FLUCTUATIONS OF EFFECTIVE ANNUAL PRECIPITATION

BY

Vujiva M. Yevdjevich

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INTRODUCTION

Subject. The subject of this paper is fluctuation of effective annual precipitation in river basins. The effective annual precipitation is defined as the total precipitation minus total evaporation and evapotranspiration for a water year in a river basin. These fluctuations may serve as a measure of climatic fluctuations as related to water resources. They are an indicator which gives the outlooks for the prediction of future long-range water yield. Their properties enable the statements on the probability of future effective annual precipitation and annual river flow.

Characteristics of effective precipitation. Effective precipitation represents the net water yield of the atmosphere to the earth surface for a given area and time interval. A very strict distinction between precipitation and evaporation is difficult. These two climatic processes are interwoven, occurring either in sequence or simultaneously, both in time and in space. The evaporation may be theoretically treated as negative precipitation. For several water resource problems the main interest is the total balance of water interchange between the atmosphere and the earth surface.

The data on precipitation and evaporation measured at points may be highly inconsistent and non-homogeneous. The errors in their total values over a river basin, computed from measurements at limited number of points are often large, because the precipitation and evaporation vary greatly both in space and in time. For these reasons the preference is given here to the analysis of effective annual precipitations, determined from annual river flows by correcting flows for carryover of water in a river basin.

Investigation method. The random time series was used in this paper as the yardstick series. The series of effective annual precipitation and annual flow were compared with random series, and differences were analyzed. The statistical technique used in this paper was exclusively the serial correlation, though the similar techniques have been applied in other authors' approaches by using the analyses of ranges and runs. The method of moving average of annual values in order to detect the patterns in sequence has been avoided because of its inherent properties (ref. 1).

MODELS AND COMPILATION OF EFFECTIVE ANNUAL PRECIPITATIONS

General model and types of series. The effective annual precipitation on a river basin can be expressed in these four different ways:

$$P_e = P_c - E_a - E_i = P_i - E_i = V_i + W_e - W_b = V_i + \Delta W_i \quad (1)$$

where: P_e = effective annual precipitation for a water year; P_c = annual precipitation immediately below rain and snow producing clouds; E_a = annual evaporation in the atmosphere during precipitation, between clouds and earth surface; E_i = annual evaporation and evapotranspiration for earth surface; $P_i = P_c - E_a$ = annual precipitation on the earth surface; V_i = measured annual flow from the river basin during the same water year; W_e = total stored water in the river basin at the end of a water year; W_b = total stored water in the basin at the beginning of the same water year; ΔW_i = change in stored water in the basin from one water year to another, positive in wet years, negative in dry water years, with $\Delta W_i = W_e - W_b$.

The general model of eq. (1) shows that the relationships of four variables P_c , P_i , P_e , and V_i depend on the properties of the other three variables E_a , E_i , and ΔW_i . The annual values of these last variables were deducted from or added to the variables P_c , P_i , and P_e or V_i in order to derive any one variable from another. If E_a , E_i , and ΔW_i would be independent of P_c , P_i , P_e , and V_i, which is not the case, the random component of P_c-series would be increased in comparison with P_i-series, of P_e-series in comparison with P_i-series and V_i-series in comparison with P_e-series. It is assumed here that series of each variable P_c , P_i , P_e , V_i has a non-random component, and the addition or deduction of one or more random variables would increase their random component and decrease their non-random component. The concept of a larger or smaller random or non-random component should be understood here, that a series is more close or less close to a random series or vice versa. If there would be a simple linear relationship of P_c and E_a , P_i and E_i , and V_i and ΔW_i , the serires of all four variables P_c , P_i , P_e , and V_i would have the same character, with the same non-random or random components. The relationships $E_a = f_1 (P_c , x_i , x_2 , . . .)$, $E_i = f_2 (P_i , W_i , y_i , y_2 , . . .)$, and $\Delta W_i = f_3 (P_e , E_i , V_i , z_1 , z_2, l l l)$ are complex, where x_i , y_i , and z_i are the other non-mentioned variables of climatic and river basin factors. If the variables other than x_i , y_i , and z_i would dominate the above three relationships and in a non-linear way, then generally a series with larger random component would become a series with smaller random component by deduction or addition of a new variable

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2/ Professor in Civil Engineering, Colorado State University, Fort Collins, Colorado

$(E_a, E_i, \Delta W_i)$. They would, therefore, increase the non-randomness of derived series. If the variables x_i, y_i, and z_i would, however, dominate the above expressions for E_a, E_i, and ΔW_i with relatively small effects of specified variables in these expressions, the addition or deduction of E_a, E_i and ΔW_i would increase on the average the randomness of new derived series.

Carryover effect. The carryover difference ΔW_i is positive and great for a large P_e, and negative for a small P_e. The larger the available river basin water storage and slower its water outflow, the greater and longer in time is the carryover of stored water from a water year to the next ones. The relationship of ΔW_i and P_e makes the V_i-series less random than the P_e-series. This model may be approximated by the following linear model equation:

$$V_i = A_o P_{e(i)} + A_1 P_{e(i-1)} + A_2 P_{e(i-2)} + A_3 P_{e(i-3)} + \dots \quad (2)$$

where A_o, A_1, A_2, A_3 . . . are coeffecients with the four following properties in this case: (1) they are monotonically decreasing coefficients, (2) they are positive, (3) they are smaller than unity, and (4) their sum is unity, $\Sigma A_j = 1$, and where $P_{e(i-j)}$ is effective annual precipitation of the year preceding i-th year for j years. Theoretically there should be an infinite number of members on the right side of eq. (2), assuming that a river flow recession curve was an exponential function. However, the practical considerations limit the number of members to m, with m depending on two factors: (a) available storage spaces in the river basin during large effective precipitations; and (b) outflow ratings from these spaces (fast or slow outflow). For great storage spaces the number m may be of the order of ten (St. Lawrence River at Ogdensburg, N. Y., with large storage in the Great Lakes and slow outflow of stored water), but usually m is 1 to 2.

Equation (2) with m members on the right side represents a type of moving average model (Markov process). For the four previously mentioned conditions to be satisfied by coefficients A_1, A_2, . . . A_m, it can be proved that the time dependence of V_i-series is greater than than of P_e-series. If P_e-series would be random or close to random, V_i-series becomes non-random for sufficiently large water carryover from a year to the next ones. As an example, St. Lawrence River has the first serial correlation coefficients: for P_e-series $r_1 = 0.094$; and for V_i-series $r_1 = 0.705$. However, the carryover in computing P_e from V_i was only considered for the water storage in the Great Lakes, and not for the rest of river basins also, which factor would still reduce the r_1-value for P_e-series.

Effect of evaporation and evapotranspiration. For the relationship $P_e = P_i - E_i$, it is difficult to assume a priori how E_i affects the P_e-series when the characteristics of P_i-series are given, or vice versa, because the relationship of E_i and P_i is usually complex, and in the most general case it is non-linear. This relationship depends on many factors, but mostly on the precipitation distribution in time and in space, water storage in river basins, and especially on the other climatic factors like radiation, relative humidity of the air, wind velocities, water vapor pressurs, etc.

The effect of E_a on the difference between P_c and P_i in the relationship $P_i = P_c - E_a$ depends on E_a as a function of several factors. A simple and very approximate relationship is $E_a = P_c (1-e^{-kH^2})$, where H = elevation difference between the clouds producing precipitation and the earth surface, and k = parameter dependent on many climatic factors and also on the value P_c. In this case if P_c is random in time, the P_i-series would not be, or vice versa. It is not possible to tell a priori what would be the effect of E_a on the P_i, if P_c would be known, because in a general case E_a is not simply and linearly related either to P_c or to P_i.

True and homogeneous values of effective annual precipitation. Equation (1) gives the first approximation of $P_e = V_i = \Delta W$. Taking into account the errors and non-homogeneity, the true values of P_e are, however, different from the first approximation of eq. (1) and are:

$$P_e = V_i + W_i \pm e_i \pm i_i \pm h_i \pm q_i \quad (3)$$

where e_i = random errors in V_i ; i_i = inconsistency (systematic errors) in V_i ; h_i = non-homogeneity of data (man-made influences) in V_i ; and q_i = errors in the determination of ΔW_i.

The random errors e_i, and random part of errors q_i increase the random component of the computed P_e-series, if by true and homogeneous values it is non-random. The effects of the errors i_i, h_i, and the non-random part of errors q_i is converse. They introduce on the average an artificial dependence into the random series, or increase the dependence of already non-random series. The inconsistency and non-homogeneity are introduced in time series in the form of jumps (steps), trends, and their combinations.

As the random errors in annual river flows are small, but as there are often some inconsistencies and non-homogeneities in flow data of many rivers, as well as in the computed ΔW-series, one portion of non-randomness in both V_i-series, and from it computed P_e-series, comes from these errors (i_i, h_i, and q_i). It can be proved theoretically that these errors create on the average a positive serial correlation when introduced into a random time series , or increase the serial correlation of non-random series toward a greater positive correlation.

Compilation of effective annual precipitations. Equation (1), in the form $P_e = V_i + W_e - W_i = V_i + \Delta W_i$ was used to compile the effective annual precipitations. The available annual flows of river gaging stations with sufficiently consistent and homogeneous records were used as V_i-series. By using the average flow recession curves, fitted by exponential functions, and knowing the discharge at the end of a water year, the integration of the recession curve from the time of this discharge to infinity gives the water volume stored at the end of a water year in a river basin. This W_e-value of a water year becomes the W_b-value for the next water year. This general procedure was used in the computation of P_e-values for 140 river gaging stations from several parts of the world: 72 from the U.S.A., 13 from Canada, 37 from Europe, 11 from Australia and New Zealand, 4 from Africa and 3 from Asia (ref. 2).

REGIONAL DISTRIBUTION OF FIRST SERIAL CORRELATION COEFFICIENT

Regional distribution. The first serial correlation coefficient is defined as the correlation coefficient of simple linear association of pairs of successive members of a time series.

Figure 1 shows the values of the first serial correlation coefficient (r_1^f) of annual river flows (upper number), and (r_1^e) of effective annual precipitation (lower number) for 72 river gaging stations in the United States. The length of observation is 40 years or more. The r_1-values for effective annual precipitation, greater than 0.10 are given a special sign, as well as the values below 0.10, and smaller than zero.

Figure 1 shows roughly that the more arid is a region, the greater is on the average the positive value of the first serial correlation coefficient of effective annual precipitations. The annual river flows have in general a greater r_1-value than the effective annual precipitations. This last fact shows a large influence of river basin water carryover from one water year to the next years.

Regional effects. A general trend is that the r_1-values increase with a decrease of mean water yield of a river basin, $q = Q/A$, in cfs/sq mi (mean discharge divided by river basin area). For the 140 river gaging stations (ref. 2) mentioned above the simple linear correlation and regression analysis of r_1^e-values of effective annual precipitation versus q-values gives the regression straight line: $r_1^e = 0.169 - 0.0244\, q$, with the correlation coefficient $r = -0.61$, and the standard deviation of estimates $s = 0.164$. Though the correlation is not very high, the value $r = -0.61$ points out that an increase in aridity of a region. . . . . augments on the average the first serial correlation coefficient of effective annual precipitation.

The same simple linear regression and correlation analysis of r_1^f-values, the first serial correlation coefficient for annual river flows, versus the mean water yield q in cfs/sq mi for 140 stations gives the correlation coefficient $r = -0.69$, and regression straight line $r_1^f = 0.218 - 0.0298\, q$, with the standard deviation of estimates $s = 0.176$. The correlation is a little better for annual flow ($r = -0.69$) than for effective annual precipitation ($r = -0.61$).

The correlation and regression analysis for 140 stations of $\Delta r_1 = r_1^f - r_1^e$ versus q gives the following results: $\Delta r_1 = 0.0488 - 0.00545\, q$, with $s = 0.0896$, and $r = -0.213$. There is a small trend for r_1 to be greater for smaller values of q. For the same other river basin conditions, the smaller the mean water yield, the tendency is for a larger difference of Δr_1, or there is more storage space per unit of q, and the relative carryover is greater in this case.

It can be indirectly concluded form above analyses, that the semi-arid and arid regions have a greater effect of evaporation and evapotranspiration on the dependence of time series of effective annual precipitation, than it is the case with the humid regions. It is assumed for this conclusion, that the annual precipitation (P_c and P_i) have approximately the same characteristics in fluctuations for both humid and arid regions.

CUMULATIVE FREQUENCY DISTRIBUTION OF FIRST SERIAL CORRELATION COEFFICIENT

Distribution of first serial correlation coefficient for 140 stations. As this coefficient has a relatively large standard deviation for small samples, the analysis of the coefficient for any individual station cannot produce a reliable conclusion on the general patterns in sequence of annual flow and effective annual precipitation. The distribution of coefficients for many stations, sufficiently separated to avoid the regional bias, gives a much better general picture of the fluctuation patterns.

Figure 2 shows the cumulative frequency distribution of first serial correlation coefficient for 140 river gaging stations for three series, with graphs in probability paper: (1) Series of annual flow; and (2) Series of effective annual precipitation on the corresponding river basin; and (3) Random series of normally distributed variable, for which r_1 is also normally distributed (straight line cumulative frequency) with expected mean $E(r_1) = -1/(N-1)$, and the variance of r_1, as $s_r^2 = (N-2)/(N-1)^2$, (ref. 3). The comparison shows that the r_1-coefficients of the two first series are also close to a normal distribution. Approximately the standard deviation of r_1 for the range of probability 20% - 95% is the same as that of the random series, but with different means or medians. For $N = 55$ (equal to the average length of 140 series) the random series has $E(r_1) = -0.018$ and $s_r = 0.135$. The mean r_1 for annual flows is 0.176, and that for effective annual precipitations is 0.130. The corresponding median values are 0.160 and 0.115 respectively. The difference is about 40% of the last median value. Therefore, about 2/5 of the positive first serial correlation coefficient of annual flow may be explained by the water storage effect, in the form of water carryover from one water year to the following ones.

Distribution of first serial correlation coefficient for the region in or around the Upper Colorado River Basin. A semi-arid region is selected for showing the same distributions as in fig. 2 (ref. 4).

Figure 3 gives the same cumulative frequency distributions for some river gaging stations in the Upper Colorado River Basin and around it (altogether 14 stations). The parameters for

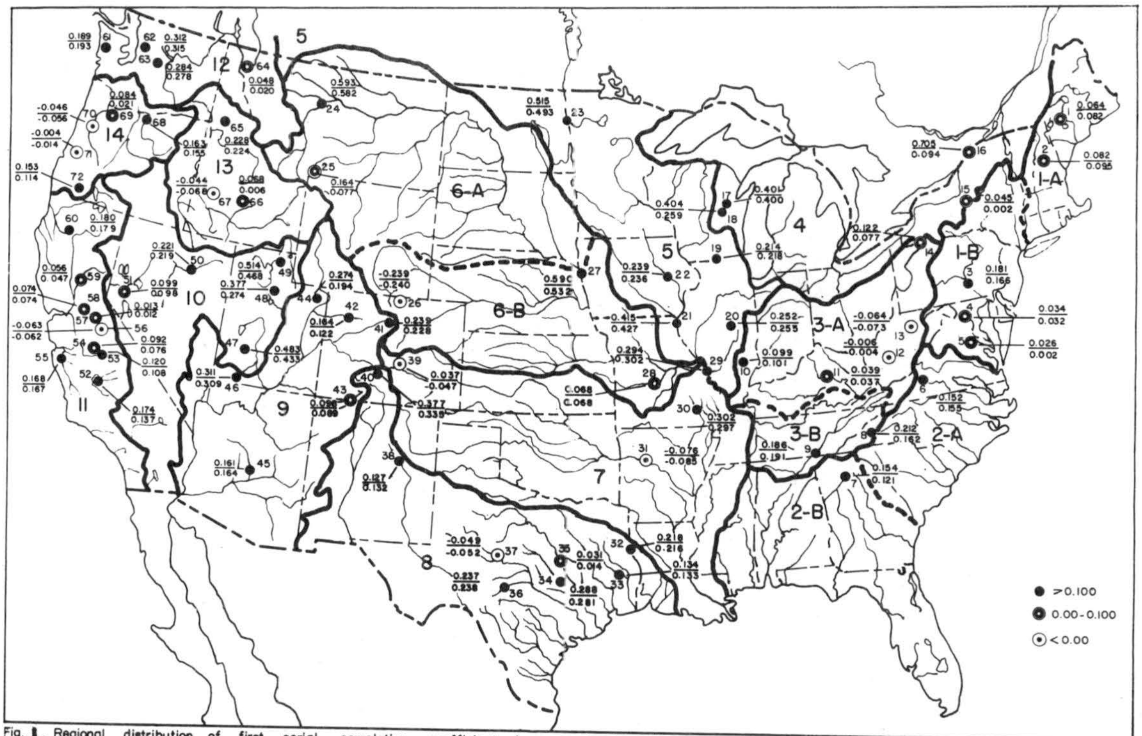

Fig. 1. Regional distribution of first serial correlation coefficient for annual flows (upper figure) and effective annual precipitations (lower figure) for 72 river gaging stations in the United States.

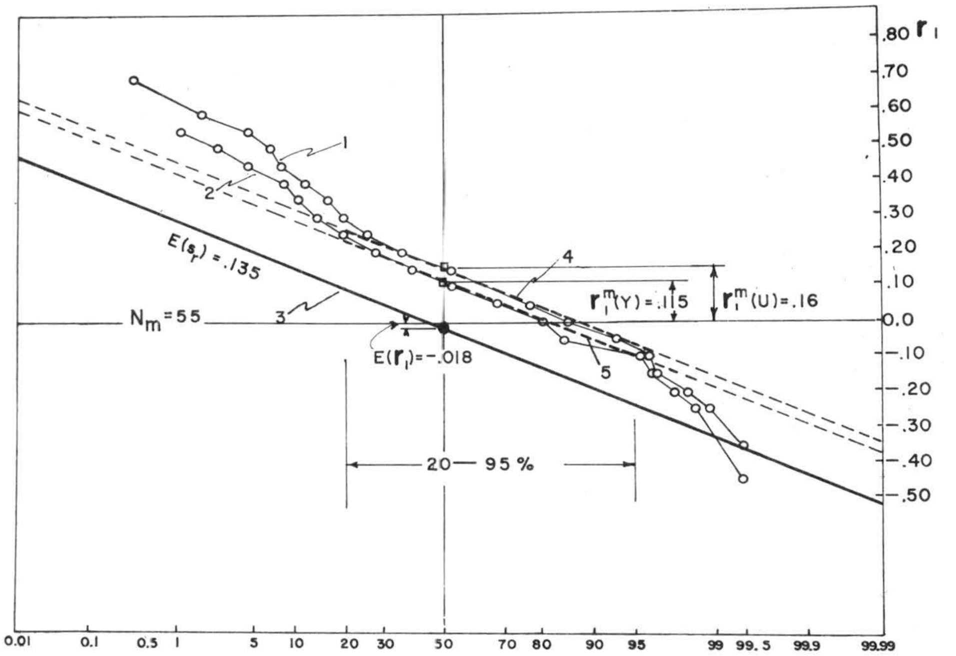

FIG. 2. CUMULATIVE FREQUENCY DISTRIBUTIONS OF FIRST SERIAL CORRELATION COEFFICIENTS (r_1) FOR 140 RIVER STATIONS, USING CARTHESIAN-PROBABILITY SCALES: (1) U_i SERIES, COMPUTED; (2) Y_i SERIES, COMPUTED; (3) RANDOM SERIES FOR N=55; (4) U_i SERIES, FITTING A STRAIGHT LINE FOR RANGE 20%-95%; (5) Y_i SERIES, FITTING A STRAIGHT LINE FOR 20%-95% RANGE OF CUMULATIVE FREQUENCY.

random series ($N = 47$, average length of 14 series) are: $E(r_1) = -0.0217$, and $s_r = 0.145$, while the median values of r_1 for annual flows and effective annual precipitations are 0.220 and 0.180 respectively, with their standard deviation of distribution very close to that of random series (0.145). The water carryover in river basins is, therefore, responsible for the positive first serial correlation coefficient of annual flows for 22% (or about 1/5) of the coefficient for effective annual precipitations.

Effect of inconsistency and non-homogeneity. It is likely that one part of the positive first serial correlation coefficient of effective annual precipitations is produced by inconsistency and non-homogeneity in data. This may be especially the case in arid and semi-arid regions where the non-homogeneity in data is likely to have the largest relative values. The above example of semi-arid region, which has been subject to many small man-made influences in the last 50-60 years (by selection criteria the river gaging stations with large man-made changes in river basins have been discarded) seems to show this trend. It can be proved theoretically that the inconsistency and non-homogeneity of data, introduced in the middle of a series as a jump change of flow, would increase the first serial correlation coefficient (ref. 2) approximately by $\Delta r_1 = i^2/C_v^2(2+i)^2$, where C_v = coefficient of variation of the series, and i = percentage of the change in comparison to the mean flow. For $i = -10\%$, and $C_v = 0.25$, $\Delta r_1 = 0.044$.

Distribution of first serial correlation coefficient for annual precipitations. A total of 30 precipitation gaging stations in the Upper Colorado River Basin, and their P_i-series of annual precipitation were used also to study the first serial correlation coefficient for comparative purposes. The cumulative frequency distribution of first serial correlation coefficients r_1^p of these series is given for 30 r_1-values in fig. 3. The random series for $N = 53.4$ (average length of time series of annual precipitations) has $E(r_1) = --0.020$ and $s_r = 0.137$. The straight line of normal cumulative distribution for this random series is also given in fig. 3.

These 30 stations are a small sample of annual precipitation from approximately the same region as the above 14 series of annual flows and effective annual precipitations. The mean or median value of r_1^p for 30 stations is 0.074. The difference $\Delta r_1 = r_1^e - r_1^p = 0.106$, so that P_{ep}-series has a mean r_1-value about 2.5 times the mean r_1-value of P_i-series. The distribution of r_1^p of annual precipitations is much closer to the r_1-distribution of random series, than are the r_1^e--values of effective annual precipitations. The slope of r_1^p-distribution is very close to the slope of random series for the mean N. The evaporation and evapotranspiration from river basins are partly responsible for a greater mean positive first serial correlation coefficient of effective annual precipitation than that of annual point precipitation. In other words, the series of annual precipitation on the average are closer to random time series than the series of effective annual precipitation or the annual river flow.

CORRELOGRAMS

Correlograms of individual rivers. As examples of correlograms for individual rivers of long records, only two cases will be given here. Correlogram is defined as the discrete graph or serial correlation coefficients r_k versus the lag k between the correlated values.

Figure 4 gives the correlograms for the River Rhine at Basle, Switzerland, for both series, U-series (annual flow) and Y-series (effective annual precipitation), as an example for long record river gaging station (150 years of observation), with a relatively small positive serial correlation in both series.

Figure 5 gives the same for St. Lawrence River at Ogdensburg, New York, with 97 years of observations, and a relatively large positive serial correlation of annual flows.

The correlograms of figs. 4 and 5 (as well as of some other rivers of long record, which are not given here) show that the series of effective annual precipitation are close to random series, and that by the statistical test of significance they cannot be distinguished from random series on a 95% level of significance. The annual flows have a signigicant positive value of r_1 for the Rhine River on about 85% level, but r_1 to r_9 of series of annual flow for the St. Lawrence River are significantly different from zero (or from a random time series) at a 95% level of significance.

Average correlogram. Figure 6 gives the average correlogram for 140 river gaging stations, obtained by using the mean value of each r_k. As the time series were of different length N, and the number of computed r_k was N/4, the mean number of r_k for each k is either $n = 140$ (refer to $k = 1$-10), or smaller than 140, with only $n = 2$ for $k = 37$. The confidence limits are computed by the formulas for random series (ref. 3), and for 95% level it is approximately $R_{95\%} = (-1 \pm 1.64 - \sqrt{N-K-2})/(N-k-1)$. For the graphs in fig. 6 the confidence limits are obtained by averaging the confidence limits of individual series for a given lag k. Figure 6 gives also n-values as well as standard deviations of r_k about mean r_k for both series, annual flows (U-series), and effective annual precipitations (Y-series), The confidence limits decrease with k, because of averaging procedure. Theoretically they should increase with an increase of lag k. The limits in fig. 6 are, therefore, on the conservative side.

The fluctuations of the average correlogram do not show any significant cyclical movement which exceeds the confidence limits. The annual flows have, however, a significant positive r_1-value on 90% level of significance.

DISCUSSION

The serial correlation analysis of series of annual flow, effective annual precipitation and

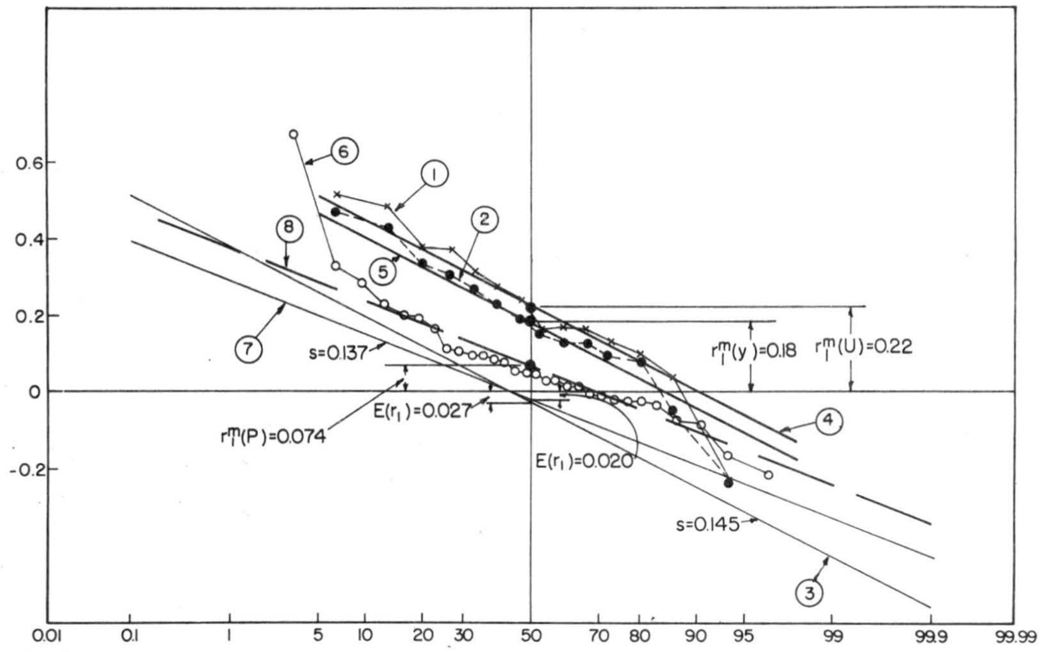

Fig 3. Cummulative frequency distributions of first serial correlation coefficent: (1) For series of 14 stations and annual flows; (2) Same as under (1) but for effective annual precipitation; (3) For random series, $N_m = 47$; (4) Line parallel to line (3) through r = 0.22; (5) Same as (4) through r = 0.18; (6) For series of 30 point stations of Upper Colorado and annual precipitation; (7) For random series, $N_m = 53.4$; (8) Line parallel to line (7) through r = 0.074.

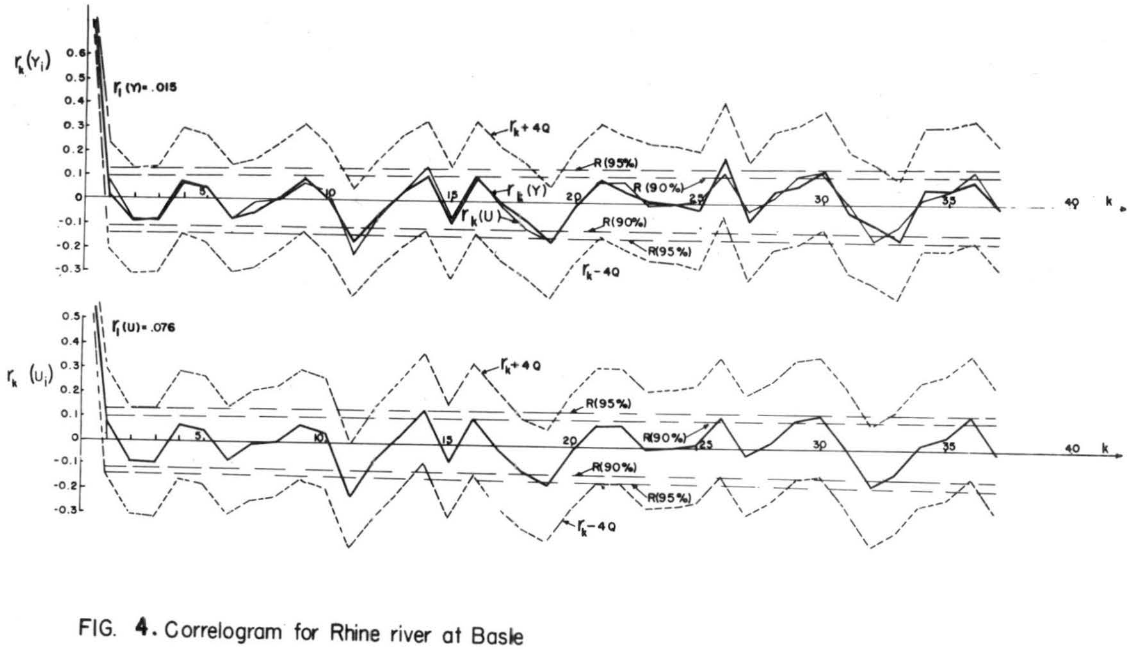

FIG. **4.** Correlogram for Rhine river at Basle

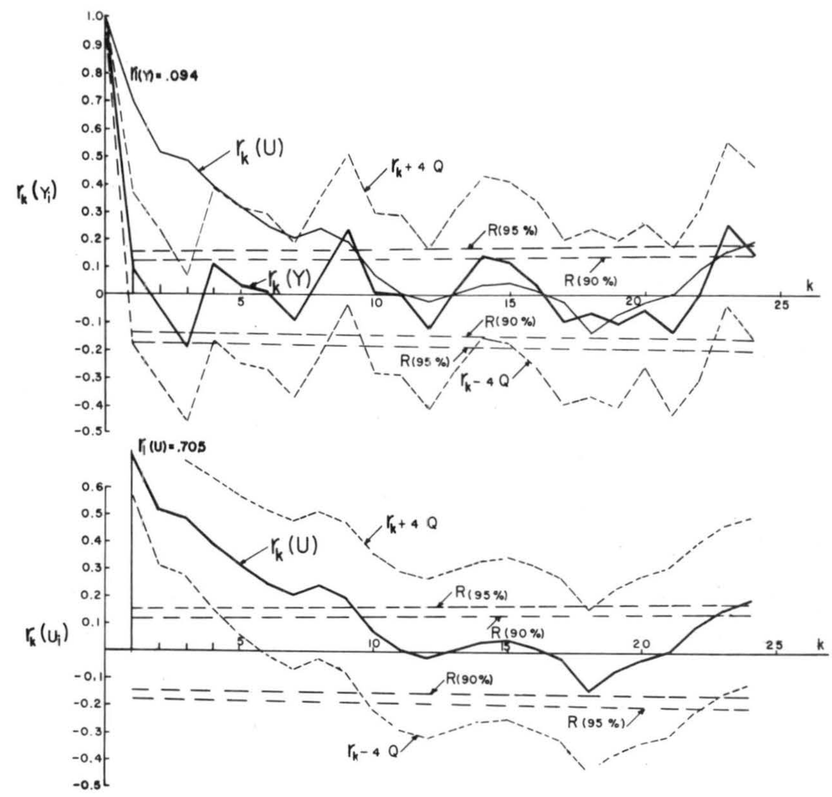

FIG. 5. Correlogram for St. Lawrence river at Ogdensburg

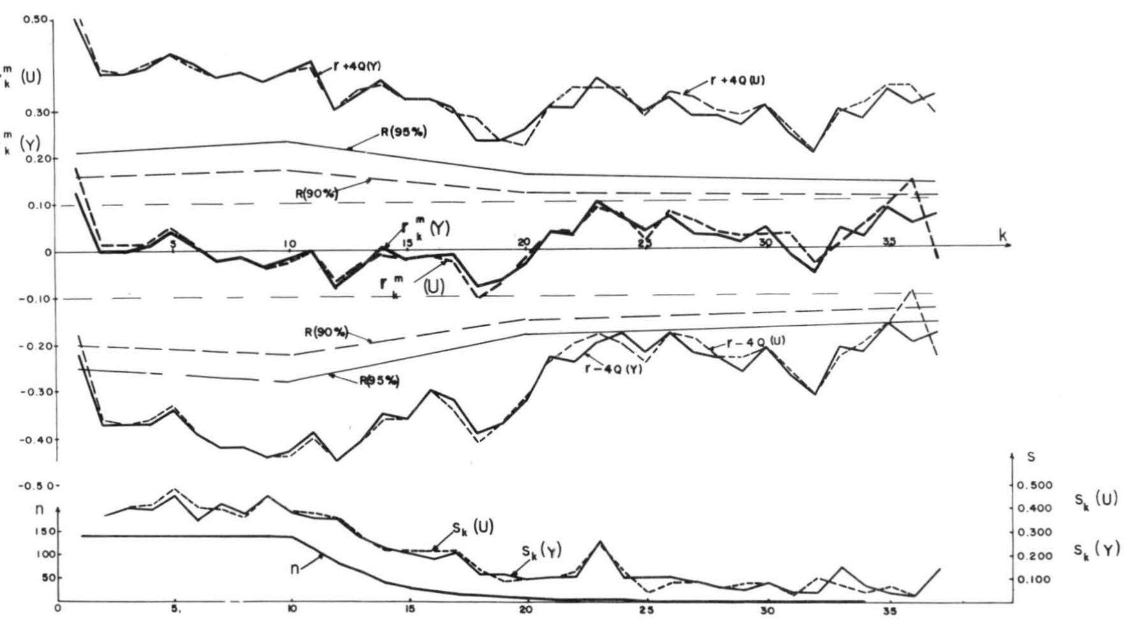

FIG. 6. MEAN CORRELOGRAM FOR 140 RIVER STATIONS, WITH MEAN CONFIDENCE INTERVALS ($r_k \pm 4Q$), R (95%) AND R (90%), WITH NUMBER n FOR EACH r_k, AND THE STANDARD DEVIATION s_k OF r_k VALUES AROUND THE MEAN VALUE $\bar{r}_k$

in one case of annual point precipitation has shown the interesting results. The dependence of series of annual flow is greater than the dependence of series of effective annual precipitation. The water carryover from year to year in surface and underground storage spaces of a river basin is the main cause of this increase in non-randomness. The series of annual flow may be considered as a stochastic series, created from a random series, from a series very close to random series, or from another stochastic series, which are represented by series of effective annual precipitation.

The average positive dependence in time series of effective annual precipitation is small. In some practical applications these series may be considered as series very close to random series.

The radar observation of differences between the precipitation just below the rain and snow producing clouds, and the precipitation at the earth surface has shown, that this difference is large in arid regions, especially in summer time. The recorded rainfall is only 10-15% in some cases of the amount of rainfall estimated by radar observations to have existed below rain producing clouds.

The differences in non-randomness of time series for effective annual precipitation, annual precipitation on the earth surface, and annual precipitation below clouds depend on the physical relationships of evaporation to other factors. These relationships should be described by physical and statistical models.

The series of annual precipitation on an area may have on the average in a region either a positive or a negative first serial correlation coefficient. Depending on evaporation, it is not excluded that the series of effective annual precipitation may be in some regions and in some rare cases closer to a random series than the series of annual precipitations. The P_c-series of annual precipitation below clouds may be or may not be closer to a random series than the P_i- or P_e-series. All depends on the properties of variables E_a and E_i . According to fig. 3 it may be expected that P_c-series would be still closer to a random series than P_i-series.

While the ΔW-series has always an affect of increasing the non-randomness in V_i-series in comparison with P_e-series, it is not possible to conclude a priori what would be the effects of E_a-series and E_i-series on P_i-series and P_e-series respectively. It is to expect, however, that on the average and in the majority of cases E_i-series would increase the positive serial correlation of P_e-series in comparison with P_i-series.

A hypothesis is advanced here, that the effect of E_a-series may be of a special type. Assuming that the P_c-series is random, and that the E_a is much greater in percentage of P_c for small values of P_c that for large values of P_c, the E_a-series would force the P_i-series to a more zig-zag series, with an average first serial correlation coefficient of P_i-series negative. Some computations for P_i-series but for selected consistent and homogeneous data show that $r_1{}^P$ is negative on the average. To produce the P_e-series with a positive mean first serial correlation coefficient, the E_i-series must on the average increase the positive correlation. The available data on P_c and E_a are, however, limited still in order to test this hypothesis.

The sampling variance of statistical parameters which measure the non-randomness of time series is usually large. It is especially the case for the small and medium samples which characterize the records of river flow and precipitation. It is, therefore, necessary to investigate the data of a large number of rainfall and river flow stations in a climatically sufficiently homogeneous region, in order to derive the general properties of time series of annual precipitation and of annual river flow in that region.

If the average value of statistical parameters which measure the non-randomness of series of effective annual precipitation shows a positive serial correlation, and if the effect of systematic errors and non-homogeneity in the annual flows and carryovers is neglected, the causes of non-randomness should be first attributed to and tried to be explained by the influence of evaporation, either that from the earth surface, or that in the atmosphere during the rainfall or snowfall.

If the investigation shows which of time series of four variables P_c, P_i, P_e, and V_i is closest to a random time series, and also gives the models of relationship P_e versus V_i, P_i versus P_e, and P_c versus P_i, it is possible to derive theoretically the properties of other three non-random series from the general properties of random series by applying the properties of stochastic processes, as soon as the main parameters of random variables are known.

It is a fact derived from the experience, that one of the above series of four variables for a region is on the average much closer to random series than the others, usually the P_i-series.

It can be assumed, therefore, that the water carryover in a river basin, the evaporation regularities (either for evaporation in the atmosphere, or for evaporation and evaportranspiration from the earth surface), as well as the inconsistency and non-homogeneity in data are significant factors affecting the interdependence of members of time series of annual flow or of effective annual precipitation.

CONCLUSIONS

As the properties of random series and of series derived from random series by known processes (stochastic processes) may be determined theoretically, or by approximate integration of the theoretically derived equations, this fact may be used efficiently in the analysis of time series of annual river flows and effective annual precipitation.

In the case a time series is close to a random series, i. e. annual precipitation or effective annual precipitation, and in the case the model which relates the annual precipitation to effective annual precipitation, or effective annual precipitation to annual flow can be determined for a river basin, the properties of distribution and dependence of non-random series may be derived theoretically.

The study of the relationship between precipitation below clouds and precipitation on the earth surface may contain the key for explaining some small non-randomness in the sequence of annual precipitation, especially in arid and semi-arid regions. The radar observation of precipitation should contribute to the study of this problem.

The above analysis and discussion show, that after the effects of evaporation, water carryover, inconsistency and non-homogeneity in series of annual flow and/or effective annual precipitation are accounted for, the room left for the causes of non-randomness in series of annual precipitation, which causes come from beyond the atmosphere, is relatively small.

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