Some major implications of climatic fluctuations on water management

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Climatic fluctuations affect water management in a variety of ways. Much emphasis has been placed in recent years on climatic changes that may occur in the future due to global warming resulting from increases in greenhouse gases. If and when global warming takes place, water availability and use patterns will most certainly change. At our present state of knowledge it is not possible to predict the onset of climatic changes, including their magnitude and spatial distribution, with any degree of confidence so that they can be explicitly incorporated into water management in a cost-effective manner. The problem of climatic fluctuations appears to be more complex than the water resources profession has so far realized. Development of new methodologies to deal efficiently with climatic fluctuations is urgently needed.

The issue of climatic change and its possible impacts on mankind has become a major topic for discussion in recent months. The possibility of global warming due to the greenhouse effect is now firmly on the world's scientific and political agenda. Numerous meetings on climatic change are now being held all over the world, which are scientific, political or even pseudo-scientific in nature. Unquestionably ozone depletion and global warming have primarily been responsible for rekindling the interest of the general public in various environmental issues, to a level that has not been witnessed since the early 1970s.

Much has been said and written in recent months about the impacts of potential climatic changes on global food production, primarily through the modification of prevailing water regimes caused by climatic changes. Many predictions have been made, mostly catastrophic, on how global food production is going to suffer due to changing patterns of rainfall and temperature, and on the attendant problems facing water control and management. There is no question that if existing rainfall and temperature patterns change during forthcoming decades, there could be important implications for agricultural production and water management, at global as well as regional and national levels, depending on the rate, magnitude and spatial distribution of such changes.

Climatic fluctuations and water management

While climatic fluctuations affect water management in a variety of ways, it should be clearly noted at the outset that climate is one of the many factors, albeit an important one, that have major impacts on the availability and use of water resources. Among other important factors that affect water management are population levels and densities; extent and level of economic activities, especially in terms of agricultural and industrial development; standard of living and efficiency of water use. These issues are generally closely interrelated.

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The most important implications of climatic fluctuations as they relate to water management are in terms of water availability from both surface and groundwater sources; drought and flood management (including efficient operation and safety of reservoirs); choice of proper cropping patterns to ensure crop-water requirements are met reliably; proper functioning of agricultural and urban/rural drainage systems; maintenance of water quality of rivers, lakes, canal systems and aquifers; and management of vulnerable, low-lying areas, especially in the deltaic and coastal regions.

A fundamental aspect of design and operation of any water-resources system is to ensure reliable availability of water for various purposes by mitigating the impacts of droughts and floods. Water planners and hydrologists have always considered annual, seasonal, and sometimes daily variations, in precipitation as well as river discharges. Dams and reservoirs are designed explicitly to overcome impacts due to high and low river flows. Generally, design criteria for dams and operating rules for reservoirs are based on past climatological data in terms of rainfall and runoff. It is implicitly assumed that past experiences and climatological patterns hold the key to future events. This assumption may not be correct, since current analyses indicate that some of the present hydrological techniques and water-management methodologies may not be adequate to deal successfully with the extent of climatic fluctuations witnessed in the past, or those that can be expected within the designed life periods of existing or proposed hydraulic structures.

If the world experiences warming due to increases in the concentrations of carbon dioxide and other greenhouse gases, as the majority of scientists are predicting at present, water availability and use patterns would most certainly change. The rates of such changes would differ from place to place as well as over time. For example, on a global basis, nearly 80% of water used at present is for agricultural purposes. If global warming takes place, irrigation water requirements are likely to increase due to higher evapo-transpiration losses. Land-use patterns, including cropping patterns, would change over a period of time, either by direct policy changes to make more efficient use of scarce water resources due to socio-economic pressure, or by a series of *ad hoc* individual decisions as a direct response to changing climatic regimes. Both would have water use implications. However, at our present state of knowledge, estimates of potential climatic changes can at best be considered to be informed guesses. We cannot go any further than that because of lack of knowledge and reliable data in many areas, which hinders our understanding of numerous interrelated phenomena and feedback systems which define the various climatic patterns. The current signals of climatic fluctuations are neither strong enough, nor observed over a sufficiently long period of time, to predict confidently the onset of any climatic change with any reliable degree of scientific accuracy. In spite of such uncertainties, however, many climatologists have already 'confidently' predicted that global climatic regimes have already started to change due to global warming caused by greenhouse gases.

It should further be noted that, in the area of agricultural production, it is not enough to consider changes in annual average rainfall and temperature. Distribution of rainfall and temperature over the cropping period, and the beginning and the end of the rainy seasons, are crucial factors which determine the yields for rainfed agriculture, which is still the dominant form of agriculture in vast areas of the world. Currently the possible changes in rainfall and temperature patterns in specific areas of the world, even on an annual basis, cannot be predicted with any degree of certainty. Accordingly, it is even more hazardous to forecast inter- and intra-annual changes in rainfall and temperature patterns in specific agricultural project areas. Prediction of changes of onset and end of rainy periods are simply not possible in our existing scientific state-of-the-art. Under these conditions, estimation of changes in crop production due to climatic changes are still too uncertain and vague and thus cannot be considered for explicit incorporation into any specific planning and management of water and low agricultural development projects.

Climatic forecasting

Despite recent advances in climatology, climatic forecasting is still a very complex and difficult process. Increasing attention must be paid to improve not only existing monitoring and forecasting techniques but also the facilities available for such activities in nearly all developing countries. Without a functional and efficient monitoring and forecasting system, rational planning, design and operation of water-resources systems is very difficult, if not impossible, even under the best of circumstances.

The global circulation models (GCMs) available at present are still far from infallible. Among many other shortcomings which seriously constrain their actual use for planning and management purposes are the need for better representation of clouds and more reliable modelling of oceans and the way they interact with the atmosphere. Equally, very limited data are available from oceans, which cover a major part of the world. Available temperature-distribution data are primarily based on observations on land surfaces where, often, higher temperatures might be noted due to urbanization and other related human activities. Thus, available global surface temperatures are highly skewed in favour of land surfaces. These shortcomings seriously affect the reliability of predictions of the current generation of GCMs.

The preliminary nature of GCMs can be illustrated by the fact that, in late 1988, the level of global warming forecast by one of the GCMs for about 50 years' time, when concentration of carbon dioxide is expected to double, was around 5.5°C. By changing the way the clouds were treated within the model, a recent prediction by the same model is that the average global temperature would increase by 2°–3°C during the same period. Regional changes, as indicated by the model, however, show similar patterns. It should be noted that from a policy point of view, the difference between an average warming of 5.5°C and 2°C could mean devastation or manageable disruption of agricultural production and/or land submergence in coastal areas in many parts of the world. Similarly, economic impacts of the two scenarios would not even be close; cost implications, and thus investments required to ameliorate potential impacts, would be at completely different levels of scale.

The problem is further complicated by the fact that all models also do not necessarily forecast consistent patterns and/or magnitude of potential regional climatic changes. For example, some models predict intensification of monsoon rains over south Asia, which could contribute to increased magnitude of annual floods with consequent devastation and very heavy economic losses. In contrast, others show weakening of monsoon rains, which could mean droughts and crop failures. Policy measures that need to be taken, even at such a macro-scale, to alleviate these two conditions are of vastly different types. Because of such uncertainties, policy-makers have in general been reluctant to make the heavy investments necessary in advance, in anticipation of such potential catastrophic events due to climatic changes.

Even if the predictions made by global circulation models on such macro-level regional climatic changes were accurate, they are of minor interest at present for water management in terms of planning, design and operation of individual projects. This is because the current generation of GCMs cannot provide usable climatic information on specific river basins, sub-basins or agricultural project areas at a scale that can be used successfully by planners. Equally, general information like average annual rainfall and average annual runoff in an area is simply inadequate for the planning and management of water resources projects. Hydrological characteristics of water projects must consider and incorporate short time-scale events which are extreme in nature, like floods or 10-day low flows, into the design, safety and operation of dams and reservoirs. Such data are simply not available at present with any degree of accuracy from any of the existing GCMs.

Dilemma of water planners and managers

A major dilemma at present facing nearly all water planners and managers in developing countries is the urgency of developing and managing water projects on the basis of inadequate and/or unreliable data. With the continually increasing pressure resulting from higher population growth levels and the demand for better standards of living, developing countries are now trying very hard to increase their agricultural production in order to become more and more self-reliant in food availability, and simultaneously to generate more energy from indigenous sources. Water development is an essential requirement to ensure a reliable supply of water availability to increase areas under agriculture and to produce higher crop yields. Since agriculture is an intensive user of water, large-scale water developments are often necessary. The same water resources developed for irrigation also generally produce hydroelectric power. Thus there is often considerable social, economic and political pressure for the immediate execution of water projects, irrespective of the quality and extent of hydrometeorological data available. Developing countries often do not have the luxury of waiting until reliable data are available, over a reasonable length of time, before the planning and execution of large-scale water development projects can be initiated.

Since water projects often have to be planned and managed on the basis of inadequate and/or unreliable data, a common technique used in recent years has been to generate synthetic streamflow based on whatever short-period data are available. This practice has been so widespread in recent years that it has been generally considered to be a fully acceptable standard procedure. Very few hydrologists or research workers have questioned the efficiency of its use. The main research emphasis has been, almost exclusively, to fine-tune the techniques available for synthetic streamflow generation by more and more complex mathematical manipulations and the use of more powerful computers.

At present, hydrologists and water resources planners, at least in developing countries, generally consider themselves fortunate if they have 10–15 years of reliable and continuous streamflow data. It is now not entirely uncommon to find that large-scale water projects are being planned, based on less than 10 years of reliable hydrometeorological data. On the basis of the information currently available, and the experiences of the recent past, one must question the efficiency and appropriateness of many such designs, and the desirability of continuing the practice of generating synthetic streamflow on the basis of rather short periods of data.

Analyses of climatic fluctuations observed during the past five or more decades in many countries of the world indicate that the concept of generating synthetic streamflow on the basis of short periods of data is flawed, to the extent that its continued use to plan large-scale and high-investment water projects should be seriously questioned. It is becoming increasingly evident that complex mathematical manipulations are no real substitute for better information if the short period of data on which such manipulations fundamentally depend are unrepresentative of the long-term pattern. The probability that a short period of data availability is really representative of the long-term pattern cannot be very high. It is thus imperative that hydrologists and other water-resources experts reconsider their research focus, in order that a new methodology can be urgently developed which will enable us to handle river-flow fluctuations more effectively within the planning and management framework.

The problem of climatic flutuations appears to be more complex than the water-resources profession has generally realized so far. The magnitude of this problem may vary from country to country, and conceptually it is not going to be an easy problem to resolve. For example, Figure 1 shows the annualized Nile flow at Aswan, Egypt, as a percentage of long-term mean covering nearly 120 years. If, as an illustrative example, it is assumed that a major water-development project had to be designed in 1900 based on the previous 30 years of data, in 1950 based on the preceding 50 years of data, or in 1990 based on the previous 30 years of data, the project designed for the identical river at the same location would most probably have shown significant design differences. This means that the benefits and costs of a water project

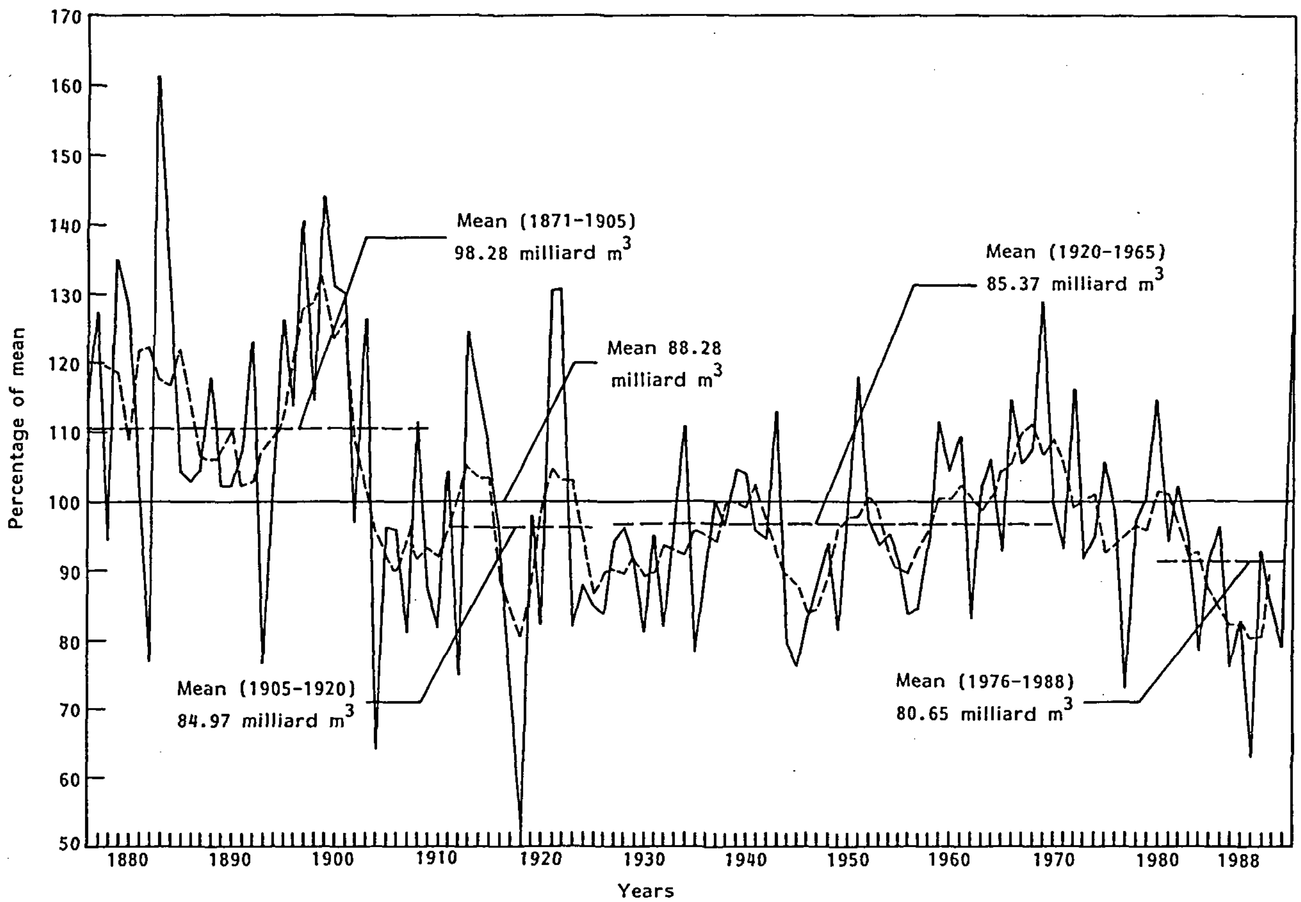

Figure 1. Annualized Nile flow at Aswan.

for an identical location could have been very different, depending on the periods of data available to, and used by, the planners.

Similar problems would have occurred for the White Nile (Figure 2) at Mogren and the Blue Nile at Khartoum (Figure 3). The issue can be seen very clearly in the case of the White Nile at Mogren, where the 73-year river flow could easily be divided into two distinct periods, 1912–61 and 1962–85. The mean annual flow during the period 1912–61 was 25.6 billion m^3 but if the period 1962–85 is considered it was 33.9 billion m^3, which is nearly 33% higher than the earlier period. Thus, hypothetically, a water-development project for the White Nile at Mogren designed in 1962 on the basis of earlier data would have had very different characteristics compared with another designed in 1986 on the basis of the 1962–85 data.

It should also be noted that hydrologists and climatologists have often assumed that 30 years of continuous observations can reliably define the statistical parameters of long-term rainfall or runoff patterns. A quick analysis of Figures 1–4 will clearly indicate that this hypothesis can be seriously questioned in terms of its accuracy. Depending on which 30-year period is selected, the main statistical parameters could be quite different when compared with another 30-year period. The issue is even more complex if shorter periods of observation (say 10–15 years) are considered for the design of water-resources projects.

It is possible that the complexity of the problem could vary from one river basin to another, or even from one part of a river system to another for major rivers. It could also vary from country to country, as shown in Figure 4 by the rainfall patterns for four different Sahelian countries: Burkina Faso, Niger, Mali and Senegal (after Todorov, 1985). Again, depending on which 30-year period is selected, one could obtain some very different results.

Rainfall pattern is an essential consideration in water management for rainfed agriculture. Both cropping patterns and yields depend on the extent and distribution of rainfall during the cropping period. If a cropping pattern was decided in an agricultural area on the basis of an earlier regime which was com-

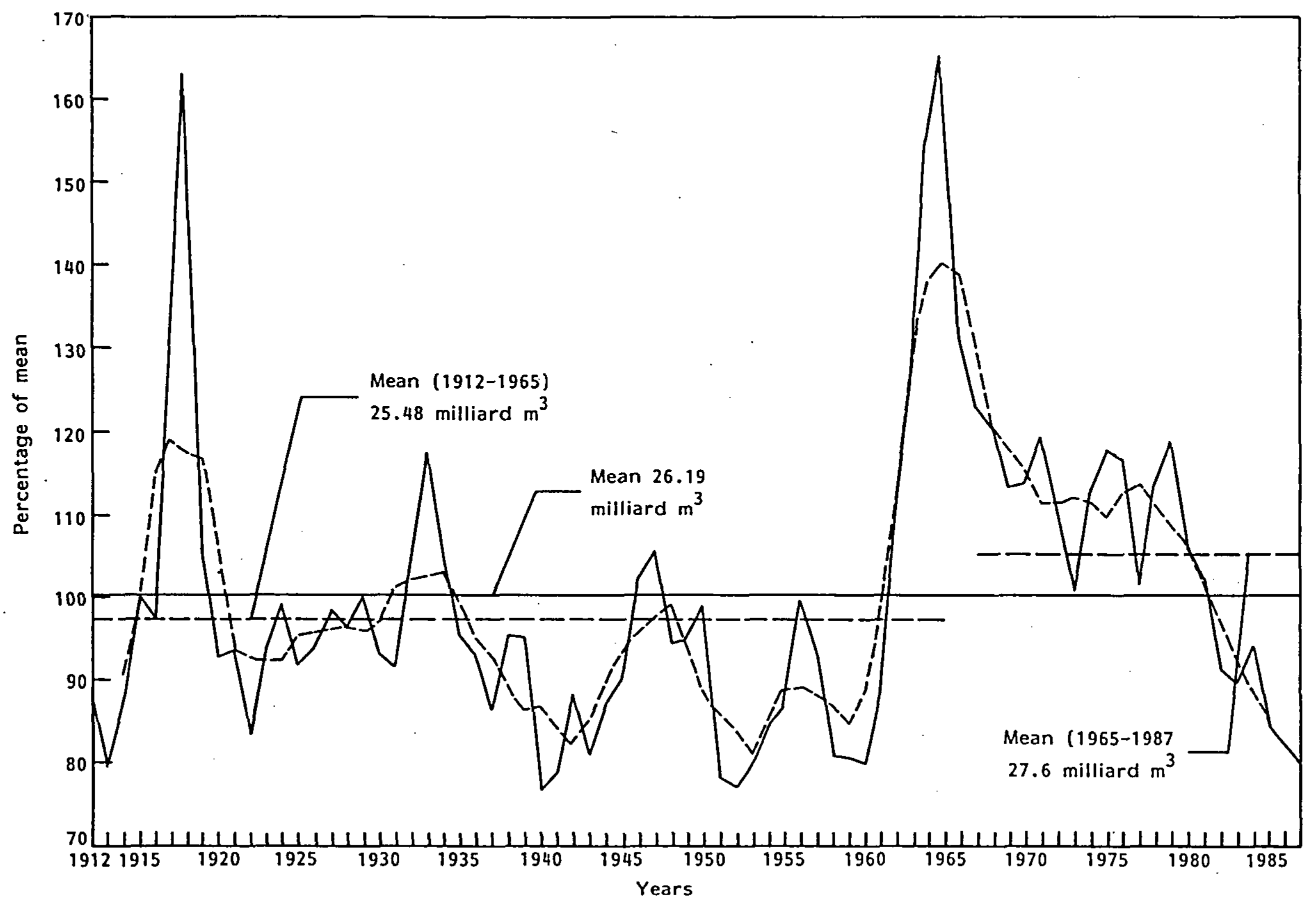

Figure 2. Annualized Nile flow at Mogren.

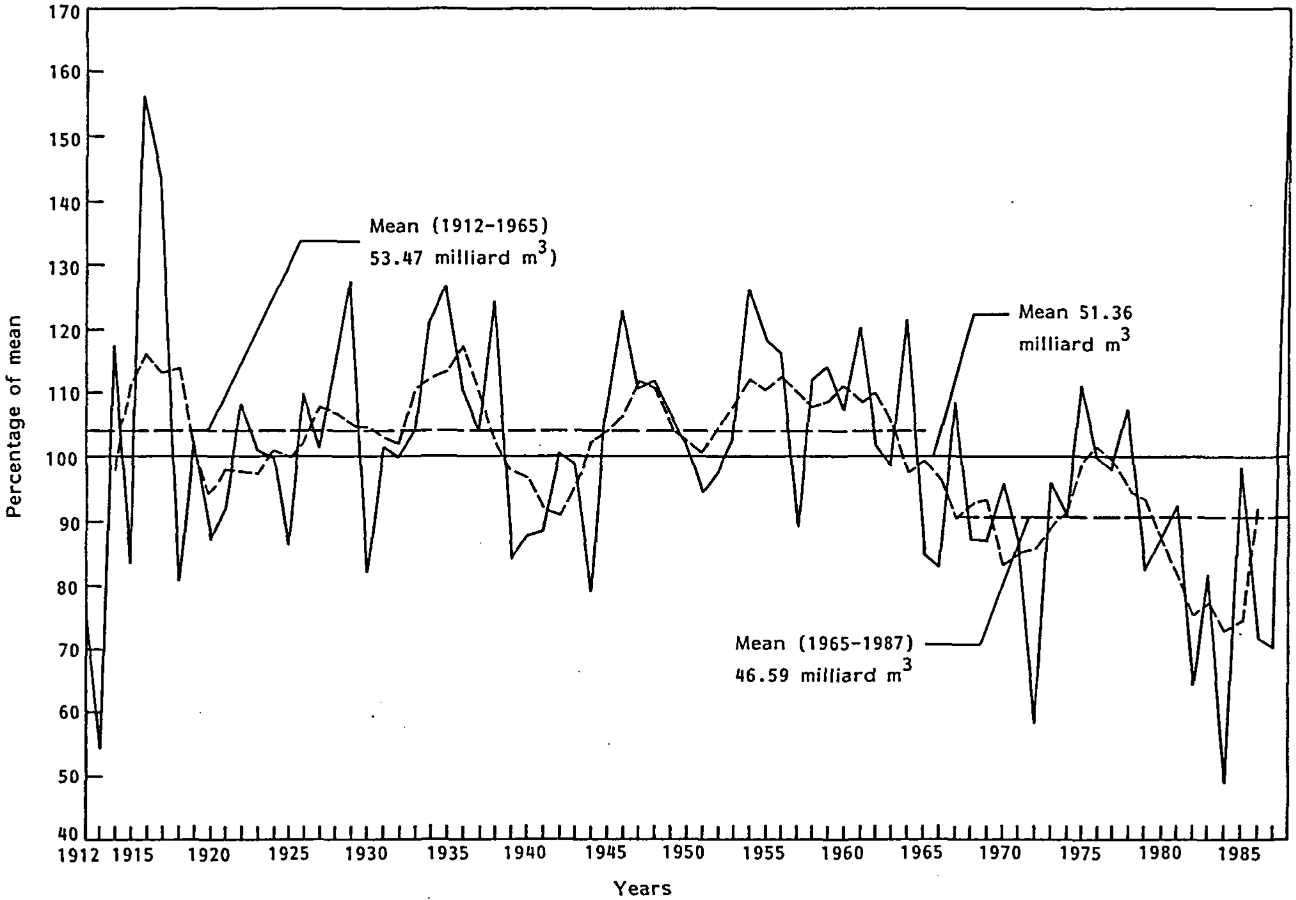

Figure 3. Annualized Nile flow at Khartoum.

paratively wetter, and the same pattern is continued during a lower rainfall regime, clearly crop yields would suffer. This, in turn, would reduce farm incomes and, under severe conditions, threaten the lives of farmers and their livestock.

Of the four Sahelian countries considered in Figure 4 it can be noted that the decline in rainfall was most significant for Senegal, followed by Mali and Burkina Faso, but it was also evident in Niger. A comparison between the earlier isohyets of mean annual rainfall for Senegal and those on the basis of rainfall for the 16-year period 1968–83 indicates that the earlier isohyets have to be moved southward by 113 km to reflect the latter pattern (Todorov, 1985). If this period is extended to 30 years, the earlier isohyets have to be moved south by some 61 km. Such changes of course have significant implications for water control and management of agricultural production. These are shown in Figure 5 (Todorov, 1985).

In addition to the complexities already referred to, ie how to handle methodologically 'normal' climatic fluctuations within the context of water resources development and management in an efficient manner, another issue further complicates the situation. This is to what extent human activities, such as land-use changes and increased production of greenhouse gases, may be changing the climate on a micro- and/or macro-scale. The problem becomes even more difficult if one attempts to separate what percentage of climatic changes are induced by human activities and what are 'normal' climatic fluctuations which are inherent in any climatic regime. While many hypotheses have been put forward in recent years, it must be admitted that at our present state of knowledge it is simply not possible to answer such important questions with any degree of accuracy. Furthermore, it is highly unlikely – in spite of accelerated research in this area – that this question can be answered satisfactorily during the remaining part of the twentieth century.

Thus, water planners and managers in developing countries are under considerable pressure to provide urgently reliable water control in order to ensure that existing food production and hydropower generation systems may not only be maintained but also be

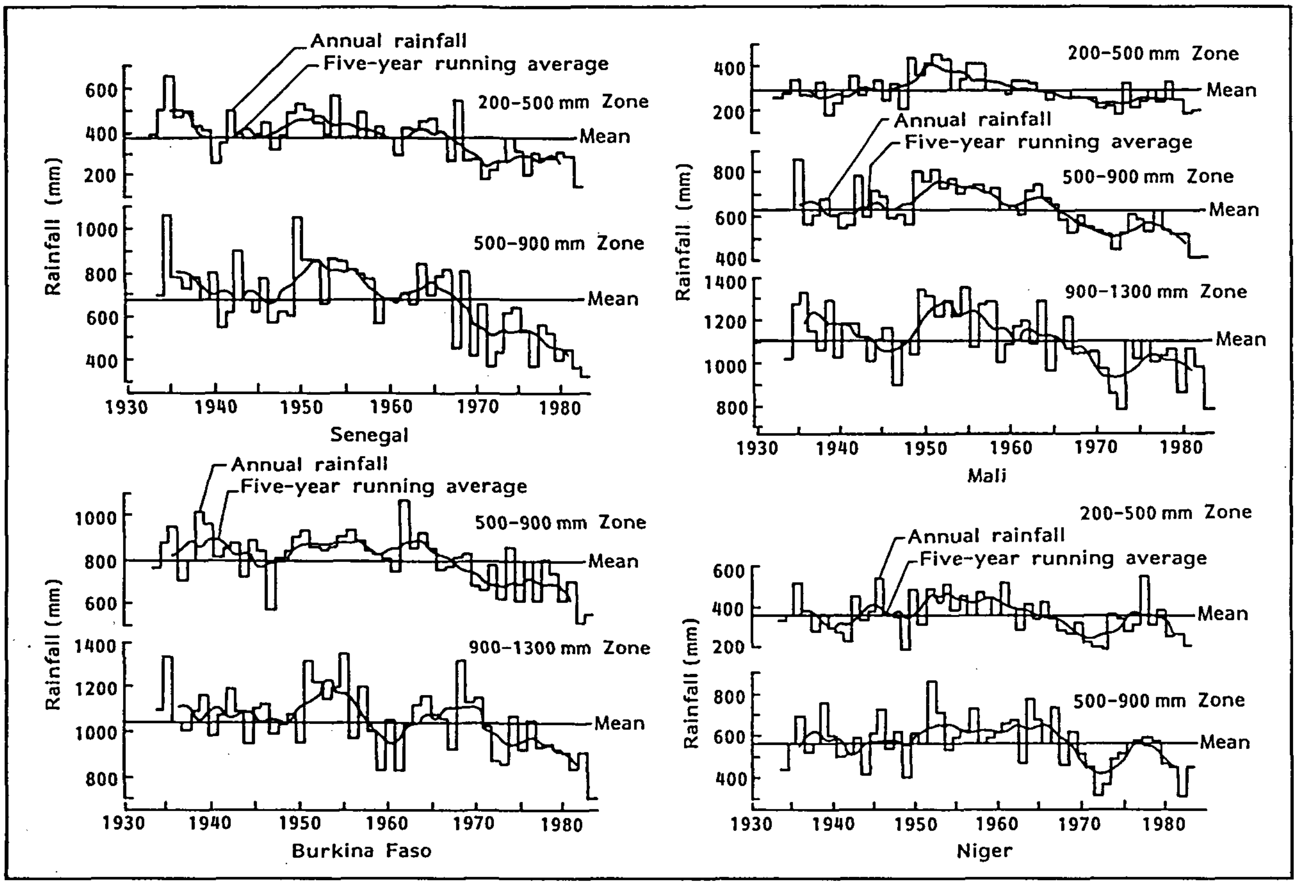

Figure 4. Annual amounts of rainfall, five-year running average and mean annual rainfall in Senegal, Burkina Faso, Mali and Niger, 1934–83.

increased to provide a better standard of living for an expanding population base. Simultaneously, on the other hand, the planners are confronted with the fundamental methodological problems of developing and managing water projects on the basis of inadequate and sometimes unreliable data, which makes water planning and management a risky task at the best of times. Furthermore, present experiences indicate that some of the recently tried, so-called sophisticated methodologies used in water management are in many cases not as reliable as their proponents have advocated them to be.

During recent years, an important research focus in most parts of the world has been an attempt to predict climatic changes that may occur in the future, say in 20 to 60 years' time. This concentration of research emphasis primarily on potential future climatic changes unfortunately appears to have diverted the attention of hydrologists, climatologists and other water professionals from the urgent necessity of how to cope efficiently with climatic fluctuations which have already been clearly observed in many river basins during the past few decades. Such fluctuations are not merely part of a hypothesis: they are a reality. This is an area that must receive priority attention in the near future.

Conclusion

Climatic fluctuations have always been considered to be an inherent part of any water-resources planning process. On the basis of recent experiences from many parts of the world, it is now clear that existing planning processes and hydrological methodologies need to be substantially improved, at least for certain areas of the world where such fluctuations have been considerable, in order that both water management and agricultural development processes may be optimised on a long-term sustainable basis.

Much concern has been expressed, especially during the past five years, about the prospect of climatic changes induced by global warming due to increasing concentrations of carbon dioxide and other greenhouse gases. While the threat of global warming

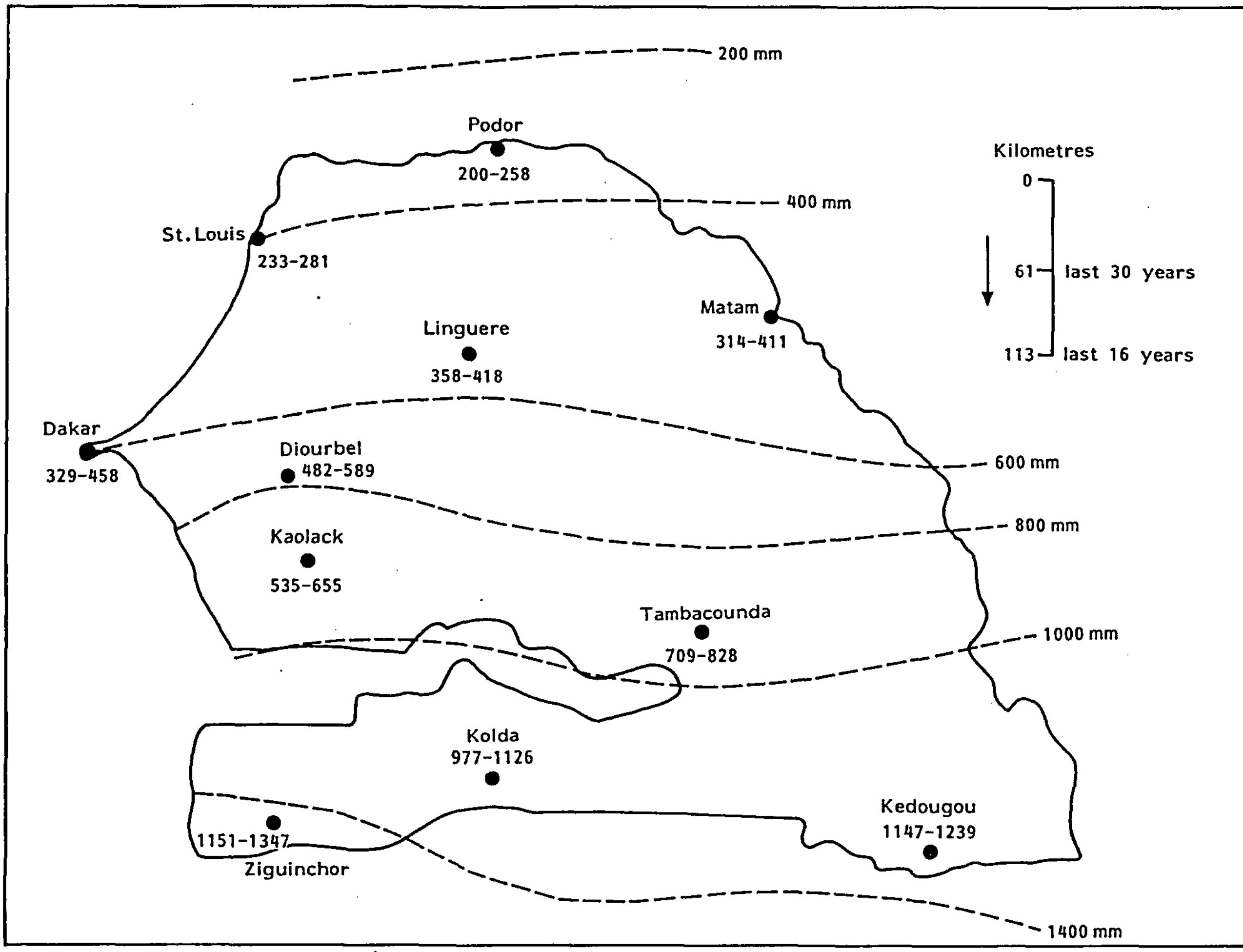

Figure 5. Isohyets of mean annual rainfall in Senegal.

Notes: Mean amounts for the last 16 and 30 years are shown for selected stations. Also shown are the distances by which the isohyets should be moved southwards for the more recent averaging periods.

has to be taken seriously, it is argued that not enough detailed information and data are currently available on potential climatic changes to enable water resources planners and managers to incorporate such changes into individual water projects in any specific way. The type of information available at present is primarily of a macro nature which, even if it is considered to be reliable, can at best be incorporated into the planning process in a very broad fashion. The problem is further complicated since, even for such macro-scale information, there is no consensus among scientists on the magnitude, spatial distribution and time-scale of such changes.

While climatic change is a long-term potential threat, there is no question that proper consideration of climatic fluctuations within the water-resources management process is a real, major, current problem. And yet, paradoxically, most of the present research efforts have been directed towards the implications of potential climatic changes for water management; very limited work is being undertaken on how to deal effectively with climatic fluctuations, which can already be identified as a serious problem. Hydrologists, climatologists and other water-resources professionals must redress this balance.

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