DEFINITIONS AND EFFECTS OF DROUGHTS

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Dionysia G. Panagoulia
National Technical University of Athens

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Dionysia Panagoulia[1] and George Dimou[2]

[1]National Technical University of Athens, Department of Civil Engineering,
Division of Water Resources – Hydraulic and Maritime Engineering,
5 Iroon Polytechniou, 15780 Zographou, Athens, Greece
Tel. +30 210 7722858, e-mail: dpanag@hydro.civil.ntua.gr
[2]Civil engineer, 7 Voutyra, 16673 Voula, Athens, Greece

1. INTRODUCTION

Man has always faced weather and climate vagaries and problems related to droughts. However, the recent problems of inadequate water quality, which effectively reduced the available resources, increased the severity of water deficits. Drought-related disasters have been more devastating than other natural hazards (earthquakes, volcanoes, etc), as far as deaths, suffering and economical damages are concerned. Apart from destructive direct effects, drought events have been followed by secondary, indirect calamities, such as famine, epidemics, fire, etc. Despite the progress in science and technology, man is still vulnerable to extreme drought events. The losses increase due to the continuing development of costly infrastructure, rise in population density, and decrease of the buffering capacities (deforestation, urbanization, drainage wetlands, etc). Understanding droughts, their occurrences, mechanisms, characteristics and regularities is of great importance for the design and management of water resources systems.

The study of drought problems includes the following topics:

- identification of meteorological causes and drought forecast
- evaluation of hydrologic drought characteristics at a site and over a region
- analysis of economic, environmental and social effects of drought
- definition of appropriate policy and management strategies for mitigating and controlling drought effects.

Although an analytical literature review of droughts is not attempted, an outline of the most important philosophies in drought definition and effects is given below:

(a) Drought definition stage. In this stage, several disciplines recognize the importance of the analysis of such a natural hazard and try to identify the essential features of a definition of drought phenomenon. Among-possible references, pioneering works from a hydrological point of view include Eredia (1922), Blumenstock (1942) and Yevjevich (1967); from an agricultural point of view Van Bavel (1953) and Palmer (1965); from a socio-economic point of view Tannehill (1947) and Russel *et al.* (1970).

(b) Drought description stage. This stage includes methods for analyzing historical droughts aiming at:

- evaluating the risk of future droughts
- determining the consequences on economy, environment, and society
- adopting an appropriate policy for mitigating drought effects

Regarding this stage, there are many references which could be mentioned, for instance Glantz (1966), Rosenberg (1980), Doornkamp and Gregory (1980), French (1983), Grigg and Vlachos (1989), Dracup and Kendall (1991), etc.

(c) Integrated system approach stage. In this stage, the single variable and single discipline approaches are recognized to be insufficient for providing a good understanding of drought problems. Many attempts have been made for a more comprehensive analysis in order to characterize adequately the drought phenomenon and also for developing a more effective action against its consequences. As a reference for this stage, several books can be considered (Campbell, 1968; Warrick, 1975; Yevjevich et al., 1978), as well as the proceedings of several international symposia (Yevjevich et al., 1983, Urbistondo and Bays, 1987; Wilhite et al., 1987; Siccardi and Bras, 1989; Tardieu and Plus, 1989).

The aim of this report is to provide a description of the background of the definition and the available methods characterizing point and regional droughts. Emphasis is given to the spatial variability over a region, and the effects of drought over the water consumption and use sectors, such as domestic, agricultural, industrial, etc activities. Existing data and studies are presented. Finally, some implications for policy and action programs are provided.

2. DEFINITIONS OF DROUGHTS

Many drought definitions are adopted in different fields (meteorology, hydrology, economy of water resources), with reference to various hydrometeorologic variables.

Meteorological drought

Meteorological definitions of drought are the most prevalent. They often define drought solely on the basis of the degree of dryness and the duration of the dry period. Thus, meteorological drought has been defined as a period of more than a particular number of days with precipitation less than some specified small amount (Wilhite and Glantz, 1985).

Hydrologic Drought

Definitions of hydrologic drought are concerned with the effects of dry spells on surface or subsurface hydrology, rather than with the meteorological explanation of the event. The frequency and severity of hydrologic drought is often defined on the basis of its influence on river basins. Hydrologic droughts are often out of phase with both meteorological and agricultural drought.

Agricultural Drought

Agricultural drought occurs when soil moisture is depleted to the extent that crop and pasture yields are significantly affected. Agricultural drought definitions link various characteristics of meteorological drought to agricultural impacts, focusing, for example, on precipitation shortages, departures from normal, or numerous meteorological factors such as evapotranspiration (Wilhite and Glantz, 1985).

Socio-economic Drought

Definitions which express features of the socioeconomic effects of drought can also incorporate features of meteorological, agricultural, and hydrological drought (Wilhite and Glantz, 1985). They are usually associated with the supply and demand of some economic good. YevJevich (1967) has suggested that the time and space processes of supply and demand are the two basic processes that should be considered for an objective definition of drought.

3. MANAGEMENT USE OF DROUGHT INDICES

To water managers, drought means problems in meeting demand. In that sense, drought means not having sufficient water to meet demands because supplies fall below expected levels. The "expected levels" are socioeconomic, because expectations can be adjusted. Because of this link with socioeconomics, a drought index that will be useful to management must incorporate aspects of demand—that is, how adequate are supplies to meet demand? To design an index for a particular situation, the following approach might be used:

$$\text{Index}=\frac{\text{available water supplies}}{\text{expected or mean water supplies}} \tag{1}$$

Available water supplies might include surface water, stored water, groundwater, and soil moisture. The definition given earlier from the City of Portland (Grigg, 1996) leads to the "Portland water supply index". This index provides guidelines for the city to assess the adequacy of its water supplies.

9. THE IMPACTS OF DROUGHTS

Yevjevich *et al.* (1978) suggested that the study of drought problems would be facilitated if drought was considered in a systems context. As Yevjevich *et al.* (1978*)* noted, the physical aspects of drought are derived from the atmosphere–ocean–continent system. Each drought is unique in its set of physical characteristics as well as in its geographic scope and location. In is interesting to note that Yevjevich considers the physical characteristics of drought to be dictated by the physical environment. Drought events are shown as inputs to a physical environment system and a social system. The characteristics of drought events, physical-environment systems, and social systems combine and interact to produce impacts on the physical environment and social system. The social system responds to mitigate or alleviate drought-related impacts. This view of drought reflects the focus of previous studies of drought on the physical aspects of the phenomenon. Yet the ultimate significance to society of drought lies in its impacts.

10. EXISTING DATA AND STUDIES

During the 1980s and 1990s the United States and other nations were hit with a number of droughts, some quite severe. These droughts were so widespread and the effects and measures so variable that it is impossible to describe all aspects. Some examples related to Greece will serve to illustrate the range of problems.

Characteristics of Meteorological Droughts of the Last 132 years in the Plain of Attika

Characteristics of meteorological droughts of the last 132 years in the plain of Attika, Greece, are critically analyzed (Baloutsos *et al.*, 1993). The purpose is to point out the necessity of the development of a national drought policy which would help to minimize adverse effects before the occurrence of intense drought phenomena. The data were collected from the Meteorological station of the National Observatory of Athens.

For the quantification of the intensity of drought the index $Y=\left(R-\overline{R}\right)/S_R$ is used and is estimated from the annual amount of precipitation (*R*), the mean annual value

$\left(\overline{R}\right)$ and the standard deviation (S_R). A drought is characterized as severe, if Y ~ -1.5 units.

From analysis of the data, it was found that 11 severe droughts occurred during the past 132 years having a mean return period of 12 years. Certain evidence that droughts were more frequent during the last 90 years than the previous 40 years of this period eventually appeared to be due to the method of analysis and not to actual events. Most droughts lasted for one year and only a few having a duration of two years. The most severe droughts occurred during the period 1988-1990. It was also found that droughts commence any month from October to January randomly and terminate in October of the next hydrological year.

Drought and its Potential Causes in Greece

The monthly totals of precipitation of 21 Greek stations for the period 1950-1990 as well as the calendar of classification of the types circulation were studied (Maheras, 1992). The mean and standard deviations of rainfall totals were calculated for every station and for all stations. The dry years and seasons were defined. The trend of seasonal and annual precipitation were also examined. In this study was founded that (1) the most intense drought occurred in the period 1989-1990, (2) an intense trend of precipitation for annual and seasonal values was appeared, (3) a trend of increase in the frequencies of the stable types of circulation in annual and seasonal scale was revealed , and (4) the droughts in Greece are accompanied with positive anomalies of the atmospheric pressure over the Southern Europe and the Mediterranean.

Climatic Instability and Low-Flow Regimes in Greece

The low-flow regimes of Acheloos river at the outfall of the mountainous Mesochora catchment in Central Greece were analyzed under conditions of global climate change (Panagoulia amd Dimou, 1995). The climate change pattern was simulated through a set of hypothetical and monthly GISS (Goddard Institute for Space Studies) scenarios of temperature increase, coupled with precipitation changes. The daily flow of the catchment, which is diminated by spring snowmelt runoff, was simulated by the coupling of the snowmelt and soil moisture accounting models of the US National Weathewr Service River Forecast System. A low-flow day was defined as a day during which the streamflow did not reach the quarter of the long-term mean daily streamflow. In this case the low-flow parameters (occurrences, duration, magnitude, etc.) were determined. Despite the complicated response of low-flow occurrences to climate changes, both hypothetical and monthly GISS representations of climate changes resulted in more and longer low flow episodes foe climates with reduced precipitations (Fig. 6). All climates yielded larger low-flow mean deficits and smaller mean values of minimum sreamflows. These results could possibly further jeopardize the river quality, the reliability of the storages and dams, as well as the water supply from local groundwater sources.

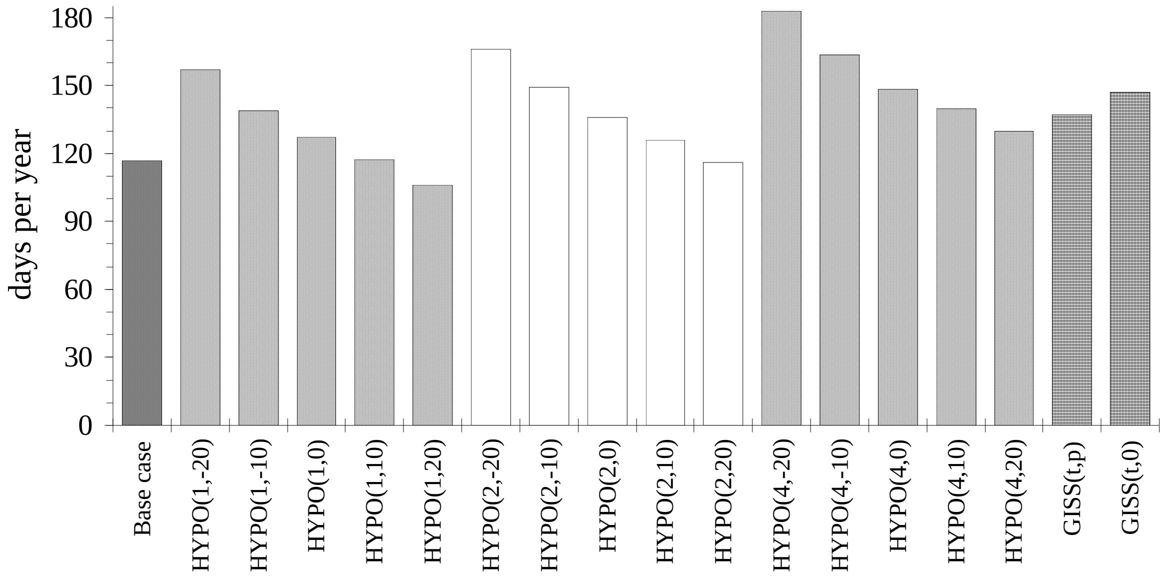

Figure 6 Mean number of low-flow days per year of Acheloos river at Mesochora catchment outfall for the HYPO, GISS and base case climate scenarios.

Droughts in Water Reserves in Athens, Greece

Water resources of the greater Athens area are unevenly distributed. In this regard, the context of the metropolitan Athens area may be summarized in the following

Water reserves in Mm^3

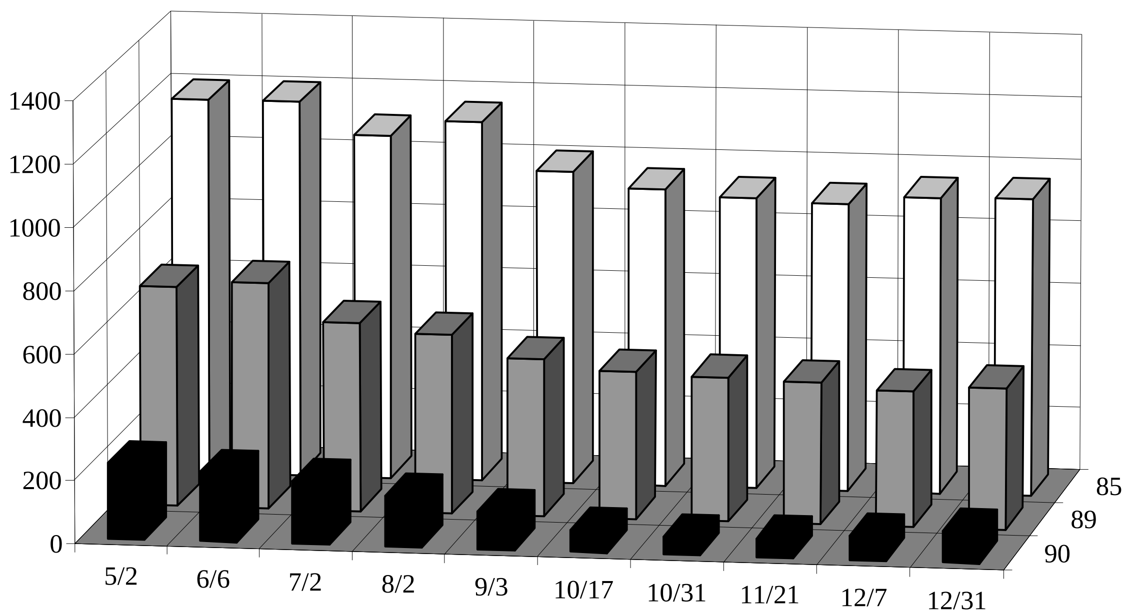

Figure 7 Drought impacts on the city of Athens, Greece.

components: the area is semiarid and subject to shocks due to the water scarcity; there has been a rapid and high concentration of population and activities with marginal and decaying infrastructure; and the management experience of complex systems seems to be limited. Hence, Athens is under stress with very little resilience to natural hazards.

Karavitis (Grigg, 1996) found that for the 1990-1992 droughts in Athens (the 1990 drought was the worst on record), the databases were neither complete nor reliable and the water allocation plan was at best haphazard. To illustrate the severity of the drought, the water reserves of Athens are presented in Fig. 7. To give an indication of the magnitude of the problem, in October 1990 the Athens metropolitan area had water reserves of only 56 days.

Karavitis found that in Athens, drought impact assessment, alert mechanisms, and contingency planning were generally not satisfactory; responses were piecemeal, with an emphasis on short-range actions. Measures were applied well after the onset of the event, with little consideration to the crucial timing factor. Moreover, response since the drought has not moved to solve the underlying problems of supply and preparedness.

11. MANAGEMENT STRATEGIES

Like floods, management strategies for drought can be summarized as structural and nonstructural, hardware and behavior. Figure 8 illustrates the range of responses identified by Grigg and Vlachos (Grigg, 1996).

12. CONCLUSIONS

The lack of a precise and objective definition of drought in a specific situation has been an obstacle to understanding drought, which has led to indecision and/or inaction on the part of managers, policy makers, and others. There should not be a universal definition of drought. Available definitions demonstrate a multidisciplinary interest in drought. It is useful to subdivide definitions into four types on the basis of disciplinary perspective (meteorologic, hydrologic, agricultural, and socioeconomic). Most scientific research related to drought has emphasized the physical over the societal impacts of drought. Drought severity is sometimes expressed by its societal impacts, although the precise nature of those impacts is difficult to quantify. Secondary and tertiary effects often extend beyond the spatially defined borders of drought. Human or social factors often aggravate the effects of drought.

The vulnerability of large cropland areas, as well as the steady development of large-scale complex water systems, emphasizes the importance of the regional drought definition/ estimation in order to plan in advance, the necessary drought control measures.

Despite the fact that many statistical methods and mathematical models allow the extraction of available information on the underlying hydrologic process from the station series within a region, a consolidated definition of regional drought is still lacking.

The review of the several studies devoted to the regional drought analysis allows us to distinguish: (i) a simple description of the areal coverage of historical regional drought events; (ii) the probabilistic estimation of drought characteristics through the direct use of historical samples; (iii) the analysis of the statistical properties of a few indices, which describe the space-time variability of the drought phenomenon (in particular, on the basis of rainfall or streamflow depths).

A number of challenging research and study areas could be distinguished therein as the agenda for the scientific community during the next decade, related to three classes of problems dealt with by three working groups:

(1) Descriptive studies and models.
(2) Monitoring.
(3) Forecasting

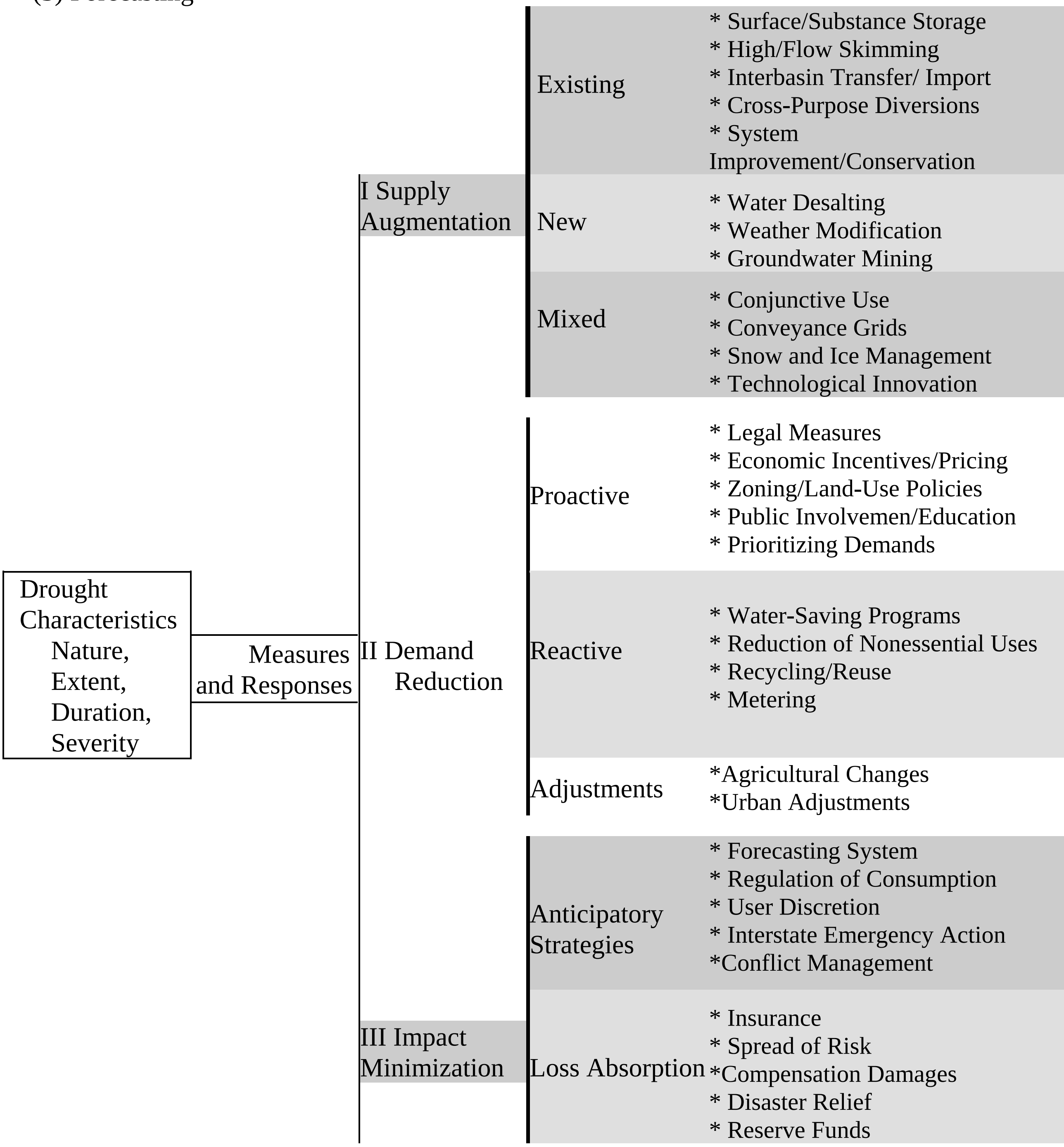

Figure 8 Management strategies for drought. (from Grigg, 1996)

The most challenging research areas are:

(a) Representation of the temporal and spatial structure of the variability of the drought phenomena.
(b) Study of the effects of anomalies in atmospheric circulation systems.
(c) Development of a drought taxinomy, that includes, drought descriptors, probabilities, causes and impacts.
(d) Detecting variations in water quality in surface freshwater bodies and aquifers related to occurrence and duration of droughts.
(e) Inherent predictability of drought variability as a function of various parameters.
(f) Determination of the relative importance of local and regional physical feedback in intensifying and/or perpetuating drought.

A strong growth area is the study of tele-connections, i.e. linkages of drought events with other geophysical features (e.g. Indian summer monsoon rainfall versus snow cover in Eurasia in the preceding winter, ENSO, i.e. El Nino Southrn Oscillations phenomena).

Altough the possibility of controlling drought events seems, illusory, it is certain that people will continue to strive towards the progress in understanding, modelling, and forecasting droughts. This will happen even under the assumption of stationary natural conditions.

It has been typical that the occurrence of drought events and significant losses gives the impetus to the targeted research. This has been called sometimes a “hydro-il-logical cycle”. A prolonged dry spell triggers the initiation of drought-related studies.

Finally, there is no doubt about the fact that computerization of drought management is rapidly progressing all over the world. However, in this context one should stress the significance to the human factor. Machines, without men would probably deteriorate the socieytal resistance and resilience against disasters.

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