ESTIMATION OF TIGRIS-EUPHRATES STREAMFLOW FROM REGIONAL PALEOENVIRONMENTAL PROXY DATA

PAUL A. KAY
Department of Geography, University of Utah, Salt Lake City, UT 84112, U.S.A.
and
DOUGLAS L. JOHNSON
Graduate School of Geography, Clark University, Worcester, MA 01610, U.S.A.

Abstract. A six thousand year history of streamflow in Mesopotamia is derived from a synthesis of regional paleoenvironmental proxy data. The proxy data are interpreted with consideration to the climatic signals represented in the records and to the temporal resolution of the records. A consideration of modern synoptic climatology suggests the spatial patterns of streamflow-generating precipitation in relation to atmospheric circulation. These patterns provide a framework for the interpretation of streamflow from the regional proxies. Given the nature of the data at hand, only a low frequency signal is reconstructed. Assessment of the role of small scale climatic fluctuations as a forcing function of population dynamics must await the availability of finer resolution environmental data.

1. Introduction

A frequently invoked paradigm of physical geography holds that climate is the major control of the nature and distribution of biomes. In the early twentieth century, the extension of the paradigm to human geography was popularized by Huntington (1924) and others. Recent decades have seen a swing towards complete rejection of such deterministic mechanisms of societal change. Yet it is clear that societies do display some adjustments to the earth's various climates. As societies become ever more interdependent and reliant on diminishing resources, adjustments to fluctuation of climate away from the expected become more critical. Instructive analogs to current questions regarding societal responses may be found from a concurrent study of climate and history (*e.g.*, Bowden *et al.*, 1980; Rotberg and Rabb, 1980).

In most instances, the historic period of interest considerably predates available meteorological records. It is then necessary to use paleoenvironmental proxy data to reconstruct a climate chronology (see Lamb, 1977, for a review of proxy data). The use of proxy data demands particular care. If several types of data are considered, the climatic signal represented in each must be known if the best interpretation is to result. Often, however, the signals are inappropriately specified. Several questions of time must be considered. What is the response time of proxy system to climate control? What are the frequency domains of the reconstructed records, given the sampling design? If the study is areally confined but the proxy data are drawn from a wide region, the spatial homogeneity of climate elements must be determined to allow proper interpretations applicable to the study.

Climatic Change 3 (1981) 251–263. 0165–0009/81/0033–0251$01.30.

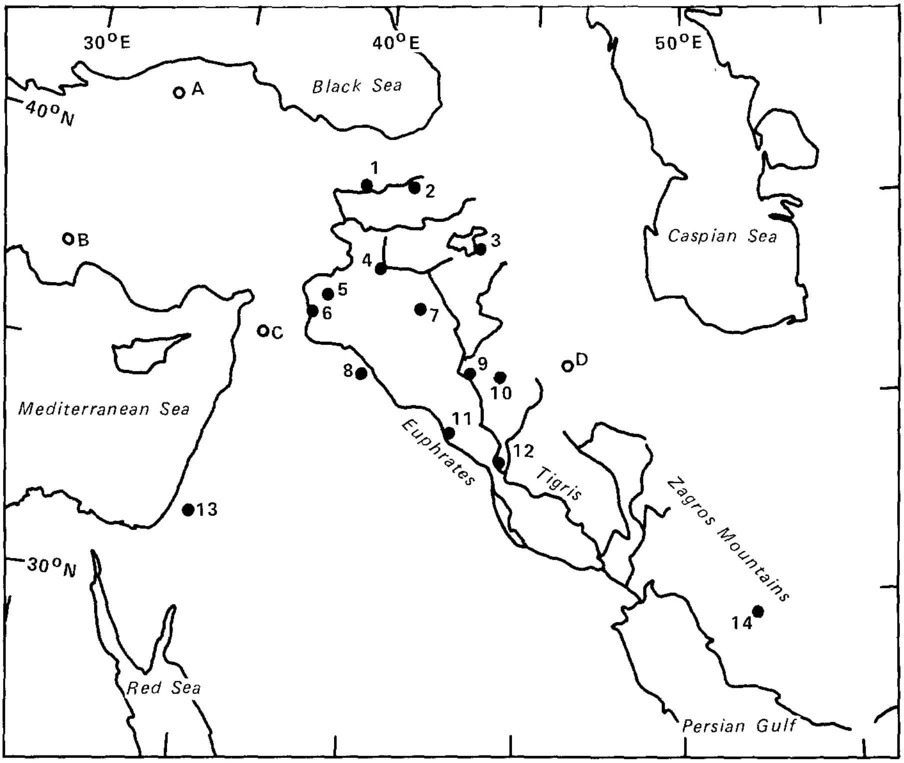

Fig. 1. Location map, Mesopotamia and surrounding region. Solid circles, climate and streamflow stations: 1. Erzincan, 2. Erzurum, 3. Van, 4. Diyarbakir, 5. Urfa, 6. Birecik, 7. Qamlichye, 8. Deir ez Zor, 9. Mosul, 10. Kirkuk, 11. Hit, 12. Bagdad, 13. Jerusalem, 14. Shiraz. Open circles, pollen sites: A. Yenicaga, B. Sogut, C. Ghab, D. Zeribar.

We illustrate some of the foregoing concerns in a study of the Tigris-Euphrates culture region. Mesopotamia (Figure 1) provides an interesting test case because of its record of population dynamics for nearly six millennia. Textual, archaeological, and historical research provide data on population change, rise and fall of political entities, warfare and invasions, and technological developments (Adams, 1965; 1978, personal communication). To what extent can this record of population dynamics be related to climatic fluctuations? To answer this question, we need an equally long history of environmental dynamics. The Tigris-Euphrates lowlands, however, do not provide a long written record of climatic or hydrologic data. Neumann and Sigrist (1979) suggested that barley harvest records contain some paleoclimatic information, but they provide only two examples of data reduction. Some paleohydrologic data may be extracted from texts now being analysed, but the results apparently will not soon be available (Adams, 1979, personal communication).

Paleoenvironmental proxy data, then, are currently the major sources of information on climate change in Mesopotamia. The data, as Butzer has noted in several recent reviews (1971, 1975), are fragmentary and of variable quality. We here go beyond Butzer's regional synthesis, identifying streamflow as a climate-related variable critical to Mesopotamian society, and reconstructing the history of streamflow in the past 6000 yrs. A study of modern synoptic climatology patterns provides the framework within which the data are correlated and interpreted.

1.1. The Reconstructed Variable

Agriculture in the Tigris-Euphrates lowlands is subjected to many environmental stresses throughout the year (Clawson *et al.,* 1971). The primary crop season extends from November (germination) to April-June (harvest). The crop is subject to possible winter frosts, moisture stresses generated by hot, dry winds in mid- to late-winter, inadequate water supplies during the growing season, and/or flooding at harvest time. A second crop, restricted to the banks of the rivers and major irrigation canals, grows and is harvested in the low flow season. Irrigation has long been essential in this semi-arid region. Peak mean monthly streamflow was therefore selected as an appropriate variable to model.

Peak flow on the Tigris and Euphrates occurs in April or May, and thus is important both for the harvest of the first, main crop, and for the success of the second crop. While it is difficult to imagine any one flow event, large or small, affecting significant societal change, there well may be cumulative effects. Frequent large peak flows may damage dwellings, field, crops, and irrigation works, thus leading to societal adjustments. Frequent small peak flows may lead to low agricultural productivity, with concomitant societal adjustments. Generally equitable peak flows may be concomitant with societal stability, at least with respect to environment as a forcing function.

2. Modern Climate

We begin by assessing the relationship of streamflow in the Tigris-Euphrates lowland to precipitation over the basin. We then consider the relationship of critical precipitation to atmospheric circulation patterns.

Streamflow data for nine stations in the Tigris and Euphrates system are available as mean monthly flow in cubic meters per second, for various periods from the 1920's to the 1960's (Clawson *et al.,* 1971). The lengths of precipitation records and the completeness of data are highly variable, limiting the choice of stations (Smithsonian Institution, 1947; U.S. Department of Commerce, 1959, 1961 et seq., 1966, 1967). Complete, or nearly so, records from 1952-1974 are available for Erzurum, Erzincan, Urfa, and Diyarbakir, Turkey, for Qamichliye and Deir ez Zor, Syria, and for Kurkuk, Iraq; data for Erzurum and Diyabakir begin in 1929, and for Kurkuk in 1940. Heights of the 700-mbar surface, on a ten degree latitude and longitude grid, are taken from mean monthly maps in *Monthly Weather Review* (U.S. Department of Commerce, 1952-1973). The different periods of records necessitated various combinations of data sets in the several analyses.

2.1. Relation of Streamflow to Precipitation

The Tigris-Euphrates basin experiences a Mediterranean climate regime, with wet winters and dry summers. The seasonal contrast is especially marked in the lowlands. The rivers and their tributaries head in the mountains of eastern Turkey and the Kurdistan region of Iraq and Iran. We may expect, therefore, that winter precipitation in the mountains will be the major determinant of streamflow through the Mesopotamian culture region (al-Khashab, 1958).

The relationship of streamflow to precipitation in the mountains is modeled by regression of mean May discharge (as a surrogate for peak flow) of the Euphrates at Hit on mean monthly precipitation in the twelve months preceeding and including May at Erzurum, for 1939-1964. Erzurum here serves as a surrogate for precipitation in the headwaters region. The values of the regression coefficients are plotted as a response function (Figure 2). Error bars, derived from the standard error of estimate, indicate the 95% confidence

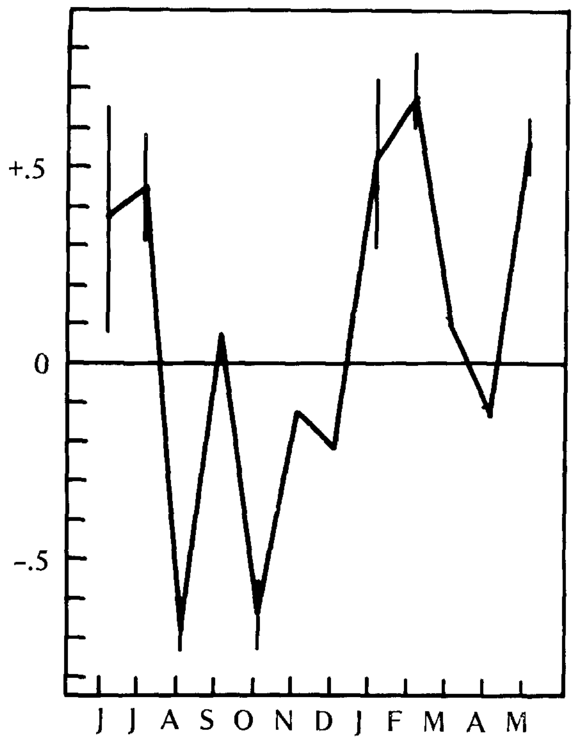

Fig. 2. Response function, May discharge of Euphrates at Hit, Iraq, with monthly precipitation at Erzurum, Turkey. Vertical bars (95% confidence intervals) displayed for significant relationships only.

interval for those coefficients significantly different from zero. The relationship is complicated in that the Euphrates is regulated by dams and reservoirs, but the reported streamflows are not adjusted to account for withdrawals. Thus, the negative response to August and October precipitation may reflect times of reservoir depletions greater than precipitation recharge. The largest significant positive correlations are with January and February precipitation, confirming the key role of winter precipitation in the headwaters for streamflow through Mesopotamia. Maximum mean monthly streamflow of the

Euphrates at Hit correlates well ($r = 0.74$, significant at 0.05 level) with winter (December to February) areal precipitation in the headwaters (for 1952-1964). Areal precipitation is the sum of areally-weighted precipitations at Erzurum, Erzincan, Urfa, Diyarbakir, Qamlichliye, Deir ez Zor, and Kirkuk.

The seasonal flow regime of the Tigris in the Mesopotamian lowlands is similar to that of the Euphrates (Clawson *et al.*, 1971, Figure 3.5). Both annual average and peak monthly flows from the Turkish headwaters of both rivers correlate positively ($r = 0.61$, significant at 0.05, for 1937-1951), indicating regional homogeneity in this source region of wet and dry years. Annual average flows in the two rivers in the lowlands are not significantly correlated, as the Tigris rises in two major source regions. The Turkish headwaters provide nearly 90% of the flow in the Euphrates at Hit, but only about 40% of the flow in the Tigris below the Diyalah junction. Some 45% of the Tigris flow originates in Kurdistan, south of Turkey.

The correlations of winter precipitations among the seven stations suggest a northern group (Diyabakir, Erzincan, Erzurum) and a southern group (Deir ez Zor, Kirkuk). Further evidence for an apparent north-south contrast in precipitation climatology is presented in the next section.

2.2. *Synoptic Patterns*

Relating streamflow or precipitation to atmospheric circulation patterns serves two purposes. First, the synoptic patterns which produce wet or dry seasons, or high or low flow, are elucidated. Second, regional teleconnections are made clear, so that the phase relationships between various parts of the region can be determined. The proper interpretation and correlation of proxy data from a large region is dependent on a correct understanding of these phase relationships.

The years for analysis were selected on the basis of regional homogeneity of signs of anomalies for winter precipitation at the seven headwaters stations. A year was classified as wet (dry) if all stations, or at least six, had positive (negative) anomalies from station averages (based on the period 1952-1974). Wet winters were 1952, 1953, 1962, 1963, and 1968; dry winters were 1955, 1959, 1961, 1970, 1971, and 1973. For these eleven 'extreme' years, we constructed correlation fields for winter precipitations with winter average 700-mbar heights (cf. Stidd, 1954).

For areal precipitation in the headwaters, a negative anomaly is centered over Greece (Figure 3a), suggesting that anomalously wet winters occur when cyclonic flow draws storm activity from the eastern Mediterranean across eastern Anatolia towards the Caspian Sea. For precipitation at Van, the center of negative correlation is shifted eastward to the eastern Black Sea (Figure 3b), suggesting a somewhat more northerly storm track than in Figure 3a. These patterns are consistent with the storm tracks across the Black Sea, and parallel to and south of Turkey's southern border, shown by al-Shalash (1966, Figure 7). These patterns suggest that the central Turkey and northeastern Iraq source regions may not always experience in-phase wet and dry anomalies. Erinç (1950), for example, illustrated interannual spatial variability of precipitation in Turkey.

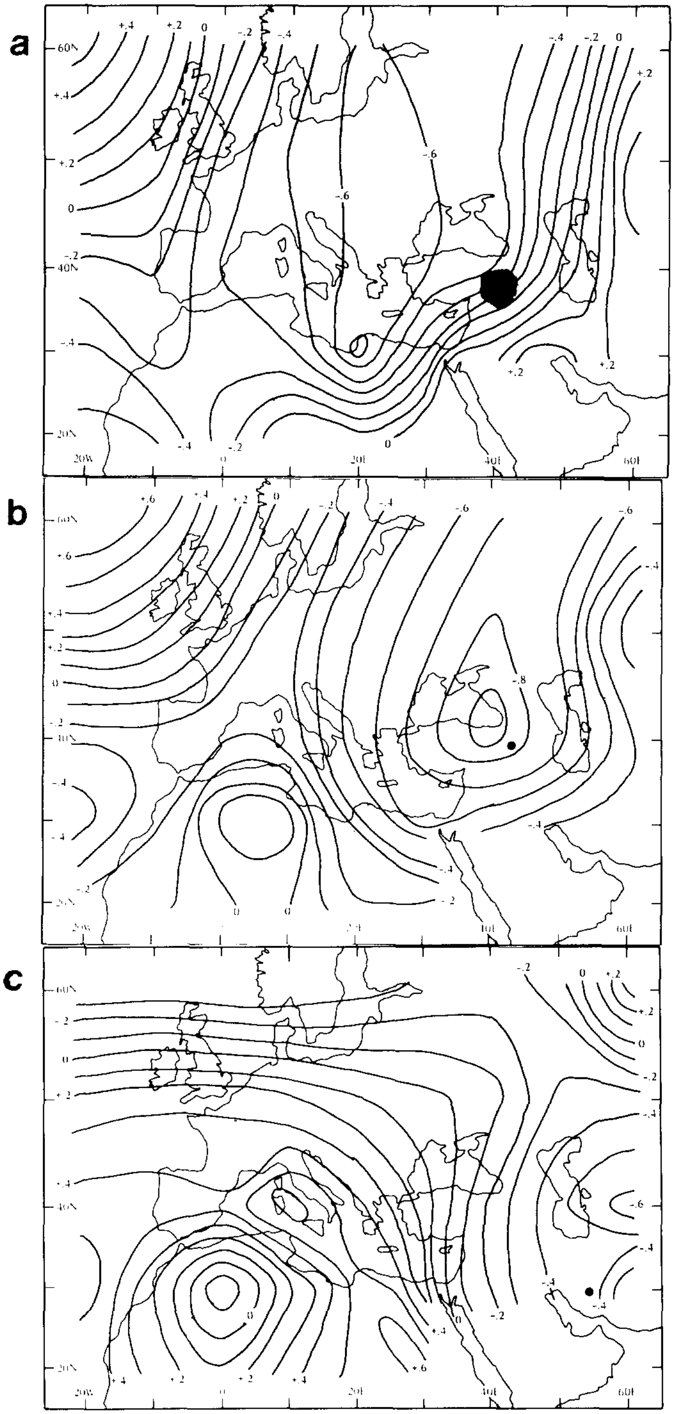

Fig. 3(a). Correlation field, winter headwaters precipitation with winter 700-mbar heights. Direction of anomalous flow is counter-clockwise about negative centers, clockwise about positive centers. (b) Correlation field, winter precipitation at Van, Turkey, with winter 700-mbar heights. (c) Correlation field, winter precipitation at Shiraz, Iran, with winter 700-mbar heights.

The correlation field analyses also suggest that anomalously large streamflow through Mesopotamia need not be related to high precipitation over Mesopotamia. The southern Zagros Mountains of Iran would similarly be out-of-phase with Anatolia. The correlation field of winter precipitation at Shiraz, Iran, with the 700-mbar height field, yields a much different picture than that above (Figure 3c). Wet winters in the southern Zagros seem related to more local flow patterns, perhaps moisture being advected from the Arabian Sea and Persian Gulf.

2.3. Implications

The above analyses suggest spatial variability of precipitation anomalies on several scales. At a large scale, anomalies in the source regions of the Tigris and Euphrates, and hence in streamflow through Mesopotamia, are not in phase with anomalies in Mesopotamia itself and regions to the south. Thus, we may adduce oppositely-signed anomalies in streamflow from proxy evidence from the southern parts of the study region. At a finer scale, anomalies within the source regions may not be in phase. In particular, there may be a contrast between anomalies in Turkish and the northeastern Iraq headwaters. The importance of this relationship in the proxy records will be determined by the temporal resolution of the records. If resolution is on the order of decades or more, it is probable that the source regions will assume the same anomaly sign. At these longer time-scales, the fine pattern of anomalies, related to slight shifts of storm tracks, is lost, with only the patterns related to major circulation adjustments retained.

The importance of storm track positions, which are controlled by the position of the trough in the eastern Mediterranean, is also illustrated by an analysis of temperature-precipitation relationships at Jerusalem (Striem, 1979). There, colder winters tend to be wetter than warmer winters; a southern storm track bringing precipitation activity to the Judean Hills is accompanied by cold front passages, whereas a northern storm track means that Jerusalem is within the warm sectors away from much activity. Thus we may expect that proxy evidence for cool conditions in Anatolia may be added to evidence for wet conditions in the headwaters, as evidence of high streamflows, especially when the temporal resolution is in decades or a century.

3. Paleoenvironmental Proxy Data

We now examine the available paleoenvironmental data, in light of the climatic patterns discussed above. The more useful data are summarized in Figure 4. In all cases, cited dates, whether absolute or inferred, have been converted to calendar years before the present (BP), with 'present' set at 1950 (Suess, 1979).

Nearly every problem concerning the use of proxy data for paleoenvironmental reconstruction arose in this study. Some data were presented without time control. For example, Wilkinson (1978) presented evidence for Holocene erosion in the upper Euphrates, and Erol (1978) reported Holocene lake levels in central Anatolia. Such information was of no value to our effort. Other studies report only poor dating control. Diester-Haass (1973), for example, reported general humidity characteristics for the southern Zagros

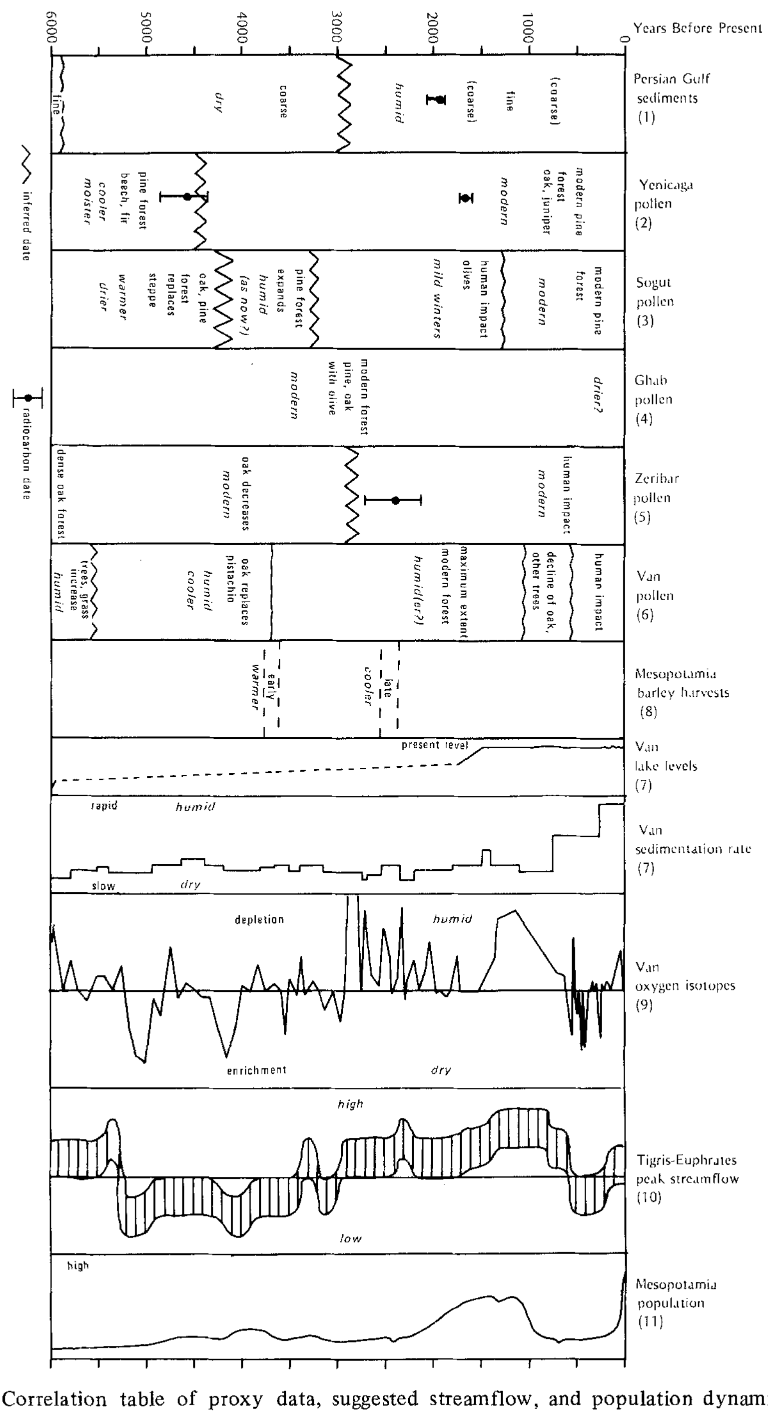

Fig. 4. Correlation table of proxy data, suggested streamflow, and population dynamics. Ages in calendar years before present ('present' = 1950). Sources: (1) Diester-Haass, 1973; (2) van Zeist *et al.*, 1975; (3) Beug, 1967; (4) Niklewski and van Zeist, 1970; (5) van Zeist and Bottema, 1977; (6) van Zeist and Woldring, 1978; (7) Kempe and Degens, 1978; (8) Neumann and Sigrist, 1978; (9) Schoell, 1978; (10) this paper; (11) after Bowden *et al.*, 1980.

Mountains inferred from Persian Gulf sediments, for four episodes which may correlate with northwestern Europe pollen chronology; only two radiocarbon dates were available. Most of the pollen studies (e.g., Beug, 1967; Niklewski and van Zeist, 1970; van Zeist, 1967; van Zeist and Bottema, 1977; van Zeist and Woldring, 1978; van Zeist *et al.,* 1968/69, 1975) relied on only one or two radiocarbon assays. Associated with the poor dating control, the temporal resolution in most studies was very coarse, on the scale of centuries and even millenia. Thus we could derive only generalized characteristics.

There were examples of inferences made across space inappropriately. Nutzel (1976), for example, read the results of Diester-Haass (1973) as indicative of a Mesopotamian moisture index. In addition to the separation of the source regions in the southern Zagros and in Anatolia, this reading did not give due regard to the synoptic patterns as delineated above.

All studies exhibited to some degree problems associated with interpretation of climatic signal contained in the proxy record. In the pollen records, for example, the distinction between local and regional signals was often unclear. Thicknesses of sediments were often interpreted as directly indicative of humidity (Diester-Haass, 1973; Lamb, 1977, pp. 613-17; Kempe and Degens, 1978). Yet there was some question as to whether thickness might rather indicate extremes in arid periods (Diester-Haass, 1973, p. 221; cf. Lamb, 1977, pp. 613-17). In many cases, too, a climatic signal was confounded or masked by human alteration of environment. For example, rapid delta progradation in western Turkey *c.* 2250-2050 BP might have been as much culturally as climatically forced (Eisma, 1978; Erinç, 1978). Might a similar situation prevail in the Tigris-Euphrates delta (cf. Larsen and Evans, 1978; Vita-Finzi, 1978), or in Lake Van for the past 700 yrs (Figure 4; Kempe and Degens, 1978)? In many pollen diagrams, human impact on vegetation was detectable, such as *c.* 1500 BP at Sogut (van Zeist *et al.*, 1975) and *c.* 600 BP at Zeribar (van Zeist and Bottema, 1977) and at Van (van Zeist and Woldring, 1978).

Given the above considerations, the general regional picture which emerges is as follows. The southern Zagros experienced a change from humid to arid climate *c.* 5900 BP, and remained arid until *c.* 3000 BP. The last 3000 yrs have been humid, with perhaps two brief arid interludes (Diester-Haass, 1973). The Iranian Plateau to the northeast had a somewhat similar history: humid conditions prevailed *c.* 6400-5200 BP, followed by aridity to c. 3100 BP; until *c.* 1300 BP, it was moister than now (Ganji, 1978). In Anatolia, the history of Lake Van levels (Kempe and Degens, 1978) indicated a secular increase in humidity throughout the period considered here, especially rapid just prior to *c.* 6000 BP and again at *c.* 1800-1500 BP. Evidence of glaciation in Turkey at *c.* 5300-4500 BP suggested a cold, perhaps wetter, time (Erinç, 1978). The pollen evidence indicates that the modern vegetation and climate prevailed for the last 6000 yr or more at Ghab (Niklewski and van Zeist, 1970) and Zeribar (van Zeist and Bottema, 1977), south of the headwaters. To the north, modern vegetation and climate developed later, *c.* 3700 BP or later at Van (van Zeist and Woldring, 1978) and at Sogut (van Zeist *et al.,* 1975). The north-south contrast in the pollen results is consistent with the climatic patterns elucidated above. We infer, then, a secular increase in streamflow through Mesopotamia throughout the last 6000 yrs.

Finer resolution interpretations were possible from the results of a multifaceted geological study of Lake Van, which by its proximity to the Tigris and Euphrates headwaters should provide a very good analog. Kempe and Degens (1978) reported a 10,000 years varve record. The variability in varve thickness and in sedimentation rate (see Figure 4) was a signal of spring maximum discharge and therefore of winter and spring precipitation. Schoell (1978) reported oxygen isotope variations, tied to the varve record (see Figure 4). Times of oxygen-18 depletion marked cold-wet climates, when the water balance was positive and lake levels were high. The interpretation was consistent with patterns in the organic carbon and carbon-13 records. We infer that the major features in these studies are indicative of streamflow through Mesopotamia. The fine structure, however, cannot be confidently transferred, given the spatial and temporal variability in the Tigris-Euphrates system discussed above.

Very fine resolution data are generally lacking. Erinç (1978) cites some historical documents pertaining to climate at Istanbul, and one dendroclimatological study covering the past two centuries. The relationship to our study is not clear.

4. Discussion

Our suggested record of streamflow is shown in Figure 4. The general features are consistent with the global synthesis of Lamb *et al.* (1966). The coarse resolution of most proxy records and poor dating control confounds precise correlation. Thus, the streamflow curve is depicted on Figure 4 as a band, rather than a line indicating mean flow, to suggest both the margin of error and the variability in the system.

Adams (1978; 1979, personal communication) suggests that changes in interannual variability of water resources might be a critical factor in Mesopotamian population dynamics. The modern flow records of the Tigris-Euphrates system reveal a large degree of interannual variation in spring flood levels (Clawson *et al.*, 1971). Did interannual variability differ in generally wet times from that in generally dry times? Streamflow in arid and semi-arid environments is typically more variable than is streamflow in humid environments. It is not clear, however, if one can reasonably substitute space for time and make an analogy to episodes in the Tigris-Euphrates system. As a possible answer to the question, we calculated Hurst coefficients (Hurst, 1951; Mandelbrot and Wallis, 1969) from the very long series of flows reconstructed from tree-rings for the Colorado River of the western United States (Stockton, 1975). The Hurst coefficient is a measure of the long-term persistence, or conversely of the interannual variability, in a time series, with h = 0.50 representing randomness of data (no persistence). On the Colorado River, the 17th century was one of generally high flows and had a Hurst coefficient of 0.65, whereas the 19th century experienced generally low flows and had a coefficient of 0.59. Apparently the dry century exhibited greater variability than did the wet century. In contrast, the Nile discharge data in Riehl *et al.* (1979) suggest greater variability in periods of high peak flows than in periods of low peak plows. Similarly, centuries with greater mean thicknesses of varves at Lake Saki (supposedly indicating more humid climate) experienced greater variability than did centuries of thin deposits (Lamb, 1977, pp. 613-17). The 27-yr record of streamflow on the Euphrates at Hit is not sufficient to test the relationship. The width of the streamflow band on Figure 4 therefore does not vary.

The resolution of the streamflow curve is much coarser than that of the cultural record (Figure 4). Comparison of the two curves yields little in the way of consistent relationships. Although growth modes of population appear coincident with episodes of increasing streamflows, the relationship is not firm. The qualitative and general nature of the streamflow curve precludes any quantitative time series analyses in conjunction with the population curve.

Jacobsen and Adams (1958) suggested that Mesopotamia experienced three major episodes of salinization of agriculture lands, approximately 4400 to 3700 BP, 3300 to 2900 BP, and post 800 BP. There is some indication (Figure 4) that these were times of somewhat lower streamflow. Increased irrigation, without adequate drainage, or insufficient irrigation because of a shortage of water, could have promoted the salinization. Jacobsen and Adams (1958) relate at least one episode to raised water tables following the construction of major irrigation canals. The environmental forcing may be to a large extent masked by technological and social factors.

Many possible environmental controls other than streamflow cannot be modeled with the available data. Thus, for example, we have had to neglect the role of early rains in the Mesopotamian lowlands, the differences between aggregated and seasonal streamflows, the effect of increased precipitation in the headwaters on vegetation and runoff, and so on. The determination of the role of these factors will depend upon the procurement of environmental data capable of temporal resolution finer than the century scale. The environmental factor, then, can at this stage be viewed only as one of several contributing factors to population change. Environmental factors may have set the stage for population change, but the coarse resolution of the environmental record precludes any attribution of direct forcing.

5. Conclusion

Although we are disappointed in our failure to derive firm correspondence between climate and population, we are confident that we have elicited several important points for research along these lines. Careful consideration of the climatic signals represented in the various proxy records, including response times and temporal resolutions, is needed to ensure the best interpretation. The study of synoptic climatology provides a framework for assessing the spatial homogeneity of climate variables. Elucidation of the teleconnections ensures appropriate interpretations of data from a large region. In Mesopotamia, the proxy evidence, which would allow a carefully formulated test of societal response to climate fluctuations, is not yet available. The schema presented here is the best possible at this time, but only permits of broad-scale assessment of the inter-relationships.

Acknowledgements

The authors gratefully acknowledge many useful discussions with their colleagues in the Climate and Society Research Group, Center for Technology, Environment, and Development, Clark University. In addition, members of the consultant panel, in particular R. McC. Adams and K.W. Butzer, offered valuable advice in the preparatory stages of the part of the project reported here. The project was in part supported by a National Science Foundation grant ATM 77-15019. The opinions expressed in this paper are those of the authors and do not necessarily reflect the views of the National Science Foundation.

References

Adams, R. McC.: 1965, *Land Behind Baghdad, A History of Settlement on the Diyala Plains,* University of Chicago Press, Chicago.

Adams, R. McC.: 1978, 'Strategies of Maximization, Stability, and Resilience in Mesopotamian Society, Settlement, and Agriculture', *Proceedings, American Philosophical Society* **122**, 329.

Beug, H.-J.: 1967, 'Contributions to the Postglacial Vegetational History of Northern Turkey', In E. J. Cushing and H. E. Wright, Jr., (eds.), *Quaternary Palaeoecology,* Yale University Press, New Haven, pp. 349-56.

Bowden, M. J., Kates, R. W., Kay, P. A., Riebsame, W. E., Warrick, R. A., Johnson, D. L., Gould, H. A., and Weiner, D.: 1981, 'The Effect of Climate Fluctuations on Human Populations: Two Hypotheses', In G. Farmer, M. Ingram and T. L. Wigley, (eds.), *Climate and History,* Cambridge University Press, Cambridge (forthcoming).

Brice, W. C., (ed.): 1978, *The Environmental History of the Near and Middle East Since the Last Ice Age,* Academic Press, New York.

Butzer, K. W.: 1971, *Environment and Archeology,* Second edition, Aldine-Atherton, Chicago.

Butzer, K. W.: 1975, 'Patterns of Environmental Change in the Near East during late Pleistocene and Early Holocene Times', In F. Wendorf and A. E. Marks, (eds.), *Problems in Prehistory: North Africa and the Levant,* Southern Methodist University Press, Dallas.

Clawson, M., Landsberg, H. H., and Alexander, L. T.: 1971, *The Agricultural Potential of the Middle East,* American Elsevier Publishing Co., Inc., New York.

Diester-Haass, L.: 1973, 'Holocene Climate in the Persian Gulf as Deduced from Grain-size and Pteropod Distribution', *Marine Geology* **14**, 207.

Eisma, D.: 1978, 'Stream Deposition and Erosion by the Eastern Shore of the Aegean', In W. C. Brice, **q.v.**, pp. 67-81.

Erinç, S.: 1950, 'Climate Types and the Variation of Moisture Regions in Turkey', *Geographical Review,* **40**, 224.

Erinç, S.: 1978, 'Changes in the Physical Environment in Turkey since the End of the Last Glacial', In W. C., Brice, **q.v.**, pp. 87-110.

Erol, O.: 1978, 'The Quaternary History of the Lake Basins of Central and Southern Anatolia', In W. C. Brice, **q.v.**, pp. 111-39.

Ganji, M. H.: 1978, 'Post-glacial Climatic Changes on the Iranian Plateau', In W. C. Brice, **q.v.**, pp. 149-63.

Huntington, E.: 1924, *Civilization and Climate,* Yale University Press, New Haven.

Hurst, H. E.: 1951, 'Long-term Storage Capacity of Reservoirs', *Transactions, American Society of Civil Engineers,* **116**, 770.

Jacobsen, T., and Adams, R. McC.: 1958, 'Salt and Silt in Mesopotamian Agriculture', *Science* **128,** 1251.

Kempe, S., and Degens, E. T.: 1978, 'Lake Van Varve Record: The past 10,420 years', In E. T. Degens and F. Kurtman, (eds.), *The Geology of Lake Van,* The Mineral Research and Exploration Institute of Turkey, Ankara, pp. 56-63.

al-Khashab, W. H.: 1958, *The Water Budget of the Tigris and Euphrates Basin,* University of Chicago, Department of Geography, Research Paper 54.

Lamb, H. H.: 1977, *Climate: Present, Past and Future, Volume 2. Climatic History and the Future,* Methuen, London.

Lamb, H. H., Lewis, R. P. W., and Woodroffe, A.: 1966, 'Atmospheric Circulation and the Main Climatic Variables between 8000 and 0 B. C.: Meteorological Evidence', In J. S. Sawyer (ed.), *World*

Climate 8000-0 B. C.: Proceedings of an International Conference, Royal Meteorological Society, London, pp. 174-217.

Larsen, C. E., and Evans, G.: 1978, 'The Holocene Geological History of the Tigris-Euphrates-Karun Delta', In W. C. Brice, **q.v.**, pp. 227-44.

Mandelbrot, B., and Wallis, J. R.: 1969, 'Some Long-run Properties of Geophysical Records', Water Resources Research **5**, 321.

Neumann, J., and Sigrist, R. M.: 1978, 'Harvest Dates in Ancient Mesopotamia as Possible Indicators of Climatic Variations', *Climatic Change* **1**, 239.

Niklewski, J., and van Zeist, W.: 1970, 'A Late Quaternary Pollen Diagram from North-Western Syria', *Acta Botanica Neerlandica* **19**, 737.

Nutzel, W.: 1976, 'The Climatic Changes of Mesopotamia and Bordering Areas 14,000 to 2000 B. C.', *Sumer* **32**, 11.

Riehl, H., Al-Bakry, M., and Meitin, J.: 1979, 'Nile River Discharge', *Monthly Weather Review* **107**, 1546.

Rotberg, R. I., and Rabb, T. K. (eds.): 1980, 'Climate and History', *Journal of Interdisciplinary History* **10** (4), 583-858.

Schoell, M.: 1975, 'Oxygen Isotope Analyses on Authigenic Carbonates from Lake Van Sediments and their Possible Bearing on the Climate of the Past 10,000 Years', In E. T. Degens and F. Kurtman, (eds.), *The Geology of Lake Van,* The Mineral Research and Exploration Institute of Turkey, Ankara, pp. 92-97.

al-Shalash, A.: 1966, *The Climate of Iraq*, The Cooperative Printing Presses Workers Society, Amman.

Smithsonian Institution: 1947, *World Weather Records, 1931-1940,* Smithsonian Miscellaneous Collections, Volume 105.

Stidd, C. K.: 1954, 'The Use of Correlation Fields in Relating Precipitation to Circulation', *Journal of Meteorology* **11**, 202.

Stockton, C. W.: 1975, *Long-Term Streamflow Records Reconstructed From Tree Rings,* Papers of the Laboratory of Tree-Ring Research, Number 5, University of Arizona Press, Tucson.

Striem, H. L.: 1979, 'Some Aspects of the Relation between Monthly Temperatures and Rainfall, and its Use in Evaluating Earlier Climates in the Middle East', *Climatic Change* **2**, 69.

Suess, H. E.: 1979, 'A Calibration Table for Conventional Radiocarbon Dates', In R. Berger and H. E. Suess (eds.), *Radiocarbon Dating,* University of California Press, Berkeley, pp. 777-84.

U.S. Department of Commerce: 1961 *et seq., Monthly Climatic Data for the World.*

U.S. Department of Commerce: 1952-1973, *Monthly Weather Review.* (1952-1965, Weather Bureau; 1966-1970, Environmental Science Services Administration; 1970-1973, National Oceanic and Atmospheric Administration).

U.S. Department of Commerce, Weather Bureau (1959, 1966, 1967). *World Weather Records.* (World, 1951-1960, published 1959; Europe, 1951-1960, published 1966; Asia, 1951-1960, published 1967).

van Zeist, W.: 1967, 'Late Quaternary Vegetation History of Western Iran', *Review of Palaeobotany and Palynology* **4**, 9.

van Zeist, W., and Bottema, S.: 1977, 'Palynological Investigations in Western Iran', *Palaeohistoria* **17**, 19.

van Zeist, W., and Woldring, H.: 1978, 'A Postglacial Pollen Diagram from Lake Van in East Anatolia', *Review of Palaeobotany and Palynology* **26**, 249.

van Zeist, W., Timmers, R. W., and Bottema, S.: 1968/69, 'Studies of Modern and Holocene Pollen Precipitation in Southeastern Turkey', *Palaeohistoria* **14**, 19.

van Zeist, W., Woldring, H., and Stapert, D.: 1975, 'Late Quarternary Vegetation and Climate of Southwestern Turkey', *Palaeohistoria* **17**, 53.

Vita-Finzi, C.: 1978, 'Recent Alluvial History in the Catchment of the Arabo-Persian Gulf', In W. C. Brice, **q.v.**, pp. 255-61.

Wilkinson, T. J.: 1978, 'Erosion and Sedimentation along the Euphrates Valley in Northern Syria', In W. C. Brice, **q.v.**, pp. 215-26.

(Received October 24, 1980: in revised form May 4, 1981).