DROUGHT RISK AND VULNERABILITY IN WATER SUPPLY SYSTEMS

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SUMMARY: This paper provides an overview of the challenges presented to the managers of water supply systems by drought and water scarcity. Risk assessment is an essential tool for the diagnostic of water scarcity in this type of systems. The evaluation of the risk of water shortage is performed with the use of complex mathematical models. Different alternatives to address the problem are presented, covering a range of methodological approaches. The actions adopted to prevent or mitigate the effects of water scarcity should be properly organized in drought management plan. The process of development and implementation of drought management plans is briefly described presenting several examples taken from the Mediterranean region.

Key words: Drought, risk management, vulnerability water resources management

***RESUME**: Aquí la traducción al francés, en cursiva…*

***Mots-clés**: Format*

INTRODUCTION

Water supply systems are designed to provide enough water to satisfy users' needs and fulfil the established standards of service. The development of these systems has to cope with the result of a territorial, economic and social development model in an environmental and institutional context that dictates many of the peculiarities and conditions under which this activity is developed and very often the water supply systems have to face changing conditions over time: hydrologic variability, growing demands, evolution of standards of service, etc.

In the urban water sector, the important temporary evolution that major cities around the world have undergone is in general linked to fast growth, representing a challenge involving opportune adaptation of urban services to the needs and expectations of the citizens and in particular to water. Increases in population, changes in climate conditions, modifications in the availability of resources and increased social demands determine a higher than desirable frequency of episodes with a high risk of service disruption.

Within this context, with such important dynamic components, droughts occur very frequently in Mediterranean countries, placing water supply systems under additional stress. These non-desired situations may have significant effects and impacts, with severe economic and social consequences also connected to the vulnerability of water supply systems, agricultural systems and of society in general. Such vulnerability could be due to situations of permanent water scarcity, quality deterioration or increasing water demands.

Societies in the 21st Century measure the degree of development by the capacity for reaction to these situations, through their prevention, mitigation and effective resolution, amongst other parameters. That is why drought management procedures are a kernel part of water supply systems management.

DROUGHT RISK IN WATER SUPPLY SYSTEMS

Water supply systems are a combination of natural, technological and socioeconomic elements, which are coordinated to provide adequate service to water users. Water supply systems are designed to get water from aquifers and rivers, store it and distribute if to users under a set of acceptable conditions regarding water quality and quantity. Reliability and vulnerability of water supply systems to water shortages are required parameters to design and operate the systems. Usually, these factors are evaluated with the help of water resources simulation and optimisation models, which provide a framework to extract additional information that can be very useful for decision makers.

Droughts, understood as periods with low precipitation patterns, are a normal phenomenon although of little frequency of occurrence. Droughts, understood as a climatic phenomenon triggering episodes of high-risk of non-fulfilment of service standards, constitute a main part of the planning, designing and management work of a water supply system. Not all water resource systems suffer water shortage under a given drought situation. From the management perspective, water shortage is the inability of a water system to serve whole its water demands. This scarcity is related with the absence of rainfall, the reduction of streamflow or the depletion of water table levels, but also with other non-meteorological factors, such as lack of infrastructures for water storage or transport, excess of demand, inadequate operating rules or constraints for water management (water rights, infrastructure failures, floods).

Practices involving the design and operation of supply systems have historically incorporated different principles to address these problems in accordance with the economic capacity of each case and circumstance and social expectations involving continuity, stability and quality of service. Even so, applied technical procedures have adapted to the new legal and cultural frameworks and to the needs that have derived from the changing conditions of each system.

Currently, risk constitutes one of the fundamental components in the management of water supply systems. Risk is understood as the probability of certain threats arising that cause damage or impact one or more social agents. Risk is a circumstance that corresponds to each system under certain conditions. In the case of supplies, the effects are always measured in terms of number of users and the time interval during which they do not continuously enjoy the service conditions established as satisfactory or “standard”. Under the present situation of each system there is a risk that corresponds to each one of the possible threats. In turn, a risk will correspond to each threat under any of the scenarios, horizons and future hypotheses considered.

METHODOLOGIES FOR DROUGHT RISK EVALUATION

Risk assessment in water supply systems consists on identifying demands that may not be fully satisfied with available water resources, and quantifying the estimated impacts of water shortage. There is a range of tools and models that can be used in this diagnostic process -- from simple indices to complex water resource systems simulation models. Mathematical simulation and optimisation models may be used to obtain quantitative results accounting for all system complexities in an uncertain context (Labadie, 2004). These models provide guidance for identifying unsatisfied demands, evaluating the effect of yield enhancement or water conservation measures, and scheduling available actions (Andréu et al, 2003).

In the context of risk assessment, it is unavoidable to assign a probability of occurrence to unwanted events. For planning purposes, unconditional risk assessment is applied to quantify and compare different planning alternatives on a long term basis. For operational management purposes, risk assessment is conditioned to the current state of the system, and it is used to identify and compare management strategies to prevent or mitigate adverse effects of droughts. The acceptable risk level is conditioned by available water resources and infrastructures and is determined by the demand characteristics and their elasticity. In this context, risk assessment should consider the following aspects: (a) Probability of failure occurrence (probability of not satisfying the demand); (b) Severity of failures (magnitude of the deficit); (c) Failure duration (time span when deficits occur); and (d) Economic impact of failures.

These probabilities may be estimated through different methodological approaches. The simplest approach consists on analyzing a set of droughts, which are selected as representative of droughts of certain severity and associated to a given probability of occurrence. These droughts may correspond to actual episodes registered in the past or to synthetic droughts derived from the probability distribution of annual or monthly flows (Garrote et al., 2007). A water resources system model may be used to analyze the consequences of such period of low flows in the system, as a function of current storage volumes, and to develop operating rules to minimize impacts.

A more elaborate approach is stochastic simulation, which consists on repeated simulation of system behaviour with a synthetic set of inflows that is representative of the ensemble of future inputs. For instance, the model SimRisk (Sánchez Quispe et al., 2001) was used to generate Figure 1, which represents the probabilities of shortages of different intensities over time for a certain group of demands. These results or other equivalent reliability measures are normally used for decision making, identifying demands that do not comply with a pre-specified minimum standard.

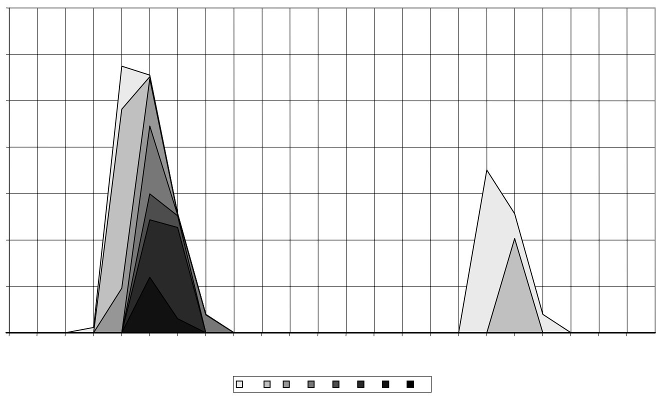

Figure 1: Risk of water shortages for a given system state

An elaboration of the data included in Figure 1 may be used to generate Figure 2, which represents the probability distribution of supply for a given demand in different time horizons. For instance, the probability that supply is at least 90% of the demand for the month of August is 27%, while the probability that supply is at least 70% of the demand for the same month is 14%. These data may be used as a basis for decision making in system management.

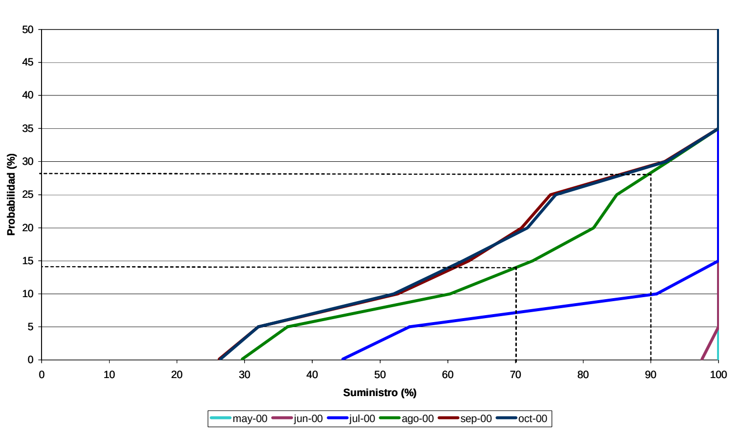

Figure 2: Probability distribution of supply for different time horizons

From the operational perspective, risk assessment may also be used to establish thresholds in system state to activate different types of risk management actions. Since future reservoir inflows are uncertain, these thresholds should be formulated in probabilistic terms. Thresholds are defined as the available storage in the system, *S*, that is required to satisfy a fraction, *f*, of the demand in a time horizon, *h*, with a given probability, *p*. Values of *f*, *h* and *p* are model parameters that should be fixed though discussion with stakeholders. They depend on several factors: the type of the demand in the system (urban, irrigation, hydropower, etc.), the reliability of the current water supply system, the alternative management strategies that can be applied during shortages, the vulnerability of the demand to deficits of a certain magnitude, etc.

Some systems, like Canal de Isabel II in Madrid (Spain) are using this type of method from the 90s as part of its procedures for operational planning and risk assessment. Figure 3 and 4 show the threshold managed for this purpose and reported in its Supply Manual.

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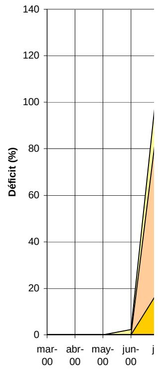

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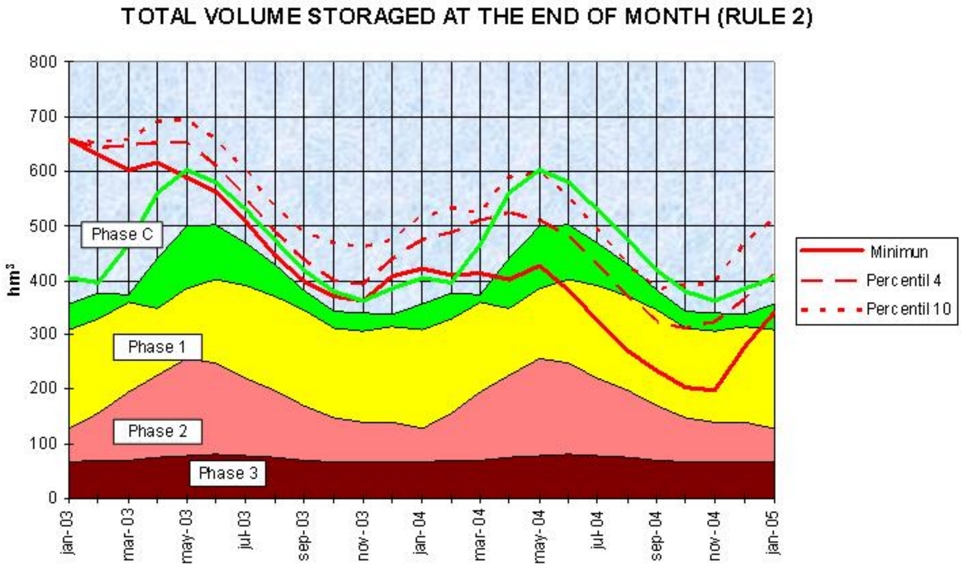

Figure 3: Forecasted short term evolution of storage related to threshold of impacts and probability of occurrence.

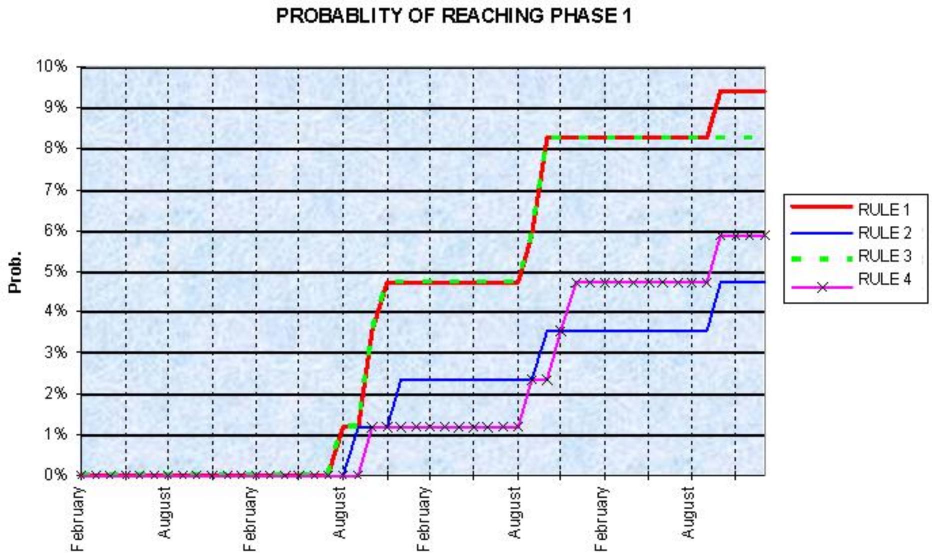

Figure 4: Assessment of risk of shortages for different operational rules.

DROUGHT RISK MANAGEMENT PLANS

There are two main approaches to drought risk management: the crisis management approach and the preventive approach. The crisis management approach is based on the implementation of measures and actions after a drought event has started and is perceived but without a clear definition of procedures to follow. This approach often results in inefficient technical and economic solutions since actions are taken with little time for evaluating optimal actions and stakeholder participation is very limited. It has also been proved (Wilhite, 1997) that this approach increases drought vulnerability through a series of adaptive strategies adopted by the exposed population if they believe that aid will be provided in the event of drought. The preventive approach includes all the measures designed in advance, with appropriate planning tools and stakeholder participation. Proactive drought risk management may be developed along two non-excluding courses of action. On the one hand, measures to avoid drought-induced water scarcity in the water resources system should be identified, prioritised and implemented. Timely availability of these means (supply enhancement and water conservation measures) increases the system's reliability to droughts and avoids demand deficits. On the other hand, mitigation actions should be planned to be taken while the drought is developing. Anticipation of possible mitigation actions may reduce the system's vulnerability to droughts by minimising the magnitude of damages through management strategies (water distribution among users, emergency supply works, etc.) and administrative measures (limitation of water consumption, water markets, emergency relief funds, etc.)

In order to achieve proactive drought management, a Drought Management Plan should be drafted and implemented. The Plan should include continuous monitoring of hydrometeorological variables and of the status of water reserves in order to identify possible water crisis situations and to apply the necessary measures before real water emergency occurs. The mitigation measures should be clearly defined together with the instructions for their implementation. No single management action, legislation or policy can respond to all the aspects and achieve all goals for the effective drought management. Multiple collaborative efforts are needed to integrate the multidimensional effects of drought on society.

A clear assignment of competences among the different institutions involved is a key issue; therefore a legislative act which defines the responsibilities is necessary in each country. For instance, in Spain, the Law of the National Hydrologic Plan, approved in 2001, established new legal instruments for drought management. The action is based on three main instruments (Estrela, 2006): (1) A drought monitoring system based on drought indicators for each Basin Authority and for the entire country; (2) Special Drought Management Plans for Basin Authorities; and (3) Emergency Drought Plans for urban water supply systems serving more than 20,000 inhabitants.

The National System of Drought Indicators was developed during 2006 by the Spanish Ministry of the Environment. It is currently operational, and may be accessed on the web page of the Ministry of the Environment, in the National Drought Observatory. The system of indicators is a general reference for Basin Authorities for formal declaration of drought situations, which can activate drought emergency measures with legal constraints or specific budget application.

Spain has recently completed the process of drafting Drought Management Plans for all Basin Authorities. Special Drought Management Plans (SDMP) at river basin level are complementary to River Basin Management Plans (RBMP) for drought conditions. SDMPs are mainly targeted to identify the conditions and schedule the activation of tactical measures to prevent or mitigate drought effects. Therefore, measures involved are mainly water demand management or water conservation measures and, with the progressive application of the Water Framework Directive schedule, measures to achieve and comply with good environmental status.

At local level, specific emergency plans for all public water supply systems serving more than 20,000 inhabitants will have to be developed. The objective of these plans (Cubillo and de Castro, 2007) is to ensure that a proactive approach is adopted for drought management in urban water supply, avoiding the need to implement improvised emergency measures under the pressure of imminent water shortages. Some agencies, like Canal de Isabel II, which provides water supply to the city of Madrid and its metropolitan area, have already developed and implemented such plans. For instance, the Supply Manual (Cubillo, 1999) of Canal de Isabel II expresses the protocols and good practices to:

- Establish the risks of scarcity and incapacity of the supply system to satisfy all demands.
- Establish efficient management policies of the resource and water demand.
- Ensure an integrated and sustainable management of resources.
- Establish guidelines to operate the supply system handling short-term outlook.

- Integrate the satisfaction of environmental constraints and sustainability of related ecosystems into the operation of the supply system.
- Manage the supply under conditions of drought and scarcity of resources.
- Manage the supply system in case of large-scale contingencies and anomalies, such as floods.
- Plan actions to guarantee the water supply in the medium and long term with the established risk level.

Recently, the MEDA-Water project MEDROPLAN has published Drought Management Guidelines (Medroplan, 2007) to provide Mediterranean countries with a framework for effective and systematic approach to prevent and/or minimize the impacts of drought on people. The Guidelines give the tools to analyse drought management in selected Mediterranean countries promoting a risk based preparedness and mitigation approach, and can be used as a starting point for this type of initiatives.

CONCLUSIONS

Water supply systems are designed to provide water in adequate conditions of quantity and quality. In many areas, growing demands associated to socioeconomic development have led to important water scarcity problems. Drought conditions impose additional stress on water supply systems, which have to face the risk of frequent water shortages and significant socioeconomic impacts. The diagnosis of the problem is an essential first step to proceed with management actions. Risk assessment is currently standard practice for this diagnostic process. There is a range of tools and models that can be use for risk assessment in water supply systems, ranging from very simple indices to highly complex decision-support systems. These methodologies provide a framework for objective analysis, which is essential in the process of decision making.

Risk management actions should be properly organized in drought management plans. Many Mediterranean countries are involved in the process of development of drought early warning systems and risk management plans at different levels, from local urban supply systems to national initiatives, as a result of the increasing challenges of water management and the growing awareness of citizens and governments. These efforts provide opportunities to test the proposed methodology for drought risk assessment and management.

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