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Determination of decadal climatic cycles in runoff fluctuation of a hydrologic unit

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RESUMEN

Se analizó un grupo de 60 series de gastos medios anuales y 15 de precipitación total anual, localizadas en una unidad hidrológica en el suroeste de México, en la vertiente del Océano Pacífico. Se analizó la homogeneidad interna de las series a partir de métodos estadísticos apropiados y posteriormente, las series se completaron al período de cálculo. Con ayuda de la matríz de correlación se definieron tres regiones homogéneas dentro de la zona de estudio. Los ciclos climáticos en décadas fueron determinados con ayuda de las curvas de diferencias integradas. El impacto antropogénico sobre las corrientes se estimó con el uso de las curvas de homogeneidad. La longitud de los ciclos varía de 30 a 40 años. La estructura de los ciclos en décadas permitió estimar la duración de los períodos de deficiencia, abundancia y normalidad de los escurrimientos en cada región. La estructura cíclica de los escurrimientos en cada región se explica a partir de la precipitación. El impacto antropogénico fue importante en la parte media de la corriente principal, en donde las dos corrientes principales se conectan a través del Lago de Chapala. Se demuestra que, a pesar del impacto antropogénico ejercido en parte del sistema hidrológico, éste continúa siendo regulado en forma natural por los factores climáticos y todavía constituye una unidad hidrológica. La estimación de la longitud de las diferentes fases del ciclo en 'ecadas puede usarse para administrar los recursos hidráulicos regionales.

ABSTRACT

A group of 60 runoff and 15 precipitation time-series, all belonging to a hydrological unit in Southwest Mexico, in the Pacific watershed was analyzed. The internal homogeneity of the time series was tested and then they were completed for the calculation period using suitable statistical methods. Three homogeneous regions were defined in the studied zone through correlation matrices. The climatic decadal cycles were determined with the help of the integrated differences curves. The anthropogenic impact on the runoffs was estimated through the homogeneity curves. The length of the cycles were ranged from 30 to 40 years. The structure of the decadal cycles permitted the estimation of the duration of deficiency, abundance, and normality runoff periods in each region. The cyclical structure of the regional runoffs can be explained by precipitation. The anthropogenic impact was important in the middle of the general streamflow, where the two main streamflows connect through Chapala Lake. It was demonstrated that, in spite of the anthropogenic impact on part of the hydrologic system, it continues to be naturally regulated by climatic factors and still constitutes a hydrological unit. The estimation of the lengths of different phases of the decadal cycle can be used for the management of the regional water resources.

Key words: runoff cycles, hydrologic unit, management of water resources.

1. Introduction

The study of historical fluctuations of the river currents has its origin in the past century, when the Russian climatologist A. V. Voyeikov formulated in 1884 the fundamental law of hydrometeorology: streamflows are a product of the climate (Vladimirov, 1990). Since then, many researchers have explained the cyclical behavior of streamflows by means of their relationship to large-scale atmospheric phenomena (Shelutko, 1973, 1980, 1981, 1984 and 1989; Gutnichenko, 1979; Sakhariuk, 1981). The study of the cycles of climatic processes is of great importance for the control of environmental quality and the administration of water resources. It is a central topic in the investigation of climate variability (Arnell *et al.*, 1996; Rothschild, 1995; Lluch-Belda *et al.*, 1991). Arnell *et al.* (1996) suggested that hydrological variability can be related to large scale climatic anomalies, such as those associated with El Niño/Southern Oscillation (ENSO), and there are strong relationships between hydrological anomalies in different parts of the world (e.g. Redmond and Koch, 1991; Aguado *et al.*, 1992; Mechoso and Iribarren, 1992; Simpson *et al.*, 1993; Dracup and Kahya, 1994; Ely and Cayan, 1994). Poveda and Mesa (1996) mention that El Niño and La Niña represent climatic events associated with hydrological anomalies occurring in tropical southwest America, and other regions of the world, on monthly or interannual time scales. For instance, in Colombia rivers el Niño produces stronger and longer drought periods, while La Niña increases the rainfall and maximum streamflow. Arnell *et al.* (1996) indicate the necessity of research for understanding and modeling of land-atmosphere exchange processes over a range of spatial and temporal scales for the understanding of the El Niño/Southern Oscillation (ENSO) and other large-scale atmospheric features effects on hydrological characteristics, and the changes caused by global warming.

Long-term, irregular water-level fluctuations occur mainly in semiarid and dry tropical regions with distinct wet and dry seasons and high interannual variability (John, 1986). We can expect the principal long-term cyclogenesis mechanisms would be strongly dependent on the regional atmospheric characteristics. The short term anomalies (of the order of 10 years) will be dependent mainly on either atmospheric or oceanic conditions (Reyes and Mejia-Trejo, 1991). For this approach, Zehnder (1989) suggests the importance of southeasterly winds during the initial stages of tropical cyclogenesis in southwestern Mexico.

Among the characteristic cycles of the climatological phenomena, the annual cycle can be considered basic. It is present not only in the series of the climate elements, as rainfall and temperature, but also in a more complex process, "El Niño/Southern Oscillation", a phenomenon of ocean-atmosphere interaction on a global scale (Saravanan, 1997; Rajagopalan *et al.*, 1997; Mark *et al.*, 1986; Barnett *et al.*, 1988). In all cases, the basic cycle is modulated by cyclical fluctuations of different duration and amplitude. Vladimirov (1990) highlights, for streamflows, the existence of regular 2 to 6 year cycles of different amplitude, contained within cycles of several decades. These cycles at present studied are generically known as decadal cycles. Pérez-Peraza *et al.* (1996) confirm the presence of statistically significant cycles of the level of Lake Tchudskoye with periods of 2.6, 11.2, 22, and 80~90 years.

In this work, we analyze the data on runoff and rainfall recorded at stations of the hydrological system Lerma-Chapala-Santiago, in southwest Mexico in the Pacific Ocean watershed. Our main purpose is to determine the climatic decadal cycles of the areas that typify the system and to define the structure of the cycles, i.e. the duration of the normal, drought, and wet periods, and determine the area of greatest anthropogenic impact in the studied zone.

2. Accumulation curves

a) The integrated differences curve (IDC)

In this work, to identify the climatic decadal cycles we used a method based on the *integrated* *differences curve* (Vladímirov, 1990), which show the accrued increment of the anomalies divided by the standard deviation of the runoff for each $i = 1, 2, \ldots, n$. It can be written:

$$S_n = \frac{\sum\limits_{i=1}^{n} (k_i - 1)}{C_v} \tag{1}$$

where S_n is the integrated differences curve (IDC), n is the length of the time interval of the series beginning at $i = 1$ and

$$K_i = \frac{x_i}{\bar{x}}, \quad C_v = \frac{\sigma}{\bar{x}}, \quad \bar{z} + \frac{1}{N}\sum_{i=1}^{n} x_i, \quad \sigma = \sqrt{\frac{1}{N-1}\sum_{i=1}^{N}(x_i - \bar{x})^2}.$$

N is the total length of the series. Some of the properties of S_n are:

1. According to the definition of the IDC, S_n will increase when the corresponding series

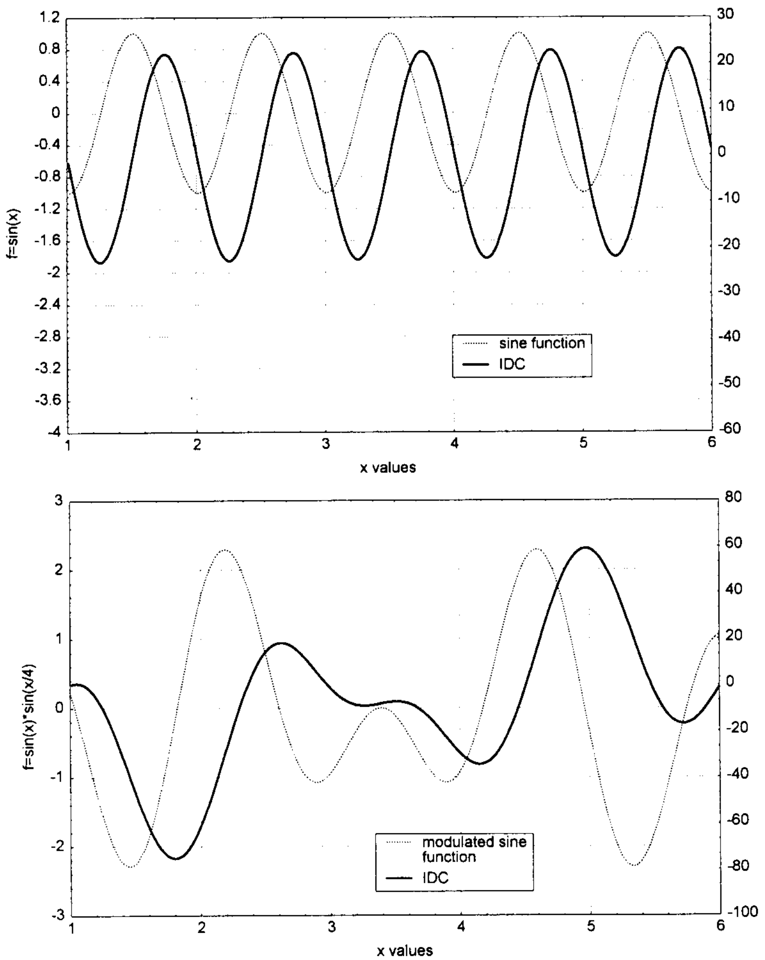


Fig. 1. Example of identification of a cycle a) sine function, b) modulated sine function.

is found above the norm (***periods of abundance***) and decrease when below the norm (***periods of shortage***). In effect, as can be verified easily:

$$k_i - 1 < 0 \quad \text{for} \quad x_i < \overline{x}, \quad k_i - 1 > 0 \quad \text{for} \quad x_i > \overline{x}, \quad \text{and} \quad k_i - 1 \approx 0 \quad \text{for} \quad x_i \approx \overline{x}.$$

If for a given time, the points of the IDC lay on a horizontal line, it means, over that interval, the series are closed to a mean value (***periods of normality***). The maxima and minima of the IDC correspond to points where $(k_i - 1)$ is equal to zero. The maxima correspond to the change of the parameter from abundance periods to periods of shortage and the minima to the reverse (Fig. 1).

2. The IDC characterizes the present cycles in a process even when the length of the series of available records is less than the length of the corresponding decadal cycle. In this study we define the decadal cycle as the fluctuation of runoff of more than one decade of length either from maximum to maximum or minimum to minimum. The IDC will show that part of the cycle corresponding to the length of observation period, identifying part of the cyclical structure. It will not be possible under these conditions to determine the duration of the complete cycle (Fig. 2).

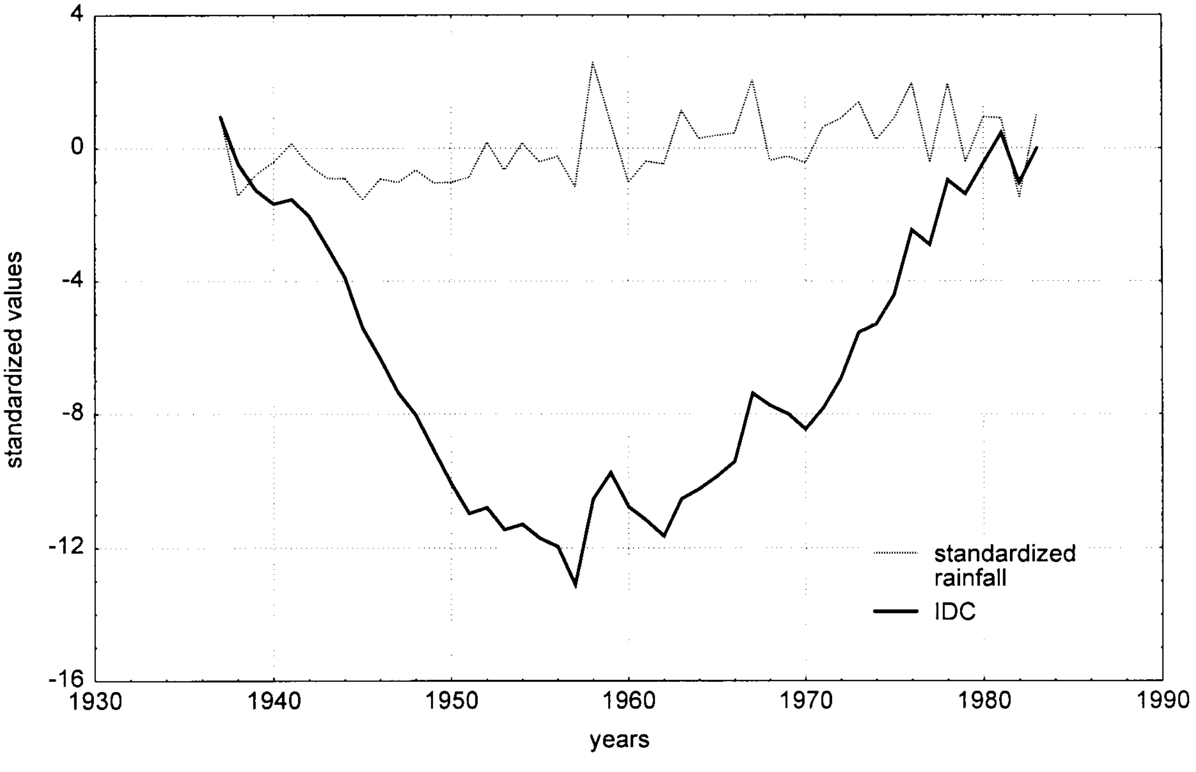


Fig. 2. Example of identification of an incomplete historical cycle in a series of snort duration.

3. If the series has a period of sufficient length, the historical cycles can be distinguished, using values with different resolutions over time. The resolution of the data will only affect the smoothing of short-term fluctuations (Fig. 3).

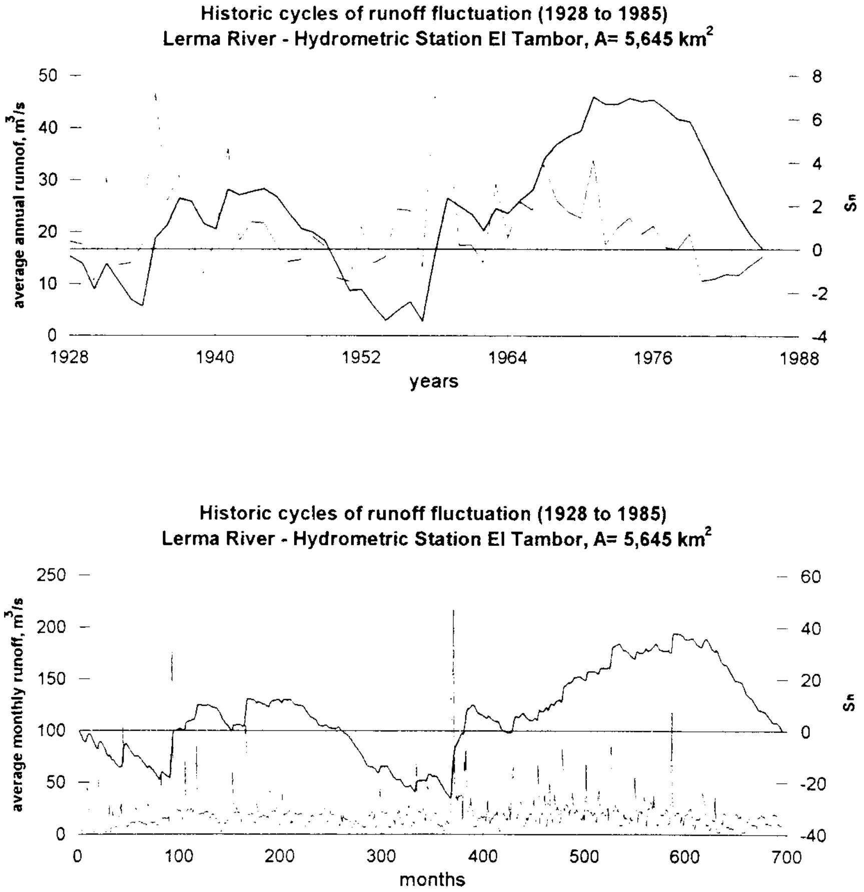


Fig. 3. Example of identification of a cycle in series with two different time resolutions: monthly and annual values.

4. The last ordinate of the IDC (1), i.e. for $n = N$, will always be equal zero. In effect, equation (1) for $n = N$ is:

$$\sum_{i=1}^{N}(k_i - 1) = \frac{\sum\limits_{i=1}^{N}(x_i - \bar{x})}{\bar{x}} = \frac{\sum\limits_{i=1}^{N} x_i}{\bar{x}} - \frac{\sum\limits_{i=1}^{N}}{\bar{x}} = \frac{n\bar{x}}{\bar{x}} - \frac{n\bar{x}}{\bar{x}} \equiv 0 \tag{3}$$

The homogeneity curve is similarly defined to the integrated differences curve.

b) The homogeneity curve

The homogeneity curve was used by V. E. Vodogretski (1990) to determine the existence or absence of historic alterations in the runoff. This curve, as such of integral anomalies, is also a sum and is defined as:

$$R_n = \sum_{i=1}^{n}(K_i) \tag{4}$$

The curve R_n allows determination of meaningful anomalies in the runoff by sharping changes of its slope at given points, called ***break points***.

3. Materials and methods

Study zone. The study zone is the hydrological Lerma-Chapala-Santiago System. This watershed is between 19°04' and 23°25' N latitude, and 99°19' and 105°29' W longitude (Fig. 4). The altitude of the basin varies from 3,500 m over sea level in the highlands to 0 m in the mouth. The Lerma - Santiago river has a length of 1,163 km. Its watershed has an area of 125,400 km^2. It is the second largest basin of Mexico, with large agricultural production and great hydraulic potential (SARH, 1960 - 1961). The annual rainfall varies from 1400 mm in the low portions to less than 400 mm in the high elevations of the basin. The average annual rainfall is 900 to 1000 mm. In according to the climate classification of Thornthwaite, there are 14 different types of climates in the watershed, from arid in the high elevations to the wet low portions, and semidry in the transition zone of the runoff.

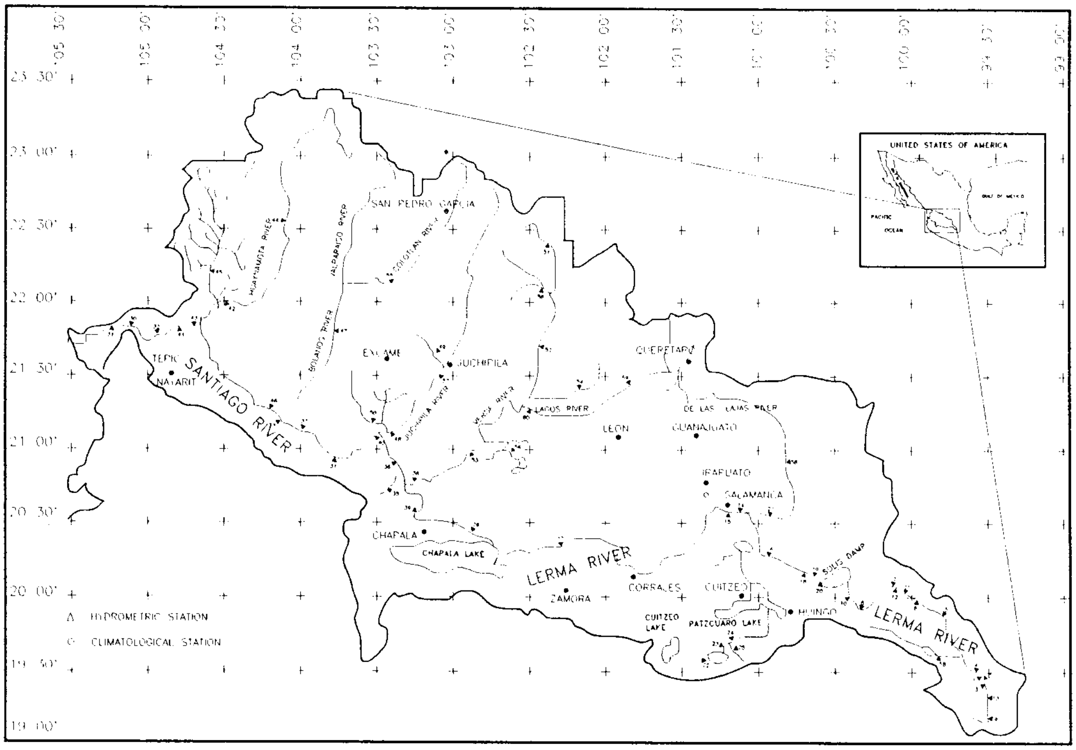


Fig. 4. The zone of study.

The data. We used series of mean annual runoff of 60 hydrometric and 15 climatological stations in the study zone, with different periods of observation, but covering from 1928 to 1985 interval, corresponding to the observation period of the longest series. The data were obtained from bulletins published by the Ministry of Agriculture and Hydraulic Resources (SARH 1973a, b, c) and from the Federal Electricity Commission (CFE)

Period of calculation and internal homogeneity. Using a method proposed by V. A. Shelutko (1984), the determination of the calculation period is made based on the climatic decadal cycles (CDC) of the series set of greater length than needed for the study. The period of calculation will have to cover the historic cycle, guaranteeing the incorporation of the total variance of the process in the analysis. The series with an observation period less than the calculation period are evened out to the period of calculation by using of regression methods, simple as well as multiple

(Kuznetsov, 1930; Shelutko, 1968; Rozhdestvenski *et al.*, 1990). Before the series were completed for the period of calculation, thus we proceeded to verify the internal homogeneity by using the criteria of Fisher and Student, to the 5% significance level (Kriukov, 1973; Rozshdestvenski and Lobanova, 1984), so nonhomogeneous series were not included in the calculations.

Regionalization. In this work, group of stations in homogeneous areas was done considering the correlation between the series. To form the first homogeneous area, we chose the series of the best correlation with respect to all the others and associated with it stations with correlation coefficients greater than 0.8. Deleting the set of stations of this area, we repeated the same procedure to constitute the second homogeneous area, and so on.

Climatic decadal cycles. Once the homogeneous regions were defined, the series of regional runoff were built and the corresponding IDC calculated. Based on these curves, we identified the regional decadal cycles, whose interpretation was accomplished according to the properties of the IDC described earlier.

Anthropogenic influence. The anthropogenic influence on the currents was studied in the two main streams. We built the homogeneity curve of the runoff series of the stations located along the Lerma River and the Santiago River. The series with important break points were those corresponding to stations of the Lerma River near its outlet in Chapala Lake and to stations near the output of the lake on the Santiago River.

4. Results and discussion

Period of calculation. The calculation period was chosen according to the features of the decadal cycles of the longest series measured that had no omissions. Upon verifying that the period of observation of these series (1928 to 1985) covered, in all the cases, the decadal cycles of the series, we defined it, as the calculation period, because, in this way, we guaranteed the incorporation of all the variability of the series in the subsequent analyses.

Internal homogeneity. For the analyses of internal homogeneity, 32 out of 60 series were found homogeneous, by using the mean value (Student's t-test), and the variance (Fisher hypothesis test). Through the variance test 16 were *nonhomogeneous*, and 8 were by the mean value, and 4 by both. By using the 32 homogeneous series and using simple and multiple regression, we were able to estimate the data omitted and to extend the period of calculation to a total of 51 series. The rest did not show significant correlation ($-0.7 < r < 0.7$).

Regionalization. The group of stations by the level of correlation between the runoff series revealed the existence of three homogeneous regions (Fig. 5). The regions are as follows:

1. "Lerma"- includes the watershed of Lerma River to its outlet at Chapala Lake and the transition zone of the three main tributaries of Santiago River, Bolaños, Juchipila, and Verde Rivers.

2. "Santiago"- includes the main stream of Santiago River and the lower portion of its tributaries Bolaños, Juchipila and Verde Rivers.

3. "Lakes"- includes the closed watershed of Patzcuaro, Cuitzeo, and Yuriria Lakes.

Climatic decadal cycles. The three regions, "Lerma", "Santiago" and "Lakes", show the existence of a main climatic cycle (of several decades duration) on which are superimposed some short-term fluctuations. These fluctuations do not allow precise identification of the inflection points (maxima and minima) nor the duration of the wet and dry runoff periods (Fig. 6).

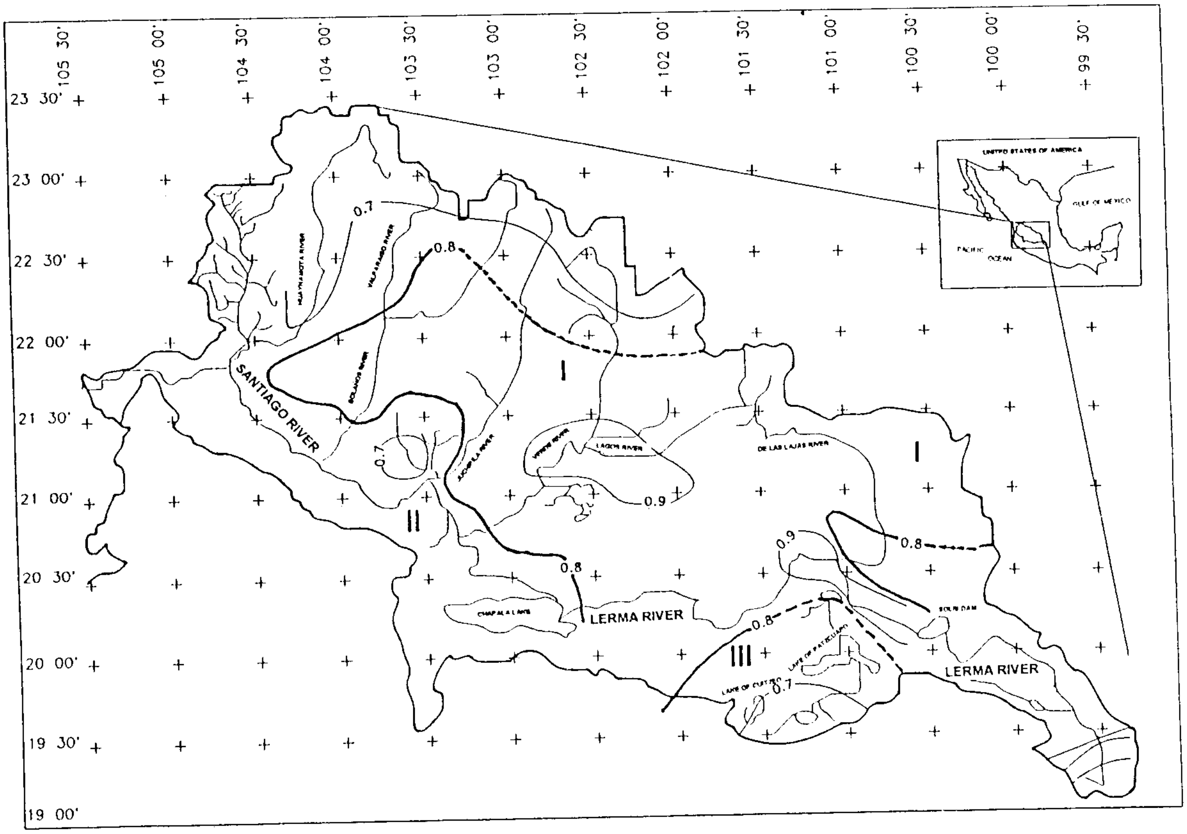
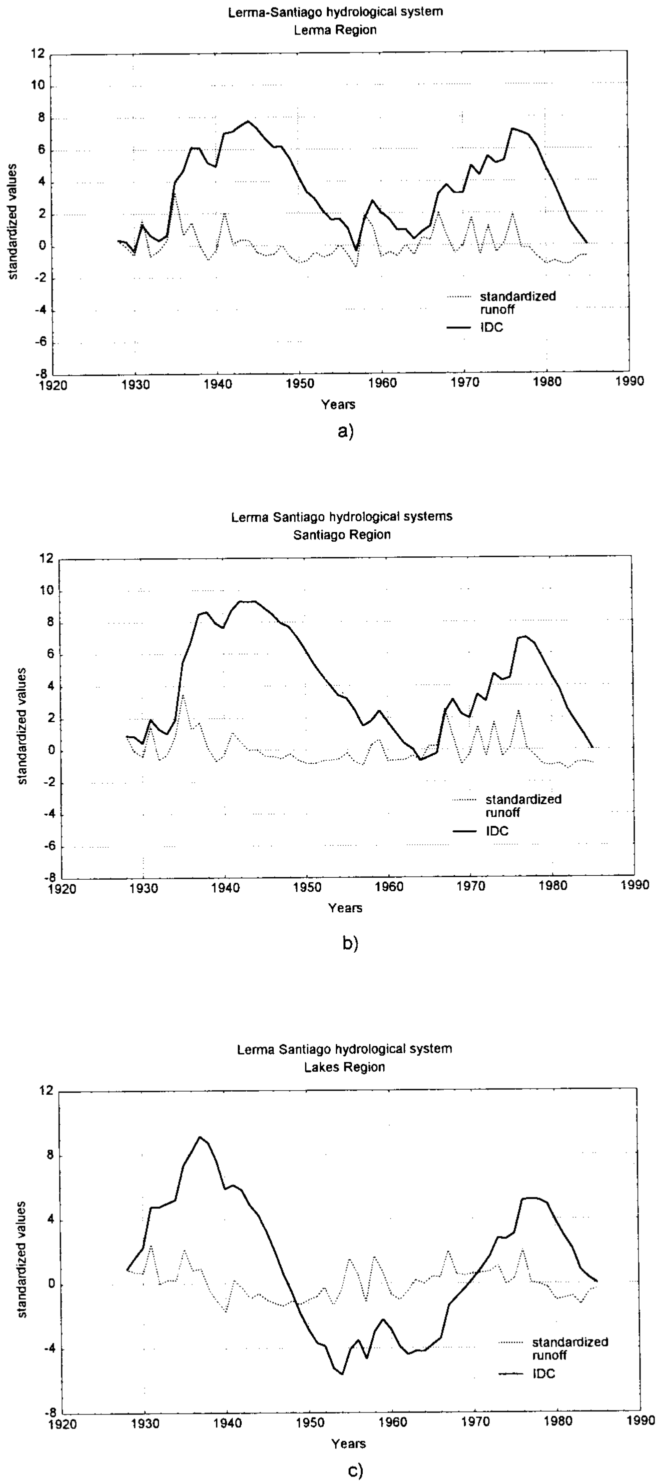


Fig. 5. The homogeneous regions I) Lerma region, II) Santiago region, III) Lakes region.

To specify the inflection points of the decadal cycle more precisely, and with this the duration of its different phases, the series of regional runoffs were smoothed using 9-year running averages. Based on them, we calculated the corresponding IDC (Fig. 7). From these results, the duration of the decadal cycle is 30, 36, and 38 years in "Lerma", "Santiago" and "Lakes". The discrepancy is in the normal periods associated with first maximum of the IDC. In effect, even though in "Lerma" and "Santiago" this period encompasses the same time interval (1941 to 1945), in "Lerma" the normality is almost absolute, whereas in Santiago the slope, though small, has negative values, being formally part of the period of shortage. In the case of the "Lakes" region, the duration is also 4 years (1935 to 1939). However, for this region the slope of the IDC has positive values, being part of the period of abundance of the previous decadal cycle. The most recent maximum can be called a normal period, lasting two years, in "Lerma" and "Santiago" regions, but not in "Lakes", where the transition from abundance to shortage of the next decadal cycle is relatively mild.

Within the complete decadal cycle, the periods of shortage in "Lerma", "Santiago" and "Lakes" are 16, 21, and 14 years, and periods of abundance 14, 15, and 24 years. Forming part of the abundance phases, there are periods of relative normality associated with cycle minimum: 4 years in "Santiago", and 8 years in "Lakes". In "Lerma", there was no proper normal period associated with the minimum.



a)

b)

c)

Fig. 6. Series of regional runoffs time and integrated differences curves: a) The annual runoff and the IDC for the Lerma region, b) The annual runoff and the IDC for the Santiago region, c) The annual runoff and the IDC for the Lakes region.

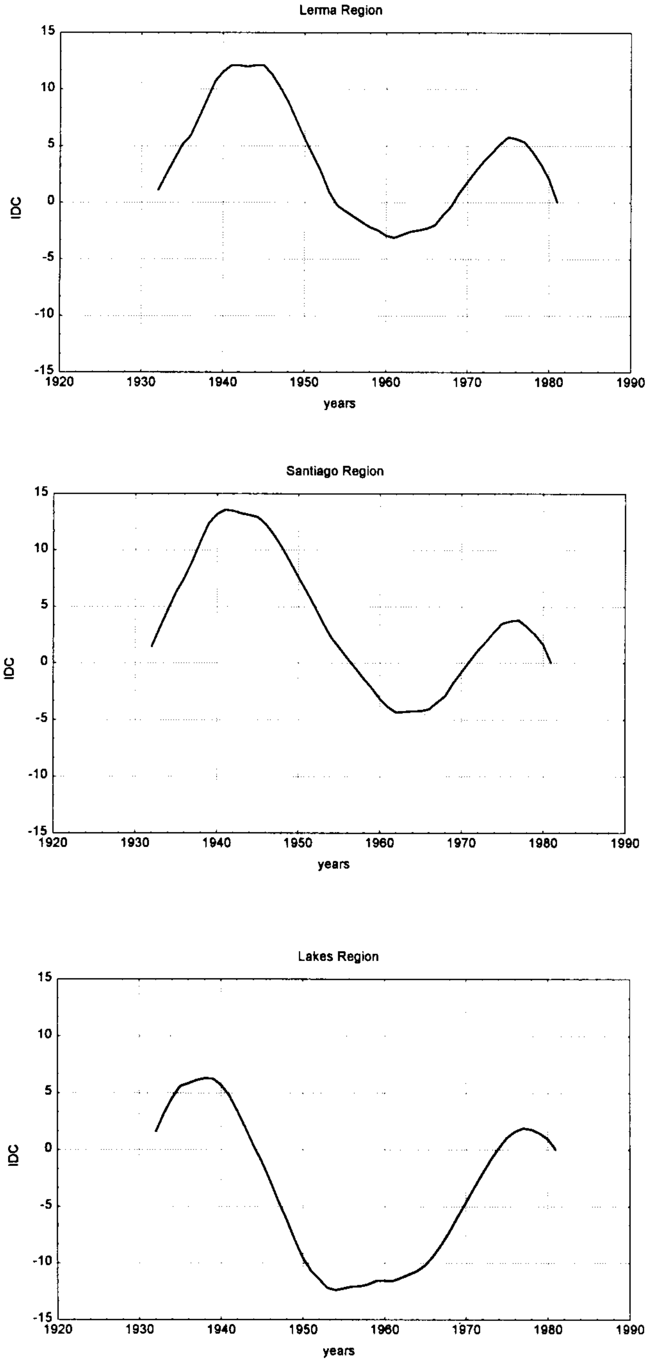


Fig. 7. Just as Fig. 6, for series smoothed by 9-year running averages.

5. Conclusions

Different regions (defined by a correlation matrix) reflect the discrepancies observed in the runoff means of the stations and, the physiographic and climatic features of the study zone. As can be seen in Figure 5, Lerma and Santiago areas correspond to the main stream of the lower hydrological system study, and Lakes area is located in the closed watershed, geographically near to the basin of Lerma River, but independent of it. Without needing statistic tests, the comparison of the mean values of the runoffs of each of the areas, all of different orders of magnitude, justify their separation into independent areas.

The regions, a result of the identification of a historical cycle in the original data and of the subsequent application of traditional technical statistics is in concordance with the physiography and climatology of the general basin. Thus, such regions identified the areas influenced by the two main streams, Santiago and Lerma Rivers, and an internal lacustrine watershed, Patzcuaro, Cuitzeo, and Yuriria, Lakes.

Although the three areas have significantly different average runoff, what justifies their definition as different areas is the character of their fluctuation, which have many similarities and accountable discrepancies. The period of observation covered, from maximum to maximum, a decadal cycle in the three areas.

Thus, with a similar total duration (~35 years), the duration of the shortage, abundance and normality, is different in each case. In the area of the first maximum, there is a normal period of the same duration (4 years) in the three areas, shown simultaneously in Lerma and Santiago (1941 to 1945) and a little earlier (1935 to 1939) in Lakes.

The structure of the climatic decadal cycle has its explanation in the regional climatology. As has been recorded, between 1945 and 1955 there was a high deficit of runoff in all Mexico related to annual rainfall totals below historic normal (Fig. 8). The driest year in all of Mexico was 1945 (Hernández-Unzón and Espinosa-Cruickshank, 1995). In northern Mexico, 1948 to 1954 was a period of critical drought (SEMARNAP, 1996). Although between those two rivers, Lerma and Santiago, there are meaningful discrepancies, a product of the artificial regulation of the incoming waters from Chapala Lake to Santiago River, their short-scale fluctuations are similar. The similarity of the length of the historical cycle of the three areas (~35 years), the simultaneity in the occurrence of the second maximum (1975~1977), and the presence of short-term cycles in the three areas at the same time are arguments to conclude that the three areas continue being part of the same hydrological system, and that the respective runoffs answer to the natural regulation of the corresponding areas, in spite of strong anthropogenic influence in part of them.

It is certain that the hydrological system Lerma - Chapala - Santiago operates as hydrological unit, despite the runoff of this last river from Chapala Lake being controlled from early in the present century (SARH, 1960 - 1961). The natural regulation of the runoff to the long main riverbed Lerma - Santiago modulates this anthropogenic effect and is manifested in the water downstream of Santiago River (Fig. 9). Currently there are meaningful discrepancies between the rivers which is reflected in the similarities of their climatic decadal cycles, though they are mutually bound by the climatic and physiographical conditions of their basins. We can conclude that the homogeneous areas that constitute the hydrological system under study, though different, form part of a single hydrological unit and that can explain the general behavior of this unit.

An important conclusion is that the structure of the historical cycles permits us to estimate the duration of the periods of normality, shortage, and abundance of the regional throughputs, which can be used for the decision making in the planning and management of the use of the regional hydraulic resources.

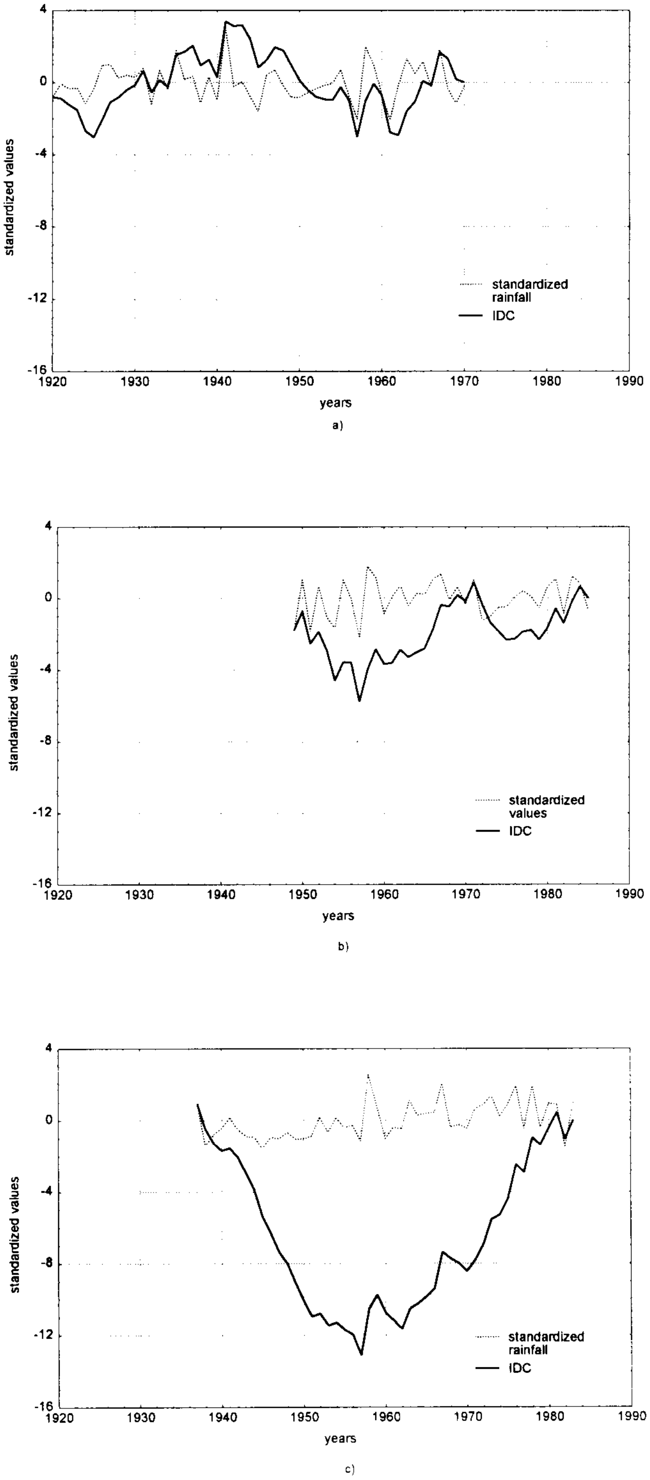


Fig. 8. The integrated differences curves for 3 series of representative rainfall. a) Station Irapuato-Guanajuato (Lerma region), b) Station Tepic-Nayarit (Santiago region), c) Station Cuitzeo-Michoacán (Lakes region).

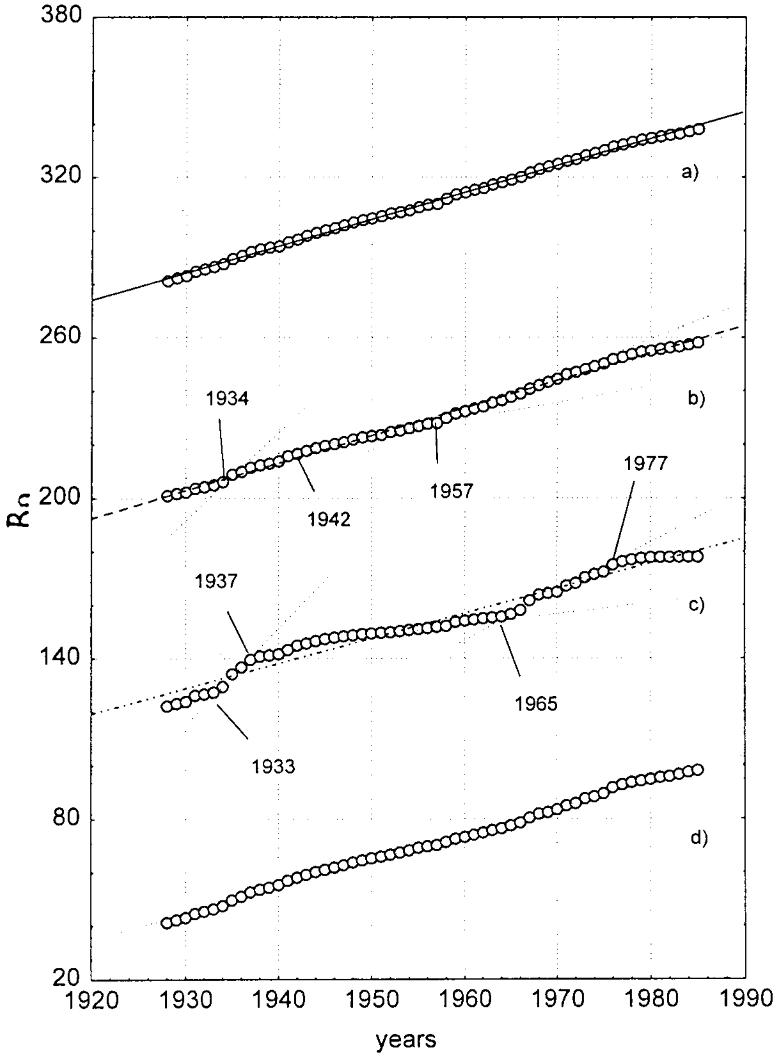


Fig. 9. The homogeneity curves for 4 representative runoffs. a) San Bernabé st. (Río Lerma), b) Yurécuaro st. (Río Lerma), c) Corona st (Río Santiago), d) Despeñaderos st (Río Santiago).

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REFERENCES

Aguado, E., D. Cayan, L. Riddle, and M. Ross, 1992. Climatic fluctuations and the timing of west coast streamflow. *Journal of climate*, Vol. 5, pp. 1468-1483.

Arnell, N., B. Bates, H. Lang, J. J. Magnuson, P. Muholland, 1996. Hydrology and Freshwater Ecology. In: *Climate Change* 1995: Impacts, Adaptations and Mitigation of Climate Change: Scientific-technical Analyses. Contribution of Working Group II to the Second Assessment Report of the Intergovernmental Panel on Climate Change. Watson, R. T., M. C. Zinyowera, R. H. Moss, and D. J. Dokken (Eds.). Cambridge University Press, pp. 327-355.

Barnett, T., N. Graham, M. Cane, S. Zebiak, S. Dolan, J. O'Brien, D. Legler, 1988. On the prediction of the El Niño of 1986-1987. *Science*, Vol. **24-I**, 8 July 1988, pp. 192-196

Dracup, J. A. and E. Kahya, 1994. The relationships betwen U. S. streamflow and La Niña events. *Water Resources Research*, **30**(7), 2133-2141.

Daniel, S. Wilks, 1995. Statistical methods in the atmospheric sciences: an introduction. Academic Press, Inc., pp. 41-43, 81.

Ely, L. L., and D. R. Cayan, 1994. Anomalous North Pacific atmospheric circulation and large winter floods in the southwestern United States. *Journal of Climate*, **7**, 977-987.

Gutnichenko, V. G., 1979. Isliedovanie dinamiko-statisticheskiye zakonomiernostei v riadaj srednego godovogo stoka Dynamic statistical periodicity in annual runoff series. Ph. D. thesis, Leningrad Hydrometeorologic Institute, Leningrad, Russia. 233 pp. (In Russian).

Hernández-Unzón, A., and J. Espinosa-Cruickshank, 1995. La precipitación en la República Mexicana. *Tlaloc*, Organo informativo de la Asociación Mexicana de Hidráulica. Año II, núm. 5, pp. 6-11

John, D. M., 1986. The inland waters of tropical West Africa. An introduction to and botanical review. *Arch. Hydrobiology*, **23**, 1-244.

Kriukov, V. F., 1973. Statisticheskiye kriteri proverki odnorodnosti dvuj riadov (Statistical criteria for testing the homogeneity of two series). Papers of the State Hydrologic Institute, N. 196, pp. 97-123. (In Russian).

Kuznetsov, V. C., 1930. Matematicheskiye osnovi udlinienia korotkij riadov navliudenii k raschiotnomu periodu (Mathematical principles of lengthening short time series to the period of calculation). Papers of the Main Geophysical Observatory, N. 2. (In Russian).

Lluch-Belda, D., S. Hernández-Vázquez, D. B. Lluch-Cota, C. A. Salinas-Zavala, F. de Lachica, and F. Magallon, 1991. Variación climática y oceanográfica global y alguno de sus efectos en el Noroeste Mexicano. *Ciencia y Desarrollo*, Vol. **XVII**, num. 98, mayo-junio 1991, pag. 79-88. (In Spanish).

Mechoso, C. R. and G. P. Iribarren, 1992. Streamflow in southeastern South America and the Southern Oscillation. *Journal of Climate*, 5, pp 1535-1539.

Mark, A., E. Stephen, S. Dolan, 1986. Experimental forecast of El Niño. *Nature*, vol. **321**, pp. 827-832.

Pérez-Peraza, J., A. Leyva, M. Valdés-Barron, I. Libin, K. Yudakhin, A. Jaani, 1996. Influence of solar activity on hydrological processes: spectral and autoregressive analysis of solar activity and levels of lakes Patscuaro and Tchudskoye. Instituto de Geofísica, UNAM, Reportes Internos, V. 95, No. 3.

Poveda, G., O. J. Mesa, 1996. Las fases extremas del fenómeno ENSO (El Niño y La Niña) y su influencia sobre la hidrología de Colombia. *Rev. de Ing. Hidráulica en México,* vol. **XI**, N 1, pp. 21-37.

Rajagopalan, B., U. Lall, M. A. Cane, 1997. Anomalous ENSO Occurrences: An alternate view. *Journal of Climate*, vol **10**, pp 2351-2357

Redmond, K. T. and R. W. Koch, 1991. Surface climate and streamflow variability in the western United States and their relation to large-scale circulation indices. *Water Resources Research*, **27**(9), 2381-2399.

Reyes, S. and A. Mejia-Trejo, 1991. Tropical perturbations in the eastern pacific and the precipitation field over north-western Mexico in relation to the ENSO phenomenon. *International Journal of Climatology*, vol. **11**, pp 515-528.

Rothschild, B. J., 1995. Fishstock fluctuations as indicators of multidecadal fluctuations in the biological productivity of the ocean. p. 201-209. In R.J. Beamish Climate change and northern fish populations. *Can. Spec. Publ. Fish. Aquat. Sci.* 121.

Rozshdestvenski, A. V. and A. G. Lobanova (Eds.). 1984. Posobie po opredeleniu raschitnij guidrologicheskij kharakteristik (Handbook of calculations of hydrologic characteristics). Lenigrad, Guidrometeoizdat Publishing House. 448 pp. (In Russian).

Rozhdestvenski, A. V., A. V. Ezhov, A. V. Sakhariuk, 1990. Otsenka tochnosti guidrologuicheskij raschiotov (Evaluation of the accuracy of the hydrologic computations). Leningrad, Guidrometeoizdat Publishing House. 278 pp. (In Russian).

Sakhariuk, A. V., 1981. Otsenka statsionarnosti mnogolietnego kolebania riechnogo stoka (Evaluation of stationary long-term runoff fluctuations). Papers of the Hydrologic State Institute (HSI), N. 282, pp. 78-87. (In Russian).

Saravanan, R., and J. C. McWilliams, 1997. Stochasticity and Spatial Resonance in Interdecadal Climate Fluctuations. *Journal of Climate*, vol. **10**, pp. 2299-2320.

SARH, 1973a. Descripción de la región hidrológica no. 12. Parcial: cuenca del Lerma River desde su nacimiento hasta la presa Solís. Boletín hidrológico no. 50. Subsecretaría de Planeación. Dirección General de Estudios. Dirección de hidrología. (In Spanish).

SARH, 1973b. Descripción de la región hidrológica no. 12. Parcial: cuenca del Lerma River desde la presa Solís hasta su desembocadura en el lago de Chapala. Boletín hidrológico no. 51. Subsecretaría de Planeación. Dirección General de Estudios. Dirección de hidrología. (In Spanish).

SARH, 1973c. Descripción de la región hidrológica no. 12. Parcial: zona del Santiago River desde la cortina de Poncitlán hasta su desembocadura en el Océano Pacífico. Boletín hidrológico no. 52. Subsecretaría de Planeación. Dirección General de Estudios. Dirección de hidrología. (in Spanish).

SARH, 1960-1961. Atlas general de la cuenca Lerma-Chapala-Santiago. Comisión Lerma-Chapala-Santiago. 29 láminas. (In Spanish)

SEMARNAP, 1996. Programa Hidráulico 1995-2000. Poder Ejecutivo Federal, 55 pp. (In Spanish).

Shelutko, V. A., 1989. Statisticheskiye modeli y metodi issledovania mnogoletnij kolebani riechnogo stoka (Statistical models and methods of study of long-term runoff fluctuation). Art. of 5th Hydrological National Congress. Leningrad, Guidrometeoizdat Publishing House. Vol. VI, 9 pp. (In Russian).

Shelutko, V. A., 1984. Statisticheskiye modeli y metodi issledovania mnogoletnij kolebani riechnogo stoka (Statistical models and methods of study of long-term runoff fluctuation). Leningrad, Guidrometeoizdat Publishing House. 160 pp. (In Russian).

Shelutko, V. A., 1983. Tekhnika statisticheskij vuichislenie v guidrologui (Statistical methods in hydrology). Leningrad, Leningrad Politechnical Institute Publishing House, 153 pp. (In Russian).

Shelutko, V. A., 1981. Vtorichniye korrelatsionniye y vtorichniye spektrralniye funktsii v primenenii k otsenke strukturi kolebanii sriednogo godobogo stoka (Secondary spectral and secondary correlation functions and their application in assessing the structure of mean annual runoff fluctuation). Leningrad, Leningrad Politechnical Institute Publishing House, N 74, 11 pp. (In Russian).

Shelutko, V. A., 1980. Sovremenniye matematicheskiye modeli mnogoletnikh kolebanii stoka (State-of-the-art mathematical models of long term runoff fluctuation). Moscow State University Publishing House , 16pp. (In Russian).

Shelutko, V. A., 1973, Niekotoriye periodmcheskiye zakoni kolebania mnogolietniego stoka riek SSSR (Some periodic regularities of the USSR rivers long-term runoff fluctuations). Papers of the Hydrological State Institute, N. 196, pp. 228-243. (In Russian).

Shelutko, V. A., 1968. Providenie stoka k rashiotnomu periodu s uchiotom vnutrenei korreliatsionoi sviazi (Lengthening of the runoff series to the period of calculation taking into account the internal correlation). Papers of the Leningrad Hydrometeorological Institute, N. 30, pp. 26-48. (In Russian).

Shelutko, V. A., and V. G. Gutnichenko, 1993. GIDSTAT v. 1.0 Guidrologuicheskaja Statistica. (Software applied to hydrological calculations). Russian State Hydrometeorological Institute, St. Petersburg, Russia.

Simpson, H. J., M. A. Cane, A. L. Herczeg, S. E. Zebiak, and J. H. Simpson, 1993. Annual river discharge in southeastern Australia related to El Niño Southern Oscillation forecasts of sea surface temperatures. *Water Resources Research,* **29**(11), 3671- 3680.

Vladímirov, A. M., 1990. Guidrometeoro-loguícheskiye raschioti (Hydrometeorological calculations). Leningrad, Gidrometeoizdat Publishing House, 366 pp. (In Russian).

Vodogretski, V. E., 1990. Antropogueniye izminienia oviomov richnij vod (Anthropogenic changes of runoff volumes). Leningrad, Gidrometeoizdat Publishign House, 176 pp. (In Russian).

Zehnder, J. A., 1989. Orographically induced tropical cyclones in the eastern North Pacific, IV Mexican Meteorological Congress, Chihuahua, 4-6 October, OMMAC, Mexico, 262 pp. 23