# FLOW CHARACTERISTICS OF THE SANTA ANA RIVER

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# INTRODUCTION

The drainage system of the Santa Ana River and its tributaries covers 1485 square miles above the lower canyon of the river. The total water crop for the last ten years has been estimated at over 300,000 acre feet per annum, and from this water, the counties of San Bernardino, Riverside and Orange have obtained their water supply. Part of the water is spread to underground basins, part is stored in numerous reservoirs and a large amount runs off. Due to lack of control at many points large floods have resulted and considerable damage done. In 1914 and 1916 these damages were estimated at $10,000,000. In February 1927 destroyed bridges alone cost Riverside County $400,000. In Orange County the 1916 flood resulted in a loss of $1,000,000.

In 1925 the three counties interested in the Santa Ana sought aid from the state in studying and controlling the river. Chapter 476 of the Statutes of 1925 provided for $25,000 to be expended between 1925 and 1927 in the investigation. Each county provided a consulting engineer to work with the State Engineer, J. P. Lippencott representing Orange County, A. L. Sonderegger from Riverside County and C. S. Hinckley from San Bernardino County. The river, its drainage system, and hydraulic structure were investigated; an underground contour map was made and several plans were offered by which the water could be better conserved and the floods more completely controlled. The systems included additional dams for reservoirs, increased spreading areas and rip-rap and concrete channels.

In the study here presented the work has been confined to a study of the river flow. Yearly floods were chosen as being of paramount interest rather than monthly, daily, or short duration floods, since the problems of the Santa Ana, with the work being carried on in increasing reservoirs and spreading grounds will be dependent more on long time flow than on flash runoff.

The statistical characteristics of the Santa Ana River are computed, a study of the frequency and magnitude of yearly floods is presented and the possibility of cyclic flow is examined.

## DATA

The data used in this investigationw as drawn from three sources--"Water Supply Papers", "The Santa Ana Investigation" and "Stream Flow in the United States". The first covered the period 1897 - 1934, the second covered the period 1895 - 1928 and the t hird covered a period 1872 - 1921. The data from the three sources do not check. "Stream Flow" gives Santa Ana Tributaries, the Santa Ana Investigation gives Santa Ana at Mentone corrected for storage at Bear Valley and Water Supply Papers give flow of Santa Ana at Mentone as observed. In order to check these sources the flow indicated in one source was plotted against the flow in one of the other sources. As might be expected the controlled flow of the Santa Ana, as indicated by the Water Supply Papers showed no correlation with unrestrained flow. A correlation curve between Santa Ana Tributaries and Santa Ana at Mentone was plotted and from this curve it was possible to extend the flood records at Mentone back 12 years to 1872 and the flood records of Tributaries up to 1928. In the extrapolation of Mentone records thef low of 1884 was omitted since it fell outside of the correlation curve. It must have been, however, very high. It was believed that perhaps a r elationship between local yearly rainfall and yearly runoff could be deduced and from such a relationship even a more complete extension of the records might be possible. Points were plotted for yearly rainfall vs. Santa Ana at Mentone. No curve could be drawn through the resulting points so the graph was abandoned.

Although the correlation curve of Tributaries vs. Mentone is satisfactory and reasonably accurate in the lower ranges of flow, the variation above 200% of mean flow may be ± 30%. For this reason extrapolated points were not taken in the computations and in the studies of cycles. For statistical studies the 34 year data gathered from the Santa Ana investigation was used. For cyclic investigation the longer, 50 year record of Santa Ana Tributaries was used.

"The guide stream adopted is the Santa Ana River at Mentone. The last 10 years show a substantial agreement with the other streams of the basin with the exception of San Antonio Creek." This statement taken from the Santa Ana investigation has been checked by the correlation curve. In other words hydrographs, curves, etc., made at Mentone, if expressed as percent of mean will have approximately the same values as those of the Tributaries. Conversely the Tributaries will have the same percent scale and form as flow at Mentone.

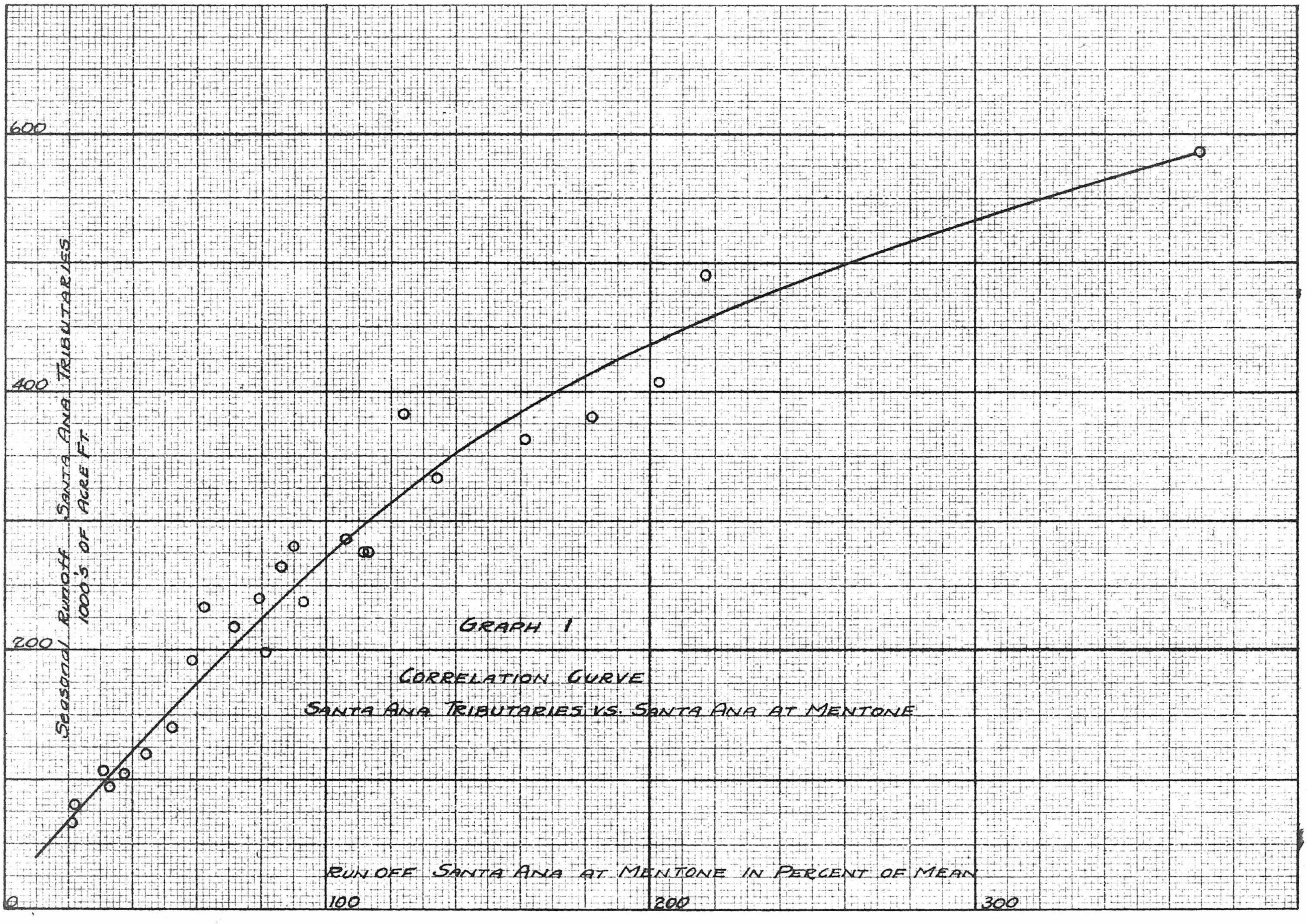
## DATA

| Stream Flow in California Tributaries to Santa Ana | | | Bulletin No. 19 S. A. Investigation | | Water Supply Papers |
|---|---|---|---|---|---|
| Yr. Ending | Runoff | % of Mean | Runoff | % of Mean | Acre Feet |
| 1872 | 93.1 | 37 | 22* | 29* | |
| 73 | 218.1 | 86 | 51* | 67* | |
| 74 | 450.9 | 178 | 162* | 214* | |
| 75 | 183.8 | 72 | 48* | 63* | |
| 76 | 338.2 | 133 | 101* | 132* | |
| 77 | 102.9 | 41 | 25* | 33* | |
| 78 | 397.0 | 157 | 127* | 168* | |
| 79 | 80.9 | 32 | 18* | 24* | |
| 80 | 308.8 | 122 | 89* | 117* | |
| 81 | 142.1 | 56 | 36* | 48* | |
| 82 | 112.7 | 44 | 27* | 36* | |
| 83 | 88.2 | 35 | 21* | 27* | |
| 84 | 720.5 | 284 | * | * | |
| 85 | 129.9 | 51 | 33* | 43 * | |
| 86 | 321.0 | 127 | 94* | 124* | |
| 87 | 147.0 | 58 | 38* | 50* | |
| 88 | 355.3 | 140 | 107* | 141* | |
| 89 | 357.8 | 141 | 108* | 142* | |
| 90 | 529.3 | 209 | 223* | 294* | |
| 91 | 308.8 | 122 | 88* | 117* | |
| 92 | 161.7 | 64 | 42* | 55* | |
| 93 | 308.8 | 122 | 88* | 117* | |
| 94 | 98.0 | 39 | 22.8* | 30* | |
| 95 | 406.8 | 161 | 154 | 203 | |
| 96 | 98.0 | 39 | 25 | 33 | |
| 97 | 264.7 | 104 | 65 | 86 | 55.2 |
| 98 | 105.4 | 42 | 28.8 | 38 | 28.5 |
| 99 | 66.2 | 26 | 16 | 21 | 16.5 |
| 1900 | 88.2 | 35 | 16.5 | 22 | 16.5 |
| 01 | 223.0 | 88 | 47.4 | 62 | 44.4 |
| 02 | 107.8 | 43 | 23.4 | 31 | 20.2 |
| 03 | 281.8 | 111 | 67.9 | 90 | 59.6 |
| 04 | 110.3 | 44 | 24.6 | 32 | 30.6 |
| 05 | 198.5 | 78 | 61.36 | 81 | 53.7 |
| 06 | 360.2 | 142 | 123.1 | 162 | 66.3 |
| 07 | 490.1 | 193 | 164.6 | 217 | 114.0 |
| 08 | 240.2 | 95 | 60.1 | 79 | 15.7 |
| 09 | 274.5 | 108 | 85.7 | 113 | 35.8 |
| 10 | 247.5 | 98 | 86.8 | 114 | 15.4 |
| 11 | 333.3 | 137 | 101.6 | 134 | 51.0 |
| 12 | 191.2 | 75 | 43.8 | 58 | 4.49 |
| 13 | 120.1 | 47 | 33.2 | 44 | 2.45 |
| 14 | 382.3 | 151 | 94.2 | 124 | 31.9 |
| 15 | 379.9 | 150 | 138.2 | 182 | 58.2 |

**DATA** (cont.)

| | Stream Flow in California Tributaries to Santa Ana | | Bulletin No. 19 S. A. Investigation | | Water Supply Papers |
|---|---|---|---|---|---|
| Yr. Ending | Runoff | % of Mean | Runoff | % of Mean | Acre Feet |
| 1916 | 585.7 | 231 | 280.5 | 370 | 118.8 |
| 17 | 237.7 | 94 | 71 | 93 | 10.8 |
| 18 | 274.5 | 108 | 84.2 | 111 | 51.2 |
| 19 | 142.1 | 56 | 39.7 | 52 | 2.62 |
| 20 | 286.7 | 113 | 80.5 | 106 | 26.3 |
| 21 | 218.1 | 86 | 53.7 | 71 | |
| 22 | 495* | 195* | 192.7 | 254 | |
| 23 | 225* | 89* | 60.6 | 80 | |
| 24 | 151* | 59* | 38.9 | 51 | 2.4 |
| 25 | 119* | 47* | 29.8 | 39 | 2.24 |
| 26 | 200* | 79* | 49.3 | 65 | 15.6 |
| 27 | 355* | 160* | 111.6 | 147 | 51.9 |
| 28 | 105* | 41* | 25.8 | 34 | 1.83 |
| 29 | | | | | 3.84 |
| 30 | | | | | 4.59 |
| 31 | | | | | 2.65 |
| 32 | | | | | 23.8 |
| 33 | | | | | 1.43 |
| 34 | | | | | 31.45 |

*Note: Asterisk indicates extrapolated values.


GRAPH 1
CORRELATION CURVE
SANTA ANA TRIBUTARIES VS. SANTA ANA AT MENTONE
Seasonal Runoff Santa Ana Tributaries
1000's of Acre Ft.
Runoff Santa Ana at Mentone in Percent of Mean
0
100
200
300
200
400
600

## STATISTICAL COEFFICIENTS AND FREQUENCY CURVES

In a statistical study the coefficient of variation, C.V. and the coefficient of skew, C.S. are often used. The coefficient of variation $= \sqrt{\frac{\Sigma v^2}{n - 1}}$ is an indication of the variation of the plotted curve to the probability curve while the coefficient of skew $= \frac{\Sigma v^3}{(n - 1) \times C.V.^3}$ is an indication of the shifting of the curve axis from the mean flow axis. The coefficients were computed as shown in Table 2 and have the values C.V. = .756 and C.S. = 1.65. Hall, writing in the Transactions of the A.S.C.E. Vol. 84 on "Probable Variation in Yearly Runoff from a Study of California Streams" determines, from a 16 year record, the C.V. = .56 Hazen in his book on Flood Flows determines the C.V. = 1.06 and the corrected coefficient of skew as 2.5. The corrected coefficient of skew = C.S. x F where $F = 1 + \frac{8.5}{n}$, in which n = number of years in data. This correction must be applied to the coefficient of skew as it can be shown that C.S. is a function of the number of observations taken. The corrected value of C.S. as determined in this paper would then be (since the 34 year record was taken) $1.65 \times (1 + \frac{8.5}{34}) = 2.06$

By comparing these results it is obvious that the statistical coefficients, particularly the c.s. is very sensitive to large or small floods and will vary considerably if a large flood enters into the record. The importance of the coefficients lies in the fact that from them a curve can be plotted, using values developed by Hazen, which should indicate the probable distribution of flood magnitudes. The apparent importance and value of these coefficients is somewhat decreased by noting that they change so rapidly when subject to the addition or omission of of one flood from the record that the shape of the curve is materially changed.

A probable flood distribution curve was drawn by a method of moving averages. (Figure 2) The two sets of dotted lines represent the actual distribution at the points considered ± 20% of the magnitude and the curve represents the approximate distribution when smoothed out. This curve checks in shape at least typical curves for river flow. The scale on the left shows the number of times in 34 years which the flood of the bottom ordinate (+ and - 20%) took place. The right ordinates are expressed as percent of time in which this flow took place. From this graph the most probable flow 54% (± 20%, i.e. 34% - 74%) can be expected 10.5 times in 34 years or about 31% of the time.

A curve somewhat similar in value but quite different in shape is shown in figure 3. This curve was determined by making a table showing the percent of mean value of the flow and the times equalled or exceeded. (The values in Table 2 are arranged in this order.) The points were plotted on rectangular coordinates and the curve drawn as shown. Scales are indicated on the graph. This curve is the one on which design of structures subject to floods would be used. By following over the ordinate

4, for example, we find that four times in 34 years, or , on the average, once every 8.5 years, there would be a flood of 200% of the mean flow or greater. It might be pertinent to remark at this point that when the floods will occur is not considered. They may occur in four consecutive years, or in any form of distribution. All that is shown is that, on a basis of past records, four floods 200% or greater of the mean flow may be expected during a 34 year period. For this reason the scale on the right or the percent of time scale is preferable to use in expressing the results. From this scale it would be said that 11.75% of the years a flood of 200% or greater is expected.

The curve plotted on rectangular coordinates was then plotted on logarithmic paper and the resulting curve was concave downwards, indicating that perhaps a semi-logarithmic plotting would result in a straight line. The curve was plotted on semi-log paper and a straight line was obtained by plotting values up to 240% of the mean flow. This straight line was extrapolated as a straight line and it was noticed that the maximum flood recorded (370% of the mean) was not a representative flood, that it should not have occurred once in 34 years, but .38 of a time in 34 years, or, following the percentage time magnitude line, it was a 1.28% flood instead of a 3% time flood as the data would indicate.

From this straight line relationship the relationship between frequency and magnitude was deduced as follows:

On semi-log paper a straight line is of the form

$y = c \cdot 10^{mx}$ or $y = ce^{m'k}$

where slope = - 1.403

$km = - 1.403$ $.4343km' = - 1.403$

k = scale value (distance on x- axis which corresponds to one unit on y- axis. k = 280

c = y intercept

c = 45.0 for times line c = 132.4 for % line

$m = \frac{-1.403}{280} = -.00501$ or $m = \frac{-1.403}{.4343 \times 280} = -.0156$

For times curve

$T = 45 \times 10^{-.00501p}$

$T = 45 \times e^{-.0156p}$

For % curve

$P = 132.4 \times 10^{-.00501p}$

$P = 132.4 \times e^{-.0156p}$

where T = times equalled or exceeded in 34 year period

P = percent of time equalledor exceeded in 34 year period

p = percent of mean flow.

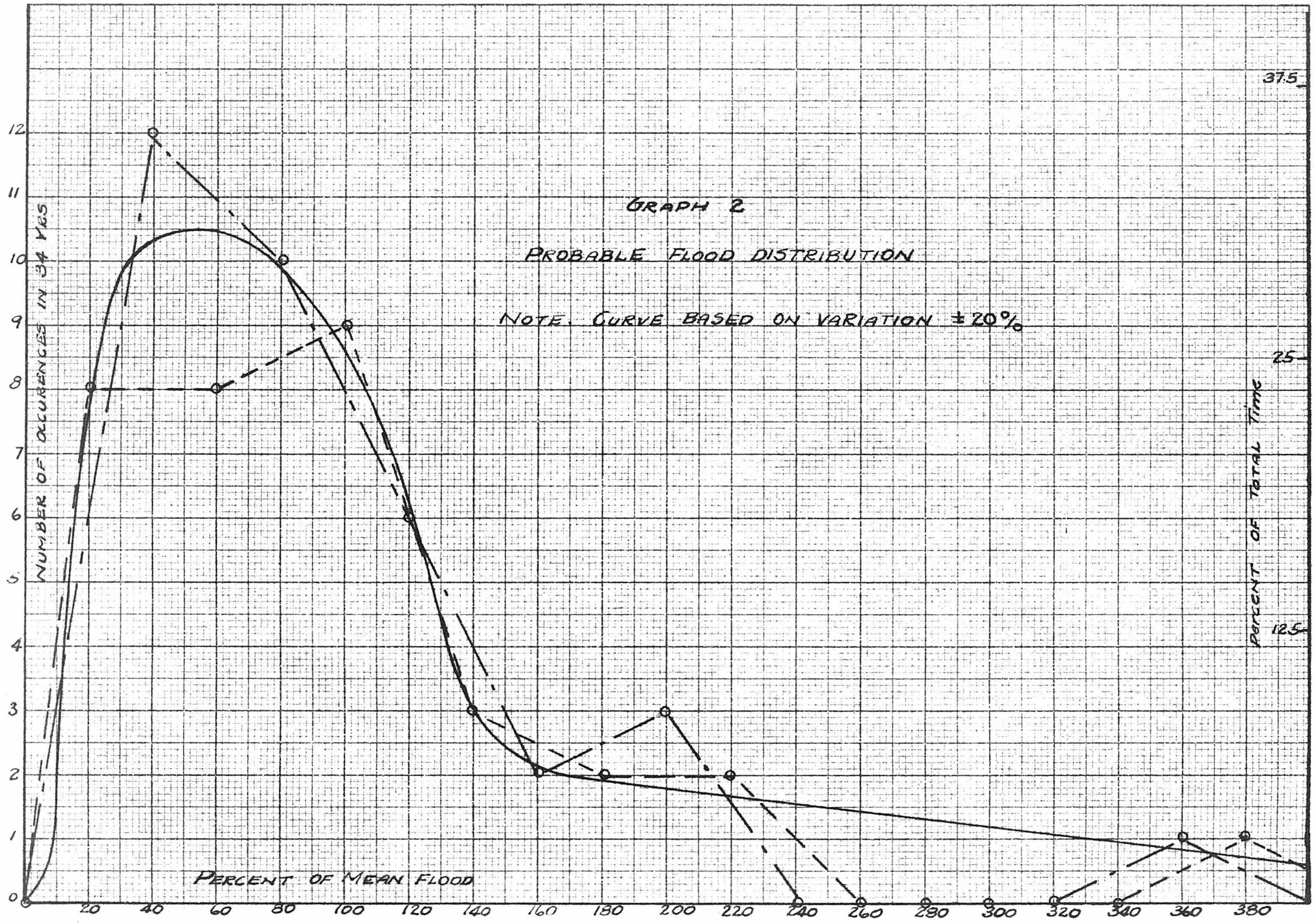
## DETERMINATION OF STATISTICAL COEFFICIENTS

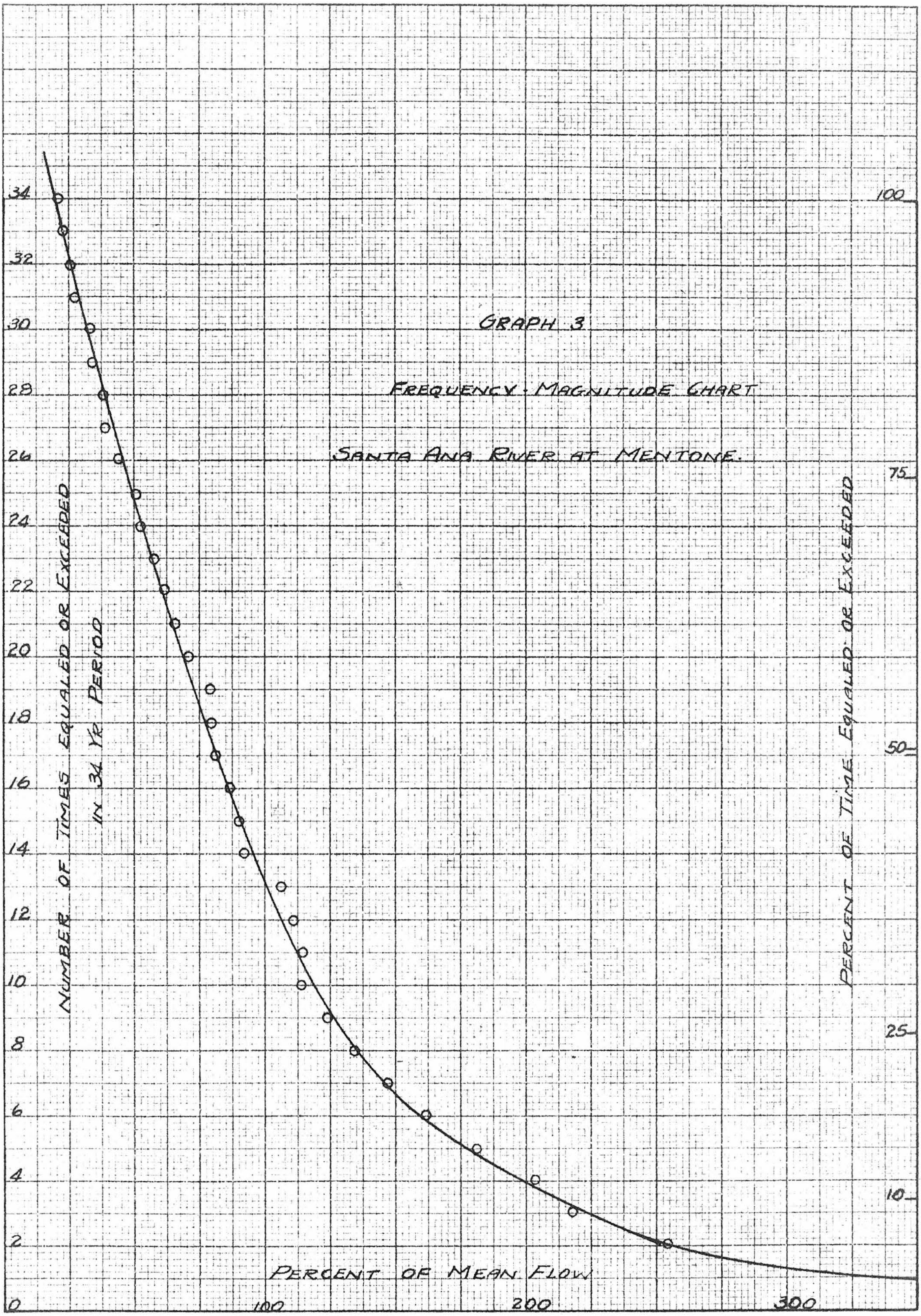
| Times Equalled or Exceeded | Flow % of Mean | Variation v | $v^2$ | $v^3$ |
|---|---|---|---|---|
| 1 | 370 | + 2.7 | 7.3 | +19.60 |
| 2 | 254 | 1.54 | 2.36 | 3.64 |
| 3 | 217 | 1.17 | 1.36 | 1.60 |
| 4 | 203 | 1.03 | 1.06 | 1.09 |
| 5 | 182 | .82 | .67 | .57 |
| 6 | 162 | .62 | .37 | .23 |
| 7 | 147 | .47 | .22 | .10 |
| 8 | 134 | .34 | .10 | .04 |
| 9 | 124 | .24 | .06 | .01 |
| 10 | 114 | .14 | .02 | +26.88 |
| 11 | 113 | .13 | .02 | |
| 12 | 111 | .11 | .01 | |
| 13 | 106 | + .06 | .01 | |
| 14 | 93 | - .07 | .01 | |
| 15 | 90 | .10 | .01 | |
| 16 | 86 | .14 | .02 | |
| 17 | 81 | .19 | .04 | - .01 |
| 18 | 80 | .20 | .04 | .01 |
| 19 | 79 | .21 | .06 | .01 |
| 20 | 71 | .29 | .09 | .02 |
| 21 | 65 | .35 | .12 | .04 |
| 22 | 62 | .38 | .14 | .06 |
| 23 | 58 | .42 | .18 | .07 |
| 24 | 52 | .48 | .23 | .11 |
| 25 | 51 | .49 | .25 | .12 |
| 26 | 44 | .56 | .31 | .18 |
| 27 | 39 | .61 | .37 | .23 |
| 28 | 38 | .62 | .38 | .24 |
| 29 | 34 | .66 | .43 | .29 |
| 30 | 33 | .67 | .45 | .30 |
| 31 | 32 | .68 | .46 | .31 |
| 32 | 31 | .69 | .47 | .33 |
| 33 | 22 | .78 | .60 | .47 |
| 34 | 21 | .79 | .62 | .49 |

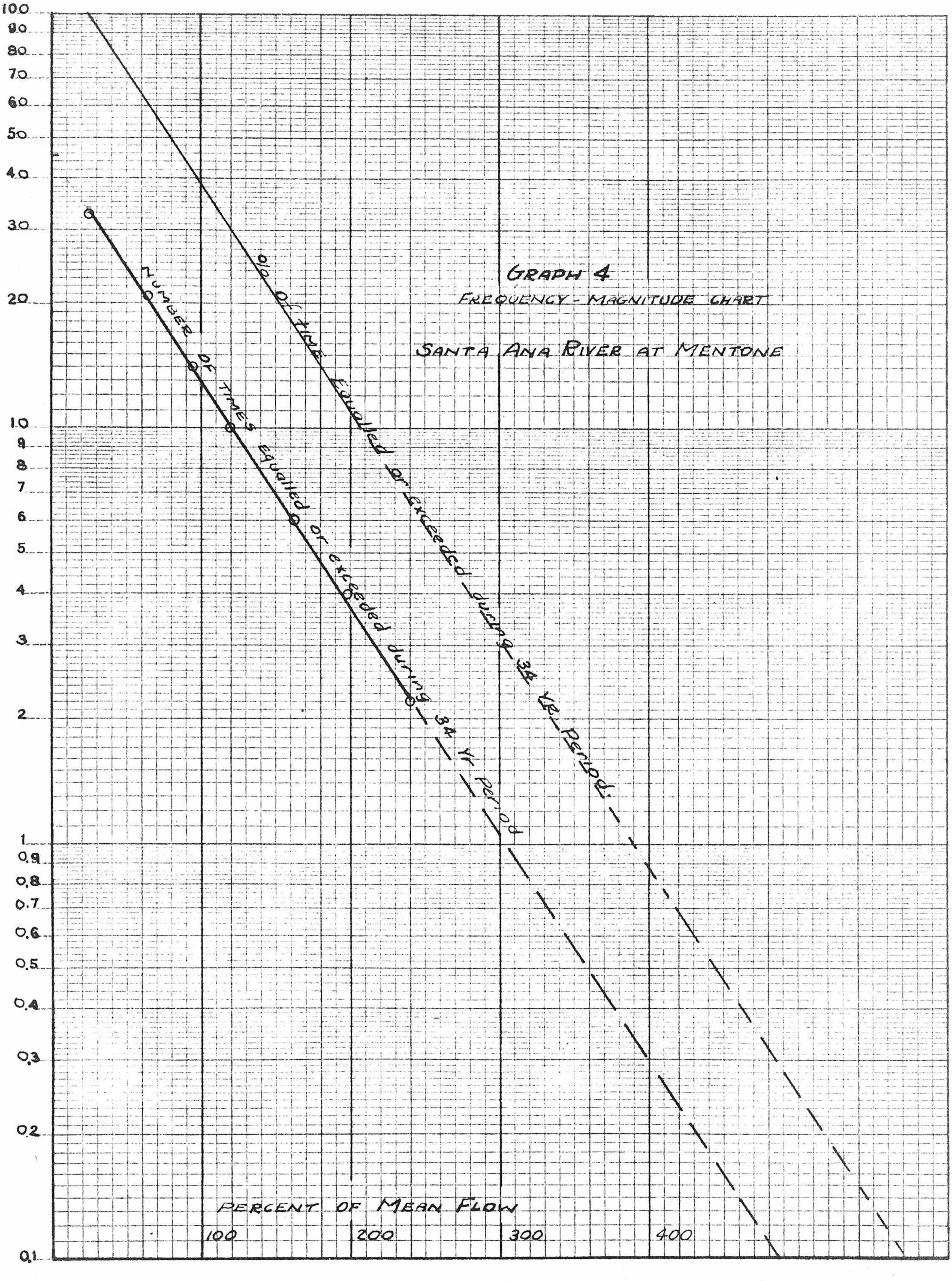
$\Sigma v^2 = 18.82$ $\Sigma v^3 = 23.59$

$$C.V. = \frac{18.82}{33} = .756$$

$$C.S. = \frac{v^3}{33 \times C.V.^3} = \frac{23.59}{33 \times .4321} = 1.65$$


GRAPH 2
PROBABLE FLOOD DISTRIBUTION
NOTE. CURVE BASED ON VARIATION ±20%
NUMBER OF OCCURENCES IN 34 YRS
PERCENT OF MEAN FLOOD
PERCENT OF TOTAL TIME
0
1
2
3
4
6
7
8
9
10
11
12
20
40
60
80
100
120
140
160
180
200
220
240
260
280
300
320
340
360
380
12.5
25
37.5


GRAPH 3
FREQUENCY - MAGNITUDE CHART
SANTA ANA RIVER AT MENTONE
NUMBER OF TIMES EQUALED OR EXCEEDED IN 34 YR PERIOD
PERCENT OF TIME EQUALED OR EXCEEDED
PERCENT OF MEAN FLOW
34
32
30
28
26
24
22
20
18
16
14
12
10
8
6
4
2
0
100
200
300
100
75
50
25
10


GRAPH 4
FREQUENCY - MAGNITUDE CHART
SANTA ANA RIVER AT MENTONE
% of time Equalled or exceeded during 34 yr. period
Number of times equalled or exceeded during 34 yr period
PERCENT OF MEAN FLOW
100
200
300
400
100
90
80
70
60
50
40
30
20
10
9
8
7
6
5
4
3
2
1
0.9
0.8
0.7
0.6
0.5
0.4
0.3
0.2
0.1

## FLOW CYCLES

In considering flow of streams one may consider that the magnitude is purely fortuitous, purely cyclic, or a combination of both. At the present time the prevailing opinion seems to be that flow is mostly chance for the majority of cases and that cycles, although they may be present, are either so complex to analyze or are subject to so much variation that they are of little value in predicting future flows. Shuman, discussing cycles of the River Nile in the January 1936 Proceedings points out that cycles may be determined from year to year by harmonic analysis, which consists essentially of breaking up flow records by Fourier Series. These cycles cannot be satisfactorily projected into the future. Shuman proposes cyclic analysis which "consists of breaking up data into component elements, by suitable reducing means into, quite differently than in harmonic analysis, and deriving certain pattern curves or cycles, which are similar to curves derived from sunspot data, giving thereby something to which terrestial phenomena can be tied, and thus an inkling of what is to come and of what has gone before, beyond the periods of known data." By a method of moving averages and residuals he indicates that there is evidence of cycles in flood flow.

Cycles which have been developed are: Clough Cycle, 2 to 3 years, Wolf Cycle, dependent on number and area of sun - spots, Double Wolf Cycle, 5.5 years, Solar Cycle, 11 years, Bruckner Cycle, 22.23 years, Double Wolf Secular, twice period of Bruckner, and Secular Cycle, variable amplitude and frequency.

Although cyclic analysis seems to work satisfactorily in some cases, the variation fromthe cycle seems to be too great to justify any attempt to do long range forecasting. An indication of the inaccuracy of suchcycles is given in a later issue in the Proceedings in which the standard deviation from a developed cycle ( $\frac{v^2}{n}$) is shown to be greater than 300% of the magnitude of the cycle. In attempting cyclic analysis, long time records are necessary, far longer than the 50 year records available on the Santa Ana River.

The other method of attempting to determine the magnitude and frequency of cycles consists of inspection and trial. The method used in this paper consists of 3 steps which may be repeated as often as desired:

1. The hydrograph of the river is plotted as shown in I, Figure 5. This hydrograph is inspected for evidences of cycles. The most prominent cycle is plotted along the mean flow line.

2. The differences between the cycle chosen and the original hydrograph are then plotted on a second graph, still using the mean flow as the axis.

3. These differences, or residuals are then treated as the original hydrograph, new cycles, if any noted, plotted and the differences again replotted. The procedure is repeated until further cycles no longer reduce the residuals. The cycles are then added algebraicly to give the complete cycle. The residuals left after the final cycle then indicate the variation from the combination of cycles deduced.

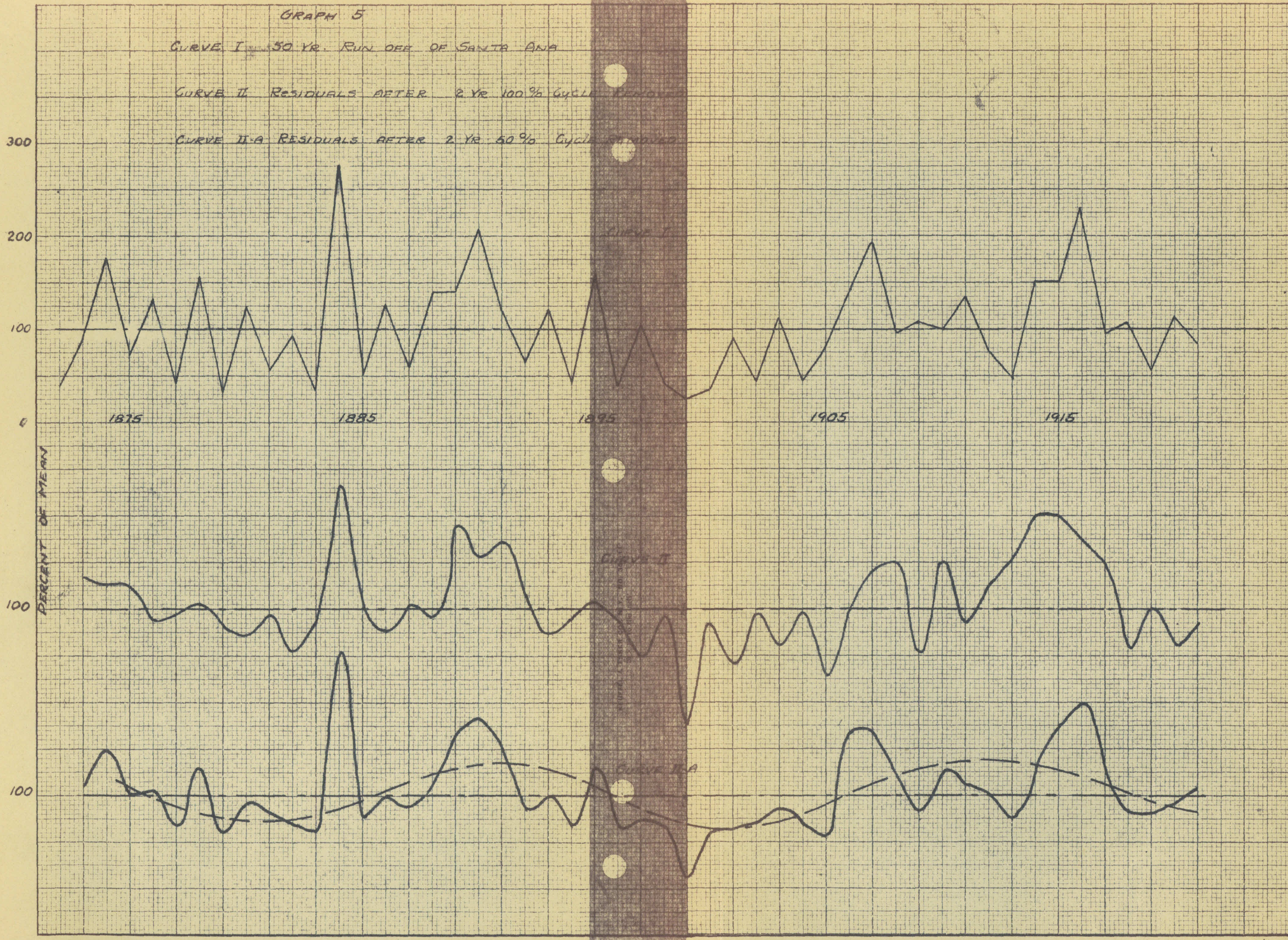
In this study the hydrograph was analyzed in this manner and broken down into 4 cycles by starting with a 2 year cycle with an amplitude of ± 50% of the mean flow. By starting with a 2 year cycle of 25% of the mean flow (plus and minus) more satisfactory results were obtained by using 2 cycles.

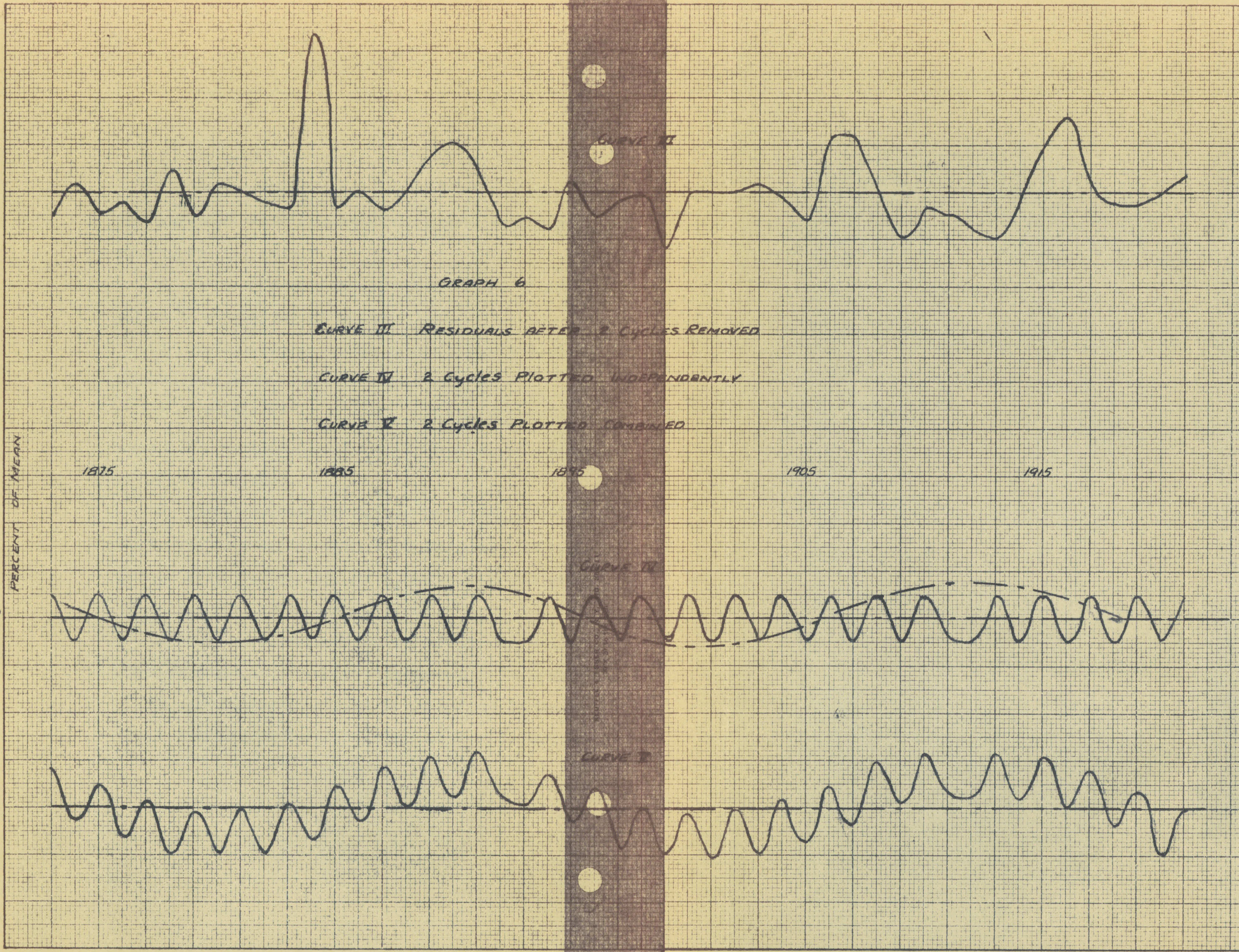
Figure 5, curve I shows the hydrograph of Santa Ana Tributaries from 1872 to 1922. Curve II shows the residuals after a 2 year cycle of 50% mean flow amplitude has been removed. Curve IIa shows the residuals after a 2 year cycle of 25% of mean flow has been removed. The dashed line shows a 10 year cycle with 35% amplitude placed on the residuals. Curve III indicates the residuals after the longer cycle has been removed. Curve IV shows the 2 prevailing cycles plotted independently. Curve V shows cycles plotted combined. The mean deviation, $\frac{\Sigma v}{n}$ and the standard deviation, $\frac{\Sigma v^2}{n}$ were computed.

| | Mean Deviation | Std. Deviation |
|---|---|---|
| From mean flow records | 43.2% | 53.3% |
| From 2 year 25% cycle | 33.3 | 44.5 |
| From 2 year 25% cycle and 10 year 35% cycle | 25.4 | 39.8 |

By comparing graphs II and IIa it appears that the magnitude of the two year cycle may be variable. A 60% amplitude seems to fit better during the earlier years, and a 25% amplitude seems to fit better in the later years. By plotting the differences in successive years an attempt was made to determine how the magnitude of this cycle varied. Results were unsatisfactory. It should also be noted that at 1893 and 1912 the 2 year cycle reverses. Unfortunately the hydrograph is not long enough to determine whether this cyclic reversal is periodic or merely chance. The definiteness of the 2 year cycle would indicate, however, that chance alone does not control flood flow.

Theresiduals in Curve III, Figure 6, should be further investigated for cycles, but inspection indicates that another cycle would have a large amplitude and long period (approximately 50% and 10 years) out of phase with the 10 year 35% cycle adopted. A large discrepency would occur about 1895. With the length of the hydrograph a cycle of this nature would not be justified with such major discrepencies.


GRAPH 5
CURVE I 50 YR. RUN OFF OF SANTA ANA
CURVE II RESIDUALS AFTER 2 YR 100% CYCLE REMOVED
CURVE II-A RESIDUALS AFTER 2 YR 50% CYCLE REMOVED
300
200
100
0
1875
1885
1895
1905
1915
CURVE I
CURVE II
CURVE II-A
PERCENT OF MEAN
100
100


GRAPH 6
CURVE III RESIDUALS AFTER 2 CYCLES REMOVED
CURVE IV 2 Cycles PLOTTED INDEPENDENTLY
CURVE V 2 Cycles PLOTTED COMBINED
CURVE III
CURVE IV
CURVE V
100
100
100
PERCENT OF MEAN
1875
1885
1895
1905
1915

## CONCLUSIONS

1. The coefficient of variation of the Santa Ana River is .756

2. The coefficient of skew, corrected, is 2.06

3. These coefficients are very sensitive to changes in data and should not be relied upon for the determination of the probable flow curve.

4. The most probable flow is 54% of the mean (± 20%) and may be expected 31% of the time.

5. The relationship between percent of time and percent of mean flood may be expressed by the equations

$P = 132.4 \times 10^{-.00501p}$ or $P = 132.4 \times e^{-.0156p}$

where P is percent of time which will have a flow of p percent of the mean or greater.

6. There are apparently at least two cycles evident in the flow of the Santa Ana River, a two year cycle with an amplitude 25% of the mean flow, and a 10 year cycle with an amplitude of 35% of the mean flow.

7. The records available are not sufficiently long to obtain more than an approximate determination of the cycles.

8. From the records available it appears that chance has as much influence on flow at the Santa Ana River as do cycles.

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