ASSESSING THE IMPACT OF CLIMATE CHANGE ON THE DEVELOPMENT OF SURFACE WATER RESOURCES

V. Klemeš

National Hydrology Research Institute
Department of the Environment
Ottawa, Ontario, K1A 0E7, Canada

J. Němec

Hydrology and Water Resources Department
World Meteorological Organization
Geneva 20, Switzerland

1. INTRODUCTION

Large storage reservoirs with controllable rates of release are, at the present time, the most effective means for the development of surface water resources. They are the only means capable of redistributing the irregular natural streamflow in accordance with water needs of a region, in particular of increasing streamflow during dry periods and reducing it during wet periods.

There are several reasons why the planning of these reservoirs calls for an accurate knowledge of future climate. The first and most basic is that the size of a reservoir required for a given degree of water resource development depends on streamflow properties during its period of operation which in turn are a result of climate during that period. In the current practice, the design of these reservoirs is based on the assumption that the climate is approximately stationary - that during the next several decades it will not be significantly different from its conditions in the past 50 to 100 years. If this should not be the case then our present estimates of reservoir sizes, feasible levels of water resource development, and the overall water resource planning would be in error. The second reason is that these errors might easily involve billions of dollars since, as a rule, the reservoirs involve the construction of large dams, new roads, bridges, etc., which all are expensive undertakings. And the third reason is that all these structures, once finished, are rather difficult to change so that any errors made are literally cast in concrete.

It seems obvious that an accurate forecast of climatic conditions (not to mention an accurate forecast of streamflow in specific rivers) over the period of, say, the next 50 years is an unrealistic proposition, notwithstanding the repeated attempts to discover deterministic trends in climate associated with a wide variety of phenomena ranging from the wobbling motion of the Earth to the enigmatic sun spots (the hypothesis that the 11 year sun spot cycle is the key factor enjoys a popularity which itself seems to exhibit an 11 year period - now again it may be passing through a maximum because of the periodicity of the presently fashionable layers in the Pichi-Richi Pass; Williams, 1981; Pittock, 1983).

Thus the fact remains that contemporary water resource development planning must take the uncertainty regarding future climate into account. In general, taking uncertainty into account is not new to water management. For example, the uncertainty resulting from the stochastic nature of streamflow series was first considered in reservoir design about 70 years ago by the famous American hydrologist and engineer Allan Hazen (the inventor of "probability paper").

The first problem that water resource management is facing vis-à-vis a possible climate change in the near future is to estimate the range of the consequent change in the runoff and compare it with the range of random fluctuations of runoff which can be expected even under the assumption of a stationary climate. Only if it can be conclusively shown that runoff changes during the next two or three decades (beyond which horizon no serious planning activity is now possible) are likely to be much higher than those due to the stochastic nature and the attendant sampling variability of a stationary runoff process, only then can the water resources planner face a practical problem of what can now be done about them. In other words, the first task is to find out whether runoff changes due to a climate change are statistically significant within the context of 1) our knowledge of the stochastic structure of the runoff process, 2) a planning horizon of about 20 years, and 3) the hydrological data base used for the design of large storage reservoirs.

The aim of this paper is to examine these problems and to indicate ways that may lead to their better understanding.

2. QUANTIFYING THE WATER RESOURCE DEVELOPMENT POTENTIAL

A convenient means for quantifying the potential for development of surface water resources at a given point along a river is the so called reservoir regime function which shows the reliability with which a given constant rate of flow can be sustained in the river by a reservoir of a given storage capacity. This rate of flow is usually referred to as the target release (from the hypothetical reservoir) or safe yield, and its reliability (or degree of safety) is expressed either as a percentage of time during which the release does not drop below the target value, or as a probability that it does not drop below the target during a period of one year, or by some similar characteristic. As an example, a reservoir regime function for the Leaf River (at Collins, Mississippi) is shown in Fig. 1.

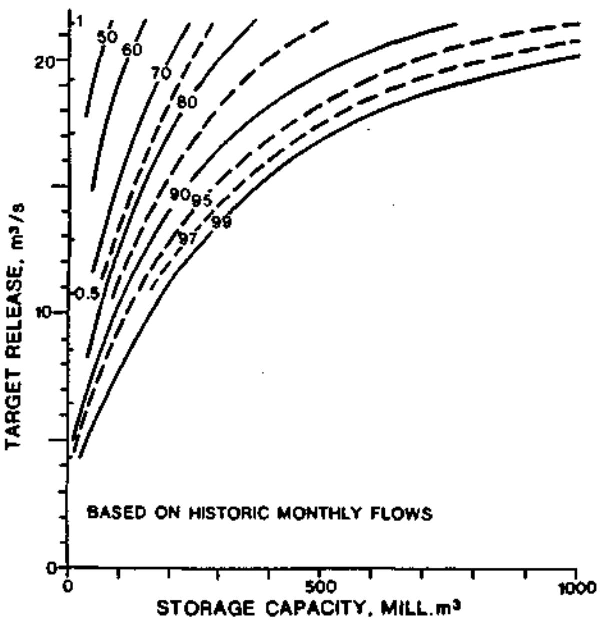

Fig. 1. Reservoir regime function for Leaf River (isolines are drawn for time-based reliability, in percent).

Quantitative relations between the three variables of the regime function (the target, storage, and reliability) are uniquely specified by the properties of the stochastic process representing the streamflow. Thus, in theory, the effect of climate change on the potential for surface water development can be determined from the difference between regime function based on the stochastic process representing the historic streamflow and regime function based on the stochastic streamflow process corresponding to the conditions after a climatic change. The effect of climatic change could thus be expressed either as a difference in the reliability with which a given reservoir could maintain a given target release, or as a difference in the value of target release corresponding to given values of reliability and storage capacity, or finally as a difference in the storage capacity of a reservoir needed for the maintenance of a given release with a specified reliability.

Since both of the stochastic streamflow processes (pre- and post-climate change) would be estimated from finite data samples, and the regime functions constructed for some finite period of reservoir operation, each of the three variables being compared would have a probability distribution. In general, the extent of the overlap of the pre- and post-climate change distributions would indicate the degree of statistical significance of the climate change impact on the surface water resource development potential.

3. PROBLEMS INVOLVED

While the program outlined above is theoretically straightforward, its practical execution poses several serious problems. One is a quantitative estimate of the changes in the primary climatic variables such as air temperature, radiation, precipitation, and evapotranspiration; moreover, it is not only the changes in the long-term normals that are of interest here but also the changes in seasonal variability and, in general, in the properties of the associated stochastic processes. The second problem, which in theory should be less difficult to overcome but in practice does not seem to be so, is the modelling of the mechanism by which the primary climatic variables are transformed into the streamflow process. To be sure, a large number and a great variety of such models (commonly called hydrological) exist, ranging from purely black-box input-output (transfer function) models to "grey-box" conceptual models of various shades of grey. However, none of them qualifies as a climate-transferable model, or at least none has so far been conclusively proven to qualify as such (Klemeš, 1982b). A third problem is our lack of understanding of the stochastic structure of the streamflow process even under stationary conditions (Klemeš, 1974) - a sine qua non for establishing a firm basis for meaningful comparisons; this problem is of a fundamental nature since our streamflow records are generally short and do not contain enough information for solving it (Moran, 1957; Wallis and O'Connell, 1973).

4. THE OPTIONS

Under the circumstances outlined in the preceding section there are basically two options: one is to refrain from any attempts to assess the impact of climate change on the development of water resources; the other is to see how far one can get using the current state of the art. The first approach is rigorous and safe; the second is likely to be just the opposite but, we believe, more productive. It may, and often will, lead to wrong answers and dead ends. But by forcing the currently available concepts, models, etc. to work and interact in a clearly defined framework designed with a specific aim in mind, it should be possible to identify more readily the weakest links, to see where, and what kind of, research is needed, and whether one direction is likely to be more promising than another. As a matter of fact, the more suspect and contradictory the results, the greater the incentive for

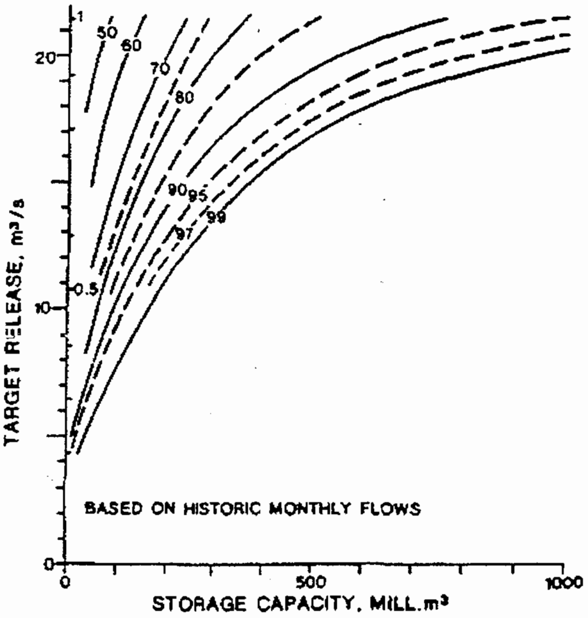

Fig. 1. Reservoir regime function for Leaf River (isolines are drawn for time-based reliability, in percent).

See Fig 1 in
"A Hydrological Perspective
for the difference
among the 12 scenarios
when standardized

improvement and rethinking of the concepts employed. It may be pertinent in this context to quote the Nobel prize winner in physics, Richard Feynman: "The thing that doesn't fit is the thing that's the most interesting, the part that doesn't go according to what you expected...[our laws] sometimes look positive, they keep on working and all of a sudden, some little gimmick shows that they're wrong. And then we have to investigate the conditions under which [they are wrong] and so forth, and gradually learn the new rule that explains it more deeply" (NOVA, 1983).

The only real danger posed by this second approach is not that its results may be wrong, but that they might be accepted uncritically as correct, either because of the prestige of their authors, or of the institutions with which the authors are associated, etc., and then used as sacred dogma to suppress whatever might contradict them. To put it more positively, the second approach can be productive only if perceived as a catalyst in a learning process.

5. SOME RESULTS

An example of the second approach is a recent attempt to assess the impact of climate change on the development of surface water resources in two specific locations of the United States made by Němec and Schaake (1982) and followed up by Klemeš (1982a, 1983).

The first two authors considered 12 different scenarios of climate change covering the approximate range of possibilities presently considered compatible with the buildup of atmospheric CO_2. These scenarios were characterized by all combinations of three different changes in air temperature converted into three corresponding values of evapotranspiration (E) changes of 12%, 4% and -4%, and the following four precipitation (P) changes, 25%, 10%, -10% and -25%. These changes were then introduced as perturbations of the E and P variables in a Sacramento conceptual hydrological model (which had been calibrated on historical records of climate variables and streamflow) for two U.S. basins described in Table 1, and 12 hypothetical post-climate-change streamflow series were generated for both basins. The third author then constructed reservoir regime functions of the type shown in Fig. 1 for the historic streamflow series and for the 12 simulated series.

Table 1. Characteristics of River basins under study

	Leaf R. Collins, Miss.	Pease R. Vernon, Tex.
Basin area	1949 km^2	9034 km^2
Annual precip.	1314 mm	540 mm
Annual runoff	409 mm	11 mm
Record length	18 y	11 y

An example of the result is presented in Fig. 2a, b, c, d. It shows how the reliability of four different levels of development (for the Leaf River), for all of which the reliability under a stationary climate is 95% (black circle), might change for any of the 12 climate change scenarios (open circles). We do not claim that the reliability values shown are accurate; most likely they are not because of the presently inevitable imperfections both in the representation of the post-change climatic forcing functions and in the hydrological model employed. However, they give an idea of a possible order of magnitude of the impact and of some of its likely features that may be of interest to the water manager, for instance: 1) the drop in reliability might be - percentagewise - much faster than the drop in precipitation or the rise in evapotranspiration; 2) the impact of a drier climate would be more severe where the present level of development is high (Fig. 2a, b) than where it is low (Fig. 2c, d); 3) the relative effect of the precipitation change would probably be greater than that of the evapotranspiration change.

6. STATISTICAL SIGNIFICANCE AND ITS PROBLEMS

While the changes such as those shown in Fig. 2 are interesting, they lack a proper perspective unless their statistical significance is assessed, i.e. unless they are compared with conditions that might occur simply because of sampling fluctuations of a stationary climate or, in the present context, streamflow. Such a perspective can be provided by confidence limits corresponding to a given reliability value for stationary climate, e.g. to the value of 95% in our case. As mentioned before, these limits can be derived if the stochastic process of the streamflow is known. Unfortunately, in our case the length of the historic flow record is very short so that the stochastic structure of the process cannot be satisfactorily identified. Respecting Occam's razor, one has to settle for a random (uncorrelated) series model for the annual flows. On this basis, and taking into account the variability inherent in a sample of size 18 (see Table 1), 90% confidence regions were constructed for a 20-year planning horizon (Klemeš, 1982a); they are represented by the shaded areas in Fig. 2. In all likelihood, these confidence regions are too narrow since their underlying stochastic model probably is grossly oversimplified. It is important to see that this cannot be corrected by any amount of mathematical-modelling legerdemain involving the given historic data since, because of the shortness of the record, there is no more information in them.

In this context, one problem should be emphasized which is not always appreciated. It is common knowledge that the statistical significance of a difference between two hypotheses, parameters, etc., drops as the underlying data base shrinks and the sampling uncertainty increases. This reduction of significance follows from the flattening of the sampling distribution and is graphically

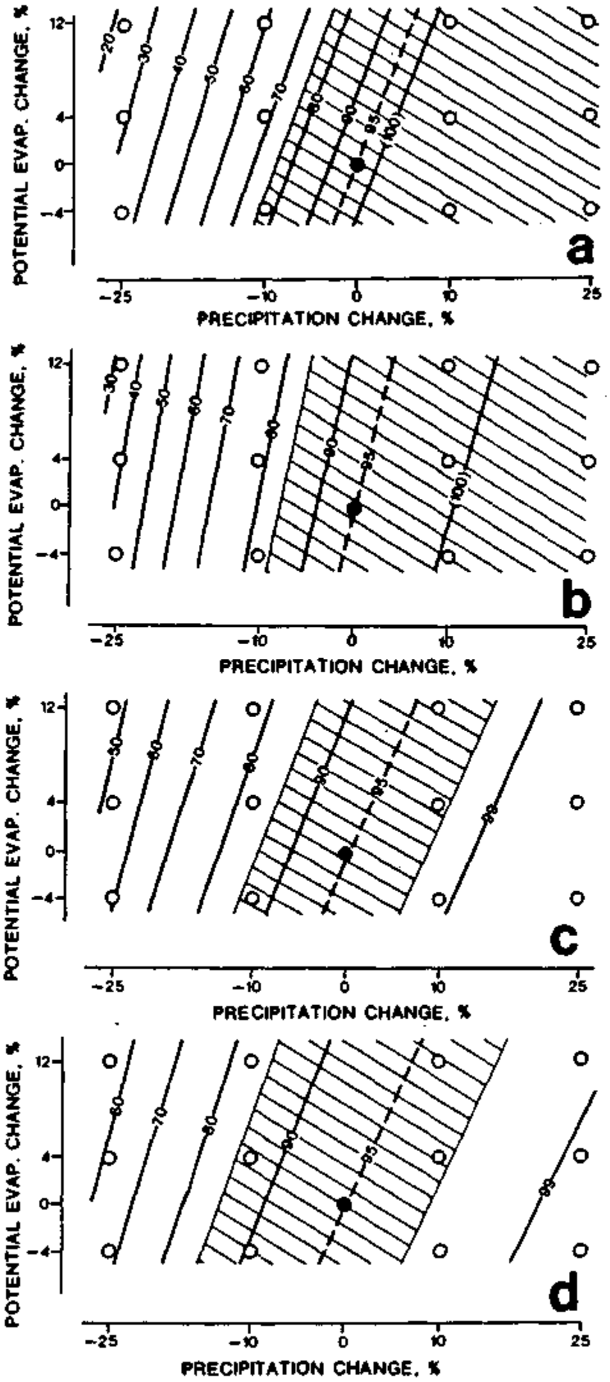

Fig. 2. Reliability (for Leaf River data) as a function of precipitation and potential evaporation changes, for the following 4 levels of development (all with an original 95% reliability):

Level	a	b	c	d
Target (m^3/s)	19.3	15.0	10.8	6.5
Storage (mill m^3)	600	280	125	40

Shaded areas represent 90% confidence regions (for the 95% reliability contour) computed on the basis of a stochastic model fitted to data, for sample size N=18 and a 20-year planning horizon.

reflected in the widening of the confidence interval. It thus seems to follow that, because of the shortness of the flow series underlying the results shown in Fig. 2, the shaded confidence regions are, if anything, too wide rather than too narrow as claimed in the preceding paragraph. The point is however that the above claim does not refer to the confidence region width as a function of sample size but rather to the width as a function of process structure for a given sample size. In other words, in the claim, the shortness of the record was invoked as a reason for our inability to see a greater complexity which is probably inherent in the process and which would lead to wider confidence regions for N=18 than those shown in Fig. 2.

Thus, ironically, if we are concerned with assessing statistical significance of climate change impact on the basis of a short record, the paucity of data may lead to an inflation of its statistical significance because of an underestimation of the complexity of the natural climate process. While it is true, as Němec and Schaake (1982) point out in quoting Katz (1980), that "...without reliable statistical inference, any climatic changes reportedly discovered could just as well be attributed to the chance variation of essentially unpredictable natural fluctuations", it must also be remembered that reliable statistical inference is not possible without a knowledge of the dynamic structure of the climate process which a short record does not reveal. As Bartlet put it as early as 1954, "unless the statistician has a well defined and realistic model of the actual process he is studying, his analysis is likely to be abortive" (Klemeš, 1978).

It follows that statistical and dynamic (physical) analyses are inseparable if they are to be meaningful and that neither can benefit from ignoring the other.

7. INSIGHTS THROUGH PROXY DATA

In cases where historic samples of data against which the effect of climate change is to be evaluated are too small and inadequate for reliable statistical inference, proxy data may provide some insights. In general, best results are to be expected from proxy data which are most closely related to those on which information is being sought (some dangers inherent in the use of remotely related proxy data will be discussed later). In our case, the first choice obviously is streamflow data from basins as similar as possible to the two basins under study (Table 1), but with longer records. The similarity criteria may vary and in practice will often by dictated by the information available. Our data source (Yevdjevich, 1963) called for the adoption of mean annual runoff depth and basin area. The basins selected on this basis are listed in Table 2.

In order to simplify the analysis, we refrained from assessing the reliabilities (as

Table 2. Characteristics of proxy river basins

	Annual runoff mm	Basin area km^2	Record length years
A. Leaf River Proxy Data			
Current R., Van Buren Missouri, U.S.A.	390	4320	45
Petit Jean Creek, Danville Arkansas, U.S.A.	394	1910	41
Kaweah, near Three Rivers, California, U.S.A.	380	1345	53
Feather, Boidwell Bar, California, U.S.A.	476	3500	45
Boise, Twin Springs, Idaho, U.S.A.	486	2150	45
Saugeen, Walkerton, Ontario, Canada	428	2200	40
Elbe, Děčín Czechoslovakia*)	186	51100	100
B. Pease River Proxy Data			
North Llano, near Junction Texas, U.S.A.	26	2380	42
Pecos, near Anton Chico, New Mexico, U.S.A.	48	2720	46
Verde, below Barlett Dam, Arizona, U.S.A.	43	15900	50
Humbolt, Palisade, Nevada, U.S.A.	25	13000	46
Avoca, Coonoorer Bridge Victoria, Australia	27	2600	59

*) Novotný (1963)

in Fig. 2) and concentrated on the annual runoff instead, in particular on its mean and standard deviation which represent the two most important parameters on which the reservoir regime function (and hence the reliability) depends. Within this framework, the objective is to compare these two streamflow parameters of the 12 climate-change scenarios with those of the historic flows. This comparison is shown in Figs. 3 and 4 where the four connected triads of full circles show the parameters of the 12 scenarios and the double circle those of the historical flow series (base). Both parameters are made dimensionless with respect to those of the base series which are set equal to unity. To be able to relate, at least approximately, Fig. 2 with Figs. 3 and 4, the latter figures contain ellipses representing 90% confidence regions for the true population parameters, on the assumption (see section 6) that the annual flows form random series.

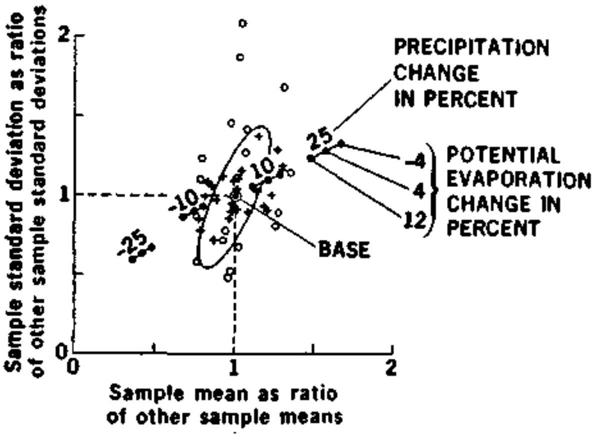

Fig. 3. Climate-change induced changes in sample parameters of annual flows for Leaf River (connected triads) compared to natural parameter variability in samples of equal size (N=18) from proxy basins listed in Table 2 (crosses; open circles correspond to Elbe River data).

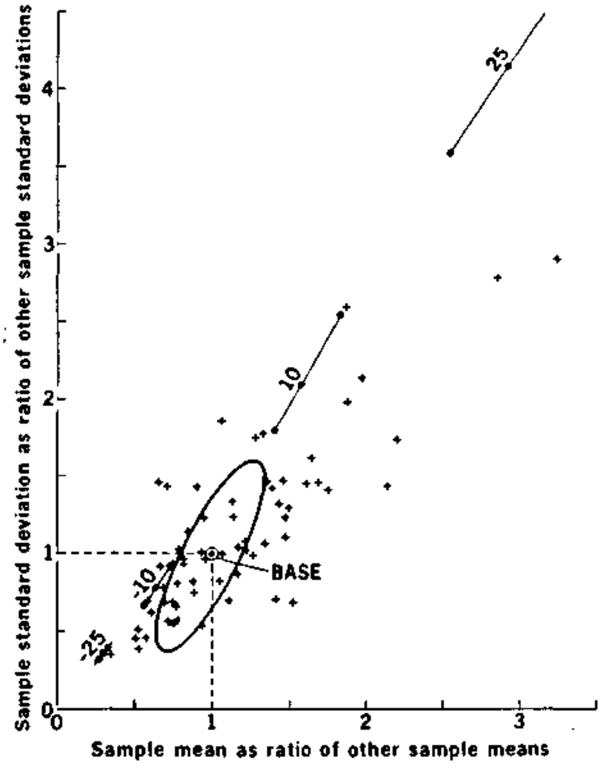

Fig. 4. Climate-change induced changes in sample parameters of annual flows for Pease River (connected triads - see legend in Fig. 3) compared to natural parameter variability in samples of equal size (N=11) from proxy basins listed in Table 2 (crosses).

If statistical significance of the differences between the "post-change" parameters and the "base" parameters were to be judged solely on the basis of primary data (i.e. without any reference to proxy data) it would have to be done as follows. Any point within the ellipse could be regarded as defining the population parameters and would serve as a centre of a "sample confidence" ellipse for parameters of samples of size equal to the planning period (if the planning period were of the same length as the historic period, this sample-confidence ellipse would be similar to the one shown). Those scenarios whose parameters would fall inside the sample confidence ellipses could then be considered statistically indistinguishable (at a given level of significance) from the historic period since their sample parameters would be compatible with the same population. In our two cases, this analysis leads to a conclusion that annual flows corresponding to a precipitation change of about ±10% would not be significantly different from those that might be expected under a stationary climate.

However, taking into account the proxy data shown in Table 2, the above conclusion seems rather conservative as indicated by the spread of the crosses in Figs. 3 and 4. These crosses were constructed in such a way that nonoverlapping segments of the same length as the base series (N=18 for the Leaf River, N=11 for the Pease River) were formed from the proxy series, the parameters of each segment were in turn set equal to one and those of the other segments expressed as their ratios. This representation shows the range of relative differences between compatible samples. The variability indicated by the crosses, while not associated with any specific confidence level, is much higher than that indicated by the procedure described in the preceding paragraph. The variability of the Pease River proxy data seems to be markedly higher than that for the Leaf River. This is suspected to be an artefact of the analysis and caused by the fact that the Pease River sample has size N=11 as compared to N=18 for the Leaf River. Because of this, more independent samples can be formed from a proxy series of a given length in the former case than in the latter so that the sampling variability of the latter case will be lower. To get a spread at the same level of significance for both basins, the Leaf River would require proxy series about 80-100 years long to produce the necessary number of independent samples. The most similar flow series of such a length that we could find was one for the Elbe River at Děčín in Czechoslovakia (Novotný, 1963). Its variability is believed to be of the same order as that of the Leaf River despite the differences both in mean annual runoff and in basin area (Table 2) since their effects would tend to compensate each other. Parameters of the Elbe River samples of size N=18 are shown by open circles in Fig. 3.

In general, the proxy data indicate that the inherent long-term variability of a stationary annual runoff series is higher than that of a random series and, consequently, that a blind statistical analysis of climate-change impact, based on short historic records, can be grossly in error. This conclusion is in agreement with results of some related earlier studies (Klemeš, 1979; Klemeš and Bulu, 1979).

8. RELEVANCE OF PROXY DATA AND OF THEIR ANALYSES

The main reason for the use of proxy data is to extend the length of record of a process under study in the hope that a longer proxy record will reveal important features of the process that are not apparent from a short primary record. While this objective is legitimate, the methods for its achievement are often inadequate and the inferences wrong. The most common inadequacy is an exclusive reliance on formal statistical methods both in the assessment of the closeness of the relation between the proxy and the primary data, and in the analysis of the proxy time series. Such an approach can lead to correct results only in exceptional circumstances, to quote Norbert Wiener, only if "the main elements of the dynamics of the situation are either explicitly known or implicitly felt" (Klemeš, 1978) as they are in our case. Here the main elements of the dynamics are relatively clear since both the primary and the proxy data are streamflows and most of the proxy data come from basins with similar climatic and hydrologic conditions. Moreover, and this is important, the information being sought is concerned only with relative statistical variability of successive short samples and definitely not with extrapolation of deterministic features (trends, periodicities, etc.) depending on real-time connectedness between the proxy and primary data.

Instances where the main elements of the dynamics are not so straightforward involve all the cases where the proxy data relate to a different physical process than the primary data; for instance when properties of a runoff process are being inferred from records of lake levels, tree rings, varves, etc. In such cases, the physical (deterministic) transfer mechanism between the two processes must first be identified and included in the analysis since it can cause drastic differences in the statistical properties of the two processes.

To illustrate the point, the use of lake level records as proxy data for streamflow will be discussed in more detail. In general, both processes tend to follow a similar long-term pattern in the sense that during long dry periods both lake levels and streamflows are lower than in long wet periods. However, this similarity can be grossly distorted in shorter periods. This has been repeatedly pointed out by hydrologists but routinely ignored by the modern "correlation hunters" mass-produced by typical contemporary graduate programs in hydrology. Thus, for instance, Langbein (1961) warned that, in using the fluctuations of lake levels as indexes of climatic variations, it must be remembered that "The interpretation of lake levels depends on the value of the response times, k. The longer the response time, the greater is the possibility that climate and lake levels may be out of phase". More recently, Kurdin (1975, 1977) showed by an analysis of levels of Lake Balkhash that the dynamics of its water balance (in particular, the conditions in the delta of its tributary, the Ila River) may reduce or amplify long-term fluctuations of lake levels caused by climate variability.

The main reason why lake levels and streamflow may exhibit markedly different fluctuation patterns is that, in principle, lake level fluctuations reflect a running integral of the net precipitation process while streamflow may reflect either this process itself, or its running integral, or a mixture of both. For example, if the precipitation process were a random (serially uncorrelated) process, a lake level record would be highly serially correlated, streamflows in some rivers of the basin could be only weakly serially correlated while in other rivers they could exhibit high serial correlation. Moreover, in some rivers the streamflows could belong in the category of short-memory processes while in others they could form long-memory processes. This is because 1) lake levels reflect a storage process (equivalent to running integral) of the (net) precipitation process; 2) streamflow formed on an impervious part of the basin would have a structure similar to the precipitation process, with only a slightly stronger persistence (short memory); and 3) rivers fed from large lakes may have streamflow structure similar to that of the lake levels, i.e. belong in the long-memory category (Klemeš, 1974, 1978). Hence to use statistical analysis (stochastic model) of a lake level record for inferences about statistical properties of streamflow in all rivers in the area (or of rainfall, etc.) could be very misleading.

A specific example of this situation is the case of Lake Victoria levels. Their record shows a sudden rise of about 2.5 m around 1964, then a gradual drop of about 1 m followed, in 1978 and 1979, by a rise almost back to the 1964 level. A classical statistical analysis of the record would point to a nonstationary process, perhaps indicative of a climate change in the early sixties. However, precipitation records do not indicate any such change. This apparent discrepancy can be explained by the above-mentioned fact that lake levels behave, in general, like an integral of (net) precipitation. Precipitation which was quite high (and probably still underestimated) in the early sixties was capable of shifting the lake level to a new quasi-equilibrium. This was demonstrated by Kite (1981) with the aid of a deterministic water balance model for the lake. In a later, purely statistical, analysis of Lake Victoria levels, Kite (1982) found that the lake level record could not be homogenized without removing the above mentioned step and rightly concluded: "...if a [stochastic] model must include the possibility of random jumps of such a magnitude its usefulness for planning purposes is doubtful". The latter study also demonstrates the validity of point 3 above. It shows that the streamflow record of Victoria Nile (which is the Lake Victoria outflow) closely follows the lake level record including the sudden rise in the early sixties which does not appear in streamflows of rivers in the area not originating in Lake Victoria or in other large equatorial lakes.

9. CONCLUSIONS

The importance of an accurate assessment of the impact of climate change on the development of water resources must not be underestimated. But neither should be its difficulty which stems from the following:

a) uncertainty in quantitative estimates of change of primary climate variables which is mainly due to our imperfect understanding of climate dynamics;
b) the limited capability of current hydrological models which is a consequence of our imperfect understanding of hydrological mechanisms;
c) shortness of historic records which hinders the identification of the correct structure (and parameters) of the streamflow stochastic process which constitutes the basis of any assessment of a statistical significance of climate change impact;
d) inadequacy of current statistical methods for making useful inferences on the basis of small samples;
e) difficulties with information transfer from proxy variables in the absence of solid understanding of dynamic relationships between them and the primary variables, namely streamflow.

In short, the quality of climate impact modelling as well as that of the assessment of statistical significance of the impact depend primarily on our understanding of the physical mechanisms involved. With the present state of knowledge, and with the aid of the current tools reflecting it, only a very crude picture can be obtained whose usefulness to the planning process is extremely limited.

10. REFERENCES

Katz, R. W., 1980: Statistical evaluation of climate experiments with general circulation models: inference about means. Rep. No. 15, Climatic Research Inst., Oregon State Univ.

Kite, G.W., 1981: Recent changes in level of Lake Victoria. Hydrological Sciences Bull., 26(3), 233-243.

Kite, G. W., 1982: Analysis of Lake Victoria levels. Hydrological Sciences J., 27(2), 99-110.

Klemeš, V., 1974: The Hurst phenomenon: a puzzle? Water Resour. Res., 10(4), 675-688.

Klemeš, V., 1978: Physically based stochastic hydrologic analysis. Adv. Hydroscience, 11, 285-355.

Klemeš, V., 1979: The unreliability of reliability estimates of storage reservoir performance based on short streamflow records. In: Reliability in Water Resources Management, pp. 193-202, Water Resour. Publ., Fort Collins, Colorado.

Klemeš, V., 1982a: Effect of hypothetical climatic change on reliability of water supply from reservoirs. Report of National Hydrol. Res. Inst. of Environment Canada to WMO.

Klemeš, V., 1982b: The desirable degree of rigour in the testing of rainfall-runoff models. Amer. Geoph. Union, Fall Meeting, San Francisco.

Klemeš, V., 1983: Climatic change and the planning of water resource systems. Proc. 6th Canad. Hydrotech. Conference, pp. 485-500, Canad. Soc. Civil Eng., Ottawa.

Klemeš, V. and A. Bulu, 1979: Limited confidence in confidence limits derived by operational stochastic hydrologic models. J. Hydrology, 42, 9-22.

Kurdin, R.D., 1975: On long-term fluctuations of levels of large natural lakes in Kazakhstan and in Central Asia (in Russian). Proceedings, 4th All-Union Hydrological Congress, Vol. 5, Gidrometeoizdat, Leningrad.

Kurdin, R.D., 1977: On the role of the dynamics of the delta of the Ila river and of climatic factors in the fluctuations of water levels in lake Balkhash (in Russian). Water Resources, No. 1, USSR Academy of Sciences, Moskow.

Langbein, W.B., 1961: Salinity and hydrology of closed lakes. Geol. Survey Professional Paper 412, U.S. Government Printing Office, Washington, D.C.

Moran, P.A.P., 1957: The statistical treatment of flood flows. Eos, 38, 519-523.

Němec, J. and J. Schaake, 1982: Sensitivity of water resource systems to climate variation. Hydrological Sciences J., 27(3), 327-343.

NOVA, 1983: The pleasure of finding things out. WGBH Educational Foundation, Boston, Massachusetts.

Novotný, J., 1963: Hundred-year streamflow series from two Czech rivers (in Czech). Transactions of the Hydrometeorological Institute (HMU), No. 2, Prague.

Pittock, A.B., 1983: Solar variability, weather and climate: an update. Quat. J. R. Met. Soc., 109, 23-55.

Wallis, J.R. and P.E. O'Connell, 1973: Firm reservoir yield - how reliable are historic hydrological records? Hydrological Sciences Bull., 18(3), 347-365.

Williams, G.E., 1981: Sunspot periods in the late Precambrian glacial climate and solar-planetary relations. Nature, 291, 624-628.

Yevdjevich, V.M., 1963: Fluctuations of wet and dry years, Part I. Hydrology Papers, No. 1, Colorado State Univ., Fort Collins, Colorado.

II INTERNACIONAL MEETING ON STATISTICAL CLIMATOLOGY

II IMSC
EIEC

Primary sponsors:

World Meteorological Organization
U.S. National Science Foundation
U.S. Office of Naval Research

Co-sponsors:

Academy of Sciences of Lisbon (Portugal).
American Meteorological Society.
American Statistical Association (Section on Physical and Engineering Sciences).
Bernoulli Society for Mathematical Statistics and Probability (International Statistical Institute).
Faculty of Sciences of the University of Lisbon (Department of Statistics, Operations Research and Computation).
Meteorological Society of Japan
and
National Institute of Scientific Research (Portugal).

Host Organization:

National Institute of Meteorology and Geophysics

Sep. 26-30 * 1983