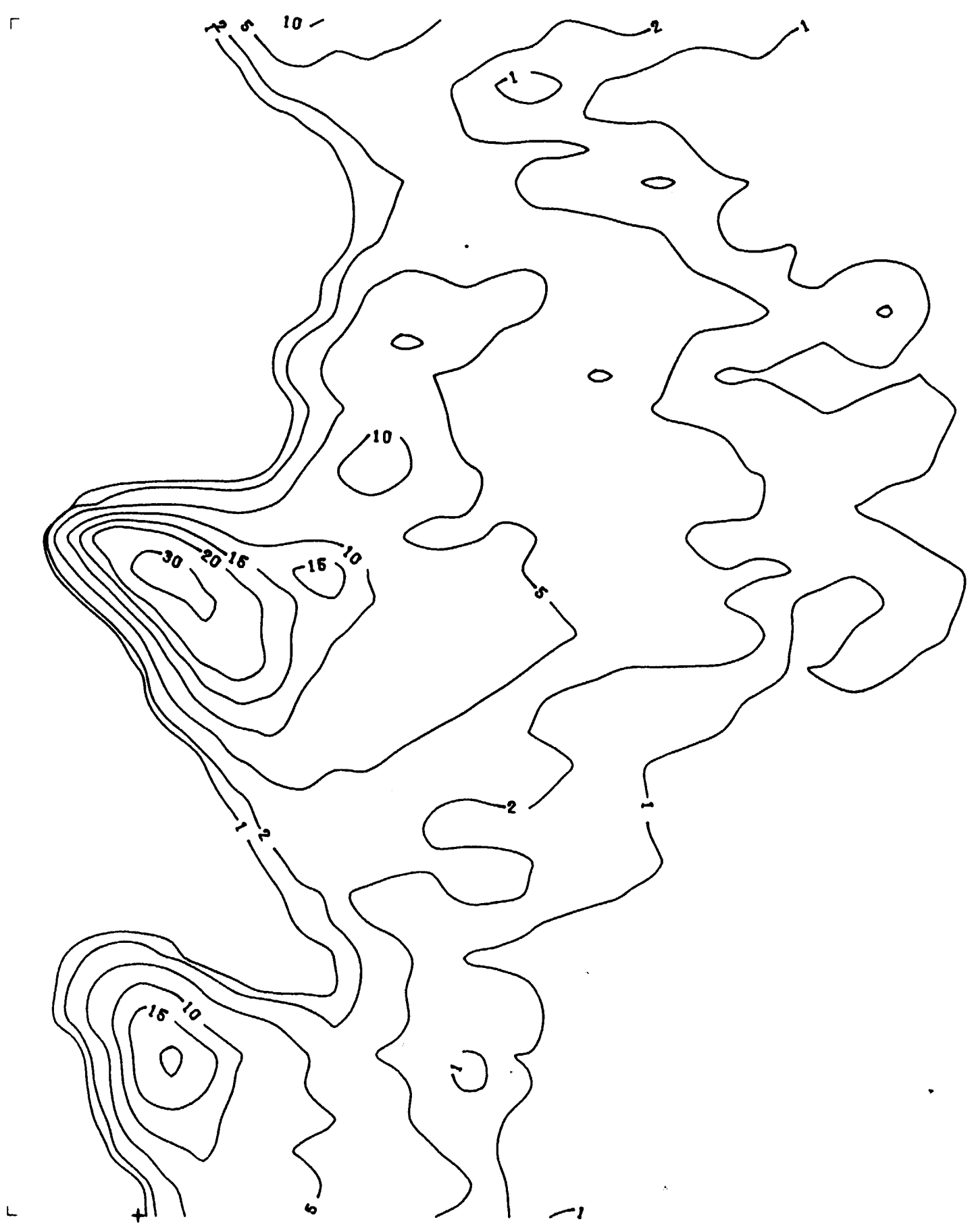
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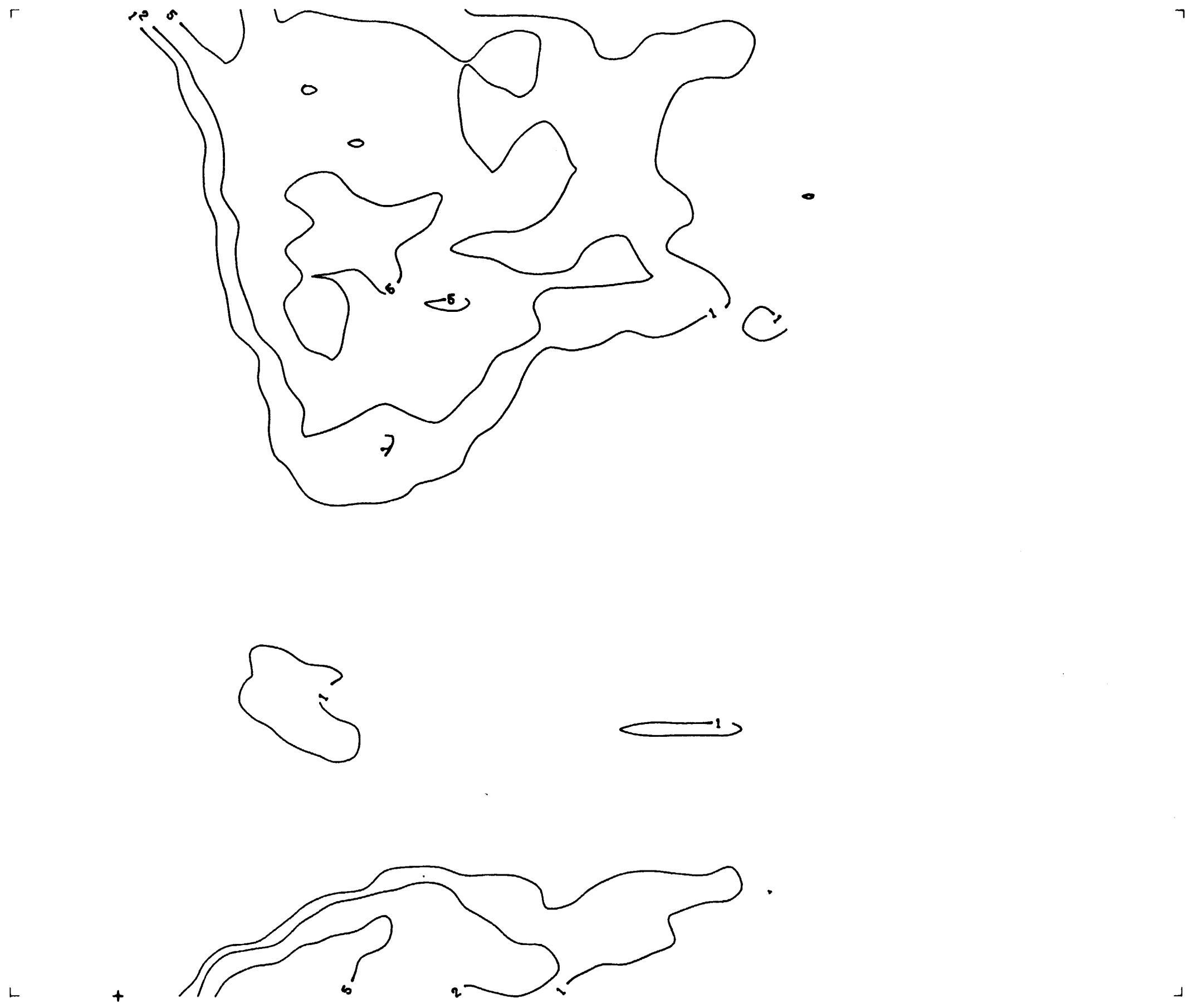
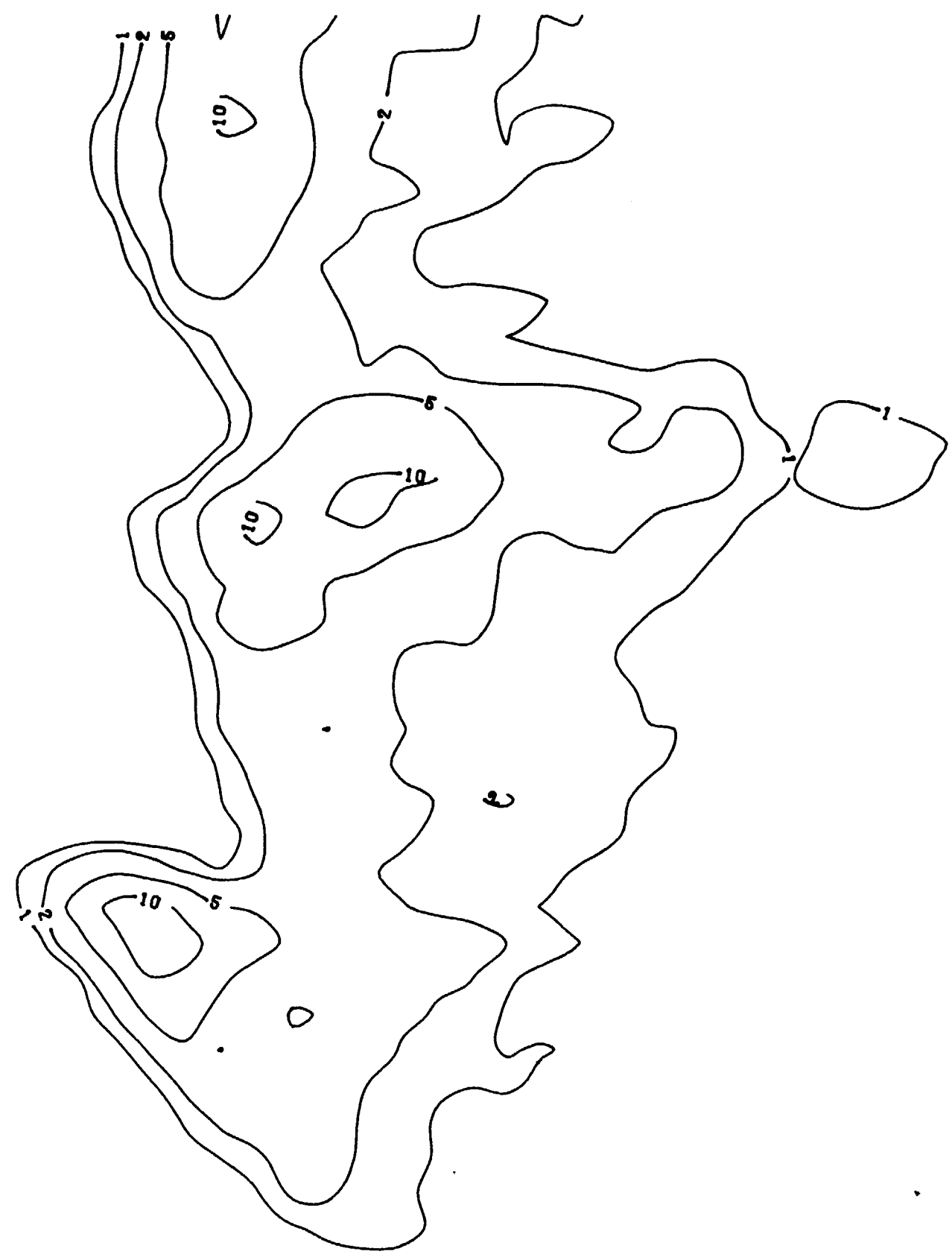


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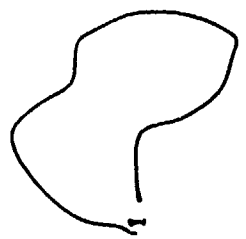
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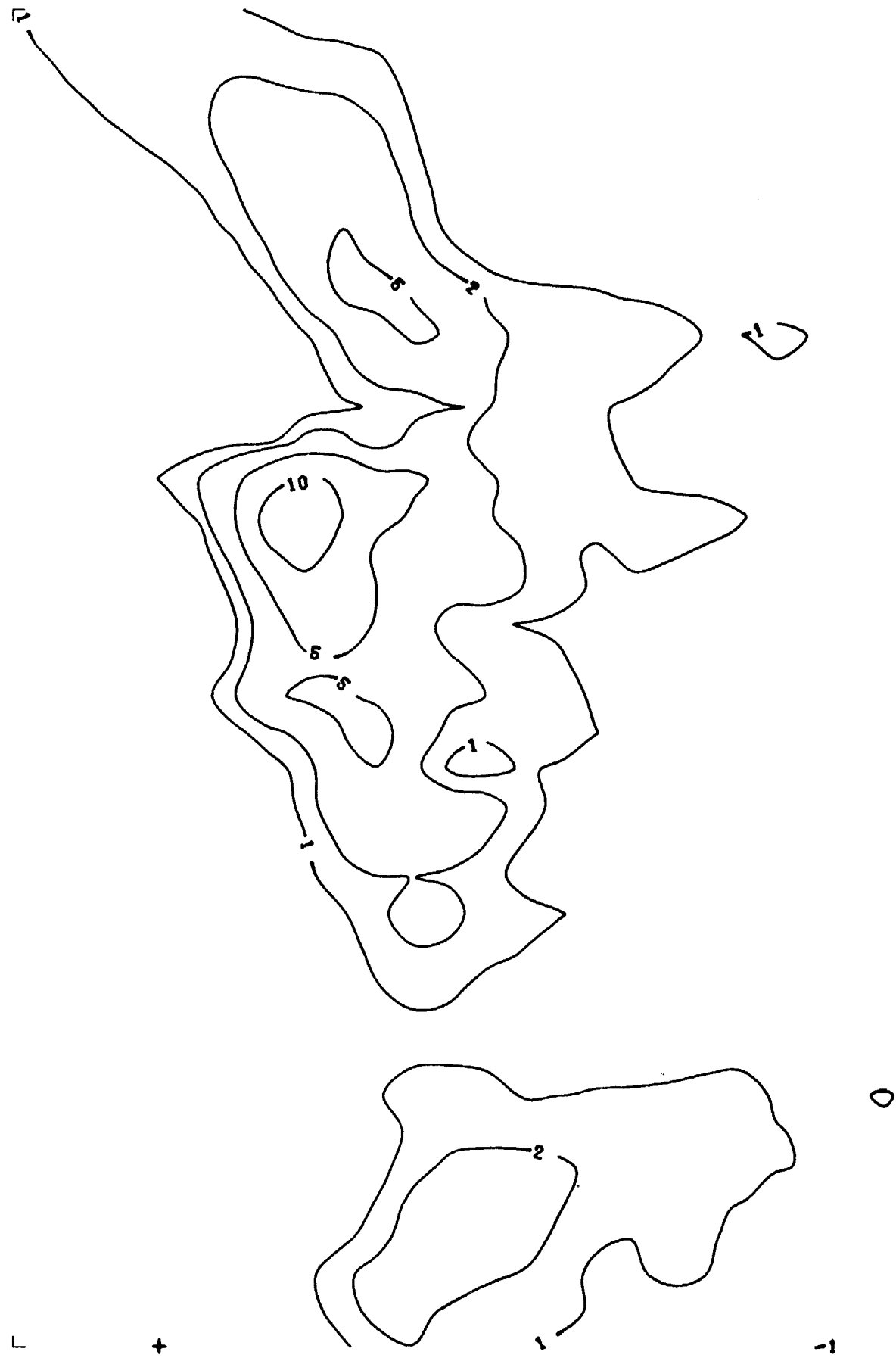
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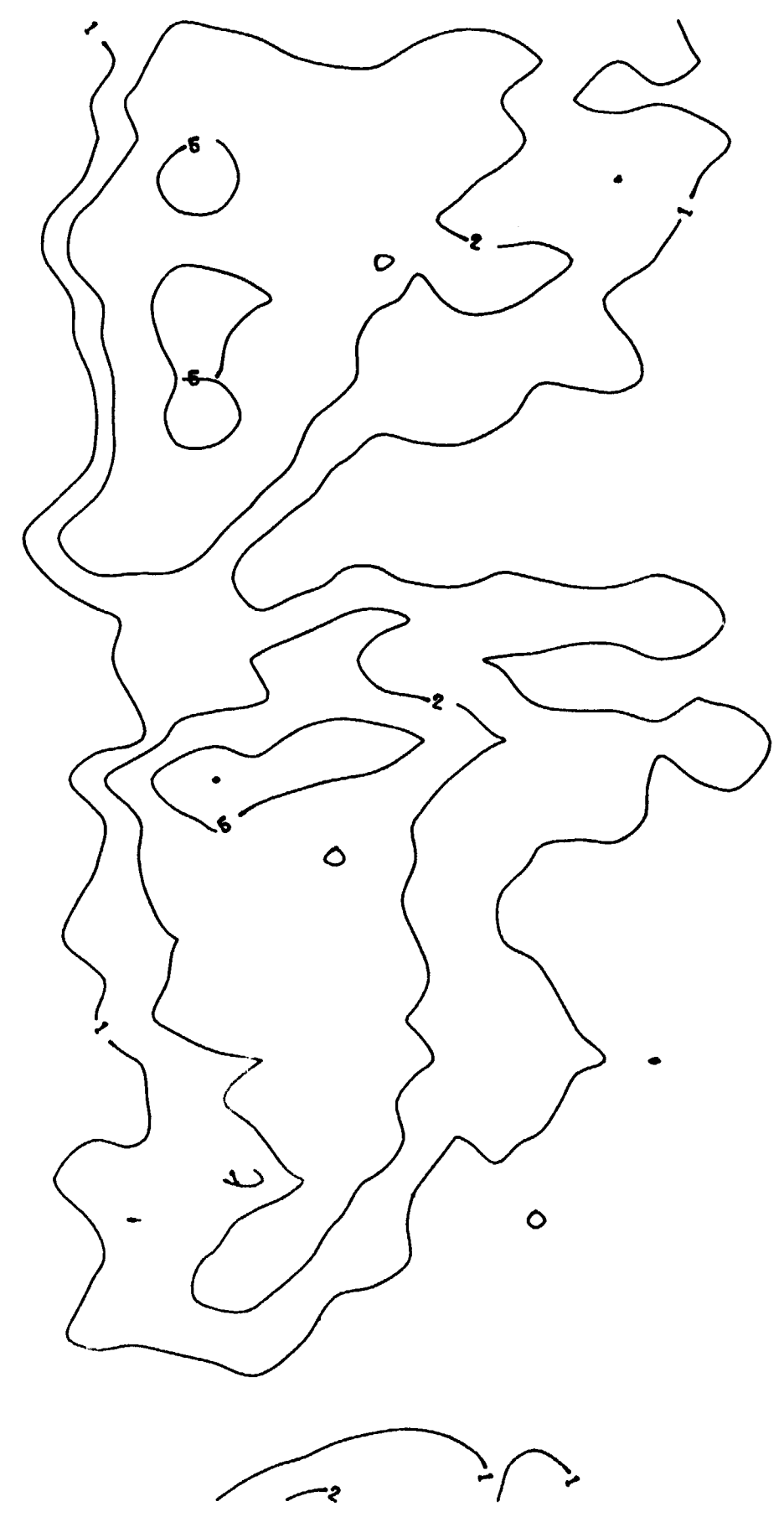


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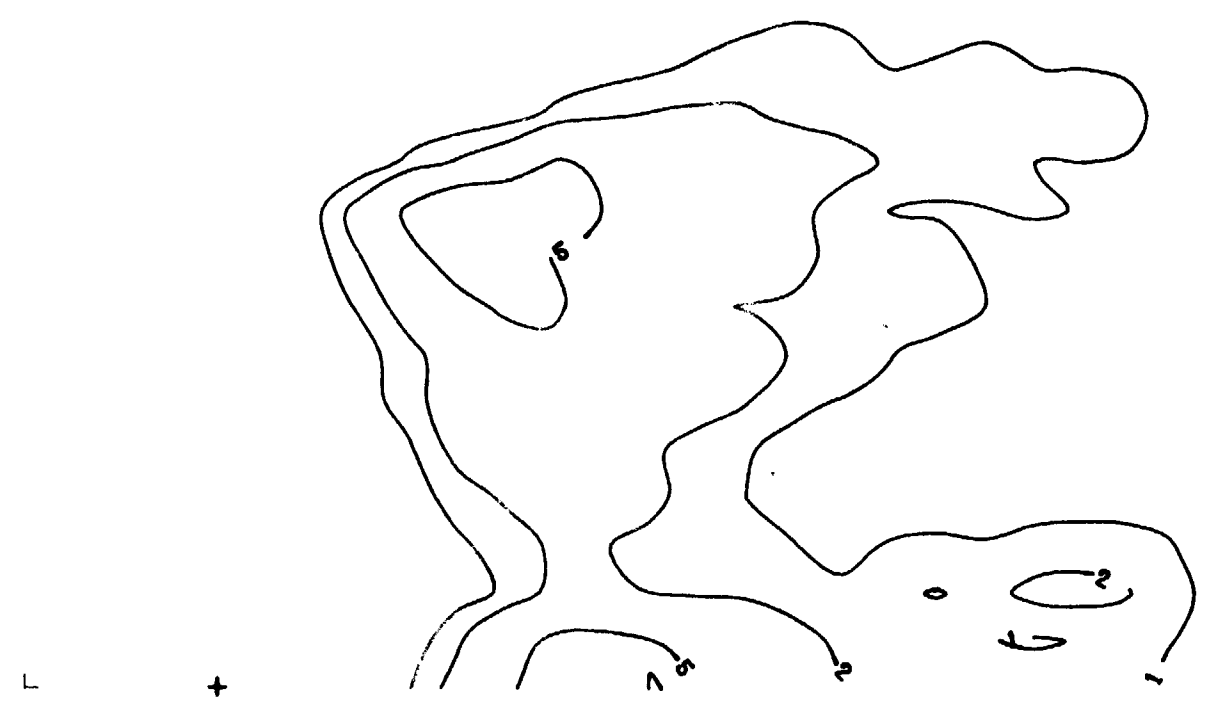
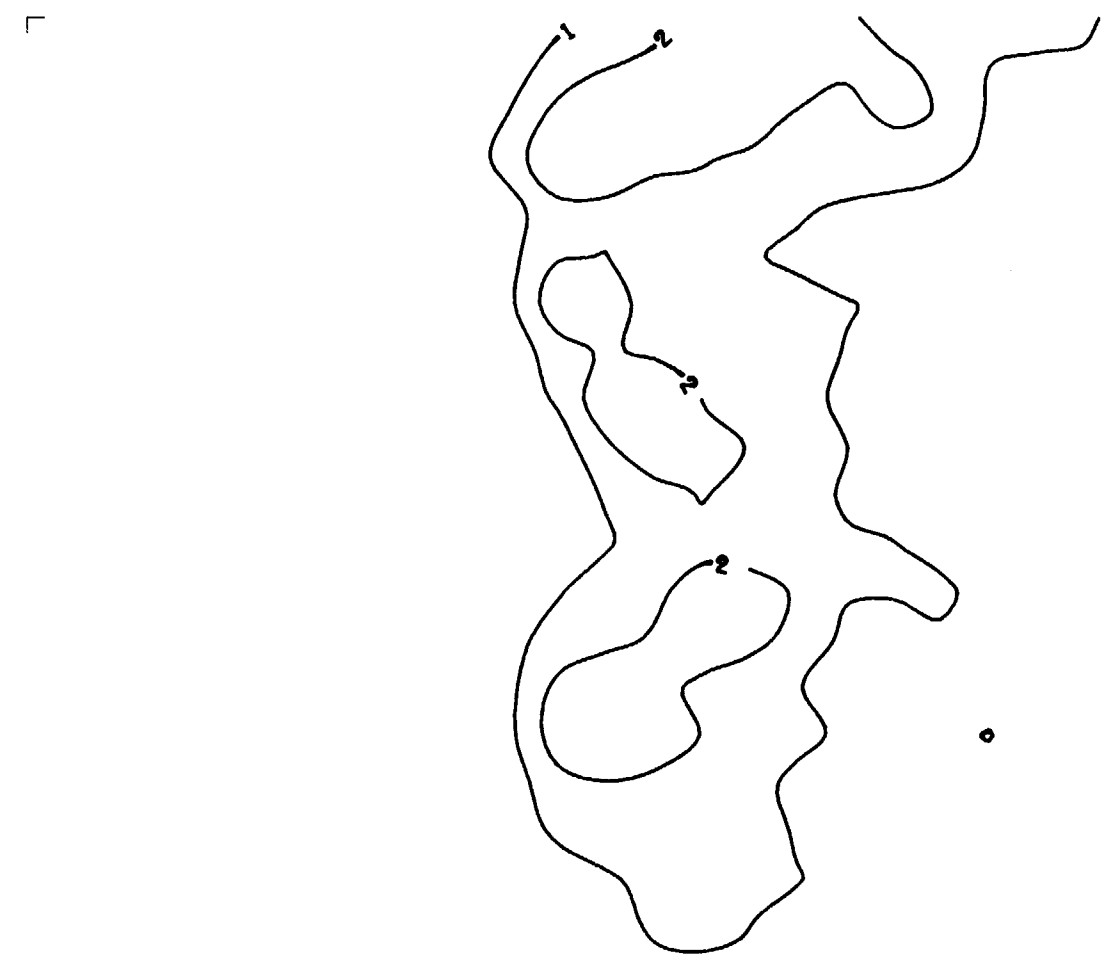
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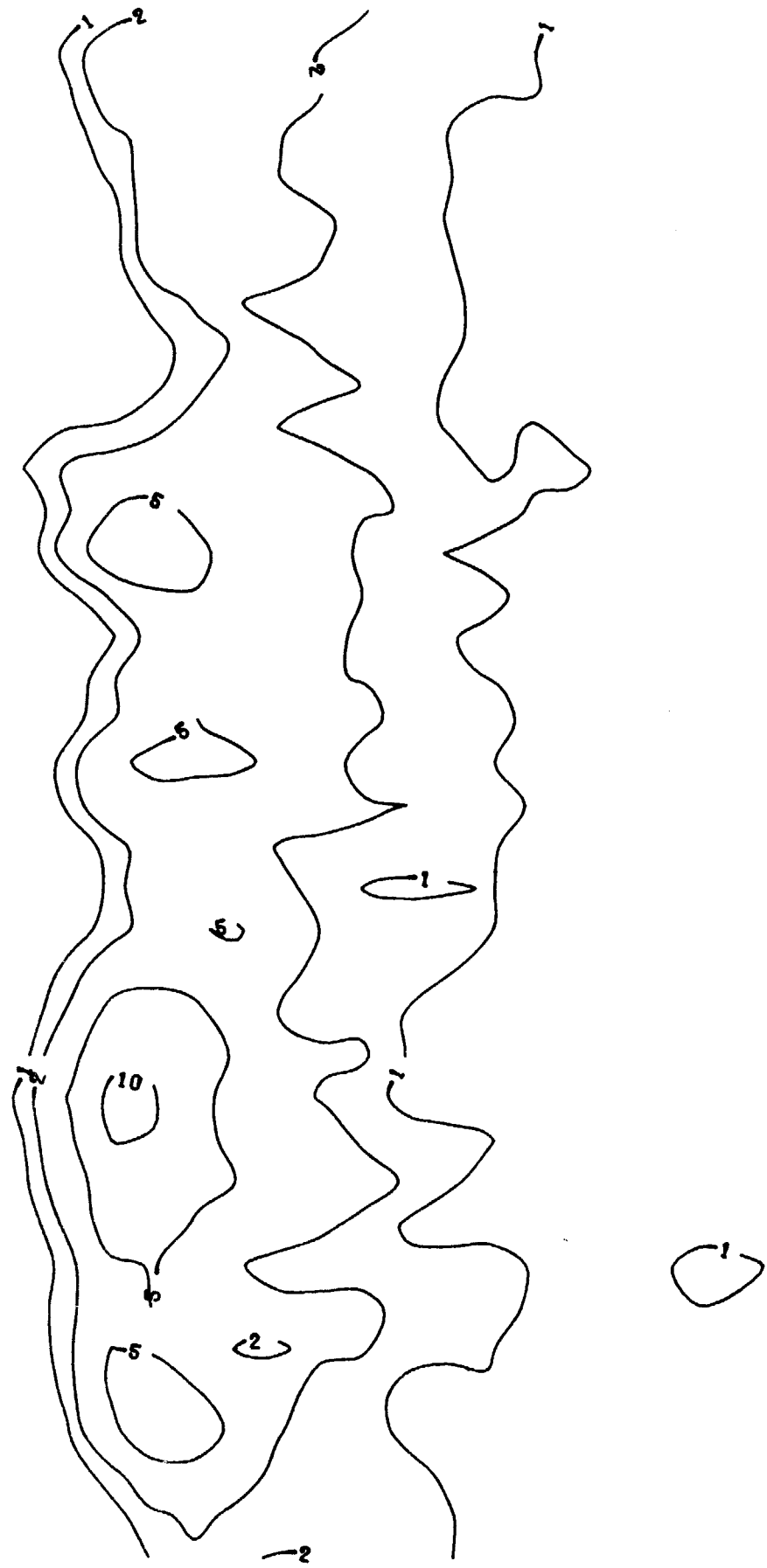


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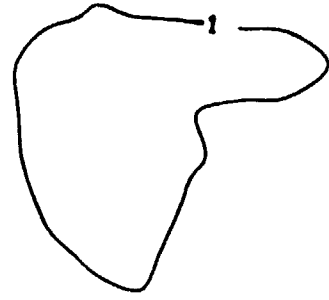


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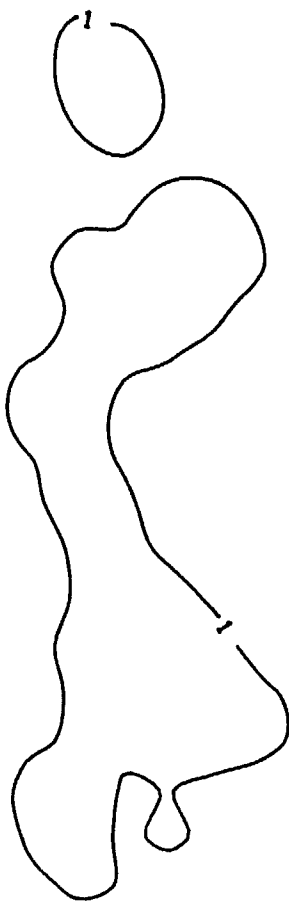


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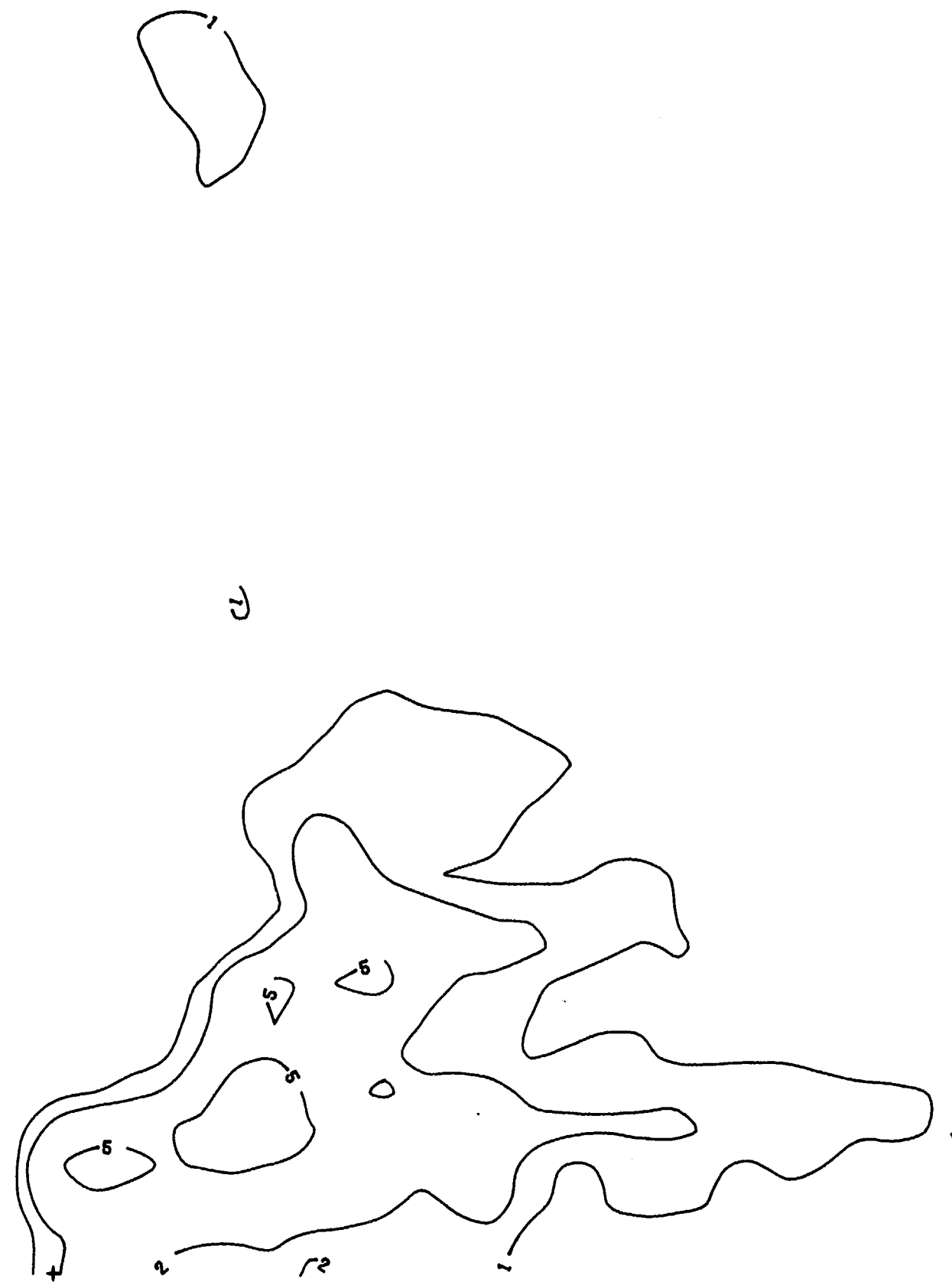
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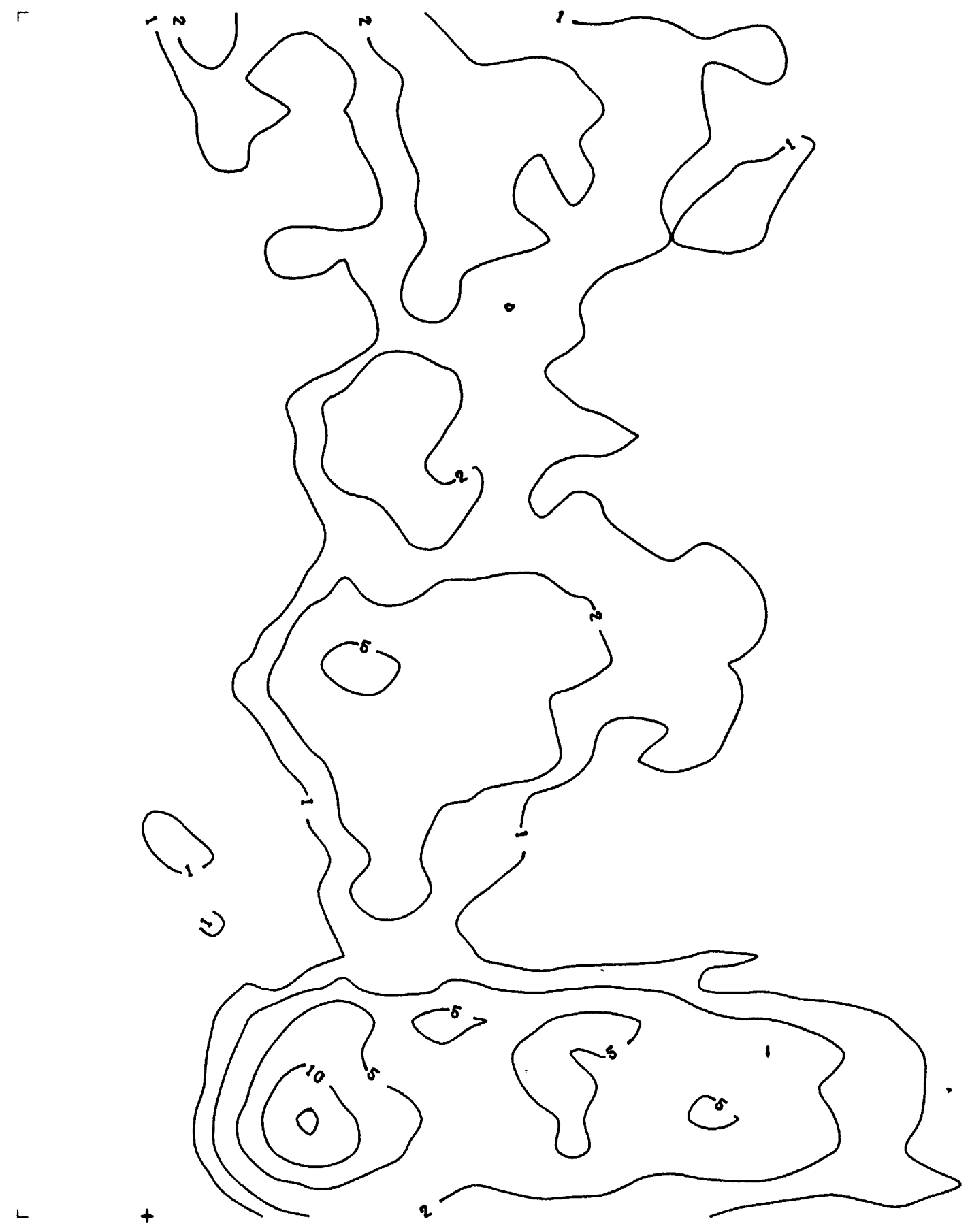


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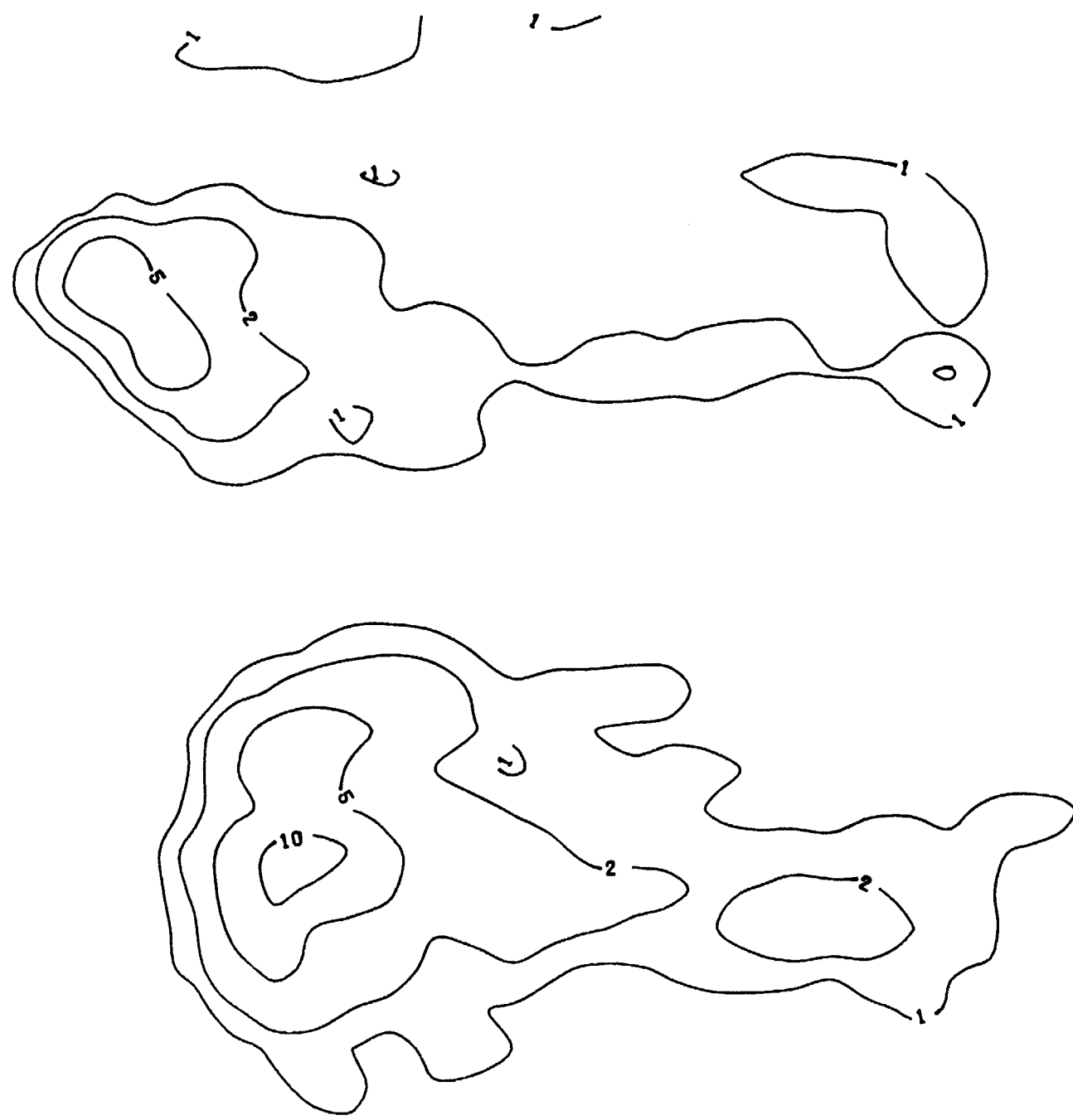
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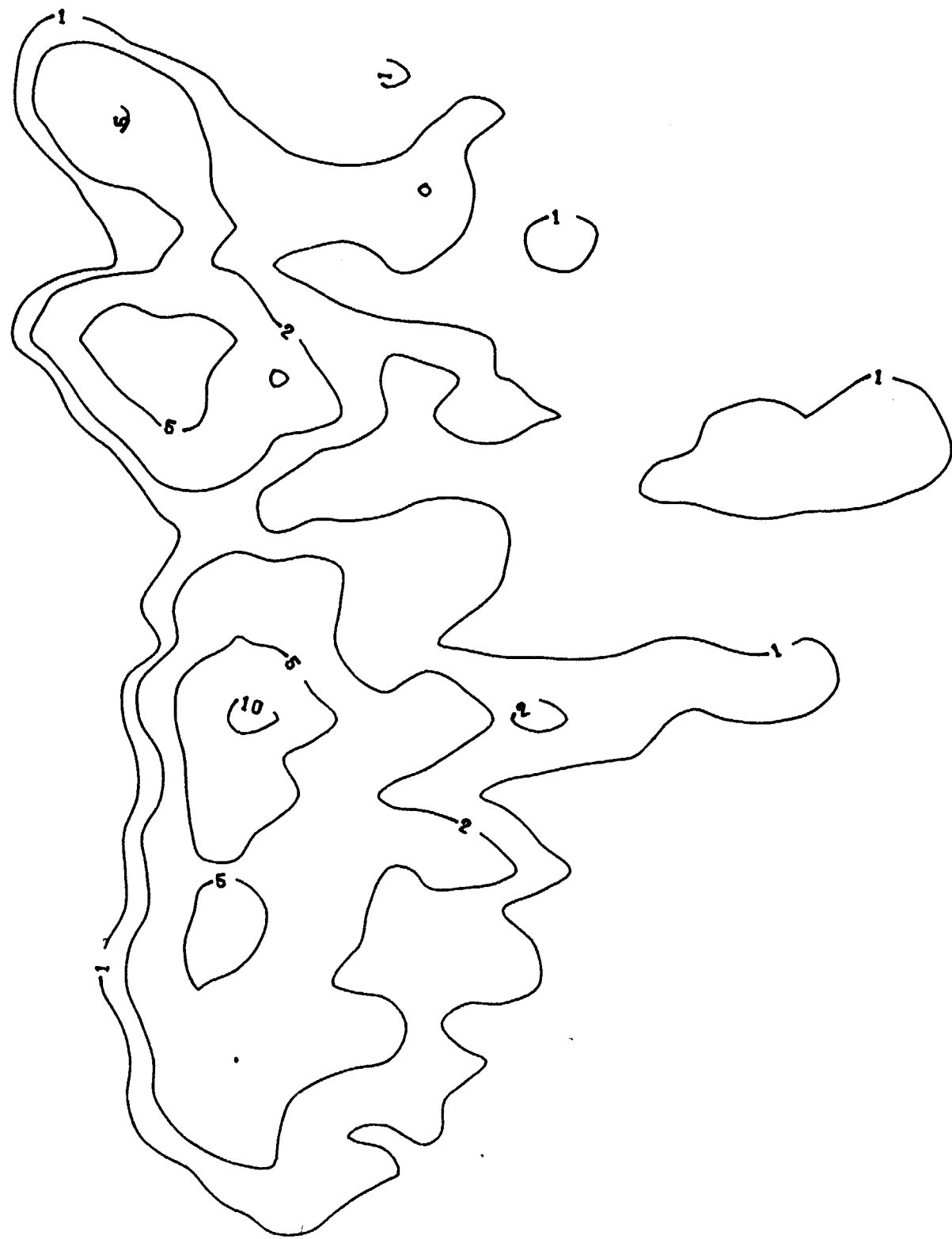
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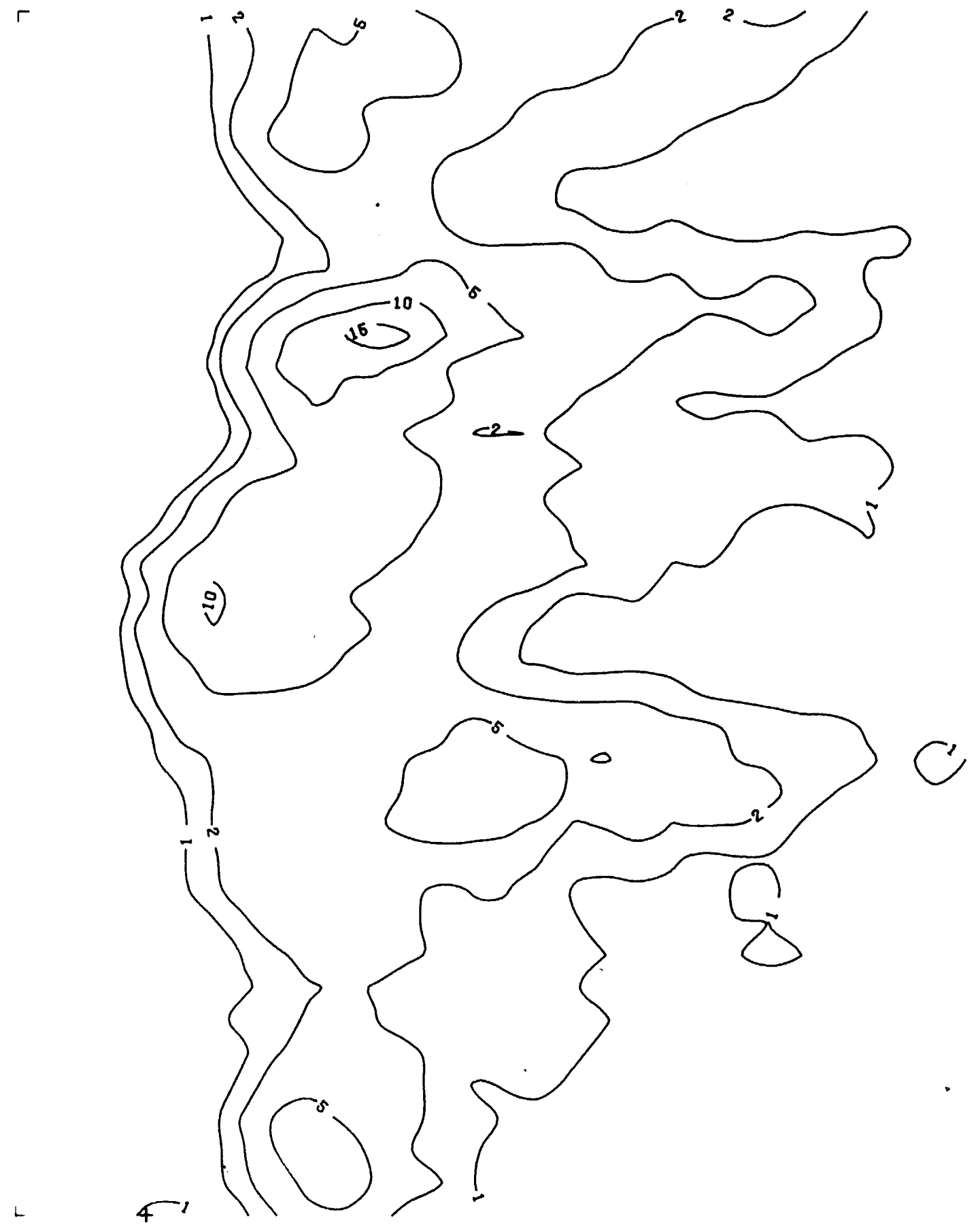


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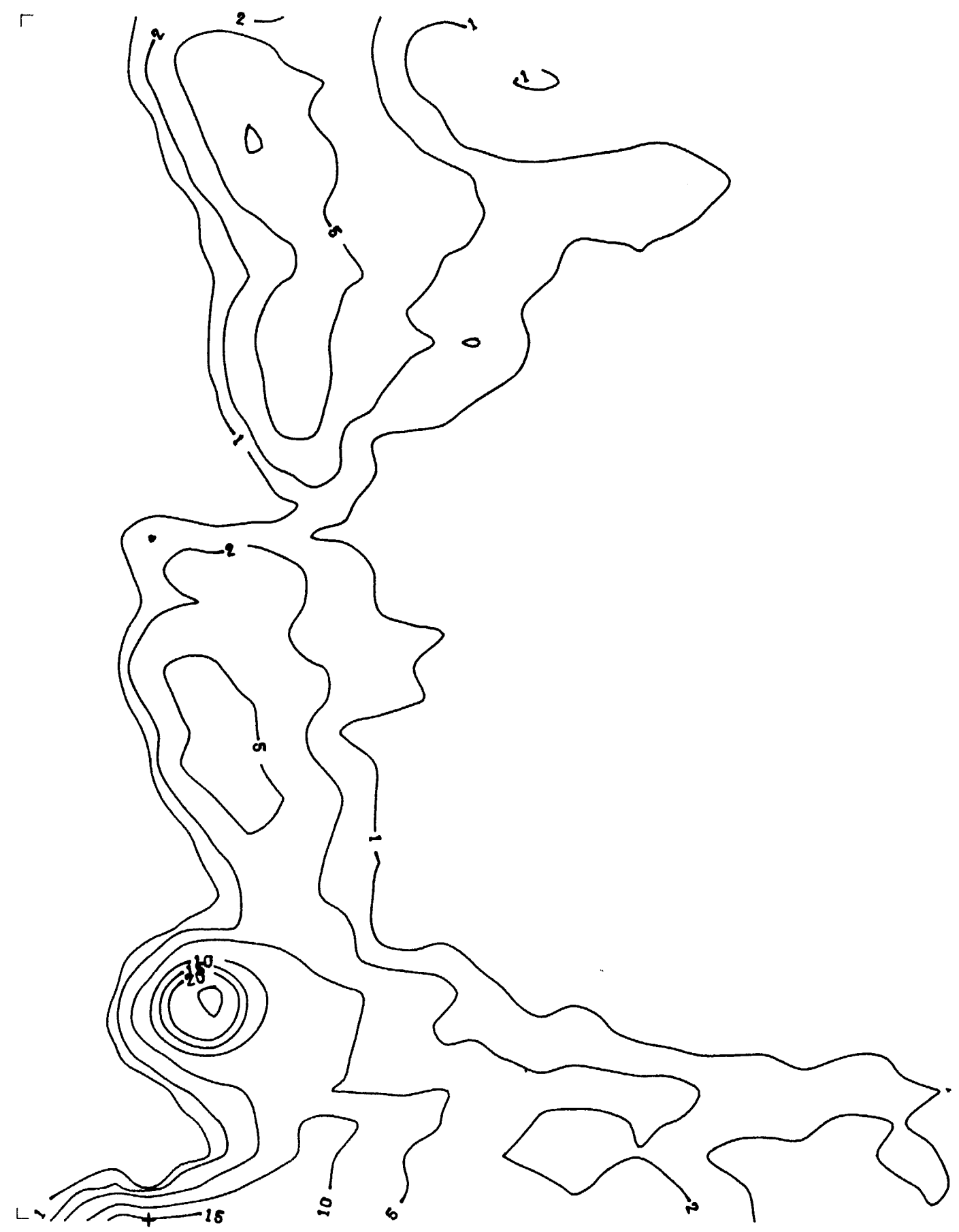
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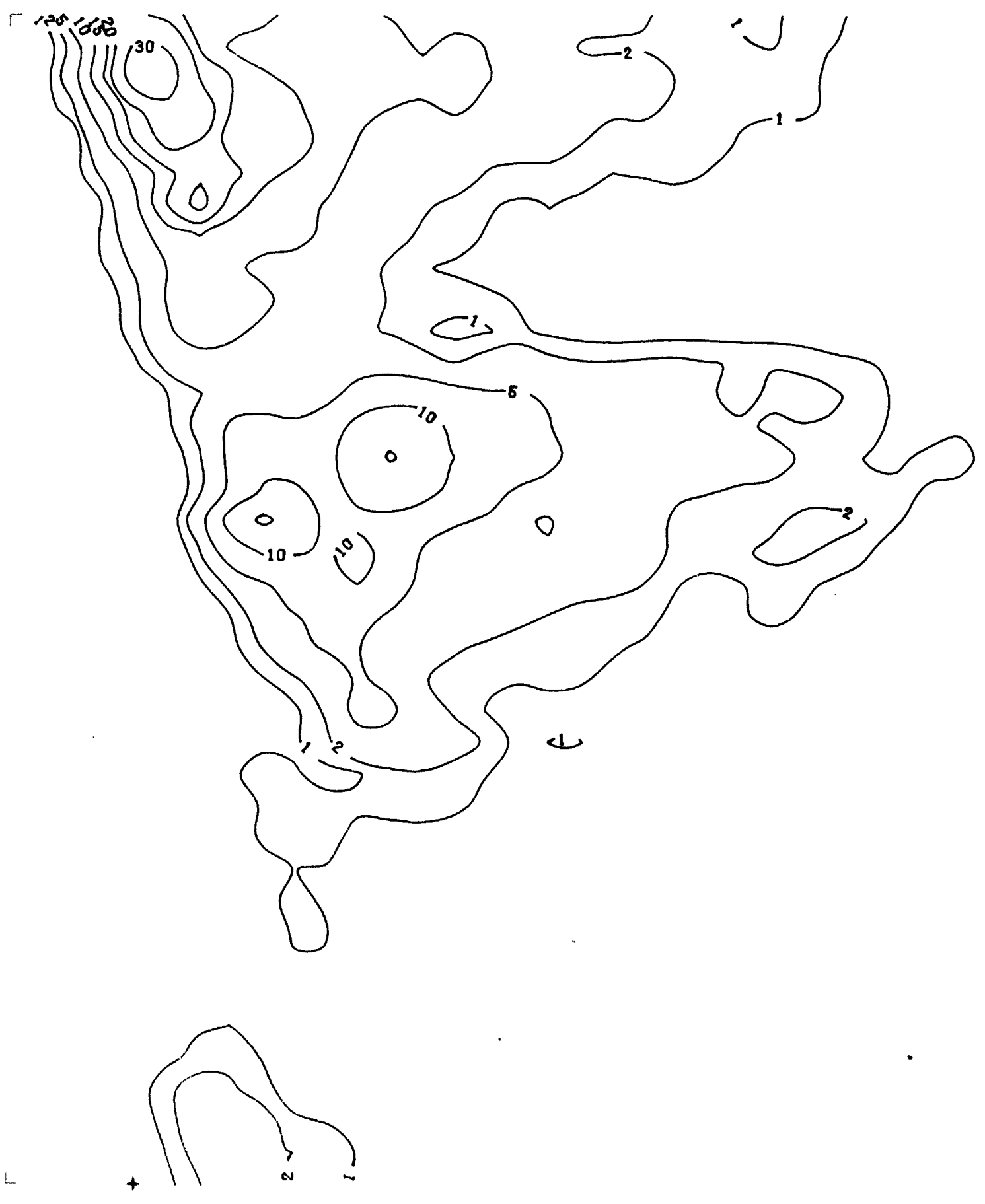


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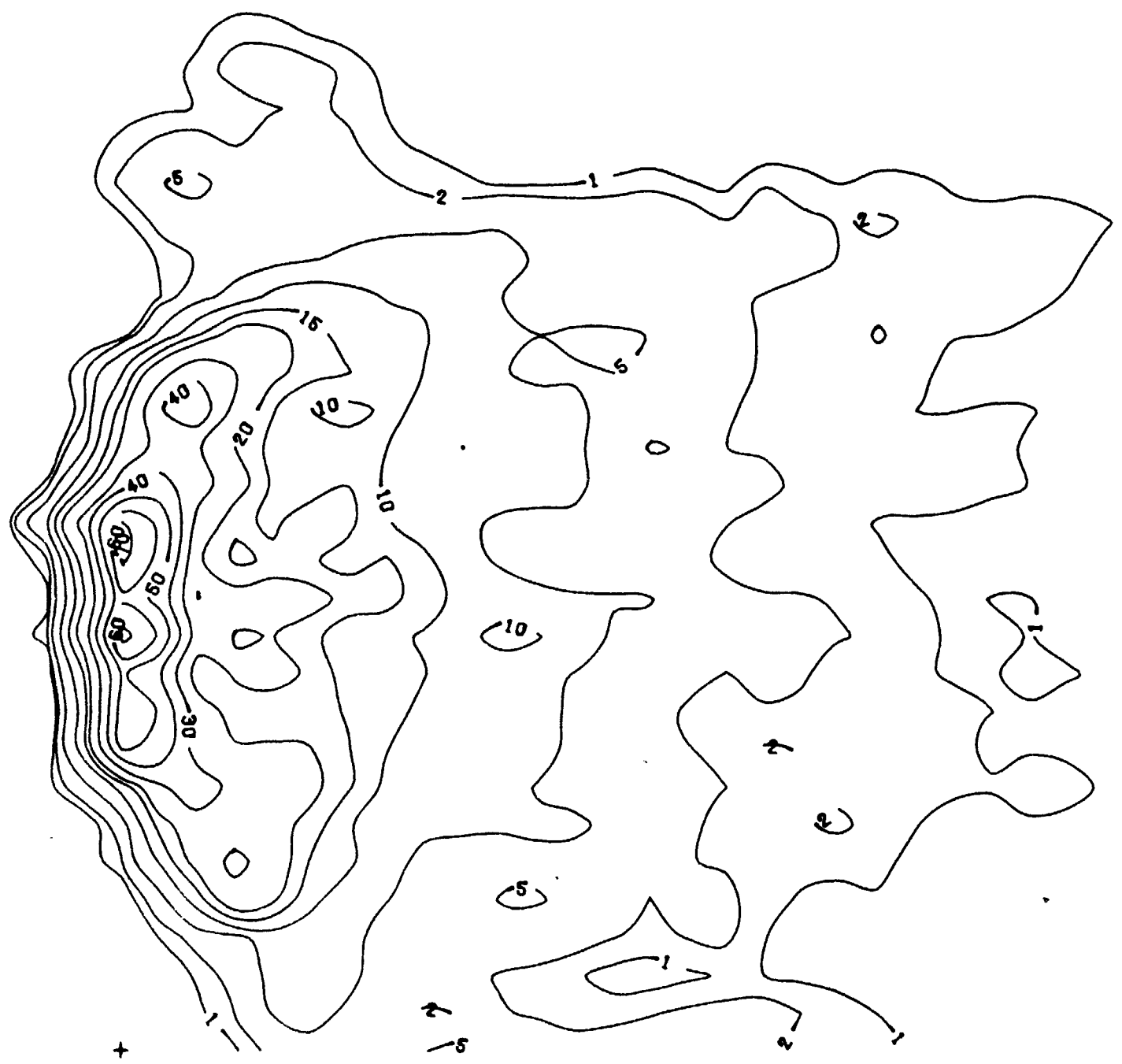


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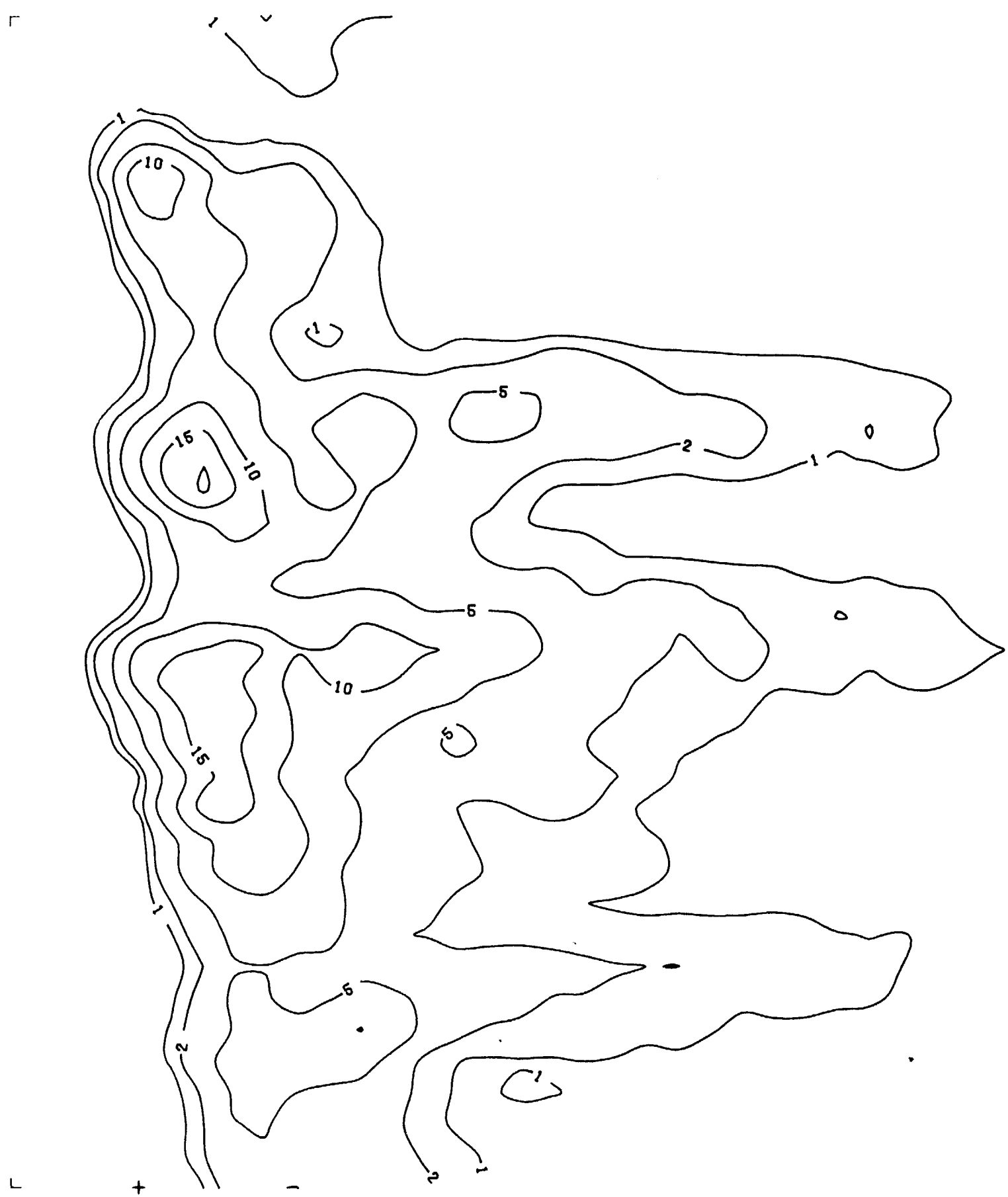
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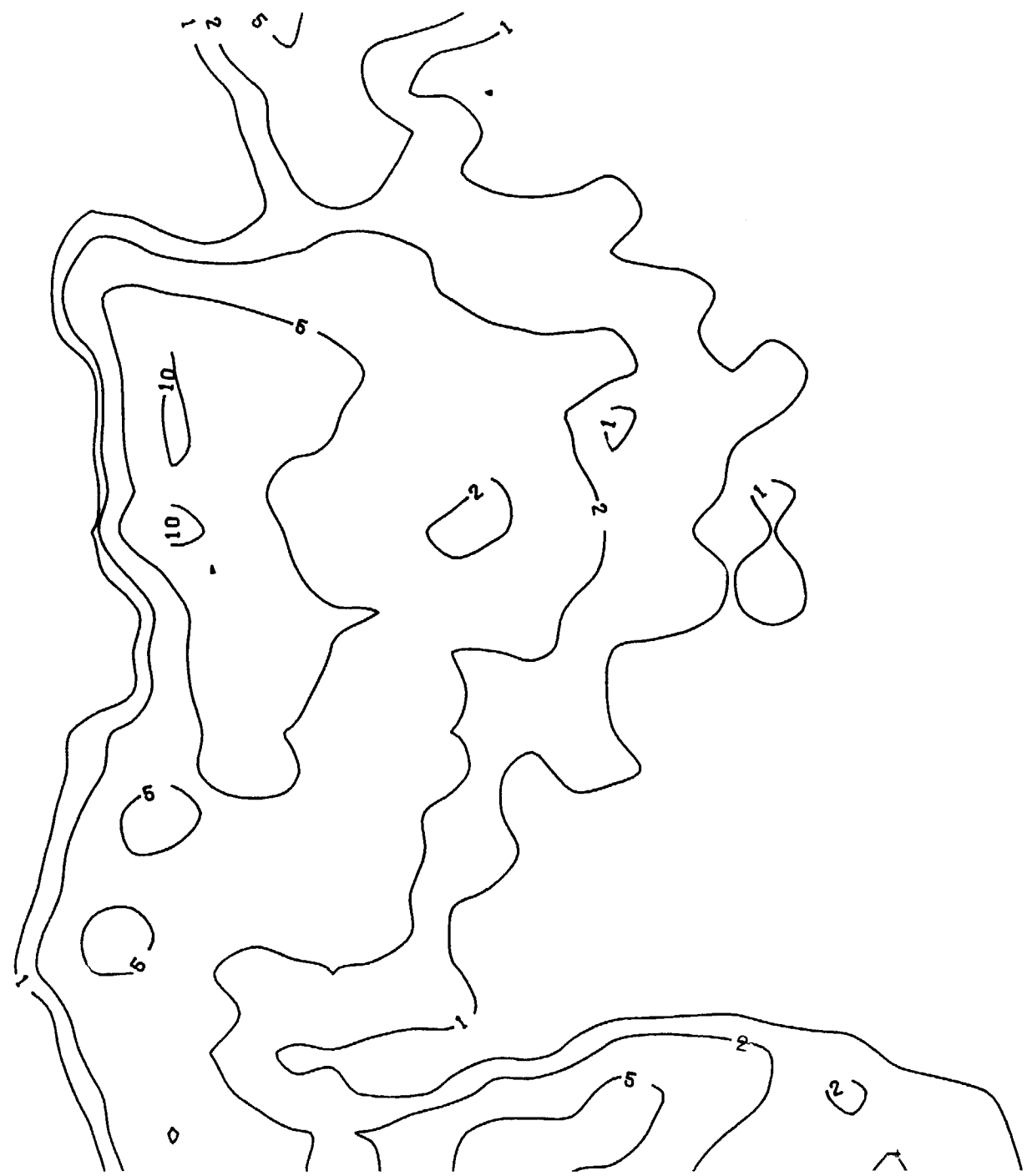
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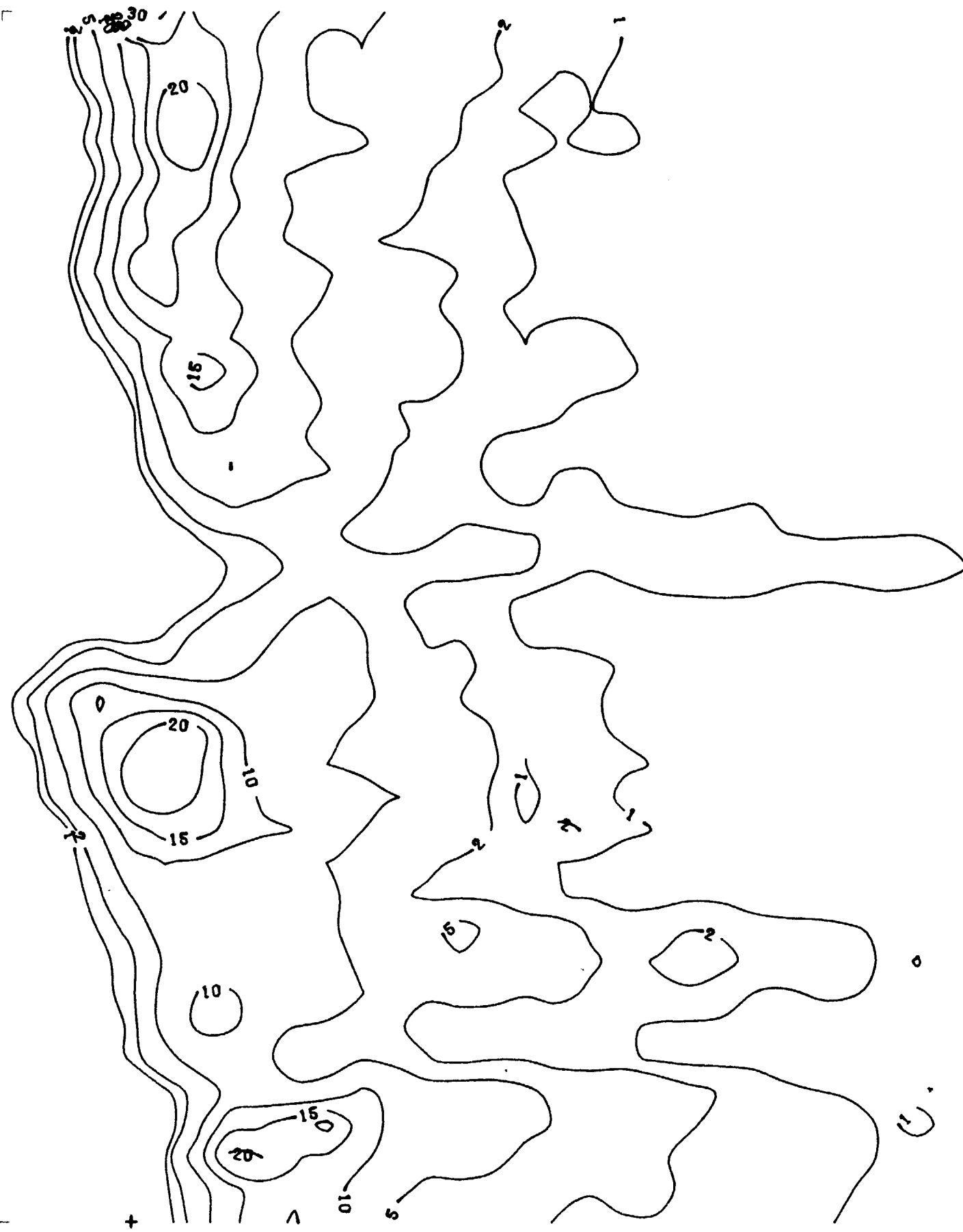
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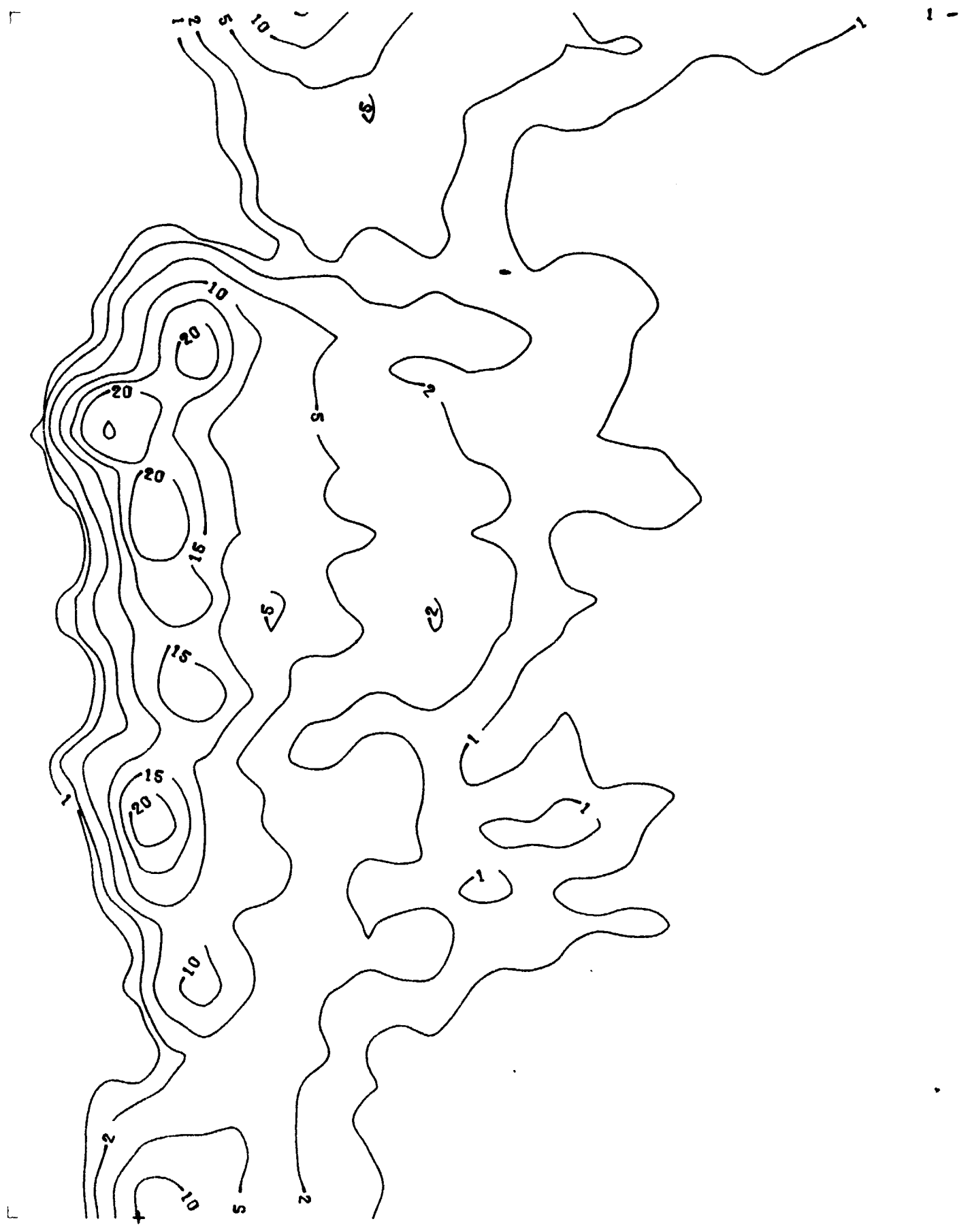
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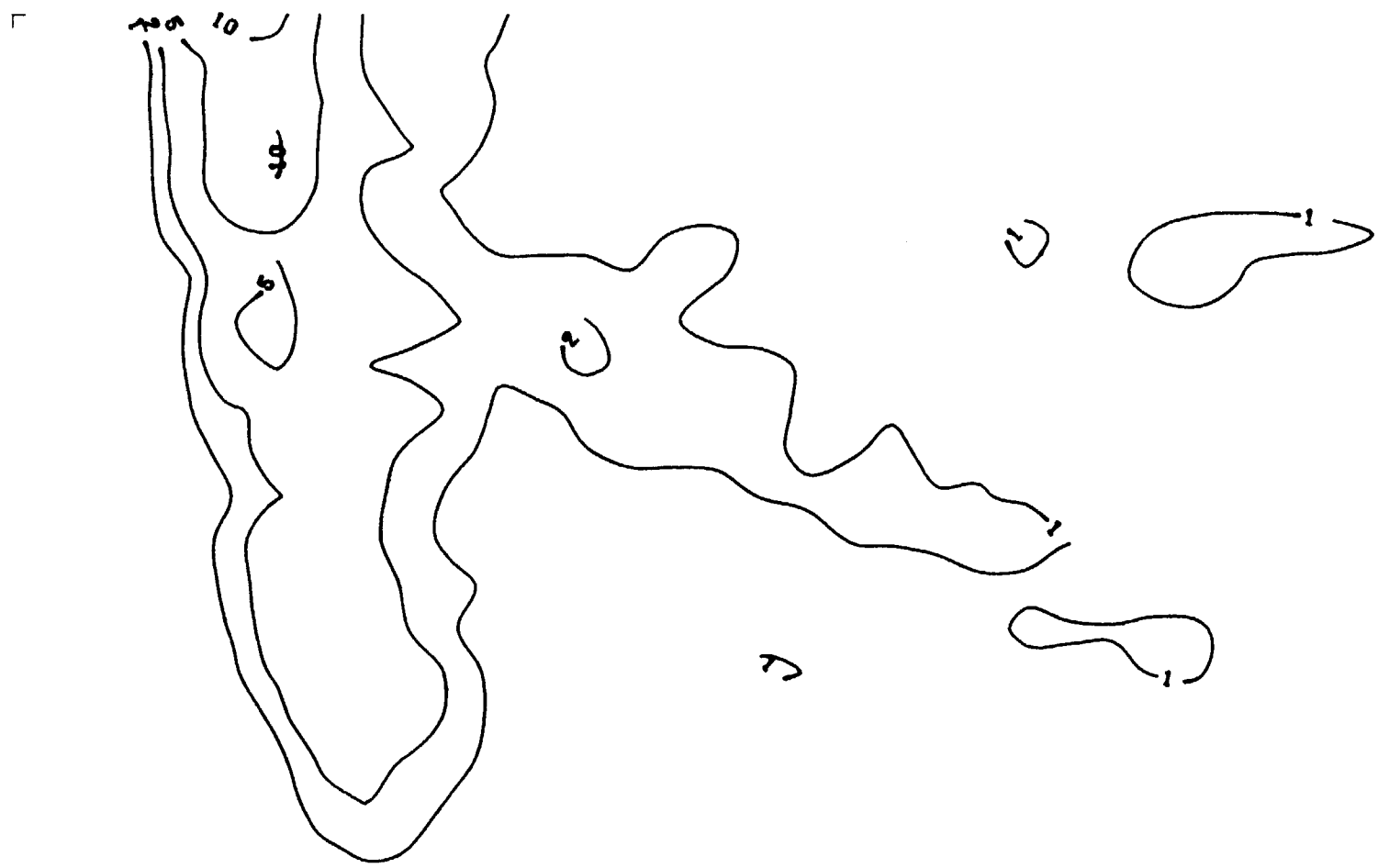
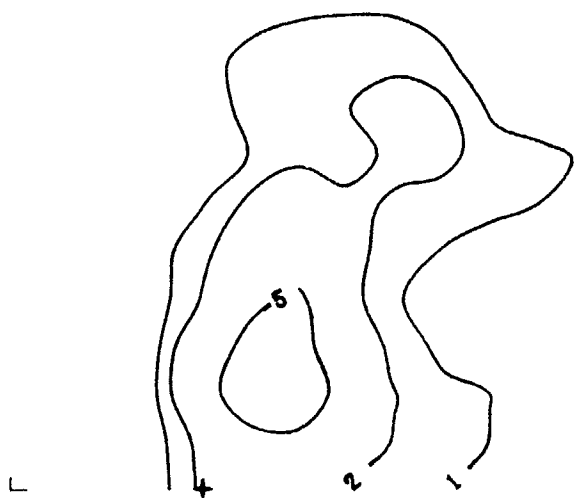
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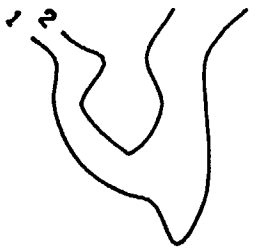
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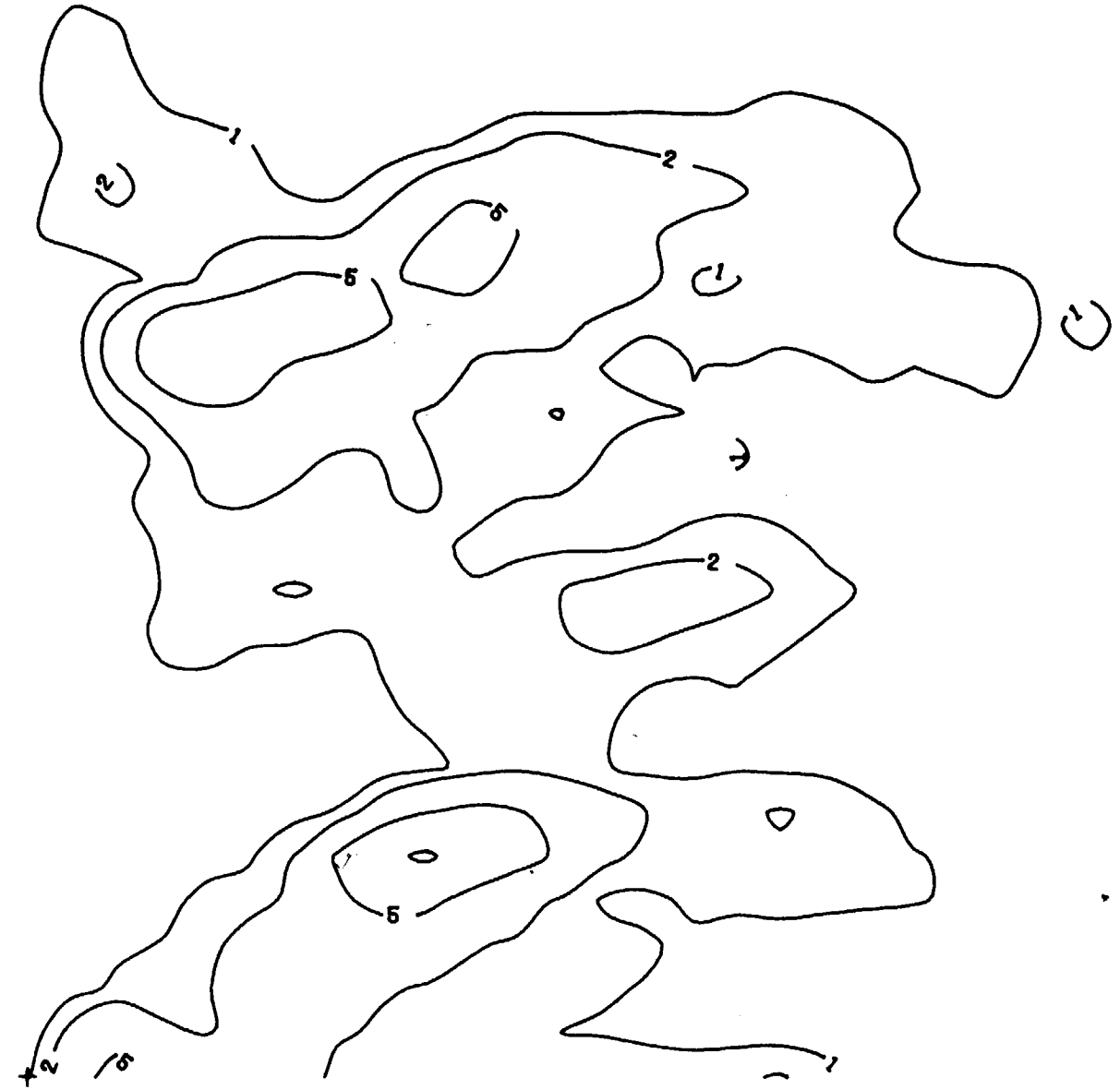
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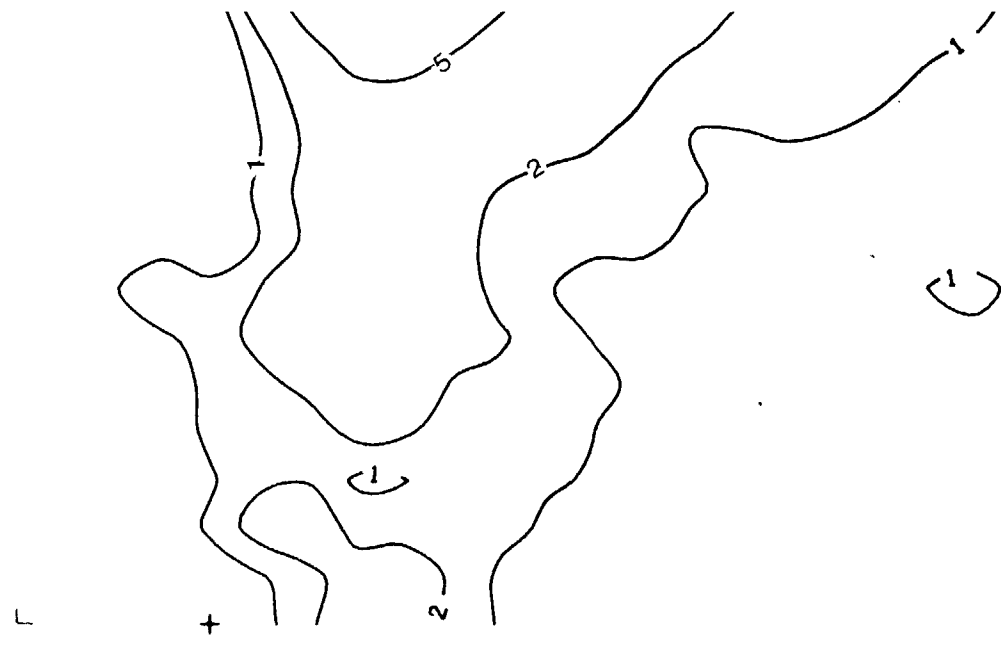
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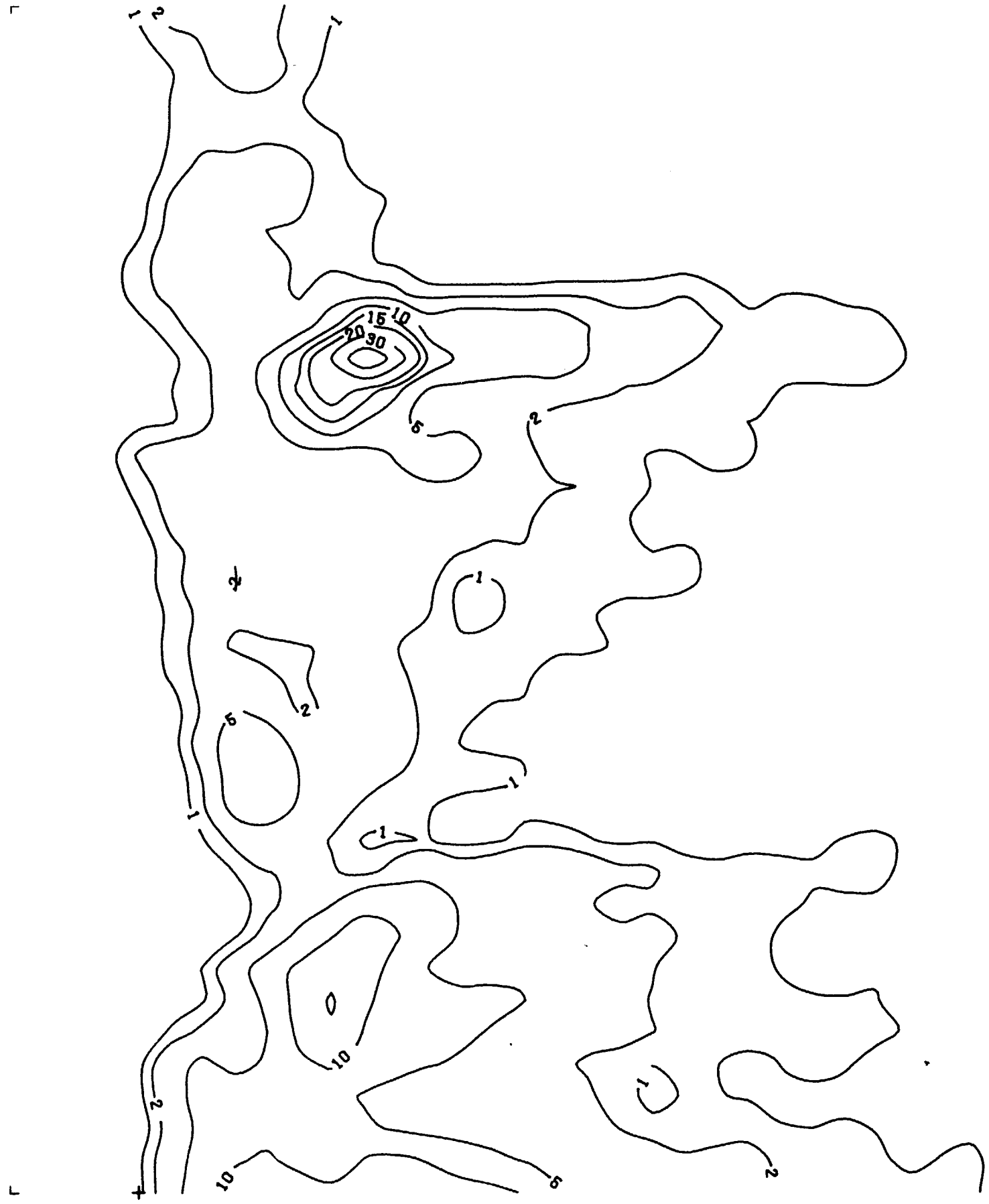
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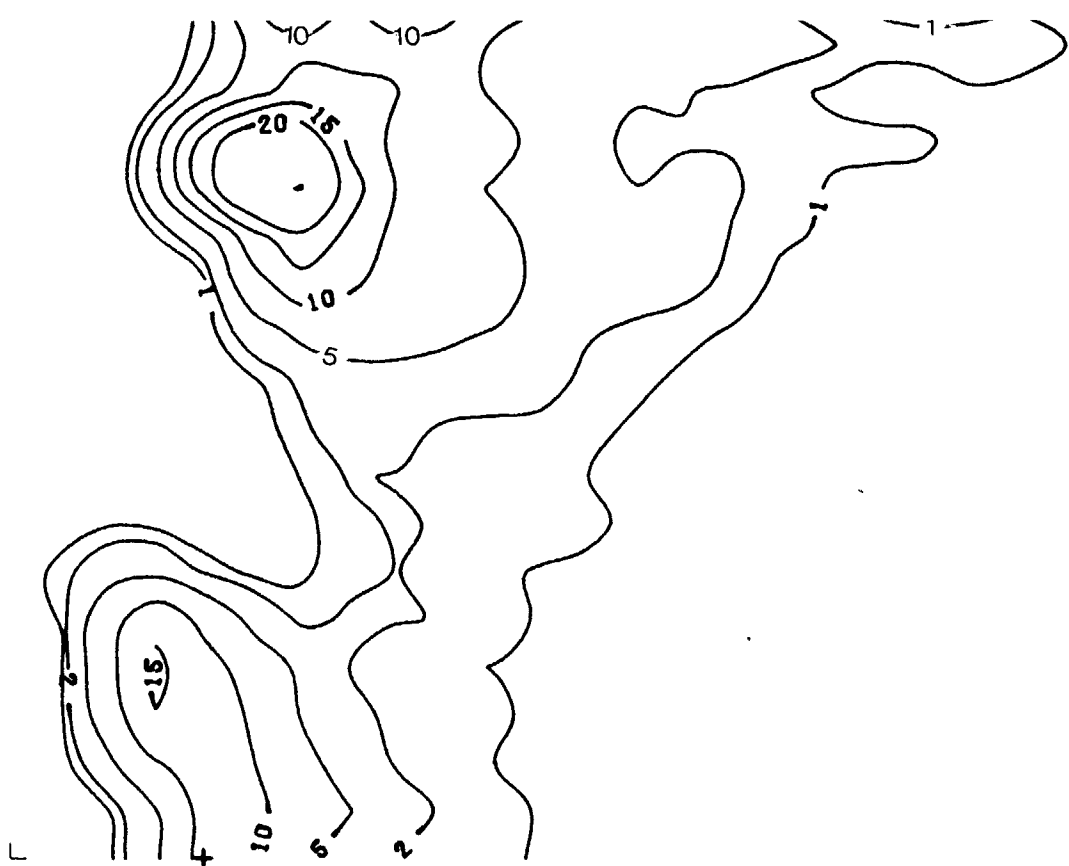
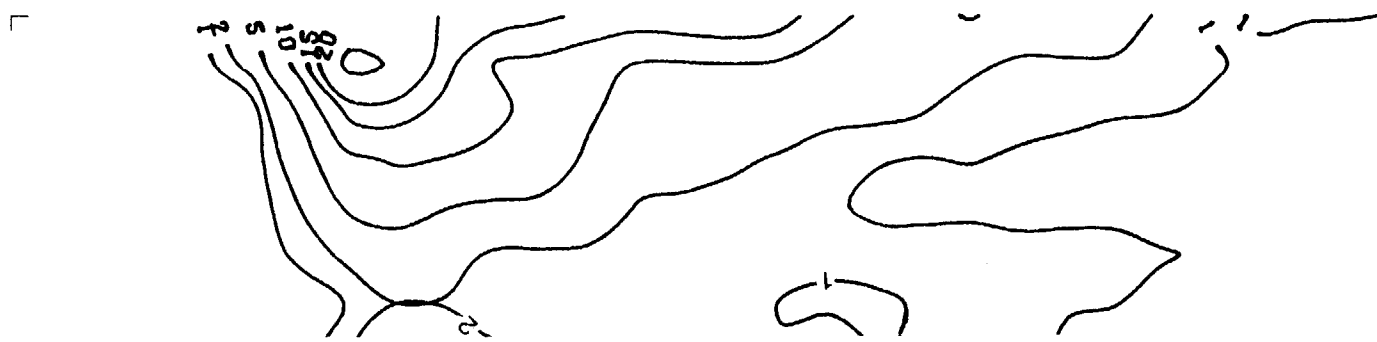
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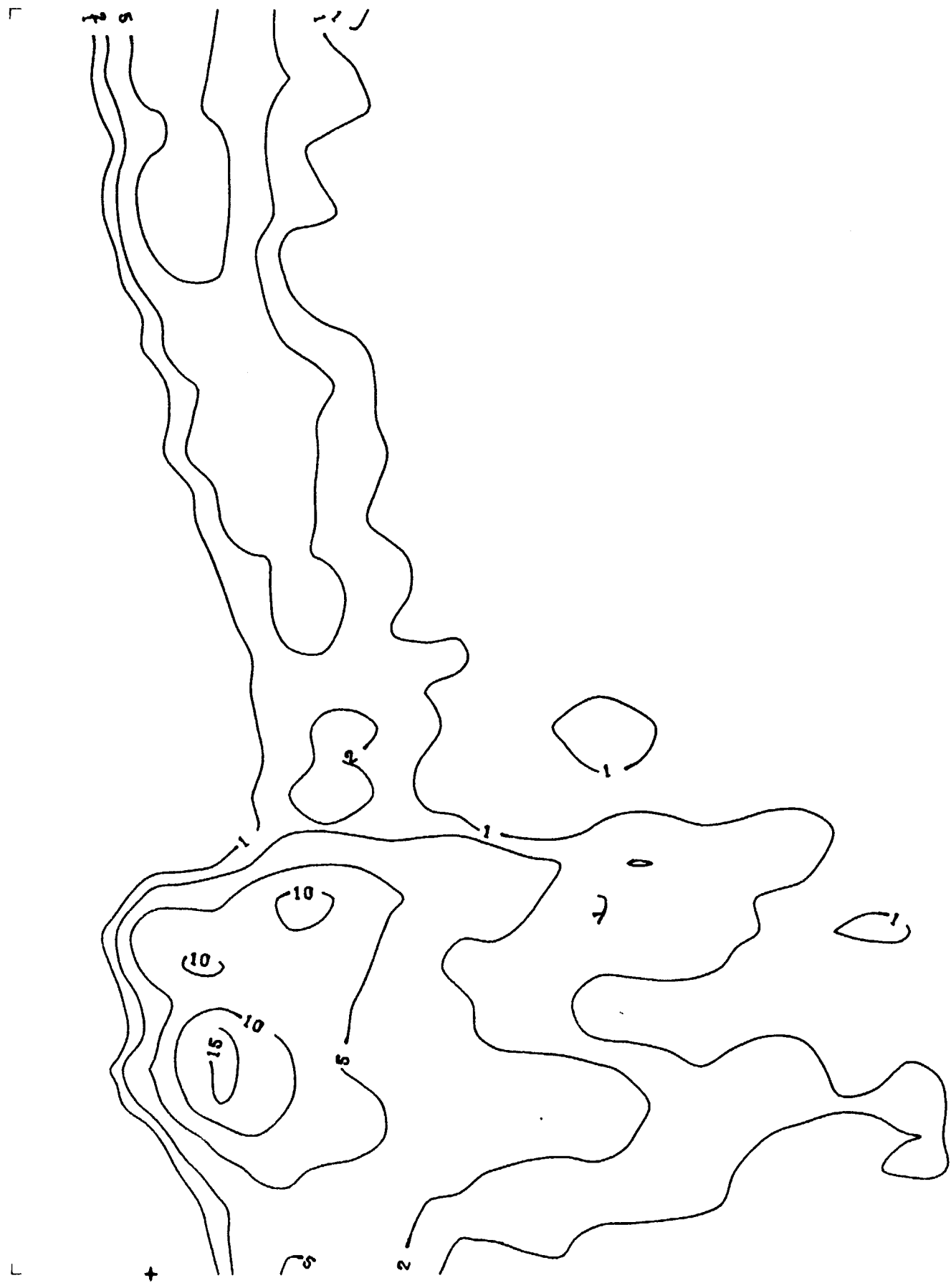


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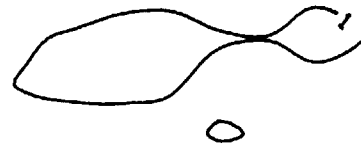
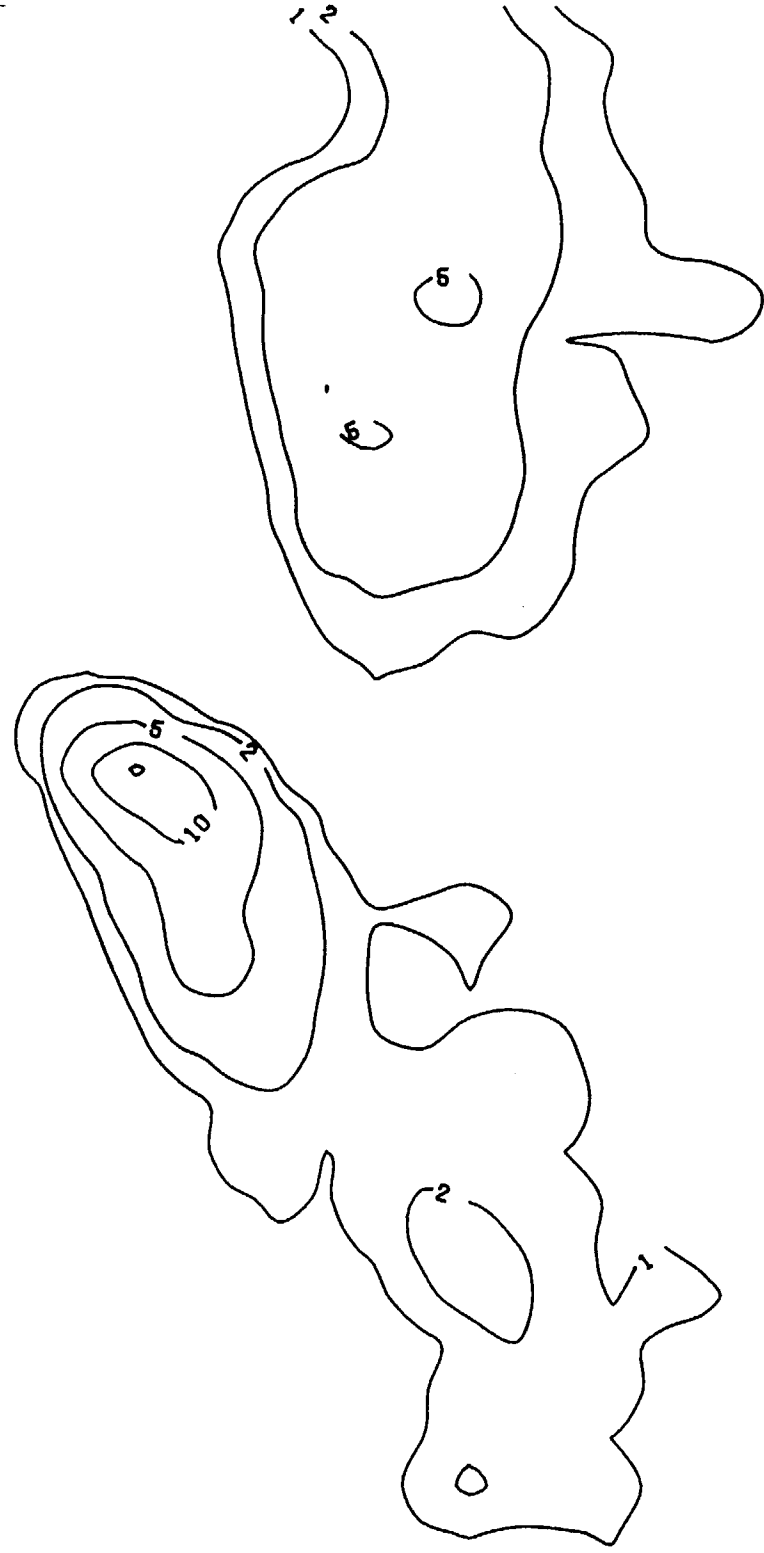


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APPENDIX I - DETAILS OF SYSTEM CALIBRATION AND MAINTENANCE

I.1 Method of calibration of Waverider buoys using the facilities of the National Maritime Institute, Hythe.

The Waverider is clamped between two rigid parallel bars, which are supported at their mid-points on bearings mounted at the apexes of two supporting A-frames. The Waverider is driven through a vertical circle, 3 metres in diameter, by a variable speed motor through belt-drives. The buoy is maintained in the vertical position throughout by chain-drives.

Rig-speed is electronically controlled, and is monitored by a tachometer giving speed in revolutions per minute. However all IOS calibrations are made using a stop-watch to time several revolutions; an average rotation period is then calculated.

Height-modulated radio emissions are received from the buoy on a standard Waverider receiver. The receiver converts the signals into a pen-deflection on a chart recorder, and into an analogue voltage-output at the back.

Early IOS calibrations were expressed simply as a percentage of the nominal value of sensitivity (see section 2 of this appendix), after amplitude-corrections had been made for imperfect electronic integrator response at the longer rig-rotation periods (greater than 10 seconds). The procedure has now been refined however; buoys and receivers are calibrated separately to high accuracy, and a combined figure in volts output per metre of buoy displacement is presented.

I.2 Results of calibrations performed.

(i) Buoy no 6459 laid 28 February 1976; previously calibrated 22 April 1975; sensitivity approximately 2 per cent low.

(ii) Buoy no 6459 removed from mooring, and buoy no 6242 fitted 3 Aug 1976; previously calibrated 13 April 1976; sensitivity approximately $\frac{1}{2}$ per cent low. NB When a sensitivity lower than the nominal is obtained, this implies that the actual wave heights are higher than the measured values of wave height, by a factor equal to the reciprocal of the sensitivity figure. Measured wave heights are then corrected by multiplying by this factor.

I.3 Description of the mooring system used.

The first Waverider was laid on 28 February 1976 using the RV Challenger. The mooring used was similar to that described in Humphery (1975), except that it was modified to suit local conditions. The chain linking the anchor and sub-surface float was uprated to 9mm, and its length adjusted so that the float was approximately 15m below the surface. The total length of mooring components above the float was increased to 35m to allow the Waverider to

follow the larger waves anticipated at the South Uist site. Waverider maintenance visits would normally be possible only in the summer; accordingly, heavy zinc sacrificial anodes were used to protect metal parts where appropriate.

The Waverider was replaced in August 1976, using divers to connect the new upper part of the mooring to the sub-surface float, which was left in position. This Waverider was in position until 18 April 1977, when it was recovered, again using the RV Challenger.

I.4 Maintenance procedure

The receiving and recording equipment is located on a hill (Rueval, 87m OD) on South Uist. Routine servicing of the equipment (including changing charts, magnetic tapes and cassettes) is carried out on site by a local agent. Major servicing is carried out by IOS personnel at approximately 6 month intervals, or whenever a significant fault is reported.

I.5 Reference

Humphery, J.D., 1975. Waverider moorings and their modification at IOS. Pp 42-46 in Technology of Buoy Systems. London: Society for Underwater Technology.

APPENDIX II - METHODS OF DATA VALIDATION

Magnetic tapes from the logger were returned to the laboratory each month where they were translated and processed by a computer program designed to check for timing or tape formatting errors. In addition the program subjected each (1044 second) wave record to a number of tests to check for characteristics not normally associated with wave records of this type. The tests were based on the assumptions that a wave record should display certain simple properties consistent with the behaviour of a random process with an approximately normal distribution, and that the water surface should conform to certain well-established steepness criteria.

The tests were for the following fault conditions:

- (1) Test for lost data points due to format errors or telemetry failure (the latter indicated by a special signal derived from the receiver).
- (2) Check for the occurrence of ten consecutive points of equal value (instrument failure test).
- (3) Check for an interval between successive up-crossings of the record mean level of greater than twenty-five seconds (wandering mean test).
- (4) Comparison of the difference in magnitude between successive data points with a test value based on maximum probable water slope.
- (5) Comparison of absolute magnitude of data points with a test value equal to four times the record standard deviation.

Actions taken by the program were:

Single lost data points, up to a maximum number of fifteen per record, identified by the first test, were replaced by the average value of the two neighbouring points. Two or more adjacent lost points caused the record to be rejected.

Failure of either test (2) or (3) caused the record to be rejected.

Faulty points, up to a maximum number of five, identified by test (4), were replaced by the average value of the two neighbouring points. Two or more adjacent faulty points caused the record to be rejected.

No alterations to the record were made on failures of test (5). Six failures, up to three of which could be consecutive, were allowed before rejecting the record.

The results of these tests are recorded with each record written to the data (time history) file as a group of ten error flags, KFLAG (1-10). Note that the record was written to the data file (and subsequently processed) whether or not it was considered acceptable.

An explanation of the error flags is now given.

- KFLAG (1) not used
(2) " "
(3) " "
(4) " "
(5) record start not at correct nominal time
(6) time interval between start of current and previous records not 3 hours
(7) not used
(8) " "
(9) record rejected (If set to zero the record may be assumed to be valid)
(10) record length incorrect

The above check procedures were applied to all the records obtained during the period covered by this report, the only records rejected from the contouring being those for which KFLAG(9) is not zero.

APPENDIX III - METHOD OF SPECTRAL ANALYSIS OF THE WAVE RECORDS

Each wave elevation time series was multiplied by a window function of the form $\frac{1}{2} \left(1 - \cos \frac{2\pi t}{T}\right)$

where T is the length of record analysed and t elapsed time, and a Fast Fourier Transform was performed on 2048 points of the series. The spectra thus calculated were smoothed by averaging over ten adjacent harmonics to give a final resolution of 0.00977 Hz.

The smoothed spectral estimates were multiplied by a factor to restore the energy removed in the windowing process. This factor was calculated separately for each spectrum and ensured that the variance of the record, calculated as the zeroth moment of the spectrum, was the same as that calculated from the wave elevation time series. The estimates were then adjusted to compensate for the overall frequency response of the buoy, receiving and recording systems, as described below.

It is hoped to produce a report giving more information about the effects of a cosine taper on the spectral estimates, including their random sampling error.

Figure III-1 shows the frequency responses of the four main components in the measurement and recording system, viz.

- (i) the hydrodynamic response of the buoy, (a vertical mooring force of 240 Newtons has been assumed);
 - (ii) the electronic integrator within the buoy;
 - (iii) the Warep receiver;
 - (iv) the interface circuitry between the Warep receiver and the data logger;
 - (v) the combined response, ie the product of (i), (ii), (iii) and (iv).
- (The responses of (i), (ii) and (iii) were drawn from information supplied by Datawell).

During the analysis of the data, corrections were applied to the spectra to compensate for these responses, except that (see Figure III-2):

- (i) the double integrator correction was curtailed at a frequency of 0.04 Hz. That is, above this frequency the reciprocal of the response was used to correct the spectra, and below it the correction appropriate to 0.04Hz was applied regardless of the actual frequency. This was done as it was considered that the low frequency spectral estimates would be dominated by noise, and that it would therefore be unprofitable to apply large correction factors.

(ii) No correction has been applied to compensate for the hydrodynamic response of the buoy. This means that spectral values between 0.5Hz and 0.64Hz are too high. The error at 0.64Hz is of the order of 20 per cent in amplitude or 40 percent in amplitude squared.

These errors are of little or no practical significance since spectral densities at these frequencies are very small (they may be two, three or four orders of magnitude below the peak energy density of the spectrum). The effect of this error on the spectral moments should be considered. Comparisons were made between two methods of calculating m_2 . In method (a) an f^{-5} tail was substituted for the measured spectrum between frequencies of 0.5 Hz and 1.0 Hz, and m_2 was calculated using an upper truncation frequency of 1.0 Hz. Method (b) was the method used in the routine calculations, ie truncation of the summation at $f = 0.64$ Hz. The differences found for a variety of spectral forms were insignificant.

Figure III-3 shows the combined frequency response of the measurement and analysis systems and illustrates the above points. Also shown are the frequency range over which spectral estimates are available (see section 4) and the more restricted range contoured in this report. The frequency range used in the calculation of the spectral moments is also shown.

The moments have been calculated using the equation

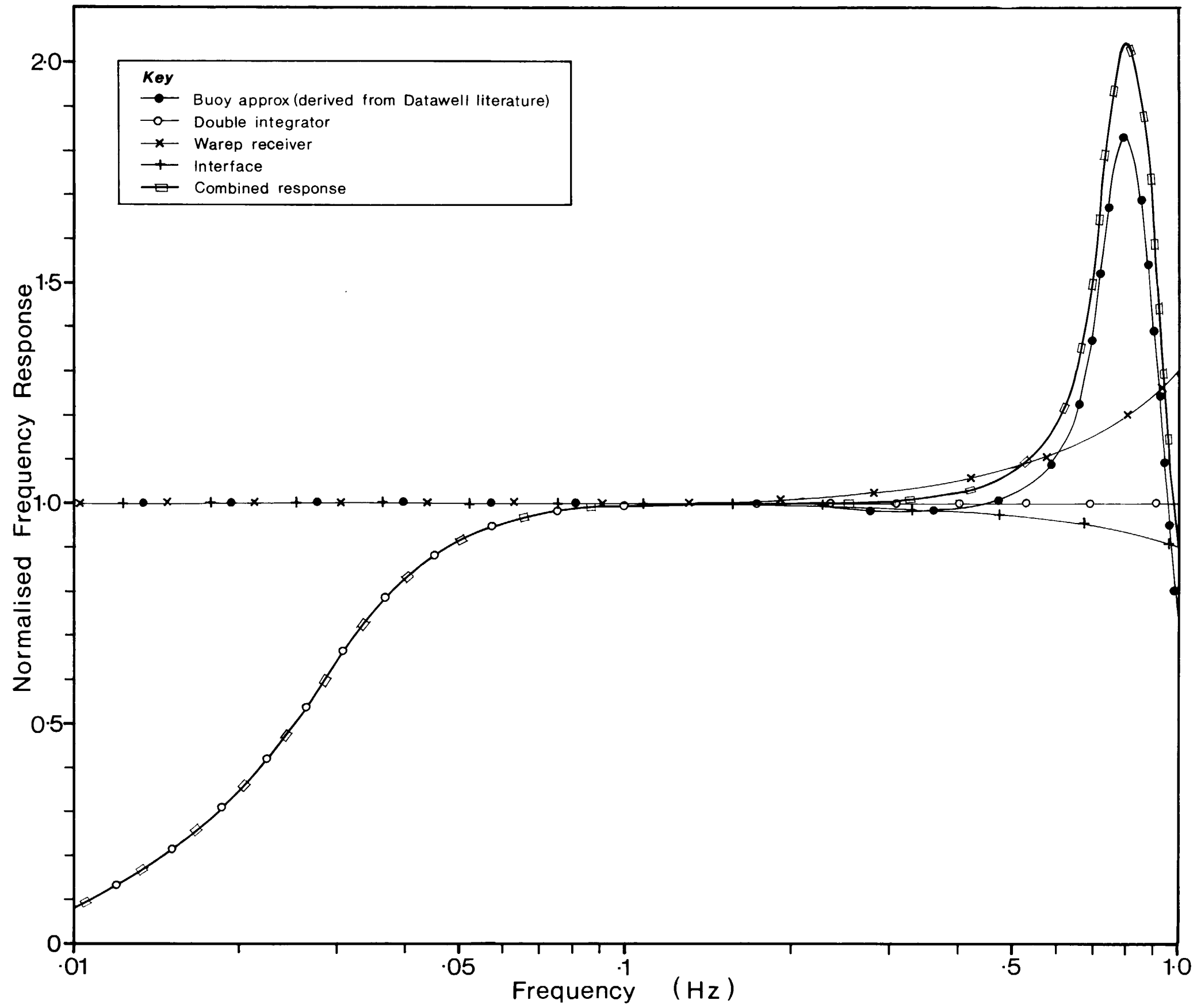
$$m_n = \frac{10}{T} \sum_{i=5}^{70} f_i^n S_i$$

where i is the harmonic number of the spectral estimate S_i at the frequency f_i ; $f_5 = 0.0444$ Hz and $f_{70} = 0.6792$ Hz.

The values of H_s and T_z have been calculated from

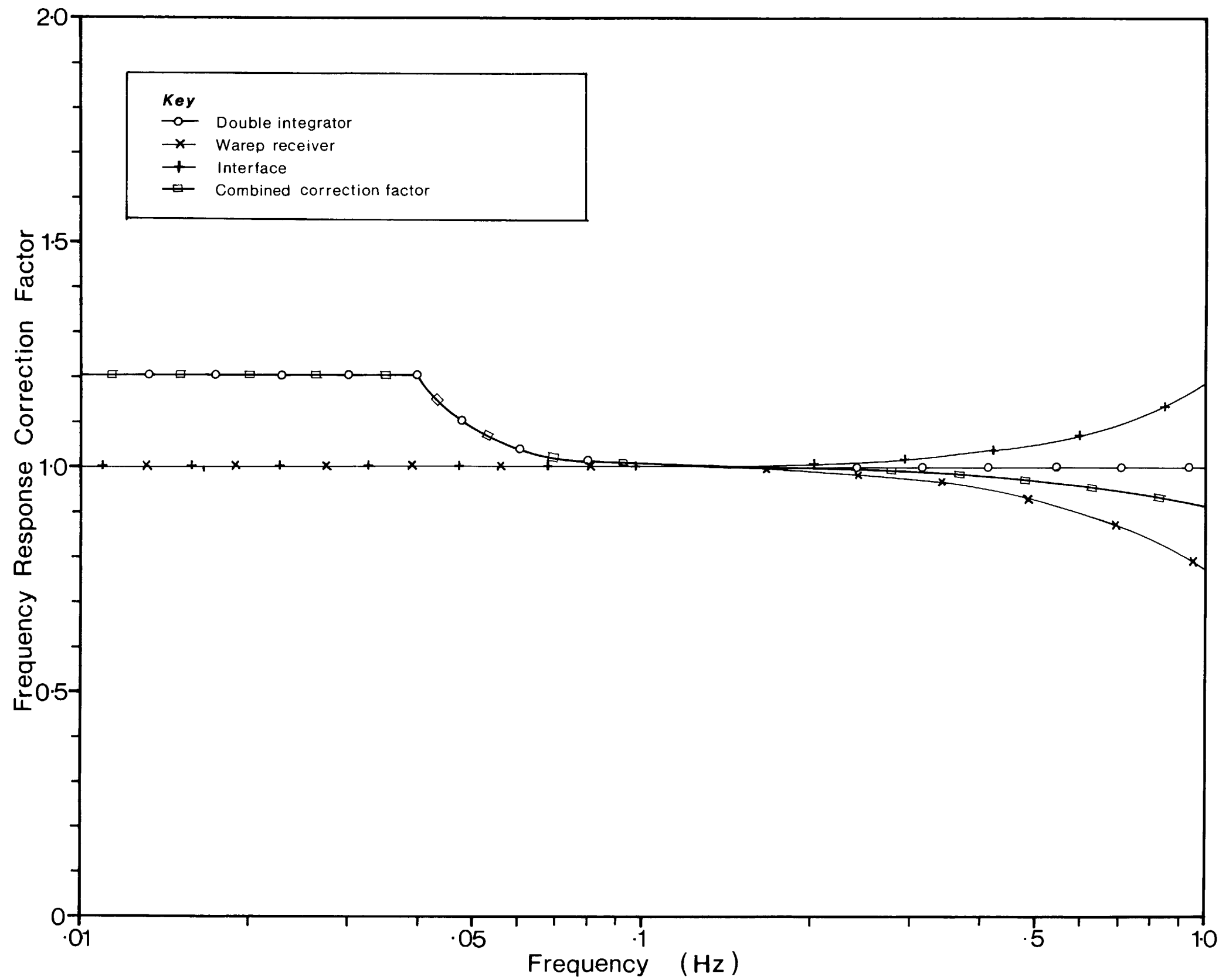
$$H_s = 4\sqrt{m_0}$$

$$T_z = \sqrt{\frac{m_0}{m_2}}$$

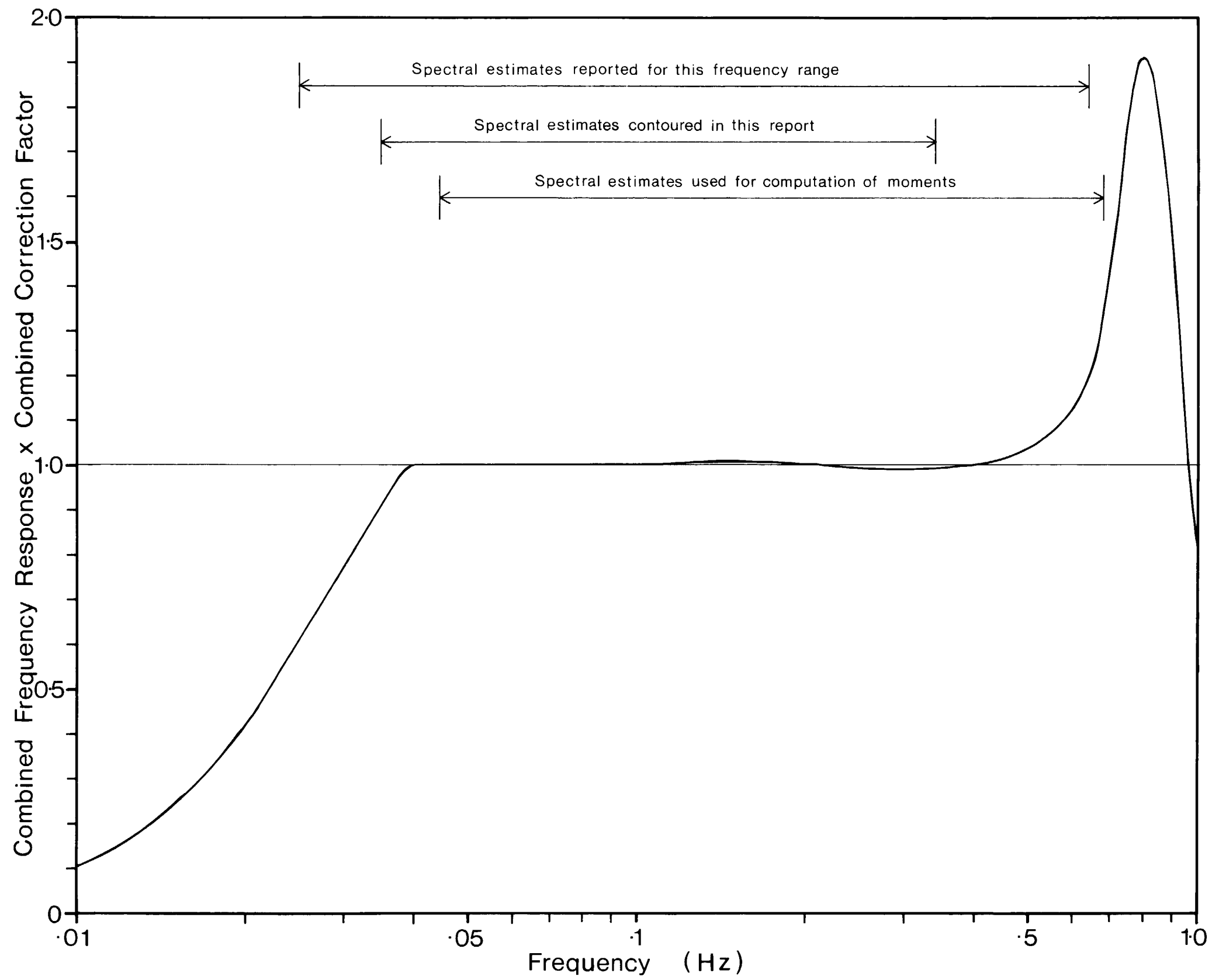


Frequency Responses of Waverider Buoy and Recording System.

Fig. III-1



**Frequency Response Correction Factors for Waverider Buoy & Recording System.
Fig. III-2**



Combined Frequency Response of Measurement & Analysis Systems.

Fig. III-3

APPENDIX IV - METHOD OF CALCULATION OF STORM DISTANCES USING THE CONTOURED PLOTS

Let the wave generating centre be a distance d away from the wave measuring location, and let the waves be generated instantaneously at time t_0 . Linear wave theory shows that the speed with which the wave energy travels (the 'group velocity', c_g) is given by

$$c_g = \frac{g}{4\pi f}$$

Then waves of frequency f will travel the distance d in time T given by $\frac{d}{c_g}$

$$\text{ie } T = d \frac{4\pi f}{g},$$

and will arrive at the location at time $t = t_0 + T$

$$\text{ie } t = t_0 + d \cdot \frac{4\pi f}{g} \dots \dots \dots (1)$$

Differentiating equation (1) wrt f gives

$$\frac{dt}{df} = d \cdot \frac{4\pi}{g} \dots \dots \dots (2)$$

Therefore when all values of f and their corresponding values of t are plotted on a graph as t against f (as occurs on the plots in this report), then

- (i) the points lie on a straight line of slope $d \cdot \frac{4\pi}{g}$,
- (ii) the straight line crosses the time-axis at t_0 , the time of the storm.

However it is not usually practicable to produce plots with equal scaling, but instead the time-axis needs to be compressed relative to the frequency-axis. Let the time-axis be multiplied by a factor k (< 1). Then using equation (2) the actual angle of slope α is given by

$$d = \frac{g}{4\pi k} \cdot \tan \alpha$$

or $d = \frac{0.7807}{k} \cdot \tan \alpha \dots \dots \dots (3)$

when units of metres and seconds are used.

The value of k derived from the scales used in this report is given in section 3 of the main body of the report, so that equation (3) may be applied to find d .

In practice, a straight line does not appear on the contoured plot, for a number of reasons, which include the following:

- (i) the waves are not generated instantaneously;
- (ii) waves other than those generated by one particular storm are measured simultaneously with those from that storm;
- (iii) the storm may be moving;
- (iv) the contours are based on smoothed spectral estimates at discrete frequencies.

Instead there is a pattern of increasing contours culminating in a peak, the whole pattern having a noticeable (usually) orientation to the frequency-axis. A line drawn through the peak in the direction of orientation of the pattern may be used to derive approximate values of d and t_0 .