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Drought Management Guidelines Technical Annex

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Foreword

Natural rainfall variability is a recurrent characteristic of Mediterranean climate and intensive drought events have been more frequent in the last four decades with significant damages derived from water scarcity and low water quality at the local and national levels. The Mediterranean Region's development is strongly dependent on water resources availability, and the uncertainty derived from drought leads, undoubtely, to a condition of underdevelopment and degradation. It seems likely that climate change will be an additional stress in the process.

In this context, Mediterranean countries have adapted to their climate and have extensive legislation, institutional capabilities, and technical resources to face drought. Nevertheless in most cases a proactive drought management based on anticipatory planning is not implemented. It is not unusual to observe a response to immediate needs during a drought period and to implement costly remedies attending to balance competing interests. In many cases, this may not be an adequate response in the long term nor does it contribute to lessen future drought impacts. There is a need to formulate plans for drought management that shift from a reactive approach (crisis approach) to a proactive approach based on risk analysis, adapted to the current natural and social resources and taking into account the dynamics of the social and environmental pressures.

MEDROPLAN is a Project funded by the European Commission within the framework of the Euro-Mediterranean Regional Programme for Local Water Management. The Project is coordinated by the Mediterranean Agronomic Institute – CIHEAM. The objectives of the MEDROPLAN Project are to provide Guidelines for Drought Preparedness Plans and the Framework for the setting up of a Drought Preparedness Network for the Mediterranean countries. The Guidelines have been elaborated following a common methodology for the analysis of drought risk and drought management and have been specifically formulated to address the physical, socio-economic, and environmental issues of the Mediterranean countries. The Guidelines incorporate the scientific background and knowledge on droughts, the meteorological, agricultural and hydrological drought aspects, their onset and end, their frequency of occurrence, water resource availability and water demand in relation to the climate, the water shortage observed and the impacts of water shortage caused by droughts in the six Partner countries of the Project (Cyprus, Greece, Italy, Morocco, Spain and Tunisia).

The MEDROPLAN Drought Management Guidelines are a tool to help and orient decision makers, technicians and stakeholders to cope with drought through the design and application of pro-active drought management plans. The Guidelines describe all the components needed in drought planning and are aimed to be understood by a wide audience.

The Technical Annexes of the MEDROPLAN Drought Management Guidelines, that constitute the present document, compile the technical and scientific results of the MEDROPLAN Project. They are addressed to a more specialized public, scientists and technicians interested in drought issues and in charge of dealing with drought problems in the water management and agricultural sectors. In the present publication, the reader can find in-depth information on the different components which constitute the drought planning methodology proposed by MEDROPLAN (the planning framework, the organizational, methodological, operational and public review components), and a compendium of examples of application that illustrate in detail and analyse some aspects of the Guidelines to specific situations, and include the description of effective measures taken in the past.

All the information contained in the Drought Management Guidelines and in these Technical Annexes can be consulted on the MEDROPLAN web page (www.iamz.ciheam.org/medroplan) and on a CD that is enclosed in the Drought Management Guidelines.

We gratefully acknowledge the organization and supporting institutions, the members of the MEDROPLAN team, and all the stakeholders that have participated in different ways in the Project, for their valuable input.

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I.4. Operational Component

PART II. EXAMPLES OF APPLICATION

Chapter 1. The Medroplan project: Process and key lessons

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Background

MEDROPLAN (Mediterranean Drought Preparedness and Mitigation Planning) is a project funded through the Euro-Mediterranean Regional Programme for Local Water Management (Meda Water Programme) whose first Call for Proposals was launched in January 2002.

The specific objective of this call was to enhance regional co-operation in the areas of sustainable and integrated management of water resources through institutional strengthening, raising the awareness of society, capacity building and participation. The Call for Proposals included six areas of action and four horizontal themes. The Areas of Action were: (i) Integrated management of local drinking water supply, sanitation and sewage; (ii) Local water resources and water demand management (quantity and quality) within catchment areas and islands; (iii) Prevention and mitigation of the negative effects of drought and equitable management of water scarcity; (iv) Irrigation water management; (v) Use of non-conventional water resources; and (vi) Preparation of national and local scenarios for the period until 2025 that enable precise objectives to be set and actions to be taken for sustainable water management. The Call also included four Horizontal Themes: (i) Strengthening institutional capacities and training; (ii) Exchange of information and know-how; (iii) Transfer of know-how and technology; and (iv) Awareness raising, mobilisation and promotion of commitment from the population.

The area of action "Prevention and mitigation of the negative effects of drought and equitable management of water scarcity" underlined the major interest of drought monitoring both to enable adoption of policies for appropriate response and to study the causes and possible evolution of this phenomenon with a view to developing methods for forecasting drought, including the effects of possible climate change. Other important facts included the appropriate early response to prolonged periods of drought –that is often not integrated into water management– and the fact that drought episodes are most often managed as crisis or emergencies without the proper overall adjustments in basic water management and in the agricultural systems. These facts, underly the importantce of changing current drought management practices and ensuring that water management and agricultural systems, in areas with recurrent droughts, fully integrate long term sustainable responses, as well as coherent emergency responses that are planned in advance.

The Mediterranean Agronomic Institute of Zaragoza (IAMZ-CIHEAM) had already initiated activities in this area by the time of the call for proposals. A training course on "Management strategies to mitigate drought in the Mediterranean: Monitoring, risk analysis and contingency planning" was organised in Rabat, Morocco, 21-26 May 2001, jointly organised by the CIHEAM, through the Mediterranean Agronomic Institute of Zaragoza and the Institut Agronomique et Vétérinaire Hassan II of Morocco, with the contribution of the European Commission (DG I). The goal of the course was to provide participants with methodologies and technical tools to develop and implement a comprehensive drought preparedness plan. The programme included an analysis of drought and future prospects for water supply and demand in the Mediterranean region, the methodologies for drought monitoring, risk assessment and the strategies for planning and policy development. The course was followed by 26 participants from universities, research centres and public administrations of 10 countries: Algeria, Egypt, Jordan, Malta, Morocco, Portugal, Spain, Syria, Tunisia and Turkey. During the course, a proposal to set up a network activity on drought strategies between Mediterranean countries and international organisations (FAO, ICARDA, UN Convention to Combat Desertification) was discussed and the need for international cooperation in this field was highlighted.

During 2001, the "FAO-ICARDA-EU Expert Consultation and Workshop on Drought Mitigation in the Near East and the Mediterranean" took place in Aleppo, (Syria (27-31 May 2001). Participants from 12 countries in WANA Region (West Asia and North Africa), along with specialists from the EU INCO-DC Project "A Decision Support System for the Mitigation of Drought Impacts in the Mediterranean Regions" and invited keynote speakers presented their experiences and discussed necessary future action and follow-up. The meeting concluded that due to the recurrence of drought waves with their detrimental socio-economic and environmental and socio-economic consequences to communities, serious and concerted efforts are to be exerted from all stakeholders in the Region to adopt and implement long-term preparedness and mitigation plans. Among the main recommendations made at the Meeting were the need to establish a Network on Drought for the WANA Region (which includes FAO Near East countries) and interested member countries of the European Union (EU), for facilitating the exchange of knowledge and experience relevant to the aspects of drought, including: early warning, drought characterisation, agro-meteorological and hydrological data and analysis, methodologies, impact assessment, evaluation and monitoring.

When the Meda Water call was launched, the IAMZ-CIHEAM took the lead to prepare a proposal, counting on some of the participants in the two previously mentioned initiatives. A meeting was organised at IAMZ in April 2002 in order to form the consortium and to discuss and write the proposal, that was finally submitted at the call deadline, at the end of May 2002. The consortium was constituted by two teams from MEDA countries, Morocco (Institut Agronomique et Vétérinaire Hassan II) and Tunisia (Direction Générale des Barrages et des Grands Travaux Hydrauliques, Ministère de l'Agriculture) and eight teams from UE: from Italy (Department of Civil and Environmental Engineering, University of Catania), Greece (National Technical University of Athens), Cyprus (University of Cyprus) and from Spain (Universidad Politécnica de Madrid, Confederación Hidrográfica del Tajo, Canal de Isabel II, Fundación Ecología y Desarrollo). The appointed project coordinator was IAMZ-CIHEAM. The consortium was to cover most of the needed expertise on the different matters to be dealt with in drought plans: meteorology, hydrology and water management, agriculture, urban water supply, environment and societal communication.

The project was approved and started on 15 June 2003.

Objectives, expected results and workplan of the project

The main final objective of the Project has been to provide Guidelines for Drought Preparedness Plans, adapted to the physical and socio-economic environment of the Mediterranean countries, and elaborated following a common methodology. It is expected that the Guidelines will provide partner countries with a logical and integrated approach to minimise the impacts of drought on their people and resources, and to change the way of facing drought from the present "Crisis Management" approach to proactive "Risk Management".

Another important objective of the project was to provide the framework for the setting up of a Drought Preparedness Network for the Mediterranean countries.

The Workplan of the project included the following main activities:

(i) Map the organisations and institutions working on meteorological data, hydrological data and those working on water resources management and drought mitigation. Collection, review, study and analysis of existing information on drought and drought mitigation plans in the Mediterranean countries and in the World.

(ii) Prepare Terms of Reference for Risk Analysis, a study on Drought Identification and Best Practices Report.

(iii) Educate and train partner countries participants in drought and risk analysis.

(iv) Carry out drought risk analysis and collect information on drought mitigation practices in the partner countries.

(v) Produce draft Guidelines for Drought Preparedness Plans.

(vi) Disseminate know-how and draft guidelines.

(vii) Verify and test Drought Guidelines in the member countries.

(viii) Prepare and propose a framework for the setting up of Drought Preparedness Network for the Mediterranean countries.

(ix) Present, analyse and disseminate the Guidelines in Mediterranean countries for formulating their own plans.

Project development and outputs

The project has been following the designed workplan quite accurately, although the precise definition of the methodologies to be used to carry out some parts of the project (risk analysis and testing of the guidelines, for example) that were not exhaustively described in the proposal have needed long and deep discussions. The decision on the different outputs derived from the project has been another issue which has also needed concertation and balanced efforts in order to reach an equilibrium between ambition and realism. The final agreement is that the outputs are structured into three main elements:

(i) The Drought Management Guidelines, which is a summary of the five components developed within the framework of the project: the planning framework, the organisational, methodological, operational and public review components. A compendium of examples of application to different case studies from Mediterranean countries is likewise included. The Guidelines are designed to appeal to a broad audience, with special reference to policy makers. Each component includes information that can be understood by a non-technical user and academic, technical and operational issues are also included, therefore linking scientific and policy communities. The document has been published in 6 languages (Arabic, English, French, Greek, Italian and Spanish) and is followed by examples in English and French of drought management experiences in the 6 countries participating in the MEDROPLAN consortium: Cyprus, Greece, Italy, Morocco, Spain and Tunisia.

(ii) The Technical Annex to the Drought Management Guidelines (this book), which is published as a special issue of the CIHEAM journal "Options Méditerranéennes". A CD version of the Technical Annex is included in a sleeve inside the back cover of the Drought Management Guidelines. The Technical Annex contains a deeper development of the issues dealt with in the Drought Management Guidelines and is aimed at specialists and experts in drought.

(iii) The MEDROPLAN website that contains all the information contained in the two documents mentioned previously also provides a tutorial that guides the user to finding and selecting the relevant information on the different aspects of developing a drought management plan, and provides examples of application of the proposed methods and models.

In addition to that, the book "Coping with drought risk in agriculture and water supply systems" will be published by Springer. This book will collect the most relevant scientific contributions obtained through the project.

Lessons learned

Regarding the first component of the elaboration of the Drought Guidelines, the Planning Framework, the first important issue is to have the certainty that the target country or region is in a real drought situation. **Drought** is a natural casual (random) temporary condition of consistent reduction in precipitation and water availability with respect to normal values, spanning a significant period of time and covering a wide region. Drought is not a permanent situation as for example **water scarcity** which indicates a permanent condition of unbalance between water resources and water demands in a region or in a water supply system, or **water shortage**, which is a man-induced temporary water imbalance.

For the organisational component, we have learned that the decision-making instances and the implication of stakeholders in drought plans is very diverse in the different countries, even in the EU countries where the Water Framework Directive (WFD) indicates that water management plans have to be elaborated at the level of the river basin and where "drought management (sub) plans" should also be elaborated at this level. For this reason, it is important to be sure that in the elaboration of a drought plan for a given country or region all relevant decision making instances and stakeholders are adequately represented, their relations and linkages are well known, as well as the legal framework is taken into account.

The methodological component implies drought characterisation, evaluation of possible impacts, risk analysis and evaluation of vulnerability to drought of different societal and economic sectors. Here the key aspect is to construct a system that provides and elaborates all the data needed in order to reliably inform decision makers and stakeholders of the overcoming of a drought and what level of impacts can be expected in the water systems, agriculture, economy and society in general. This component, is the one which probably needs greater and more stable collaboration between scientists and technical experts from various fields of knowledge (meteorology, hydrology, agriculture, etc.) and decision makers and stakeholders from different administrations and types of organisations. In this respect it is important that the person or institution which has the ultimate responsability in the elaboration of the drought plan is able to attract all the people and institutions mentioned and to create structures that allow them to work in a stable manner for the drought management plan.

The operational component, which has to identify both the long and short term actions to prevent and mitigate drought impacts, as well as the procedure to implement them, is the component of the plan which affects directly the whole or important parts of society and which has a higher economic, social and political impact. This component is directly linked with the previous one that provides the information to declare accurately and objectively the situation of drought and the corresponding level of emergency, that triggers the actions to be carried out to prepare and mitigate the situation. The specific actions or measures taken may depend very much on the approach, reactive or proactive, to cope with drought. Proactive measures are taken before the initiation of a drought event and aim to reduce the vulnerability to drought or improve drought preparedness. They are long-term measures oriented to increase the reliability of water supply systems to meet future demands under drought conditions through a set of appropriate structural and institutional measures. The reactive measures taken after the start of a drought are short-term measures which attempt to mitigate the impacts of the particular drought event within the existing framework of infrastructures and management policies, on the basis of a plan developed in advance and adapted to the ongoing drought, if necessary. Both types of measures are necessary and are in fact adopted in all MEDROPLAN partner countries, but the challenge rises after the adoption of the MEDROPLAN Guidelines, when Mediterranean countries will adopt more proactive measures in order to prepare them to face drought episodes in such a way that society in general is protected from the most negative effects of this natural event.

Challenges for the future

The methodology proposed by MEDROPLAN to produce Drought Management Plans can be applied throughout the Mediterranean region and most probably in other regions of the world that have to face drought episodes. The need for Drought Management Plans is increasing, given the recent drought episodes in most of Mediterranean countries and the projections of the effects of climate change, where recent reports, such as for example the IPCC WGII Fourth Assessment Report, predict worse climatic conditions for the Mediterranean area, with high temperatures and droughts and a general reduction in water availability and crop productivity, with other important sectors such as hydropower production and tourism also affected. With this background, we expect that the MEDROPLAN Guidelines will be useful as a tool to prevent and mitigate the effects of drought in the Mediterranean region and that the proposed Mediterranean Network on Drought Management may constitute the framework in which the Guidelines will be disseminated and utilised.

Chapter 2. Defining the planning purpose, framework and concepts

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SUMMARY – This component of the MEDROPLAN Guidelines for Drought Management defines the purpose for developing drought planning at the local, regional and national levels, and highlights the need to respond to changing pressures in the environment and society. Drought has a wide range of effects in different sectors, social groups, or the environment. Whether the drought plan addresses the full range of possible risks or focus in a few, it is necessary to establish the final purpose from the onset. The purpose determines the choice of methodologies for developing the plan. Proposed drought management actions can be applied at different time scales, with different objectives and at different points of the system. All these aspects are to be taken into account and defined throughout the management plan so that timeframes and responsibilities are clear enough to ensure the adequate application of the management plan.

Key words: Drought, impacts, language, stakeholders, proactive, reactive.

Defining the planning purpose and process

This component of the MEDOPLAN Drought Management Guidelines defines the purpose for developing drought planning at the local, regional and national levels, and highlights the need to respond to changing pressures in the environment and society.

Mediterranean countries are continuously adapting to their structural limitations and pressures –imbalanced distribution of water resources, conflicts among users, and between countries, large demographic changes, and recent globalization– but it seems likely that climate change will lead to further development of adaptation of different systems and populations.

Farmers and agricultural policy will have to adapt to the slow evolution of climate. If projections become a reality, water scarcity is expected to rise in the next decades posing additional problems to water managers and users. The combination of temperature increase and changes in the hydrological cycle limit some of the current adaptation measures, such as the increase of the volume of irrigation water. The human dimension of climate change impacts in the Mediterranean might not stop at the country level. There is the potential for more pronounced water conflicts with neighbouring countries (i.e. transboundary issues in rivers and many shared aquifers).

Adaptation capacity in the Mediterranean region is challenged in particular, as climate change comes in conjunction with high development pressure, increasing populations, water management that is already regulating most of available water resources, and agricultural systems that are often not adapted (any more) to local conditions.

Defining the purpose

Drought has a wide range of effects in different sectors, social groups, or the environment. Whether the drought plan addresses the full range of possible risks or focus in a few, it is necessary to establish the final purpose from the onset. The purpose determines the choice of methodologies for developing the plan.

The dynamic character of drought management plans

Drought management plans are always in progress. As technologies evolve, new programs are developed, and institutional responsibilities change, these plans have to be revised and updated; therefore all components need to be considered dynamic (Fig. 1).

The proposed guidelines for drought planning are the result of more than three years of research and they should be considered as an integrating framework, which takes into account almost every aspect of mitigating drought for the time being. It is true, though that from time to time it should be reviewed and probably edited and updated.

Fig. 1. Development and revision of a drought management plan based on the guidelines.

Defining a common language among stakeholders

The need to establish multi-stakeholder dialogue from the onset

(i) To increase the quality and acceptance of drought management plans.

(ii) To increase acceptance of or trust in the science that feeds into the planning.

(iii) To provide essential information and insights about drought preparedness, since the relevant wisdom is not limited to scientific specialists and public officials.

Challenges for involving stakeholders

(i) What are the incentives and means for engaging stakeholders?

(ii) How to represent stakeholder decision making in realistic terms?

(iii) How to ensure that complex models are transparent and provide insight to individual users?

Basic concepts for drought management

Drought, aridity, water shortage and desertification are common and overlapping processes in Mediterranean countries (Fig. 2) and often are misinterpreted and used. Starting with clear and agreed definitions and concepts contributes to the development of clear methods and the interpretation of the results for developing drought management plans. A glosary of terms in included at the end of this document.

	Nature produced	Man induced
Temporary	• Drought	• Water shortage
Permanent	• Aridity	• Water scarcity • Desertification

Fig. 2. Basic concepts related to water availability.

(i) *Drought:* Natural causal (random) temporary condition of consistent reduction in precipitation of water availability with respect to the normal values, spanning along a significant period of time and covering a wide region. It results from persistent lower-than-average precipitation.

(ii) *Aridity:* Natural permanent climatic condition with very low average annual or seasonal precipitation.

(iii) *Water shortage:* Man-induced temporary water imbalance. Water shortage in a water supply system represents a water deficit with respect to the demand, which can occur due to a drought or other antropic causes (e.g. low water quality, ill services).

(iv*) Water scarcity* indicates a permanent condition of unbalance between water resources and water demands in a region (or in a water supply system) characterized by an arid climate and/or a fast increasing of water demand, associated to growth of population, extension of irrigated agriculture, etc.

(v) *Desertification:* The degradation of land in arid, semi-arid and other areas with a dry season; caused primarily by over-exploitation and inappropriate land use interacting with climatic variance.

According to the different component of the natural hydrologic cycle affected by a drought event, it is possible to distinguish among: meteorological, agricultural or hydrological drought (see Fig. 3).

In particular, a *meteorological drought* indicates a condition of reduction of precipitation with respect to normal values, consequent to precipitation variability probably caused by earth processes (as geophysical and oceanographic interactions), interactions with the biosphere and maybe by sunlight energy fluctuations.

As a direct consequence of meteorological drought, a soil moisture deficit occurs (agricultural drought), depending on the entity of the *meteorological drought* transformed by the water storage effect. In particular, such water storage causes a delay in the deficit occurrence and modifies its entity in relation to the initial condition and to the evapo-transpiration process. Agricultural drought affects especially agriculture and livestock systems in rainfed conditions.

Subsequently, when the previous deficit affects surface water bodies (rivers) and underground bodies (aquifers), a *hydrological drought,* as a surface and/or groundwater flow decreasing with respect to the normal values, occurs.

Finally, drought can have effects on water supply systems leading to water shortages. The latter is sometimes defined as *operational drought,* and in relation with the environmental, economical and social system features it can have economic and intangible impacts. Both the water availability reduction and its impacts depend, besides the importance of the drought event, on the efficiency of the mitigation measures adopted in water supply and social-economic systems.

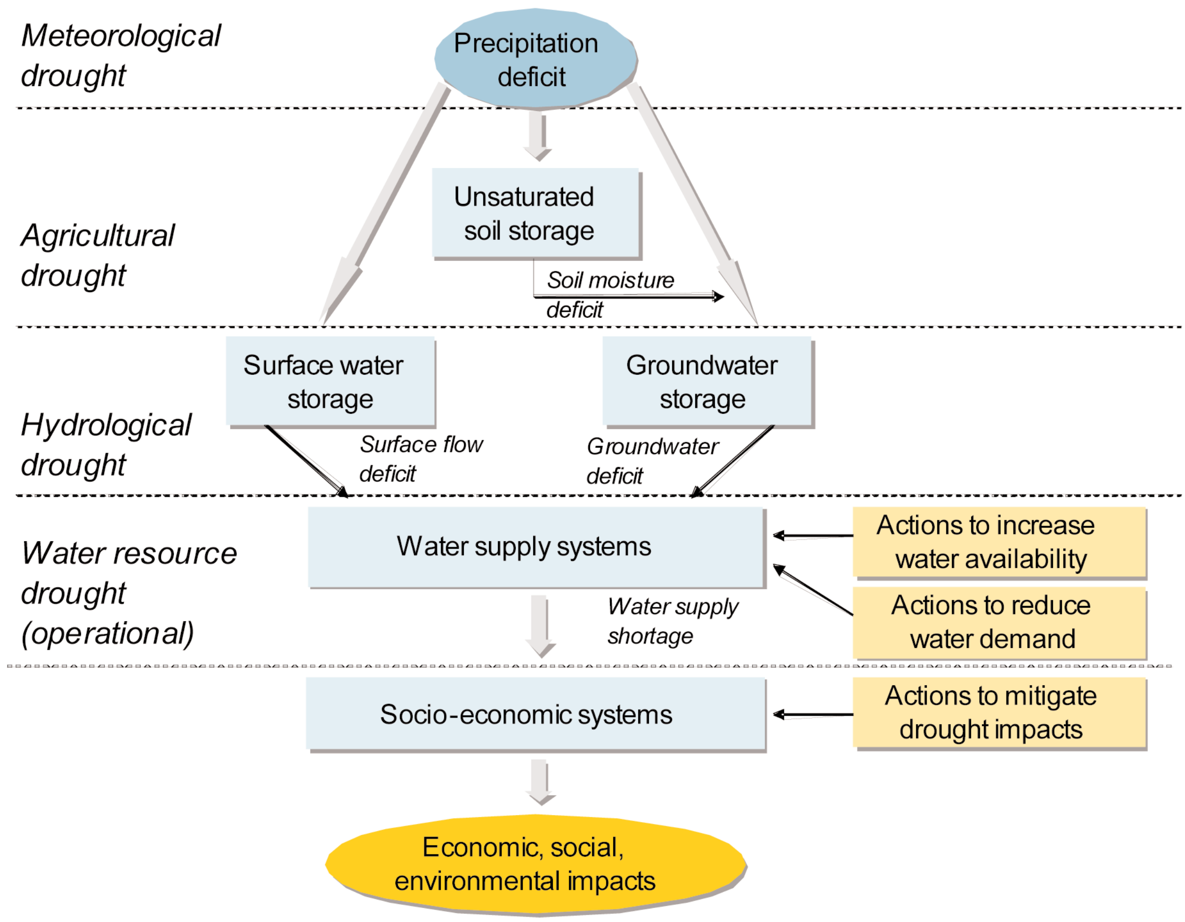

Fig. 3. Drought phenomenon and role of drought mitigation measures (adapted form Rossi, 2005).

Sometimes, the definition of *socio-economic drought* is also used to indicate impacts of water shortage on population and economy. Hereafter, the latter will be examined in terms of economic, environmental and social impacts produced by a drought.

Defining the drought management approaches

Drought management actions can be applied at different time scales, with different objectives and at different points of the system. All these aspects are to be taken into account and defined throughout the management plan so that timeframes and responsibilities are clear enough to ensure the adequate application of the management plan.

Drought management timeframe

A *reactive approach* is based on the implementation of measures and actions after a drought event has started and is perceived; this approach is taken in emergency situations. 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.

A *proactive or preventive approach* includes all the measures designed in advance, with appropriate planning tools and stakeholder participation. The proactive approach provides both short term and long term measures and includes monitoring systems for a timely warning of drought conditions. It also includes a contingency plan for emergency situations. It can be considered an approach to "manage risk". Water and agricultural managers in USA and Australia have promoted the proactive approach for decades. Table 1 summarises the characteristics of these two approaches.

Table 1. Characteristics of the approaches to drought management

Approaches to drought management	Characteristics	Limitations
Reactive approach	Based on the implementation of actions after a drought event has occurred and is perceived Taken in emergency situations but not based in a contingency plan	Often results in inefficient technical and economic solutions since actions are taken with little time for evaluating optimal actions Limited stakeholder participation
Proactive or preventive approach	Actions designed in advance, with appropriate planning tools Includes stakeholder participation Provides both short and long term measures and includes early warning systems Includes a contingency plan for emergency situations	The ineffective coordination and cooperation among institutions and the lack of policy to support and revise the proactive plan may result in obsolete and inadequate planning

Figure 3 shows the theoretical sequential evolution of drought, the consequences of intensified drought events and the potential management actions that can be applied to mitigate the effects of drought in a water supply system. In the figure we can appreciate the different time steps followed by drought, affecting in the first place to rainfed agricultural systems, evolving to affect components of the hydrological system, such as surface or groundwater storage and deriving into affection to water supply systems, either for urban or irrigation purposes. In relation to this sequence, the objectives and the timeframe of application of management actions vary from preventive actions oriented to modify supply or demand before or during the drought event, to other actions oriented to minimize the potential impact of drought in combination with the previous actions or when these ones have not been successful.

Assignment of responsibilities for drought management

The implementation of a proactive approach implies drafting plans in which the mitigation measures are clearly defined together with the instructions for their implementation. At this end, a clear assignment of competences among the different involved institutions appears to be a key issue; therefore a legislative act which defines the responsibilities is necessary in each country. Such act could be part of national water resources policy and/or strategy to fight desertification (within the U.N. convention).

Other important aspects to take into account are:

(i) Stakeholders' participation.

(ii) Management and changes in water rights legislation allowing water exchange during droughts.

(iii) Definition of standards of efficiency to foster water saving and sanctions for who does not respect them.

The need for drought management plans in Mediterranean countries

Climate is an essential component of the natural capital in the Mediterranean Basin. Different from other environmental assets, climate is subject to a great degree of natural variation. Mediterranean climates are among the most variable of the world and recurrent drought problems often affect entire countries over multi-year periods and often result in serious social problems, such as water scarcity stress and low quality of water. The intensive demand of water for agriculture contributes to the conflicts among water users. Over the last three decades spring rainfall has decreased in many areas of the region exacerbating the severe problems associated with drought. Fresh water has undergone increasing pressures and has also suffered quality degradation in many regions limiting options for sustainable development.

Mediterranean Region's development is strongly dependent on water resources availability. A main element for the development of social-economic activities is to ensure that water will be always available; the uncertainty derived form drought leads, without doubt, to a condition of underdevelopment and degradation. The purpose of developing drought management guidelines is to contribute to formulate comprehensive water management plans that take into account the probabilistic nature of the drought phenomena, encouraging a risk based rather than a crisis based approach. The MEDOPLAN Guidelines respond to the analysis of the current resources and dynamic social and environmental pressures.

Mediterranean countries are diverse from the point of view of climate and water infrastructure (Table 2). Rainfall and water resources are limited, scarce, and difficult to predict from year to year. The average annual potential water availability per capita considering the total freshwater resources in southern Mediterranean countries is less than 1000 m^3 per capita and year. In addition, real available water resources are always less than potential water resources in all cases. For example in Spain real available water resources are less than half of the total freshwater resources (Iglesias *et al.*, 2005) and the potential use of surface water under natural regime is only 7% (Garrote *et al.*, 1999). In the areas where demand is above the available resources, drought usually results in crisis. Due to the current imbalance between availability and demand, water management problems are significant even without drought events.

In all countries, demand is raising due to demographic shifts, economic development and lifestyle changes. The remarkable demographic increase (population in the Mediterranean areas, especially in the south and east areas, increased three times in few dozens of years), the rising level of life style, the industrialization, the ongoing climatic change, are all together causing a continuous reduction in water availability and quality often causing many emergencies, nearly everywhere.

Water use in the region is mainly for agriculture, accounting for over 50% of total water use in all countries except France where water used in agriculture is only a 10% of the total use, nevertheless the other economic and social water demands are rapidly increasing, such as tourism and ecosystem services (Aquastat, 2005). There is a clear difference in the proportion of water usage in the different sectors between northern countries, where industrial use shows a larger share than domestic use, and southern countries, where agriculture is the main use followed by domestic and finally industrial use.

Drought events in the Mediterranean have been frequent after 1970 (Iglesias and Moneo, 2005; Hisdal *et al.*, 2001; Vogt and Somma, 2000) and have had serious effects on the economy, the environment, and on the population's well being. The economic damage caused by drought in the Mediterranean during the last twenty years is about five times more than in the entire United States (CRED, 2005). Drought events affect water supplies for irrigation, urban, and industrial use, ecosystem's health, and give rise to conflicts among users that limit coherent integrated water resource management. For example, the major drought of the mid 1990s affected over 6 million people in the region and had severe effects on the agricultural economy of southern Mediterranean countries (Iglesias and Moneo, 2005).

Drought impacts are generally non-structural and also difficult to quantify (UNISDR, 2002). This is especially significant in regions where economic resources and technology can buffer the effect of negative environmental changes (insurance, public support). Therefore, characterization of drought episodes is complex, and includes both physical aspects and social consequences.

Agriculture in the Mediterranean is both the main use of the land in terms of area and the principal water-consuming sector. Therefore the adverse effects of drought are perceived to be associated with agricultural activities, leading to conflicts over the use of resources with other sectors. These conflicts especially affect ecosystem sustainability and imply the need to incorporate substantial changes in current water management.

Groundwater resources play a vital role in meeting water demands, not only as regards quality and quantity, but also in space and time, and are of vital importance for alleviating the effects of drought. (Garrido *et al.*, 2000; Llamas, 2000). However, groundwater pumping should be controlled because excessive use of the aquifers can cause overexploitation problems with the consequent negative environmental, social and economic impact.

Most Mediterranean freshwater and groundwater resources are shared among countries (Wolfe, 1999), being the Nile river a key global example. Within the countries, shared water among administrative units is also common in the Mediterranean. Disputes exist, especially during drought

Table 2. Total freshwater resources, available resources, use, and water availability in selected Mediterranean countries

Country	Total area (km^2) [Population (million)] †	Rainfall (mm/yr) ††	Internal renewable water resources (km^3/yr) †††	Renew-able water resources (km^3/yr)	Internal groundwater (km^3/yr)	Total water use (km^3/yr)	Total water use (km^3/yr) (% Renew -able)	Potential total renewable water resources per capita (m^3/capita per year)
Algeria	2.381,740 [30]	89	13.90	14.32	1.70	5.74	40	473
Egypt	1.001,450 [68]	51	1.80	58.30	1.30	61.70	106	859
Libya	1.759,540 [5]	56	0.60	0.60	0.50	5.73	954	113
Morocco	446,550 [30]	346	29.00	29.00	10.00	12.23	42	971
Tunisia	163,610 [9]	313	4.15	4.56	1.45	2.58	57	482
France	551,500 [59]	867	178.50	203.70	100.00	35.63	17	3439
Greece	131,960 [11]	652	58.00	74.25	10.30	7.99	11	6998
Italy	301,340 [58]	832	182.50	191.30	43.00	43.04	22	3325
Portugal	91,980 [10]	855	38.00	68.70	4.00	7.40	11	6859
Spain	505,990 [44]	636	111.20	111.50	29.90	35.90	32	2794

† The values refer to both regulated and unregulated water. Real available water resources in all cases are a fraction of these values.

†† These values include transboundary water. See also Wolfe, 1999.

††† A proportion of these values is included in the total renewable water resources.

Source of data: Aquastat, 2005.

conditions, and potentially will increase due to the increasing water imbalances. Policies of a single government or basin unit cannot resolve issues over shared water bodies, and local interests are likely to diverge. International Institutions play a key role as formal mechanisms to deal with water related conflicts in the region.

Drought characterisation in the Mediterranean

Characterization of drought episodes provides the adequate framework for developing indicators of risk. Drought indicators may be used to evaluate the levels of drought risk, linking science to policy.

Droughts differ from other natural hazards in several important ways: (i) no universal definition exists; (ii) its spatial extent is usually very large; (iii) slow-development that makes difficult to determine the onset and end of the event; and (iv) its duration may range from months to years.

Drought occurs in most climatic regimes, and is often described as a natural hazard. It is a temporary anomaly, unlike aridity, which is a permanent feature of the climate. Defining drought is therefore difficult; it depends on differences in regions, needs, and disciplinary perspectives (Wilhite, 2005; Iglesias and Moneo, 2005). Meteorological drought is caused by a deficit in precipitation and hydrological drought is caused by the decrease or deficiency in ground water and reservoir levels when the meteorological drought is very intense or persistent. Whatever the definition, it is clear that drought cannot be viewed solely as a physical phenomenon, as its severity depends on the impact on people or ecosystems and their ability to cope and recover. Although drought may cause water scarcity –the extent to which demand exceeds available resources– human actions such as population growth or water mismanagement may also be the cause.

The impacts of drought in agriculture result directly from decreased precipitation (in dryland crop production) and from decreased water storage (in irrigated agriculture). It is therefore important to distinguish between meteorological and hydrological drought for a correct analysis.

Drought characterization in highly regulated systems is complex and calls for multiple indicators. Classical drought indices, such as the Standardized Precipitation Index or the Palmer Drought Index, are widely used to characterize meteorological drought. These indices do not correlate well with hydrological drought periods or historical drought impacts, due to the effect of storage (Garrote *et al*., 2003). Many of the more complex indices that take storage and management into account are not easily interpreted across the regions and cannot be validated with the data available over wide geographical areas (Rossi *et al*., 2003). Therefore, managers of water resources tend to rely on precipitation and streamflow variables to determine the onset of alarm, alarm, and emergency situations (see below: Current strategies for drought management).

Figure 4 shows the time series of aggregated precipitation in Morocco and Spain defining meteorological drought episodes, and the SPI calculated at 24 month intervals, defining hydrological drought. The two variables are correlated (correlation coefficient = 0.75) and a threshold value of the SPI index of -1.0 may be taken as an alarm indicator of drought (Hayes *et al*., 1999). Many studies have characterized comparable precipitation patterns at different geographical scales (De Luis *et al*., 2000; Estrela *et al*., 2000). Figure 4 also shows the extremely large variability characteristic of Spanish precipitation and the recurrent multi-year drought episodes.

Figure 4 shows at least two periods with different precipitation trends, highlighting the importance of choosing the adequate reference period for developing indicators for management. Precipitation in the latest period, from the 1960s has clearly decreased. The very low precipitation of the 1940s defined the historical drought during that period, with severe consequences for the economy. The structural water deficit of many areas in the country has been aggravated during three severe drought episodes (1975-76, 1981-82, and 1992-95), each more severe than the previous one (Fig. 4). During these droughts, besides the collapse of irrigation water supply, urban water supply series were affected significantly.

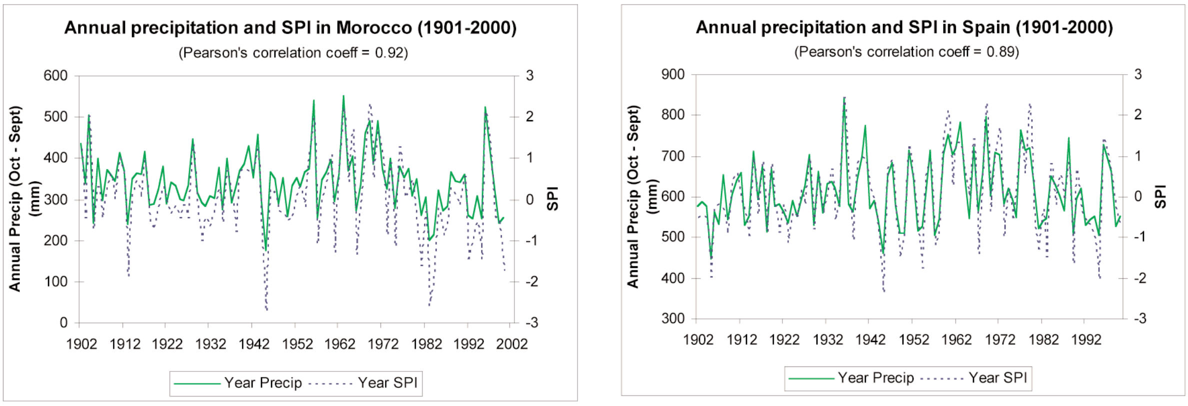

Fig. 4. Time series of aggregated annual precipitation and SPI values (12 month time scale) in Morocco and Spain. (Data source: The Tyndall Center database TYN CY 1.1; Mitchell *et al.*, 2002).

Current drought management

The national governments and the local authorities have responded to extreme drought vigorously, taking emergency measures, but so far the responses have focused on the effects of drought ex post, rather than on anticipatory measures ex ante. In general, these efforts have neglected to build the capacity needed to deal with similar situations in the future. Information on possible longer-term climate forecasts and/or development of plausible scenarios has not yet been incorporated into any specific action plans.

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. The United Nations Convention to Combat Desertification (UNCCD, 2000) provides the global framework for implementing drought mitigation strategies. The United Nations International Strategy for Disaster Reduction (UNISDR, 2002) establishes a protocol for drought risk analysis.

Current legislation on water and drought management shows different development stages for the Mediterranean countries that lead to important differences in the way droughts can be faced. While some of the countries have a stable and long tradition legislative framework with functional river basin authorities and clearly defined responsibilities, others are still developing institutions and organizations that take care of water management issues.

A common characteristic of the countries in the region is the weak cooperation among the different institutions related to water management, and the fragmented roles of the State, the administrative regions and the river basin authorities, that result in administrative conflicts that are an impediment for adequate water management (Iglesias and Moneo, 2005). The key issue of transboundary water management is included in drought management plans. Other Mediterranean countries, especially in the southern basin, share a significant portion of groundwater, but the regulation during drought needs to be further developed.

In general, decisions related to drought are taken in the context of formal legal system. There are legal provisions for emergency actions in case of crisis situations, such as extreme drought. Informal customs may evolve into formal decisions, for example, historical users of groundwater without formal rights may be legalized. The legislation does not provide explicit regulations about how to calculate the ecological discharge during drought situations; this important question is being left to the discretion and responsibility of the various river authorities.

A main advantage of the explicit linkage of legislation and management to the basin level is the opportunity to address directly the needs and problems of the natural hydrological system and the stakeholders represented in management board of the river basin. Water managers can establish priority of users or right holders, or can approve emergency works and projects according to each level of risk. In contrast, when water resources management is linked to administrative units, responses to drought tend to be "crisis based" rather than "preparedness based".

Historically, policy-makers with competence in agriculture at the national and sub-national levels have been responsible for both natural and economic resource management. These agricultural managers already use short-term weather forecasts in irrigation scheduling with success, since cropping systems must be matched with seasonal water supply, a major component of risk for farmers (Iglesias *et al.*, 2000; Wilhite and Vanyarkho, 2000; Wilhite, 1996). These managers, therefore, have already incorporated quantitative estimates of probabilistic climate conditions and modelling output into their decision-making process. It is reasonable to expect that this current situation may lead to an effective dialog among resource managers and scientists on methods of quantitative assessment, therefore paving the way for improving the development of adaptation strategies for longer-term climate change.

The structural water deficit of many Mediterranean countries has been aggravated during the drought episodes in the last thirty years. Since the 1990s, Mediterranean countries have improved drought preparedness strategies but have also experienced severe drought impacts. Drought indicators, although imperfect, contribute to understand the temporal characteristics of drought and to define alarm situations. Past efforts to manage drought have built capacity to deal with similar situations, but have failed to solve the conflict among users, especially with the environment.

Drought management needs to be integrated into the long-term strategies for water management. When water resources are managed at the basin level, there is an opportunity to respond directly to the needs and problems of the natural hydrological system with policy decisions. Monitoring and early warning systems continue to improve and are being incorporated into the planning processes.

Drought planning with future uncertainties

Drought management in both regulated and unregulated systems will have to adapt to the slow evolution of water supply and demand. The combination of temperature increase and changes in the hydrological cycle, limit some of the current adaptation measures, such as the increase of the volume of irrigation water. The human dimension of drought management in the Mediterranean might not stop at the regions' boundaries. There is the potential for more pronounced water conflicts with neighbouring regions (i.e. transboundary issues in shared surface waters and aquifers) and demographic shifts due to the collapse of agricultural activities in some areas.

Although scientific projections of future climate evolution are highly uncertain and subject to numerous hypotheses, there is a growing concern among the scientific community about the impacts of climate change on drought magnitude and frequency in the Mediterranean region (IPCC, 2001). The combination of long-term change (e.g. warmer average temperatures) and greater extremes (e.g., droughts) can have decisive impacts on water demand, limiting further ecosystem services. If climate change intensifies drought impacts, current Mediterranean water management plans may become increasingly unstable and vulnerable. Water managers may find planning more difficult. Current water management strategies based on changes in mean climate variables should be revised to account for the potential increase in anomalous events.

Uncertainties and opportunities for the future

Historically, policy-makers with competence in agriculture at the national and sub-national levels have been responsible for both natural and economic resource management. These agricultural managers already use short-term weather forecasts in irrigation scheduling with success, since cropping systems must be matched with seasonal water supply, a major component of risk for farmers (Iglesias *et al.*, 2000; El-Shaer *et al.*, 1997; Wilhite and Vanyarkho, 2000; Wilhite, 1996). These managers, therefore, have already incorporated quantitative estimates of probabilistic climate conditions and modelling output into their decision-making process. It is reasonable to expect that this current situation may lead to an effective dialog among resource managers and scientists on methods of quantitative assessment, therefore paving the way for improving the development of adaptation strategies for longer-term climate change.

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Climate change projections indicate an increased likelihood of droughts. Variability of precipitation –in time, space, and intensity– can directly influence water resources availability. The combination of long-term change (e.g. warmer average temperatures) and greater extremes (e.g. droughts) can have decisive impacts on water demand, limiting further ecosystem services. If climate change intensifies drought impacts, Spanish water delivery systems and control may become increasingly unstable and vulnerable. Water managers may find planning more difficult. Current water management strategies based on changes in mean climate variables should be revised to account for the potential increase in anomalous events.

Climate change

Climate change scenarios for the region are derived by using the Magicc Scengen software of the University of East Anglia (UK) with input data form the HadCM3 global climate model driven by the A1 and B2 SRES socio-economic scenarios (IPCC, 2001; Eid *et al*., 2001). The scenarios result in an increase of temperature (1.5°C for the B2 scenario and 3.6°C for the A1 scenario) and precipitation decreases in most of the territory (about 10 to 20% decreases, depending on the season).

Agriculture in the Mediterranean is both the main use of the land in terms of area and the principal water-consuming sector (see above). Therefore the adverse effects of climate change are perceived to be associated with agricultural activities, leading to conflicts over the use of resources with other sectors. Under all climate change scenarios, water supplies decrease and irrigation demand increase in the Mediterranean region (El Shaher *et al*., 1997; Minguez and Iglesias, 1995; Iglesias and Minguez, 1997; Iglesias *et al*., 2005; Mougou *et al*., 2005). These results will affect ecosystem sustainability, implying substantial future changes in water management.

Under current conditions all Mediterranean countries face significant problems due to the unbalanced distribution of water resources, conflicts among users, and between countries and it seems likely that climate change will lead to an intensification of these problems. The effects of sea level rise in North Africa, especially on the coast of the Delta region of Egypt, would impose additional constraints to the use of resources (IPCC, 2001).

Northern Africa's adaptation capacity is challenged in particular, as climate change comes in conjunction with high development pressure, increasing populations, water management that is already regulating most of available water resources, and agricultural systems that are often not adapted (any more) to local conditions. Evidence for limits to adaptation of socio-economic and agricultural systems in the Mediterranean and North African region can be documented in recent history. For example, water reserves were not able to cope with sustained droughts in the late 1990's in Morocco and Tunisia, causing many irrigation dependent agricultural systems to cease production. In addition, effective measures to cope with long-term drought and water scarcity are limited and difficult to implement due to the variety of the stakeholders involved and the lack of adequate means to negotiate new policies.

The human dimension of climate change impacts in Northern Africa might not stop at the regions' boundaries. There is the potential for more pronounced water conflicts with neighbouring regions (i.e. transboundary issues in the Nile and in many shared aquifers). There is the risk of climate change induced refugee flows to Europe from the region.

Although scientific projections of future climate evolution are highly uncertain and subject to numerous hypotheses, there is a growing concern among the scientific community about the impacts of climate change on drought magnitude and frequency. Global increases in temperature and changes in the hydrological cycle are expected to have a major impact on drought in the Mediterranean region (IPCC, 2001). Future risk assessments require the development of environmental change scenarios at different time-scales. These scenarios should include estimates not only of changes in the climatic baseline, but also estimates of possible future changes in socio-economics.

Chapter 3. Diagnostic of the situation

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SUMMARY – Water shortages can be the result of drought phenomena but can be also the result of human actions such as increase of water demand due to population growth or changes of people habits, or due to bad water management plans. This chapter outlines the diagnostic search that water policy makers, water managers, decision makers and other stakeholders, should take before embarking on the preparation of drought preparedness plans, so that they know the causes of water shortage and that drought preparedness plans are necessary. If the results from this search are negative, the relevant authorities must take the necessary measures and actions so that the proper environment is created in each of the items so that the preparation and implementation of Drought Preparedness Plans is facilitated, and it is effective and efficient.

Key words: Drought, water shortage, water balance, Institutions, laws, knowledge, environment, education.

The purpose of diagnostic search

The immediate result of a drought phenomenon is water shortage with impacts on the economy and social life and the environment. However water shortages or better water scarcity can be caused by human actions such as population growth, wasteful use of water, inefficient water of water and in many cases by non rational water balanced water management plans. Since the drought preparedness plans constitute a part of the water resources management plans and since the drought preparedness plans (which involve too many economic, social and other measures and actions), are put into operation when certain indicators or water supply alarms levels are realized, it is imperative that before preparing the drought preparedness plans that a diagnostic search is carried out to find out that the water scarcity or water shortage are the result of drought and not the result of human actions and inefficient water management plans. In view of the above those responsible for the preparation of the drought preparedness plans in close cooperation with those responsible to prepare the water management plans, should carry out a diagnostic search which is outlined below.

Steps in diagnostic search

In view of the need to carry out a diagnostic search the following items should be investigated:

Are there sufficient Institutional and Legal Frameworks?

The preparation of drought management plans, requires continuous monitoring of the meteorological conditions, the hydrological conditions, the water demand change, the nature of the activities taking place within the perimeter of the project, the physical and operational condition of the structures and equipment of the project, the set up and performance of the operation and maintenance personnel of the project and generally the overall project performance in meeting the projects objectives. The collected information on each and every activity has to be analyzed and evaluated on a continuous basis, enabling the water managers to deduct conclusions and make projections concerning the water availability, water demand and water scarcity and the proposal of additional works to increase efficiencies, and water resources availability if necessary. The above can be carried out within an institution, which shall be given the legal rights and the power and means to execute their functions in the best possible manner. Governments should have established the appropriate institutions whose duties and responsibilities shall be clearly defined with their rights and powers to execute the duties and responsibilities defined in the legal frameworks. If the appropriate Institutional and Legal Frameworks, for the preparation of the water resources management plans and the preparation of drought mitigation plans, are not available both plans shall suffer from deficiencies and most probably shall not be effective and efficient. Every country which considers seriously the good governance of its limited, fragile, and threatened water resources, if it has not sufficient institutional and legal frameworks should prepare and establish one the soonest possible.

Is water shortage caused by droughts or else?

Water governance includes all those institutional, legal and administrative actions and measures which together with the national or regional policies set the framework for water management. Good water governance means that water demand to a project does not exceed the water supply resulting to zero scarcity except under drought conditions. This means that water scarcity (see definition in Annex 2 Glossary of terms and concepts) under normal conditions is equal to zero. In order to achieve this, water managers must be able to revise continuously the water management plans to take into account the increase in water demand (population growth, irrigation growth, industrial growth, rising of standard of living and increase in environmental demands etc.), and the water supply changes mainly water supply decrease due to climatic changes, or groundwater depletion. While water demand increases due to population growth and due to other reasons, the water supply usually remain the same or even decreases due to environmental reasons, resulting to water scarcity. The increasing water scarcity of a project with demand exceeding the available water resources, at the national, the regional or project level, due to human actions (population growth, irrigation growth, industrial growth, rising of standard of living and increase in environmental demands etc.), if not taken into account in the preparation of the general water management plans, will result into frequent water shortages, which together with drought events may create an intolerable situation. With the above in mind it will be advisable to carry out the following diagnostic search and analysis:

(i) Are adequate Institutional and Legal Frameworks established? If not the responsible authority should take actions to establish them the soonest possible.

(ii) Are the water management plans updated on a continuous basis with zero water scarcity under normal average conditions? If the water management plans are not updated then it is necessary to take this action the soonest possible. If water scarcity is increasing then either water demand should be reduced or additional water resources should be made available to the project so that the average demand does not exceed the average water resources available to the project.

Is there sufficient scientific knowledge and acquaintance with the methodologies and in depth knowledge of the project in general?

The preparation and implementation of water management plans and drought preparedness plans requires scientific knowledge, and methodologies which are provided within this guidelines, but it also requires good knowledge of the project (water impounding structures, aquifers, their yields, the structures capabilities etc), their design specifications and limitations. All above require continuous educational and training both in office and in the field of those involved in these activities. Water management plans and drought preparedness plans are project specifics and those involved in these activities should be well acquainted with the project operational capabilities on top of the scientific and methodological know-how. Water Institutions must encourage and facilitate their personnel to acquire the scientific knowledge and the methodologies required for the risk analysis and drought characterization necessary for drought preparedness plans but also on the preparation of rational water resources management plans.

Are environmental needs taken into consideration?

Water supply under drought conditions is very critical since the satisfaction of the environmental needs in business as usual are rated very low compared to domestic and industrial water supply, and supply for agricultural consumption and usually are not taken into consideration under drought conditions. Environmental needs must be estimated and the benefits derived evaluated. According to the water needs and the benefits derived, they must be ranked in priority of supply in comparison to the other economic sectors. This will enable the decision makers to take into account these needs during the allocation and distribution of the limited water resources under drought conditions and contribute towards the satisfaction of the basic environmental needs.

Is a common language used by all stakeholders?

Drought, water scarcity, hazards, vulnerability, and other terms and concepts have a different meaning for different stakeholders. It is necessary that all the stakeholders have a common language concerning the water resources management and drought preparedness plans. Acquaintance and knowledge of the terminology is a must for those involved in the drought preparedness plans and on water management preparation and implementation plans.

Are the consumers aware of the water issue and educated to use water?

The preparation and implementation of water management plans and drought preparedness plans requires that consumers have knowledge on the efficient and effective uses of water. Since water is a very important commodity for the social, economic and environmental development of a country and since water is treated by many as a social good, with the supply and demand not defined by the free market but by the demand and willingness of the consumers, it is not easy to regulate the supply of water. In view of the above the supply and demand, should be regulated by the consumers, by being aware that the water resources are limited, fragile and threatened by the unwise, inefficient and ineffective use. Governments not willing or due other reasons not being able to apply water tariffs for the regulation of supply and demand should intensify their efforts to create water awareness by educating the consumers on the water availability issues and on the efficient and effective use and utilization.

Remedy of the issues. Conclussions of the diagnostic search

If during the diagnostic research it is concluded that there exist deficiencies in any of the investigated items, it would be advisable that the relevant authority takes steps to remedy or improve the situation. Institutional and legal frameworks should be adequate to enable the collection, process, storage and analysis of the data and information required for the preparation of rational water management plans and efficient and effective drought preparedness plans. The legal frameworks should give the right, the power and means to those responsible to implement the water management plans under drought conditions to act within legal and rational frameworks so that they are effective and efficient. It is also necessary to make sure that drought preparedness plans are made for water shortages caused by drought phenomena and not by human actions. To avoid this all stakeholders should contribute to the formulation of rational water management plans, which under normal conditions do not create water shortages or water scarcity. Other deficiencies such as scientific know-how and methodologies of those responsible with the execution of these operations should be made up with the attendance of training and educational courses including the use of common language. Finally but most important is the creation of awareness on the water issues and the education of the consumers to use water in an efficient, and effective way. The best Drought Preparedness Plans are probably destined to fail if the consumers' cooperation and understanding is not secured, because they do not know the problem or cannot mitigate the water shortage problem.

Chapter 4. Institutional and legal framework for drought management

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The scope of the analysis and objectives

This work analyses the organizations and institutions involved in drought preparedness and mitigation and/or on water management, with special emphasis in agriculture and irrigation water supply. The Chapter includes a description of the current drought management plans and the explicit linkages and hierarchical relations among the institutions involved. The importance of identifying such relations among institutions lies on the need to design coherent drought management plans that mitigate the effects of such hazard on agriculture, water supply systems and economy.

This Chapter provides a common methodology for analysing the organizations and institutions relevant to water scarcity and drought management. The common methodology is adequate to provide information that will contribute to compare among and across countries and to promote the cooperation with the existing institutions, organizations, networks, and other stakeholders in the Mediterranean. The methodology proposed and described in this Chapter is supported by previous leading experiences synthesised by Wilhite *et al.* (2000), Rossi *et al.* (2003) and Vogt *et al.* (2000). Although the objectives of the Guidelines are not directly focused on the institutional Analysis per se, it is important to understand the conceptual bases, to identify the organisations and institutions and to map them to ensure the relevance of subsequent drought management analysis. The approach is intended to cover the following areas:

(i) Explicit description of institutions and organizations with competence in water policy and administration, planning, decision making, operation of water supply systems and in drought preparedness, and emergency action with particular emphasis in municipal and irrigation water supply.

(ii) Explicit description of the linkages and hierarchical relations among the organizations and institutions.

(iii) Information on existing drought preparedness and management plans.

(iv) Documentation of the institutional experience on the application of the existing drought preparedness and management plans.

(v) Description of the data collection system in each country, specifying the institutions responsible, the type of reporting and accessibility, and the primary uses of the data.

The analysis aims to provide insights to the following key questions:

(i) Do the set of organisations and institutions interact within a formal or an informal network?

(ii) Are there networks to provide communication and hierarchical flows of command?

(iii) Are the stakeholders included in the network?

(iv) What is the degree of influence and dependence of the stakeholders' decisions on the institutions' core themes?

The Chapter takes into account drought and water scarcity. The underlying rationale of this separation is based on two facts. First, artificial and natural reservoirs eliminate, alleviate and delay the effects of abnormally low precipitation and run-offs. Second, the conditions and the processes of drought (meteorological) evolve along temporal and spatial scales with little bearing on the processes that characterize water scarcity (hydrological droughts) situations. Resulting from this desegregation, the Chapter analyzes two institutional mappings pertaining to drought and water scarcity contexts. The analysis includes the stakeholders that ultimately benefit from drought preparedness and management (primary stakeholders) and the stakeholders that are intermediary in delivering aid to the first group (secondary stakeholders) and describes the participation of the stakeholders in the processes. The Chapter attempts to provide a dynamic analysis of the institutional frameworks of different Mediterranean countries with regards to drought risks and planning.

Drought risks

Ensuring water availability and protecting the environment are the main focus for coming years in order to address questions on drought management. Few countries have realistic policies, operational strategies or plans for integrating drought management plans into water policy, particularly in the southern Mediterranean Countries. In fact most of the strategies for drought management are typically based on ex-post approaches and address only part of the issue of social and environmental sustainability. Examining the experiences of a wide range of Mediterranean countries with the same methodology makes possible to define strategies that have proved environmentally and financially sustainable, with possibilities to be used in other areas.

Starting from the *institutional* setting of each country it is possible to define the characteristics of the particular policies that need to be modified in order to promote sustainable drought management plans. During the next years water management and spatial planning in European countries will be focused on the implementation of EU Water Framework Directive in the EU Member States with potential impact also in candidate countries as well as in other Mediterranean Area countries. The resulting new responsibilities in spatial planning and water management have to be clarified at the administrative level. Additionally, this requires a contribution of environmental sciences as "trans-border" water bodies (as Mediterranean Sea) will require integrated and coordinated tools and efforts for proper water management.

Communities must often give priority to water either for agriculture, industry, tourism or other users. Therefore there is the need to define a careful strategy for sustainable use of water resources, based on the principle that water is not a "worldwide good" but a "worldwide need". As a consequence, the only policy will have to apply correctly the "integrated water management", that is the management of water cycle according to technical – economical logics. Current drought management plans are not always effective because they rely too much on decision processes under stress situations.

The relations among organizations and institutions are essential for understanding current drought management plans and for improving future actions that mitigate the effects of drought on agriculture, water supply systems and the economy. To understand the national institutional regime is a key factor for establishing effective and integrated drought management plans that incorporate monitoring, public participation, and contingency planning (Iglesias and Moneo, 2005). Combating drought risks is viewed in most societies as a public good that justifies government action. Therefore societies must develop policies that deliver significant drought risks reduction and lesser social vulnerability.

Methodology

The methodology developed here comprises five main tasks:

(i) Elaborate a mental model of organisations and institutions in each country and describe the institutional and legal frameworks.

(ii) Collect additional information by interviews and/or other dialog methods. The interview should include "problem analysis" (i.e., what actions did your institution take during a historical drought in a specific year?) and identification of the stakeholders affected by the decisions of each institution.

(iii) Validate the model structure. Communicate back to the organizations and institutions the results of the previous two tasks and complete the analysis.

(iv) Analysis of the strengths and weaknesses of the system organizational processes to take decision within the institution and within the hierarchical structure in each country.

(v) Discussion of the challenges and opportunities to improve drought management.

The Legal Framework

Legislation and normative

Drought management policies should be based on integrated evaluation of all those measures required to implement the objectives of the water policy, together with those measures required under other policies and relevant legislation. This section reviews the existing legal initiatives and present legislation explicitly focussing on drought risks. The section provides a description, ordered hierarchically, of all laws, rules, norms, and statutes that are presently in force in each country with connection to water uses, management, conservation as well as land uses and the natural environment, as it concerns or are influenced by all types of drought. The water and drought legal framework includes all acts and regulations related to water resources management, wastewater management, non-conventional water resources and environment related issues. The legal framework includes all laws applicable at national, regional, district and local levels including international agreements or regulations in force.

Mediterranean countries have extensive legal provisions (legislation and normative) related to water management focusing on water scarcity. The existing legislation enables governments to develop specific drought mitigation plans, both of proactive and reactive nature. The legislation is an instrument that allows governments to implement drought mitigation plans and drought relief policies. Effective legal provisions need to include budget for implementation of the measures. In general, the laws focus on drought management strategies adopted under stress situations, providing conditions for emergency actions.

The United Nations Convention to Combat Desertification (UNCCD, 2000), provides the framework for implementing drought mitigation strategies. The convention is especially relevant to Southern Mediterranean countries.

In the MEDROPLAN countries, the legislation has evolved as a consequence of severe drought episodes, such as 1993-95, and 2001. An attempt has been made to identify the legal base in Mediterranean Countries that enables governments to develop specific drought mitigation plans, both of proactive and reactive nature. The current legislation offers opportunities to governments to use instruments to develop, and allocate budget, to mitigation plans and drought relief policies. Ultimately, the legislation is the instrument that provides the means to produce drought management plans.

The idea is to obtain an overview of the measures needed to achieve sustainable drought management in relation to a particular geographical area (e.g. a basin in a country). This approach allows a degree of rationalisation and co-ordination of the different existing measures taken by integrating politic decisions (e.g. economic incentives of fees) with technical analysis of the area.

The drought policy must be flexible to avoid imposition of inappropriate or unnecessarily strict requirements simply for the sake of harmonisation. Such flexibility would also ensure that, where a problem is regionally specific, measures appropriate to that particular area could be taken. The range of environmental conditions in the Mediterranean basin is very diverse and this must be taken into account.

A cost-effective strategy implies assessment from an economic perspective of advantages and disadvantages of the three basic sets of policy instruments: Regulations and standards, new technology and internalisation of external pollution costs through pricing and market-based incentives.

These sets of policy instruments are not mutually exclusive and can be used as complementary or alternative measures depending on their relative cost-effectiveness to address water pollution as well as water scarcity issues.

Drought policy is not to be seen in isolation, but as a contributory element in the wider search for a balanced and sustainable development. And such a sustainable approach can be neither planned nor implemented in a satisfactory and efficient way without providing for broad consultation and participatory procedures of all actors concerned.

Most of the Mediterranean countries recognize drought as a direct consequence of water resources availability and management, therefore the legal base related with drought is directly derived from the water code of each country. This is a legal body that is on the top of the hierarchy of laws which cover all issues and aspects related to water policies, organization, procedures, finance, civil work planning and public participation. Consequently this legal framework considers drought a hydrological phenomenon. There are no specific legal provisions that consider drought as a meteorological phenomenon.

Legal provisions in Mediterranean countries

Table 1 summarises the legal provisions related to water scarcity and drought contingency plans in Cyprus, Greece, Italy, Morocco, Spain, and Tunisia. Only Spain and Cyprus have developed an Agricultural Insurance Law that includes drought hazards. Italy conceives drought as a natural hazards or disaster, so it has developed a legislation to implement competencies and action of public institutions to face a natural disaster (Law 225/1992). Cyprus developed a General Disasters Law to provide for the definition of the scope of action, economic compensation for losses. Only Spain, Cyprus, Morocco and Tunisia have developed specific drought mitigation plans, both of proactive and reactive nature. In Spain, the Law of the National Hydrological Plan (Law 10/2001 Art. 27[1]) explicitly deals with drought and establishes the bases for a proactive and reactive response against hydrological and meteorological drought. The contingency plans include supply reliability and the future development of supply plans for large cities. The reactive responses include emergency works, decision on reservoir management and users strategies. The legal base to meteorological drought is based on the development of an agricultural insurance law.

Tunisia has developed a specific contingency plan (Operation Drought Management Plan Setting) but it not based on a specific legal provision. In this case the plan is implemented requiring a drought announcement and on the MARH (Ministère de l'Agriculture et des Ressources Hydrauliques) minister decision which establish a drought committee and design an operation program for drought mitigation instead its crisis management. Cyprus' approach is similar to Tunisia's and has developed a specific proactive plan but it is not envisaged by any law. The legislation related to drought in Morocco is very advanced but its control is not very well developed. The Water Law of 1994 included a lot of consideration related with water management in drought period at regional and local level. The Law introduces elements like Water Basin Agencies whose decision in must be submitted to the Superior Council for Water and Climate.

Italy has a great amount of laws related with water management, soil conservation, water quality, and civil protection. The 183/1989 Law aimed to solve water and land conservation problems by an integrated approach but actually has not been yet implemented. Also there are some specific legislative indications for coping with drought impacts but unfortunately none of these is currently operational, except for the measures funded by civil protection in the form of emergency actions that operate according to a specific program drafted after drought starts.

Proactive and reactive responses to drought include some actions plans in order to prepare for drought and to mitigate his effects. The performance of these action plans can and cannot be defined by a legal framework. Spain, Morocco and Italy have defined a specific legal provision for this actions plans but only in Spain and in Morocco are currently in force. Operational proactive plans designed ad-hoc to mitigate drought are in Tunisia and Cyprus, but they are not envisage by any law.

1. Although this law was repealed by Law 2/2005, the provisions concerning drought were kept intact. Based on former article 27, the government is finalising a drought plan and contigency strategy for all Spanish basins.

Table 1. Legal provisions related to water scarcity and drought contingency plans in Cyprus, Greece, Italy, Morocco, Spain, and Tunisia

Legal provisions	Contingency Plan	Institutions / Stakeholders	Focus / Funding
All countries			
International Convention (United Nations) 1994 Agreement, 2000 Enforced	Strategy to combat drought and desertification	United Nations and National Governments	Strategies to fight desertification and mitigate drought to be implemented by all the countries that signed the Convention
Cyprus			
General Disaster Law	Disaster relief; crisis based	Water development Department (Ministry of Agriculture, Natural Resources and Environment) Drought Management committee	Payments of losses Prepare an action plan based on the most probable scenario: water transfer, emergency scheme, water cuts, water reallocation, water saving campaign. Based on crisis management National budget
Agricultural Insurance Law (1978)	Agricultural drought	Agricultural Insurance Organization, Department of Agriculture, the Planning Bureau, Ministry of Finance, Council of Ministers. Council of Ministers and Parliament to approve the funds for remaining crops	Payments of losses National budget
Greece			
National Action Plans for Combating Desertification (2002)	Plans for Combating Desertification	Common Ministerial Decision (six Ministries) Central direction of waters River Basin Authorities: Regional direction of waters. Consultative committee of water (Ministry of Environment, Physical Planning and Public Works)	The development of the new law of water management will provide a plans for each basin containing drought mitigation measures Neither compensation policy nor insurance
No legal provisions, actions taken case-by-case in response to crisis	Drought mitigation	Same as above	No plan for drought mitigation In the past decisions concerning drought were taken in case to case basin Construction of dams and off-stream reservoirs Reactive measures: drilling, repairing irrigation networks, water transfer Neither compensation policy nor insurance
Italy			
Legislative Decree 152/1999 regulating the identifications areas vulnerable to drought and desertification	National program against drought and desertification	National Committee to combat drought and desertification	

Law 36/1994 identifying areas affected by water crisis	National program of prediction, prevention of contingency and assistance plans	Civil Protection Department Authority of optimal territory unit. Regional Government or Basin Authority National Committee to combat drought and desertification	Proactive: long term measures to reduce vulnerability, such as new water infrastructures Reactive: emergency measures such as transfer to urban use, aquifer over exploitation, restriction on irrigation National Funds for Natural Calamities
Law 225/1992 regulating civil protection service	Crisis management strategies	Civil Protection Department Authority of optimal territory unit. Regional Government or Basin Authority National Committee to combat drought and desertification	Reactive: emergency measures such as transfer to urban use, aquifer over exploitation, restriction on irrigation Reactive: subsidies to farmers for covering agricultural damage National Funds for Natural Calamities
Morocco			
Spain			
Basin Hydrological Plan (2001)		River Basin Authorities, (Ministry of Environment) Drought Permanent Committee Ministry of Agriculture, Agricultural Insurance Agency Finance Ministry, Reinsurance Public Agency Permanent Office for Drought (officials of the Ministry of Agriculture) reactive response	Reactive: new insurance products Proactive: taxation abatements or deferrals, drilling wells Proactive: Water supply reliability, urban priority Reactive: emergency works, decision on reservoir management and users strategies
1983, 1999	Crisis management plans	Civil Protection Permanent Office for Drought	Creation of committees that will define the action terms in case of drought Different performance environments, social or agricultural
1995-2000	Emergency measures	Most of them undertaken after the most severe drought periods as mitigation measures	Laws, Royal decrees and orders created to mitigate the impacts of drought Hydraulic supply measures Transfers of water between different river basins Measures for sub sectors of agriculture (apiculture, livestock, tree crops)
Definition of the areas where the emergency measures are applied; 1993, 2000, 2001	Crisis management		Definition of the criteria used to delimit areas affected by drought Establishment of criteria for aid supply Final criteria used Amount of rainfall Stocking rate

Agricultural Insurance Law (1978). 2001, 2002	Insurance	Agricultural Insurance Agency	Definition of the conditions, application areas and other characteristics of drought insurance
Albufeira Convention, 1998	Transboundary		Albufeira Convention between Spain and Portugal for transboundary basins under the framework of sustainable water resources management and common environmental protection
Tunisia			
Legal actions developed upon "Drought announcement", as established by the Ministry of Agriculture, Environment, and Water Resources (MAERH)	Operation Drought Management Plan Setting	National Commission (supervision of the execution of operation actions) Regional commission (inform about necessary measures Specialized commission (preparation of the drought indicators) Supervised by MAERH	Depends on the phase of drought plan: Preparation actions: insuring forage and seeds, preparing for eventual importation of forage and seeds, identifying drought farmers Drought management: identification of affected and sensitive zones, enhancing complementary irrigation State budget because the absence of insurance system Plan not implemented yet

Actions plans define different pro-active responses by means of programmes of measures. Some measures are specifically defined by water resources law, for example the definition of order of priorities of users during scarcity or the possibility to carry out of some economic instruments. The first is considered in most of water law evaluating here, establishing that urban use have priority over agricultural, industrial o recreation use. Economic instruments that allow water allocation mechanisms are included in the Spanish water code. In these sense, Spanish Water Law gives competencies to the River Basin Authorities to create Water Exchanging Centers (now called "Water Banks"), through which right holders can offer or demand use right in periods of drought or sever water scarcity situation. In other cases, the agency itself can offer right holders compensations for surrendering their rights and allocate the resources to alternative users or to environmental purposes. The rest of the countries have not considered this possibility, perhaps because water rights are not allways well defined. In Morocco there is a coexistence of the modern legal system based on public property and the inheritance of Islamic law, so the administration recognizes private appropriation and free transactions on water rights, forming a mixed system not yet fully solved. Italy legislation views water resources as a primary good that cannot be traded, but there is a general opinion against deregulation of water market.

In general terms in all countries the advisory authorities have competencies to allocate and reallocate water during drought periods. Legal framework in Cyprus gives competencies to the Council of Ministers to allocate and reallocate water resources according to the existing water availability and the priority of needs. Also the Council of Ministers has the right to expropriate private or other water rights for the public interest. Morocco, based on the 10/95 Water law, created the Superior Council of Water and Climate which constitutes a real forum of dialogue of the stakeholders group in the water sector. This Council formulates the general orientations of the national water and climate policy, water national plans and integrated management plans on water resources.

EU Water Framework Directive forces in the long term to the adoption of full cost recovery pricing criteria to ensure that tariffs charged to users cover all cost of the service. These criteria can be considered as economic instruments to save water by means of demand management. Currently, European countries have not yet implemented this kind of economic instruments, but in the near future this will be a clear possibility to develop a proactive response to drought improving the efficiency of water use.

Other demand management instruments like awareness campaigns for water conservation or adoption of water saving measures have a clear framework for implementation in Tunisia, Morocco or Cyprus where there are some specific contingency plans containing these kinds of mitigation measures. In Spain and Morocco, the National Hydrological Plans, regulated by law, include these kinds of measures. Cyprus also has specific contingency plan not regulated by law. In this case water transfers, emergency scheme, water cuts or water reallocations are examples of the measures considered. Operation Drought Management Plan setting of Tunisia is not based on a specific law. The Drought National Commission has the role of supervision of the execution of the operation actions. A Drought specialized commission establish drought indicators, which are the triggers of the preparation actions designed such as dams management plans according to climate condition or store water evaluation and demand identification. In Morocco the Superior Council of Water and Climate grants the distribution of water between user sectors, the transfer of water and the protection of water resources.

In Italy the National Program of prediction, prevention of contingency and assistance plans and the National Program against drought and desertification are the specific instruments to implement proactive measures in order to reduce vulnerability such as the construction of new water infrastructure. This plan has not been yet implemented. The situation of proactive legislation in Greece is similar to Italy. The future establishment of river basin plan opens the possibility to develop some proactive measures like construction of dams and off-stream reservoirs. But up to day the problems of drought are solved case to case.

Contingency plans based on legal provisions

Table 2 summarizes the legal provisions that support the contingency plans and Table 3 summarises the drought contingency plans in Cyprus, Greece, Italy, Morocco, Spain, and Tunisia.

Table 2. Summary of the drought contingency plans in Cyprus, Greece, Italy, Morocco, Spain, and Tunisia

Country	National strategy plans	Specific drought plans	Crisis and emergency measures	Insurance	Committee	Budget provisions
Cyprus	x	x	x	x	National	x
Greece	x	x	x			
Italy	x	x	x			x
Morocco	x	x	x	x	National, local	x
Spain	x	x	x	x	National, local, stakeholders	x
Tunisia	x	x	x		National, local	x

Table 3. Summary of the drought contingency plans in Cyprus, Greece, Italy, Morocco, Spain, and Tunisia

	Cyprus	Greece	Italy	Morocco	Spain	Tunisia
Specific reactive measures, economic compensations, such as taxation abatement, and emergency measures, such as drilling wells and water transfer	x	x	x	x	x	x
Water reallocations	x	x		x	x	
Demand management		x		x	x	x
Insurance scheme	x			x	x	
Long-term measures: New water infrastructure			x	x	x	
Reactive measures depend on the scenario of drought	x					x
Policy planning process				x	x	
Proactive plan that anticipate costs and effects	x			x	x	x
Operational drought management depends on the phase of drought: Combined methods of physical and socio-economic data					x	x
Proactive Action Plans based on most probable scenarios	x				x	
Hydrological National Plan: supply reliability and supply plans for cities					x	
Operational drought management depends on the phase and severity of drought (National Drought Plan), National Water Plan: water supply for drinking water and irrigation				x	x	

Coordination and cooperation with relevant EU policies: WFD and CAP

The Framework Legislation for European countries is the European Union Water Framework Directive (2000) (WFD). The European Parliament and Council Directive 2000/60/EC of 23 October 2000 establish a framework for Community action in the field of water policy (Official Journal L 327, 22/12/2000 P. 0001 – 0073). The WFD contains a series of principles that affect water policies in all EU Member States in areas such as water tariffs (Article 9); programmes of measures (Article 11); demarcation and description of basins' territories (Articles 3 and 5); monitoring of all waters' quality (Article 8); and hydrological plans (Article 13). The purpose of the WFD is to establish a framework for the protection of surface waters and groundwater. It aims at contributing to: (i) the provision of a sufficient supply of good quality surface water and groundwater, as needed for sustainable, balanced and equitable water use; (ii) a significant reduction in pollution of groundwater; and (iii) the protection of territorial and marine waters. The WFD introduces the following elements: (i) water management based on river basin approach; (ii) maintenance of the good water status where already exists; and (iii) cost recovery in accordance with the polluter-pays principle.

Agriculture is the most important economic sector in Spain in terms of land and water use, and irrigated agriculture contributes with more than 50% of the final agricultural production in many regions of the country. As the main water user, it seems logical to discuss and analyze the implications that new regulation on water might have for agriculture. There is a need to coordinate both policies in order to avoid confronted objectives that lead to the deterioration of such a vulnerable and at the same time key sector as agriculture.

There is actually an intense debate among the different stakeholders. While institutional representatives express their absolute support to the complete implementation of the WFD, with all the associated instruments (incentive pricing, cost recovery, and the application of the principle "the polluter pays"), there are some concerns coming from the farmer's unions and irrigators communities who doubt about the future of the agricultural sector depending on the mechanisms adopted for the implementation of such instruments. As an example of this, many speakers expressed their concerns about the negative effects that water pricing might have on the farm's standards of living that the CAP is trying to protect from the other side.

One of the central issues agreed in general by all the speakers is the necessity of irrigation modernization in Spain. The OECD determines a global efficiency of 47% for Spanish irrigation system, what implies huge losses of usable water every year. Both the General Director of the AGUA Programme and the General Director of Rural Development agree on the important savings of water that could be reached trough this modernization process. In addition, other aspects such as environmental demands could be satisfied with a higher security level.

Irrigated agriculture is seen by farmer's unions and agricultural management institutions as a key promoter for rural development (through the creation of labour, stabilization of rural population, industrial development and environmental benefits) and they support the implementation of the WFD as long as their opinion and concerns are taken into account for the process, demanding a higher level of public participation and control in water management for the coming future.

Other speakers presented the calendars for the coming years of the two policies in parallel, underlining the opportunities for coordination and the necessity of regional implementation for the effectiveness of the measures.

The general conclusion is the importance of adopting the WFD as a horizontal directive that will have implications for every other sectoral policy and the actual uncertainty about the real implementation of the directive further than the programmes development by 2015, which is the deadline for implementation across the member states.

Drought contingency *vs* water resources planning

Droughts provide a good opportunity to implement water policy. Society claims that something should be done. Additional funds are made available. In political terms, we are "solving a problem created by others" (Fig. 1).

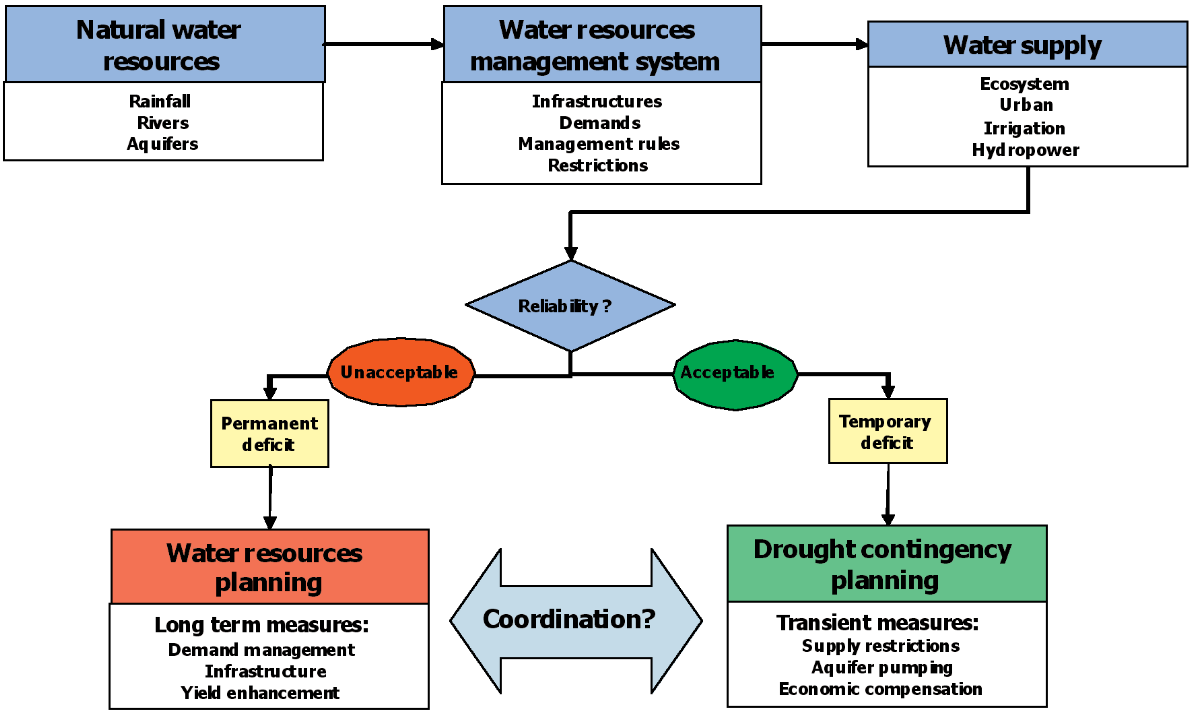

Fig. 1. Overview of the coordination between basin and drought policy to derive legislation.

The Institutional framework

Linkages between institutions and stakeholders

The objective of the research is to co-ordinate the knowledge and experiences of the Northern and Southern Mediterranean Countries in order to implement and apply an innovative management for droughts and water scarcity aiming to operate into the framework of integrated management of the water sources and provide instruments to manage droughts in a more effective way.

This mental model is applicable to basins. It is the result of the exchange of knowledge and experiences among Mediterranean Countries on policies and implemented proactive and reactive action plans. The results are analysed to assess the contribution to the sustainable management of water resources.

The mental model complies with the principles introduced by the EU Water Directive and aims at contributing to achieve the objectives of protection, enhance and restore all bodies of surface waters and groundwater, ensure a balance between suction and recharge of groundwater. It can be useful to target those cases where it may be feasible or reasonable to achieve effective drought management plans.

The mental model is developed on the basis of the assumption that in each basin a proper policy of drought management can be carried out when the privileged target is the safeguarding of stakeholders rights belonging to the same area. Applying this mental model to basins in the Northern and Southern Mediterranean Countries, assuming as the target is the minimisation of social risks derived form drought, it should be possible:

(i) To examine specific features of each country. The institutional profile, to evaluate the status of water management, the effectiveness of those plans in historical situations, and assess the level of improvement of drought management plans.

(ii) To define both the characteristics and the institutional changes necessary to improve current drought management plans.

The use of such a mental model may have a crucial role in creating positive outcomes in those situations detectable according to different scenarios. As examples four typical scenarios can be individuated: Proactive and reactive meteorological and hydrological droughts. These four scenarios are quite widespread in all countries of the Mediterranean basin. The proposed model promote an improvement of drought management plans oriented to increase of water availability in Mediterranean countries, minimising the social risk of drought as well taking in account the socio-cultural differences of the Mediterranean countries. The use of the proposed model to develop drought management plans can play a crucial role in contributing to ensure water supply in the area and socio/economic development. The mental model provides a methodology to analyse integrated drought management plans, to involve the stakeholders and users, and to define the possible incentives supporting proposed changes. As a result of this approach to drought management analysis, a better understanding of specific needs of different areas is promoted. The use of a common methodology for management evaluation promotes better trans-border integration and process learning.

An exact technical definition of the best solution for drought management for a certain area requires to rank the different possible alternatives, demonstrate actual needs for drought management improvement, and demonstrate that needs of extensive and expensive actions are based on rigorous analysis. The research contributes to define these elements by evaluating recognized standards for drought management intended as a part of environmentally and socially sustainable growth.

Water and drought institutional framework are all organizations and institutions related with the management of water resources. The institutions are classified into policy-level institutions, executive-level institutions, user-level institutions and the NGO's institutions, at national, regional, district and local levels. A correct definition of the roles of the different levels of government in planning and co-ordination is a primary need in the preparedness and management processes. This component of the mental model includes a topology-type graph and a written description. The organizations and institutions to be included are those within the formal framework of the political and government structures in each country (i.e., Ministries, General Directorates, Commissions, etc.) and the Official

Institutes and Offices with relevant roles in drought preparedness and management, including water management organisations (e.g. municipal supply agencies, irrigation district consortia), institutions responsible of disaster's defence and ad-hoc drought emergency Committees or Offices. Figure 2 provides an overview of the institutional framework within which meteorological and agricultural droughts may be faced, mitigated and alleviated. Figure 2 illustrates a general guide and road mapping that may be used as conceptual framework in the specific country analysis. In all cases, the analysis and evaluation of this institutional performance takes into account the reactive capacity, the scope, and the social learning process.

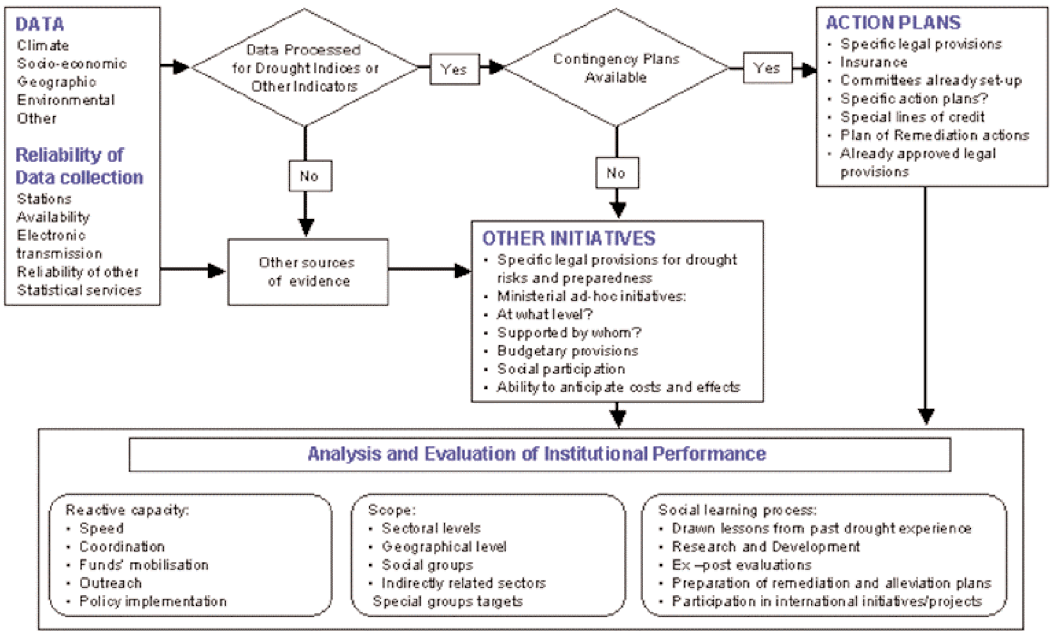

Fig. 2. Overview of the institutional framework within which meteorological and agricultural droughts may be faced, mitigated and alleviated.

Description of the roles of institutions and organizations

A complete detailed description of each of the following points:

(i) Description of the organizations and institutions included in the flow-chart.

(ii) Description of the formal and informal means of communication and hierarchical command among the organisations and institutions described above. This should include both regular, and ad-hoc modes of interaction, both at the pre-active and pro-active levels.

(iii) Description of the various governing boards, commissions and groups' actions that have direct responsibility in drought preparedness, planning, management and mitigation. Under pre-crises and crises situations, a very detailed description of these should be provided

(iv) List, description and location of each stakeholder that either influences drought preparedness and management or is directly affected by it. Description of the means of communication, interaction and dependency with the map of organisations and institutions.

(v) At the local and stakeholders level, it would be of special interest reporting on the customary rules and actions, and their dependence from upper organisations.

In the context of the MEDROPLAN Drought Management Guidelines we define Organization as a group of people who work together in a systematic way arranged in a structure. An Institution is an entity defined interactively by birth in a formal or an informal way, as well as at the macro and micro level, that establish sets of rules, norms, and shared strategies for their operation in relation to law, policy, and administration. Network is a group that interacts or engages in informal communication for mutual assistance or support. The institutions relevant to drought management are those that are concerned with water law, water policy, and water administration in relation to water shortages, risks, and impacts. Institutions are not simply organisations and they transcend organizations. This complex broad definition implies the following ideas about institutions have regularised patterns of behaviour, informal and formal rules, explicit and implicit rules, kinds or/and levels of rules' and laws' enforcement, and formal and informal sanctioning rules.

Proactive and reactive plans and actions

This component of the mental model includes a description of the proactive and reactive drought preparedness and management plans that have been developed or are already developed and put in action in the past or are applied in the present, detailing the responsible organisation, and sources of funding for the plan or its actions. If no drought preparedness or management plan has been applied to the present time, focus on plans that are currently being developed. The analysis should be done at the country level and examples should be provided.

An example of a proactive plan may be an insurance policy for dry-land cereal and forage growers. An example of a reactive plan may be a list of water plants to be realized for increasing water resources (new wells, conduit for water transfer or desalination plants) or for reducing water losses in conveyance and distribution network. An example of a reactive plan may be a programme of water use restrictions for cities (prohibition to water public parks or to clean streets).

Each plan should at least include: objectives, list target groups, logic and rationale, attempt to judge and determine its performance, either proved or potential, budget and funding sources, and bodies and offices that are responsible in design, development and application.

The revision of the plans will contribute to the interview process by identifying the potential candidates for the interview, and by outlining the main themes and questions that may be of interest to them.

Model validation

The mapping models presented above are validated with the participation of the stakeholders interviewed. The process included four sequential steps. First, the theoretical involvement of the stakeholders was included in the mental model. Second, key stakeholders were interviewed to validate the model. Third, the participation of the stakeholders in the process was defined. Finally, the four mapping models were reviewed, identifying omissions, redundancies and other diverging elements. To do so, it is essential to follow the same structure developed to present the mappings.

The mental model structure validation includes the following steps:

(i) Final collection of information and data needed for the institutional analysis.

(ii) Ensure that the mental model components provide a realistic representation of each country's drought preparedness and management plans as well as the country's capacity to implement them.

(iii) Contrast the mental model with the interviews' insights and results.

(iv) Set the framework of reference for the analysis of the strengths and weaknesses of the institutions and the Conclusions.

Strengths and weaknesses of the model structure

This task should clearly identify the institutions strengths and weaknesses for implementing or developing drought preparedness and management plans. The analysis should consider all aspects of the model. Table 4 outlines the major issues to be evaluated.

Table 4. Summary of the major issues to be evaluated in the analysis of the model structure.

Topic	Relevant issues

Data and Information	Representation (spatial and temporal)
	Adequacy for risk analysis
	Appropriate for historical analysis
	Accuracy
	Handling
	Accessibility
	Legal data:
	    Water right-holders records
	    Updated registries
	Socio-economic data:
	    Water users
	    Sectorial distribution
	    Demographics
	Other

Institutional Organization	Organisational set-up Legal set-up Personnel capacity and training Coordination among institutions Information flows and utilisation Units in charge of drought preparedness actions Bodies in charge of developing proactive and reactive management plans NGOs and stakeholders participation
Institutional Performance	Based on the most recent drought episode Based on the present state of approved contingency plans Based on the strategies developed as a response to recent drought episodes Based on the capacity to conduct risk analysis Based on the capacity to pool risks and ensure compensation mechanisms at the lowest cost
Conflict Resolution	Levels at which conflicts are faced and solved Means to solve conflicting issues Stakeholders and users participation Groups left unattended or disenfranchised

The analysis may consider the following aspects:

(i) Synthetic and comprehensive view of the current state of institutions in each country in relation to all issues related to drought preparedness and management.

(ii) Concise and specific conclusions about the institutions' performance (both based on past episodes and future contingencies) in relation to mitigation of drought impacts and anticipatory measures.

(iii) Discussion the major strengths and challenges (impediments and weaknesses) that stand against drought preparedness and the capacity to develop and carry out management plans. Following the analysis, tentative recommendations as to what specific institutional changes would be needed to improve the current preparedness plans can be made. In some cases, specific identified changes may take place within the current political and administrative context in each country.

Stakeholder participation

In relation to drought management, stakeholders can be individuals, organisations, institutions, decision-makers, or policy-makers, who determine or are affected by water use and exposure drought and water scarcity. Stakeholders enact institutions - sets of rules, norms, shared strategies - and they are constrained by them in their responses to drought preparedness and management. Therefore a purposeful description of the map of legitimate actors, as well as an analysis of their interests, values and approaches to risk is a pre-requisite for the understanding of their link with institutional drought policy. The participation of the stakeholders serves two purposes: the validation of the mental model and the raise of awareness of the need to change drought management policies. Recognizing the importance that representative stakeholders are formally incorporated within the structure of the Guidelines, the stakeholders are interviewed and further engaged in model validation. As result, the models described in each country have been accepted by the stakeholders. This will contribute to the acceptance and trust of the science that feeds into the Guidelines for drought mitigation and preparedness planning that will result from the drought management plan.

The stakeholders considered are those actors who are directly or indirectly affected by drought and water scarcity and who could affect the outcome of a decision making process regarding that issue or are affected by it. Table 5 outlines the stakeholders considered and included. The stakeholder analysis is conducted by mean of interviews. The objectives of the interviews are to: confirm that the mental models described above provide an accurate representation about drought preparedness and management plans; complete the findings and fill the gaps that may exist in the mental models; and collect personal and subjective views of the country's level of preparedness and capacity for developing and carrying out management plans. The target individuals for the interviews are: policy makers/practitioners at the highest technical level and leading researchers with experience in drought's analyses and characterisation. The number of interviews should be six to eight. The interview's structure is described in Appendix 1, at the end of this document).

Table 5. Stakeholder identification and participation

Stakeholder	Characteristics and structure	Interests and expectations	Potential and deficiencies	Involvement and participation
1. Mediterranean rainfed farmers	Sometimes in collective organizations or Unions. Very interested in guidelines development	Plan and adopt practices adapted to drought. Anticipate drought effects on livestock. Avoid decreasing livestock capitals	Some with low financial margin to invest in new technologies. Some with insurance coverage Increasing experience in alternative sources of livestock feeding	Benefit from new insurance products R&D for insurance activities Alert in case of drought
2. Mediterranean irrigated area farmers	Frequently, in irrigators associations. Interested and positively involved	Same as above	Same as above	RB plan design and functioning Represented by irrigation Communities R&D insurance Alert in case of drought
3. Urban water consumers and water utilities	Directly affected by water shortages. Sometimes represented by consumers associations Aware of need to save water	To avoid water shortages, increase supply guarantee levels and water standards' reduction	High potential of saving water	RB plan design and functioning Represented in Assembly of Users
4. Tourism companies	Directly affected by water shortages Represented by tourist companies associations	To avoid water shortages and bad quality that limits sector development	Very influential in economic policies Sometimes the tourism model is water-wasting	RB plan design and functioning Represented in Assembly of Users

5. Industrial companies	Depend on national Directly affected by water shortages Represented by employers' organizations	To avoid water shortages and bad quality that limits sector development	Very influential in economic policies Sometimes the industry development model is not water-sustainable	RB plan design and functioning Represented in Assembly of Users
6. Water Basin Authorities	Depend on the State Government In charge of administration and distribution of water	Directly affected by water shortages Need to develop water policies based on risk analysis	Main actors in drought guidelines Need to take into account different and opposed interests	Pro-active: Design, management, decision-making, and implementation of RB plans Reactive: Permanent Committee, emergency works strategies
7. Local Water Authorities & Water Suppliers	Depend on the local authorities Also private companies in some cases	Directly affected by water shortages. Need to develop water policies based on risk analysis	Main actors in drought guidelines	RB plan design and functioning. Priority in water allocation Represented in Assembly of Users
8. Meteorological and Hydrographical Institutions	Depend on national and/or regional governments	Interested in the use of their data in risk analysis	Main actors in drought guidelines. In some countries, difficulties to provide data	Provide information for plan designing and monitoring
9. Ministries of Agriculture, Environment, Water, Tourism, Industry	Depend on national and/or regional governments	Directly concerned by water shortages In charge of the implementation of mitigation policies	Key actors In some countries, coordination between them is to be improved	Approval of Basin Plans. Funding of Insurance Premia Funding for subsidies, tax abatement. Create Permanent Office for Drought
10. Insurance companies	Depend on national and/or regional governments	Directly concerned with the reduction in agricultural production due to drought periods	Key source of data for risk analysis in some countries Main actors in drought preparedness guidelines	R&D New insurance products Approval of products
11. Agricultural banks and rural lending institutions	Depend on national and/or regional governments, or private	Directly concerned with the need of extraordinary financial resources due to drought periods	Key source of data for risk analysis in some countries Main actors in drought guidelines	Credits to farmers
12. Research, Training and Development Institutions	Depend on national and/or regional governments, or private	In charge of development, adaptation and adoption of technologies for efficient water use	Key human capital in some disciplines but limited financial resources	New insurance products Water planning Transfer of technology and knowledge
13. International Cooperation Organizations	Intergovernmental	Drought and water are key issues. Key actors in technology transfer and knowledge	Good network of contacts and human resources Limitation of financial resources	Networking. Facilitate International agreements Use common tools for water management Capacity building
14. NGO´s	Non-profit, non-governmental	Environmental and social improvements	Very active and sharp users of scientific results. Limitations resulting from their clear political standpoints	Indirect participation in RB plans. Link between society and institution. Press governments to include environmental topics in political agenda. Information

Discussion and conclusions

Current legislation on water and drought management show different development stages for the Mediterranean countries that lead to important differences in the way droughts can be faced. While some of the countries have a stable and long tradition legislative framework with functional river basin authorities and clearly defined responsibilities, others are still developing institutions and organizations that take care of water management issues. Drought preparedness requires adequate institutions and agencies with competences to develop and enforce plans. In the absence of them, governments must necessarily resort to emergency actions and alleviation programmes, but very little can be done to reduce the likelihood and severity of drought risks.

In general, decisions related to droughts are taken in the context of formal legal system. There are legal provisions for emergency actions in case of crisis situations, such as extreme drought. Informal customs may evolve into formal decisions. For example, historical users of groundwater without formal rights may be legalized. The legislation does not provide explicit regulations about how to calculate the ecological discharge during drought situations; this important question is being left to the discretion and responsibility of the various River Authorities. Tables 6 and 7 summarise drought management characteristics and the key aspects of drought management plans, respectively, in the MEDROPLAN project partners countries. Specific drought management plans have been developed at different administrative levels. A main advantage of the explicit linkage of legislation and management to the basin level is the opportunity to address directly the needs and problems of the natural hydrological system and the stakeholders represented in the Assembly of Users. For example, Basin Authorities in Spain can establish priority of users or right holders according to each situation, can approve works and projects needed to solve emergent scarcity problems, and can create Water

Table 6. Summary of the drought management characteristics in selected Mediterranean countries

Country	Summary of drought management
Cyprus	Current proactive action plans for drought management based on crisis management. Good approach to risk management
Greece	Centralised system of collecting and processing of data: National Bank of hydrological and meteorological information Modern GIS system for spatial analysis Large experience in drought preparedness and mitigation by institutions Good starting point to develop actions plans for drought management: New Water Law adapted to EU Water Framework Directive
Morocco	Good technology to monitor hydrological system (RIBASIM) Modern technology for remote sensing and GIS system for spatial analysis of drought Good performance basin agencies: Social participation and planning process Several years experience with drought agricultural insurance River basin agencies established: Regional water and drought management Good starting point to develop action plans for drought risk management; National Drought Observatory; new Water Law and National Drought Mitigation Plan
Spain	Modern technologies to monitor hydrological system Solid base insurance system: Knowledge of drought risk Good performance basin agencies: Social participation and planning process Drought adapted legal framework: Establish priorities, reallocations mechanism and legal mandate to develop contingency plans Insurance system for dryland agriculture Sound connection within river basin agencies between water planning and drought preparedness planning, in the context preparations for EU WFD's article 4
Tunisia	Drought is considered in the National Development Plans Latest data collecting and processing techniques: Interaction between data collection and drought mitigation process: SINEAU system Drought indices are considered in drought management process Adaptations of reactive and proactive measures to phases of drought Adequate start point: First Drought Mitigation Guideline

Exchanging Centres, through which right holders can offer or demand use rights in periods of droughts or severe water scarcity situations (Article 71). This initiative must be proposed by the Environment Ministry and be approved by the Ministerial Cabinet.

Table 7. Summary of the drought management actions in selected Mediterranean countries

Concept	Cyprus	Greece	Italy	Morocco	Tunisia	Spain
Surface water ownership	Public	Public	Public	Public	Public	Public
Groundwater ownership	Partially private	Public	Public	Partially private	Public	Mixed
Water Law	Not include drought	Includes drought	Includes drought	Includes drought	Includes drought	Includes drought
River Basin Authorities	Not developed	Developed	Developed	In developed	Partially developed	Developed
Drought contingency plan	Not developed	In development	Regional	In development	National	At river basins and urban supply levels
Drought monitoring system	Partially developed	Partially developed	River basin	National	National	River basin
Agricultural insurance	Rainfed agriculture	Not developed	In development	In development	Not developed	For rainfed agriculture
Relation among institutions	Low	Low	Low		High	Medium
Public participation in water management	Low	Medium	High	Low	Low	High

In all cases, there is a clear and constant conflict between water uses during drought periods, however, in some countries agencies actions are generally accepted and perceived as legitimate. And yet in some other related regulations still need development and evaluation. Also the view on water use rights exchange varies dramatically from one institution to another, making more difficult the real application of approved plans and initiatives. There is also a conflict concerning emergency works. On the one hand some of these works are necessary for the normal functioning of the basin and the emergency situation accelerates the approval process, on the other hand these works result in larger costs and efforts than would have normally implied. The traditional treatment of drought has rarely incorporated environmental issues. The European Water Framework Directive highlights the importance of improving the "ecological status of the heavily modified water bodies", and mandates that the ecological water quality be integrated as an objective of the programmes of measures. However, it foresees derogations of quality targets if severe drought conditions prevail or social costs are high.

A common characteristic of the countries in the region is the weak cooperation among the different institutions related to water management. Another similarity is the fragmented roles of the State, the administrative Regions and the River Basin Authorities, which result in administrative conflicts that are an impediment for adequate water management. The key issue of transboundary water management is included in drought management plans. Spain shares a large amount of surface water resources among basins in the country and basins that extent to Portugal. The agreements on water transfer amounts between national basins (such as the Tagus-Segura) or between countries sharing a common basin (such as the Spanish and Portuguese portions of the Tagus Basin) include strategic regulations in the case of drought. The EU mandates that international basins which include EU member states must approve agreed programmes of measures applicable for the entire demarcation. Other Mediterranean countries, especially in the southern basin, share a significant portion of groundwater, but the regulation during drought needs to be further developed.

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. The United Nations Convention to Combat Desertification (UNCCD, 2000) provides the global framework for implementing drought mitigation strategies. The United Nations International Strategy for Disaster Reduction (UNISDR, 2002) establishes a protocol for drought risk analysis.

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Annex 1. Questionnaire for stakeholders

Introduction

Name, age, organisation, current position, previous position, profession.

Organisation (history)

How many years have you been working for/an activist in……?

How, when and why was the organisation created?

What type of public does it represent and how many members does it have? (not applicable for governmental organisations and media)

Approximately how many people work in the organisation? What kind of profiles and skills do they have?

What is the socio-professional profile of the members of the organisation? (not applicable for governmental organisations and media)

Perception of drought and uncertainty

What is drought in your opinion?

In your opinion, water scarcity in the region is chronic, cyclical or irregular? Give reasons for your answer. a) Chronic ☐; b) Cyclical ☐ How often? ………..; c) Irregular ☐

Do you think that mankind can ever control droughts? Why?

Do you think that mankind can ever control floods? Why?

What sector is mostly affected by droughts? Order them from 1 (most affected) to 7 (least affected). Give reasons for your first and last choice.

	No.	Reasons
Industries		
Tourism and services		
Irrigation		
Environment		
Recreational uses		
Dry farming		
Domestic users (households)		
Others		

What sector is with whom lies the main responsibility to cope with the effects of drought?

Order the following factors of uncertainty, which affect irrigation farmers from 1 (high level of uncertainty) to 5 (low level of uncertainty). Give reasons for your first and last choice.

Factors of uncertainty	No.	Reasons
Climate		
Level of guarantee in irrigation supply		
Agricultural policies		
Work market		
Others		

Legal arrangements on water allowances and water reserves

Do you think that the current legal framework defines clearly the rights of the water permit holders? Why?

Do you think that the compensations due to users affected by a reduction in water allowance during drought periods are clearly defined in the current legal framework?

Which groups participate in the definition of water allowances during drought periods?

In your opinion, do the sectors, which are affected by water allocation during drought periods, participate sufficiently and adequately in such organisations/committees? Why? If the answer is *no*, which actors should improve their participation?

Do you think there are groups with greater capacity to make or influence decisions concerning the definition of water allowances? Give reasons. If the answer is *yes*, which groups?

How are the droughts inceptions defined or established? Is there a formal procedure to declare a "drought situation"?

Stakeholders (relations and conflicts)

In the case of drought, to which activities would you (personal opinion) give priority for the supply of water? Order them from 1 (highest priority) to 6 (lowest priority). Give reasons for your first and last choice.

Sector	No.	Reasons
Domestic use		
Services and tourism		
Environmental uses		
Irrigation		
Recreational uses		
Industry		
Other		

Do you think that these priorities correspond to the priorities that the administration defends in situations of water scarcity? Give reasons.

Do you think that the administration adequately enforces the agreements reached on water allocations? If the answer is *no*, where does the main non-compliance lie? If the answer is *yes* or *do not know*, what are the main difficulties (both internal and external) that the administration faces in enforcing the agreements?

Do you think that irrigation farming is a very, little or not at all homogeneous sector? What factors give homogeneity to this sector? What features are responsible for internal diversity? Could you list any more clearly defined/differentiated groups?

Do you think that the arguments that were put forward during the past drought in favour and against the social distribution of water –i.e. water allocation according to farm unit rather than agricultural surface– were reasonable?

Do you think that the definition of irrigation water allowances during drought periods should take into account the different irrigation systems used?

Do you think that the definition of irrigation water allowances during drought periods should take into account the diversity of crop types, in terms of different water requirements and timing of irrigation?

Mechanisms of political and media pressure

Do you think there are measures of political and media pressure that can condition or modify the decisions taken on water allowances during drought periods? To what extent are they effective? For instance, to what extent specific groups of users obtain privilege positions in times of droughts at the expense of others that are less powerful or politically active?

List in the types of actions to exert political and media pressure and the actors that normally use them.

Drought mitigation measures

Which ones of the following measures do you think are most necessary? Order them from 1 (most necessary) to 13 (least necessary). Give reasons for the first and last choice.

Action	No.	Reasons
Increase in the regulation capacity for urban supply		
Improved efficiency of the urban water distribution networks		
Freeze the increase in the irrigation surfaces		
Water markets		
Increase in the regulation capacity for conjunctive uses		
Increase in the regulation capacity for irrigation purposes		
Substitution of high- with low water-demanding crops		
Water metering		
Reallocation of water from irrigation to urban uses		
Improved irrigation efficiency		
Inter-basin transfers		
Conversion of some irrigation surfaces to dry farming		
Remote control		
Reuse of waste water		
Full cost recovery		
Other		

In your opinion, which of these measures receive the highest social acceptance and which the lowest? Give reasons.

Which of the following activities are most socially and economically important for your region/ country? Order them from 1 (most important) to 6 (least important). Give reasons for your first and last choice.

Sector	No.	Reasons
Cattle-raising		
Building sector		
Tourism		
Irrigation farming		
Dry farming		
Industry		
Other		

In your opinion, which of these functions or effects of irrigated agriculture receives the highest social acceptance? Which the lowest? Give reasons.

	Highest	Lowest
It creates jobs		
It avoids emigration from the countryside		
It contributes to the economic development of less favoured regions		
It has negative impacts on the environment		
It contributes to the distribution of wealth		
It wastes water		
Other		

Economic instruments

Do you think that water can be traded in a way similar to other natural resources (e.g. oil, gas, etc.)? Why?

If the following measures were to be carried out, how and who should make the greatest contribution in terms of investment. Give reasons.

	Users (totally)	Users (majority)	50% users 50% public sector	Public sector (majority)	Public sector (totally)
Increase in the regulation capacity for urban supply					
Improved efficiency of the urban water distribution networks					
Increase in the regulation capacity for conjunctive uses					
Increase in the regulation capacity for irrigation purposes					
Substitution of high-with low water-demanding crops					
Reallocation of water from irrigation to urban uses					
Improved irrigation efficiency					
Inter-basin transfers					
Water metering					
Remote control					
Reuse of waste water					
Other					

List the advantages and disadvantages of the water pricing systems, based either on actual abstracted volume or irrigated surface.

	Advantages	Disadvantages
Irrigated surface		
Abstracted volume		

Do you think that water prices should adjust to the real costs of the resource? Do you think that this adjustment of water prices would entail a considerable reduction of irrigation water use? To what extent?

Do you think that the option to buy and sell water would involve a considerable number of users? Would it involve a considerable volume of water? What proportion?

What should be the role of the public administration in the process?

1. To get involved as little as possible, letting the water rights holders operate freely.

2. To supervise interchanges so that certain requirements are met.

3. To control the process, by acting as an intermediary, fixing the prices, etc.

4. Other.

What would be the major cultural obstacles for the application of this new framework?

What could be its possible negative effects?

Would it lead to an uneven distribution of benefits and prejudices for different actors? If the answer is *yes*, which ones?

Institutional scenarios

Do you think that the current proportion of water assigned to irrigated agriculture (about 80%) will be reduced in the future? No ☐; Yes ☐ If the answer is *yes,* fill in the next two tables:

	5	10	20	Longer
In what time span (years) would the reduction begin?				

	70%	60%	50%	Other
What percentage would it reach?				

What would be the main factors that could condition such redistribution of water between sectors?

How likely is it (high, medium, low probability) that agricultural policy measures with a significant effect on water use are approved? Low ☐; Medium ☐; High ☐ Why? To what extent would they affect water use?

Do you think that cultural changes are taking place, which could affect the volumes of water used and its distribution between sectors? Yes ☐……………………Which ones? No ☐

Climate change

With the hindsight of the past three drought periods (1970s, 1980s, 1990s), do you think that our capacity to face the effects of drought has improved? Yes ☐ To what extent?; No ☐ Why?

How do you define climate change? Do you think you have sufficient information on this issue?

How could climate change affect the water resources and demand?

Was the problem of climate change ever discussed at your work?

Given the impacts that climate change could entail, how would it affect the level of priority of the previously mentioned measures? Give brief reasons for your answer.

Action	No.	Reasons
Increase in the regulation capacity for urban supply		
Improved efficiency of the urban water distribution networks		
Freeze the increase in the irrigation surfaces		
Water markets		
Increase in the regulation capacity for conjunctive uses		
Increase in the regulation capacity for irrigation purposes		
Substitution of high- with low water-demanding crops		
Water metering		
Reallocation of water from irrigation to urban uses		
Improved irrigation efficiency		
Inter-basin transfers		
Conversion of some irrigation surfaces to dry farming		
Full cost recovery		
Remote control		
Use of waste water		
Other		

Annex 2. Data and information systems

This component refers to the collection, recording, manipulation, processing and accessibility of variables that provide a representation of natural processes and socio-economic patterns. Table 1 outlines the types and characteristics of the data relevant to drought management. The sources of data and the reliability have to be evaluated. In some cases, data are processed to create drought indices or other indicators, and in others, other sources of evidence are used to identify drought or its impacts.

Table 1. Types and characteristics of the data relevant to drought management

Type of information	Description and variables to be included in the analysis
Data Types	Biophysical data: climate, soils, water, land, agriculture Socio-economic data: water and land uses supplies and demands, economic indicators (i.e., GDP), demographic indicators
Data Suppliers	List the organisations and institutions that have the responsibility of data collection and processing, and describe the strategic mandates or policies that dictate the data collection policies
Data Acquisition	Description of the instrumental base for data collection, processing, and recording. For example for climatic data, the information should include the number of weather stations, variables collected, length of the data series, etc
Data Accessibility	Description of the accessibility conditions of data: costs, regularity, format Documentation of the metadata, location, and publications
Data Reporting	Mention the mandatory dependencies that exist with regards to data reporting among official organisations, stakeholders and NGOs
Data Users	List the organisations and institutions that receive data on a regular basis

Chapter 5. Participation and mediation: Key elements to forewarn and resolve conflicts during droughts

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SUMMARY – Droughts can result in restrictions to water supplies, which cause alarm in towns and cities or wherever they are enforced; a situation the news media never fails to cover with photos of deserts and death disseminated far and wide. It is clear droughts place hydraulic systems under an extreme amount of strain –especially rivers and aquifers. It is therefore essential to make use of successful experiences to create a new conception of the field. It will however take some time for this to be accepted as the norm, since drought management will continue to generate situations involving conflict between the interests and values of different individuals and groups.

Key words: Drought, conflict, process, interested parts, Participation.

Introduction

Water disputes occur whenever the demand for water cannot be met by the hydrological resources in a particular region or sector. Typically the disputes are related to years of frustration, waiting, conflict, pain and emotion. Solutions therefore require the application of tools and techniques used in the alternative management of conflicts. Climatic change and drought management have made it necessary for us to be imaginative, generous and responsible when taking action.

The goal of any type of alternative conflict management must take into account not only solutions to the water use and management problems, but also the particular characteristics of the conflict so the foundations can be laid to avoid a recurrence of the conflict. Water disputes are a specific type of environmental conflict; they have specific characteristics and affect collectives; they are complex and normally difficult to quantify in economic terms; they take place in the public domain and their resolution has a significant affect on future generations. Disputes can also worsen or be resolved in accordance with temporary changes in the weather, with droughts accentuating and rains reducing the conflict. And all too often during negotiations environmental interests are underrepresented, which results in agreements that have a detrimental affect on non-renewable resources.

One of the bases for the resolution of water disputes is *prevention,* which feeds of the principles of demand management and the application of which is becoming less and less problematic, especially during droughts. When conflicts do occur, *negotiation* represents the next stage in the search for a solution. Success often depends on the correct representation of the parties involved. When negotiations fail, the next option for the resolution of the dispute is *mediation*. Success at this stage still holds the virtue of the potential control over the agreement of the parties involved. If mediation does not work, there is *arbitration.* This should be the main role of the Water Authorities when agreement is not reached between the parties or when the agreement results in an inadmissible environmental cost. To this end, the Water Authorities should aim to acquire or increase their prestige so as to be recognized by everyone involved. The second from last possibility for the resolution of the water disputes is *judicialization.* This stage should only be reached when all the previous possibilities for reaching a solution have been exhausted. And the last possibility is *imposition*. In this case one of the parties imposes their will on another. This is normally a false solution, which is only valid temporarily. History is however replete with experiences of this type.

Strategies for the resolution of water disputes can be classified in three groups: *prevention strategies,* actions aimed at pre-empting the crystallization of the conflict. *Balancing strategies,* when protest or community groups counteract unbalanced perceptions. Lastly, there are *mediation strategies* that are undertaken by individuals either in institutions or not, which bring the parties involved together and creates conditions favourable to an agreement.

In short, and as a comparative analysis between a range of experiences, we can conclude that truly participatory water planning is the best tool for the prevention of disputes. The symbolic value of water is underestimated in the majority of cases. Multidisciplinary analyses are not generally undertaken prior to the conflict and the representation of the parties involved should be improved. The role of the water authorities is fundamental in the avoidance of agreements that contravene the law, scientific principles, or transfer damages to third parties, especially when they are to the detriment of the water resources of the future.

The aim of this chapter is to make use of specific Spanish experiences arising from a situation of conflict (either manifest or dormant) in the context of water management to schematically:

(i) Describe the features that define this type of conflict.

(ii) Analyse in depth the contributions made by the range of disciplines involved and their complementariness.

(iii) Present the range of approaches to conflict resolution.

(iv) Show the potential of certain tools and techniques for social intervention in water disputes.

(v) Place the processes observed in the range of experiences in an easily understandable conceptual framework.

Water Disputes – Description of Features

Disputes can be defined in many ways, but all include the lowest common denominator which is a situation of conflict, but at the same time an opportunity. Conflict in that there is a confrontation of interests, perceptions, and/or attitudes between two or more parties. This confrontation should not be interpreted negatively, since there are positive aspects to conflicts which allow the development of beneficial outcomes for all the parties involved. Disputes can therefore be viewed as opportunities to create conditions for finding solutions which satisfy all parties ("I win you win" Cornelius and Faire (1998)), with the potential to promote changes in social conditions and introduce new ways of thinking. Consequently innovation and creativity are inherent to the management of conflicts.

The two extremes of confrontation and opportunity and the grey areas in between are in our opinion conditioned by two groups of factors: cultural conditioners and public awareness conditioners. A heterocultural perspective facilitates the management of conflicts involving collaboration in the handling of natural resources.

Water is a privileged natural resource for analysing conflicts connected to consumer and non-consumer demands; its use as a means of transport, for the maintenance of certain habitats, or as an recreational or symbolic area (well documented in publications such as González Alcantud and Malpica, 1995).

As is the case in other environmental conflicts, when we talk of water disputes, we mean a particular type of social conflict in which the problems encountered are related to the quality of life of the people involved (in its widest sense) and the environmental conditions. The following characteristics differentiate these disputes from other types of environmental conflict (Carbonell 2001):

(i) They involve collective actions. They involve or confront groups of people, who are not all organized to the same degree.

(ii) They are complex processes:

– Entailing the unstated interests of the range of parties, whose public and private positions may differ.
– On a local level, there is an extensive and continuous need for harmonious coexistence between the parties.
– There are economic, social, cultural and scientific ramifications.
– A lot of information is required.

(iii) The process is carried out in the public domain.

(iv) Conflicts are on many occasions the result of different values, perceptions and meanings, which cannot be quantified.

(v) The participants are publicly recognized, whether or not they are considered legitimate.

(vi) There are participants who are not present, and whose importance should be stressed, who are the future generations.

(vii) There is normally a high degree of uncertainty, because it is complicated to predict the environmental impact of proposed actions, or because the information required to estimate these impacts is not available.

In the end water disputes are slightly more complex because of the institutional dimension, but on whole they are similar to other conflicts involving natural resources management, in which conflicts exist due to the scarcity of the resource, or because of conflicts between values, power, information, interests, or, most commonly, an interrelation of them all.

Water disputes do however have certain specific features. They almost always occur during droughts and their resolution is often connected to the end of the period of scarcity. And since during periods of abundance there is no public demand to take decisions, actions required for the long-term solution of problems are put off until the next drought. Problems therefore become entrenched and exacerbated, the only hope being a technological miracle that never materialises.

This corollary should be highlighted. The most unpopular actions required to resolve water disputes are taken during periods of hydrological stress, normally as emergencies, with very high economic, social and environmental costs. And between droughts the conflict is forgotten, water is abundant and its price often too low. The needs that caused the problem are met, and nobody takes it upon themselves to return the water to the ecosystems from which it was taken in order to resolve the conflict.

Another defining characteristic of water disputes is the unequal levels of representation between the range of interests involved. Water users, and in particular farmers and supply companies are usually over-represented, either directly or through professionals who depend on them, whereas the representation of environmental interests is often purely symbolic. The water company typically takes on the role of the arbitrator, which is naturally inclined to tend to the more powerful interests. Water resources are therefore overexploited during hydrological crises, because those groups interested in defending them are nearly always in a position of inferiority.

In short, the alternation between periods of drought and periods of abundance marks the rhythm of the generation and resolution of water disputes, which therefore differ from other types of natural resource management conflicts. This characteristic could be of assistance in the resolution of the problem, but often leads to temporary solutions, which are erroneous, and typically only work by reducing the resources available to future generations.

Conflict Analysis – Tackling Disputes in Different Disciplines

Water disputes embrace a very wide range of disciplines: Ecology, social studies, politics, economics, etc. It is therefore very important to identify the approach or discipline used to present the analysis, because the perspective chosen will condition any subsequent actions.

The field of the management and analysis of environmental conflicts is constantly advancing as a multi-disciplinary field. We feel it is important to highlight the contributions of the following disciplinary approaches:

(i) Sociology (the work of Pont (2002) on the protest movement against the National Hydrological Plan in Spain).

(ii) Environmental psychology (the work of Corraliza and Ricardo de Castro).

(iii) Anthropology (studies on water disputes in the Pyrenees by Gaspar Mairal and José Ángel Bergua).

(iv) Political science and its contribution to the concept of environmental governance (the team of the IGOP of the UAB, of the Universidad Pablo Olavide (Paneque) and Seville (del Moral)).

(v) Socio-ecology (Ramón Folch).

(vi) Political ecology (the reflections of the school of Martínez Alier).

A comparison is also made of the tools used by each of them: discourse analysis, open interviews, questionnaires, active listening, analysis of organizations and policies, multi-factor techniques, etc.

The preliminary conclusions can basically be grouped as follows:

(i) Many approaches suffer from an excessively biased view of the conflict. To this end we have adopted the reflections of Villasante when he describes the example of the situation of violence in a Columbian neighbourhood, and the range of responses obtained according to how, who and where questions are made.

(ii) The different approaches often underestimate the role of the parties involved in the definition of the analysis of the conflict.

(iii) Efforts have been made to quantify factors, which do not connect with determinant qualitative aspects, such as power relationships.

(iv) Neither have tools been developed sufficiently for the simulation of scenarios, which could be of great interest for the creation of consensus.

Different Approaches to Conflict Resolution: The Pyramid of Conflicts

There is a range of ways of tackling the resolution of conflicts. A brief description is given below of each. If they were ordered in a pyramid, the options at the base would involve a greater degree of consensus, and the further up the pyramid the higher the level of conflict.

The ideal strategy would be to AVOID the conflicts in the first place. This would however necessitate a cultural change requiring time and money spent on prevention, which in the case of environmental conflicts would mean a strong emphasis on hydrological participation and planning, not as a strategy, but rather a profound conviction that recognises the multiple demands on the resource, and that the interests of all the parties are equally legitimate, that the problems are complex and that the management of the shared knowledge teaches us responsibility and enables us to accept the decisions taken. This is the approach of the "Nueva Cultura del Agua" (New Culture of Water); water disputes can be forecast, discussed and resolved before the event because the hostility of the conflict is greatly reduced in periods of abundance, and increases progressively during droughts. An efficient Water Authority can and should forecast conflicts and take advantage of the enhanced capacity for resolving these when they are dormant, in order to improve their prevention.

If prevention fails, it would be necessary to NEGOTIATE. The parties involved should be able to make use of a direct negotiation process, with no external assistance, to build a satisfactory agreement. There have however been several decades of pain, unfulfilled promises, and hurt pride, which have made the apparently simple exercise of debating the issues and reaching agreements impossible. Here it is necessary to once again stress the role of the Water Administration Company in defining, encouraging and bringing about the meeting of the parties involved. Lasting agreements can only be forged if the complete range of interests has been correctly defined. In addition, agreements which damage the interests of parties who for whatever reason are not involved in the negotiation process should be avoided. Agreements are often reached that have a negative affect on the sustainability of the water resources in dispute. Such solutions merely postpone the problem by damaging future resources or resources of other regions.

MEDIATION would be third from the bottom of the pyramid. It is not a universal remedy for resolving water disputes, but a powerful tool that should neither be sold short nor overvalued.

Solutions reached in a consensus enable all parties to feel empowered by the decisions taken. From this point on if the agreement respects the interests of all parties, the problem resides in encountering the appropriate means to satisfy these as far as is possible. A sensible combination of technical and political decision making, and respect for what realities live etched on the collective imagination, may be the key to making a reality of the perceived paradox which is the possibility of all the parties being winners in the resolution of the conflict.

A good agreement must enable each party to return to their field, or economic or social sector with their head held high because they are convinced the agreement reached is stronger and represents more progress than any option recognising winners and losers.

Another common method for resolving conflict is ARBITRATION. Its choice must be approved by all parties, but the decision taken by the arbitrator is always independent of their wishes. The Water Authority should once again be capable, through their actions, of earning the prestige required to be worthy of taking on the role of arbitrator, which they are awarded on many occasions in the legislation. This is a difficult task, and more so when all too often the role is executed with partiality and in response to the corporate interests of the technicians involved.

In recent times JUDICIALISATION has also often been used as a method to tackle water disputes; but this is only possible in democracies. The parties understand the procedure, and have certain legal rights, but have no effective control over their execution, the individuals involved, or the result of the process. Everyone knows how to initiate a court case, but no one know what the result will be. In the case of water disputes, as in others, the lack of specific training in water issues of lawyers and judges combined with the complexity of the problem mean there is a tendency to reach decisions in economic terms that grossly underestimate the true values of the issues under consideration.

Lastly, it is sometimes the case that due to the disparity between the strength of the parties involved, one makes an IMPOSITION upon the other and ignores any type of reasoning. Imposition may also occur when it is impossible to reach an agreement or when an agreement is patently unethical and the Water Administration Company imposes a necessary solution. In the first case, the imposition has mortgaged its future to later increases in strength of the losing party; and in the second case, success depends solely on the virtue of the imposed solution.

We have wide-ranging experiences in the history of the management and exploitation of water in our country, which has always been interpreted in terms of a confrontation between individuals, interests and territories. The conflicts are inherently good because they show us the diversity and the range of points of view concerning the same problems. However, our ability to resolve them is a measure of the health of our democracy in a society such as ours, which cannot face up to the challenges of the twenty first century without properly addressing this topic.

Intervention – Tools for the Management of Disputes

Certain people have sustained that intervention in the management of conflict is a mix of art and science, and they are not without reason in our experience. Science in terms of systematic analysis, definition of the conflict and design of the intervention process, and art in terms of flair, personal skills and know-how during its execution.

We are therefore especially interested in processes with a collaborative, informal and voluntary emphasis, which are complementary to formal mechanisms for the resolution of conflict (i.e. strict adherence to the rule of law).

Consequently good conflict management would be where the parties involved (directly or those affected by the conflict) all have a real opportunity to understand their mutual needs and to develop a range of alternatives that meet their expectations and enable them to reach a mutually satisfying solution (Lewis, 1996). To this end, we have analysed the application of tools used to avoid confrontation and hostility in the selected cases, by means of a third party who assists the collectives in conflict in reaching a mutually satisfying solution and facilitates the end of the negotiation process.

Our experience in water disputes to date enables us to group intervention methods in three general types:

(i) *Conflict prevention strategies.* These embrace a range of intervention methods aimed at being a step ahead of the emergency arising from the conflict and basically include environmental and dynamic education actions related to forecasts of the future. The following projects in which the authors have participated could be included in this group: "Voluntary Workers", "Saragossa, a City Saving Water", and the Malaga and Balearic Island Water Forums.

(ii) *Strategies* that appear confrontational and incommunicative, but in reality *seek to readjust the balance of power by means of protest organizations* to broaden the participation of the general public. The following experiences could be included in this group: the anti-dam organisations, and the Platform for the Defence of the River Ebro. These normally become direct negotiation processes.

(iii) *Strategies in which the intervention of a third party or a team of collaborators creates the circumstances required for mediation* by moving the range of parties towards a future relation of constructive, cooperative and potentially more productive work than if the conflict were left to develop by itself. The following experiences could be included in this group: "The Social Initiative for Mediation" and "The Water War in the Metropolitan Area of Barcelona" in its last phase.

It is possibly useful to make a distinction in the case of mediation between the role of an institutional mediator linked to one of the parties, and as a result closer to a political mediation, and the role of a team or individual external to the parties involved in the conflict.

We should analyse the tools used in each case (communication tools, leadership, interests *vs* positions, empathy, active listening, anger control, reformulation, reframing, etc.) and attempt to understand how the processes evolve. We should also be able to compare the tools used to support each of them: discussion analysis, open interviews, questionnaires, active listening, analysis of organizations and policies, multi-factor techniques, etc. However, in this chapter we have just presented an overview of these tools. A detailed description and analyse should be the subject of a more extended text that is out of the scope of this publication.

Conclusions

Conclusions have been reached by means of a comparative analysis of a range of experiences:

Participatory water planning is the best tool for the prevention of conflict

When discussing conflict resolution, we should not lose sight of the fact that prevention is always better than a cure. There is no better solution than the nonexistence of the problem. The quality of water planning can in fact be evaluated in terms of the number of conflicts that are avoided, the success of which would depend on the participation of interested parties. One example of many we could give was the composition of the National Water Council during the processing of the previous National Hydrological Plan. The history of the Ebro water basin has demonstrated the fact that many of the water conflicts arising in the last few decades could have been avoided by means of suitable water planning, better information for those involved, and efficient consultancy processes, in which the general public participates as well as the major users and irrigators.

Many authors cite one of the advantages of participation as being the possibility of preventing future conflict. Sadly however this benefit has not been studied in depth and the importance of the opportunities available from this type of community action, where a wide-ranging, complete, integrated and specific parcipation process is carried out, has not been assimilated. Here we refer to active public participation.

The implementation of the EU Water Framework Directive has greatly changed European Union policies for water resource management. One of its most important provisions is the requirement of public participation, which will contribute to the protection of the environment and an adequate management of natural resources.

The Water Framework Directive describes participation not only in terms of a one-way communication process, where simply more information is made available, but refers to a two-way communication process in which information and opinions are exchanged in an inquiry process. The member countries have committed to fostering a type of active participation which can never be considered either too early or excessive.

The specific methodology used to carry out a participation process must be adapted to its context, and to the interests and expectations of those invovled. Exact formulas do not eixst, because those involved are the ones responsible for the construction of the participation process, with the assistence of a facilitator who coordinates its design and execution in accordance with the will of the interested parties.

Interventions often lack a prior multi-discipline analysis of the conflict

Interventions, which require a high degree of personal dedication and involvement from everybody, can be a failure because records are not provided by other disciplines that could open new areas for negotiation between those involved.

The interests of all those involved must be respected equally

Those involved may be right or wrong from a logical or scientific point of view, their views may be supported by more or less individuals, but the interests, objectives and wishes of everybody involved must be respected.

If those involved feel the mediator does not value or respect their beliefs, confidence will soon be lost in the process and it will collapse before it even gets going. A real participation process, as described in the Water Framework Directive, ensures everybody is listened to and their ideas recognized, which increases the chances of a successful outcome agreed between everyone.

Conflicts are complex, and so are their solutions

It would be naive to think conflicts that have developed over a long period of time and become increasingly complex can be resolved easily. The time required to unravel a knot is proportional to how tangled it has become. Complex problems require complex solutions.

Agreements cannot be reached that contravene the law, science or which transfer damages to third parties

Those involved reach agreements as is the aim of the mediation process. Agreements, however, have limits. Damages must not be transferred to third parties, and neither should they be passed on to the present or future water resources. In the case of major hydraulic works, the public administration is more than just the witness to an agreement between others. It plays the lead role in the agreement. In fact it is legally competent to promote the decisions taken and must ensure agreements do not contravene existing legislation.

The critical factor: the willingness of the those involved to reach an agreement

No type of methology can replace the most critical factor: the willingness of those involved to reach an agreement. An incentive to this willingness comes in the form of the conviction that a safe agreement is preferable for all. In other words it is better to be sure of 100% of an end document which meets 85% of your expectations than to reach a doubtful and weak agreement that meets 100% of your intentions.

Consensus agreements are more practical

When agreements are made through the consensus of all involved, none places legal obstacles or obstacles of any type in the way of the implementation of the agreement. The agreement will therefore be executed earlier, and public administrations will be keen to invest in them happy in the knowledge that there is no opposition. Reaching a consensus is often laborious and time is lost during the decision making. A lot of time is gained however during the execution. The end result of an agreed plan, is that the work is normally completed much earlier than one imposed upon one of the parties involved.

Specific methodology is required for each conflict

There is no such thing as a universal methodology that can be appiled to any context and situation. Generally valid mediation priniciples need to be adapted to specific situations. The people involved, the history of the case, the socio-political situation, and the existing legal frameworks are all unique to each specific conflict. And unique components need to be tackled specifically in each case. A little craftsmanship is required, where generosity, responsibility and honesty are needed to make the best use of the materials at hand.

The role of the general public

Dialogue and mediation as the main strategies for the resolution of conflicts in water management and use can perfect the democractic process if and when the general public makes the necessary commitment. Much is still to be learned concerning the reciprocal relationships between public administrations and the general public in order to increase our understanding of participation, tolerance and consensus creation.

Mediation is not a universal remedy for the resolution of water conflicts in Spain, and neither is it the best solution. Ideally conflicts would be avoided in the first place, as explained as the first step of the pyramid for the resolution of conflicts described above in the spirit of the New Water Culture. And in the event of conflict, those involved would ideally be able to reach a mutually satifactory solution by means of a direct negotiation process without the need for external assistence.

We are however convinced that given the current culture of Spanish society, and specifically the main players in water conflicts during the droughts that are now upon us, participation, its priniciples and methodology can contribute a great deal towards the construction of a water culture that listens to the sensibilities of Spanish society at large concerning the management of the resource, and which also meets the demands of the new Water Directive of the European Union.

Chapter 6. Stakeholder dialogue for improved local water governance

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Introduction

The content of this chapter is based on EMPOWERS Working Paper No. 6 (version 2) and EMPOWERS Guidelines for stakeholder analysis.

EMPOWERS, the Euro-Med Participatory Water Resources Scenarios project (now known as the EMPOWERS partnership), funded by the European Commissions Euro-Mediterranean Regional Programme for Local Water Management, is working in Egypt, Jordan and the West Bank/Gaza to develop tools and approaches that will lead to improved water governance, with a focus on practical applications at the local level. EMPOWERS collaborates with MEDROPLAN as part of the cooperation strategic plan of the MEDA Water programme.

Objectives

The objective of EMPOWERS is to improve the development and management of water resources at the intermediate and local level by promoting increased participation and representation of stakeholders in planning and decision-making processes.

Two main activities are carried out to achieve this objetive:

(i) Developing the conceptual and methodological background for dialogue processes.

(ii) Implementation of such stakeholder dialogue methods in a structured participatory planning process.

One of the core assumptions of the EMPOWERS approach is that stakeholder involvement –particularly at the intermediate and local levels– leads to improved use and management of water resources. Improved management implies taking better account of users needs and engenders collective responsibility for interventions in the water sector.

To this end, EMPOWERS is developing a participatory planning cycle for Integrated Water Resource Management (IWRM). This cycle builds on the identification of water-related problems and the development of area specific long-term visions and strategies for water resource development. This strategizing process is supported by the collection and analysis of relevant information on water resources, infrastructure, demand and access and the validation of this information in semi-quantitative Bayesian Networks (computer software). The aim of this planning cycle is to support stakeholders at local and intermediate levels in making the technical and political decisions to plan, develop and manage their water resources within a commonly agreed future vision.

Conceptual background

Stakeholder Dialogue and Concerted Action (SDCA)

SDCA is an active and facilitated approach to bring different actors to strategic consensus on how to work together on specific issues of shared concern. It does this by making explicit the different opinions, perceptions, preoccupations, assumptions, and judgments of the actors involved. It identifies opportunities to improve the exchange of information, social organization, and decision-making between stakeholders in order to create the proper conditions for innovations. At the same time it contributes to creating awareness of the constraints and opportunities that affect the performance of relevant actors. SDCA identifies potential actors who do or could act effectively together to remove constraints and make use of opportunities for innovation. Indeed SDCA enhances institutional and technological innovation through active networking, involving all relevant actors including community members, governments, NGOs, academic institutions, and the private sector. Innovation can be seen as the outcome of a mutual learning and social change process taking place among a large number of autonomous actors in mutual interdependence challenging them to create conditions through which innovation can take place. Where innovation implies change it also implies resistance to such change.

Dialogue and strategic consensus

Stakeholders often have different if not contradictory interests, stakes, tasks and responsibilities, interests that may have political, ideological, technical and financial causes. Despite such differences there are also many joint interests among these stakeholders, who range from national authorities, through government agencies, NGOs and the private sector operating at Governorate, District and Municipality levels, to different end-users of water at the grass-roots level. It is our conviction that creating shared objectives, beliefs and visions, not to forget information among these stakeholders is the key issue to come to concerted action in the water sector. Dialogue and planning activities –often in an informal setting– will enhance coordination and cooperation in the provision of water related services: irrigation, drinking water or sanitation; or for wider issues surrounding the management of the resource base itself.

Facilitation of this dialogue is essential to help relevant stakeholders to make explicit their often different opinions, perceptions, preoccupations, assumptions, and judgments. Such a dialogue will also enable them to implement the planning cycle process and to arrive at strategic consensus for concrete action. This chapter will further detail how the enveloping process of stakeholder dialogue and concerted action in which they are applied can be enhanced.

Innovation

Embarking on a structured and facilitated process of dialogue has in many cases led to innovation in the current ways of dealing with problems and constraints. Innovation can be described, at its most basic, as "the process of introducing or developing something new". This process can occur in the technological but also in the social/cultural sphere. It often can be seen as the outcome of mutual learning and at the same time as a "social change process". Social but also technological change processes often take place between large numbers of autonomous actors in mutual interdependence. This requires social organization and competence sharing among different actors, as well as important capacities and skills in process facilitation. SDCA can challenge stakeholders in domains with different levels of complexity to create the conditions necessary for innovation.

Management of change

Innovation often implies change, and change implies resistance. Resistance and change can be seen as the two sides of a coin. Resistance is a natural and expected part of change; a force that slows or stops movement. Any system, organization or individual will resist any change that it believes will be harmful to itself.

But resistance often also means protection; resistance can thus also have the function of avoiding undesirable and imposed change. Being an active energy it is also a paradox as well as a source of information about the pace and degree of an enhanced change process. As much as one may wish for it, progress without resistance is impossible. Nonetheless, change when effectively managed can happen relatively smoothly if it is managed by good facilitation and if it is responding to widely perceived changes in the environment. As the social, institutional and ecological environment is not static, and the effects of a changing external environment on local communities increase, it becomes crucial to sustain and develop local capacities in development and long term visioning to institutionalise the change process.

Platforms for concerted action

Dialogue, strategic consensus, innovation and concerted action need to be organized and structured in one or another form. This social organization can be carried out and anchored in informal or more formal platforms. Such platforms are especially useful for IWRM with its inter-sectoral complexities of day to day decisions and long-term strategic planning. Social organization in formal or informal platforms for innovation in IWRM can contribute to the following (Engel, 1997):

(i) Creation of joint learning opportunities and hence innovation.

(ii) Mutual probing and exploring of relevant ideas and options.

(iii) Pooling of resources and capacities for innovative strategies.

(iv) Sharing and validating relevant information.

(v) Joint planning and decision-making.

(vi) Concerting actions within a framework of a shared and agreed future vision.

(vii) Providing the necessary shared ownership of problems to make difficult decisions for the future.

In the broad arena of IWRM, networking and dialogue can lead to different forms of social organization. This can range from loose communication networks for sharing and learning to strategic alignments and resource coalitions of different stakeholders where resources and capacities are pooled to come to joint planning, decision-making and action.

Communities and local stakeholders will be brought together through local water committees or community based organizations or village councils. They have to be supported by stakeholder platforms at the district or governorate level, in which relevant government water authorities, other government institutions, private water service providers and development NGOs all participate. Such SDCA platforms can analyse constraints, elaborate shared visions and possible scenarios, define priorities, identify opportunities to improve the exchange of information and decision-making process between stakeholders, and strengthen social organization for concerted action. This chapter focuses on the steps to be taken in stakeholder analysis, facilitation and setting-up of stakeholder platforms; in short, the social organization needed for participation in IWRM.

Creation of stakeholder platforms in the water arena is not an easy job. Many obstacles related to diverging or even contradicting agendas, interests and perceptions, especially in the institutional sphere have to be tackled. However, this diversity, often reflecting multiple realities, can also be turned into creative breeding ground for innovation.

Gender and right-based approaches

The approach promoted here gives a high emphasis to ensuring access and rights to water to underprivileged groups in local communities, with a strong focus on women and the poorest parts of the population. Special attention is given to the pre-conditions that are necessary for local water-users to assume accountability for the management of their local water resources.

Sustainability and replicability

Planning and management of water resources are long-term activities, that take place across a range of institutional levels and physical scales (from river basins to community projects), and involve a very wide range of stakeholders. Approaches and tools for participatory planning and stakeholder involvement have to be cost and time effective to be replicable and adopted by the institutions involved. This applies equally at community, governorate and national levels. Such replicability is essential for making approaches and tools "sustainable" and having lasting long-term impact. As a general rule a good SDCA process will depend on the following conditions for success (adapted from Engel, 1997):

(i) Recognizing that building platforms is not easy, as resource coalitions tend to be opportunistic. The existence of divergent behaviour among stakeholders must be recognized. Nevertheless, innovation through SDCA requires a sufficient degree of strategic consensus based on common concerns, shared and agreed strategies among relevant and more powerful social/institutional actors, and active cooperation among all stakeholders involved.

(ii) Recognizing that, in practice, resource coalitions will often be lead by one or several actors; from whom, over time, an effective leadership pattern will emerge.

(iii) Identifying clearly defined boundaries to the SDCA platform. Criteria: timeframe, outcome problem diagnosis, purpose of the SDCA, relative importance of actors.

(iv) Clear arrangements to facilitate: effective internal and external communication; transparency and agreement among different stakeholders with respect to interests and agendas; task division, delegation and coordination; access and transfer of resources (knowledge, labor, funds, credit) managing and disagreement.

Applying SDCA

Introduction

SDCA as described above is used here as the approach to social organization for the implementation of a planning cycle for IWRM and improved water governance in Egypt, Jordan and Palestine. A stakeholder approach without a focused and structured interest (a planning framework in our case) will not mobilize people and institutions for the longer time-spans essential to both water resource management and water service provision. At the same time a technically sound planning framework will miss the point if key actors are left out during negotiation, planning and decision-making. The Participatory Water Planning Cycle discussed in Fig. 1 provides this underlying interest and structure, to underpin an SDCA approach to IWRM.

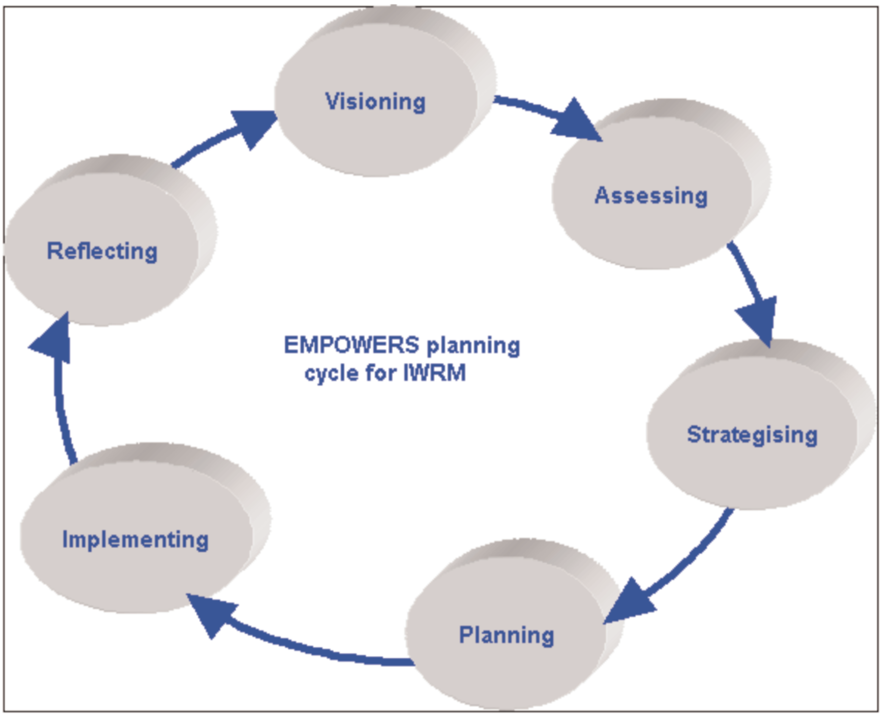

Fig. 1. The Participatory Water Planning Cycle (PWPC).

Objectives of SDCA

The objectives of SDCA can be summarized as:

(i) A comprehensive understanding of the social organization needed in IWRM.

(ii) A shared and clear vision of the stakeholders for IWRM at national and local level.

(iii) A shared understanding of the actual roles and responsibilities of the relevant stakeholders in IWRM.

(iv) Identifying other potential stakeholders with clear potential future roles and responsibilities.

(v) Agreement of key stakeholders to a greater emphasis on pro-poor and right-based approaches.

(vi) Suggestions for improvements in IWRM and a shared vision of how to implement these improvements.

(vii) A shared and validated information base, as a basis for action planning.

(viii) Shared action plans for IWRM based upon stakeholder led visions, scenarios and strategies at both village and governorate level.

(ix) Proposals to pool resources and capacities for such an action plan.

Establishment of stakeholder platforms

Stakeholder platforms can be established, for example, at three distinct levels in each country. These are: at national level a national steering committee; at governorate level a broad based action research coalition; and in selected pilot communities, multi-user groups. At the district/governorate level, the platform consists of all relevant district/governorate stakeholders (government and non-government), together with representatives from national level and the selected communities.

Table 1 gives an example of the stakeholder platforms established at national to district level in three partner countries of EMPOWERS.

Table 1. Stakeholder platforms in EMPOWERS†

Egypt	Jordan	Palestine
Ministry of Water Resources and Irrigation	Ministry of Water and Irrigation	Palestinian Water Authority (PWA)
National Water Research Centre	*Ministry of Agriculture*	Ministry of Agriculture
Ministry of Agriculture	Ministry of Social Development	Ministry of Local Government
Potable Water Authority in Beni Suef Governorate	Ministry of Interior in Balqa Governorate	Ministry of Environment
DRTPC/University of Cairo	Ministry of Planning	*Palestine Hydrological Group*
Egyptian Water Partnership	*INWRDAM (Islamic Network for Water Resource Development and Management)*	*Union of Agricultural Work Committees*
CEOSS	*JoHUD/ZENID*	*CARE WBG*
CARE Egypt	*CARE Jordan*	

† The entire Regional Programme of EMPOWERS is supported by IRC, INWRDAM and CARE International.
In italics, the EMPOWERS partners facilitating the SDCA.

The national level stakeholder platforms (or steering committees) ensure that the approaches developed are appropriate to national policy and therefore open to being scaled up and institutionalized. What is being developed, therefore, is a series of layered stakeholder platforms set up with the express intention of experimenting, learning, and replicating approaches to pro-poor water governance and IWRM. This model of applied learning within a realistic institutional structure can be referred to as a knowledge community or learning alliance.

SDCA in the Planning Cycle

Table 2 below identifies the main activities to be implemented as part of this stakeholder approach and as the six steps of the planning cycle evolve. In this table emphasis is given to those activities that require good and trusted discussion among stakeholders. In most of the cases this will take place in participatory workshops and meetings.

Table 2. SDCA for the EMPOWERS Planning Cycle

Step	Objectives	SDCA for planning in IWRM	Outputs
Visioning	Stakeholders involved and interested in work Broad scope of work identified and agreed	Stakeholder identification and analysis Problem analysis Initial visioning and scenario building Identifying priority communities for action	Stakeholder platforms Problem trees Initial visions at district or governorate level Initial scenarios
Assessing	Main causes of water problems identified Agreed and shared information-base developed	Stakeholders involved in: Information collection and analysis Quality control and cross-checking	RIDA Analysis Belief Networks Provisional data base
Strategising	Previous steps integrated to create shared basis for vertically and horizontally integrated action planning	Update visions and scenarios Develop broad strategies Assess & validate vision & scenario/strategy combinations using Bayesian Networks Select key scenario and related strategies Prioritise activities Define decision modalities	WRA reports Community and District Water Fact Sheets "final" visions, scenarios and strategies for IWRM
Planning	Detailed plan(s) for concerted action developed, budgeted and agreed	Plan community and governorate level activities Identify tasks and responsibilities Define information flows Prepare project proposals Define M&E plans (acquire funding)	Logframes for project proposals Funded IWRM Project Proposals for community, district and governorates
Implementing	Activities implemented according to plans within a transparent and high quality approach and in a concerted way	Implement activities Awareness raising Tendering (transparent) Capacity building Information sharing Quality control	Achieved results Capacities build Information basis improved
Reflecting	Implementation process documented Achievements monitored Lessons drawn out of preceding planning cycle	Documenting processes (+ video) M&E Learning and reflecting	Process reports & videos Evaluation reports Conclusions drawn as input for next planning cycle

Critical milestones for which stakeholder workshops are essential are the following:

(i) Problem tree analysis at different levels.

(ii) Selection of priority communities.

(iii) Long-term visions and scenarios.

(iv) Strategy development.

(v) Project planning.

(vi) Shared analysis of experience`s and lessons learned.

Facilitating the stakeholder process at institutional levels

The stakeholder platforms in the three countries are currently being facilitated by a multi-disciplinary country team from the EMPOWERS Partnership, consisting of a country coordinator, two field coordinators and a process documentation officer. They are staff of the organizations who have signed a Partnership Agreement in the context of the EMPOWERS Programme funded by the EC/MEDA Water programme. In the case of EMPOWERS, this project has been started with the consent of the government authorities, although the initiative to take up this approach has been taken by the members of the Partnership.

As mentioned earlier, it is assumed that by pro-actively involving all relevant stakeholders and by developing effective and participatory planning methodologies more sustainable and integrated management of scarce water resources can be attained.

Stakeholder processes are now facilitated by members of the Partnership itself, but the intention is that over time this important function will be institutionalized elsewhere. It should be underlined that facilitation, here, does not refer to facilitation of single events, advocacy platforms or other activities that bring together different actors to exchange information and coordinate actions on irregular intervals. It does refer to –in short– guiding "brokering" processes in planning and decision making between government agencies (officials) and local communities (end-users). It also recognizes that actors may opt out and see no interest in remaining involved. As this may occur it has to be assessed to what extent this will compromise decisions to be taken and what the price is of having a specific actor abandoning the process. In any case it is an intensive permanent activity where the "facilitator" takes an active role (Laban, *et al.*, 2005a):

(i) Facilitating "horizontal" communication and coordination among these players, so that planning and implementation of IWRM is done in an integrated and holistic way. In particular, attention is required to ensure that the often narrow sub-sector agendas of key stakeholders do not come to dominate. Breaking down such barriers to horizontal communication is a key part of the EMPOWERS approach.

(ii) Facilitating "vertical" communication between different institutional levels of key non-community players, in order to ensure that solutions to problems are responsive to the real needs of local stakeholders, while reflecting national/governorate level priorities; i.e. facilitating locally appropriate as opposed to top down decision making.

(iii) Facilitating communication, coordination and planning between such community based organizations and these other players at District, Governorate and National levels.

Facilitating the stakeholder process in communities

In the above paragraphs the need for professional facilitation of complex processes in the water sector has been highlighted. This need is certainly important in order to bring together different actors (government agencies, NGOs, private sector) at the same institutional level or among different levels (national, governorate, district, and municipalities) in order to create the "horizontal" and "vertical" linkages that are necessary for proper planning and decision-making.

Facilitation of processes, however, should not stop at the level of municipality or village councils. Every community has its own socio-economic configuration determined by culture, wealth, gender, land tenure, access to resources, etc. In most (if not all) communities there will be groups that are more vulnerable, have less resources and access to services, and that have less influence in decision-making. In a vision where it is also considered important that these more marginal groups have their right share to quality water (be it for household or agricultural purposes) and to proper sanitation, process facilitation becomes even more important to make sure that also these groups are involved. It requires additional skills that are sensitive to the recognition that conscious efforts have to be made to actively involve women and the poorest sections of a community. At the same time interests and priorities of different village organizations have to be taken into account. Process facilitation as mentioned in the precedent section needs to be extended to the following functions (Laban, *et al.*, 2005b):

(i) Enhancing more active involvement of the most vulnerable segments of society in planning and decision-making in water use and management, so as to ensure their access and control over water resources.

(ii) Enabling community based organizations to strengthen their capacities and "claim-making power" towards players in the water and rural development sector that operate at the district, governorate and national level (government agencies, private sector, research and other organizations).

Altogether the functions of the "facilitator" aim to enhance understanding of the different roles, responsibilities, opportunities and constraints which affect stakeholders and thus the potential for concerted action. Table 3 provides a short list of criteria that can be used for the identification and selection of host institutions for this important facilitation function.

Tabla 3. Criteria for identification of facilitation host institutes

Institutional position	Relatively neutral, no specific sector agendas and independent from government.
	An existing and well-known non-profit organization.
	Genuinely indigenous and well-rooted in the country's civil society.
	Unconventional and non-bureaucratic.
	Wide geographic presence through field offices as well as development programmes.
	Accepted by most (if not all) sectors in civil society and government.
Capacitites	Capacity in facilitating interaction and decreasing gaps between local communities and government agencies.
	Experience in working with local communities (community development, capacity building...).
	Capable and experience in communicating with government agencies.
	Interdisciplinary and divers staff capacities.
	General (but not necessarily very specific) knowledge about the water sector.
	Familiar with EMPOWERS approaches (SDCA, RAAKS, PTD, PRA, Participatory Planning framework).

When process facilitation in SDCA is understood in the way described here, it has the potential to become a powerful tool to reach the poorest sections of local communities and especially women. Such facilitation will complement other approaches such as social analysis, advocacy and political pressure.

Tools for stakeholder analysis and action (RAAKS)

Promoting a dialogue and consequently concerted action among different stakeholders requires analysis of these stakeholders and their roles. This refers to different issues, such as forms of cooperation and coordination, information and knowledge sharing, assumed tasks and responsibilities, influence on decision-making, interest and roles in planning and implementation, but also to perceptions, political and institutional agendas, power, resistance to change, etc.

Rapid Appraisal of Agricultural Knowledge Systems (RAAKS), forms a first step for analysis and decision-making in SDCA (Engel and Solomon, 1997). On the basis of a RAAKS analysis, platforms are formed of key stakeholders who together support a specific development process, having a common agenda and shared interests. It focuses on clarifying the role and responsibilities of all major actors working in a certain thematic field, such as community water management or agricultural development, identifying possible constraints in coordination, cooperation and communication, and developing appropriate actions. RAAKS follows an interactive process with the stakeholder institutions (inside and outside local communities) to draw them into the action research process and encourage ownership of its outcome. The study team makes use of a number of participatory tools that use checklists of key issues in different areas ("Windows of Analysis") such as vision and mandate of the organization as related to study area, tasks and responsibilities, strategic interest, development agendas, institutional structure and resources, information flows and decision patterns. A selection of RAAKS tools is given in Annex 1. The RAAKS process culminates in a workshop where views of respective actors or institutions are brought together, shared and systematically compared as a basis for joint problem review and action planning. The RAAKS tolls ensure that it:

(i) Makes explicit the different "appreciations" of stakeholders: perceptions, preoccupations, assumptions and judgements.

(ii) Identifies opportunities to improve exchange of information, social organization and decision-making among actors in order to create the conditions for innovation.

(iii) Creates awareness with respect to constraints and opportunities that affect the performance of actors as innovators.

(iv) Identifies (potential) actors who do, or could, act effectively to remove constraints and make use of opportunities for innovation

Actor Analysis

Actor identification

(i) What actors (organizations, groups, and individuals) are relevant in the domain of project interest and the specific geographical area of project implementation? Annex 2 gives an example of possible stakeholders in the water sector.

(ii) What are their objectives? Is there a shared objective?

(iii) What are the main problems you think each of these actors perceives (within the domain of interest, e.g health, water resource use, agricultural development, education, etc.)?

(iv) Make a simple drawing of the problem situation (cause-effect problem tree; VENN diagram). Assess weight and interest of actors and problems.

Actor analysis

(i) Who can be seen as the key actors and who should not?

(ii) What information will be needed from each key actor to understand their role in the domain/ arena in which the project has to be implemented (health, education, water, agriculture?

(iii) What contacts already exist between the various actors?

(iv) What are actual information flows among actors? What relevant information/knowledge networks do the actors already utilize? In what areas?

(v) What is the actual power and decision-making situation among actors? How could/need this be improved?

(vi) What results are expected to improve the actual situation in the project area?

(vii) What/who are driving/constraining forces behind the functioning of a stakeholder platform that could be promoted to implement the project? (Stakeholder Dialogue and Concerted Action/SDCA approach).

(viii) What tasks have to be performed by whom to achieve an optimal result?

(ix) How are these tasks implemented and coordinated? How could this be improved?

Identifying partner and key stakeholders

On the basis of answers to above questions it is important to decide with who to share responsibility for implementation of the project (partners) and which organizations (not selected as partners) are crucial for continuation and sustainability of the project activities after the end of project (key stakeholders). The latter are most probably found at policy and sector responsibility levels (national and/or Governorate) and for continued facilitation of stakeholder processes after the project has withdrawn. Some reflection on differences between partners and key stakeholders is summarized in Table 4 below.

Table 4. Differences between partners and stakeholders

Partnership	Stakeholder platform
Family	Market / Neighbourhood
Coordination	Facilitation / Mediation
Shared responsibility	Joint interest
Sharing resources	Creating access to resources

When selecting partners one should be aware that unequal "weight" and "quality" of partners (e.g. some partners seen as donors?) can build in structural difficulties in project implementation. Also potential partners can have different stakes in the project, dependent on how they see the lead partner as a collaborator, competitor, supporter or client. For a balanced partnership it is important to seek equality in terms of funding, expertise and organisational strength.

Some Guidance in using RAAKS Windows and Tools for initial analysis and decision making in a Stakeholder Dialogue and Concerted Action Process is presented in Annex 1.

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Annex 1. RAAKS Tools for different Windows

Window	Window opens to the following subject	Tools for each Window
A1	Problem definition and objectives	Problem definition exercise
A2	Identifying relevant actors	Actor identification exercise
A3	Tracing diversity of mission statements	Actor Objective Sheet
A4	Environmental Diagnosis	Environmental limits checklist
A5	Clarifying the problem situation	Prime mover septagram (or spider-web) Approximation Exercise I Approximation Exercise II
B1	Impact analysis	Impact Analysis Sheet
B2	Actor analysis	Actor Analysis Checklist
B5	Task analysis	Task Analysis Sheet
B3	Knowledge Network Analysis	Info-source Exercise Communication Network Sheet Source-intermediary-User Sheet
B4	Integration analysis	Linkage Matrix Linkage Mechanism Checklist
B5	Task Analysis	Task Analysis Sheet
B6	Coordination Analysis	Basic Configurations Prime-mover septagram (spider-web)
B7	Communication Analysis	Communication Analysis Exercise
B8	Understanding the social organization of innovation – Summing-up	Window Reporting Sheet Understanding social organization of innovation Approximation Exercise I Approximation Exercise II
C1	Knowledge Management Analysis	Knowledge Management Analysis Exercise
C2	Actor Potential Analysis	Actor Potential Checklist
C3	Strategic Commitments	Defining possible actions Strategic Commitments

Annex 2. An example of possible stakeholders and their characteristics and interests

Stakeholder	Number/ Geographical location	Characteristics structure, organisation, status, socio-economic group, attitudes, etc.	Interests and expectations	Potential and deficiencies
Farmers / Agriculture	Rainfed agriculture is practised over the largest arable crop surface area in the Mediterranean irrigated areas represent an important proportion of this surface in Mediterranean countries	Sometimes organized in professional organizations and/or Farmers' Unions. Very interested in guidelines development In some countries already integrated and positively involved in the management of water resources	To plan and adopt agricultural practices and inputs adapted to drought periods To anticipate drought effects on livestock. To avoid decreasing livestock capitals To plan and adopt agricultural practices and inputs adapted to drought periods To anticipate drought effects on livestock To avoid decreasing livestock capitals	Low financial margin in some countries to invest in new technologies Good insurance coverage in a few countries Increasing experience in the use of alternative sources of feeding for livestock
Other sectors (Tourism, Industry)	Tourism and industry are key economic activities in participants' countries	Directly affected by water shortages Represented by Tourist Company Associations and Employer's Organizations	To avoid water shortages and bad quality To avoid water being a limiting factor for sector development	Very influential in economic policies Sometimes the tourism and industrial model is water-wasting and not water-sustainable
Urban water consumers and water utilities	Urban population represents a major proportion of total population in the participant countries	Directly affected by water shortages Sometimes represented by consumers associations Aware of the need to save water	To avoid water shortages, increase supply guarantee levels and water quality standards' improvement	High potential of water saving
Water managers (water basin and local authorities)	One per river basin in some of the partner countries In all towns and villages	Depend on the state government or the local authorities. In charge of administration and distribution of water Also private companies in some cases	Directly affected by water shortages Need to develop water policies based on risk analysis	Main actors in drought guidelines Need to take into account different and opposed interests
Meteorological and Hydrographical Institutions	National and regional in some countries	Depend on national and/or regional governments	Interested in the use of their data in risk analysis	Main actors in drought guidelines In some countries, difficulties to provide data
Ministries of Agriculture, Environment, Water, Tourism, Industry	National and regional in some countries	Depend on national and/or regional governments	Directly concerned by water shortages In charge of the implementation of mitigation policies	Key actors In some countries, coordination between them is to be improved
Insurance companies	National and regional in some countries	Depend on national and/or regional governments	Directly concerned with the reduction in agricultural production due to drought periods	Key source of data for risk analysis in some countries Main actors in drought preparedness guidelines

Stakeholder	Number/ Geographical location	Characteristics structure, organisation, status, socio-economic group, attitudes, etc.	Interests and expectations	Potential and deficiencies
Agricultural banks and rural lending institutions	National, regional and local	Depend on national and/or regional governments	Directly concerned with the need of extraordinary financial resources due to drought periods	Key source of data for risk analysis in some countries Main actors in drought guidelines
Research, Training and Development Institutions	National and regional	Depend on national and/or regional governments Private	In charge of development, adaptation and adoption of technologies for water saving and sustainable use	Good human capital in some disciplines Human resources scarce in some areas Limitation in financial resources
International Cooperation Organizations	Mediterranean level	Intergovernmental	Drought and water are key issues in the Mediterranean region Key actors in transfer of technology and knowledge between countries	Good network of contacts and human resources Limitation of financial resources

Chapter 7. Drought characterization

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SUMMARY – Drought indices have been devised for identification of drought and characterization of its severity. Using drought indices, the duration, intensity and areal extent for each drought episode can be defined. They can be used to describe all types of droughts (that is meteorological drought, hydrological drought, agricultural droughts and socioeconomic drought). According to the type of drought, the appropriate drought index is selected. Drought indices are composite numerical figures incorporating mainly values of hydrometeorological indicators. The most popular drought indices presented in the report and applied in the participating countries in the MEDROPLAN project include the SPI, the PDSI, the method of Deciles, the recently developed RDI and others. Crucial elements in the procedure for calculating drought severity by using drought indices are the time step adopted and the threshold of each index selected. During the project a common methodology for applying drought indices for monitoring and assessment of droughts and estimation of drought risk was devised and applied to all case studies.

Key words: Drought indices, frecuency, duration, intensity, areal extent, type of drought.

Introduction

Drought is one of the major water related hazards. However, there is no universally accepted definition of drought. Perhaps the most general definition is the one which considers drought as a significant decrease of water availability during a long period of time and over a large area. This implies that drought should be considered as a three dimensional event characterized by its severity, duration and affected area.

Various methodologies have been proposed for identification, quantification and monitoring of drought phenomena. Among them, the most popular seem to be single factors known as *drought indices*, which are special combinations of indicators comprising meteorological, hydrological and other data.

Drought indices are important and useful elements for drought monitoring and assessment since they simplify complex interrelationships between many climate and climate-related parameters. Indices make it easier to communicate information about climate anomalies to diverse user audiences and allow scientists to assess quantitatively climate anomalies in terms of their intensity, duration, spatial extent and frequency. This allows the analysis of the historical droughts events and their recurrence probability.

It should be mentioned that drought indices may be grouped in two categories, the general indices and the specific indices. The general indices give an overview of the drought occurrence and its severity, whereas the specific indices are mostly useful for correlating drought events to the anticipated damages from drought in the various sectors of the economy, the environment and the society. This chapter gives emphasis on the general drought indices, which are analytically presented. Namely, the general indices, which were selected for application for Mediterranean countries, are the Deciles, the Standardized Precipitation Index (SPI), the Palmer Index, as well as the new Reconnaissance Drought Index (RDI). Apart from these general indices, references are also made to specific indices for the purpose of a systematic presentation.

Very important aspects, when drought indices are used, are the thresholds representing the levels of drought severity. It is needless to say that these thresholds should be associated with the anticipated damages corresponding to each level of severity.

Drought indices are employed to characterize drought and its statistical properties. Drought analysis from a stochastic point of view provide information required for the subsequent risk analysis (probabilities of drought occurrence and drought impacts).

Drought indices provide spatial and temporal representations of historical droughts and therefore place current conditions in historical perspective. They are valuable for providing decision makers with a measurement of the abnormality of recent weather for a region.

Drought management depends on indices to detect drought conditions, and thresholds to activate drought responses. Indices and thresholds are important to detect the onset of drought conditions, to monitor and measure drought events, and to reduce drought impacts.

Several drought indices are proposed and used to characterize drought and analysing observed data after fixing a threshold and a time scale.

Drought identification and characterization in a given region permit in performing water resources planning and management of their rational uses especially in the arid and semi-arid zones. For the operational management however monitoring and early warning systems base on certain indices should be developed.

Overview of drought indices

Drought-trigger indices include meteorological and hydrological drought indices. Meteorological drought indices respond to weather conditions that have been abnormally dry or abnormally wet. When conditions change from dry to normal or wet, for example, the drought measured by these indices ends without taking into account streamflow, lake and reservoir levels, and other longer-term hydrologic impacts. Meteorological drought indices do not take into account human impacts on the water balance, such as irrigation. Hydrological drought indices take into account water management and streamflow, lake and reservoir levels, and other longer-term hydrologic impacts.

Drought-trigger indices assess drought conditions in a specific time. However, it is necessary to define a drought threshold value for each one of the drought indices. This threshold distinguishes a drought category and determines when drought responses should begin and end.

A single indicator is useful for drought monitoring but is not well suited when the purpose is to identify and characterize historical droughts either at a site or at regional scale.

A method to characterize drought based on drought-trigger indices should:

(i) Provide criteria for declaring the beginning and the end to a drought.

(ii) Represent the concept drought in a particular region.

(iii) Correlate to quantitative drought impacts (via drought-responses indicators) over different geographical and temporal time scales.

Due to the complexity of drought, approaches to develop drought indices and triggers are needed (Steinemann, 2003). Because drought conditions depends on numerous factors, such as water supplies and demands, hydrologic and political boundaries and antecedent conditions indices should be sensitive to the contexts. But indices often lack spatial and temporal transferability, comparability among scale, and relevance to critical drought impacts. Thresholds often lack statistical integrity, consistency among drought categories, and correspondence with desired management goals (Steinemann, 2003). In many cases multiple indices are used but multiple indices on multiple scales can confound the complexity of single indices. Consequently it is necessary the implementation of drought identifications methods.

The parameters to be characterized for drought identification are the following:

(i) Frequency. Analyse the long-term averages in terms of rainfall to determine how many droughts occur within 10 years.

(ii) Timing.

(iii) Rate of onset.

(iv) Intensity. Intensity of the drought: ratio between cumulated deficit and duration. Drought intensity is a measure of rainfall deficiency over three months (or other index). Determine a threshold of rainfall that can de correlated with the intensity. For example, for a particular region, between 5 and 10% above the lowest on record is rated as serious and less than 5% above lowest on record is rated as severe.

(v) Cumulated deficit: Sum of the negative deviation throughout the drought duration.

(vi) Duration. Number of consecutive intervals where the variable is below the threshold. Occasionally, droughts last for 7 or 8 years, but within that period the severity may fluctuate with spells of rainfall, although still well below average. Other droughts are shorter (one or two years) but more intense with very little rain recorded.

(vii) Spatial extent. It is unlikely that an entire country could suffer drought at the same time. Some droughts can be localised with other relatively close areas receiving normal rainfall.

(viii) Predictability.

One of the options to provide an approach for expressing indices within a probabilistic framework and for evaluating their stochastic properties is to use a multistage homogeneous Markov model. This method developed by Steinemann (2003) offers an equitable basis for evaluation, ease of interpretations and direct application to water management decisions. The model based on Markov methodology is applied to describe and interpret the indices in terms of their transitioning, persistence, duration and frequency between categories. The model can provide quantitative results and the criteria for what is desirable in indices and triggers, such as degree of persistence, depends on the decision making context.

The run method allows an objective at site and regional drought identification and characterization, and therefore it represents a methodology for an analysis oriented to define best drought mitigation alternatives. The run method is based on the relationship between drought and negative runs in rainfall time series considering a hydrological variable and a critical threshold level (Yevievich, 1967; Rossi *et al.*, 2003).

Assessment of drought impacts is difficult due to the interaction of several components within the system which is affected by drought. Feedback or indirect effects might be sometimes greater than direct (first order) effects. First order interactions occur between physical components and biological components (impacts on agriculture and environment) or socio-economic components. Second order interactions occur between biological and socio-economic components. Also feedback effects from biological and socio-economic components can modify the status of some physical components of the system. Finally the third order interactions occur between institutions and policy makers with the functioning of the system.

Drought-trigger indices assess drought conditions in a specific time. However, it is necessary to define a drought threshold value for each one of the drought indices. This threshold distinguishes a drought category and determines when drought responses should begin and end.

Table 1 summarizes the most commonly used drought indices, whereas the methods of calculation are outlined in the following section. A complete analysis of drought indices is provided by Hayes (2004).

Table 1. Summary of the main drought indices

Index	Description and Use	Strengths	Weaknesses
Meteorological Drought Indices			
Percent of Normal Precipitation and Accumulated Precipitation Departure	Simple calculation Used by general audiences	Effective for comparing a single region or season	Precipitation does not have a normal distribution Values depend on location and season
Deciles Gibbs and Maher (1967)	Simple calculation grouping precipitation into deciles Used by the Australian Drought Watch System	Accurate statistical measurement Simple calculation Provides uniformity in drought classifications	Accurate calculations require a long climatic data record
Standardized Precipitation Index (SPI) McKee *et al.* (1993)	Based on the probability of precipitation for any time scale. Used by many drought planners	Computed for different time scales, provides early warning of drought and help assess drought severity	Values based on preliminary data may change Precipitation is the only parameter used
Palmer Drought Severity Index (PDSI) Palmer (1965) Alley (1984)	Soil moisture algorithm calibrated for relatively homogeneous regions Used in the USA to trigger drought relief programs and contingency plans	The first comprehensive drought index, used widely Very effective for agricultural drought since includes soil moisture	PDSI may lag emerging droughts. Less well suited for mountainous areas of frequent climatic extremes Complex Categories not necessarily consistent, in terms of probability of occurrence, spatially or temporally
Crop Moisture Index (CMI) Palmer (1968)	Derivative of the PDSI Reflects moisture supply in the short term	Identifies potential agricultural droughts	It is not a good long-term drought monitoring tool
Recoinnaissance Drought Index (RDI) Tsakiris (2004)	Similar to SPI Basic variable P/PET	Drought is based on both precipitation and potential evapotranspiration Appropriate for climate change scenarios	Data needed for calculation of PET
Hydrological Drought Indices			
Palmer Hydrological Drought Index (PHDI) Palmer (1965)	Same as PDSI but more exigent to consider a drought end. The drought terminates only when the ratio of Pe (moisture received to moisture required) is 1	Same as PDSI	Same as PDSI
Surface Water Supply Index (SWSI) Shafer and Dezman (1982)	Developed form the Palmer Index to take into account the mountain snowpack	Represents surface water supply conditions and includes water management Simple calculation Combines hydrological and climatic features. Considers reservoir storage	Management dependent and unique to each basin, which limits inter-basin comparisons Does not represent well extreme events

Basic notions to apply the drought indices

Once a set of general drought indices has been selected, several basic assumptions will make their use effective and easy to interpret. A similar procedure has been selected for the Drought Monitoring System proposed for USA.

Normal Conditions

Since drought has been postulated as the deficient deviation from the normal conditions, it is necessary to clarify what is meant by *normal conditions*. Some researchers use a general level, which corresponds to water balance between water availability and consumption; most of the researchers however use the mean figures of meteorological parameters to establish the normal conditions. If for instance the precipitation is the key parameter to measure annual drought, the arithmetic mean of annual precipitation for a number of years is the level taken as the basis for calculating the deviations.

From results of various studies, it can be inferred that the *median* instead of the arithmetic mean can represent more reliably the normal conditions in an area. This is mainly because extreme values of fatal outliers do not influence the median as they influence the arithmetic mean. The same happens when new data are added to the existing series of data.

As a concluding remark, it can be concluded that, in some cases, the arithmetic mean could be replaced by the median for establishing the normal conditions.

Time step and reference period

The data required for drought assessment are usually monthly data. No smaller time step has any significant effect when drought is assessed by general indices. Only in some very specialized indices related to crucial water deficit aspects, a smaller time step can be used.

Therefore, for the purpose of establishing drought-meteorological networks, monthly values of the key meteorological/hydrological parameters are required.

Further regarding the reference period of drought assessment it seems logical to consider longer period of time. If short reference period is selected, many complications will be encountered related to carry-over quantity of water from period to period. Furthermore, lag time in hydrological processes makes any kind of drought assessment unreliable if a short period of time is adopted.

Based on these thoughts, the task of assessing droughts using general indices can be more efficiently implemented if the reference period is an entire season or an entire year. A hydrological year starts the first day of October and ends at the end of September of the next year for the Mediterranean Countries. By fixing the reference period, the dimension of duration could be neglected.

Spatial integration

It is generally accepted that drought is a regional phenomenon. However, meteorological information is collected at selected stations, which can be considered as representing the area attributed to them (e.g. by Thiessen polygons). The spatial integration is based on these areas/polygons. Polygons under drought are aggregated to estimate the total critical area which is affected by drought.

However, this approach disregards the hydrological processes, which are based on the hydrological basin scale. As known, the hydrological basin is the unit for any water resources management scheme according to the natural laws. This primary principle is the cornerstone of the new Water Framework Directive of the European Union. For the small basins in particular, it is even more obvious that drought should use the whole basin as the unit since no significant variability over the area of the basin is expected.

Therefore it could be proposed that drought analysis could be applied to the basin or subbasin as the unit; after transferring the data from the existing stations on the average basin scale. There might be cases in which one station can represent an entire basin or sub-basin and in this case, calculations for drought indices can be performed directly.

In case of assessment of drought at a basin scale the "interpolate – calculate" method could also be used. By this method, all principal data (e.g. precipitation, temperature, etc) are transferred to the squares in which the basin is divided upon. Then, the weighted average is used to calculate the representative meteorological data of the entire basin and then the drought indices are calculated. The opposite procedure by which the drought indices are calculated at the locations of the meteorological stations and then they are transferred to the basin scale should be avoided mainly due to the "non-linearity" problems related to the procedure.

The above approach seems to give significant opportunities for relating meteorological drought to hydrological drought and also it will lead to a more efficient linkage between meteorological drought indices and the anticipated damage in the various sectors of the economy.

Apart from the suggested approach above, in a number of cases (e.g. very big river basins) it could be also possible to base severity indices on the data derived directly from the meteorological stations themselves. By this way we could construct isolines of the selected indices, which show the spatial variability of the drought severity.

Spatial interpolation of meteorological data

As known, the most important parameter considered in the evaluation of meteorological drought indices is precipitation. There are many available methods, which can be used for spatial interpolation of precipitation. Thiessen polygons may be used to transfer the data at the basin scale directly. The weighted average is calculated and then corrected for the deviation in the altitude.

Another popular way to transfer precipitation data from the stations to the basin level is through the mediation of squares, which the basin is divided in.

Therefore, from the stations the data are transferred to the squares and from the squares to the entire basin. In the latter case, several techniques could be used. Among the most popular are the kriging, the splines, the inverse of square distance weighting, the trend surface and the multiple linear regression.

Similar techniques can be used for transferring other meteorological data at the basin level.

Selected drought indices

Deciles

A simple meteorological index is the rainfall deciles, in which the precipitation totals for the preceding three months are ranked against climatologic records. If the sum falls within the lowest decile of the historical distribution of 3-month totals, then the region is considered to be under drought conditions (Kininmonth *et al.*, 2000). The drought ends when: (i) the precipitation measured during the past month already places the 3-month total in or above the fourth decile, or (ii) the precipitation total for the past three months is in or above the eighth decile.

The first decile is the precipitation amount not exceeded by the lowest 10% of the precipitation occurrences. The second decile is the precipitation amount not exceeded by the lowest 20% of occurrences. These deciles continue until the rainfall amount identified by the tenth decile is the largest precipitation amount within the long-term record. By definition, the fifth decile is the median, and it is the precipitation amount not exceeded by 50% of the occurrences over the period of record. The deciles are grouped into five classifications.

Table 2 presents the classification of drought conditions according to deciles.

Table 2. Classification of drought conditions according to deciles

Decile Classifications	
deciles 1-2: lowest 20%	much below normal
deciles 3-4: next lowest 20%	below normal
deciles 5-6: middle 20%	near normal
deciles 7-8: next highest 20%	above normal
deciles 9-10: highest 20%	much above normal

The advantage of the decile approach is its computational ease, but its simplicity can lead to conceptual difficulties. For example, it is reasonable for a drought to terminate when observed rainfall is close to or above normal conditions. But minor amounts of precipitation during periods in which little or no precipitation usually falls, can activate the first stopping rule, even though the amount of precipitation is trivial and does not terminate the water deficit. A supplemental third rule, that considers the total precipitation since the beginning of drought, may be used (Keyantash and Dracup, 2002). According to this rule, if the total precipitation exceeds the first decile for all drought months, then the meteorological drought may be considered terminated.

Standardized Precipitation Index

The Standardized Precipitation Index (SPI) was developed for the purpose of defining and monitoring drought (McKee *et al.*, 1993).

The SPI calculation for any location is based on a series of accumulated precipitation for a fixed time scale of interest (i.e. 1, 3, 6, 9, 12,… months). Such a series is fitted to a probability distribution, which is then transformed into a normal distribution so that the mean SPI for the location and desired period is zero (Edwards and McKee, 1997). Positive SPI values indicate greater than median precipitation, and negative values indicate less than median precipitation. Because the SPI is normalized, wetter and drier climates can be represented in the same way, and wet periods can also be monitored using the SPI.

Thom (1958) found the gamma distribution to fit well climatological precipitation time series. The gamma distribution is defined by its probability density function:

$$g(x) = \frac{1}{\beta^{\alpha}\Gamma(\alpha)} x^{\alpha-1} e^{-x/\beta} \quad \text{for x} > 0 \tag{1}$$

where: α, β are the shape and scale parameters respectively, x is the precipitation amount and $\Gamma(\alpha)$ is the gamma function. Computation of the SPI involves fitting a gamma probability distribution to a given frequency distribution of precipitation totals for a station. The alpha and beta parameters of the gamma probability density function are estimated for each station, for each time scale of interest (1, 3, 6, 9, 12 months, etc.), and for each month of the year. Maximum likelihood solutions are used to optimally estimate α and β:

$$\alpha = \frac{1}{4A}\left(1 + \sqrt{1 + \frac{4A}{3}}\right)$$

$$\beta = \frac{\bar{x}}{\alpha} \tag{2}$$

where $\mathrm{A} = \ln\left(\bar{x}\right) - \frac{\sum \ln(x)}{n}$, and n = number of observations

The resulting parameters are then used to find the cumulative probability of an observed precipitation event for the given month and time scale for the station in question. Since the gamma function is undefined for x = 0 and a precipitation distribution may contain zeros, the cumulative probability *H(x)* is calculated by the equation:

$$H(x) = q + (1 - q)\, G(x), \tag{3}$$

where q is the probability of a zero and $G(x)$ the cumulative probability of the incomplete gamma function. If m is the number of zeros in a precipitation time series, then q can be estimated by m/n. The cumulative probability is then transformed to the standard normal random variable z with mean zero and variance one, which is the value of the SPI. Once standardized the strength of the anomaly is classified as set out in Table 3. This table also contains the corresponding probabilities of occurrence of each severity arising naturally from the normal probability density function. Thus, at a given location for an individual month, moderate droughts (SPI ≤ -1) have an occurrence probability of 15.9%, whereas extreme droughts (SPI ≤ -2) have an event probability of 2.3%. Extreme values in the SPI will occur, by definition, with the same frequency at all locations.

Table 3. Drought classification by SPI value and corresponding event probabilities

SPI value	Category	Probability (%)
2.00 or more	Extremely wet	2.3
1.50 to 1.99	Severely wet	4.4
1.00 to 1.49	Moderately wet	9.2
0 to 0.99	Mildly wet	34.1
0 to -0.99	Mild drought	34.1
-1.00 to -1.49	Moderate drought	9.2
-1.50 to -1.99	Severe drought	4.4
-2 or less	Extreme drought	2.3

The SPI can track drought on multiple time-scales. The U.S. National Drought Mitigation Center (NDMC) computes the SPI with five running time intervals, i.e. 1-, 3-, 6-, 9-, and 12-months, but the index is flexible with respect to the period chosen. This powerful feature can provide an overwhelming amount of information unless researchers have a clear idea of the desired intervals. Moreover, being a standardized index, the SPI is particularly suited to compare drought conditions among different time periods and regions with different climatic conditions.

A program to calculate SPI proposed by the National Drought Mitigation Center can be obtained from:

http://www.drought.unl.edu/monitor/spi/program/spi_program.htm

The method of calculation includes the following steps:

(i) Data preparation. Computation of a time series of accumulated precipitation value for a fixed time scale. At least 30 years of data are highly recommended.

(ii) Determination of a probability frequency distribution that statistically fits the time series of precipitation data.

(iii) Calculation of the non-exceedence probabilities related to the accumulated values.

(iv) Derivation of the corresponding normal standard quantiles, which represent the SPI values.

Palmer Drought Severity Index (PDSI)

The PDSI was introduced by Palmer (1965) for the assessment of the meteorological drought. PDSI is referred to as an index of meteorological drought, however, the procedure considers precipitation, evapotranspiration, and soil moisture conditions, which are determinants of hydrological drought, i.e. the period during which the actual water supply is less than the minimum water supply necessary for normal operations in a particular region. The basic concepts and steps for computing the PDSI are presented bellow.

Step 1: Hydrological Accounting

The computation of the PDSI begins with a climatic water balance using long series of monthly precipitation and temperature records as inputs. The soil is divided into two layers, where the upper layer, called surface soil, contains 25 mm of available moisture at field capacity. This is the layer onto which the rain falls, and from which evaporation takes place. Evaporation loss from the surface layer, L_S, is assumed to take place at the potential rate which is estimated by the Thornthwaite method. Moisture cannot be removed from, or recharged to, the underlying layer until the surface layer has been depleted or saturated. The loss from the underlying layer, L_U, depends on the moisture content, computed Potential Evaporation (PE), and available water capacity (AWC) of the soil system. If PE>P, then

$$L_S = \min [S_S, (PE - P)], \quad (4)$$

$$L_U = [(PE - P) - LS]\, S_U / AWC, \qquad L_u < S_U, \quad (5)$$

where S_S and S_U are the amounts of available moisture stored at the beginning of the month in the surface and the underlying layers, respectively. Runoff is assumed to occur, if and only if, both layers are at moisture capacity, AWC.

In addition to PE, three more potential terms are used and they are defined as follows: Potential Recharge (PR) is the amount of moisture required to bring the soil to its water holding capacity given by:

$$PR = AWC - (S_S + S_U) \tag{6}$$

Potential loss (PL) is the amount of moisture that could be lost from the soil by evapotranspiration during a zero precipitation period given by:

$$PL = PL_S + PL_U \tag{7}$$

where

$$PL_S = \min\,[PE, S_S] \tag{8}$$

$$PL_U = [PE - PL_S]\, S_U / AWC,\ PL_U < S_U \tag{9}$$

The Potential Runoff (PRO) is defined as the difference between the potential precipitation and the potential recharge. Potential precipitation is equal to AWC, hence, PRO is given by:

$$PRO = AWC - PR = S_S + S_U \tag{10}$$

Step 2: Climatic Coefficients

A calibration of the water balance model to normal levels is accomplished by simulating the water balance over the period of available historical records of temperature and precipitation and so deriving the moisture capacity of the lower soil layer and four coefficients for the study area. The following four monthly coefficients are computed using the four potential terms, PE, PR, PRO and PL:

$$a_j = \frac{\overline{ET_j}}{\overline{PE_j}} \tag{11}$$

$$b_j = \frac{\overline{R_j}}{\overline{PR_j}} \tag{12}$$

$$c_j = \frac{\overline{RO_j}}{\overline{PRO_j}} \tag{13}$$

$$d_j = \frac{\overline{L_j}}{\overline{PL_j}} \tag{14}$$

where ET is the evapotranspiration, R is the soil water recharge, RO is the runoff, and L is the total water loss from the soil. The over-bars indicate the average values from the historical records for each month j.

Step 3: CAFEC Values

The derived coefficients are used to reanalyse the time series, in order to determine the amount of moisture required for "normal" weather during individual months. In particular, the Climatically Appropriate For Existing Conditions (CAFEC) values are computed, and they are denoted by a circumflex (^). For example, the CAFEC value for ET_J for month j is:

$$ET_j = a_j \cdot PE_j \tag{15}$$

where PE_j is the potential evapotranspiration for the current month j. Hence, the CAFEC precipitation value, *P*, is computing as:

$$P = a_j \cdot PE + b_j \cdot PR + c_j \cdot PRO - d_j \cdot PL \tag{16}$$

Step 4: Moisture Anomaly Index

For each month j, the difference between the actual precipitation and the CAFEC precipitation is an indicator of the water deficiency or surplus for that month at the station or area under study.

This is expressed as $D = P - \hat{P}$. These departures (D) are converted into moisture anomaly (Z) indices, known as Palmer Z-index, according to:

$$Z = K_j \cdot D \tag{17}$$

where K_j is a weighting factor for the month j, which takes into account the spatial variability of departures D, such that they are independent of time and space.

Step 5: Drought Severity

In this final step the Z-index time series is analyzed to develop criteria for the beginning and ending the periods of drought and a formula for determining drought severity. Palmer's methodology involves computing, for each month, three intermediate indices X1, X2, and X3 and a probability factor. Palmer expressed the beginning and the termination of drought (or wet period) in terms of the probability that the dry or wet spell has started or ended. A drought or wet spell is definitely over when this probability reaches or exceeds 100%, but the drought or wet spell is considered to have ended the first month when the probability became greater than 0% and then continued to remain above 0% until it reached 100%. During the period of "uncertainty" when an existing drought (or wet period) may or may not be over (i.e. when the probability is between 0% and 100%), the model computes the three intermediate indices X1, X2, and X3. X1 is the index value for an incipient wet spell, X2 is the index value for an incipient drought, and X3 is the index value for an established drought event or wet spell. All three intermediate indices are calculated using the following empirical expression:

$$X_j = 0.897 \cdot X_{j-1} + \frac{Z_j}{3} \tag{18}$$

where Z_j represents the value of the moisture anomaly index or Z-index for the month j. The Palmer's model selects the value of one of the intermediate indices and assigns to PDSI depending on the value of probability factor. For example, if the probability factor takes a value between 0 and 1, then PDSI takes the value of X1, if the probability factor takes a value between 0 and –1, then PDSI takes the value of X2 and when the probability factor takes values larger than 1 or smaller than –1 then PDSI takes the value of X3. The X3 term responds much slower than PDSI to soil moisture changes and is an index for the long-term hydrologic moisture conditions known as Palmer Hydrological Drought Index (PHDI). The classification of weather based on PDSI, PHDI, and Z-Index (Palmer, 1965) is shown in Table 4. It should be noted that the Z-Index provides an indication of the persistence of the drought phenomenon, whereas PDSI denotes the drought severity.

Table 4. Classification of weather using PDSI, PHDI, and Z-index (Palmer, 1965).

PDSI, PHDI, Z-index	Weather
> 4.00	Extremely wet
3.00 to 3.99	Very wet
2.00 to 2.99	Moderately wet
1.00 to 1.99	Slightly wet
0.50 to 0.99	Incipient wet spell
0.49 to -0.49	Near normal
-0.50 to -0.99	Incipient drought
-1.00 to -1.99	Mild drought
-2.00 to -0.99	Moderate drought
-3.00 to -3.99	Severe drought
< -4.00	Extreme drought

The Palmer method used for calculating the PDSI, PHDI, and Z-Index has a number of limitations and deficiencies (Alley, 1984). The limitations of the method can be classified into two categories: the water balance model deficiencies and the PDSI characteristics. The first category of limitations of the Palmer method includes:

(i) The use of the Thornthwaite method for the estimation of the potential evapotranspiration although other methods could be employed. However, with the limited available data required by the Palmer method, only a simple methodology for the estimation of the potential evapotranspiration, such as the Thornthwaite method, should be used.

(ii) The arbitrary amount of 25 mm of the moisture capacity of the surface soil layer. The soil moisture capacity could be widely changed depending on the climate, the soil texture, and the vegetation coverage of the area.

(iii) The assumption that the runoff is estimated without any lag in the time distribution. Thornthwaite and Mather (1955) and Mather (1981) suggested that 50%-75% of the runoff should be delayed each month in order to reproduce monthly flow volumes observed in streams. The fraction of runoff delayed varies considerably depending on the depth and texture of the soil, the physiography and size of the basin, and the nature of the groundwater system.

(iv) The "threshold-type" model of the Palmer method in that it assumes that runoff does not occur until the moisture capacity of the upper and lower soil layer is filled. This assumption tends to under-estimate the recharge during the summer and early autumn months.

(v) No allowance is given for the effect of snowmelt or frozen ground but this is not a problem in the Mediterranean climatic region where snowfall occurs only at high elevations.

The limitations of the PDSI characteristics can be summarized as:

(vi) The arbitrary definition of PDSI classes. These classes have been defined from data from central Iowa and Kansas.

(vii) The sensitivity of PDSI values to K_j factors (Equation 17). But the overall duration of droughts of various magnitudes is relatively insensitive to K_j variations.

(viii) The sensitivity of PDSI values to the climate of the calibration period.

Despite several assumptions used in the water balance calculations, other limitations and deficiencies, and the empirical nature of some of the standardized coefficients, the PDSI can be a useful tool for both research and operational drought assessment, if used appropriately and acknowledged its limitations stated above (Karl *et al.*, 1987; Rao and Voeller, 1997). It should also be mentioned that the Palmer method tackles the difficult problem of droughts using only monthly data of precipitation and temperature.

A program to calculate PDSI is available (previous registration) at:

http://nadss.unl.edu/downloads/

Reconnaissance Drought Index (RDI)

A new reconnaissance drought identification and assessment index was first presented in the coordinating meeting of MEDROPLAN project in March 2004 (Tsakiris, 2004), while a more comprehensive description was presented in Tsakiris *et al.* (2006).

The index, which is referred to as the Reconnaissance Drought Index, RDI, may be calculated by the following equations. For illustrative purposes the yearly expressions are presented first. The first expression, the initial value (α_0),. is presented in an aggregated form using a monthly time step and may be calculated for each month of the hydrological year or a complete year. The α_0 is usually calculated for the year i in an annual basis as follows:

$$\alpha_o^{(i)} = \frac{\sum_{j=1}^{12} P_{ij}}{\sum_{j=1}^{12} PET_{ij}} \text{ , i = 1 to N, and j = 1 to 12} \tag{19}$$

in which P_{ij} and PET_{ij} are the precipitation and potential evapotranspiration of the month j of the year i, starting usually from October as it is customary for Mediterranean countries and N is the total number of years of the available data.

A second expression, the Normalised RDI, (RDI_n) is computed using the following equation for each year, in which it is evident that the parameter $\bar{\alpha}_0$ is the arithmetic mean of α_0 values calculated for the N years of data.

$$RDI_n^{(i)} = \frac{\alpha_o^{(i)}}{\bar{\alpha}_o} - 1 \tag{20}$$

The third expression, the Standardised RDI (RDI_{st}), is computed following a similar procedure to the one that is used for the calculation of the SPI. The expression for the Standardised RDI is:

$$RDI_{st}^{(i)} = \frac{y^{(i)} - \bar{y}}{\hat{\sigma}_y} \tag{21}$$

in which y_i is the $\ln(\alpha_0^{(i)})$, $\bar{y}$ is its arithmetic mean and $\hat{\alpha}_y$ is its standard deviation.

It is noted that the above expression is based on the assumption that the α_0 values follow a lognormal distribution. The Standardised RDI behaves in a similar manner as the SPI and so is the interpretation of results. Therefore, the RDI_{st} can be compared to the same thresholds as the SPI.

The choice of the lognormal distribution is not constraining but it assists in devising a unique procedure instead of various procedures depending on the probability distribution function which best fits the data. However, the hypothesis that the data of the RDI_n follow a lognormal distribution seems to be the most appropriate. In all examples analyzed during the establishment of the RDI, the goodness-of-fit tests confirmed that the lognormal distribution fits the data satisfactorily.

It should be emphasised that the RDI is based on both precipitation and potential evapotranspiration. The mean initial index ($\bar{\alpha}_0$) represents the normal climatic conditions of the area and is equal to the well known Aridity Index as was proposed by the FAO.

Among others, some of the advantages of the RDI are:

(i) It is physically sound, since it calculates the aggregated deficit between precipitation and the evaporative demand of the atmosphere.

(ii) It can be calculated for any period of time (e.g. 1 month, 2 months etc).

(iii) The calculation always leads to a meaningful figure.

(iv) It can be effectively associated with agricultural drought.

(v) It is directly linked to the climatic conditions of the region, since for the yearly value it can be compared with the FAO Aridity Index.

(vi) It can be used under "climate instability" conditions, for examining the significance of various changes of climatic factors related to water scarcity.

From the above advantages, it can be concluded that the RDI is an ideal index for the reconnaissance assessment of drought severity for general use giving comparable results within a large geographical area, such as the Mediterranean region.

It should be mentioned that usually droughts in the Mediterranean are accompanied by high temperatures, which lead to higher evapotranspiration rates. Evidence for this has been produced from simultaneous monthly data of precipitation and evapotranspiration in many Greek watersheds. From the cases analyzed it seems that about 90% of them comply with the previous statement. (Tsakiris and Vangelis, 2005) Therefore, the RDI is expected to be more sensitive index than those related only to precipitation, such as the SPI. A graph comparing the annual figures of SPI and RDI is presented in Fig. 1.

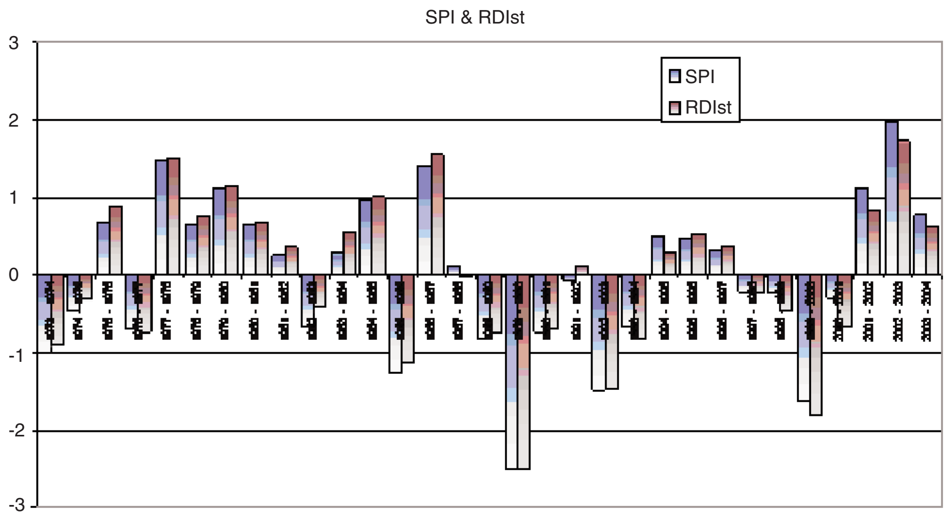

Fig. 1. Annual SPI and RDI for a series of hydrological years (Oct-Sep) (1973-2004).

The RDI can be calculated for any period of time from one month to the entire year, even starting from a month different than October, which is customary for the Mediterranean. Very significant results can be derived if the period of analysis coincides with the growing season of the main crops of the area under study or other periods related to sensitive stages of crop growth. Then, the RDI can be associated successfully with the expected loss in rainfed crop production, which in turn is linked to the anticipated damages in the agricultural sector due to drought occurrence.

As it was shown from previous studies, precipitation (and therefore SPI) was not successfully correlated to agricultural production (Tsakiris and Vangelis, 2005). However, the inclusion of potential evapotranspiration (PET) in the calculation of the RDI enhances its validity in studies aiming at risk assessment in agriculture caused by drought occurrence.

Other Drought Indices

Apart from the general indices that were presented so far for future use, it is also worth presenting concisely some specific indices that are quite widely used. These indices are used for agricultural, economic, industrial, tourist and recreational uses.

The **Bhalme-Mooley Drought Index (BMDI)** (Bhalme and Mooley, 1980) provides a good measure of the current status of drought that is the effect of short periods of dry weather, unlike the PDSI which is designed to evaluate the degree of severity and frequency of prolonged periods of abnormally dry conditions. BMDI is simple and less complex than other indices because it is not involving terms such evapotranspiration or soil water capacity, which are parameters especially difficult to estimate and it is based only in monthly precipitation.

The **Rainfall Anomaly Index (RAI)** was developed by van Rooy (1965) to incorporate a ranking procedure to assign magnitudes to positive and negative precipitation anomalies. The form of the index is:

$$RAI = \pm 3 \frac{P - \overline{P}}{\overline{\overline{E}} - \overline{\overline{P}}} \tag{22}$$

where P is measured precipitation, $\bar{P}$ is average precipitation, and $\bar{E}$ is average of 10 extrema. For positive anomalies, the prefix is positive and $\bar{E}$ is the average of the 10 highest precipitation values on record; for negative anomalies, the prefix is negative and the 10 lowest measurements are used. The index values are judged against a 9-member classification scheme, ranging from extremely wet to extremely dry. Oladipo (1985) found that differences between the RAI and the more complicated indices of Palmer and Bhalme-Mooley were negligible.

A traditional assessment of hydrological drought is the **Total Water Deficit**, which is synonymous with drought severity S. This severity is the product of the duration D, during which observed flows are consistently below some truncation level, and magnitude M, which is the average departure of streamflow from the truncation level during the drought period (Dracup *et al*., 1980). The truncation level or flow threshold might be chosen in a number of ways and the choice is amongst others a function of the type of water deficit to be studied. It is possible to apply a percentage of the mean flow (Dracup *et al*., 1980), other low flow indices (e.g. mean annual n-day flow), or a percentile from the flow duration curve (usually the 90^{th} percentile flow or Q90). The threshold might be fixed or vary over the year in a monthly or seasonal pattern (Demuth and Stahl, 2001). The total water deficit can be applied to various time scales of streamflow data, from daily to annual time series. Since this approach consists of the application of run method to streamflow it might be considered as another index.

This method basically coincides with the run method, which can be also applied to streamflow. The Run Method is presented in this text in the section of spatial extent of drought as a method for determining the areal extent of drought.

The **Palmer Hydrological Drought Severity Index (PHDI)** was presented earlier in the presentation of the PDSI. The distinction between PHDI and PDSI is that the PHDI has a more stringent criterion for the elimination of the drought or wet spell, which results in the index rebounding gradually and more slowly than the PDSI towards the normal state. Specifically, the PDSI considers that a drought episode is finished when moisture conditions begin an uninterrupted rise that ultimately erases the water deficit, whereas PHDI considers a drought ended when the moisture deficit actually vanishes. This retardation is appropriate for the assessment of hydrological drought, which is a slower developing phenomenon than meteorological drought. It should be mentioned that PDSI can be computed only when the drought event finished, i.e. only on past series, while PHDI can be computed in the current time interval.

The **Surface Water Supply Index (SWSI)**, developed by Shafer and Dezman (1982), explicitly accounts for snowpack and its delayed runoff. The mathematical formulation of the SWSI is as follows:

$$SWSI = \frac{aP_{snow} + bP_{prec} + cP_{stream} + dP_{res} - 50}{12} \tag{23}$$

where, a, b, c, d are weights for each hydrological component and a+b+c+d = 1, P_i is the probability of non-exceedence (in %) for component i, and snow, prec, stream, res are the snowpack, precipitation, streamflow, and reservoir storage components, respectively. Subtracting 50 and dividing by 12 are a centring and compressing procedure designed to make the value have a similar magnitude to the PDSI and make comparisons between watersheds (Garen, 1992). The weights are estimated from a basin calibrated SWSI algorithm that considers the typical contribution of each hydrological component to the water supply of the basin. The SWSI is a suitable measure of hydrological drought for mountainous regions, where snow contributes significantly to the annual streamflow.

Palmer (1968) developed the **Crop Moisture Index (CMI)** to monitor short-term changes in moisture conditions affecting crops. The CMI is the sum of an evapotranspiration deficit (with respect to normal conditions) and soil water recharge. These terms are computed on a weekly basis using PDSI parameters, which consider the mean temperature, total precipitation, and soil moisture conditions from the previous week. The CMI can assess present conditions for crops but it can rapidly vacillate and is a poor tool for monitoring long-term drought. The CMI begins and ends each growing season near zero, which may be appropriate for botanical annuals, but not for tracking long-term droughts. As a consequence, the assessment of agricultural drought is better suited to the related Palmer Moisture Anomaly Index or Palmer Z-Index (Karl, 1986).

The **Palmer Moisture Anomaly Index (Z-Index)** has been presented earlier in the computation of PDSI. It is the moisture anomaly for the current month, without the consideration of the antecedent conditions that characterize the PDSI. The Z-Index can track agricultural drought, as it responds quickly to changes in soil moisture values. Karl (1986) found that the Z-Index is preferable for quantifying agricultural drought than the more commonly used CMI. However, like all of the Palmer indices, it suffers from a complicated formulation and computation and it is only slightly less complex that the PDSI.

The **Soil Moisture Anomaly Index (SMAI)** was developed by Bergman and his associates (1988) to characterize droughts on a global basis. The method inherently relies upon the moisture accounting method of Thorthwaite and operates within a two-layer soil model used to track the movement of water, ultimately resulting in a running assessment of percent soil saturation. Simulation results suggest that SMAI values change at a rate centred between the rapid CMI and the relatively slow PDSI (Bergman *et al.*, 1988).

Spatial Extent of Drought

The Run Method

Use of run analysis has been proposed as an objective method for identifying drought periods and for evaluating the statistical properties of drought. According to this method a drought period coincides with a "negative run", defined as a consecutive number of intervals where a selected hydrological variable remains below a chosen truncation level or threshold (Yevjevich, 1967).

Such a threshold can be a fixed value in the case of a non-periodic (e.g. annual) stationary time series or a seasonally varying truncation level in the case of a stationary periodic series. The truncation level in each time interval is somewhat arbitrary and it must be selected on the basis of the objective of the study. Usually it is assumed equal to the long-period mean (or median) of the variable of interest, while other possible choices include a fraction of the mean (Clausen and Pearson, 1995), a value corresponding to a given non-exceedence probability (Zelenhasic and Salvai, 1987, and Correia *et al.*, 1987), or a level defined as one standard deviation below the mean (Ben-Zvi, 1987). In any case, the threshold should be chosen in such a way to be considered representative of the water demand level (Yevjevich *et al.*, 1983, Rossi *et al.*, 1992).

The advantage of using the run method for drought definition consists in the possibility of deriving the probabilistic features of drought characteristics (such as duration, cumulative deficit) analytically or by data generation, once the stochastic properties of the basic variable are known. This possibility is not limited to relatively simple cases where time dependence of consecutive values can be neglected but also when a Markov chain structure is assumed for the underlying variable (Cancelliere *et al.*, 1998; Fernandez and Salas, 1999). Furthermore, procedures to assess the return period of droughts defined according to the run method have been derived recently (Fernandez and Salas, 1999; Shiau and Shen, 2001; Bonaccorso *et al.*, 2003; Cancelliere and Salas, 2004), thus making the method an ideal candidate to perform drought risk analysis.

Drought identification and characterization both at a site and over a region based on the run method can be carried out by REDIM software, developed by the Department of Civil and Environmental Engineering of Catania University and available at the website:

http://www.risorseidriche.dica.unict.it/main_downloads.html

The Cumulative "or more" curves

A better representation of the spatial extent of the drought can be achieved using a type of curves known as cumulative "or more" curves (ogives). These curves can be produced by plotting the severity of drought (y-axis) versus the percentage of the affected area (x-axis). The severity of drought is presented by a drought index and the area refers to that affected by at least the corresponding severity level. This type of graphs can be used not only for the characterization of drought and the determination of its areal extent, but also for comparisons with the critical area percentage (related to severity) directly. Clearly, more than one thresholds referring to the percentage of critical area can be used defining different levels of severity. A representative "or more" curve is presented in Fig. 2 for the affected area, during a dry year, using the SPI as the index of drought severity.

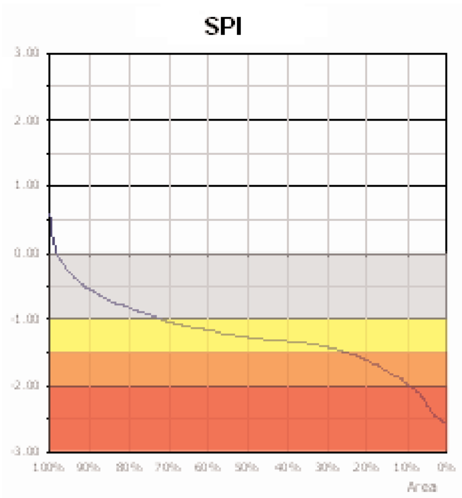

Fig. 2. The "or more" curve for a dry year using the annual SPI.

Discussion and recommendations

The basic steps for drought characterization could be summarised as follows:

(i) Collect all the necessary monthly data of each reliable meteorological station of the selected area (or areas)

(ii) Transfer meteorological data at a basin or sub-basin level (monthly time step should be used)

(iii) Calculate selected indices on an appropriate time scale (e.g. annual scale)

(iv) Display the results graphically using colours for the various levels of drought intensity

(v) Analyze the frequency of occurrence of 1-year drought (the same can be done for a 2-year and 3-year droughts) using historical data. Use one or two of the most popular uni-variate probability distribution functions (e.g. EV I/Gumbel, Lognormal, Pearson III, etc.)

(vi) The shortcoming of the above methodology is the fact that a limited number of droughts may be found even on rather long historical series. A method overcoming this drawback is the methodology proposed by Bonaccorso *et al*. (2003) and Cancelliere and Salas (2004).

Time scale of calculation

A common feature of all indices is that they are calculated over a particular period of time. The period of time to be considered depends on the characteristics of the systems to be analysed. For example, dryland agriculture is affected by the atmospheric phenomena (rainfall, temperature) of short periods of time (i.e., one or two months) while the rate at which shallow wells, small ponds, and smaller rivers become drier or wetter is affected by the atmospheric phenomena of longer periods (i.e., several months). Some processes have much longer time scales, such as the rate at which major reservoirs, or aquifers, or large natural bodies of water rise and fall, and the time scale of these variations is on the order of several years. Finally the time scale analysis should coincide with the critical period of the elements at risk due to drought hazard.

Basic indices to compare drought episodes

In the process of drought identification, it was concluded that the first step is to analyze meteorological and hydrological droughts using up to 4 indices for each climatic data set:

(i) Standard Precipitation Index (SPI)

(ii) Reconnaissance Drought Index (RDI)

(iii) Deciles

(iv) Surface Water Supply Index (SWSI)

The four selected indices for the risk analysis provide a relatively simple way to calculate the severity of droughts and make results comparable across sites.

The Standard Precipitation Index (SPI) developed by McKee *et al*. (1993) has been widely used by planners and in research. It can be used on a variety of time-scales and only requires precipitation data.

The Reconnaissance Drought Index (RDI) is as simple as the SPI and it incorporates the evapotranspiration. From a variety of applications, it was shown that the RDI behaves in a similar manner as the SPI. However, the results are differing when comparing droughts in different climatic regions.

The Deciles (Gibbs and Maher, 1967) method is applied by the Australian Drought Watch System to characterize and monitor drought. Its advantage relies in the simple calculation grouping precipitation into deciles, avoiding the problem of fitting a function to the data distribution which might be the case with SPI.

The Surface Water Supply Index (SWSI) (Shafer and Dezman, 1982) represents surface water supply conditions and includes water management in drought characterization. It combines hydrological and climatic features.

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Chapter 8. Methods for drought risk analysis in agriculture

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SUMMARY – This Chapter focuses on risk analysis methods aiming to develop a methodological base to understand drought risks in agriculture and formulate conceptual basis that allows rigorous drought impacts attribution. The method integrates both climate and agricultural system's characteristics to measure the rainfed agriculture risk to drought in a way that allows making comparisons between different places with different potential yields. Monte Carlo simulations are used to obtain the probability distributions allowing the characterization of risk. Finally, risk premium has been estimated by using statistical and risk evaluation models for some selected sites in Spain.

Key words: Rainfed agriculture, irrigation, impacts, risk factor, yields.

Risk concept

Unfavourable weather conditions are the main source of risk in subsistence farming systems, especially in marginal land and social conditions. In this case, drought has a direct relationship with farmers' income and risk is relatively simple to analyse evaluating simple variables, such as crop yield. In contrast, farming systems in economically developed regions, are greatly affected by policy, markets, technology and financial instruments, and it is complex to determine the effect of drought in individual farmers and in the aggregated agricultural sector.

Farmers need to manage the year-to-year variability of agricultural production with a range of agronomic and market-based strategies. In many regions a main source of production variability is weather-dependent.

Key issues to be considered in the risk analysis in agriculture:

(i) In general, for a given level of precipitation decrease, the magnitude of drought impacts varies with the type of farming system (subsistence or commercial).

(ii) Drought impacts vary according to location and enterprise type and the effectiveness of risk management practices adopted.

(iii) Inter-annual distribution of precipitations is a key issue in the levels of risk associated to the agricultural systems analyzed.

(iv) Synthetic series of precipitation allow to produce distribution functions of agricultural variables that enhance the risk analysis.

(v) Economic variables need to be included for determining the social risk and evaluating the potential market based and policy measures to mitigate drought.

This chapter focuses on the risk analysis methods aiming to:

(i) Develop a methodological base to understand drought risks in agriculture.

(ii) Formulate a sound conceptual basis that allows rigorous drought impacts attribution.

(iii) Broaden our perception of how drought impacts evolve and spread over space.

(iv) Enrich our understanding of successful drought preparedness practices.

The methods followed highlight the difference between risk (the probabilistic consequences of drought) and uncertainty (the imperfect knowledge of the probabilities of drought). Uncertainty arise from the imperfect knowledge of: (i) climate dynamics; (ii) interaction between meteorological, hydrological and agronomic systems; (iii) the undefined impacts on farm production and income; and (iv) the market-based responses to drought onset, inputs suppliers and financial institutions.

In the case of agricultural drought, the development level of the agricultural systems can influence vulnerability. Table 1 shows the main characteristics of two agricultural systems in the Mediterranean region that may imply different levels of vulnerability to similar levels of drought.

Table 1. Main characteristics of different agricultural systems in the Mediterranean

Characteristics	Subsistence farmers	Commercial farmers
Production strategy	Production stability	Maximize benefits
Main sources of risk	Climate	Climate, market based response
Main consequences of drought	Income reduction, migration and starvation	Financial liability, bankrupt and abandoning activity
Non structural risk management mechanism	In practice non existent	Insurance, credit (interest rate subsidies), taxes reduction, subsidies, laws
Inputs and resources	Very low	Significant
Role of livestock	Strategic resource	Production objectives

Rainfed and irrigated agricultural systems

Risk in irrigated systems is directly related to water scarcity, which differs from drought because it is related to a shortage of water availability to satisfy demands. The shortage results from an unbalance between water supply and demand, which is originated by a meteorological phenomenon, but is also conditioned by other time-varying factors, such as demand development, supply infrastructure and management strategies. The result of the unbalance is demand deficit, which is of concern for water managers. It is usually anti-economical to guarantee 100% all demands in a system, and a risk level has to be adopted in the risk management plan. Theoretical models are used to characterise risk in hydrological systems (Rossi *et al.*, 2003). The acceptable risk level is conditioned by available water resources and infrastructure and depends on demand characteristics and their elasticity.

The distribution of resources in a drought period among multiple demands in hydrological systems is a challenging task requiring careful planning. The operational rules of the system are related to resource sharing criteria, priorities among users, utilization of complementary resources and strategic reserves among others. In large systems, mathematical simulation and optimisation models should be used to obtain quantitative results accounting for all system complexities in an uncertain context. These models provide guidance in identifying critical demands, evaluating the effect of capacity building or water conservation measures, and scheduling available actions within given constraints. All models provide a measure of demands reliability, quantified as the probability that a given demand may suffer water shortages during a given drought.

Groundwater is a strategic water supply source in Mediterranean countries, and its strategic value becomes more relevant during drought conditions. Only prolonged meteorological droughts have and effect on groundwater levels. Critical level of groundwater can be derived form the minimum threshold levels associated with no impacts.

However, the availability of well-calibrated operational models is doubtful in some parts of the MEDROPLAN target area. They require a large investment in information, to evaluate resources, characterise demands, identify optimal management criteria, etc, which may not be readily available in all regions. If these models are available, they should be used in risk analysis, using indicators derived from model results to evaluate relative risks. If they are not, it can be assumed that the system is not very complex, and risk analysis can be carried out with simpler indicators.

The Chapter 9 of this publication ("Methods for risk assessment in water supply systems") makes an in-deep explanation on the ideas that are otulined in the paragraphs above.

Coping with risk in rainfed agricultural systems is a very different task of water management and the following sections focus on the components of the risk analysis within this context.

Components of the Risk Analysis in agriculture

Risk analysis in agriculture consists on identifying the productivity level that affects farmers' income (for commercial farmers) or capacity to maintain its production activity the following year (for subsistence farmers). The acceptable risk level is conditioned by each crop and area and depends on the mechanisms in place to mitigate drought, such as subsidies, policies, etc.

In this context, the risk analysis in agriculture should consider the following aspects:

(i) Probability of failure to reach an acceptable yield level for each crop.

(ii) Severity of failures (magnitude of the deficit for each crop).

(iii) Failure duration (time span when deficits occur, single year or multi-year, for each crop).

(iv) Economic impact of failures (aggregated impact on farm income).

(v) Unexpected climatic events which magnitude or duration is not included in the available time series which has to be considered when setting up the guarantees.

These factors determine also the operational rules for system management during droughts. At the aggregated level (i.e., from farm to region, or national), there are inter-dependent risk management units that implement different risk management alternatives.

The final objective of the risk analysis is to evaluate the level of risk associated with the potential consequences of drought in different systems and their underlying causes. Figure 1 outlines the sequential steps to be taken for the quantification of overall sensitivity to drought of agricultural of systems. The methodology includes the following components:

(i) Potential impacts: Ranking of agricultural impacts in the context of other potential drought impacts.

(ii) Quantification of risk: Identification of the direct consequences of drought (fair inference and attribution). This includes the application of the drought indices to establish risk level.

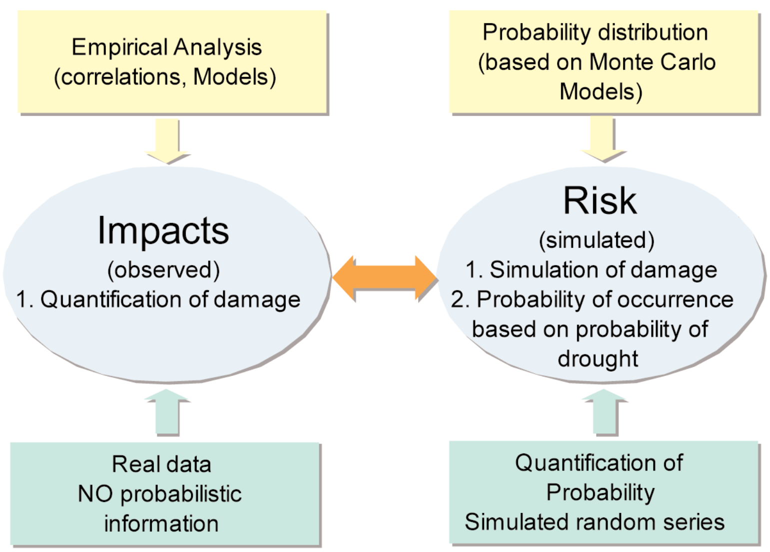

Fig. 1. Technical approach for the risk analysis in agriculture.

Definition of theoretical causal relationships between the agricultural variables and drought in order to establish solid evidence of the drought impact in the agricultural sector is essential to provide the largest possible quantitative information to place management actions or some insurance protection.

The sequential steps to be taken for the quantification of overall sensitivity to drought of agricultural of systems are:

(i) Identification of the agricultural system representative of the geographical unit and definition of the basic cost structures and revenues of the farms. For example, subsistence farmers in dryland areas or commercial irrigated farms, among others.

(ii) Definition of the variables that characterise each agricultural system. For example, crop yield, irrigation water demand, farm income.

(iii) Definition of theoretical causal relationships between the agricultural variables and drought. An empirical model may be used to find the relations between yield, climate and agriculture characteristics, using available data. The statistic tool used is the multilineal regression. The model is to be defined and calibrated for each region studied.

(iv) Statistical analysis of the correlations of drought indices with the selected variables that define the system. This step is essential for the selection and validation of the drought indices as thresholds of the drought risk. The indices that show a larger significant correlation with the impacted variables should be the ones to consider as potential triggers into the management plans. The statistical properties of the yield functions are analysed through Monte Carlo simulations, a statistical tool that allows obtaining large samples of the yield through the generation of synthetic data from the yield functions. With that large size sample, it is possible to analyse the statistical distributions of the yield function in a much more fine and precise manner.

(v) Definition and measure of a risk level. The probability distribution function measures the probability of exceeding or not surpassing a given yield in each region of study.

(vi) Definition of an aggregated measure of sensitivity of the agricultural system to drought based in the combination of the partial impacts.

Aggregation of the local results to provide regional conclusions is always a complex task, but a simple aggregated measure may be constructed by normalizing and scaling the representative variables (or proxy variables) with respect to some common baseline.

Potential impacts

Mediterranean rainfed agricultural systems are especially sensitive to drought episodes that account for large production losses, especially in marginal areas (Iglesias and Moneo, 2005). Recent drought impacts, especially if they are associated with severe to extreme droughts, are ranked more heavily than the impacts of ancient drought, since recent events reflect more accurately current vulnerabilities.

Example of calculation potential impacts in Spain

In Spain, the contribution of rainfall variability to final agricultural production has been evaluated by using empirical data (Iglesias and Quiroga, 2007). The agricultural systems under study are typical Mediterranean rainfed systems based on cereal production. The analysis was carried out in five regions of Spain that represent a range of Mediterranean farming systems.

The objective of the study is to measure the rainfed agriculture risk to drought in a way that allows making comparisons between different places with different potential yields. The method integrates both climate (hazard) and agricultural system's characteristics (that explain vulnerability and trends of the systems) through yield functions (yield is taken as impact variable). The potential impacts quantification is evaluated by empiric models to find the relations between yield, climate and agriculture characteristics, using available data. The statistic tool used is the multilineal regression. The model is to be defined and calibrated for each region studied.

The agricultural systems under study are typical Mediterranean rainfed systems based on cereal production. The localisation and characteristics of the 5 regions of study are summarized in Table 2. Yearly time series of crop yield (y) of each site for the 1940-2000 period were used to evaluate the potential impact of climate and specially drought effect. In Fig. 2 the important and increasingly variability of the crop yields can be observed for four of the sites.

Table 2. Characteristics of the sites

Site	Lat (°N)	Alt. (m)	Tavg (°C)	Annual precip avg (mm)	Wheat avg yield (t/ha)	Yield CV
Burgos	42.37	894	10.2	630	1.90	1.65
Valladolid	41.65	734	12.1	373	2.03	2.47
Logroño (La Rioja)	42.45	353	13.4	383	2.74	2.18
Cordoba	37.85	92	17.9	674	2.24	2.70
Murcia	38.00	0	17.6	305	0.83	2.45

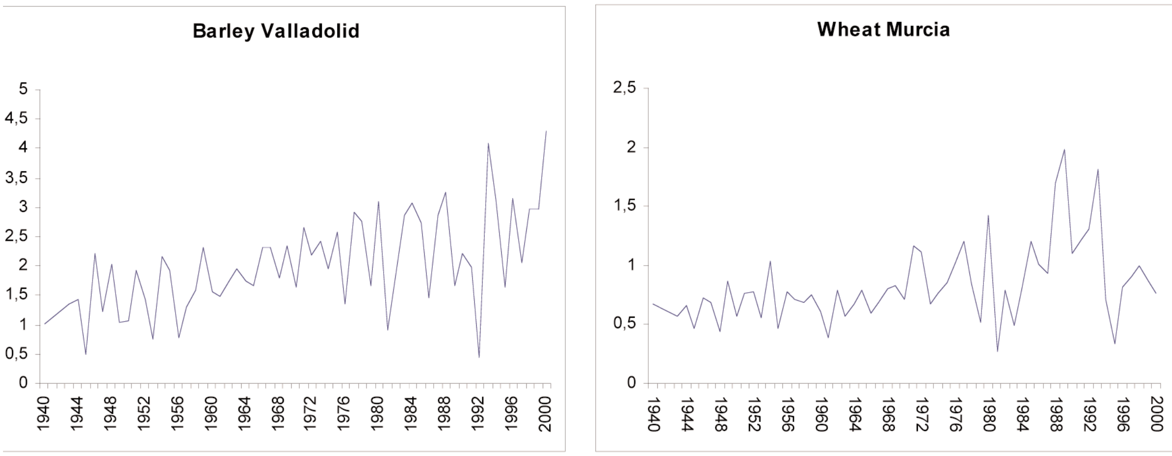

Fig. 2. Crop yield series for two of the studied sites.

The specified model has the following general form:

$$\ln Y_t = \eta Y_{t-1} + \alpha_0 + \alpha_1 Mac_t + \alpha_1 Fert_t + \alpha_1 Pest_t + \alpha_{2i} Tavi_t + \alpha_{3i} Fri_t + \alpha_{4i} Precipi_t + \alpha_{5i} Tmax_t + \alpha_{6i} Dr_t + \beta t^* Impt^*t + \gamma t^* Stpt^*t + \varepsilon t$$

Where the model output (Y_t) is the crop yield in a site on year t, and the inputs are of two types: management and climate variables. The climate variables are: temperature average (Tav_{it}), total precipitation ($Precip_{it}$), maximum temperature ($Tmax_{it}$), number of days with temperature below 0°C (Fr_{it}), and a dummy variable indicating drought years (Dr_t) based on SPI index. Management variables include farm equipment power (Mac_t), nitrogen fertilizer ($Fert_t$) and pesticide consumption ($Pest_t$), which account for large increases in crop productivity.

The results of the regressions are fully documented in Iglesias and Quiroga (2007). In which climate influence refers, the drought influence appears as a decisive factor. It can be observed, in general, that rainfed yields are affected on a negative way by the high temperature and the low precipitation on early summer time. That is because of the increase of the hydrologic stress.

For the wheat yield in Valladolid, the estimated model is:

$$\text{Ln } Y_t = 2.382126 + 0.0020Mac_t + 0.0038Precip_{may} -0.0552Tmax_{nov} -0.0937Tmax_{mam} -0.1726Dr_t -0.9205\ Imp_{1956} -1,3424\ Imp_{1992}$$

In this case, the variables that have influence on wheat yields are:

(i) The power of the mechanical equipment (Mac_t).

(ii) The precipitations on May ($Precip_{may}$), that affect positively to the yields.

(iii) The maximum temperature on November ($Tmax_{nov}$) and spring time ($Tmax_{mam}$) which has a negative influence over the yield.

(iv) The drought years causing low yields (Imp). There have been two especially low yield years (1956 and 1992).

The coefficients of the variables can be read as % of yield reduction: for example, a drought year causes a yield decrease of about 17% change in yield with respect to long-term average, being the most important factor of influence. The estimation of production functions can be useful to quantify the potential drought impact over agriculture. The analysis has derived in interesting comparisons of impact levels for future design of drought mamagement guidelines.

Quantification of risk

The methodology is the identification of the direct consequences of drought (fair inference and attribution), such as reduction in crop yield. This includes the application of the drought indices to establish correlations with the variables that represent the affected sectors, such as correlation of the SPI with the crop yields.

Applying the Monte Carlo simulations to the models, the distributions of yields are obtained. Monte Carlo simulation is a statistical tool that allows obtaining large samples of the yield through the generation of synthetic data from the yield functions (Gibbons and Ramsden 2005, Lobell and Ortiz-Monasterio 2006; Limaye et al 2004). With that large size sample, it is possible to analyse the statistical distributions of the yield function in a much more fine and precise manner.

The standardized yields are used to take into account the differences of agrarian production systems and yield potentials between the regions. After that, risk functions based on the simulated yields can be calculated to establish the relations between the drought hazard and the agricultural variables and to to quantify the probability of damage in order to establish the threshold levels of acceptable risk that trigger the operational management actions.

Example of quantification of risk in Spain

In Fig. 3, cumulative distribution functions of real and standarized yields are shown. The interpretation of the graphs is simple. For example, in Córdoba, the selected point C means that the probability of obtaining a yield of less than 4 t/ha is 0.8 (80%). Point C' indicates that a decrease of yield of 0.4 t/ha from the mean yield has a probability of 0.41 (41%).

The probability distribution functions allow the quantification of risk.

Ferreyra *et al.* (2001) propose an approach to quantify outcome risk for each station and climate scenario (ENSO and neutral years) based on comparing the chances of exceeding a given yield in each station with the corresponding chances for a reference station. Based on this approach, Iglesias and Quiroga (2007) develop a risk factor to compare yields variability and risk level across sites. The risk function is defined as:

$$RFi = \log 10\ (EPCFi/EPCFr)$$

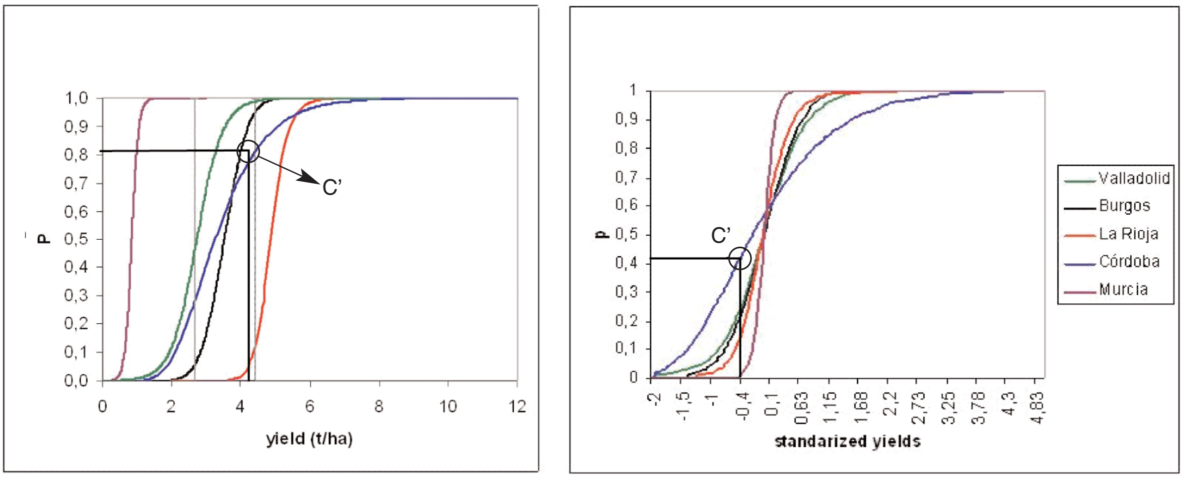

Fig. 3. Yield cumulative distributions: Real yield and standardized yield (Source: Iglesias and Quiroga, 2007).

EPCF denotes cumulative probability distribution of the variable of yield for both, the reference station (EPCFr) and the station of interest (EPCFi). In the present case, reference site is Burgos region, which was taken because it presents a yield distribution near Normal.

The RF for each location is calculated by normalising cumulative yield distributions functions that are previously derived by Monte Carlo simulations. The reference station (RF = 0) is taken as a comparison basis and two yields classes are considered: below the mean and above the mean.

For each location the RF values indicate whether yields in that station are more at risk than in the reference station. In the context of agricultural yield, the areas with highest risk are the ones that have a higher probability of having low yields. Positive RF values when yields are below the mean (lower than 0) indicate that the location has more risk because there is a higher probability of attaining low yields than in the reference station. Negative RF values when yields are above the mean (higher than 0) indicate that the risk is lower because there is a higher probability of reaching yields above the average than in the reference scenario. Figure 4 illustrates the risk factor distribution in selected Spanish locations under rainfed cereal farming systems.

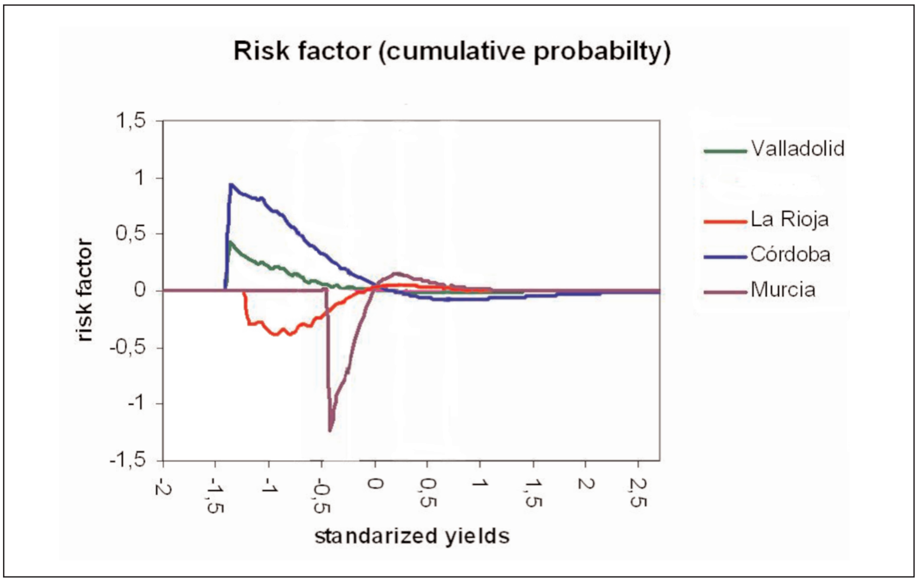

Fig. 4. Risk factor distribution in a range of standardised: below zero are lower than average yields and above zero are higher than average yields.

The risk analysis suggests the following conclusions for the selected sites:

(i) Córdoba: the probability of not exceeding yields lower than the average is much higher than in the reference region. So Córdoba has a high level of risk of having very low yields due to climatic incidences. But in the contrary, Córdoba shows also higher probability than the other regions of the study of exceeding yields above the average. The expected variation of yields in Córdoba is the highest of the 5 sites.

(ii) Valladolid shows a similar situation than Córdoba for the lower yields. Nevertheless, we can not expect exceeding the higher classes of yields.

(iii) Murcia: the risk of having much below normal yields is low. Murcia shows negative risk factors for the below normal yields, so its production has little risk of yield drops. It has also low probabilities of exceeding above normal or much above normal yields. These results mean that yields in Murcia are expected to be the most uniform.

(iv) La Rioja shows a similar distribution of risks than Murcia, although not reaching as negative values as Murcia does for the risk of having low yields.

The estimated models at the district scale detect the effect of climate, technological and management variables over different crop yields and districts, and the simulations of synthetic series of precipitation permit the generation of distribution functions adequate for the risk analysis. Inter-annual distribution of precipitations is a key issue in the levels of risk associated to the agricultural systems analysed.

Risk premium estimation

In all cases the operational risk management cannot guarantee full prevention of drought damage, and a risk level has to be adopted in the drought management plan. For example, in Spain, the drought insurance system (ENESA) has an operational drought insurance plan that establishes a risk level defined by the probability of suffering a reduction in crop yield below a pre-established threshold (acceptable risk). This threshold is defined for each crop and geographic areas and it is re-evaluated each season. Risk or Insurance premium can be estimated by using statistical and risk evaluation models and the following section shows the analysis for some of the selected sites.

Forecasts about expected future yields are very important for planning inputs production or scheduling the agrarian credits. Additional information about risk premium helps in which insurance decisions or protection levels concerns. If producers have constant absolute risk aversion (CARA), we can use the CARA utility function to calculate the risk premium from the estimated production functions and the probability of drought:

$$U(y) = -\exp\{- \rho\ y\}$$

where: "y" is the yield, and $\rho > 0$ is the Arrow-Pratt risk measure of the absolute risk behaviour (Mas-Collel *et al.*, 1995):

$$\rho = \frac{-U''(y)}{U'(y)}\ ,$$

If we denote y_{dry} as the normal yield in a dry period, which implies a reduction (η) of average yields: $y_{dry} = (1-\eta)\ y$, we can obtain the certain equivalent (as it is shown in Figure 5), as the certain value (without uncertainty) that provide the same expected utility that the expected situation, so we have:

$U[CE] = P_\theta\ U[y_{dry}] + (1- P_\theta)U[y]$, where P_θ represents the probability of drought.

Considering the CARA utility function:

$$P_\theta \exp\{-\rho\ y_{dry}\} + (1- P_\theta) \exp\{-\rho\ y\} = \exp\{-\rho[CE]\},$$

we obtain:

$$\exp\{-\rho\, y\}[P_\theta \exp\{-\rho\,\eta\, y\} + (1- P_\theta)] = \exp\{-\rho[CE]\},$$

so the expression for the certainty equivalent is:

$$CE = y - \frac{\ln[P_\theta.\exp\{-\rho\eta y\} + (1-P_\theta)]}{\rho}$$

Of course, this certain value is lower than the expected (but uncertain) value for the farmer, and risk premium can be calculated as:

Risk Premium = EV-CE where EV denotes the expected value. So:

$$\text{Risk Premium} = \frac{\ln[P_\theta.\exp\{-\rho\eta y\} + (1-P_\theta)]}{\rho} - P_\theta \eta y$$

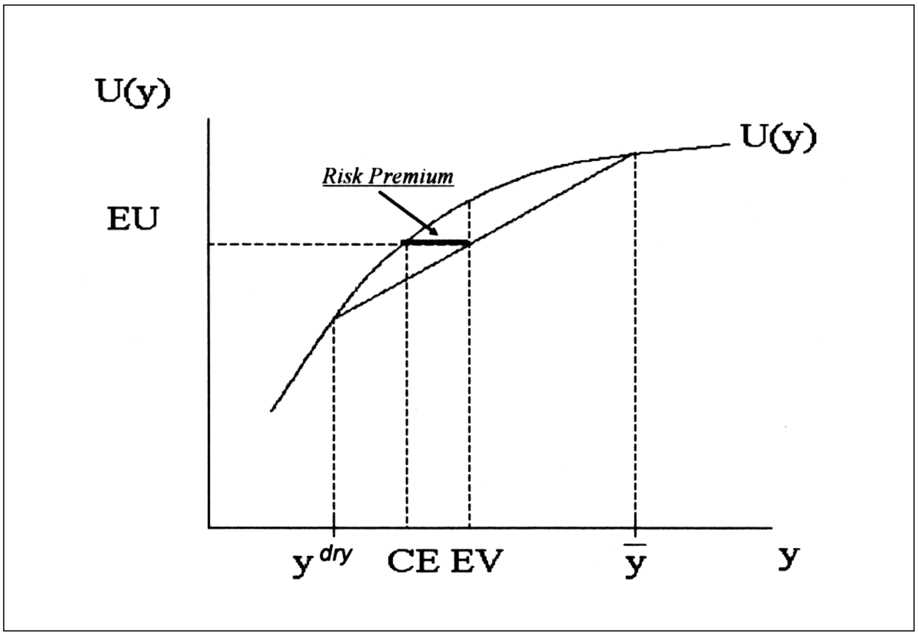

Fig. 5. Certainty equivalent (CE), expected value (EV) and risk premium given the utility function (U(y)).

Individuals' tolerance for risk varies, but, as it is mentioned on Palacios-Huerta *et al.* (2003), Goeree, Holt, and Palfrey (2002, 2003) examine several asymmetric matching pennies games and private-values auction experiments, respectively. These experiments also involve very small gambles, and total pay offs after all rounds have been completed typically range from 5 to 20 dollars per individual subject. Their estimates of ρ are virtually in all cases below 1, and highly significant across treatments and games: estimates typically range from 0.3 to 0.7, centred around 0.5. The value of 0.5 is also almost identical to that obtained in many experimental studies of similar nature that these authors cite, so we have suppose this value representing the producer's utility.

Taking into account normal yields and using the production functions and the probability of drought, we can calculate the premium risk for the cereals production as detailed above.

Example of estimation of risk premium in Spain

Table 3 summarizes the results of the calculation of risk premia for three of the Spanish sites mentioned in the previous sections.

Table 3. Risk premium (t/ha) for the wheat crop in Cordoba, Valladolid and Murcia. Pθ is the probability of drough, η is the yield reduction derived from the production functions and CE denotes the certainty equivalent (t/ha)

Site	Pθ	η	CE	Risk Premium
Cordoba	0.230	0.176	2.609	0.014
Valladolid	0.213	0.141	3.415	0.005
Murcia	0.164	0.459	1.048	0.002

We can see that in the "normal" or average yields, the most risk site is Cordoba, followed by Valladolid and Murcia, the same conclusion that we observed in the risk functions results. However, the same analysis could be conducted in the case of "bellow normal" and "above normal" yields.

Conclusions

The chapter shows a metodology to evaluate the influence of climatic and non climatic variables on final crop yield aiming to increase the capacity of the farmers to reduce climate risks, especially those associated to drought. The estimated models at the district scale detect the effect of climate, technological and management variables over different crop yields and districts, and the simulations of synthetic series of precipitation permit the generation of distribution functions adequate for the risk analysis. Inter-annual distribution of precipitations is a key issue in the levels of risk associated to the agricultural systems analysed.

Crop production functions can be used to optimise the technological inputs as an adaptation response to climate variations. Climate risk can be managed by altering decisions before and during the growing season, such as the level of inputs (low levels of fertilizers in dry seasons versus high levels to take advance of good seasons), irrigation regimens, or insurance planning. The results highlight the need for alternative strategies to manage agricultural production in areas with water stress. Northern areas may benefit from climate change conditions while most southern and eastern locations may be very negatively affected, especially when water for irrigation competes with other uses of water.

In all cases the operational risk management cannot guarantee full prevention of drought damage, and a risk level has to be adopted in the drought management plan. Estimations for risk or insurance premium can be useful as a decision tool in this context. In the chapter we also present risk premium estimation for wheat drought risk in some selected sites.

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Chapter 9. Methods for risk assessment in water supply systems

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Introduction

The present chapter introduces concepts and methods related to risk and risk assessment of water shortages due to droughts in water supply systems. The main aim of the chapter is to provide methodologies able to quantify in a probabilistic way the risk of failure of a water supply system.

Two procedures for unconditional (planning) and conditional (operation) drought risk assessment of water supply systems are proposed. Both methodologies are based on Montecarlo simulation of the water supply system, in order to better take into account the stochastic nature of the hydrological input to the system.

The proposed methodologies results in an effective aid during both the planning and operating stages of a water supply system giving valuable information about expected frequency and amount of deficits related to the demands supplied by the system under study.

Risk assessment in water supply systems

General

Different definitions of risk are adopted in various disciplines, according to the objective of the analysis, as well as to the typology of event under study. Despite the differences, the several definitions can be broadly divided into two main categories: risk defined as the *probability of an adverse event*, and risk defined as the *expected (mean) consequence of an adverse event*. The first category includes the concept of risk according to statistical hydrology, defined as the probability that an hydrological variable X (e.g. maximum annual discharge) exceeds a given threshold x_o at least once in n years:

$$\textbf{Risk} = \text{P[at least 1 year in } n \text{ years where } X > x_o] = 1\text{-P}[X \leq x_o \text{ in } n \text{ years}]$$

Assuming stationarity and independence of the events, the risk can be computed by the well known formula (Kottegoda and Rosso, 1998):

$$\textbf{Risk} = 1\text{-P}[X \leq x_o]^n$$

Similarly, in reliability theory, risk is defined as the probability of failure for the system under investigation. More specifically, risk is defined as the probability that the load L (i.e. the external forcing factor) exceeds the resistance R (an intrinsic characteristic of the system), leading to a failure (Mays and Tung, 1992):

$$\textbf{Risk} = \text{P}[L > R]$$

The second category (risk as expected consequence) includes the definitions developed within the strategies for natural disasters mitigation. In particular, risk is defined as "*the expected losses* due to a particular natural phenomenon as a function of natural hazard and the vulnerability of and element at risk" (UNDRO, 1991). In the above definition, the natural hazard represents the probability of occurrence, within a specified period of time in a given area, of a potentially damaging natural phenomenon, whereas the vulnerability is the degree of loss to a given element at risk or set of such elements resulting from the occurrence of a natural phenomenon of a given magnitude and expressed on a scale from 0 (no damage) to 1 (total loss). It follows that according to the above definition, risk is measured in some physical terms, such as economical (damages) or social (lives lost). Also, such risk definition has found widespread application in flood analysis, since it is particularly suited for the development of inundation risk maps in a given area (Kron, 2005).

When dealing with drought risk in water supply systems characterized by a high level of complexity and interactions among the different components, it is easy to recognize that none of the above definitions is able to encompass the different dimensions and consequences related to water shortages. Therefore, traditionally, characterization of the shortages in a water system has been carried out by means of a set of performance indices, attempting to capture different aspects related to concepts such as reliability, resiliency and vulnerability (Hashimoto *et al.*, 1982). Indeed, stochastic nature of inflows, high interconnection between the different components of the system, presence of many sometimes conflicting demands, definition of the elements at risk, uncertainty related to the actual impacts of extreme events such as droughts, make the risk assessment of a water supply system a problem that is better faced through a set of several indices and/or by analyzing the probabilities of shortages of different entities (Alecci *et al.*, 1986).

With regard to the *risk analysis* it is generally recognized that it can be divided into *risk assessment* and *risk management*. The former is oriented to the estimation of the probabilistic features of an adverse phenomenon, whereas the latter is generally defined as a pro-active approach for coping with risk through planned actions, as apposite to crisis or emergency management. Risk assessment therefore has the objective to quantify probabilistically the occurrence of an adverse phenomenon, as well as to estimate its consequences. Risk management has the objective to identify in advance a set of measures oriented to prevent or to mitigate consequences of the adverse phenomenon.

Risk assessment can find application either at the planning stage or during the operation of a given system. For instance, with reference to water supply system planning, risk assessment enables to quantify and compare the risk associated with different planning alternatives, generally on a long term basis. On the other hand, during the operation of the system, short term drought risk assessment can be carried out in order to compare and define alternative mitigation measures, on the basis of the consequent risk during a short time horizon (e.g. 2-3 years) in the future. The two approaches differ, not only with regard to the objective of the analysis and to the different lengths of the time horizons, but mostly because of the way the probabilistic assessment is carried out. In the first case, the assessment is generally *unconditional*, i.e. without regards to the initial state/condition of the system and therefore it provides information on what could happen at any time during the planning horizon. For instance, with reference to a water demand, one may be interested in the probability of occurrence of a given deficit during the planning horizon. The short term risk assessment, on the other hand, is generally *conditional*, in the sense that the initial state/conditions of the system are taken into account in the evaluation. Furthermore, the assessment is generally oriented to estimating what could happen at a specific time in the immediate future. For instance, with reference to a water use, one may be interested in the probability of occurrence of a given deficit three months ahead, given the present state of the system (e.g. volumes stored in reservoirs). As a such, the conditional assessment is generally adopted for early warning purposes. Since the results of the conditional risk assessment strongly depend on the initial conditions, it follows that the procedure must be repeated as new information becomes available.

Unconditional (long term) risk assessment

Unconditional risk assessment has the objective of the comparison and the selection of preferred drought mitigation alternatives through the simulation over a long time horizon (30-40 years) of the system behaviour by using generated series. Then, the risk is evaluated in terms of a synthetic assessment of failure based on the analysis of the satisfaction of consumptive demands (both in time and volume), as well as of meeting some specified objectives such as the satisfaction of ecological requirements, or target storages in reservoirs.

The term *unconditional* here refers to an assessment without regards to the initial state/condition of the system, and therefore the procedure is oriented to provide information on what could happen at any time during the explored planning horizon. To achieve the above objective the study can start at any initial condition of the system because this will be irrelevant to the overall behavior of the system during a long time horizon.

Figure 1 shows the proposed methodology for unconditional drought risk assessment for a water supply system. The procedure is divided into three main tasks, namely system identification, hazard analysis and risk assessment. The system identification tasks consists in the definition of all the relevant information regarding the water supply systems, with reference to the hydrological inputs, the physical features of the elements of the system and the different uses/sectors as well as their water demands and historical used volumes.

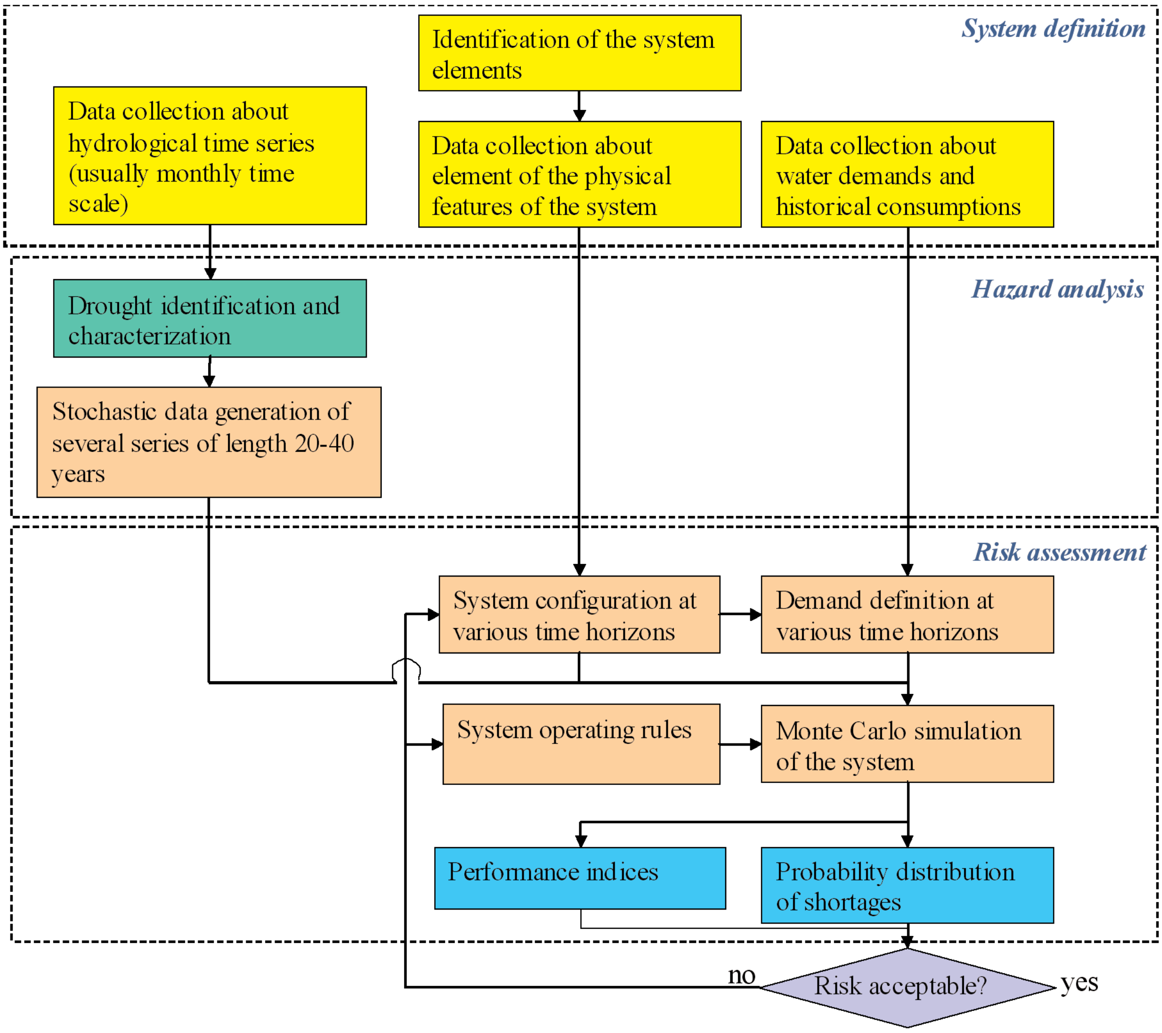

Fig. 1. Methodology for unconditional drought risk assessment in water supply systems planning.

Then, a hazard analysis is carried out, with the objective to characterize probabilistically the drought features. Such characterization can be performed by estimating the return period of droughts of different severities, by means of the methodologies presented in the Chapter on Drought Characterization of this volume, and implemented in the software REDIM.

Within the risk assessment task, one of the primary objective is evaluating the system state variables and other variables related to the satisfaction of various demands (e.g. water supply shortages) under a given system configuration and a given set of operating rules by considering, as hydrological input, several generated streamflow series. Furthermore, a similar assessment is also required for the satisfaction of ecological requirements, such as instream flow requirements, and for target storages in reservoirs. Synthetically generated series can be obtained by means of a stochastic model fitted to the observed series, such that the generated series resemble, in a statistical sense, the observed ones. Thus, each generated series can be considered as one of the possible series that will occur in the future and, as a consequence, the data resulting can be seen as a large sample from the population of all the possible system behaviors in the future (Montecarlo simulation). Then, probabilistic features of the consequences of drought can be assessed by performing a statistical analysis of the results of simulation.

The results of the Montecarlo analysis enable to verify whether the system exhibit an acceptable risk of shortage under the given configuration and set of operating rules. If this is not the case, the procedure can be repeated by analyzing different configurations and/or operating rules.

Conditional (short term) risk assessment

The proposed procedure for conditional (operational) risk assessment has the objective of evaluating of the risk of shortages in a short time horizon by using generated series. The procedure makes use of the same basic tools (namely stochastic data generation, water system simulation and synthetic assessment of performance), but in this case the analysis is performed with reference to a shorter time horizon (2-3 years) and by taking into account the initial state/conditions of the system. Thus, the results will depend on when the analysis is performed, since they will change as new information is available. Therefore, such procedure should be carried out at given time steps (e.g. every month) during the operation of the system, in order to identify potential failures in the future and to implement the necessary measures.

Different criteria could be applied to decide the length of time horizon for conditional risk assessment of a given system. In particular it should be defined taking into account the length of historic droughts, consolidated operating procedure of the system, time horizon prescript by the law, the need to avoid the growth of evaporation losses caused by a pluriannual management of reservoirs.

With reference to the scheme depicted in Fig. 2, the system identification will include the monitoring of current meteo-hydrological conditions, of the storage volumes in the reservoirs and the definition of water demands. Then an hazard analysis is carried out in order to characterize probabilistically the current drought conditions. Again, such characterization can be performed in terms of return periods of droughts identified on streamflow series. The first step of the risk analysis is carried out by generating several series over a short time horizon (2-3 years), conditioned on the hydrological observations up to the moment when the analysis is performed. Then, the system is simulated, by assuming as initial conditions (e.g. volumes in reservoirs) the actual ones when the analysis is carried out. Thus the risk assessment will enable to estimate the risk at specified intervals in the immediate future (e.g. 1 month, 2 months, etc.) since such conditional risk is strongly affected by the initial conditions.

Application of the proposed methodology enables to assess, in a probabilistic way, the short term risk of failures considering the actual condition of the system, thus giving the opportunity to explore effects of different policies of management and mitigation measures.

Tools

Simulation of water supply systems

Simulation has the objective of reproducing the real world based on a set of assumptions and conceived models of reality (Ang and Tang, 1984; Labadie, 2004). Because the purpose of a simulation model is to duplicate reality, it is a useful tool for evaluating the effects of different designs, hydrology, mitigation measures against drought and/or operating policies on system performances.

Simulation models are perhaps the most widely studied and applied methods for analyzing and evaluating alternatives to manage water supply systems. The reason for their popularity lies in the fact that such models can approximate very closely the systems using a relatively simple mathematics and are easily understood by water managers. Water supply systems are generally *complex systems* in which the components (e.g. reservoirs, diversions, etc) are arranged as a mixture of in-series and in-parallel, or in the form of a loop. When dealing with a complex system, the general approach is to reduce the system configuration, based on its component arrangement or modes of operation, to a simpler system for which the analysis can be performed easily.

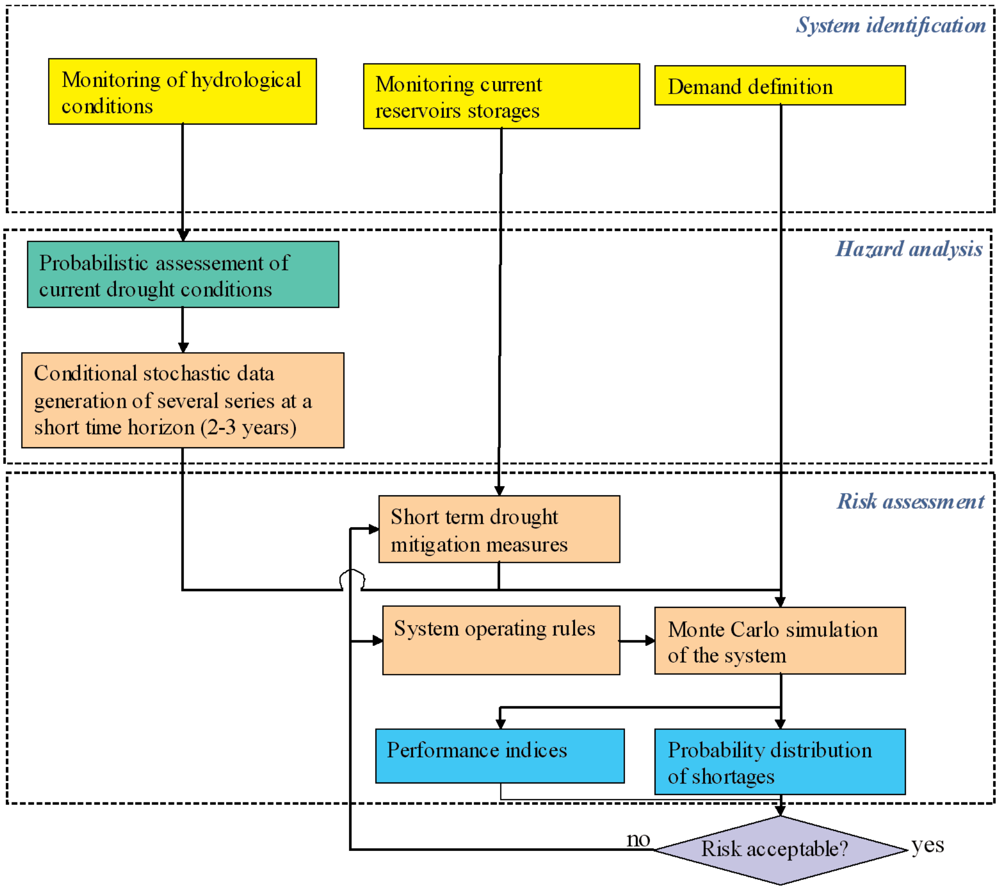

Fig. 2. Methodology for conditional drought risk assessment in water supply systems operation.

Any simulation model is typically based on mass balances of water quantities in the components constituent the whole system. The system dynamics equations are generally based on preservation of conservation of mass throughout the system and following a node-arch approach to describe the system network, and can be written as follows:

$$\mathbf{S}_{t+1} = \mathbf{S}_t + \mathbf{C}.\,\mathbf{r}_t + \mathbf{q}_t - \mathbf{l}_t\,(\mathbf{S}_t,\mathbf{S}_{t+1}) - \mathbf{d}_t \text{ for } t = 1, ..., T$$

where $\mathbf{S}_t$ = storage vector at the beginning of time t; $\mathbf{q}_t$ = inflow vector during time t; **C** **=** system connectivity matrix mapping flow routing within the system; $\mathbf{r}_t$ = downstream releases from reservoirs or diversion points; $\mathbf{l}_t$ = vector combining spills, evaporation, and other losses during time t; and $\mathbf{d}_t$ = releases from the system to satisfy demands and or water transfers. Calculation of evaporation and other water losses in the term $\mathbf{l}_t(\mathbf{S}_t,\mathbf{S}_{t+1})$ is usually difficult to evaluate correctly, and therefore approximations are generally adopted. All flow units are expressed in storage units per unit time. Spatial connectivity of the water system network can be fully described by the routing or connectivity matrix **C** having 1 in the *i,j* elements to connect node *i* to node *j* and 0 otherwise (Labadie, 2004).

The output of a simulation model include the series of releases to the water users, the series of volumes stored in reservoirs, as well as other information such as downstream releases, withdrawals from marginal resources, etc. Thus, for any set of design and operating policy parameter values, simulation provides a rapid means for evaluating the anticipated performance of a system. Simulation models do not identify optimal operating policies but they are an excellent aid to water managers in evaluating effects on the system, including risk of drought, of different alternatives (planning) or given mitigation measures and/or operating policies (operation).

Critical issues for simulation models are the definition of the boundaries of the system that is to be simulated, the level of detail within the system that should be modeled and the time scale. Furthermore there are difficulties associated with sampling in the multidimensional space which contains the vector of the operating decision variables (Mays, 1996).

Simulation models have to be able to be connected to other models (i.e. stochastic generation models); they have to be general but enough versatile to simulate peculiar features and operating conditions of virtually any system. Furthermore they have to be easy to use and to understand in order to be accepted both by decision makers and end-users making really effective the proposed mitigation measures, operating rules and/or procedures to cope with risk.

In the case of water supply systems, simulation models have mainly to help with: choice of supplies, connections between elements of the system, withdrawal order from sources in order to satisfy demand patterns and, in the case of shortages, assessment of their distribution in time and among the different users. Furthermore they have to be able to evaluate actual effectiveness of proposed mitigation measures, helping to define triggers to activate operating policies and giving results in a comprehensive manner.

Simulation models can be *time-sequenced* or *event-sequenced, deterministic* or *stochastic,* dealing with *steady-state* or *transient* conditions (Loucks, 1981). The model to use in the proposed methodology should be a time-sequenced able to deal with transient conditions, that is implementation of different alternatives for the planning (e.g. unconditional risk assessment where both changes in configuration and in operating rules must be taken into account during the simulation time horizon).

Simulation models can effectively be used to manage a complex system on a continuous basis but also to manage extreme events such as drought that occur over a relatively short-time horizon. These two different types of model applications will require models having different temporal and/or spatial resolutions. Planning models are used sequentially but, being the time horizon longer than operating models, the interest is focused on the overall behavior of the system including major changes in its configuration to compare different scenarios.

Operating models are still used sequentially. They need to be continually updated and rerun to get the most current estimates of what operating decisions should be made for each component constituting the whole system in each future decision period.

Some of the most important simulation models are HEC-PRN (Hydrologic Engineering Center, 1993), AQUATOOL (*Andreu et al.*, 1996), MODSIM (Labadie *et al*., 2000), STELLA (Stein *et al*. 2001), VENSIM (Caballero *et al*., 2001), POWERSIM (Varvel and Lansey, 2002).

Simulation models or descriptive models are surrogate for asking "what-if" questions regarding the performance of alternative operational strategies. They can accurately represent system operations and are useful for Montecarlo analysis in examining long or short-term reliability of proposed operating strategies.

Simulation models of water resources systems, whether used for planning or for operating management, merely provide information. Actual decisions need still to be taken by water managers using models as aids in order to make "informed" decisions. In order to be well accepted by water managers and thus really effective for real cases, models have to be as much versatile as possible offering a range of not prescriptive alternatives. Models cannot determine which assumptions and data are best, they can only help identify the impacts of those assumptions and data (Mays, 1996).

Synthetic series

Because of the stochastic nature of the hydrological inputs to water supply systems, Montecarlo simulation results is a powerful tool to cope with uncertainty affecting risk assessment both in planning and operating stage. In order to perform Montecarlo analysis, an appropriate stochastic model must be selected for generating numerous synthetic hydrological series that preserve some statistical properties of historical series.

The general aim of a stochastic model is to reproduce as closely as possible the true marginal distribution of seasonal and/or annual hydrological variables. Also, modeling the joint distribution of flows at a different site in different months, seasons, and years may be required for multicomponent water supply systems. The persistence of flows often described by their autocorrelation is also another important aspect, since it affects the reliability with which a reservoir of a given size can provide a specific yield.

Several models have been developed with the aim of preserving one or more characteristics of investigated series. They usually differ according to the time scale of the analysis, since for instance in the case of data aggregated at sub-yearly time scale the seasonality of the statistics must be taken into account. Accordingly, models can be stationary or periodic. Models can also be classified according to whether the interest lies in modeling one series (univariate models) or several series jointly preserving the cross correlation (multivariate models). Also, while most models are developed in the normal domain thus requiring a preliminary data transformation, in the case of non-normal observations some models are able to generate directly skewed data (Salas, 1993).

One of the most widely used stochastic model is the AR(p) model that can be written as follows:

$$y_t = \mu + \sum_{j=1}^{p} \phi_j (y_{t-j} - \mu) + \epsilon_t$$

where y_t is the stochastic variable to be modeled, p is called order of the model while ε_t is a normally distributed uncorrelated random variable called *noise*, *innovation*, *error term*, o *series of shocks* with mean zero and variance σ^2_ε and uncorrelated with the y_t process.

Since ε_t is normally distributed then also y_t is normal. Model parameters are μ, $\phi_{1\ldots}$ ϕ_p and σ^2_ε. Lower order models, with p = 1,2 or 3 have been widely used to generate synthetic annual series.

The simplest model, AR(1) can be written as:

$$y_t = \mu + \phi_1(y_{t-1} - \mu) + \varepsilon_t \tag{1}$$

with mean and variance:

$$E[y]_t = \mu \qquad Var[y] = \sigma^2 = \frac{\sigma_\varepsilon^2}{1-\phi_1^2}$$

while the autocorrelation function is:

$$r(k) = \phi_1^k$$

A more versatile model than the AR(p) is the *autoregressive moving average model* ARMA(p,q) with *p* autoregressive parameters and *q* moving average. Using the same notation adopted in (1) an ARMA(p,q) model can be written as follows:

$$y_t = \mu + \sum_{j=1}^{p} \phi_j (y_{t-j} - \mu) + \epsilon_t - \sum_{j=1}^{q} \theta_j \epsilon_{t-j}$$

A simple version of the ARMA(p,q) model is the ARMA(1,1) as:

$$y_t = \mu + \phi_1(y_{t-1} - \mu) + \varepsilon_t - \theta_1 \varepsilon_{t-1}$$

which mean and variance are:

$$E[y] = \mu \qquad Var[y] = \sigma^2 = \frac{\sigma_\varepsilon^2}{1-\phi_1^2} \ (1 - 2\phi_1\theta_1 + \theta_1^2)$$

where ϕ_1 is:

$$\phi_1 = \frac{r_2}{r_1}$$

and θ_1 is a function of ϕ_1 and r_1.

When the original series is characterized by strong seasonality PAR(*p*) and PARMA(*p,q*) (*periodic autoregressive model* e *periodic autoregressive moving average model*) are able to reproduce this character.

Assuming that a periodic hydrological process is represented by y_{nt}, in which *n* defines the year and *t* defines the season, such that t = *1*, …, w and w is the number of season in the year (seasons, months, weeks) a PAR(*p*) model is defined as follows:

$$y_{\nu,\tau} = \mu_\tau + \sum_{j=1}^{p} \phi_{j,\tau}(y_{\nu,\tau-j} - \mu_{\tau-j}) + \epsilon_{\nu,\tau}$$

in which the meaning of the symbols is the same of that given before for the AR(*p*) and ARMA(*p,q*) models with the difference that this time the parameters of the model to be estimated are μ_t, $\phi_{1,\tau}$, …, $\phi_{p,\tau}$ and $\sigma^2_\tau(\varepsilon)$ for t = 1,…, w.

By considering a moving average component, a PAR(*p*) becomes a PARMA(*p,q*) model, that can be written as follows:

$$y_{\nu,\tau} = \mu_\tau + \sum_{j=1}^{p} \phi_{j,\tau}(y_{\nu,\tau-j} - \mu_{\tau-j}) + \epsilon_{\nu,\tau} - \sum_{j=1}^{q} \theta_{j,\tau}\epsilon_{\nu,\tau-1}$$

When synthetic data generation models are used in a Montecarlo simulation of water supply system with several hydrological input, it is generally necessary to generate cross-correlated series that preserve also the correlation between the different inflows within the same water supply system. Formulation of this kind of models is similar to the one shown for AR(*p*) and ARMA(*p,q*) models with the difference that a matrix notation is now needed. Specific models such as MAR(*p*) and MARMA(*p,q*) (*multivariate autoregressive models* and *multivariate autoregressive moving average models*) are useful for this task.

Consider a multiple time series **Y**, a column vector with elements $y_t^{(1)}$, …, $y_t^{(n)}$ in which *n* is the number of series (number of sites or number of variables) under consideration. The multivariate MAR(1) model is defined as:

$$\mathbf{Z}_t = \mathbf{A}_1 \mathbf{Z}_{t-1} + \mathbf{B}\boldsymbol{\varepsilon}_t$$

in which $\mathbf{Z_t} = \mathbf{Y_t}$-**m**, $\mathbf{A_1}$ and **B** are *n* x *n* parameter matrices and **m** is a column parameter vector with elements $m^{(1)}$, …, $m^{(n)}$. The noise term e_t is also a column vector of noises each with zero mean, uncorrelated with $\mathbf{Z_{t-1}}$ and normally distributed.

Using the same notation MARMA(*p,q*) models can be introduced. The simplest MARMA(*p,q*) is the MARMA(1,1) that can be defined as:

$$\mathbf{Z}_t = \mathbf{A}_1 \mathbf{Z}_{t-1} + \mathbf{B}\boldsymbol{\varepsilon}_t - \mathbf{C}_1\boldsymbol{\varepsilon}_{t-1}$$

in which $\mathbf{C_1}$ is an additional *n* x *n* parameter matrix useful to consider the moving average component of the original series.

Using the full MAR(*p*) and MARMA(*p,q*) models often leads to complex parameter estimation, thus some model simplifications have been suggested. For instance a simpler model considers $\mathbf{A_1}$ to be a diagonal matrix. In general a *contemporaneus* ARMA(*p,q*) (CARMA) model results if the matrices $\mathbf{A_p}$ and $\mathbf{C_q}$ are considered to be diagonal. In this case the model implies a contemporaneous relationship in that only the dependance of concurrent values of the *y*'s are considered important.

Skewed hydrological processes must be transformed into normal processes before AR or ARMA models are applied. However, a direct modeling approach which does not require a transformation may be a viable alternative. For instance, the *gamma autoregressive process* offers such an alternative. It is defined as:

$$y_t = \phi(y_{t-1}) + \varepsilon_{\gamma t}$$

where ϕ is the autoregressive coefficient, (ε_t) is a random component that can be obtained as a function of *f* and the parameters of a Gamma distribution (location, scale, shape).

Stochastic data generation models are often said to statistically resemble the historic flows if the model produces synthetic flows with the same mean, variance, skew coefficient, autocorrelation, and/or cross-correlation as in the historic series. The drawback of this approach could be that it shifts the modeling emphasis on reproducing arbitrarily selected statistics of the available data. Therefore, for any particular water supply system, and depending on the purpose of the analysis one must determine what particular characteristics need to be modeled. Such decision should depend on what characteristics are important to the operation of the system being studied as well as on the data available.

Analysis and representation of results

The output of Montecarlo simulation of a water supply system consists in several series of storage levels in reservoirs, downstream releases, releases to the demands, etc. Analysis of such results therefore must be carried out by means of synthetic indices, able to capture different features of the analyzed series. Here, for the purpose of risk analysis of water shortages due to droughts, the following synthetic assessment of system failures in terms of satisfaction of consumptive demands are proposed:

(i) Water supply system performance indices (reliability, resilience and vulnerability)

(ii) Frequency plot of shortages

(iii) Histogram of monthly frequencies of shortages

(iv) Sample frequency of monthly shortages

(v) Return period of shortages defined as the average interarrival time between two annual shortages exceeding a given value

A similar assessment can be proposed for the satisfaction of ecological requirements, such as instream flow requirements, and for target storages in reservoirs.

Some of the most meaningful water supply system performance indices are:

(i) Temporal reliability

(ii) Volumetric reliability

(iii) Average shortage period length

(iv) Max monthly shortage

(v) Max annual shortage

(vi) Sum of squared shortage

Temporal reliability is defined as the probability that the system is in a satisfactory state.

$$Aff_t = \Pr[X_t \in S]$$

where X_t represent the state of the system at time t and S is the ensemble of the satisfactory states.

If by satisfactory state we indicate the complete meeting of demands, this probability can be estimated as the ratio between the number of intervals during which demand is fully met and the total number of intervals considered.

$$rel_T = \frac{n_s}{N}$$

where n_s is the number of intervals during which demand is fully met and N is the total number of intervals considered. This index gives information about the time reliability of the system on a given demand.

Volumetric reliability is expressed as the ratio between the total volume released and the total demand volume:

$$rel_V = \frac{\sum_{t=1}^{N} R_t}{\sum_{t=1}^{N} D_t}$$

where R_t and D_t are respectively the volume released and the demands at the t interval. This index helps on the evaluation of the total volumes released by the system.

The average shortage period length is defined as:

$$Av_{def} = \frac{N - n_s}{N_P}$$

where n_s is the number of intervals during which demand is fully met, N is the total number of intervals considered and N_p is the number of periods of deficit defined as a continuous series of deficit intervals.

The maximum monthly and annual shortage are defined as the maximum of the annual and monthly shortages series and gives information about the vulnerability of the system in a single interval.

The sum of squared shortages index gives information about the amount of the shortages.

The above mentioned indices give an objective estimation of performance of the system but are not sufficient to catch some interesting statistical features of the shortage series.

Histogram of monthly frequencies of shortages, sample frequency of monthly shortages and return period of shortages defined as the average interarrival time between two annual shortages exceeding a given value, expressed in form of graphs, can help to capture the stochastic features of shortages.

In particular histogram of monthly frequencies of shortages, as depicted for example in Fig. 3, represent the frequency of shortages belonging to one of the four proposed classes expressed as a percent of the demand of a given interval (0-25%, >25%-50%, >50%-75%, >75%-100). This representation gives information about the overall monthly probability of deficits and their distribution among the classes.

Sample frequency of monthly shortages, as depicted for example in Fig. 4, represents non exceedence probabilities of shortages giving the opportunity to estimate the frequency of shortages of different entity as a continuous curve.

Return period of shortages, defined as the average interarrival time between two annual shortages exceeding a given value, gives information about the rarity of the shortages.

An example of the comparison of return period of shortages for two different operations of the system (with or without mitigation measures) is depicted in Fig. 5. From the figure, it can be inferred how the return period of dimensionless shortages greater than 0.3 when mitigation measures are applied is larger than the corresponding return period when no measures are applied. Thus it can be concluded that the adoption of the measures is beneficial for dimensionless shortages greater than 0.3 since the interarrival time increases significantly.

Comparison between the above mentioned indices and graphs calculated for simulations done in correspondence of different implemented mitigation measures can help on evaluating in a statistical sense the impacts of mitigation measures on different demands relying on the system under investigation.

Even if it is not possible to define a unique synthetic index to assess the risk of a given water supply system, however an analysis based on the mentioned indices and graphs can give a good idea of the multifaceted behavior of a water supply system under drought conditions.

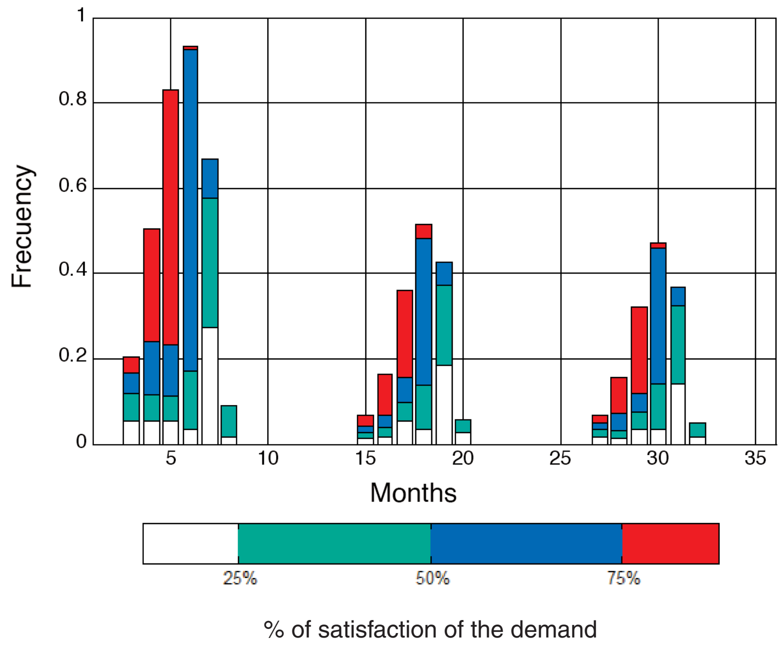

Fig. 3. Example of histogram of monthly frequencies of shortages in percentaje of demand.

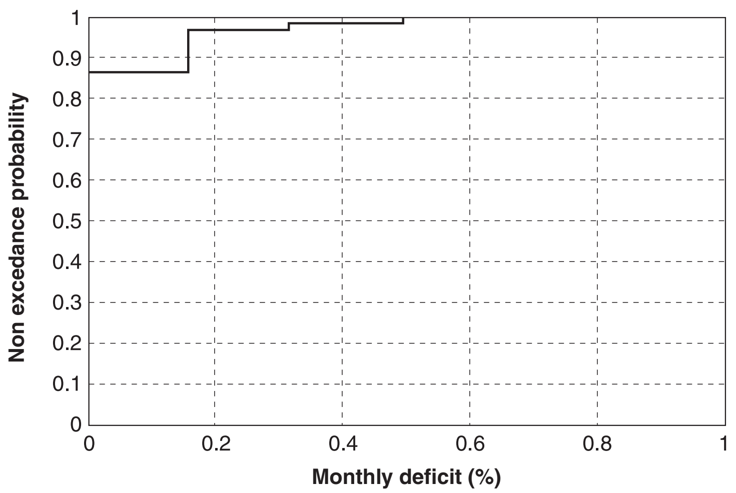

Fig. 4. Sample frequencies of monthly shortages.

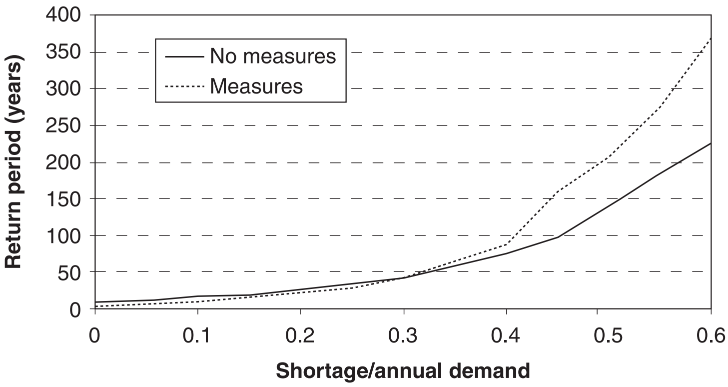

Fig. 5. Comparison of return period of shortages in two different operating modes of the system.

Conclusions

Despite several definitions of risk exists, there is a general agreement that dealing with risk is basically dealing with the uncertainty of the consequences of a given phenomenon. Such uncertainty stems from the stocasticity that characterize most of the natural phenomena, as well as from the difficulties in assessing in a deterministic way their consequences and impacts. When assessing drought risk for a water supply system, to the above difficulties must be added also the fact that the same drought can have different consequences on the same system, depending on the degree of preparedness (i.e. mitigation measures) of the system.

Therefore, a correct approach to assessing risk in water supply system must be based on tools able to fully capture the stochastic nature of the drought phenomenon, as well as to evaluate the effects of different management alternatives of the system. Within this framework, Montecarlo simulation represents the ideal tool, since it enables to overcome the limitations of a probabilistic evaluation of risk of shortage based on historical hydrological series, which is hindered by the generally limited sample length availability. Simulation of the system using synthetically generated series also enables to extend the analysis, besides the planning stage, also during the operation of the system, by assessing the conditional risk, i.e. the risk of shortages in a short term time horizon as a function of the current states of the system. Furthermore, an appropriate analysis of the results of Montecarlo simulation allows to capture the multifaceted features of water shortages, thus allowing for an improved assessment of the impacts of droughts to be carried out.

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Chapter 10. Methods for evaluating social vulnerability to drought

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SUMMARY – Social vulnerability to drought is complex but is reflected by the social capacity to anticipate, cope with and respond to drought. Here we estimate these aspects of social vulnerability evaluating the natural resource structure, the economic capacity, the human and civic resources, and aspects of agricultural innovation. The weight of each component of the index is a key determinant of the final value. Here we present the results of the index under two valuation scenarios. In Scenario 1 all components are valued equally. In Scenario 2 the human resources component is given 50% of the weight, the economic and natural resource components are given 20% of the weight each, and the agricultural technology is given 10% of the weight. This reflects the assumption that a society with institutional coordination and strengths for public participation is less vulnerable to drought and that agriculture is only one of the sectors affected by drought. The vulnerability index establishes robust conclusions since the range of values across countries does not change with the assumptions under the two scenarios.

Key words: risk, cause, socio-economic, environmental, vulnerability index.

Introduction

The objective of the vulnerability assessment is to identify underlying causes of risk derived from inadequate structures, management, and technology, or by economic, environmental, and social factors. Vulnerability refers to the characteristics of a group in terms of its capacity to anticipate, cope with, resist and recover from the impact of drought. Vulnerability assessment aims to identify characteristics of the systems that modify the level of risk derived from inadequate structures, management, and technology, or caused by economic, environmental, and social factors.

Yohe and Tol (2002) proposed a method for developing indicators for social and economic coping capacity in the context of climate change. Later, a simple index to quantify adaptive capacity was used by Ionescu *et al.* (2007) including only GDP, literacy rate, and labour participation rate of women. Yohe *et al.* (2006) used the Vulnerability-Resilience Indicator Prototype (VRIP) developed by Brenkert and Malone (2005) as a proxy to adaptive capacity index, considering the capacity to adapt to environmental change as implicit in the vulnerability assessment.

Iglesias *et al.* (2007a) develop an Adaptive Capacity index (AC index) with three major components that characterize the economic capacity, human and civic resources, and agricultural innovation. And a similar approach has been taken in the context of drought (Moneo, 2007). The approach is flexible and can be applied to managed and natural ecosystems as well as to socio-economic systems.

The overall vulnerability is determined by combining vulnerability derived from the direct exposure to drought, and vulnerability to drought derived from social and economic aspects. For example, given a specific farm, the vulnerability is directly related to the intensity of the drought event. In contrast, given a defined drought event, the most vulnerable farming system is the one that has less social and economic resiliency; in general marginal and poor farming systems suffer the largest consequences of drought.

Vulnerability directly related to drought

This component analyses the vulnerability directly related to the exposure to drought in the present. The underlying causes of risk may be related to structural problems, such as lack of adequate hydraulic infrastructures or technology, and also to management, economic and social features that increase the vulnerability of the region, watershed or water supply system under analysis. For example, the direct impact of precipitation deficiencies may be a reduction of crop yields. The underlying cause of this vulnerability, however, may be that the farmers did not use drought-resistant seeds, either because they did not believe in their usefulness, their costs were too high, or because of some commitment to cultural beliefs.

Another example could be farm foreclosure related to drought. The underlying cause of this vulnerability could be many things, such as small farm size because of historical land appropriation policies, lack of credit for diversification options, farming on marginal lands, limited knowledge of possible farming options, a lack of local industry for off-farm supplemental income, or government policies.

An index to evaluate socio-economic vulnerability to drought

An index that estimates social vulnerability to drought is developed and calculated in selected Mediterranean countries. The methodology is appropriate to integrate both quantitative and qualitative characterisations of vulnerability thus permitting the involvement of the stakeholders in the process. The index can be applied locally or spatially and with different aggregation levels of the input data. The intermediate components can be evaluated independently, allowing comprehensive interpretation of the strengths and weaknesses of each system.

The sequential steps taken for the quantification of the vulnerability index are: (i) select proxy variables for factors that contribute to the vulnerability; (ii) normalize the proxy variables with respect to some common baseline; (iii) combine the sub-component proxy variables within each vulnerability category by weighted averages; and (iv) quantify vulnerability as the weighted average of the components.

Selection of variables

The socio-economic vulnerability components (Table 1) and the variables included were selected because: (i) data are readily available and an example may be computed to assist stakeholders in defining the sensitivity of the system; and (ii) the variables are drought scenario dependent and geographically explicit. The vulnerability index may be used to understand the sensitivity of the system and to assist in the selection of measures to be adopted. For example, improving the efficiency of agricultural water use, decreasing population under the poverty line, increasing adult literacy rate, and increasing agricultural technology, are measures that result in an overall vulnerability decrease.

Table 1. Components of socio-economic vulnerability and representative variables that can be used to characterise the vulnerable groups

Components	Proxy variables
Natural component	Agricultural water use (%) Total water use (% of renewable) Average precipitation 1961-90 (mm/year) Area salinised by irrigation (ha) Irrigated area (% of cropland)
Economic capacity	GDP millions (US$) GDP per capita (US$) Agricultural value added/GDP (%) Energy use (kg oil equivalent per capita) Population below poverty line (% population with less that 1 US$/day)
Human and civic resources	Population density Agricultural employment (% of total) Adult literacy rate (% of total) Life expectancy at birth (years) Population without access to improved water (% of total)
Agricultural innovation	Fertiliser consumption (100 kg/ha of arable land) Agricultural machinery (tractors per 100 km^2 of arable land)

The components of socio-economic vulnerability and the representative variables that have been used to characterise it are provided in Table 1. A final indicator for each category of exposure may be computed as the weighted average of all the representative variables within the category.

Normalization to some common baseline

The variables in Table 1 were normalized between the different countries in order to compare the results. The standarization has been made with respect the maximum value of each variable across the countries to combine within the categories and guarantee the index being a percent rate. Combine the sub-component proxy variables within each category by using either a geometric mean (Moss *et al.*, 2000) or a weighted mean with weights inversely proportional to the impact uncertainty level.

Combination of the sub-components

Sub-component proxy variables can be combined within each category by using either a geometric mean or a weighted mean with weights inversely proportional to the impact uncertainty level. This study considers the weights separately for each of the categories, as in Iglesias *et al.* (2007a), in order to evaluate them independently, allowing noticing the strengths and weaknesses of each component of the total vulnerability index within each country. It should be noticed that the vulnerability components have inverse interpretation that adaptation capacity ones.

Quantifying vulnerability

The total vulnerability index has been quantified as the weighted average of each of the four components. The four components of the index and the total computation are shown on Table 2 and Fig. 1 also illustrates the drought vulnerability index. The scores of the vulnerability index range on a scale of 0 to 100, being 0 the least vulnerable and 100 the most vulnerable. The total index is generated as the average of all components. The final value of the index depends on the valuation of each component. Here we present the results of the index under two valuation scenarios. In Scenario 1 all components are valued equally. In Scenario 2 the human resources component is given 50% of the weight, the economic and natural resource components are given 20% of the weight each, and the agricultural technology is given 10% if the weight. This reflects the assumption that a society with institutional coordination and strengths for public participation is less vulnerable to drought and that agriculture is only one of the sectors affected by drought.

Table 2. Components of the social vulnerability index and total values of the index under two different scenarios of valuation of the vulnerability components. Source of data: FAO 2007, Iglesias and Moneo 2005

Country	Drought Vulnerability Index (%)					
Component of the index	Cyprus	Greece	Italy	Morocco	Spain	Tunisia
Renewable natural capital	40	26	36	69	37	70
Economic capacity	34	37	4	96	15	88
Human and Civic Resources	1	5	7	65	7	39
Agricultural innovation	29	26	4	91	57	90
Drought Vulnerability Index (Scen 1)	26	24	13	80	29	72
Drought Vulnerability Index (Scen 2)	18	18	12	75	20	60

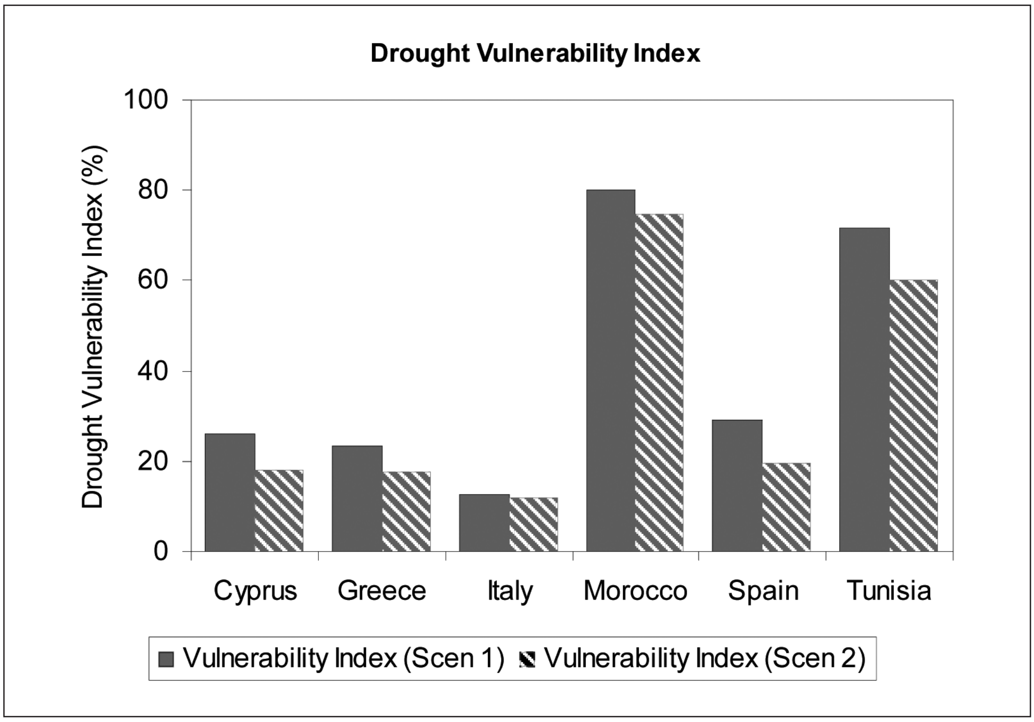

Fig. 1. Social vulnerability index across MEDROPLAN countries under two different scenarios of valuation of the vulnerability components.

The results of this evaluation lead to the identification of actions to minimize risk by reducing the underlying causes (vulnerability). The results contribute to increase the adaptive capacity and develop policy decisions to increase adaptation options. The vulnerability assessment bridges the gap between impact assessment and policy formulation by directing policy attention to underlying causes of vulnerability rather than to its result, the negative impacts, which follow triggering events such as drought (Wilhite, 2005). The vulnerability evaluation helps defining the sensitivity of the systems to external shocks and identifying the most relevant aspects that decrease the level of risk.

Discussion

Vulnerability to drought in the Mediterranean region may be intensified, as climate change comes in conjunction with high development pressure, increasing populations, water management that is already regulating most of available water resources, and agricultural systems that are often not adapted (any more) to local conditions. Evidence for the vulnerability of socio-economic and agricultural systems in the Mediterranean region can be documented in recent history. For example, water reserves were not able to cope with sustained droughts in the late 1990's in Morocco and Tunisia, causing many irrigation dependent agricultural systems to cease production. In 2007, the vulnerability of Moroccan agriculture to drought is a reality. In addition, effective measures to cope with long-term drought and water scarcity are limited and difficult to implement due to the variety of the stakeholders involved and the lack of adequate means to negotiate new policies. Climate change projections indicate an increased likelihood of droughts (Kerr, 2005). The combination of long-term change (e.g., warmer average temperatures) and greater extremes (e.g., droughts) can have decisive impacts on the vulnerability of many regions (Arnell, 1999). If climate change intensifies drought impacts, Mediterranean water delivery systems and control may become increasingly unstable and vulnerable (IPCC 2007; Reilly and Schimmelpfennig, 1999; Iglesias *et al.* 2007b, Burton 1997). Water managers may find planning more difficult and current agricultural water management strategies based on irrigation should be revised.

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Chapter 11. Tools and models

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Medbasin - A Mediterranean rainfall-runoff model and software

Introduction

Medbasin is a daily-monthly rainfall-runoff model and software with a Windows interface and additional tools.

Numerous rainfall-runoff models have been proposed over the last four decades. To a great extent the complexity of these models seem to follow the advancement in computing and computer technology rather than the advancement in understanding of the physical processes. Therefore, new complicated models do not offer substantially to the improvement of representation of hydrological processes in a watershed.

Very important is also the fact that most rainfall-runoff models have been produced based on observations related to the study area, therefore being region related. It can be easily deduced that most conceptual models developed for the northern part of Europe cannot be used successfully in Mediterranean countries. Further physical models are not usually recommended for practical and operational studies.

In an attempt to model rainfall-runoff, FAO produced a comprehensive conceptual model for the Mediterranean Island environment called MERO. However, MERO was not used extensively during the sixties when it was proposed, due to computing difficulties. Based on this "old" model a modern computer package, *Medbasin*, was recently produced at the Laboratory of Reclamation Works and Water Resources Management of the National Technical University of Athens, in the framework of Medroplan project.

Model structure of the daily rainfall-runoff model

Medbasin's rainfall-runoff simulation procedure is based on the basic principles of MERO model, which had been used in several projects of F.A.O. in Mediterranean basins (e.g. Underhill *et al.*, 1970, Schenkeveld, 1971). MERO is a comprehensive conceptual rainfall-runoff model, based on the hydrologic cycle processes. These processes and the interactions between them are described by empirical relationships such as the overland flow function, the interflow function and the soil water storage-recharge relationship (Giakoumakis *et al.*, 1991). Daily values of average basin's rainfall and potential evapotranspiration are used as input data, while daily and monthly runoff is the output of the model.

The model is essentially an accounting procedure, in which the input (precipitation) passes through storage zones, from each of which some outflow is removed, until the whole input has been accounted for (Underhill *et al.*, 1970). The river flow is finally made up of outflow from four different reservoirs: the overland flow reservoir, the interflow reservoir, the temporary spring reservoir and the permanent spring reservoir (Fig. 1).

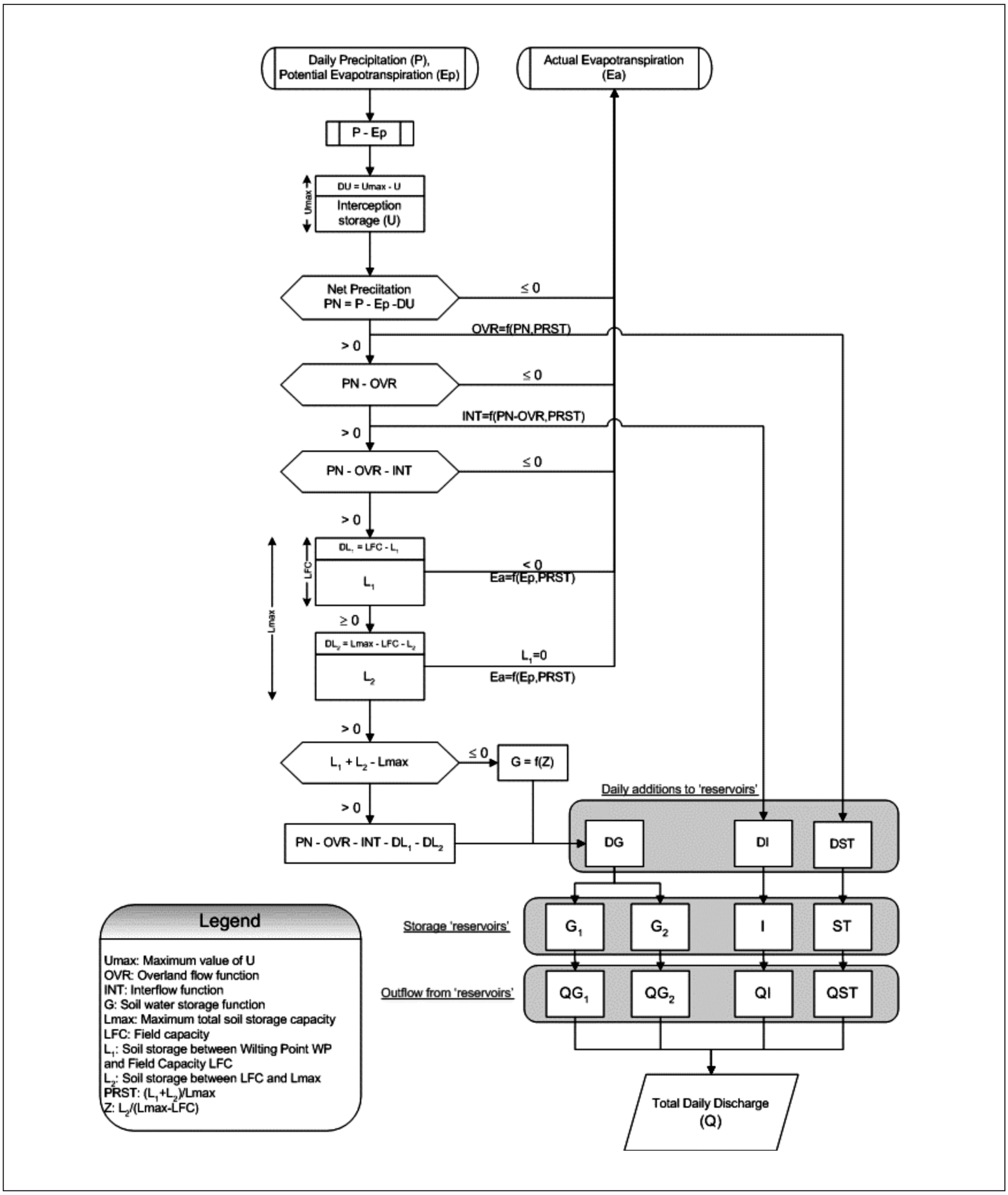


Fig. 1. Structure of the Medbasin model (Tigkas and Tsakiris, 2004).

According to the principles of the model, the soil has been divided into two different interconnected storage reservoirs: the interception storage U and the total groundwater storage L. In turn, the latter has been divided into two soil-water storage zones: the upper soil zone L_1 that may be considered as the root zone and in which soil moisture can reach a maximum value, up to field capacity LFC, and the lower zone L_2 that receives moisture from above when field capacity is exceeded (Giakoumakis *et al.*, 1991).

The river flow is made up of outflow from four reservoirs: the overland flow reservoir ST, the interflow reservoir I, the temporary spring reservoir G_1 and the permanent spring reservoir G_2. The distribution of moisture over the various storage zones occurs according to the following rules: Evaporation takes place from the interception storage U and the precipitation P is added to U. If U is less than the potential evapotranspiration EVPD, evaporation takes place from the soil moisture L. If the interception storage has a value greater than its maximum Umax the addition STPR to the storm runoff reservoir STmm and the addition GPR to the interflow reservoir INmm are calculated. If I is less than Imax, there is an addition to the interflow reservoir only if the soil moisture L is greater than its maximum Lmax. The addition GWPR to the shallow and deep spring reservoirs occurs when the soil moisture L is greater than the field capacity LFC.

The maximum value of interception storage Umax as well as the maximum total soil moisture capacity of both zones Lmax and the field capacity LFC, are not usually based on actual field measurements, but they are determined during the model calibration stage to give the best possible fit with the measured runoff volumes.

The reservoirs release water to the river according to a delay function:

$$F = (1\text{-}\exp(1\text{-}/T_0)) \tag{1}$$

where T_0 is a characteristic value for each of the reservoirs.

In the model each of the reservoirs has a certain intake area. The total area of the basin is allocated to storm runoff reservoir. To the remaining reservoirs parts of the basin are allocated which normally make up the total area. When there are losses from the basin through underground flow, the whole area should not be allocated to the remaining reservoirs. On the other hand, if there is underground inflow, the sum of the allocated areas should be greater than the area of the basin. The volume of this flow (deep percolation) is equal to the total moisture flow to the spring reservoir multiplied by the area, which is not allocated.

For a more extensive theoretical description of the model the reader can refer to Tigkas and Tsakiris (2004).

Model calibration

The model has fourteen calibration parameters which represent the physical characteristics of the basin:

(i) Umax, Lmax and LFC limit the size of the basin.

(ii) A1, A2, A3 and A4 represent the intake areas for the reservoirs determining their respective outflow.

(iii) T01, T02, T03 and T04 are the delay constants for the outflow of the reservoirs.

(iv) Constants that used for the size of the storm runoff: CT as a multiplier and Q0 as the amount that should be added or subtracted initially.

(v) CL2 controls the flow to the spring reservoirs.

Calibration process is usually applied to a portion of the available dataset and may follow a manual (trial-and-error) or automatic (based on objective functions) procedure by comparing the model estimated runoff values with the measured ones. Medbasin uses the Route Mean Square Error (RMSE) objective function:

$$\min_{\theta} RMSE(\theta) = \sqrt{\frac{1}{n}\sum_{t=1}^{n}[q_t^{sim}(\theta) - q_t^{obs}]^2} \tag{2}$$

where q_t^{sim} is the simulated discharge q_t^{obs} is the observed discharge and *n* is the total number of observations. This function is the unbiased, minimum variance estimator, and it is the Maximum Likelihood Estimator under the assumption that measurement errors ($et = q_t^{sim} - q_t^{obs}$), are normally distributed with zero mean and constant variance σ^2 (Yapo *et al.*, 1998).

Model validation

For the verification of the results five criteria are used (WMO, 1975, 1986, 1992; Cavadias and Morin, 1986):

The coefficient of variation of the residual of errors for the discharge variables

$$Y=\frac{\left[\frac{\sum(q_{sim}-q_{obs})^2}{n}\right]^{1/2}}{\bar{q}_{obs}} \tag{3}$$

The ratio of relative error to the mean of the discharge variables

$$R=\frac{\sum(q_{sim}-q_{obs})}{n\bar{q}_{obs}} \tag{4}$$

The ratio of absolute error to the mean of the discharge variables

$$A=\frac{\sum|q_{sim}-q_{obs}|}{n\bar{q}_{obs}} \tag{5}$$

The arithmetic mean of the discharge variables

$$D=\frac{\sum q_{sim,obs}}{n} \tag{6}$$

One minus the ratio of the sum of squares of the daily residuals to the sum of squares of the deviations of the observed flows from their mean

$$NTD=1-\frac{\sum(q_{sim}-q_{obs})^2}{\sum(q_{obs}-\bar{q}_{obs})^2} \tag{7}$$

where $q_{obs,sim}$ is the observed and the simulated discharge and

$$\bar{q}_{obs}=\frac{\sum q_{obs}}{n}$$

Monthly rainfall-runoff model

Apart from the daily rainfall-runoff component, another simple conceptual rainfall-runoff model, namely the Simple Water Balance Model (SWBM), is included in Medbasin. SWBM operates on monthly basis, therefore it can be useful when daily data are not available. The SWBM is based on the assumption that the water storage in the basin takes place only into the upper soil zone (e.g. root zone). Monthly precipitation P and potential evapotranspiration E_p data are used as inputs, while monthly values of runoff R are calculated.

SWBM uses two calibration parameters: the maximum total soil storage capacity, Smax and C which is taking into account the deep percolation losses.

According to the model, the soil may be taken to be a container with maximum total storage capacity Smax. The monthly precipitation P_i is added to this container, while the monthly value of potential evapotranspiration Ep_i is subtracted, as well as the losses because of the deep percolation D_i. The amount of water that exceeds Smax is splitting in two parts, based upon the value of C parameter: the first part is added directly to runoff R_i, while the second is considered as deep percolation loss D_i (Fig. 2).

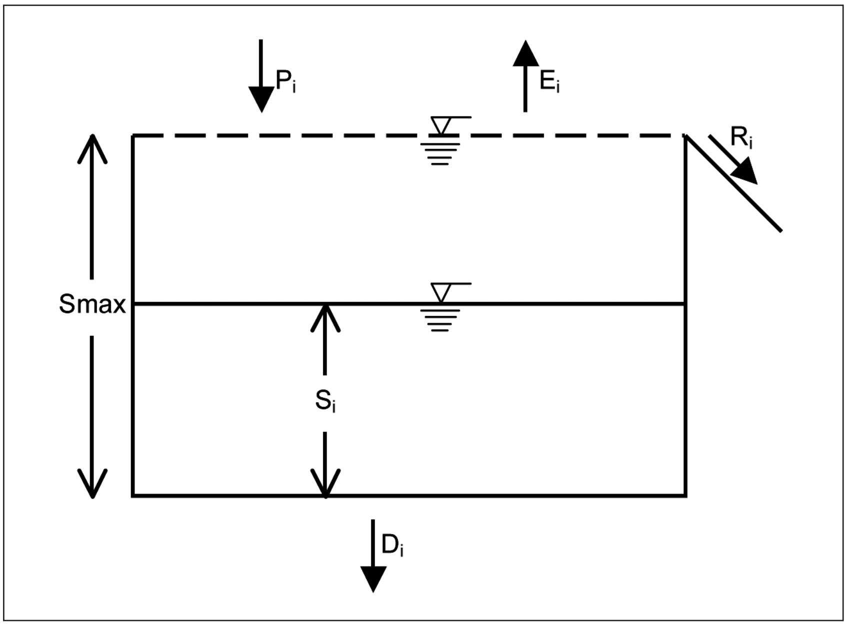


Fig. 2. Simplified Medbasin monthly water balance model.

The first step is to compute a trial value of depth S'_i of the water in the container, by the following equation:

$$S'_i = S'_{i-1} + P_i - Ep_i$$

where: i = 1,2,…,n subscript denoting number of months.

According to the magnitude of this trial depth, the values of the output R_i and D_i are determined as follows:

If $S'_i < 0$, then:
$S_i = 0$
$R_i = 0$
$D_i = 0$

If $0 \leq S'_i \leq Smax$, then:
$S_i = S'_i$
$R_i = 0$
$D_i = 0$

If $S'_i > Smax$, then:
$S_i = Smax$
$R_i = (1 – C) (S'_i – Smax)$
$D_i = C (S'_i – Smax)$

Medbasin software interface

General description

The software interface of Medbasin has been programmed in Visual Basic 6. The recommended system requirements are a Pentium 4 processor computer with 256MB of RAM, running on a Windows operating system.

In the Main window of the program (Fig. 3) the model's parameters, the values of the initial conditions for the deep and shallow spring flow ($S1_{in}$, $S2_{in}$) and the upper soil moisture (L_1), as well as the EVPC evaporation constant, can be assigned. The number and the actual period of water years are also defined in this window. This information must be accurate in order to calculate the leap years.

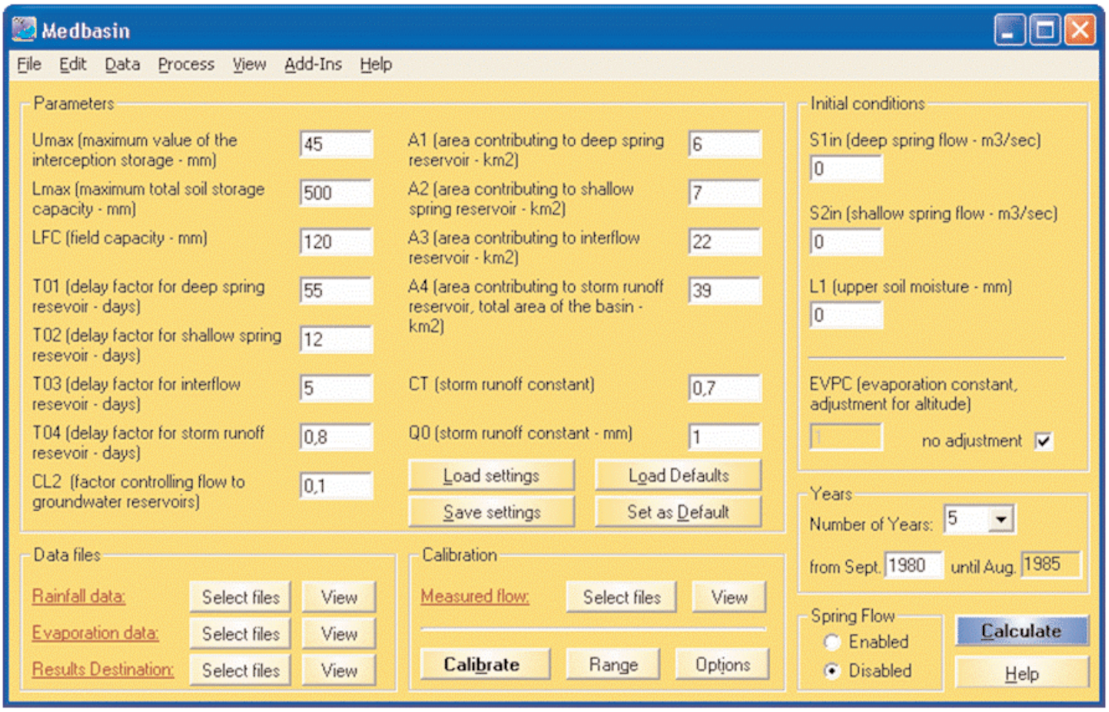


Fig. 3. Medbasin's Main Window.

All the basic commands, user's preferences and other settings can be accessed or executed directly from the menu list of the program (Fig. 4). There are also web links to Medbasin website (*www.ewra.net/medbasin*) for technical support and other information.

Data input

The main data requirements of the program are surface average rainfall and potential evapotranspiration. If there is a spring which contributes to the river runoff and its water supply is located in an area outside the basin, average monthly spring flow data is accounted as input to the model. For the calibration process, measured river flow data is also required.

Datasets can be imported in the program from Excel worksheet archives. To select and load the data files there are 4 data-selection windows, for rainfall, evaporation, river flow and spring flow data, respectively. Regarding the evaporation data, there is the ability to use directly potential evapotranspiration (PET) values (calculated outside the program e.g. with the Penman method) or to use pan evaporation data (E) and calculate PET by multiplying either with a standard annual constant or with monthly constants (if the correlation between E and PET is known for the specific region).

In case of existing gaps in the datasets (empty cells in source file), they will be automatically replaced by a zero value. Especially for evaporation data an interpolation algorithm is used to fill gaps not greater than 40 days.

Calibration procedure

The optimization algorithm used in the calibration procedure is based on an iterative routine. Initially, the limits of each parameter as well as the loop step are defined in the "Calibration Range" window (Fig. 5). The selection of the limits depends on basin's characteristics.

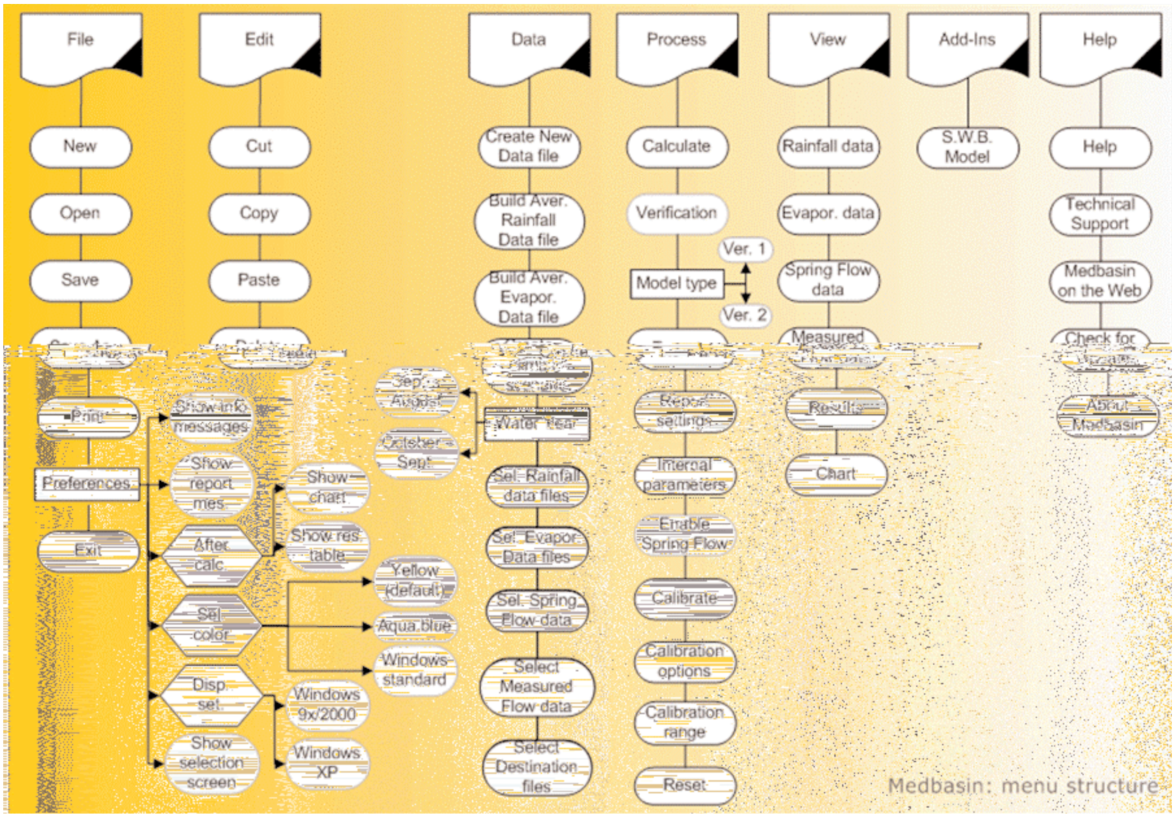


Fig. 4. The structure of the program's menu.

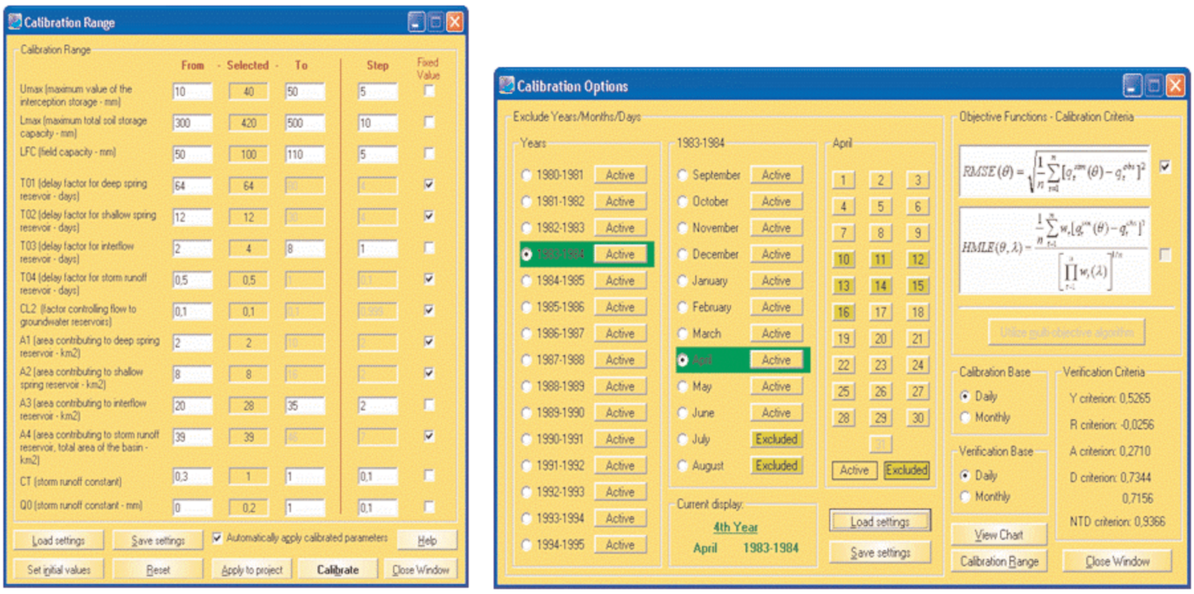


Fig. 5. The "Calibration Range" and the "Calibration Options" windows.

The optimization process intents to specify the set of parameters which minimizes the selected objective function. The procedure may be repeated several times, by changing the range and the "fixed value" option of the parameters, until a satisfying value of the objective function is being achieved.

In the "Calibration Options" window it is possible to exclude data from the calibration procedure. Data exclusion is a way to avoid problems caused by incorrect or incomplete data. However, it can also be used as a technique to focus the optimization on specific parts of the hydrograph (e.g. peaks).

Results and Reports

Loaded data and the runoff simulation results are displayed in data grids and they can also be projected graphically in the Chart window (Fig. 6), as single series or combination charts. There are several 2D and 3D projection options, on daily or monthly basis for the specified period of years. The charts can be printed, saved as bitmaps or exported to compatible grid-based programs.

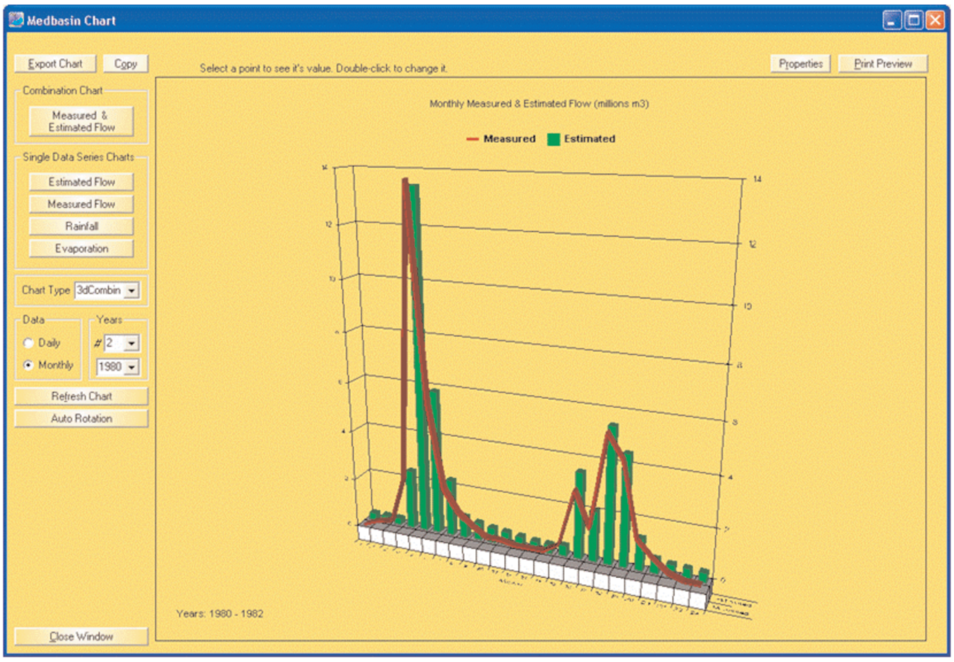


Fig. 6. The "Chart" window.

A list of the values of the internal parameters of the model and a report of the calibration and verification criteria is been created, after the end of the calibration or the runoff simulation.

A detailed calibration report file may also be created, containing the optimum parameters' sets (depending on the objective function's value) with their calibration and verification criteria, respectively.

Climatic scenarios

An important task for water resources management is to assess the changes of runoff in various climatic conditions. Medbasin includes a tool which uses an algorithm to alterate the original datasets of precipitation, potential evapotranspiration and inflow by defined percentages. If several years are selected, which represent the normal conditions of the watershed then the produced climatic scenarios can indicate the variation of runoff from the normal conditions for each scenario (Tsakiris *et al.*, 2004).

There is also the ability to use climatic scenarios together with drought indices (Tigkas *et al.*, 2005). The climatic scenarios can be formulated either by using the daily or the monthly rainfall-runoff component of Medbasin (Fig. 7).

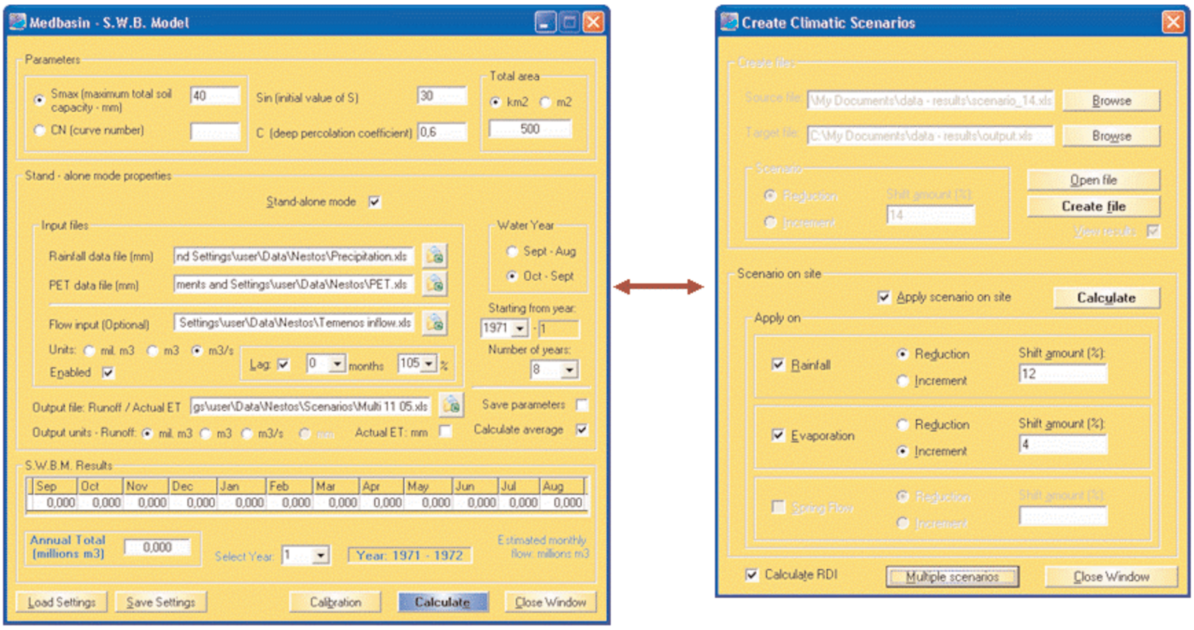


Fig. 7. Climatic scenarios.

Data requirements

Table 1 shows the optimum and minimum data requirements for the simulation of runoff with Medbasin and the calculation of drought indices.

Table 1. Data requirements

	Daily	Monthly	
Precipitation	■ (Medbasin – Optimum)	■ (Medbasin – Minimum) ■ (RDI – Optimum)	
PET	■ (Medbasin – Optimum)	■ (Medbasin – Minimum) ■ (RDI – Optimum)	
Penman - Monteith		Temperature, Humidity, Wind Speed, Sunlight h/day	■ (RDI – Optimum)
Thornthwaite		Temperature	■ (RDI – Minimum)
Pan evap. method		Pan evaporation	■ (RDI – Minimum)
Runoff	■ (Medbasin – Optimum)	■ (Medbasin – Minimum)	

Medbasin – *Optimum* ■ *Minimum* ■
RDI – *Optimum* ■ *Minimum* ■

Redim[1]

The package REDIM (Rossi and Cancelliere, 2003) is an user friendly software which allows to perform drought analysis on hydrological series both at a site and over a region. It, also, allows to test statistically for the existence of nonstationarity in a time series, whose presence would lead to misleading drought analyses (Fig. 8). REDIM is freeware and it can be downloaded from the following web site: http://www.risorseidriche.dica.unict.it.

1. The REDIM software has been developed by A. Cancelliere, G. Rossi, B. Bonaccorso (Department of Civil and Environmental Engineering, University of Catania) and L. Cavallaro (Department of Civil and Environmental Engineering, University of Messina).

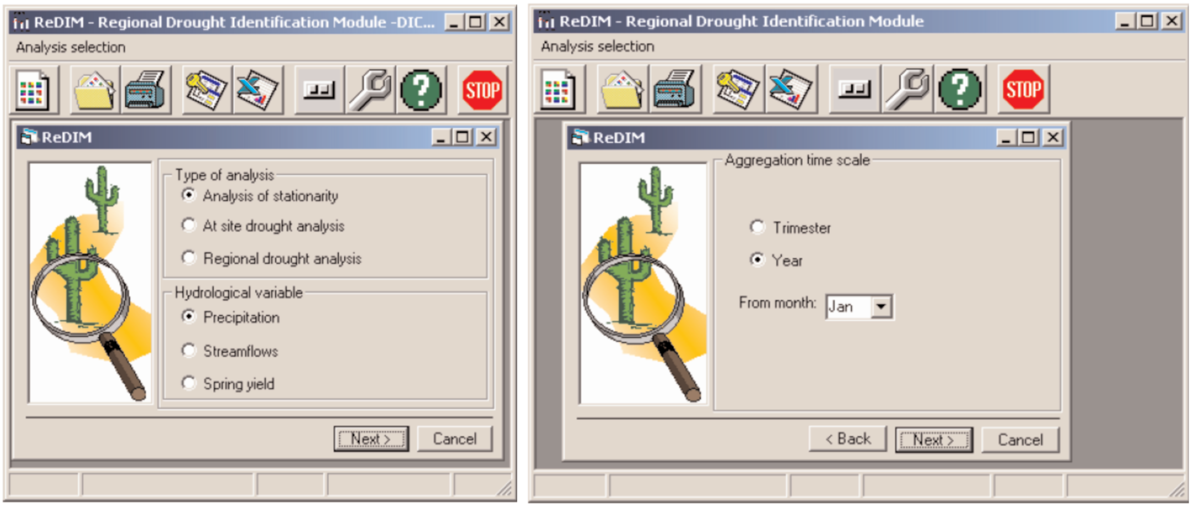


Fig. 8. Main dialog box and aggregation time scale dialog box of REDIM.

The software is written in Visual Basic, runs under Windows platforms, and is structured as a succession of dialog boxes which guide the user throughout the analysis of stationarity and drought identification and characterization steps.

The main features of REDIM can be listed as follows:

(i) Different aggregation time scales can be used (monthly, three months and yearly), with the possibility to select the initial month of aggregation in order to take into account water years instead of calendar years.

(ii) Testing for stationarity in hydrological series is carried out by means of six different statistical test namely: Student's t-test for linear trend, Kendall's t or rank correlation test and turning points, Mann-Withney rank-sum test for detecting the homogeneity of the series, F test for detecting change in variance, and t test for detecting change in mean.

(iii) Identification and characterization of drought is performed by means of run method or the Standardized Precipitation Index.

(iv) Return periods of at site drought characteristics are computed.

(v) Graphical output of results to easily identify droughts and related characteristics are provided.

(vi) Results can be saved in a report file in rtf format.

Drought analysis at site through the run method can be customized by specifying the threshold level, as well as the options to compute return period (Fig. 9).

With reference to the evaluation of drought return period, the user can select either the non-parametric approach or the parametric approach to compute the parameters of the probability distribution (gamma) adopted for accumulated deficit. In the former case (non parametric), such parameters will be computed from the sample moments of the single deficit identified on the series. In the latter case (parametric), the parameters will be estimated by assuming a normal, log normal or gamma distribution for the underlying hydrological series.

Once that the drought analysis is performed by clicking "Next", a table containing the number of identified droughts and, for each drought, the related characteristics (duration, accumulated deficit, intensity), as well as the return periods, corresponding to different combinations of such characteristics, is shown (Fig. 10).

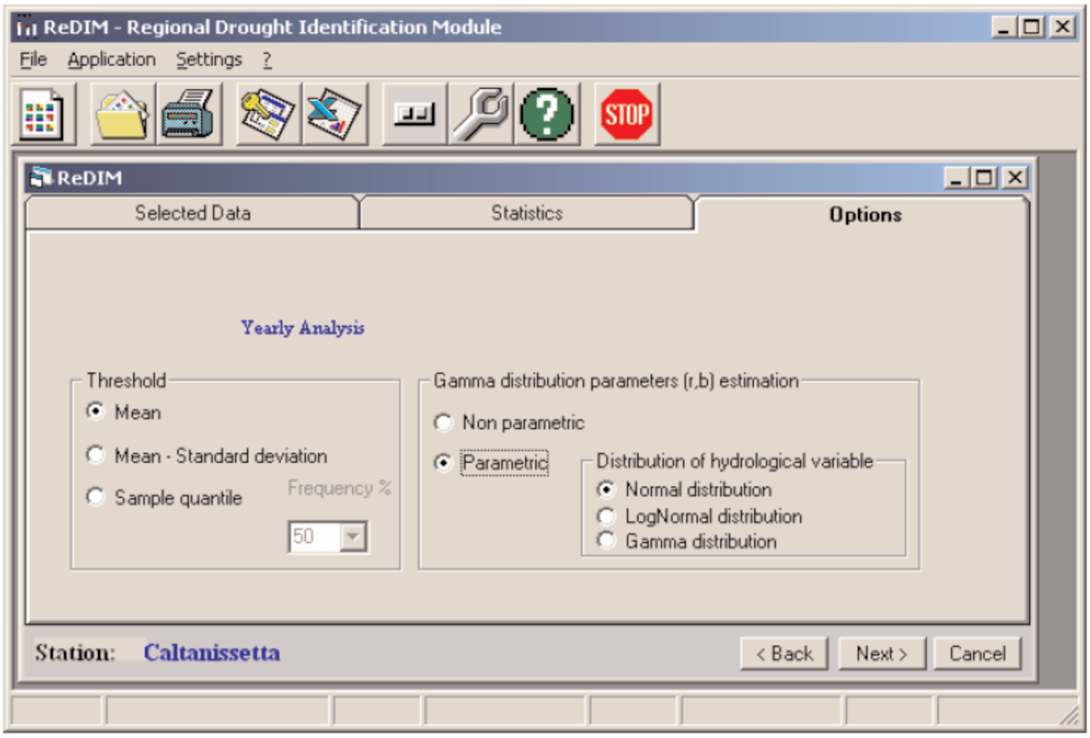
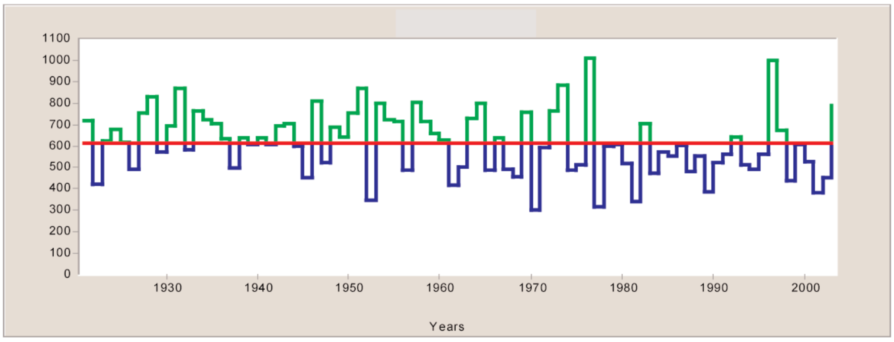


Fig. 9. Drought analysis at site through the run method.

Drought identification - Site analysis (trough REDIM)



Station name: Simeto
Hydrological variable: Precipitation
Aggregation time scale: year
Initial month: January
From year: 1921 To: 2003
Threshold (Average 50%):613.91 mm

Number of drought periods: 20

N	Begin.	End	Durat.	Cum. Def.	Drought Int.	Tr(L=l)	Tr(L=>l)	Tr(D>d)	Tr(L=l,D>d)	Tr(L=>l,D>d)
			[years]	[mm]	[mm/year]	[years]	[years]	[years]	[years]	[years]
1	1922	1922	1	189.84	189.84	8.58	7.55	8.39	61.67	8.57
2	1926	1926	1	123.43	123.43	8.58	7.55	6.23	24.70	6.20
3	1929	1929	1	39.29	39.29	8.58	7.55	4.46	10.09	4.32
4	1932	1932	1	29.47	29.47	8.58	7.55	4.32	9.45	4.20
5	1937	1937	1	116.38	116.38	8.58	7.55	6.04	22.59	6.00
6	1939	1939	1	6.79	6.79	8.58	7.55	4.06	8.63	4.03
7	1941	1941	1	6.49	6.49	8.58	7.55	4.06	8.63	4.03
8	1944	1945	2	181.81	90.91	16.13	14.19	8.09	27.39	9.70
9	1947	1947	1	90.55	90.55	8.58	7.55	5.42	16.55	5.32
10	1952	1952	1	267.25	267.25	8.58	7.55	12.10	199.17	12.55
11	1956	1956	1	126.17	126.17	8.58	7.55	6.30	25.59	6.29
12	1961	1962	2	312.21	156.11	16.13	14.19	15.05	88.97	16.29
13	1965	1965	1	127.16	127.16	8.58	7.55	6.33	25.92	6.32
14	1967	1968	2	275.60	137.80	16.13	14.19	12.60	61.00	13.88
15	1970	1971	2	329.82	164.91	16.13	14.19	16.42	107.77	17.64
16	1974	1975	2	230.16	115.08	16.13	14.19	10.13	40.00	11.52
17	1977	1981	5	689.83	137.97	107.07	94.14	103.30	539.97	121.36
18	1983	1991	9	823.28	91.48	1335.45	1174.21	208.38	1744.18	730.45
19	1993	1995	3	268.62	89.54	30.32	26.66	12.18	46.82	17.64
20	1998	2002	5	662.11	132.42	107.07	94.14	89.38	445.58	109.45

Fig. 10. Example of drought analysis carried out on the areal precipitation series over the Simeto river basin by using REDIM software.

If the SPI method is selected for drought analysis at site, the results of the analysis are shown for five aggregation time scales defined by default, i.e. k=1, 3, 6, 12 and 24 months (Fig. 11). The dialog box contains a table with the identification of drought periods, corresponding to SPI < -1.00, and a table with mean and minimum value of the SPI index and the duration for different classes. The analysis can be repeated for aggregation time scales selected by the user.

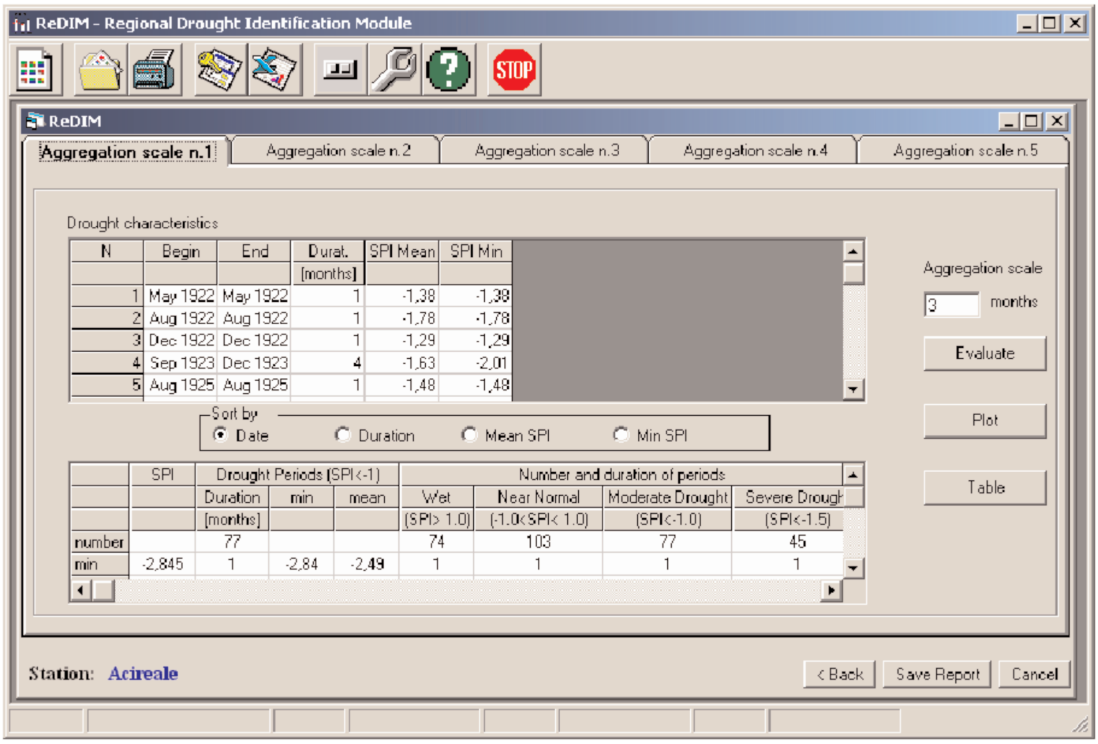


Fig. 11. SPI analysis at site results.

The regional drought analysis can be carried out based on either the run method and the SPI follows a similar approach.

Regional drought identification through the extended run method

Run method can be extended to the case of regional droughts by considering several series of the variable of interest and selecting, besides the truncation level at each site, an additional threshold, which represents the value of the area affected by deficit above which a regional drought is considered to occur. In particular, once the threshold levels $h_0(k)$ for each site k=1,..,K are defined, it is possible to identify for each time interval *i,* sites which present deficit:

$$h_0(k) - h(i,k) > 0 \tag{1}$$

with *h* the generic variable under investigation (e.g. precipitation).

Then, it is assumed that the deficit at each site is extended to an influence area around the observation station, which for example can be estimated by Thiessen polygons method (Fig. 12). Such area S(k) is usually expressed in terms of the total area under investigation as:

$$A(k) = S(k)/S_{tot} \tag{2}$$

where the total area S_{tot} is obviously:

$$S_{tot} = \sum_{k=1}^{K} S(k) \tag{3}$$

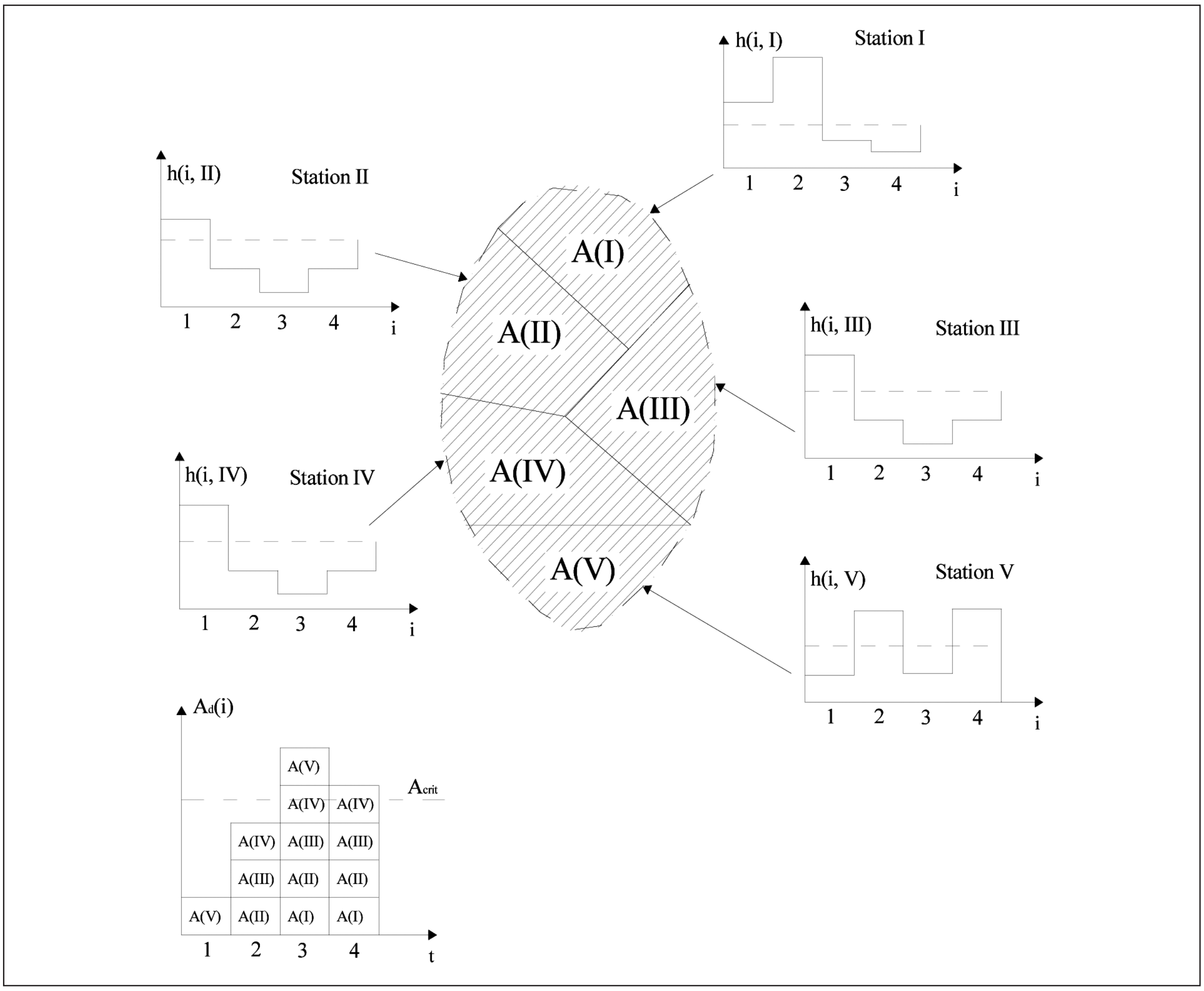


Fig. 12. Regional drought identification.

By fixing the areal threshold A_{crit}, two indices can be computed, namely the areal coverage of deficit $A_d(i)$:

$$A_d(i) = \sum_{k=1}^{K} I[h(i,k)]A(k) \tag{4}$$

where:

$$I[h(i,k)] = 1 \quad if \quad h(i,k) < h_0\ (k)$$
$$I[h(i,k)] = 0 \quad if \quad h(i,k) \geq h_0\ (k)$$

and the areal deficit d(i) in the interval i:

$$\begin{aligned} d(i) &= \sum_{k=1}^{K} [h_0(k) - h(i,k)] \cdot I[h(i,k)]A(k) \quad &if \quad A_d(i) \geq A_{crit} \\ d(i) &= 0 \quad &if \quad A_d(i) < A_{crit} \end{aligned} \tag{5}$$

The $A_d(i)$ index is a measure of the area affected by deficit, expressed as a fraction of the total area, ranging between 0 and 1. The second index provides some insight on the total amount of the deficit in the area.

For each drought r, regional drought duration is defined as:

$$L(r) = i_f(r) - i_i(r) + 1 \tag{6}$$

where i_f and i_i are such that $d(i) > 0$ for $i_i(r) \leq i \leq i_f(r)$ and $d(i_i(r) - 1) = 0$, $d(i_f(r) + 1) = 0$.

The accumulated areal deficit is computed as:

$$D(r) = \sum_{i=i_i}^{i_f} d(i) \tag{7}$$

while the regional drought intensity is given by:

$$\mathrm{ID}(r) = \mathrm{D}(r)/\mathrm{L}(r) \tag{8}$$

Finally, the mean areal coverage of drought can be computed as:

$$AD(r) = \sum_{i=i_i}^{i_f} Ad(i)/L(r) \tag{9}$$

To perform this type of analysis, first stations to be considered for regional drought identification have to be selected (Fig. 13).

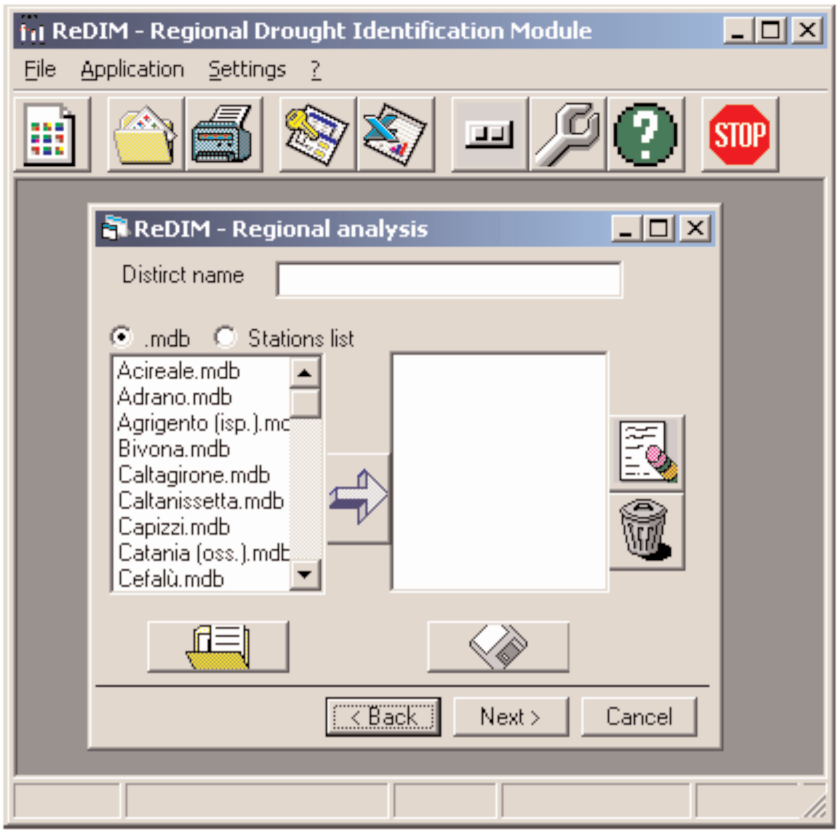


Fig. 13. Selection of stations for regional drought analysis.

By clicking Next, a dialog box appears prompting for the total area of the region of interest and for the influence areas of each station, expressed as a percentage of the total area. By clicking Next, the areas expressed in km^2 appear, as well as the common period of observation. The time span to be analyzed can be changed at this stage if needed. By clicking Next again, the dialog box in Fig. 14 appears.

Note that the user must provide the areal threshold expressed as a percentage of the total area. The option tab allows to select the threshold, the Statistics show the threshold values and the Selected Data allows to check that the analyzed data is correct. By clicking Next, the drought analysis results appear (Fig. 15).

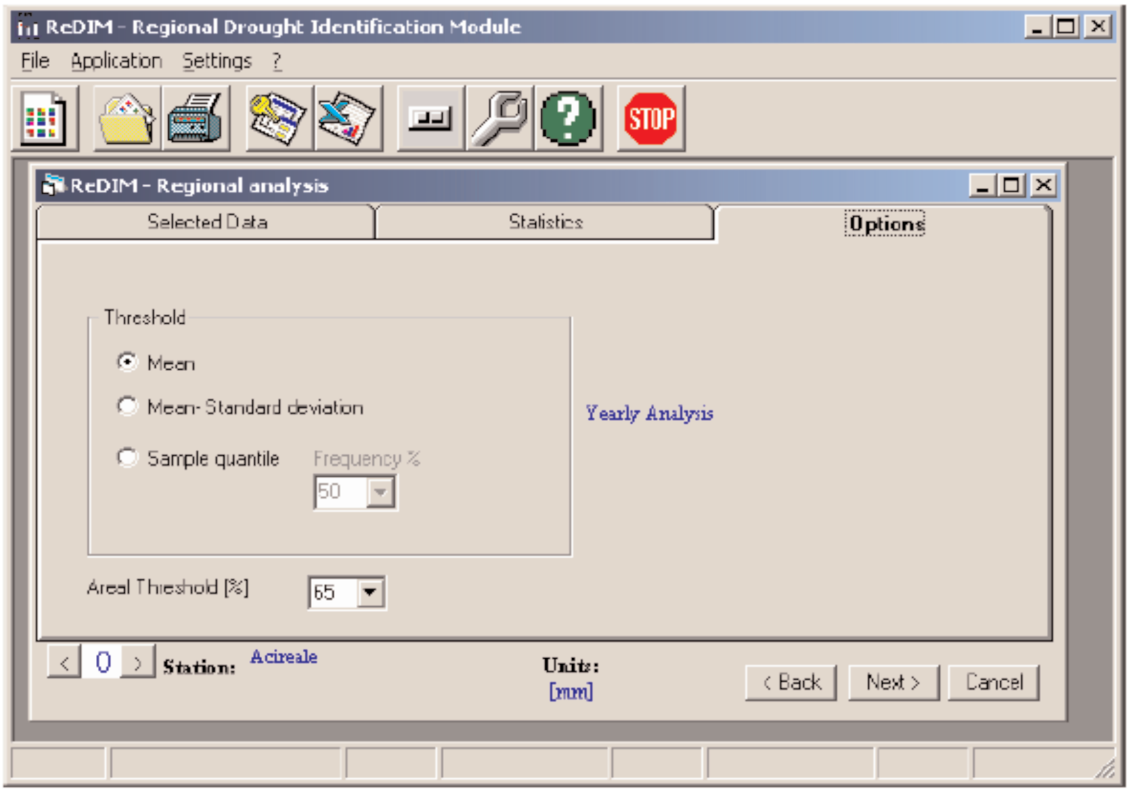
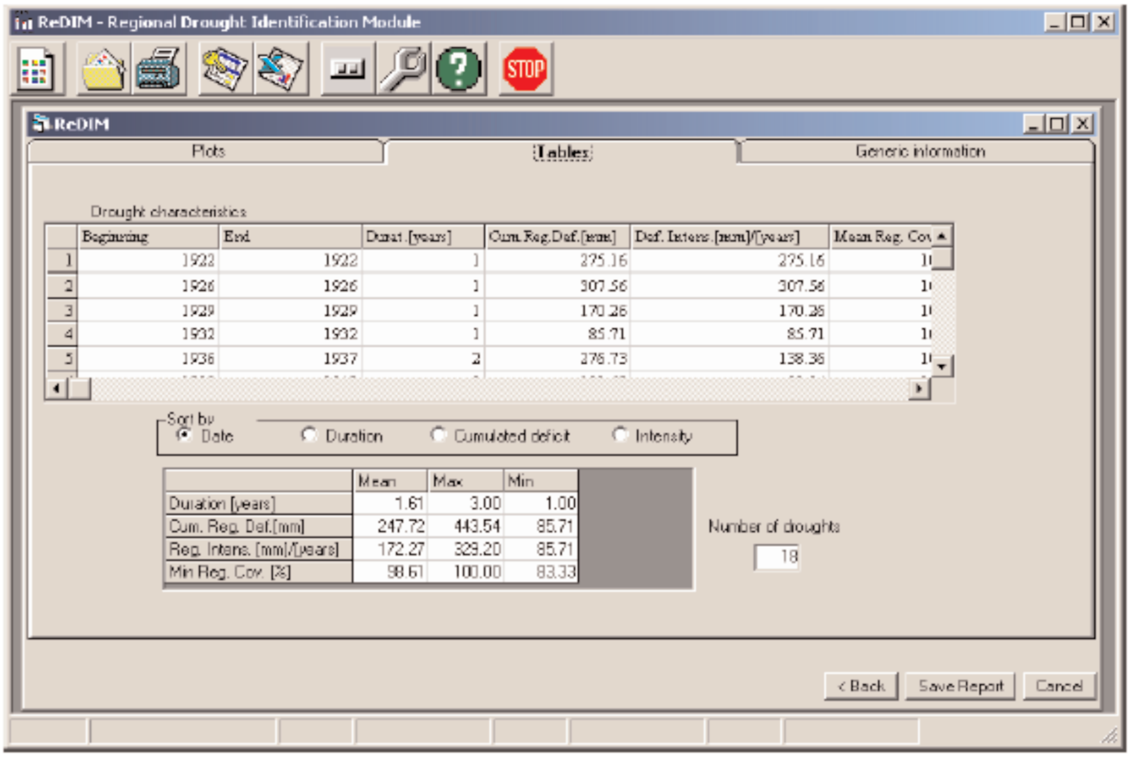


Fig. 14. Regional drought analysis options dialog box.



	Beginning	End	Durat. [years]	Cum. Reg. Def. [mm]	Def. Intens. [mm]/[years]
1	1922	1922	1	275.16	275.16
2	1926	1926	1	307.56	307.56
3	1929	1929	1	170.26	170.26
4	1932	1932	1	85.71	85.71
5	1936	1937	2	276.73	138.36

	Mean	Max	Min
Duration [years]	1.61	3.00	1.00
Cum. Reg. Def.[mm]	247.72	443.54	85.71
Reg. Intens. [mm]/[years]	172.27	329.20	85.71
Min Reg. Cov. [%]	98.61	100.00	83.33

Fig. 15. Regional drought analysis results.

The windows has three tabs. The tables tab (shown below) contains the number of identified droughts, a detailed list of their characteristics, as well as their mean, max and min values. The Plots tab shows the areal coverage and areal deficit plots. An example of such plots is reported in Fig. 16. The Generic Information tab contains plots of the thresholds and other information, such as the total number of periods and the extensions of the critical area.

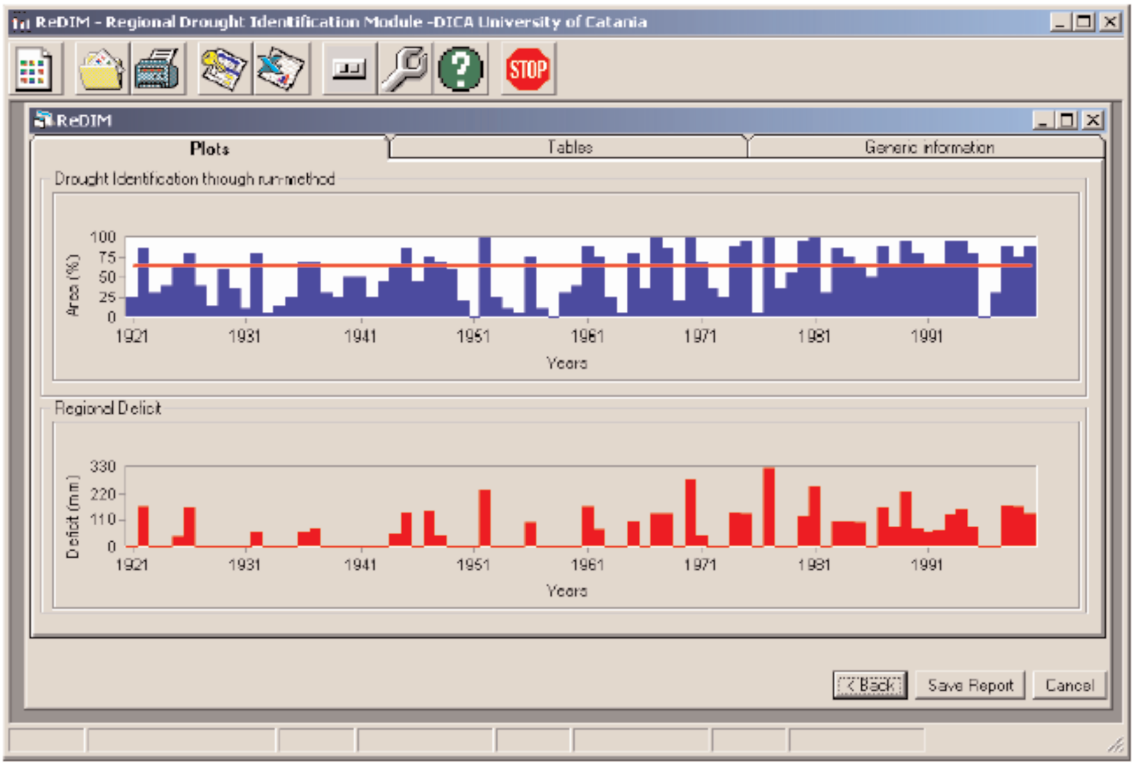


Fig. 16. Example of regional drought identification.

Regional drought identification through the SPI

A regional drought analysis can be carried out based on the SPI values computed for a given month *i* and a given aggregation time scale *k* at different sites. In particular, a similar approach adopted for the regional run method can be considered.

More specifically, once that the SPI series for a fixed aggregation time scale are computed at several sites, local drought conditions at each site *p* and at each month *i* can be identified if SPI (*i*, *k*) < SPI_{th}, where SPI_{th} is a fixed value of SPI considered as a threshold level for drought identification.

Drought conditions detected at each site *k* can be extended to influence areas S(*k*) (or polygons) around the stations, so that a drought areal coverage Ad(*i*) for each month *i* can be determined by summing polygons corresponding to the stations affected by drought according to the SPI values.

$$A_d(i) = \sum_{k=1}^{K} I[\mathrm{SPI}(i,k)]A(k) \quad (10)$$

where:

$$I[\mathrm{SPI}(i,k)] = 1 \quad if \quad \mathrm{SPI}(i,k) < \mathrm{SPI}_{th}$$
$$I[SPI(i,k)] = 0 \quad if \quad \mathrm{SPI}(i,k) \geq \mathrm{SPI}_{th}$$

Finally, the drought areal coverage $A_d(i)$ is compared to a fixed areal threshold A_{crit}, representing the value of the area above which a regional drought is considered to occur. If $A_d(i)$ is greater than or equal to A_{crit}, then a regional SPI series for the considered aggregation time scale, is computed based on the areal rainfall h_{areal}, obtained as the weighted rainfall mean with respect to the polygons of the stations under drought conditions. Further for each regional drought, the regional drought characteristics can be computed as in the case of the regional run method.

In REDIM, after selecting the stations and the corresponding influence area, the dialog box showed in Fig. 17 appears. This dialog box contains two tabs: the former contains the selected data, the latter the statistics of the selected data on a monthly scale. The last one contains also two combo-box for the selection of the areal and SPI thresholds for the identification of regional drought.

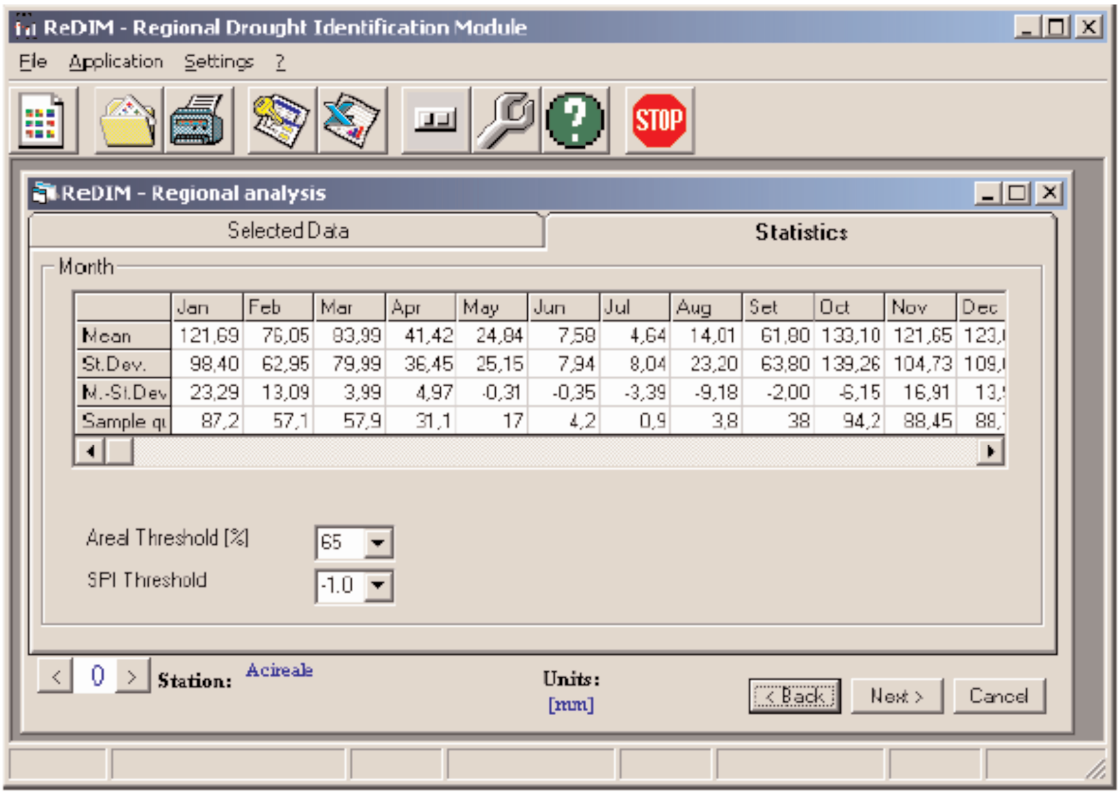


Fig. 17. Selected data, statistics and selection of threshold dialog box.

By clicking on the "Next" button the dialog box showed in Fig. 18 appears. Such dialog box contains five sub-dialog box which show the results of the analysis for five different aggregation scale. Each tab shows two tables. The former contains a detailed list of the drought period characteristics, the latter contains the mean, maximum and minimum values of duration, SPI index and the drought areal coverage. By changing the aggregation scale and clicking on the "Evaluate" button the analysis is repeated for the new aggregation scale.

By clicking on the "Plot" button the graphical representation of the SPI time series appears showing the areal coverage and SPI index evaluates obtained by taking into account the areal hydrological variable, computed on the basis of the sites for which the SPI values are below the fixed threshold. An example of such plots is reported in Fig. 19.

By clicking on the "Table" button the graphical representation of the SPI time series disappears and the table results appears again. By clicking on Save Report button, it is possible to save a report file for the selected aggregation time scales.

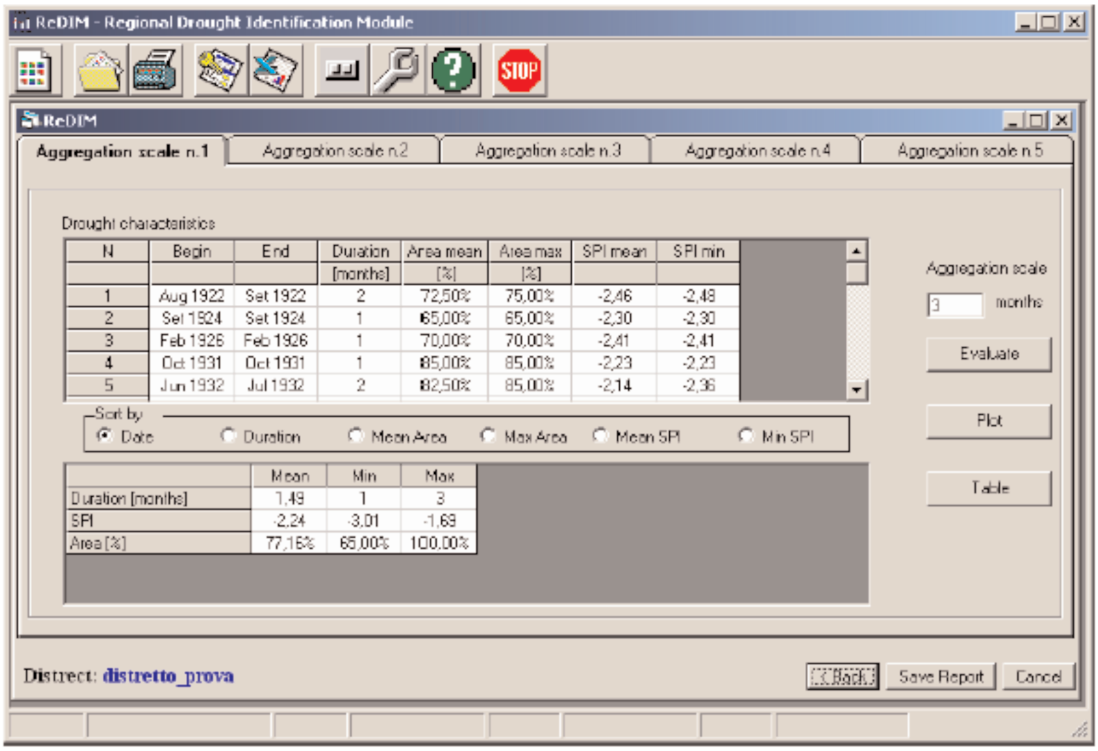


Fig. 18. Regional drought identification through SPI index.

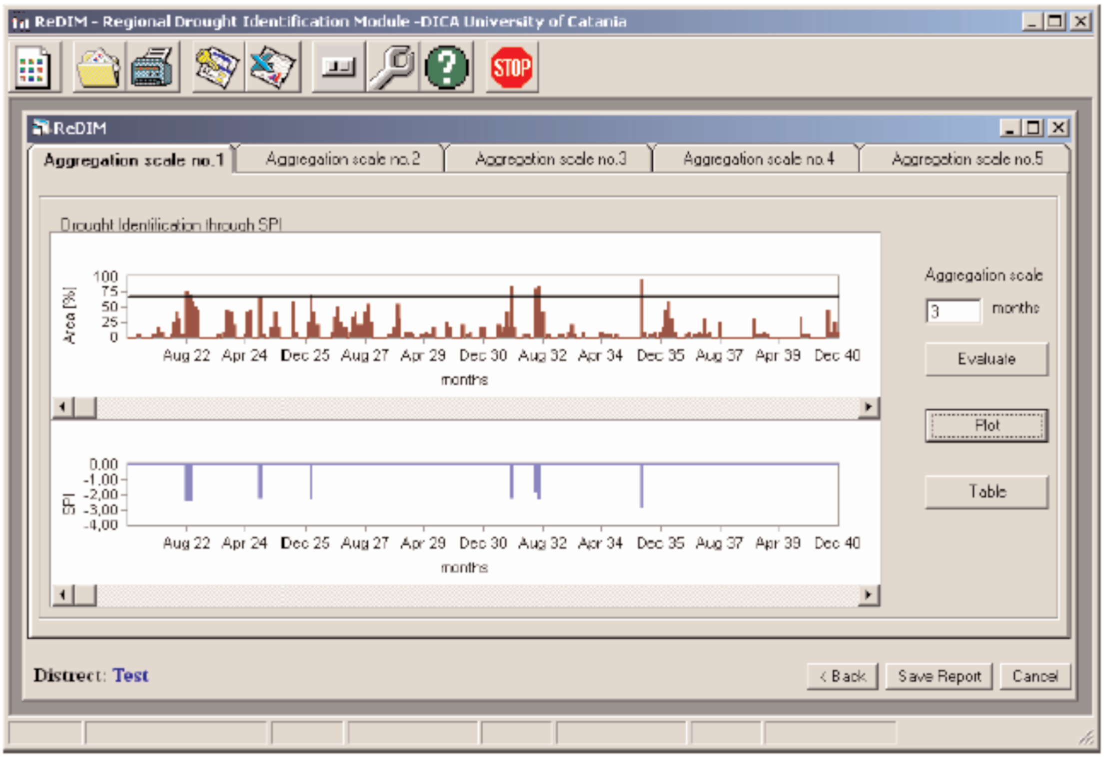


Fig. 19. Regional drought identification through SPI index – graphical results.

Simdro[2]

SIMDRO (SIMulation of water supply systems under DROught conditions) is a software package specifically oriented at simulating complex water supply system with particular reference to the the implementation of mitigation measures against drought impacts (Nicolosi, *et al.*, 2007a,b). Coupled with an appropriate data generation model it can be used to perform Montecarlo simulation of water supply systems providing statistically-based information about the system behaviour corresponding to different management policy in order to draft plans to cope with drought.

The SIMDRO 1.0.0 Italian release (the English version is in progress) has been developed by the Department of Civil and Environmental Engineering of the University of Catania (Fig. 20). The software package is written in Visual Basic and runs under Windows platforms. Use of the software is simplified through a succession of dialog boxes which guide the user throughout the description of the water supply system network, the representation of activation process of planned mitigation measures against drought effects and the analysis of the results of the simulations.

Fig. 20. SIMDRO 1.0.0 Introductory window.

SIMDRO simulates a water supply system through a node-link network, where sources (reservoirs, diversions) and demands (municipal, irrigation, industrial,…) are represented by nodes whereas system connections (rivers, channels, pipes,…) are represented by links characterized by origin node (source) and final node (source or demand).

The system configuration is defined specifying in appropriate windows (varying on the specific features of the type of node/link represented) all the peculiar characteristics both of nodes and links.

Simulation of the system is carried out at a monthly timescale respecting for each reservoir the following mass-balance equation:

$$V_{t+1} = V_t + I_t - E_t - R_t - Sf_t \pm Tr_t$$

Where

– t is the current step defined as [$t = \tau + 12^* (\nu - 1)$] with $1 \leq \tau \leq 12$ month of the *n* year;

– V_t is the stored volume at the beginning of the month t;

2. The SIMDRO software has been developed by A. Cancelliere, G. Rossi, N. Nicolosi and G. Cristaudo (Department of Civil and Environmental Engineering, University of Catania).

– I_t is the net streamflow to the reservoir at month t;

– E_t is the evaporation at month t;

– R_t is the release at month t;

– Sf_t is the spill at month t occurring when volume V_{t+1} is greater than the maximum capacity of reservoir;

– Tr_t is the transfer between two sources at month t.

In addition the constraints, such as minimum and maximum storages, are implemented.

Net streamflow to reservoirs is computed as the difference between regulated inflows and a priori defined in-stream ecological releases.

Monthly evaporation losses are computed considering monthly evaporation heights times an average area function of the areas obtained by the storage-area relationship for the beginning and the end of the current timestep. Due to the fact that stored volume at the end of the timestep is unknown an iterative procedure till convergence is carried out.

As an example in Fig. 21 the window to define the characteristic of a node representing a reservoir is depicted. Reservoir characteristics are defined in terms of maximum storage capacity, dead storage and initial stored volume. Coefficients of storage-area relationships (assuming a relationship of the type $A = a + bV + cV^2$ with A = area and V = storage) and monthly evaporations have to be defined as well.

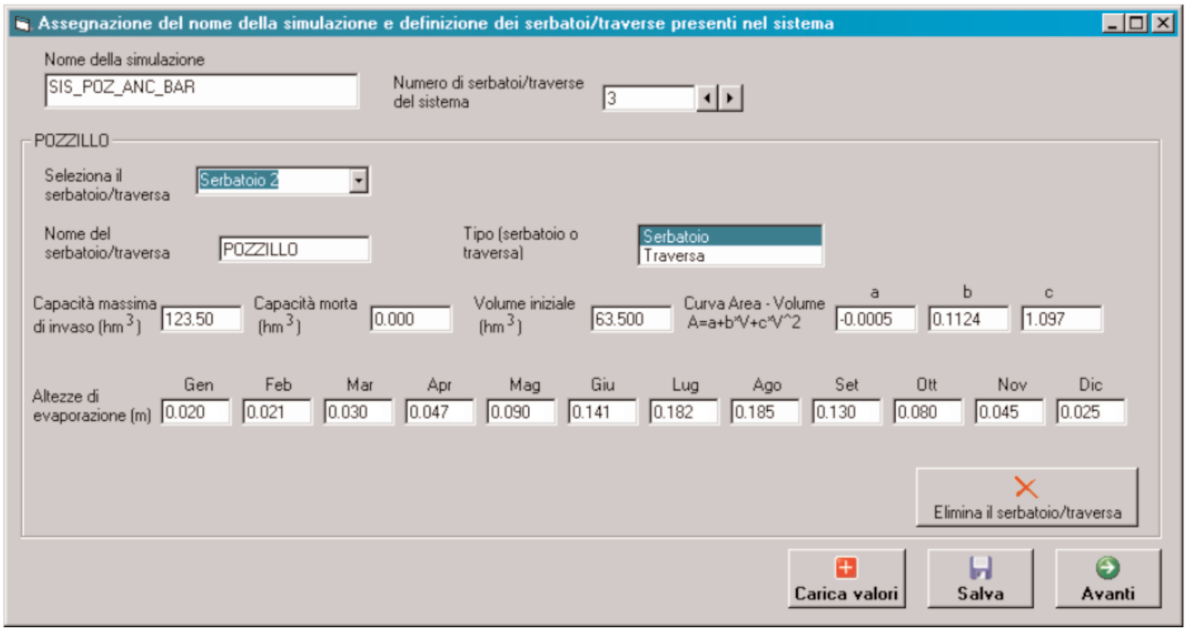


Fig. 21. Definition of the characteristics of a node representing a reservoir (source).

For nodes representing diversions it is possible to define a minimum volume that can be diverted and monthly utilization coefficients in order to take into account the effective water availability at the diversion in relation to its technical features (Fig. 22). Once demand node have been defined it is possible to implement the water supply system network linking the several nodes defining the link typology through the window shown in Fig. 23.

One of the most important features of SIMDRO is that it is able to simulate different management configurations of the system to which correspond different possible drought mitigation measures defined by the user, according to different hydrological conditions or states.

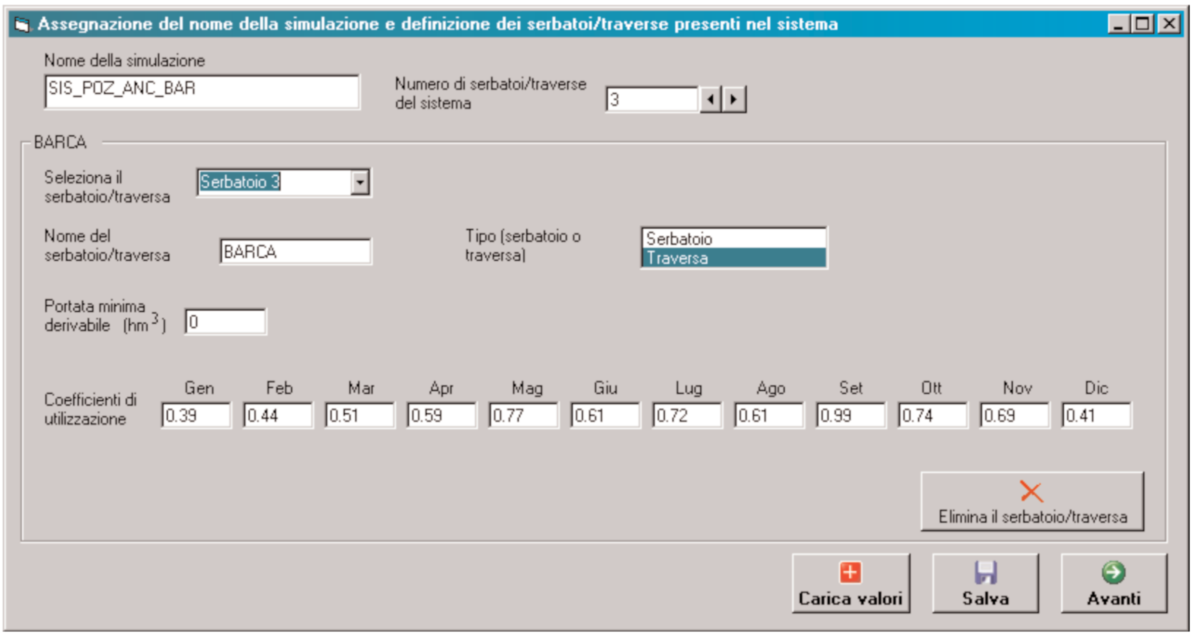


Fig. 22. Definition of the characteristics of a node representing a diversion (source).

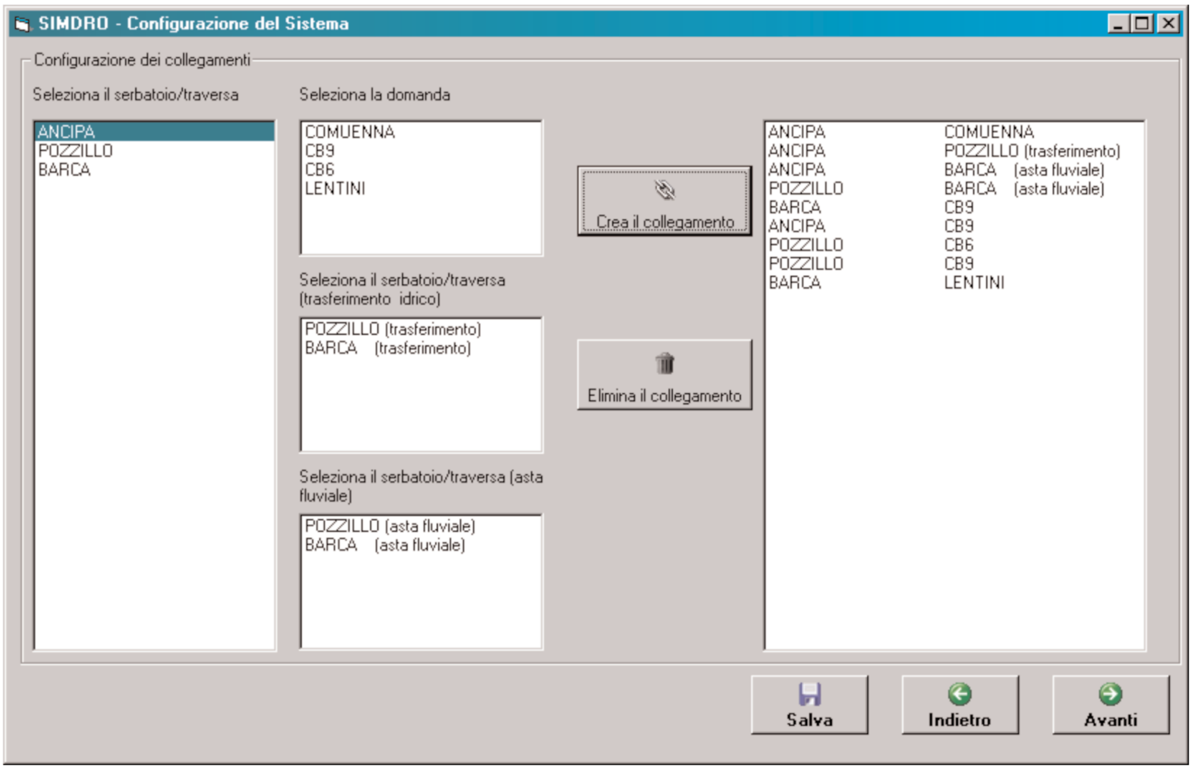


Fig. 23. Building the water supply system network.

The hydrological state of the system is defined at each time step by comparing water availability at selected reservoirs and/or diversions, with predefined levels. Current release of SIMDRO considers three different hydrological states namely *normal*, *alert* and *alarm*. Accordingly, different drought mitigation measures are triggered corresponding to each hydrological state (Fig. 24).

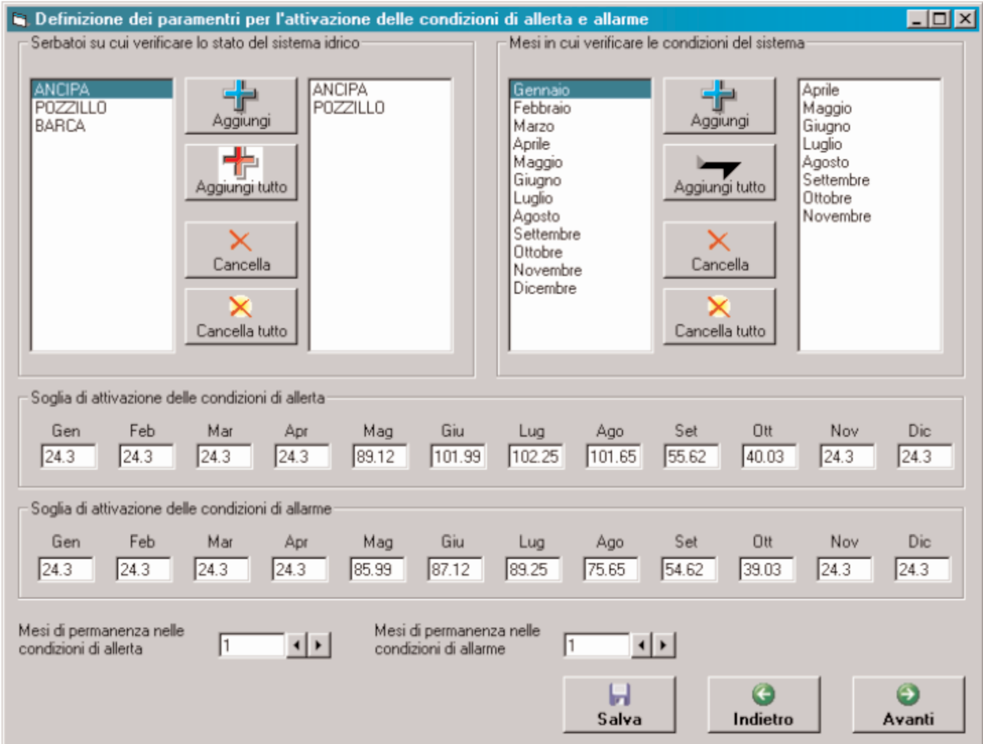


Fig. 24. Definition of the monthly thresholds to trigger alert and alarm condition to which correspond different mitigation measures.

Thus, for instance, if in a given month water availability is less than the trigger defined for the hydrological state characterized by normal conditions the system will switch from normal condition to alert conditions, implementing the corresponding drought mitigation measures. The measures can consist in release hedging, release reduction to the water demand reduction levels for each type of demand, fulfilment of municipal demand before other uses, etc.

The system will remain in alert or alarm conditions for a period of time defined by the user; at the end of this pre-defined period SIMDRO will re-check the hydrological state of the system switching to different states if it is the case.

The different management configurations, to which correspond the different drought mitigation measures in alert or alarm conditions are listed below:

(i) priority of demands;

(ii) priority of sources to meet a specified demand;

(iii) maximum release in a given month;

(iv) maximum in stream ecological release for a given month;

(v) minimum stored volume on reservoirs under which not consider low priority demands;

(vi) demands and their monthly distribution.

As an example Fig. 25 shows the definition of the management configuration of the system for normal conditions; similar windows have to be filled by the user in order to represent the mitigation measures to be implemented in alert or alarm conditions.

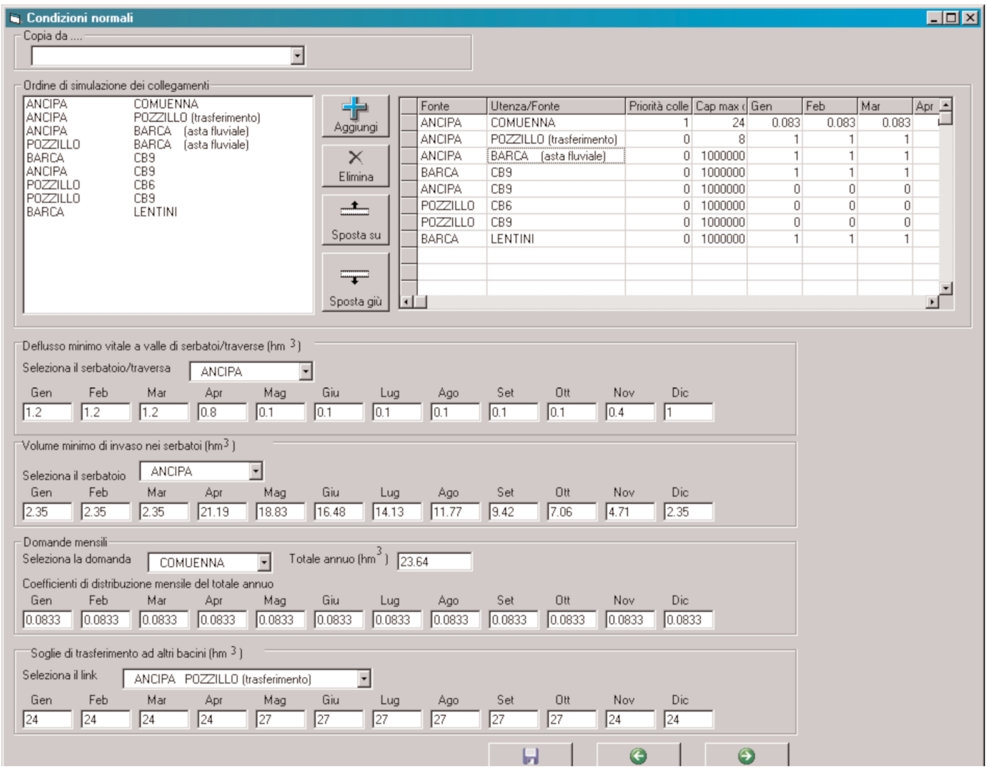


Fig. 25. Definition of the simulation of the system for normal conditions.

Results of the simulations can be represented in tabular or graphic form and some elaborations such as the probability of shortages belonging to different classes (0-25%, >25%-<50%, >50%-<75%, >75%-100%) expressed as percentage of the total demand for the different uses (Fig. 26) or the non-exceedence probability of monthly shortages (Fig. 27) are available. An examples of application of SIMDRO for the analysis of a complex water supply system is reported in the Chapter "Methods for risk assessment in water supply systems" of this document.

Calculation of Drought Indices - DrinC Software

For the calculation of three drought indices, the SPI, the Deciles and the RDI, the new software *DrinC – Drought Indices Calculator*, was developed at the Laboratory of Reclamation Works and Water Resources Management of the National Technical University of Athens. *DrinC* is a stand-alone PC software and operates on Windows platforms (Fig. 28).

The input data are the annual or monthly precipitation for the calculation of Deciles and SPI, while potential evapotranspiration (PET) data are also required for the calculation of RDI.

In order to improve the interface of the software the input and output files are in MS Excel worksheet format. The data files are selected in the File Management window (Fig. 29). For the calculation of the indices in annual basis, data may be either annual or monthly, while for calculations in seasonal basis (monthly, 3-months, 6-months), monthly data are required. The software includes an algorithm in order to recognize automatically the position of the data and to ignore other information included in the file.

The calculation of the indices is performed from the Indices window (Fig. 30). Each index (or all indices at once) will be calculated by ticking in the relevant boxes. The outputs may be saved either in separate files, or in the same file for all the indices. For each index there are different output options. For the Deciles each decile threshold may be displayed in the output file, whereas for the RDI, each one of the different forms of the index can be selected for output. Four time steps are available for calculation: monthly, 3-months, 6-months and annual.

For more information about DrinC the reader can refer to the website *www.ewra.net/medbasin/DrinC.html.*

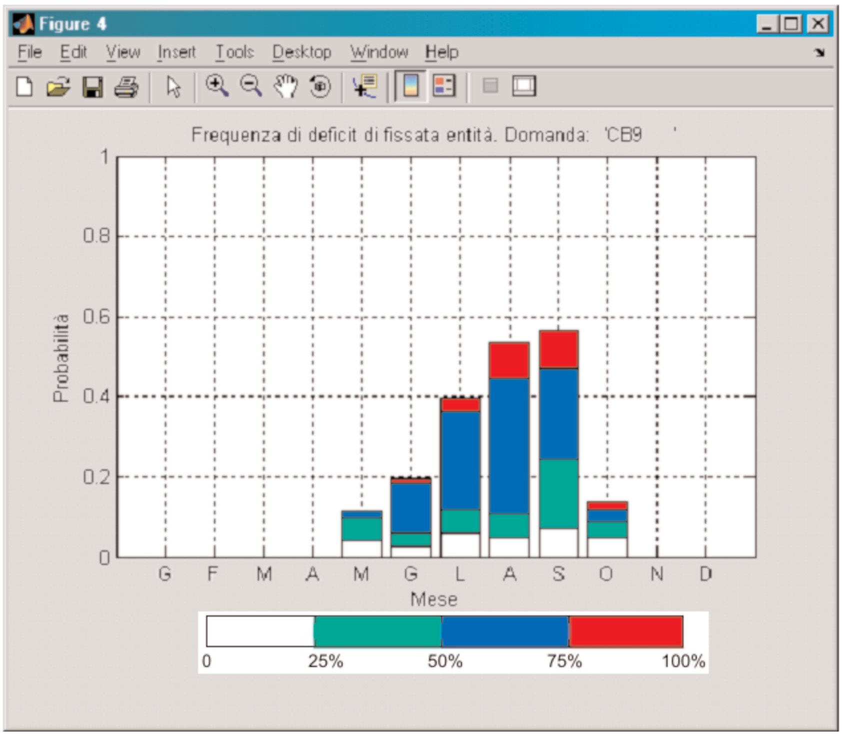


Fig. 26. Probability of shortages belonging to different classes expressed as percentage of the total demand.

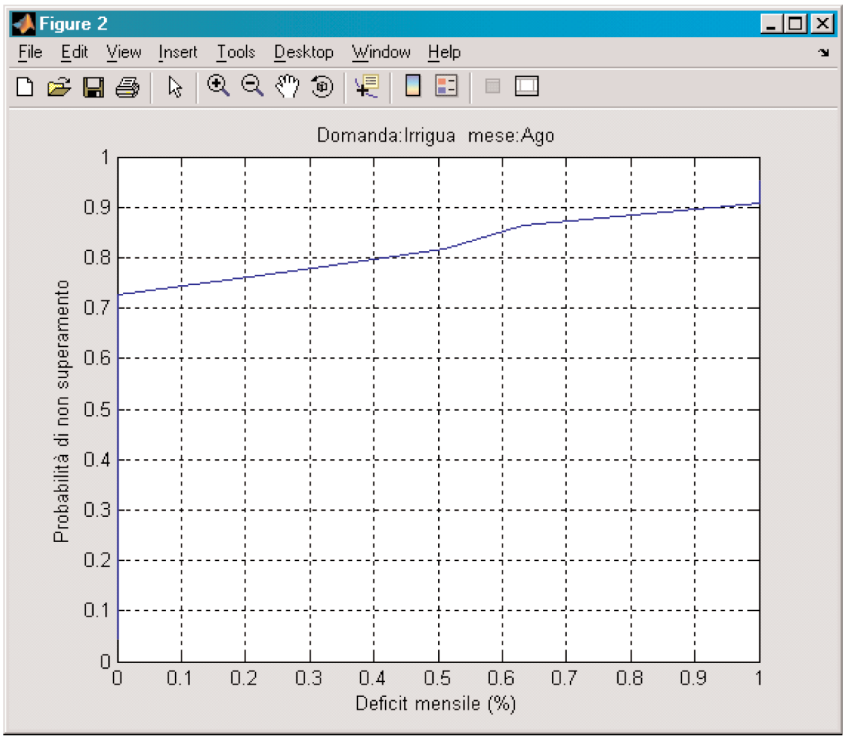


Fig. 27. Non-exceedence probability of monthly shortages.

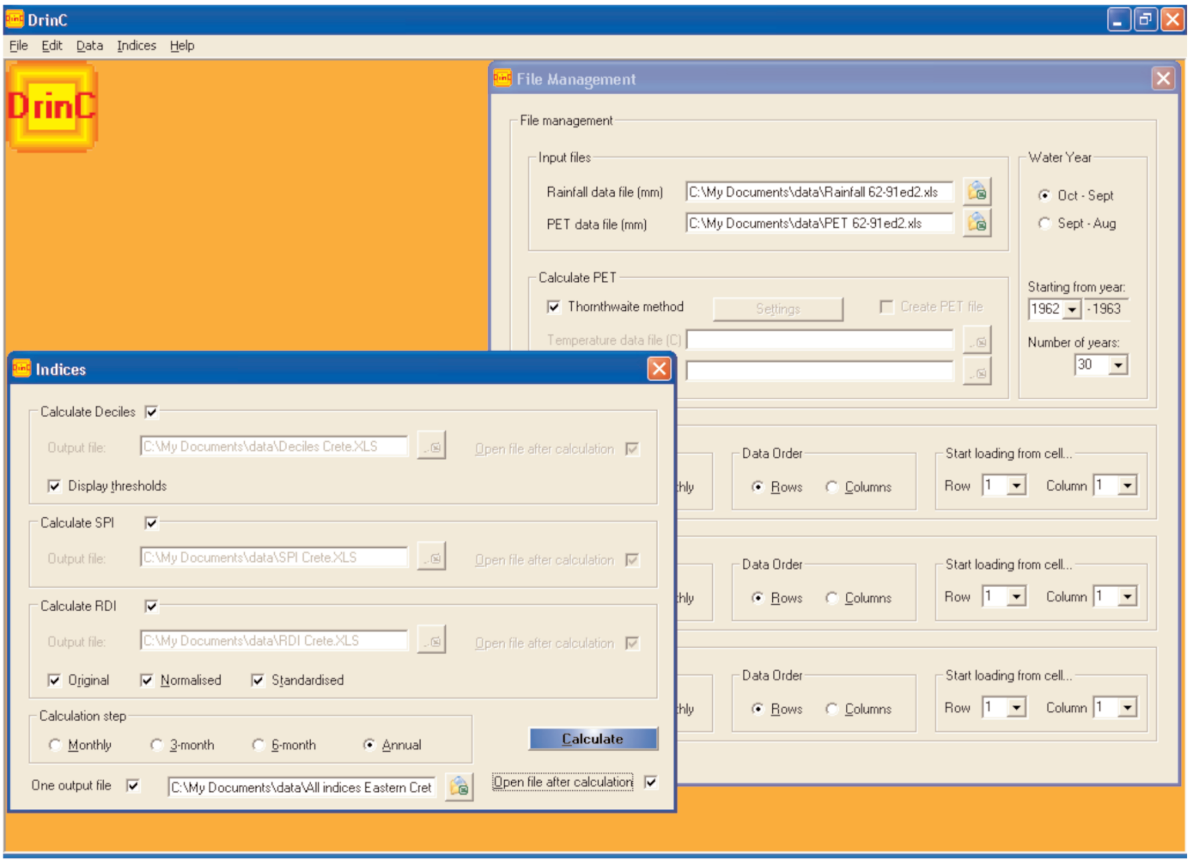


Fig. 28. Main window of DrinC software.

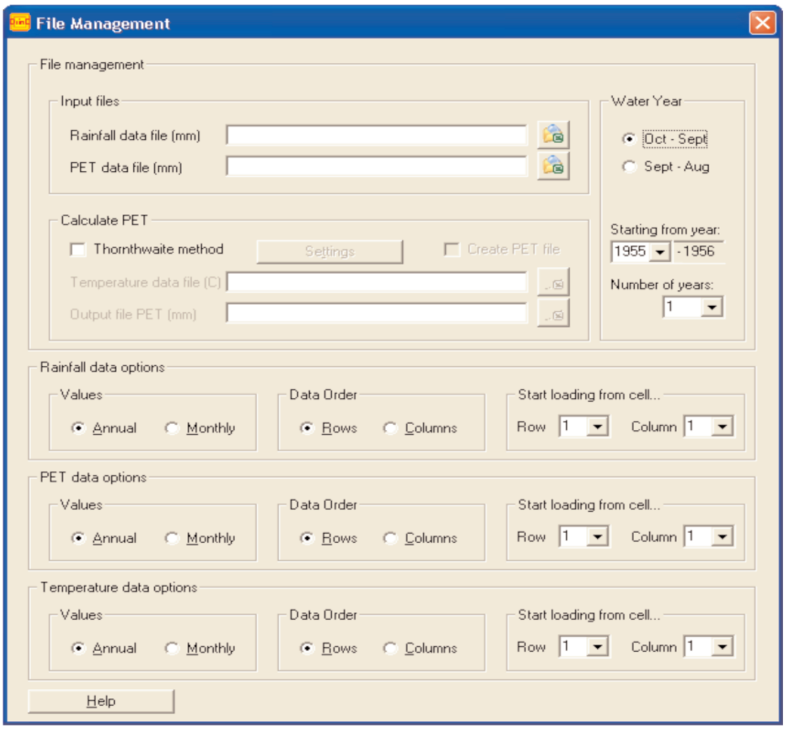


Fig. 29. File management window.

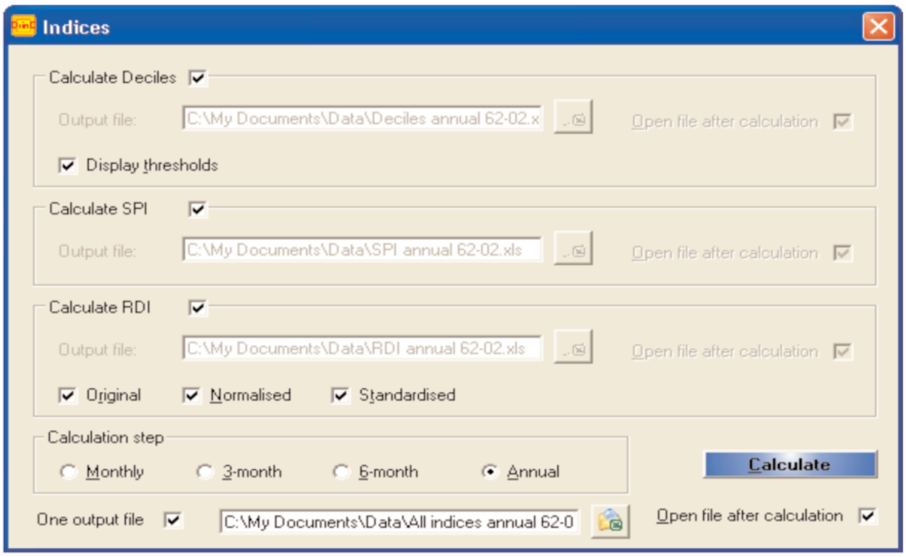


Fig. 30. Indices calculation window.

WEAP

The Water Evaluation and Planning model Version 21 (WEAP21) attempts to address the gap between water management and watershed hydrology and the requirements of an effective integrated water resources management that can be useful, easy to use, affordable, and readily available to the broad water resource community.

WEAP 21 presents a user-friendly, geographically based interface helping the user to understand the hydrological system of the basin. A conceptual model of the hydrologic cycle is defined for each sub-catchment using a semi-distributed water balance approach that yields streamflow and groundwater recharge throughout the watershed (Yates, 1996; Yates and Strzepek, 1998). It operates at a monthly step on the basic principle of water balance accounting. The user represents the system in terms of its various sources of supply (e.g. rivers, groundwater, and reservoirs), withdrawals, water demands, and ecosystem requirements (Fig. 31).

WEAP applications generally involve the following steps (SEI, 2001):

(i) Problem definition including time frame, spatial boundary, system components and configuration.

(ii) Establishing the current accounts', description of the average situation that provides a snapshot of actual water demand, resources and supplies for the system.

(iii) Building scenarios based on different sets of future trends for policies, technological development, and other factors that affect demand, supply and hydrology.

(iv) Evaluating the scenarios with regard to criteria such as adequacy of water resources, demand satisfaction, costs, benefits and environmental impacts.

This model has a long history of development and use in the water planning arena and presents several advantages that make it a very useful tool in water management:

(i) It uses a Water balance database: provides a system for maintaining water demand and supply information.

(ii) It has scenario generation tools: simulates water demand, supply, runoff, streamflows, storage, pollution generation, treatment and discharge.

(iii) It can apply Policy analysis tools: evaluates a full range of water development and management options, and takes account of multiple and competing uses of water systems.

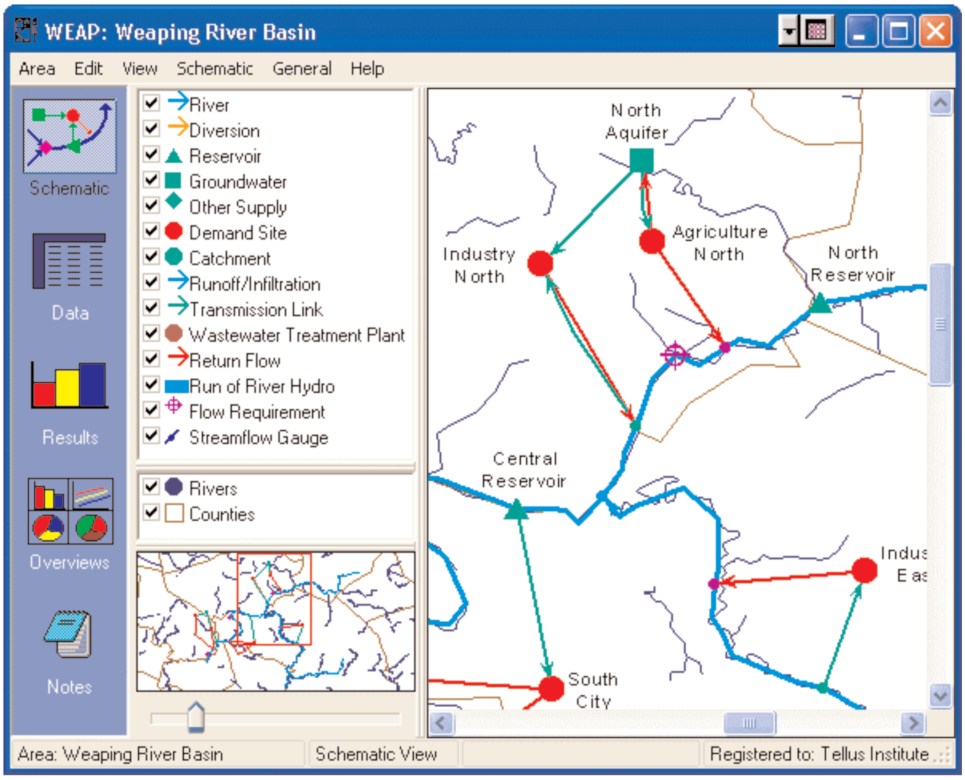


Fig. 31. Schematic view of WEAP.

The scenarios can address a broad range of "what if" questions, such as: What if population growth and economic development patterns change? What if ecosystem requirements are tightened? What if irrigation techniques and crop patterns are altered? What if various demand management strategies are implemented? What if water availability changes? What if drought frequency increases?

An intuitive graphical interface provides a simple yet powerful means for constructing, viewing and modifying the system and its data. The main functions –loading data, calculating and reviewing results– are handled through an interactive screen structure. WEAP also has the flexibility to accommodate the evolving needs of the user: e.g. availability of better information, changes in policy, changes in demand priorities, planning requirements or local constraints and conditions (Levité *et al.*, 2003).

WEAP21 model simulations are constructed as a set of scenarios, where simulation time steps can be as short as one day, to weekly, to monthly, or even seasonally with a time horizon from as short as a single year to more than 100 years. The use of this kind of model is especially relevant for evaluating the consequences of drought management on the hydrological system and the changes in demand satisfaction. The different drought management actions can be applied in order to evaluate the results over the hydrological system and propose an optimal combination through simulations.

Agricultural models

In the context of drought risk analysis in agricultural systems, the use of agricultural models can be useful for several reasons:

(i) Evaluate changes in water demand for the different crops, regions and meteorological conditions.

(ii) Evaluate changes in leached water quality due to the variations in water availability.

(iii) Evaluate the adaptation of different crop varieties to drought.

(iv) Evaluate the consequences of changes in irrigation periods as a measure for drought adaptation.

The methods for assessing crop production in different meteorological conditions and adaptation strategies are extensively developed and used widely by scientists, extension services, commercial farmers, and resource managers.

There is a number of different approaches to assess the impacts of climate on agriculture and many studies have been developed to date. Approaches used to assess biophysical impacts include:

(i) Agroclimatic indices and geographic information systems (GIS).

(ii) Statistical models and yield functions.

(iii) Process-based models.

Process-based models use simplified functions to express the interactions between crop growth and the major environmental factors that affect crops (i.e., climate, soils, and management), and many have been used in climate impact assessments. Most were developed as tools in agricultural management, particularly for providing information on the optimal amounts of input (such as fertilizers, pesticides, and irrigation) and their optimal timing. Dynamic crop models are now available for most of the major crops. In each case, the aim is to predict the response of a given crop to specific climate, soil, and management factors governing production. Crop models have been used extensively to represent stakeholders management options (Rosenzweig and Iglesias, 1998).

The ICASA/IBSNAT dynamic crop growth models (International Consortium for Application of Systems Approaches to Agriculture – International Benchmark Sites Network for Agrotechnology Transfer) are structured as a decision support system to facilitate simulations of crop responses to management (DSSAT – Decision Support Tool for Agrotechnology Transfer). The ICASA/IBSNAT models have been used widely for evaluating climate impacts in agriculture at different levels ranging from individual sites to wide geographic areas (see Rosenzweig and Iglesias, 1994, 1998, for a full description of the method). This type of model structure is particularly useful in evaluating the adaptation of agricultural management to climate change or extreme weather events.

The DSSAT models use simplified functions to predict the growth of crops as influenced by the major factors that affect yields, i.e., genetics, climate (daily solar radiation, maximum and minimum temperatures, and precipitation), soils, and management. Models are available for many crops; these have been validated over a wide range of environments and are not specific to any particular location or soil type. Modeled processes include phenological development, growth of vegetative and reproductive plant parts, extension growth of leaves and stems, senescence of leaves, biomass production and partitioning among plant parts, and root system dynamics. The models include subroutines to simulate the soil and crop water balance and the nitrogen balance.

The primary variable influencing each phase of plant development is temperature. Potential dry matter production is a function of intercepted radiation; the interception by the canopy is determined by leaf area. The dry matter allocation to different parts of the plant (grain, leaves, stem, roots, etc.) is determined by phenological stage and degree of water stress. Final grain yield is the product of plant population, kernels per plant, and kernel weight. To account for the effect of elevated carbon dioxide on stomatal closure and increased leaf area index, a ratio of transpiration under elevated CO_2 conditions to that under ambient conditions is added.

The DSSAT software includes all ICASA/IBSNAT models with an interface that allows output analysis (Fig. 32).

Crop models are assisting tools for assessing the vulnerability and adaptation to climate variability: the stakeholder participation is essential. A mandatory first step is that technical stakeholders need assemble field agricultural data for calibration and validation of the crop models. Subsequently, regional stakeholders evaluate the representativeness of the agricultural model results for spatial upscalling of the model results. Table 2 summarizes some of the essential data needed as input for the model and the potential sources for these data.

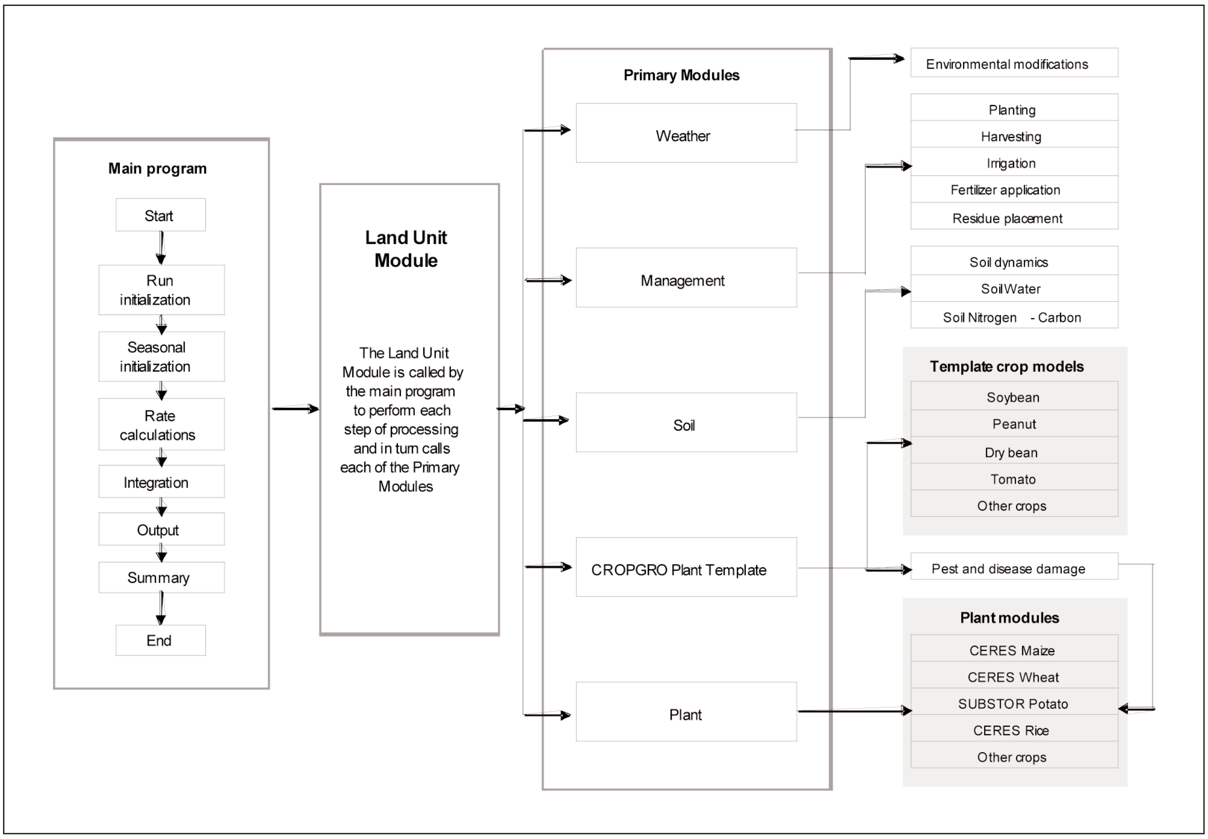


Fig. 32. Structure of models included in DSSAT.

Table 2. Input data for DSSAT and potential sources

Type of data	Requirements	Source of data
Average climatic conditions	Daily maximum and minimum temperatures and solar radiation for at least a 20-year period	National meteorological or research institutions. Daily data simulated from monthly averages.
Modified conditions (drought event conditions)	Modified daily maximum and minimum temperatures, precipitation, and solar radiation for a period of drought	National meteorological or research institutions
Crop management	Crop variety, sowing date and density, fertilizer and irrigation inputs (dates and amounts)	Agricultural research institutions
Soils	Soil albedo and drainage, and a description of the different layers of the soil profile (texture, water holding capacity, organic matter, and nitrogen)	Agricultural or hydrological research institutions
Economics (optional)	Cost of labor and price of unit production	Agricultural statistics
Outputs: Variables included in the summary output file are the main phenological events, yield and yield components		

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Chapter 12. Process for implementing drought management actions

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SUMMARY – The implementation of actions is a major task in the operational component of drought management. The purpose is to provide planners with a framework for effective and systematic approach to develop strategies that respond to the drought risk situation, the objectives of water and land management and water right priorities, and the stakeholder needs. Although this component has been developed in the context of Mediterranean countries, it exemplifies many other situations with limited water supplies and conflicting users. The approach emphasizes risk-based drought management as a critical approach to mitigate the impacts associated to drought-induced water shortages. The operational process links science and policy and can be applied to other regions different from The Mediterranean.

Key words:

Introduction

In recent years there has been a great effort to integrate drought management into the long-term strategies for water management and development (UNISDR, 2006). The effective management plans are the ones that include a major component of monitoring and early warning systems (Wilhite, 1997; 2005) since this decreases the vulnerability of exposed systems and populations in a significant way (Wisner *et al.*, 2004). The development of specific drought management plans is at early stage in most countries; this chapter offers a guide to complement the ongoing efforts.

Permanent planning and planning during drought

The operational component of the Drought Management Guidelines defines strategies to adopt drought management actions. This includes both the long and short term activities and actions that can be implemented to prevent and mitigate drought impacts. This chapter describes the process for implementing the actions and Chapter 13 of this publication describes the actions.

The operational component includes permanent planning and planning during a drought event (Fig. 1). Monitoring and preparedness planning is the first essential step for moving from crisis to risk management in response to drought, and can be viewed as permanent measures to cope with drought events. The management actions related to agriculture and water supply systems are presented together with a common conceptual framework based on the use of drought indicators for evaluating the levels of drought risk (pre-alert, alert, and emergency), that allow establishing linkages between science and policy. The rationale is that the actions relevant to all sector are derived based in common institutional organization, legal framework, and are implemented by a unique decision making structure (defined in the organizational component of the Guidelines).

Preparedness, early warning, monitoring systems

Preparedness and early warning are the key factors for later operational management and determine the success of the overall drought management plan since they help to: (i) establish the drought plan; (ii) reduce social vulnerability; (iii) identify alert mechanisms; and (iv) establish the links between drought and water and development policies. Preparedness is the main process that encloses all subsequent tasks to be carried out during normal conditions and during drought periods.

Scientific advancements in seasonal to inter-annual climate forecast and monitoring systems offer the possibility for making the early warning systems effective in many regions, especially where the data and information systems are in place.

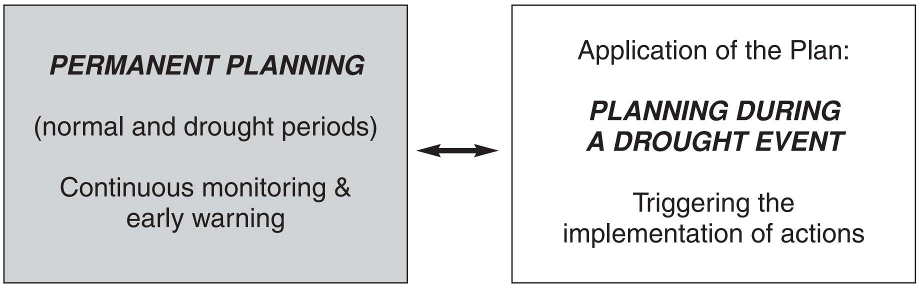

Fig. 1. Summary of the aspects of the preparedness and implementation aspects of the operational component.

Advances in weather forecasts in the Mediterranean

The climate context for the region is one of very strong variability requiring careful management, together with a limited amount of seasonal forecast skill. Nevertheless research does suggest that sea-surface temperature forcing does yield some seasonal forecast skill for part of the rainy season, especially in the western region where the latter part of the rainy season (March-April) is correlated with the El Niño / Southern Oscillation (Rodo *et al.,* 1997, Ward *et al*., 1999; Bolle, 2002). This provides specific opportunities for incorporation of forecast information into water management strategies, especially related to irrigation. The North Atlantic Oscillation (NAO) exerts a strong control on rainfall in the region, especially through boreal winter (Lamb and Peppler, 1987, Rodo, *et al.,* 1997). Generally, there is considered to be little predictability in the NAO, though a repeating signal in NAO evolution from about August to the following March has been noted and offers prospect for some anticipation of NAO evolution (Lamb *et al.,* 1997). In addition to these small prediction signals, the very large interannual and decadal climate variability that is now known to exist in the region itself requires careful evaluation in the context of current methods and temporal scales for communicating risk to resource managers. The appropriate adoption of mechanisms of communicating climate information and sectoral risk should permit regional planners to reduce the devastating effects of drought and the uncertain effects of climate and weather in the more favourable seasons.

Major advances in understanding the Mediterranean climate have been made in recent years. Atmospheric scientists can now predict some of the medium-term (one or two seasons ahead) features of our climate with a reasonable level of skill. This provides specific opportunities for incorporation of forecast information into water management strategies, especially related to irrigation. Several regional studies are looking at the benefits of climate information and seasonal climate forecasts for different farm types and cropping systems in both northern and southern Mediterranean countries (Iglesias *et al*., 2002). The work focuses on improving timing of production and efficiency of irrigation water use. The regional studies focus on optimising traditional production systems since they are the current basis of agricultural production in the Mediterranean, but the research also has benefits for large-scale commercial systems.

Integrated monitoring systems

The effective response to drought events relies on having a monitoring system able to provide adequate and timely information for an objective drought declaration and for avoiding severe water shortages through effective water resource management under drought conditions (Rossi, 2003). The goal is to incorporate the information about climate, soil, water supply, and potential yields in the monitoring system. Information should be in the public domain, sufficient to gauge the level of risk and make informed decisions about the future.

The appropriate adoption of mechanisms of communicating climate information and sectoral risk should permit regional planners to reduce the devastating effects of drought and the uncertain effects of climate and weather in the more favourable seasons. Integrated climate monitoring is an important element of adaptation strategies.

The main objective of a monitoring system is to help decision-makers identify the drought warning conditions and to provide useful information for identifying the best drought mitigation measures on the basis of a continuous monitoring of the drought evolution in terms of meteorological and hydrological variables and water resource availability.

A common feature of these systems is the particular emphasis generally given to the graphical representation of the results in order to foster an immediate and easy assessment of the drought severity and its evolution. Access to information is ensured through public web sites aiming to reach as many users as possible in addition to the public institutions.

Drought monitoring systems in operation are increasing, as their importance becomes essential and recognized at the institutional level. In recent years the information technology that simplifies the collection, elaboration and dissemination of hydrometeorological and agricultural data is widespread. These effective preparedness is based upon the deep knowledge of the processes that make the climatic system work and the statistical analysis of the past. Predictions, therefore, give "probabilities" of happening for a precise event, but at the moment they are still not infallible. An effective way of presenting the drought early warning is by maps, which show the variations in probability of drought events of a given level of severity (e.g., the probability of a 50 per cent reduction in annual rainfall). Several national and international efforts are currently underway to incorporate drought monitoring and prediction into early warning systems. Some examples of well established efforts include the National Drought Mitigation Center in USA, the Early Warning Systems for Agriculture from the Australian Bureau of Meteorology, agro-meteorological analysis by the Joint Research Centre of the European Commission, the Famine Early Warning System initiative of the US Agency for International Development, and the South African Weather Bureau. In Mediterranean countries, the National Drought Observatory of Morocco has been recently established to provide the agricultural community with a product easily interpreted by local stakeholders.

If drought indices are adequately calibrated to represent local features of the water resources system of the basin, they can be used as auxiliary tools for drought monitoring and forecasting. Droughts are slowly-evolving phenomena, and one of the most difficult tasks is identifying the beginning (or the end) of a drought. Drought effects are usually delayed in time, and once the economic or social impacts begin to be perceived it is usually too late to adopt mitigation measures. Systematic computation of drought indices, together with a thorough statistical analysis of historical droughts can be used effectively to identify the onset of drought and to make probabilistic forecasts about its magnitude, intensity or duration. For instance, drought onset can be identified using threshold values for a given drought index, according to historical information. Once the drought is started, the knowledge of the statistical properties of drought can be used to estimate the probability that the drought will reach a given magnitude or that the drought will last a given span of time.

Since drought index computation requires the ready availability of many meteorological and hydrological data, in certain real time and early warning systems it is better to use just a few representative variables to monitor drought occurrence and development. A statistical analysis can be performed on drought indices and raw hydrological variables to identify just a few key values that can explain most of the variance of the drought index time series.

Establishing priorities for water use

Planning for droughts tends not to receive priority attention of decision and policy makers because drought has diverse impacts. The slow initiation and undefined end of a drought makes it difficult to select the opportunity to take defensive or remedial action. The measures are generally organized to protect water uses with different levels of priority. In all cases the first priority is to ensure adequate supplies of domestic water are available for public health, safety and welfare. The second priority is to minimize adverse drought effects on the economy, environment, and social well-being. The other priorities for water use depend on the water system can be established by stakeholders through a participative consultation process. In most cases conflicts arise when establishing priorities. The methodologies for stakeholder dialogue and conflict resolution are developed in more detail in Chapters 5 and 6 respectively.

Defining the conditions and thresholds to declare drought levels

Key issue: Drought declaration

The formal declaration of drought is both a controversial and an important issue. Most public institutions approach formal declaration with caution, and is only taken when a water shortage situation is of extreme magnitude, therefore in many cases, only emergency actions are possible. The MEDROPLAN Guidelines address this key issue by linking technical indicators of pre-alert, alert, and emergency to manage actions.

Pre-alert, alert and emergency thresholds

In recent years there has been an effort to establish thresholds for drought management defined by using objective indicators in both academic publications (Garrote *et al.*, 2007; Iglesias *et al.*, 2007) and technical documents by a range of administrations, such as the EU Water Scarcity Groups or some river basin plans in Spain, among others. MEDROPLAN has synthesised these efforts, proposing the application of an indicator system to define three levels of drought. Table 1 summarises the thresholds for drought risk levels and the objectives and measures associated with these levels.

Table 1. Summary of the thresholds for drought risk levels and associated objectives and measures

Levels of risk	Monitoring indicators	Objective of the plan in each stage	Measures
Preparedness	Indicators show a normal situation	To ensure that a preparedness and early warning plan is in place	Development of a management plan and strategy for revision and review Implementation of a monitoring and early warning system Structural, new infrastructure, intra-basin, inter-basin and transboundary transfers Integration with development and land use policies
Pre-alert	Indicators show initial stage of danger; no observed impacts (meteorological drought)	To ensure acceptance of measures to be taken in case of alarm or emergency by raising awareness of the danger of drought	Low cost, indirect, voluntary Non structural directed to influence water demand and avoid worse situations Focus on communication and awareness Intensification of monitoring and evaluation of worse case scenarios
Alert	Drought is occurring and impacts will occur if measures are not taken (meteorological and hydrological drought)	To overcome the drought situation and to guarantee water supply while emergency measures can be put in place	Low cost, direct, coercive, direct impact on consumption costs Non structural directed to specific water use groups Water restrictions for uses that do not affect drinking water Changes in management Revision of tariffs Rights Exchanging Centres
Emergency	Drought is persistent and impacts have occurred; water supply is not guaranteed (socio-economic drought)	To minimize damage, the priority is drinking water	High cost, direct, restrictive, approved as general interest actions Structural, new infrastructure Non structural, such as permission for new groundwater abstraction points Water restrictions for all users, including urban demand

The classification of drought risk in different levels responds to the need to design measures in the most effective way to ensure that they are accepted and supported by the stakeholders. Each of these risk levels is associated with a clearly defined objective that determines the type of measures to be implemented.

The *pre-alert scenario* is declared when monitoring shows the initial stage of drought development, which corresponds to moderate risk (i.e. greater than 10%) of consuming all water stored in the system and not being able to meet water demands. The management objective in the pre-alert scenario is to prepare for the possibility of a drought. This means to ensure public acceptance of measures to be taken if drought intensity increases by raising awareness of the possibility of societal impacts due to drought. The kinds of measures that are taken in the pre-alert situation are generally of indirect nature, are implemented voluntarily by stakeholders and are usually of low cost. The goal is to prepare the organism and the stakeholders for future actions. Regarding the Basin Authority, main actions are intensification of monitoring, usually through the creation or activation of drought committees, and evaluation of future scenarios, with special attention to worst case scenarios. Regarding the stakeholders, the focus is communication and awareness. Generally, non structural measures are taken, aimed to reduce water demand with the purpose of avoiding alert or emergency situations.

The *alert scenario* is declared when monitoring shows that drought is occurring and will probably have impacts in the future if measures are not taken immediately. There is a significant probability (i.e. greater than 30%) having water deficits in the time horizon. The management objective in the alert situation is to overcome the drought avoiding the emergency situation by enacting water conservation policies and mobilizing additional water supplies. These measures should guarantee water supply at least during the time span necessary to activate and implement emergency measures. The kind of measures that are taken in the alert situation are generally of direct nature, are coercive to stakeholders and are generally of low to medium implementation cost, although they may have significant impacts on stakeholders' economies. Most measures are non structural, and are directed to specific water use groups. Demand management measures include partial restrictions for water uses that do not affect drinking water, or water exchange between uses. This may be a potential source of conflict because user rights and priorities under normal conditions are overruled, since water has to be allocated to higher priority uses.

The *emergency scenario* is declared when drought indicators show that impacts have occurred and supply is not guaranteed if drought persists. The management objective is to mitigate impacts and minimize damage. The priority is satisfying the minimum requirements for drinking water and crops. Measures adopted in emergency are of high economic and social cost, and they should be direct and restrictive. Usually there has to be some special legal coverage for exceptional measures, which are approved as general interest actions under drought emergency conditions. The nature of the exceptional measures could be non structural, such as water restrictions for all users (including urban demand), subsidies and low-interest loans, or structural, like new infrastructure, permission for new groundwater abstraction points and water transfers.

Defining the actions

The actions are defined in two steps: description and ranking.

Description

The description of the actions includes: a precise and quantified description of the action; definition of the organizational unit responsible for the action; and timeframe of implementation. In addition the description of the action needs to include comments on the application to other areas. Chapter 13 describes the actions and includes some of these aspects.

A first aspect to be described focuses on the type of response to drought events, distinguishing between a reactive and a proactive approach. A second aspect focuses on the public or private nature of the action. Finally a very important aspect refers to the time horizon of the scope of the action. Proactive actions are designed to prevent the potential consequences of drought rather than to remediate them. But this is not possible in most cases, and in fact, the only proactive actions are the design of a drought management plan.

The action is "public" when it is initiated and implemented by governments or administrative bodies at all levels. In this case, actions that are the result of a deliberated policy decision, based on an awareness of risk, and address collective needs. In contrast an action is private when it is initiated and implemented by individuals, households, private companies, or non-governmental organizations. It this case the action responds to the actor's rational self-interest.

Long term actions are established before impacts of drought are observed (anticipatory) to lower the risk of damage. In this case, the action addresses preparedness and risk reduction. In contrast, short term actions take place after impacts of drought have been observed, focussing on crisis management. Actions that are taken before the initiation of a drought event aim to reduce the vulnerability to drought or improve drought preparedness. They are long-term measures oriented to increase the reliability of water supply systems to meet future demands under drought conditions through a set of appropriate structural and institutional measures. The measures taken after the start of a drought are short-term measures which attempt to mitigate the impacts of the particular drought event within the existing framework of infrastructures and management policies, on the basis of a plan developed in advance and adapted to the ongoing drought, if necessary.

In order to incorporate the actions to drought management plans it may be useful to determine the proactive or reactive, as well as the public or private character of the measures. Table 2 summarises examples of short terms and long term measures. Chapter 13 extends the example and lists a range of long-term and short-term actions, subdivided into the three categories of water supply increase, water demand reduction and drought impact minimization. For each action the affected sectors are also indicated.

Table 2. Examples of long term and short term private and public measures to reduce drought risk

	Public(1)	Private(2)	Mixed
Long term measures (3)	Insurance plan for agriculture	Education programmes by NGOs	Education programmes under private initiatives with Government funds
Short term measures (4)	Tax abatement to farmers impacted by drought	Water use reduction in households	Issue emergency permits for water use by a private company that manages urban water and/or River Basin Authority

Ranking

The general objective of every operational action is to minimize impacts of drought and water scarcity while maintaining social and ecological services of water. However, not all actions are suitable and applicable in every situation and moment. The ranking of actions allows for a certain level of prioritization depending on the evaluation of selected aspects, such as: (i) consideration of effectiveness to minimize the risk of impacts, cost, feasibility, and assistance required for adoption; (ii) consideration of adequacy for situation without drought (win-win strategy); and (iii) ranking according to different valuation criteria. These processes need to include stakeholders to ensure adequate action ranking according to the needs of each group and acceptance of the results. Table 3 gives an example for ranking and valuating the actions.

Table 3. Valuation of attributes to establish ranking of the actions

Value	A Effectiveness	B Cost	C Feasibility	D Assistance required for adoption	E Adequacy for non drought situation
0	none	none	non feasible	very high	highly inadequate
1	very low	very low	very low	very low	inadequate
2	low	low	low	low	somewhat inadequate
3	medium	medium	medium	medium	indifferent
4	high	high	high	high	adequate
5	very effective	very high	very high	none	very adequate

Criteria for selecting the actions

Drafting drought management plans requires the selection of the most appropriate combination of long term and short term actions with reference to the vulnerability of the specific water supply system or agricultural system and to the drought severity. Given the high number and the different types of mitigation measures, it is necessary to adopt a proper evaluation procedure for the choice of the best combination. A selection procedure based on purely economic criteria could include equating the marginal costs of long term measures with the marginal costs of implementing short term measures. A more advanced procedure could be based on assessing the expected cost of each combination of long and short term measures using the Montecarlo simulation. However, due to the variety of drought impacts and in particular to the difficulty of assessing environmental and social impacts in economic terms, a purely economic analysis does not seem adequate to simulate the real decisional process. On the other hand, application of a multi-criteria analysis may overcome the above difficulties because of its ability to take into account the points of view of different stakeholders on the different alternatives (Rossi, *et al.,* 2003).

Implementation of the actions

A key point for efficient drought prevention and mitigation is represented by the way of selecting and implementing different interventions on the basis of the priority of water allocation among the various uses, the indications provided by drought monitoring systems and the method adopted to assess drought risk. The choice of drought management interventions has to consider two different priorities: the first is to ensure adequate supplies of domestic water available for public health, safety and welfare; the second is to minimize the negative effects of drought on the economy, the environment and the social well-being. Figure 2 summarises the process of the implementation of the actions. As described above, permanent planning takes place at all times, while the implementation of the actions takes place according to the drought risk level. The onset of the pre-alert actions is triggered by indicators that suggest that a drought may develop, but there are not measured impacts of drought.

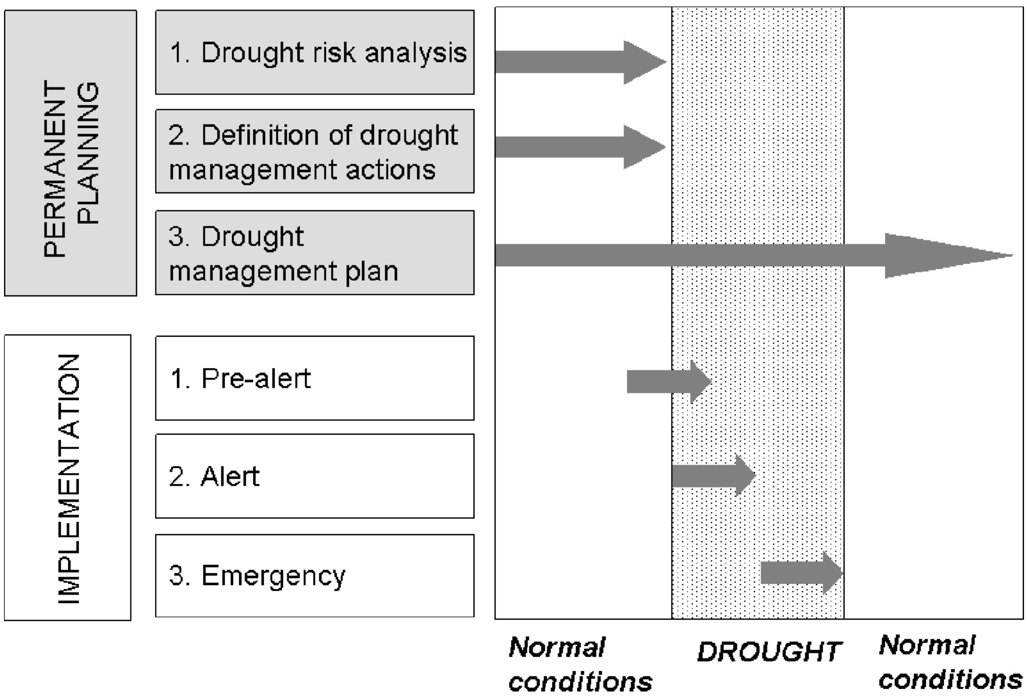

Fig. 2. Sequential steps for implementing drought management actions.

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Chapter 13. Description of drought management actions

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SUMMARY – This chapter presents a compendium of drought management actions related to agriculture and water supply systems together with a common conceptual framework based on the use of drought indicators for evaluating the levels of drought risk (pre-alarm, alarm, and emergency), that allow establishing linkages between science and policy. The rationale is that the actions relevant to all sectors are derived based in common institutional organization, legal framework, and are implemented by a unique decision making structure (defined in the organizational component of the Guidelines).

Key words: Long term actions, short term actions, demand, impact, supply.

General drought management components and impediments

Some countries have emergency drought provisions within their water-rights system, and others do not appear to have plans in place for managing water resources during droughts. In those countries where comprehensive water-management plans are established, they generally incorporate all of the basic concepts for effective drought management while some countries modify the rules for allocating water.

Droughts can be one of the major causes for reduced freshwater flows, and methods should be established to control or to minimize the causes of reduced freshwater flows.

Governmental role has generally been to provide financial assistance to citizens after the droughts have occurred, but, as water demands continue to grow, even minor droughts will become more serious, and countries will be compelled to develop water-management plans.

There are some general drought management components that should be taken into account independently from the affected system and as previous steps to defining drought-risk levels and the measures associated to each of these levels:

(i) Define the available resources: Water may be available from several sources to meet demands in time of drought.

(ii) Define the demand: The quantity, quality, and location requirements of all users must be defined.

(iii) Describe possible shortfalls in supply: Managing the resources to best accommodate the shortfall in meeting demand under a given drought event calls for sound preparation.

(iv) Describe the management measures for potential events: Define the adopted measures necessary in response to projected shortfalls for various drought events.

(v) User and public involvement: It has been repeatedly proven that the success of drought management depends most on the understanding and support of the users and the public.

(vi) Securing legislation agreements, rules, and procedures: Any water management under conditions of shortage usually calls for new authority, rules, and procedures; for example, new legislation and specific legal agreements.

(vii) Drought management plan: Any drought requires a specific set of management actions tailored to the specific event and a mechanism to forecast event dates (Frederiksen, 1992).

Just as many other phenomena there are some important impediments for planning for drought, varying from the perception of people, to political considerations or the lack of information to design an adequate drought management plan. The most common impediments are listed below:

(i) Repeating phenomena. People perceive drought as part of the normal climate (and it is). But also the randomness of drought induces the public to think that there is nothing to be done about it.

(ii) The tragedy of the commons. Droughts are a community problem having characteristics of Hardin's famous "Tragedy of the Commons" (Yevjevich *et al.* 1978). The self-interest of each individual using communal property is to maximize it for immediate gain. The net result can well be the destruction or deterioration of the communal property. In Hardin's example, the overgrazing and destruction of the common pastures occurred because each person sought to graze all the animals possible. The sum of the actions by each individual was not "best" for the sum of the individuals. This phenomenon makes the best policy infeasible unless the individuals reach a consensus themselves or are compelled to do so by a government.

(iii) Lack of information about the cost of droughts. The 1930's drought in USA had an effect on a whole generation of Americans, wherever they lived and however they made their living (Harrison, 1977). Even if the value of human life is ignored, the total economic losses from droughts can be staggering.

(iv) Political considerations. Water management of necessity, must be at the core of any program to mediate the effects of water shortages that occur during droughts, but political factors can substantially dampen the interest in managing water resources even during droughts.

Classification of drought management actions

For the selection of the most appropriate measures in each level of drought-risk, actions are classified in the following Table 1 attending to a number of criteria:

(i) Timeframe of action (long – short term measures). Depending on the timeframe of application or effect, there are long-term measures, taken before the initiation of a drought event aim to reduce the vulnerability to drought or improve drought preparedness. They are oriented to increase the reliability of water supply systems to meet future demands under drought conditions through a set of appropriate structural and institutional measures. The short-term measures try to mitigate the impacts of the particular drought event within the existing framework of infrastructures and management policies, on the basis of a plan developed in advance and adapted to the ongoing drought, if necessary.

(ii) Action strategy (demand, impact or supply management). Depending on the strategy selected actions can be oriented to act upon water demand, trying to decrease it before, during or after drought periods; upon water supply, increasing the availability of water to be used; or upon impacts, trying to minimize them.

(iii) Affected system. Actions can be oriented to different systems: Hydrological, supply, agricultural or institutional systems.

Table 1. Drought management actions

Strategy	System	Action
LONG TERM ACTIONS		
Demand management	Systems maintenance and management	Adopting demand delivery scheduling in pressurised systems
	Water saving practices and management	Water pricing Legislation and regulations Information and education Water recycling
	Water savings in agriculture	Crop resistance to water stress and water use efficiency Crop management Soil management Improving surface irrigation measures Improving sprinkler irrigation systems Microirrigation systems Irrigation scheduling Adopting water prices that induce farmers to irrigate by night Adopting water prices that induce farmers to save water Users and farmers information Involving farmers in decisions to change delivery schedules dictated by limited supply
Impact management	Contingency planning Emergency actions for drought impacts mitigation	Early warning systems development Insurance development
Supply management	Artificial recharge of all water bodies	Terracing Small dams (farm ponds) Runoff enhancement Runoff collection Water holes and ponds
	Emergency supply for drought mitigation	Develop conjunctive use Reinforcing the use of non-conventional waters Hydrological forecasting and drought watch systems
	Groundwater use and recharge	Groundwater recharge
	Improving reservoir operation	Upgrading monitoring of reservoirs Application of optimisation, risk, and decision models
	Reservoir management	Need for reservoirs Single large reservoir management
	Water conservation, systems maintenance and management	Improving conveyance and distribution systems Monitoring and metering the water supply and distribution system The use of information systems and modern technologies Maintenance of urban water supply systems Dual distribution networks for high quality and for treated reusable water Improved regulation and control

		Improved regulation and control Automation and remote control in canal management Adopting low-pressure pipe distributors Changing from supply oriented to demand oriented delivery schedules Intermediate storage Information systems Application of optimisation tools for water allocation and to schedule deliveries Effective systems maintenance Water metering Monitoring The assessment of the system performances Training of personnel in operation, maintenance and management Water conservation measures for drought preparedness
LONG/SHORT TERM ACTIONS		
Supply management	Use of non-conventional resources	Water transfers
SHORT TERM ACTIONS		
Demand management	Water saving practices and management	Incentives and penalties Campaign for imediate water saving Water use restrictions
Impact management	Compensations for income loss Public aid for crop insurance Tax reduction, payment redemptions Temporary reallocation of water	
Supply management	Alternative storage of water Control of water losses and non beneficial uses of water	Tanks Leak detection and repair Location of losses
	Emergency supply for drought mitigation	Transfer of water rights Use of low quality water and reuse of wastewater
	Groundwater use and recharge	Groundwater use/overexploitation
	Use of non-conventional resources	Water harvesting Reduction of waste of water Flood spreading Rainwater collection
	Water conservation, systems maintenance and management	Relaxing ecological or recreational use constraints
	Water harvesting	Reduction of evaporation Changing reservoir water release equipment Canal lining

The following descriptions of measures have been summarised from a document devoted to the compilation of water scarcity management measures elaborated by Pereira, Cordery and Iacovides for UNESCO in 2002.

Long Term – Demand management measures

Systems management

Adopting demand delivery scheduling in pressurised systems

This is generally the most appropriate for the required flexibility to the farm use of sprinkler and micro-irrigation systems. As analysed above these systems may be managed for a variety of irrigation depths and frequency, thus for adopting water savings at farm too. When water supply is limited and restrictions to the demand have to be enforced the respective decisions should better involve the farmers.

Water saving practices and management

Water pricing

Historically, in most countries, water costs have largely been or still are subsidised. In others, water is supplied free. It is of importance to establish rate policies that emphasise greater user involvement in water conservation and saving. When users are charged appropriately for water services, the water use as well as the water waste tends to decrease. Water pricing can help to save water if the price structure meets some essential conditions:

(i) prices must reflect the actual costs of supply and delivery to the customers to ensure the sustainability of the water supply services and the maintenance of conduits and equipment;

(ii) the price rate should increase when the water use also increases to induce customers to adopt water saving and conservation;

(iii) different price rates should be practiced for diverse types of water use in municipal supply, e.g. differentiating domestic indoor uses from gardening water uses; when water is more scarce than usual, prices for less essential uses could be modified earlier;

(iv) differential increases in price must be large enough to encourage water savings;

(v) prices must reflect the quality of service, i.e. poor and non reliable service cannot be provided at high cost but costs must change as soon as service is improved; and

(vi) any change in pricing must be accompanied by information and education programs that support an increased awareness of the customers of the value of water and water supply services.

Water benefits are different for each type of user. In urban areas there are several types of water use: domestic, public, industrial, commercial, services, construction, and recreational. Each of these categories reacts differently to the same financial spur in charging for the service, so it is important for the rate structure to be properly designed (Arreguín, 1994). This involves knowledge on trends in costs and the respective price structure, on trends in the water market including its seasonal variations, and information on users' categories and their ability to pay. Other variables that affect decisions are the policies on subsidies and on fines and penalties for water misuse and abuse.

Legislation and regulations

Water laws give each country its general framework for water use and conservation, and are complemented by regulations, which establish the practical application of the legal water policies.

Regulations to improve water savings are often of a restrictive nature. In most cases, they are established for long-term application, but they may be applicable only during periods of limited water availability such as droughts. In that case they generally require very strict surveillance and should only be applied when they are really necessary.

Long term regulations concern questions such as the characteristics and standards for indoor plumbing fixtures, or maximum volumes per flush in toilets (e.g. 6 l/flush), or maximum discharge in showers (e.g. 10 l/min.). Regulations also include requirements to replace old type toilets, compulsory use of equipment for filtering, treating and recycling the water in swimming pools, etc. Temporary regulations may concern the prohibition of use of hoses to wash motor vehicles or sidewalks.

Information and education

Water saving programs need the users participation to be successful. Furthermore, information and education campaigns are required. The same requirements exist for successful implementation of legislation and regulations or to achieve water saving objectives in relation to the adoption of water metering and water pricing.

Information to the users may include leaflets sent out with bills, publicity campaigns in the press, radio and television, billboards on streets and public transport vehicles. Special campaigns for water saving may also include the free distribution of water-saving devices, assistance with the cost of investments required to renovate or upgrade household water systems, or allow tax deductions for specific water saving investments.

Education mainly concerns the introduction in primary and secondary school curricula of the essential aspects of the hydrological cycle and water sources. It should also cover limitations in water use, causes and other considerations related to water scarcity, the costs to mobilise and supply water, the main water uses and benefits, and, finally, how to properly use both water indoors and outdoors.

Water recycling

Recycled water (re-use water) results after the biological and physical treatment of the collected domestic wastewater. This water may be used for the irrigation of many crops and for the flashing of toilets. The treated recycled water can take two forms, the re-use water from biologically and physically treated wastewater that occurs in sewage treatment plants, which may include black and grey water effluents, and the re-cycled grey water (which includes only grey water from the wastewater, after a physical process that takes place in a small local grey-water treatment plant.

Water savings in agriculture

The role of farmers in reducing the demand of farm irrigation systems is limited both by the farm system constraints and by their capabilities to be in control of the discharge rate, duration and frequency of irrigation. These limitations are probably more important relative to deficit irrigation because farmers require some flexibility in the deliveries to decide the optimal irrigation timings and depths, as well as that deliveries be reliable, dependable along the irrigation season and equitable among upstream and tail end users. Therefore, the adoption of reduced demand strategies largely requires improved quality of supply management.

Crop resistance to water stress and water use efficiency

In dryland agriculture, crops and crop varieties are selected taking into consideration their tolerance to the water stress conditions that characterise the environments where they are cultivated. In general, these crops correspond to centuries of domestication of plants native to these environments, but new varieties have been introduced in the last decades following scientific plant breeding and improvement programmes. The most common food crops are wheat, barley and millet among cereals, and beans, cowpea and chickpea as legumes (pulses), as well as mustard and sunflower.

Crop management

Water conservation in dryland agriculture mainly refers to crop management techniques and to soil management practices. They relate to three main approaches: (i) Techniques to manage crop risk, which concern crop management; (ii) techniques designed to minimise the risks of crop failure; and (iii) techniques to increase the chances for beneficial crop yield using the available rainfall. They refer to:

(i) The selection of crop patterns taking into consideration the seasonal rainfall availability and the water productivity of the crops and crop varieties. Here the aim is to lower the water stress effects on crop development and, therefore, to reduce impacts on yields, including under drought conditions. This approach provides high effectiveness in coping with water scarcity.

(ii) The adoption of water stress resistant crop varieties instead of high productive but more sensitive ones particularly when there is the possibility of a drought.

(iii) The use of short cycle crops or crop varieties, thus having smaller crop water requirements than varieties or crops with longer growth seasons.

(iv) To adapt planting dates such as to plant after the onset of the rainy season to ensure more effective conditions for crop establishment.

(v) Early seeding to avoid terminal stress of the crop.

(vi) Early cutting of forage crops to avoid the degradation of the stressed crop.

(vii) Grazing drought damaged field crops to permit an alternative use of the biomass for livestock when the yield is lost due to drought damage.

(viii) To adopt supplemental irrigation of dryland crops at critical crop growth stages to avoid loosing the crop yield when a drought occurs. This can be a highly effective technique when water may not be enough to adequately irrigate a dry season crop.

Soil management

Soil management practices for water conservation refer to tillage and land-forming practices that favour rainfall infiltration into the soil, water storage in the soil zone explored by roots, capture of runoff to infiltrate the soil, control of evaporation losses from the soil and weeds, extraction of water by plant roots, and crop emergence and development.

These practices have long been known to have positive impacts on water conservation in dryland farming. However, results of any soil management technology depend upon the soil physical and chemical characteristics, the land-forms and geomorphology, the climate and the kind of implements used. All these factors interact, creating variable responses in terms of crop yields. When a technique is to be introduced in a given environment and it is substantially different from the traditional and well-proved practices adopted by local farmers, it is advisable to perform appropriate testing before it is widely adopted. However, the principles of soil management for water conservation are of general application, regardless of the size of the farm, the traction used, or the farming conditions.

Improving surface irrigation systems

Several surface irrigation methods are used in practice. The main ones are:

(i) Basin irrigation, which is the most commonly used irrigation system world-wide. Basin irrigation consists of applying water to levelled fields bounded by dikes, called basins.

(ii) Furrow irrigation: Water is applied to small and regular channels, called furrows, which serve firstly to direct the water across the field and secondly act as the surface through which infiltration occurs. There is a small discharge in each furrow to favour water infiltration while the water advances down the field. Furrow irrigation is primarily used for row crops.

(iii) Border irrigation: water is applied to short or long strips of land, diked on both sides and open at the downstream end. Water is applied at the upstream end and moves as a sheet down the border. Border irrigation is used primarily for close growing crops such as small grains, pastures, and fodder crops, and for orchards and vineyards. The method is best adapted to areas with low slopes, moderate soil infiltration rates, and large water supply rates.

Improving sprinkler irrigation systems

Main sprinkler systems are:

(i) Set systems: The sprinklers irrigate in a fixed position and can apply small to large water depths. Set systems include solid set or permanent systems as well as periodic-move systems, which are moved between irrigations, such as hand-move, wheel line laterals and hose-fed sprinklers. These systems are the least costly and the best adapted for small farms. A wide range of sprinklers can be selected for a variety of crops and soils as well as for environmental conditions.

(ii) Travelling guns: a high pressure sprinkler continuously travels when irrigating a rectangular field. The high application rates and the characteristics of the moving system make travelling guns unsuitable for applying very small or large depths, or to irrigate heavy soils and sensitive crops. In addition, these systems have a high energy requirement and may have low performances and high evaporation losses when operating under hot, arid and windy conditions.

(iii) Continuous move laterals: the sprinklers operate while the lateral is moving in either a circular or a straight path. Large laterals are used, equipped with sprinklers or sprayers.

Microirrigation systems

Microirrigation, also called trickle or drip irrigation, applies water to individual plants or small groups of plants. Application rates are usually low to avoid water ponding and minimise the size of distribution tubing. The microirrigation systems in common use today can be classified in two general categories:

(i) Drip irrigation, where water is slowly applied through small emitter openings from plastic tubing. Drip tubing and emitters may be laid on the soil surface, buried, or suspended from trellises.

(ii) Microspray irrigation, also known as micro-sprinkling, where water is sprayed over the soil surface. Microspray systems are mainly used for widely spaced plants such as fruit trees but in many places of the world they are used for closed space crops in small plots.

Irrigation scheduling

Research has provided a large variety of tools to support improved irrigation scheduling, i.e. the timeliness of irrigation and the adequateness of volumes applied.

Irrigation scheduling techniques may be used with diverse objectives in the practice of farmers. More commonly, farmers seek to avoid any crop stress and maximise crop yields.

When water is plenty, farmers tend to over-irrigate, both anticipating the timing of a need for irrigation and applying excessive water depths. Thus, the application of appropriate irrigation scheduling techniques permits them to optimise the timeliness and the volumes applied, thus controlling return flows, deep percolation, transport of fertilisers and agro-chemicals out of the root zone, and avoiding waterlogging in the parts of the field receiving excess water.

Adopting water prices that induce farmers to irrigate by night

Adopting water prices that induce farmers to irrigate by night is a policy particularly appropriate for pressurised systems but that can also be used for open canal systems when some kind of metering is adopted. It consists in differentiating the day-time and night-time water prices to induce night irrigation, which gives larger flexibility to the system operation, improves the service performance and reduces operational losses due to excess water flowing in the systems at night, when the demand is lower.

Adopting water prices that induce farmers to save water

Adopting water prices that induce farmers to save water may be an appropriate policy for pressurised systems where metering is available. It can also be used for open canal systems but its application is then quite difficult. It consists in water prices that vary in accordance with the water use, which increase after a given volume is diverted to the farm. The price structure ideally varies with the type of crop following policies on cropping patterns, and with the available supply, both affecting the minimum volume and the rate for increasing the prices. Water metering is essential for a fair application of this policy. Systems where water costs are associated with the land surface cropped may adopt alternative pricing policies differentiated by crop and water volume but its enforcement requires appropriate field surveys to check the areas declared by the farmers.

Users and farmers information

Users and farmers information is of paramount importance to increase the awareness of the value of the water and the importance of water savings. Information is required to involve farmers and other users in water saving and conservation programmes.

Involving farmers in decisions

Involving farmers in decisions to change delivery schedules dictated by limited supply. During periods of limited water supply the delivery schedules have to be modified in order to satisfy the priority uses and to enforce restrictions for other uses. When farmers are involved in the decision process that leads to modify the delivery schedules, or to fix the respective water quotas, the farmers may negotiate these emergency measures in order to adopt the best practices that accommodate with water constraints to be enforced. This involvement may be difficult in systems serving a large number of small farms but the involvement of farmers in this decision is important for the effective adoption of emergency water saving programmes.

Long Term – Impact management measures

Contingency planning

Early warning systems development

An early warning of drought is recognized as a key factor for a successful drought management effort. The effective response to drought events relies on monitoring system able to provide adequate information for an objective drought declaration and for avoiding severe water shortages through an effective water resources management under drought conditions.

Emergency actions for drought management mitigation

Insurance development

In all cases the operational risk management cannot guarantee full prevention of drought damage, and a risk level has to be adopted in the drought management plan. For example, in Spain, the drought insurance system (ENESA) has an operational drought insurance plan that establishes a risk level defined by the probability of suffering a reduction in crop yield below a pre-established threshold (acceptable risk). This threshold is defined for each crop and geographic areas and it is re-evaluated each season. Risk or insurance premium can be estimated by using statistical and risk evaluation models.

Long Term – Supply management measures

Artificial recharge of all water bodies

Terracing

Terracing can be used to collect water for two purposes. Firstly a horizontal surface reduces runoff and maximises the infiltration of water into the soil. If the soil surface is kept tilled and free of vegetation except for the desirable crop, almost all rain falling on the terrace will be used for crop growth. In regions of low rainfall, soil water can be stored over long periods provided the soil surface is kept tilled or mulched and vegetation free.

Small dams

In regions of high evaporation, small and shallow dams are usually a cause of high evaporation losses. However in groundwater recharge areas, small dams, or even low embankments across floodways, can be used to increase aquifer recharge. On grasslands used for grazing the encouragement of infiltration by low embankments which reduce flow velocities and hold water for a few hours after rain events can increase soil water and greatly increase the time after rain that water is available to vegetation roots. By this means it may be possible to double annual biomass production in semi arid regions.

Runoff enhancement

In places of water scarcity where the availability of water needs to be increased it is possible to enhance runoff from rainfall events by partially sealing the soil surface. This can be done by applying surface sealing materials or by compacting the soil surface.

Runoff collection

In undulating to flat terrain where runoff collects into large numbers of very small stream channels, the available water resource may be quite large, but its diversity makes it difficult to use. Under these circumstances it is often possible to capture part or all of the flow in a small channel and divert it to another channel. Diversion channels which run almost parallel to the contours can be used to carry this diverted flow to a different location.

Water holes and ponds

Natural water holes and ponds can be exploited for water supply purposes. There is a need to ascertain the source of the water. If the supply is from groundwater it may be possible to treat the pond as a well and increase the extractable water by making the pond deeper and increasing the hydraulic gradient towards the pond. If the water is supplied by surface flows in a stream bed there are several possible ways to increase the water availability.

Emergency supply for drought mitigation

Conjunctive use of surface and ground water

Develop conjunctive use of the surface waters that are mobilised through the existing water systems and the waters from emergency sources such as groundwater mining and non-conventional waters mentioned above. Adopting a conjunctive use approach provides for rational and sound water resources allocation.

Sound water resources development and management seeks to maximize the water resources availability at the least cost. This is even more important in arid and semi-arid climates and where droughts are quite frequent. In those regions and in areas with great fluctuation of demand, conjunctive use of surface and groundwater storage is often relied upon to offset deficits in the dry season and accommodate storage and recharge of excess water in the wet season. This is also the case for small to medium size islands, where the economic dimensions of dams is usually small, whilst the water supply demand in tourist areas increases disproportionately due to the seasonal character of tourism.

Use of non-conventional resources

Reinforcing the use of non-conventional waters such as rainfall harvesting for domestic uses –drinking water cisterns– and fog collection. These issues apply to areas where water collection systems are already available and in use since during drought they may not mobilise the required water quantities.

Whenever good quality water is scarce, water of inferior quality will have to be considered for use in agriculture, irrigation of lawns and gardens, washing of pavements, and other uses not requiring high quality water. Inferior quality water is also designated as non-conventional water or marginal quality water. Non-conventional water can be defined as water that possesses certain characteristics which have the potential to cause problems when it is used for an intended purpose (Pescod, 1992). Thus, the use of non-conventional water requires adoption of more complex management practices and more stringent monitoring procedures than when good quality water is used.

Non-conventional waters most commonly include saline water, brackish water, agricultural drainage water, water containing toxic elements and sediments, as well as treated or untreated wastewater effluents. All these are waters of inferior or marginal quality. Also included under the designation of non-conventional waters are the desalinated water and water obtained by fog capturing, weather modification, and rainwater harvesting.

Hydrological forecasting and drought watch systems

Hydrological forecasting and drought watch systems that allow for real time, or near real time prediction of reservoir inflows, evaporation and seepage, thus to better estimate the time evolution of storage that dictate the operation rules. These management tools may also be useful to estimate how the demand will evolve when appropriate feedback is developed with canal managers in case of irrigation uses. Then, the support by information systems is particularly useful.

Groundwater use and recharge

Under conditions of water scarcity diverse water sources need to be developed, such as surface and groundwater, including the development of deep groundwater, reuse of wastewater, desalination, and use of other non-conventional water sources. Intensive attention needs to be directed towards water management, including demand management.

Groundwater plays an important role in alleviating water scarcity problems due to its inherent physical and storage characteristics. Aquifers have some specific characteristics that distinguish them from other water sources and make them quite unique in their usefulness. As such, the aquifers can be extremely beneficial in supplementing other sources from which there may be diminished yield due to drought and dry spells and can constitute useful strategic reserves for coping with water scarcity. However, for groundwater to play such a key role under conditions of water scarcity an increased understanding of the aquifer system is required and its operation and management would demand greater attention than under normal circumstances taking into consideration that will never be enough abundant.

Groundwater may be found in areas where surface water is absent or difficult to transfer. In the case of temporal or seasonal scarcity of water, an aquifer can be operated as a seasonal water storage reservoir tapped during the dry season and recovered during the rainy season. Groundwater can be used as a supplementary source for blending with water from other non-conventional sources, and in conjunctive operation with other sources. Aquifers can be used for the storage and additional treatment of recycled water. Sediments in surface water are removed when water enters an aquifer and the quality of the water is improved. Aquifers often have a much larger storage capacity compared to surface reservoirs. In aquifers, the transport of water from the areas of recharge to the areas of extraction is natural and may involve very large distances. Groundwater reacts slowly to seasonal and medium term climate variations, acting as a buffer for such variations.

The main requirements for effective groundwater use under conditions of water scarcity include:

(i) Full assessment of the resource.

(ii) Development of proper operational and water allocation plans.

(iii) Awareness and consideration concerning groundwater quantity and quality protection, and enforcement of the necessary legal and institutional measures.

(iv) Application of integrated water resources management towards securing the sustainability of the source.

In arid and semi-arid regions, where water scarcity is endemic, groundwater plays an immense role in meeting domestic and irrigation demands. In these regions massive use of groundwater has been practiced for some time now for large cities and long-established irrigated agricultural developments.

Groundwater recharge

Where groundwater is an important source of water there can be considerable advantages in encouraging recharge of the aquifer. Care is needed to protect aquifer recharge areas from land use changes that can decrease the recharge. It is well established that increase in quality of vegetation, by reforestation, improvement of grazing vegetation or in some cases by introduction of cropping, generally increases infiltration, but also increases transpiration and therefore reduces recharge and runoff. Therefore care is needed to allow for the effects of such surface changes on the groundwater availability or to ensure that the vegetation characteristics of the recharge area are not changed. Change from native vegetation to cropping may lead to increased recharge because cropping involves leaving the soil fallow for part of the year. However the actual effects in any location will depend on the vegetation and crop types and rotations, the soils and the climate of the region.

Surface reservoirs can be used advantageously to increase recharge by holding water over a recharge area for some time, or by diverting water to spread it widely over a recharge area. However care is needed to ensure this does not encourage increased evaporation and a large net loss of water from the system. Precipitation is the source of all fresh water and in most situations the surface and groundwater resources are interdependent. Encouragement of recharge may mean a reduction in available surface water further downstream. Conversely impounding surface water may diminish recharge direct from the stream-bed downstream of the reservoir and hence may reduce the groundwater resource.

Under scarcity conditions, withdrawals during the dry season often by far exceed the safe yield of aquifers, resulting in the depletion of the reserves and occasionally, allowing water of inferior quality to intrude into the aquifers. As already analyzed, flash floods during the rainy season may not have sufficient opportunity to infiltrate the aquifers with the result that much needed water may not be utilized.

Among a number of management interventions that could help improve the situation is that of artificial groundwater recharge. This aims to increase the groundwater potential by artificially inducing increased quantities of surface water to infiltrate the ground and be later available at times of need. It could also help control or even reverse the sea-intrusion propagation in an aquifer caused by long-term or seasonal excessive pumping. This can be accomplished by creating positive groundwater levels through artificial groundwater recharge at selected strategic points in the aquifer. Furthermore, it could be used to improve the quality of pre-treated sewage water, and store it for subsequent development and reuse.

In areas where there is seasonal variation of stream flow availability, water can be conserved through artificial groundwater recharge in the wet season for use during the dry season. Furthermore, control and recharge of water in wet years may help reduce the impact of droughts and to some degree alleviate man induced water shortage problems.

The artificial groundwater recharge schemes may be classified under two broad groups:

(i) The indirect methods through which increased recharge is achieved by locating means of groundwater abstraction as close as possible to areas where surface water is in contact with the aquifer or areas of natural water discharge. In such cases, the natural hydraulic gradient is affected so as to cause increased recharge.

(ii) The direct methods through which surface water is conveyed from lakes, reservoirs, waste water treatment plants or is being diverted from flowing streams to suitable areas of aquifers where it is made to infiltrate to the groundwater from basins, trenches, dry riverbeds, injection wells, pits, etc.

Indirect or induced artificial groundwater recharge consists of abstracting groundwater within a short distance from a flowing stream, lake or impoundment. The pumping lowers the piezometric surface to cause a steeper hydraulic gradient, thus inducing increased recharge. The same artificially developed conditions tend to reduce the outflow of local groundwater into streams and surface water storage. The groundwater abstraction facilities could consist of well fields, a gallery or a line of wells. Depending on the hydrogeologic parameters of the local aquifer, considerable amounts of surface water could be induced to infiltrate into the aquifer. Higher permeability favors larger quantities to be recovered through pumping wells.

Artificial recharge by spreading: Artificial recharge by spreading is usually carried out when the aquifer extends close to the ground surface. Recharge is accomplished by spreading water over the ground surface or by conveying the raw water to basins and ditches. Use of spreading grounds is the most common method for artificial recharge.

Artificial recharge by well injection: When the aquifer is located at some moderate depth below the ground surface, recharge may be accomplished by introducing water through pits and shafts and, in the case of the presence of overburden of a large thickness, water can be injected through wells or boreholes which reach the aquifer. This technique is also preferred where land is scarce, when environmental reasons oppose the use of large spreading grounds, when the local hydrogeologic conditions do not favor spreading, or wells and pits are already available for use for recharge. In areas where the pervious formations are at shallow depth, recharge can be accomplished by digging pits or shafts. Abandoned gravel pits could also serve as recharge sites. Injection wells are quite versatile in that they can be used on any type of aquifer.

Recharge with surface and subsurface dams. Other types of artificial recharge schemes refer to floodwater retention dams, especially on broad wadi floodplains. The purpose of these is to delay the flow of the water and provide the opportunity for recharge into the local aquifer. The structures consist usually of low dams, including earth walls and gabions built to be toppled by floods.

Improving reservoirs operation

Improving reservoirs operation for controlling water losses, mainly operational losses, and better allocate the available water. In few cases, measures may include changes in equipment that control releases but most of improvements concern management.

Upgrading monitoring of reservoir

Upgrading monitoring of reservoir inflows and releases to better support the adoption of information tools mentioned above.

Application of optimisation, risk, and decision models

Application of optimisation, risk, and decision models to reservoir operation, to define optimised system management rules and to decide the allocation of water resources among the different users – municipal, irrigation, industrial, recreational, energy and nature. A large panoply of such tools has been made available by research, many are in use, but their adoption under water extreme water scarcity still is low due to the difficulty in gathering the information required to optimise decisions.

Reservoir management

Need for reservoirs

Most water supply schemes need to incorporate reservoirs. These may be surface storages or subsurface aquifers. The function of the storages is to smooth out the natural variability of the hydrological system to allow human activity to be supported by a constant, or a regular, seasonally varying supply. Where water is scarce it is most unlikely it will be possible to take water on demand from the natural system. In times of high flow (either surface or subsurface) it is often possible to extract whatever water is required. However in drier times the natural flow is likely to be significantly lower than the expected extraction rate. Hence surface or subsurface reservoirs serve as temporary storages, capturing high flows whose water can then be available for use during periods of low natural flow.

Operation of single and multiple reservoir systems

Here we should use the word reservoir in its broadest sense. That is we will include all water storages including surface reservoirs, natural lakes and groundwater aquifers. These reservoirs may be replenished naturally, or they may be pumped systems or even storages built up from desalting of brackish or sea water.

Without doubt the operation of several linked water sources, rather than a single reservoir system, offers the water manager many options and flexibilities with numerous opportunities to maximise the potential availability of water. This applies to all water resource situations, not just to regions where water is scarce. However the cost of this increased flexibility of management is a very large increase in the complexity of the operation of the system and a very much increased possibility of management of the system being sub-optimal. However there are very large advantages to be gained from multireservoir systems, particularly where the reservoirs within the system have different water sources. For example a system with a river-fed surface reservoir, whose storage level depends on recent precipitation and a groundwater system which varies only with long term variations in precipitation has many advantages. High rates of extraction can be obtained from the surface reservoir but only for limited periods, whereas the groundwater can provide a medium level of extraction for very long periods. Similar advantages can be obtained from inclusion of desalinated water, renovated waste water, or urban stormwater.

Surface water can often be supplied at low cost. Groundwater may involve larger costs for pumping. It may be efficient to design a system for surface water supply only, with highcost groundwater only to be used in emergencies, such as prolonged droughts, when the surface supply is exhausted.

Multiple reservoir systems also offer the advantages of redundancy. Provided there are multiple water delivery pathways the system will not be shut down by any single failure of a reservoir, a pipeline or a control valve, and therefore the security of supply can be very high.

Water conservation, systems maintenance and management

Systems maintenance and management are essential to cope with water scarcity. When these are adequate, they provide for controlling water wastes, seepage and water spills and provide for water saving. When maintenance and management are poor, not only system losses are high but the water service is poor, less reliable and non-dependable, tail end users receive the poorest service and incentives for the users to save water are lacking.

When water scarcity is due to drought, water conservation and saving requires policies and practices that are common with aridity. However, coping with drought requires a distinction between preparedness and reactive or mitigation measures, the first consisting in preparing for the application of the mitigation measures during drought.

Improving conveyance and distribution systems

Improving conveyance and distribution systems, which refers both to equipment and management software. An enormous amount of research has been recently devoted to these subjects and a very large number of papers and books refer to these matters, particularly for irrigation systems. Approaches that help coping with water scarcity are generally oriented to control seepage and operational losses, to provide for higher flexibility in water deliveries to irrigated farms, and to improve the levels of service by matching supply to demand, increasing the reliability of supplies and enhancing the dependability of deliveries along the operation season and the equity of the distribution in the areas served.

Monitoring and metering the water supply and distribution system

Metering is required at both the supply and distribution systems and at household connections. At the supply level, it concerns monitoring and measuring the water stored, being conveyed, and circulating in the distribution system. The resulting data produces information on the state of the system, and the respective variables. This information is vital for planning system developments and modernisation, for operation, maintenance and management of the systems in real time, and, in particular for planning and implementation of water conservation and water saving programmes. Metering at the household outlets is required for knowing the users consumption, for billing the customers in accordance with the respective water use, and for the support of measures to be enforced when water availability does not allow the supply to match the current demand.

Metering and monitoring the supply system has many advantages (Arreguín, 1994), provides for an updated knowledge on the actual volumes stored and the discharges flowing in the water conveyance systems and in the distribution sectors, as well as water pressure and water levels at key nodes of the networks.

The use of information systems and modern technologies

The use of information systems and modern technologies such as remote sensing, GIS, and models that provide for the state variables relative to the reserves in storage and to the uses and demand. Information systems are essential to appropriately explore reservoir decision tools mentioned below and to create information relative to users decisions in agreement to the water availability.

Maintenance of urban water supply systems

Maintenance may be preventive and reactive. It plays a major role in water conservation. The main purpose of preventive maintenance is to ensure the proper functioning of the water supply system, from the upstream water sources to the customers. Consequently, it includes the network reservoirs and conduits and respective equipment, the pumping stations, the water treatment plants, and the metering system. For the latter, meter readings need to fall within a well-defined range of accuracy. A study in Mexico reported by Arreguín (1994) has shown that 23.4% of the meters over-recorded water use, 71.4% under-metered and only 5.2% measured accurately.

Each utility and sector should have its own program of maintenance. Computer programs may be helpful in establishing and controlling maintenance programmes. Reactive maintenance needs to occur as required. Reactive maintenance takes place in response to information provided by the field personnel, meter readers and users about system failures, equipment disrepair, and inaccurate meter readings.

Dual distribution networks for high quality and for treated reusable water

Diverse water uses in urban areas require different water quality. High quality water is definitely required for uses such as drinking, food preparation, or bathing. However the largest fraction of this water is not consumed but returned as effluent with degraded quality and is not reusable for the same purposes. On the other hand, uses such as toilet flushing, heating, floor washing, or irrigation of lawns and gardens do not need such high quality water and could use treated wastewater.

Originating from these different requirements, in urban areas where extreme water scarcity exists, a feasible but expensive solution is to duplicate the distribution network, mainly in the neighbourhoods or sectors where water users can manage with inferior quality water for uses other than human consumption (Okun, 2000). At the limit, different sewage systems may be built, separating the less contaminated and less charged effluents from the more degraded ones. The two effluents may require different treatments and may attain different quality levels, and therefore may have different uses. Urban drainage rainwater may also be treated and added to the higher quality treated urban effluents.

Improved regulation and control

Improved regulation and control of canal and pipeline systems, including local or centralised automation, generally permits higher delivery flexibility and improved conditions at farm level to adopt water saving irrigation practices. Adopting appropriate regulation and control provides for reduced operation losses and for easy maintenance since water levels vary much less during operation. In general, reliability, adequacy and equity of deliveries are enhanced, while dependability depends upon the policies for reservoir management. Increasing the levels of service give better opportunity to farmers to adopt improved farm irrigation, and to include practices that lead to water conservation and saving, as well as to control environmental impacts, specially in saline environments. Appropriate regulation and control is probably the most important issue for irrigation and multipurpose water systems. However, regulation and control systems may be expensive and require technological capabilities to be fully explored despite local control automation may be easy to adopt and apply.

Automation and remote control

Automation and remote control in canal management is a step further in technological advancement in regulation and control. Remote control allows a better operation of the system particularly to take into consideration the users demand in real time. The appropriateness of these technologies to cope with water scarcity relate to improved water service, more easy application of irrigation scheduling and the farmers ability to improve the water use leading to higher water productivity and water saving. Because high technology is required and the demand has to be known in real time, these technologies adapt better to systems serving large and commercial farms.

Adopting low-pressure pipe distributors

Adopting low-pressure pipe distributors in surface irrigation systems instead of open channels and ditches is an effective solution to reduce spills and leaks, to achieve higher flexibility and service performance, and to easily adopt water metering. The investment costs may be compensated by lower operational costs when compared with open channel distributors. Benefits at farm level are once again related with the flexibility in the deliveries. This technology has no particular technological requirements.

Changing from supply oriented to demand oriented delivery schedules

Changing from supply oriented to demand oriented delivery schedules is the desirable orientation of system management when regulation and control are enough reliable. In fact, demand oriented delivery schedules assume that managers give priority to satisfy the demand rather than optimising the supply service. Thus, it makes possible that farmers apply improved irrigation schedules to save water and increase water productivity. It requires that regulation and control be modernised and some kind of communication between farmers and managers is adopted. This communication may be performed through direct contact between farmers and canal operation personnel, by phone or via computer.

Intermediate storage

Intermediate storage in canal reaches, small reservoirs linked with selected canal nodes, or farm ponds are often used to increase the flexibility of the system to respond to variations in demand, to reduce operation losses during periods of reduced water use such as the night-time and holidays, and to permit the use of farm irrigation systems having discharge and duration requirements different of those provided by the delivery schedule practiced. The latter is the case of farms adopting micro-irrigation or sprinkling where distribution systems adopt delivery schedules designed for surface irrigation.

Information systems

Information systems may play an important role when decision models are used for systems operation or to help farmers selecting the respective management to cope with water scarcity. Information systems are particularly useful to identify the state variables of the system, inclusive in real time, thus providing for better matching deliveries to demand. Information systems are even more useful in multipurpose systems to support decisions on allocation of water by user sectors, especially when the management of the reservoir and the conveyance and distribution system are linked.

Application of optimisation tools

Application of optimisation tools for water allocation and to schedule deliveries is a technique that complement those modelling and decision tools mentioned before.

Difficulties in application are due to insufficient economic information to adequately perform optimisation, and to the required feed-back information from the users.

However, when it is possible to be applied, it may support achieving higher reliability, adequacy and equity in deliveries and the enforcement of water saving.

Effective systems maintenance

Effective systems maintenance, which is required not only to avoid seepage, water spills and leaks but for adequate operation of the hydraulic structures, regulation and control, and good service to users. Maintenance needs trained personnel and equipment as well as planning. Particular attention should be paid to periods when water supply is limited, when all available water is insufficient to meet the demand.

Water metering

Water metering –flow depth and discharges in surface systems and pressure and discharges in pressurised systems– is required to support operation and, at outlets and hydrants, for billing the users. Data from metering also provides basic data on system variables useful for management. The adoption of information and decision support tools mentioned above is not possible without metering at critical nodes of the system and, for more advanced technological levels, without metering the water deliveries to users.

Monitoring

Monitoring system functioning and system performances is required to identify the critical reaches of the conduits and canals and service areas and to provide the follow-up of maintenance programmes, improvements in equipment, implementation of upgraded management tools, as well as the quality of service provided.

Monitoring allows to quantify system losses, priority areas for improvement and to evaluate upgrading programmes. Data produced are an essential input to information systems and decision support tools in addition to metering. As for metering, monitoring do not produce water savings but is essential for their effective implementation.

The assessment of the system performances

The assessment of the system performances –physical, environmental, economic and service performances– provides for the evaluation of the actual functioning of the systems complementing monitoring and metering. Actual indicators are useful for planning modernisation, rehabilitation and improving of the systems and are generally useful to base decisions required for implementing such programmes, consequently for planning for water saving and conservation.

Training of personnel in operation

Training of personnel in operation, maintenance and management is required to enhance the quality of service, for technological upgrading of the systems and to carry out water saving programmes. Training is also necessary to develop skills required to contact with the public and for the communication with users.

Water conservation measures for drought preparedness

These include: (i) development and effective implementation of drought watch systems as a main component of the meteorological and hydrological information systems; (ii) storage and regulation reservoirs to mitigate the effects of the diminishing availability of the resource during drought; (iii) controlling and planning for larger groundwater withdrawals aiming at augmenting the water availability during drought periods; (iv) improved conditions for operation, maintenance, and management of water supply systems, mainly for controlling operational losses, and providing for flexibility in operation, and high service performances; (v) establishment of water allocation policies to be enforced under drought, which take into consideration the social, economic and environmental uses of the limited water resource; (vi) planning for the augmentation of available water resources during drought, including waste-water re-use and the use of non conventional water resources; however, note that water must be in accessible storage before the drought begins because it is unlikely any water will become available for capture until the drought ends; (vii) development of water technologies and practices to be adopted by the end users that help in reducing the demand and controlling the water wastes under conditions of diminished water availability; (viii) development of institutional conditions for drought preparedness and management, including for timely application of drought mitigation measures; (ix) establishing water pricing and financial incentives and penalties aiming at reducing water consumption and use and avoiding water wastage and misuse, including the control of water quality degradation by effluents and return flows; (x) encourage households to save funds in good times, to buy water from delivery tankers during drought; institutions need to have a backup reservoir and extraction equipment to provide water for carting to villages and households where local supply is totally exhausted; (xi) augmenting the public awareness on the economic, social and environmental value of the water, particularly oriented to produce a favourable attitude in regard to the adoption of drought mitigation measures.

When a drought occurs, water conservation for drought mitigation should be implemented. Then, measures and practices include: (i) exploring the drought watch system to monitor the drought onset, development and termination, as well as to produce information for decision makers and water users; (ii) implementing changes in reservoir and ground-water management rules; (iii) enforcing drought oriented water allocation and delivery policies; and (iv) adoption of farm water storage and soil water conservation practices, which cannot help during drought but must be in place before the drought starts.

Water conservation is particularly important in the preparedness for droughts but it must be complemented with water-saving programmes, which are essentially reactive. Water saving for drought mitigation concerns measures and practices common to those for coping with, such as items (i), (ii), (iii), and (v) enumerated above, and others that might be specific for drought conditions such as: (i) adoption of drought tolerant crops and drought oriented cropping patterns, (ii) reduction of the irrigated areas and/or adoption of deficit irrigation practices, (iii) extended use of inferior quality water for irrigation, (iv) adoption of water saving tools and practices for reducing domestic, urban, and recreational water uses, including the use of inferior quality water for irrigation of golf courses and gardens, (v) ceasing supply by pipe and implementing tanker delivery (this is a drastic move but in a desperate situation it greatly reduces water consumption); (vi) enforcing specific water price policies in relation to the used water volumes, the type of uses, and the efficiency of use, (vii) adopting incentives for reducing water demand and consumption and penalties for excessive water uses, for non authorised uses, as well as for degrading the available waters with low quality effluents and return flows, and (viii) developing campaigns for end-users to adopt drought oriented water saving tools and practices.

Long/Short Term – Supply management measures

Use of non-conventional resources

Water transfers

Water transfers are used as temporal measures during an extreme drought to satisfy water deficit. Scales can vary from local transfers among different supply systems, to regional among two different river basins or even international among distanced basins. They can also be planned as a temporal solution to a drought situation or as a permanent solution for basins or regions suffering from structural water scarcity.

Short Term – Demand management measures

Water saving practices and management

Incentives and penalties

Incentives and penalties of a financial nature are required as a complement of the water saving campaigns, and as the prime measure to enforce regulations.

Incentives are often required for urban water supply companies, municipal or private, mainly in less developed areas, to implement high cost water conservation technologies, which may require an expensive investment. Examples could be the full coverage of every customer with metering, the modernisation of the network in an area of low class population where reliability and equity are low, or the investments required to install separate supply and sewage systems.

Incentives to urban customers are required when the implementation of water savings implies investments in homes and buildings, in particular for low-income populations.

Campaign for immediate water saving

The main strategy is to save an amount of domestic water per year. This objective can be met by: (i) promoting demand for water-saving technology among consumers; (ii) stimulating water-saving technology markets; and (iii) training and informing professionals in this sector. Specific actions can be directed to: (i) professionals linked to domestic water use (i.e. manufacturers, distributors, retailers, plumbers); (ii) large-scale domestic users (i.e. hotels, restaurants, gymnasiums, etc.); (iii) young people; and (iv) the general public.

Water use restrictions

When drought affects supply systems with certain intensity, it might be useful to establish water use restrictions for the different uses. For this purpose it is essential to determine in the first place an order of priorities of use so that this rationale can be followed when defining the uses that have to be restricted first.

Short Term – Impact management measures

Compensations for income loss

This particular action can take several forms depending on national legislation or institutional organization, but the general idea is the provision of aid from the government to the user (money, special loans, free supplies) to compensate for the losses generated by drought.

Tax reduction, payment redemptions

As a result of drought and its associated effects, users might find themselves in the position of not being able to face fixed costs such as taxes, loans or social security payments.

Temporary reallocation of water

Water uses with a low level of priority might be restricted during drought periods in order to satisfy those with a higher level of priority. This is a temporal action during drought periods.

Short Term – Supply management measures

Alternative storage of water

Tanks

A tank means a constructed water container. It is usually fabricated from sheet steel, cement concrete or plastic. Such containers are expensive, relative to the volume of water they store, but they have an important set of advantages over larger, landscape-type storages. They are of particular importance where the resource is very limited and needs to be protected from evaporation and/or contamination. Constructed containers also offer easy prevention of contamination since access to the stored water can be controlled. This includes prevention of access by mosquitoes and other water sourced disease vectors.

Control of water losses and non beneficial uses of water

In regions of water scarcity there should be strong motivation to prevent waste of the precious resource. There are many ways in which water is wasted. Some of these are relatively easy to prevent. In particular losses that occur once water comes within the sphere of man's control should be preventable. Other losses, such as evaporation and removal of flowing water by infiltration into stream beds are, in general, very difficult to prevent.

Leak detection and repair

System losses in urban drinking water supply systems are mainly due to evaporation and seepage in storage and regulation reservoirs, and leaks in water treatment plants, in distribution networks and in home outlets. The used volumes not metered due to inaccurate or non-existent metering, the unauthorised outlets and the unrecorded volumes used by municipal services, such as for watering public gardens or used from fire hydrants, are often accounted as losses, despite the fact that they constitute beneficial uses. Also often accounted as losses are the leaks in households. However, reported leaks in the network are low, much below what is detected by careful monitoring, particularly in old systems. Leaks in the network are generally higher in systems that breakdown very often.

Location of losses

When it is thought that significant volumes of water are being lost unaccountably from a system it is worthwhile making some effort to determine exactly where the losses are occurring. This requires some means of measurement of flows at a number of locations within the system.

Evaporation can be estimated by operating an evaporation pan adjacent to the storage, and making allowance for the higher loss from the pan than from the lake due to differences in energy transfer within the lake and through the sides and base of the pan.

Conveyance and distribution systems are often the source of large wastage of water, but some of it can be prevented.

Water use practices are a major source of wastage. Factory production processes and cooling systems which do not recycle can be very wasteful of water.

There are many opportunities to save water by changing irrigation practices. Similarly sprinkler irrigation can be very wasteful if used in windy daytime conditions in hot and dry climates.

Emergency supply for drought mitigation

Additional emergency supply for drought mitigation, which concern the exceptional use of waters during periods when the normal sources for the storage, conveyance and distribution are insufficient to meet the demand. These periods are limited in time such as the duration of a drought, but the operation of these additional sources has to be planned in advance to be effective and to prevent negative impacts on health and on the environment.

New sources of surface water, including the use of the dead storage in reservoirs and short distance water transfers from nearby systems and or sub-systems, generally associated with negotiations of water rights among farmers and non-agricultural users, including for nature, recreation, municipal and industrial uses. Since most of surface water sources in water scarce areas are already developed and water rights assigned, the use of additional waters requires appropriate planning and institutional framework.

Transfer of water rights

Transfer of water rights between users, where those having the right for a given fraction of stored volumes sell temporarily these rights to other users. This applies to societies where individual water rights are well recognised by law, thus being of difficult application in other societies.

Use of low quality water and use of waste water

Use of low quality water and reuse of wastewater for irrigation of agricultural crops, and landscape, including lawns and gulf courses, in addition or in alternative to water of good quality.

Groundwater use and recharge

Increased groundwater pumping

Changing from the exploration of the perennial yield to the mining yield. A continuous mining of the groundwater is not sustainable but a controlled use of the mining groundwater yield during periods of water scarcity is sustainable when appropriate planning, management and monitoring are adopted.

Use of non-conventional resources

Water harvesting

Water harvesting refers to methods used to collect water (i) from sources where the water is widely dispersed and quickly changes location or form and becomes unavailable, or (ii) that is occurring in quantities and at locations where it is unusable unless some intervention is practiced to gather the water to locations where it can provide benefits.

Reduction of waste of water

In regions of water scarcity, reduction of wastage of water should be part of the thinking and awareness of every individual. It needs to be taught in families to small children and in all formal education systems. In many societies the connection between simple traditional activities and waste of a precious resource is not realised. There is a need for continuous education programs to ensure everyone believes the loss of a single drop of water is a cause for sadness and concern.

Flood spreading

Flood flows are a feature of all landscapes, including regions of water scarcity. A very large part of the annual flows may occur in one or two floods, but the flow is often so large that the water passes through the region and can not be used where rain fell. Some advantage can be gained from these large flows by encouraging them to spread across flat areas. If water can be retained on flat surfaces for a day or two the upper soil layers may be saturated or water may percolate downwards to replenish the local aquifer. In both these circumstances the water thus "harvested" is available for later use, in the first case for growth of crops or to support grazing and in the second case for whatever purpose groundwater is used (Prinz, 1996; Missaoui, 1996).

Rainwater collection

Rainwater can provide a considerable water resource, not only in humid regions but also in semi arid and arid regions. Large volumes of water flow from roofs. In many regions roof water has not been collected because traditional roofing materials did not permit easy collection, and storage of collected water was difficult and expensive. However in recent years the ready availability of some form of roof sheeting and innovative ideas for water storage have made roof water a serious water resource consideration. There is a great need to encourage its use and to teach simple, low-cost means of collecting water from roofs, and constructing suitable storage facilities.

Water conservation, systems maintenance and management

Reduction of evaporation

There is no effective economic way to reduce evaporation from large water bodies. At the planning stage reservoir locations need to be chosen to minimise evaporation – by ensuring the volume to surface area ratio for the reservoir is a maximum.

Evaporation can be reduced from small, vertical sided reservoirs by providing a roof to shield the reservoir from solar radiation or by covering its surface by light coloured floating blocks.

The most effective means of evaporation reduction is to minimise the water surface exposed to the atmosphere and to the sun. Deep storages are to be preferred. Subsurface storage can be very effective for evaporation reduction. However with subsurface storage there will always be seepage losses and so these must be weighed against the gains from evaporation reduction.

Changes in reservoir water release equipment

Changes in reservoir water release equipment for more accurate control of volumes supplied, easy adjustment of discharges in the course of the time, and adopting automation when decision models are effectively operating in real time.

However, adopting rigid schedules in pressurised systems generally do not lead to easy adoption of savings at farm level.

Canal lining

Canal lining to avoid seepage losses. However, canal lining is only fully effective when canal management is improved, maintenance is carefully and timely performed, and other canal structures are also improved for enhanced conveyance and distribution service. Otherwise, investment costs may not be justified and resulting water costs may be excessive for farmers if the water service remains at low performance levels.

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Chapter 14. The testing of the MEDROPLAN Drought Management Guidelines

The MEDROPLAN team

SUMMARY – According to the MEDROPLAN project contract, Work-package 8 was devoted to testing the Drought Management Guidelines drafted in Work-package 6. Testing had be carried out by each partner with reference to a different region or watershed than the one where the risk analysis has been carried out. The outcome of such a process were conclusion reports by each partner on the testing of the Guidelines, with conclusions and recommendations on the applicability of the Guidelines to each country, and with possible improvements to the Guidelines.

Key words: stakeholder, watershed, interviews, dialogue, feedback.

Proposed methodology for testing the Guidelines

The general structure of the testing of the Guidelines can be summarized as follows:

(i) Selection of the watershed/region.

(ii) Identification of stakeholders involved in drought management in the selected watershed/region.

(iii) Contact of the identified stakeholders and distribution of the Guidelines.

(iv) Collection of the feedbacks during a local workshop through individual discussions, interviews and filling of a questionnaire.

(v) Analysis of the results and conclusions.

Selection of the watershed/region

Since the testing was to be made in a different region or watershed from that in which the risk analysis had been carried out, the first decision was to choose such a region or watershed. In order to increase the probabilities of a successful testing, the choice should be made taking into account at least the following two main elements:

(i) The region or watershed in which the Guidelines were to be tested (RGT) should have a similar or at least comparable socio-political and organizational framework to the one for which the case study has been carried out (RCS). Regarding the physical features, of course some degree of similarity was also needed.

(ii) To be sure of a good collaboration of the decision makers and stakeholders of the RCS is another key element, since they will be requested to provide an important effort in terms of intellectual contribution and of time availability.

Identification of the institutions and persons for testing the Guidelines

As already mentioned, this is a critical step for a successful testing. Indeed, the objective was not just to present the Guidelines, but rather ask the invited people to simulate their application to the selected watershed/region, pointing out their weakness and strengths. Thus, it was mandatory to select people with a strong degree of involvement in the various aspects of drought management. They should include stakeholders in all sectors of drought management – from policy-makers, to farmer's unions, to scientists. The mapping of the organizations and institutions (Organizational Component of the Drought Management Guidelines) was of help in the decision. Although a large group would be advantageous in terms of a larger scope of views, a limited group well chosen persons (e.g. six) could be the optimum, since more people would make it difficult a fruitful personal interaction during the workshop.

Contact of the identified stakeholders and distribution of the Guidelines

After the identified stakeholders agreed to collaborate, the Guidelines were submitted for reading prior to the participation to the workshop. If felt appropriate, other material could also be provided, e.g. the mapping of the institutions. Considering that the amount of requested reading may be in some cases too much a burden, it may be appropriate, to suggest which parts of the Guidelines require a careful reading, according to the peculiarities of the investigated region/watershed as well as of the specific expertise of the invited stakeholders. For instance, a person in charge of hydrometeorological monitoring in the region may be more interested (and thus contribute with a more fruitful feedback) to the drought monitoring and characterization aspects. Similarly, people in charge of rainfed agriculture may be more interested to drought impacts than to water supply system aspects, and vice-versa. In general terms, it is preferable to have interesting feedbacks on very specific aspects rather than general superficial comments on the whole.

Organization of local workshops to collect the feedbacks from the involved stakeholders

The objective of the workshops was to gather the invited stakeholders in a non-formal atmosphere in order to collect their feedbacks through individual discussions, interviews and filling of a questionnaire (see Annex 1). One and a half was sufficient, since only one day may not be enough, while a longer duration could interfere with the invited people commitments, thus limiting the active participation to the workshop.

For the success of the workshop it was important that the invited people should be aware beforehand of their active role, making it clear the objectives of the workshop, as well as the proposed agenda. The presentations by the partner team should be kept at a minimum, bearing in mind that they should not be merely informative but rather serve as a stimulus for the discussion.

In the following sections, an overview of the process followed in each country and the conclusions issued in each Workshop are presented.

Cyprus

The general structure of the testing of the Guidelines included the following:

(i) Selection of the Project; For the testing of the Guidelines, the Paphos Irrigation Project was selected. For this project all the necessary data were collected and analyzed which including catchments and serviced area precipitation series, surface inflows, groundwater safe yields, releases from the dam and ground water extraction, cropping patterns, domestic and irrigation water demands, water scarcity, drought events, measures taken during drought events, consumers reactions etc.

(ii) Identification of stakeholders involved in drought management in the selected project; Six stakeholders were identified four representing the Farmers unions and Associations, one representing the local water authority and another representing the local domestic water distributor. Two more stakeholders were invited as consultants to the project, involved mainly at the national level for drought management.

(iii) Testing of the Guidelines for the Cyprus Case Study was conducted in Paphos, Cyprus, 25 and 16 of September 2006 according to the Protocol described in the Guidelines Chapter 21.

Conclusions the of the workshop

From the presentations and discussions made during the Workshop the following can be concluded.

(i) Cyprus is suffering from frequent meteorological droughts, which in many cases end in hydrological drought.

(ii) Cyprus is in need of Drought Preparedness Guidelines and the Draft Guidelines presented during the Workshop shall be of great assistance to the Cyprus State and to the Cyprus Water Stakeholders in general for the preparation of Drought Preparedness Plans.

(iii) The Guidelines provide the scientific knowledge for carrying out the Drought Identification and the Risk Analysis studies and the methodology for the preparation of the Drought Preparedness Plans.

(iv) The Guidelines were tested on the Paphos Irrigation Project and the results from the drought identification and the risk analysis studies, as well the testing of the methodology proposed were found to agree with the project hydrological conditions and the measures proposed were similar to those implemented during the drought events in the years 1996-2001.

(v) The participants agreed that the Drought Preparedness Plans to be prepared in accordance with the Draft Guidelines shall be effective an efficient for mitigating droughts, and that the drought preparedness plans should complement the rational integrated water management plans.

(vi) Concerning the Creation of the Mediterranean Drought Preparedness Network the participants agreed that such a network shall be beneficial for the region and Cyprus if its objective and principles of association are well defined and the countries to participate shall abide by these principles and objectives.

Greece

The Naxos island was selected for Testing and Revising the Medroplan Drought Management Guidelines for the Greek Case Study. The workshop for testing the Guidelines was conducted in Naxos, Cyclades, 15-16 September 2006 according to the protocol described in the Guidelines.

The general structure of the testing of the Guidelines included:

(i) Translation and adaptation of the English Guidelines to Greek Guidelines.

(ii) Selection of the watershed/region.

(iii) Identification of stakeholders involved in drought management in the selected watershed/region.

(iv) Contact of the identified stakeholders and distribution of the Guidelines and questionnaire.

(v) Collection of the feedbacks during a local workshop through individual discussions, interviews and filling of a questionnaire.

(vi) Analysis of the results and conclusions.

The questionnaire, translated in Greek, was distributed to the participants during the meeting. The feedback was collected by the responses to the questionnaire and by group interviews during the meeting. The interviews were not conducted in private and they allowed the participation of all the stakeholders. Their structure and style was an open discussion with the participation of all the stakeholders rather than an interview in the strict sense of the term. Notes were taken down during the meeting.

Analysis of the results and conclusions

The main conclusions of the testing and revision of the Guidelines are outlined below.

The Naxos Island, as well as the whole region of Cyclades, is suffering from water management problems, especially in the administration services. The various services (municipalities, prefectures, meteorological services, etc) do not know the data that other services possess and furthermore they do not will to share these data with other services.

The Naxos dam was constructed in 2002.The dam is badly managed and it is still not handed over officially. The problem is that two different municipalities are involved (the Municipality of Naxos, which is situated on the coast shore, and the Municipality of Drymalia, which is situated on the mountains and comprises the water basin of the dam). Although the water basin of the dam is within the territory of the Municipality of Drymalia, since the dam is located within the territory of the Municipality of Naxos, it is the Municipality of Naxos who is responsible for the management of the dam. The 25% of the supply of the dam goes to the Municipality of Drymalia and 75% is consumed by the Municipality of Naxos. For the time being, the dam is being used but there is no control at all. From the dam, water is sent to a water reservoir by the only existing water pipe. Therefore, both Municipalities are being supplied with water from the water reservoir and not directly from the dam.

Water uses have not been approved yet. The water uses were supposed to be delivered from the Region until 2005 and now it is the Prefecture responsible for them. There is an urgent need of definition of the water uses. Hydrogeological studies, which will define the water uses and the water demands, for the whole island need to be conducted. The drillings on the island are incontrollable without management and without permissions. Wells exist even within the homes of the islanders and there is a constant conflict for the water uses.

Regarding irrigation wells, there is neither a need for the assessment of environmental impacts, nor permission from the Prefecture. All that is required is an application to the hydrogeological services. The farmers do overuse the water supplied (or drilled). They use water demanding crops (e.g. potato) instead of dry crops and they do produce much more than actually needed for supply to the market. Yet, the farmers are not powered enough to fight for their rights to claim water. This happens because most of the farmers are also involved with tourist activities.

During the 1989-1993 drought period, the city of Naxos did not confront serious drought problems because water was supplied by a few wells at altitude 100 m with depth 500-600 m. The owners of the wells were informed by the Municipality of Naxos to supply the island with water. The operation of the dam supported the islanders with a different education: there is no management when there is lack of control. Since then, water supply is constant at all times. During this drought period though, in the rest of the islands situated at the Prefecture of Cyclades water was supplied only from midnight until 6 in the morning to urge people to save water, in order to confront drought.

In 1991, the Municipality of Naxos was funded to carry water to fill the reservoir. A part of this funding was used to buy water. The farmers had no more interest in irrigating their crops, but to sell water (the price was about 2,29 €/m^3 – calculated with the formula of the compound interest) and the obvious result was the over-pumping of the aquifer. The water was used by the Municipality for tourism. The infrastructure developed during this period (basically for tourism) was conducted with funds from the Ministry of Agriculture, that were meant for the farmers and still, it is the tourists who are using this infrastructure and not the farmers.

There are definitely ways to save more water. Specific infrastructure must be implemented in order to exploit in the best way the water resources. For the time being, the cost accounted water is the 70% of the whole, while the other 30% is losses. The water network is much supported from wells and sources. In some villages of the island, they are still using pipes from amianthus. The restoration of the network is being implemented slowly in the island and the pipes from amianthus are being replaced by pipes from polyethylene. Every village has its autonomous water network. The situation is being monitored by the Technical Services of the Municipalities.

Naxos has actually rich water resources and if correct management is implemented, Naxos could aid essentially other arid smaller islands of the Cyclades by supplying them with water. A thorough hydrogeological study for the aquifers of Naxos must be carried out. During the summer months, people tend to overspend water and there are tankers that carry water to the villages. The water law 3199/03 is not being applied. The administration is already out of the deadline, since the Management Plans shall be applied until 2009 and no planning has started to this date. The Authorities can not comprehend the European Framework.

The aquifers of Naxos could be used for water supply, but instead the water is being lost in the sea. However, the funding of such infrastructure cannot be operating in Greece. Due to bad management, such funding does not exist.

During this year (2006) a pipeline was constructed to supply the Koufonisia Islands with water. These are small arid islands located south-east of Naxos.

There is also a problem in respect to the water quality in Naxos town. It is not the water that has poor quality, but the pipes used are so old and corrupted, that the water reaching the taps of the islanders has serious problems. The water basin of the dam is clear, though. There are no crops or cattle to this area. In fact, nobody drinks the water from the dam. This water is used for anything else, but drinking. The water that people drink comes from a source situated outside the city of Naxos, which belongs to the Municipality of Naxos.

Italy

The testing of the Italian version of the Guidelines for drought preparedness has been carried out in Siracusa, Sicily, on September 25-26, 2006. According to the TOR for testing, the following steps have been followed:

(i) Translation and adaptation of the English Guidelines in Italian.

(ii) Selection of the watershed/region.

(iii) Identification of the stakeholders/experts involved in drought management.

(iv) Contacts with the identified stakeholders and distribution of the draft Guidelines.

(v) Collection of the feedbacks during a workshop.

(vi) Analysis of results and general conclusions.

Due to the peculiarities of the Italian situation regarding drought management, which exhibits relevant differences among the regions due to climatic, as well as institutional features, it has been decided to submit the Guidelines to stakeholders originating from different watersheds. This has been done with the objective of an improved general effectiveness of the testing, less biased from the particular situations, though strictly valid at the Italian national level.

The invited stakeholders/experts have been preliminarly identified by June, 2006. In particular, water managers recently involved in recent droughts in Po basin, Sardinia, Puglia and Sicily, research experts, as well as people from national/regional governments involved in national and international water legislation have been selected. The list of participants is included in Annex A.

It may be worthwhile to mention that the direct involvment of the stakeholders/experts in the modification of the text resulted in a good interaction, which, in the opinion of the Italian team, led to an significantly improved version of the Guidelines.

Analysis of results and conclusions

The general conclusion that can be drawn is that there is a significant interest and expectation in Italy for Guidelines for drought management. This is somewhat confirmed by the fact that some of the stakeholders have requested permission to use parts of the Guidelines, for drafting planning documents of their interest.

From the feedbacks gathered during the workshop, the following main comments regarding the Guidelines can be summarized:

(i) An introductory chapter describing droughts and their main damages and impacts could be included, in order to better clarify the problems addressed by the Guidelines.

(ii) Summary and conclusions should be included before the chapter 1.

(iii) At point 2.1 a short presentation of the social perception of drought impacts which justify the necessity of the Guidelines should be introduced.

(iv) in chapter 2 at least one or two statements should be added on the economical criteria to be followed for selecting drought mitigation alternatives and to select the priority of action.

(v) in the contents of drought preparedeness Plan a reference to the need of establishing standards (e.g minimum water municipal need to be satisfied during severe shortage situations, etc.) should be made.

(vi) measures should be classified according to the affected sector.

(vii) strenght and weakness of each drought mitigation measures measure, giving a few examples on the preferred actions for specific problems to be addressed.

Morocco

On 14-15 November 2006, an expert meeting was held in Rabat for testing the Drought Management Guidelines for the Moroccan case study.

For the testing of the Drought Management Guidelines, the Tadla Sub-basin of the Oum er Rbia Watershed was selected because of its diversity in terms of agro-ecological scope (plain, mountain hill and mountainous zone), water resources availability (surface water, underground water, snowmelt) and agricultural production systems (irrigated agriculture, rainfed agriculture, pastoralism, and livestock). For the purpose of the testing, all the necessary data were collected and analyzed including precipitation historical series, surface inflows, releases from the dam and ground water extraction, cropping patterns, domestic and irrigation water demands, drought events, measures taken during drought events, drought impacts.

The workshop took place on 14-15 November 2006 in the premises of the National Drought Observatory Centre at Institut Agronomique et Vétérinaire Hassan II, Rabat, with a total of 17 participants including 5 from the central administration of Ministries of water and agriculture, 6 from the regional agriculture and water authorities, 2 from national institutions and 4 representing the IAV Medroplan Team.

The collection of the feedbacks of the stakeholders through individual discussions, interviews and filling of the questionnaire took place before and during the workshop.

(i) Integrated water resources management, Oum er Rbia River Basin.

Objective: Experience of drought mitigation through water resource management strategies based on *combination of surface and ground water usage.*

(ii) Irrigation water allocation strategies under drought conditions in the Tadla Perimeter.

Objective: Understanding priorities and mechanisms for water allocation for different crops and other uses for irrigated agriculture.

(iii) Drought management programme for Provincial Rainfed Agriculture of Beni Mellal.

Objective: Drought mitigation measures for crops and livestock under rainfed conditions.

(iv) Integrated water resources management, Sous-Massa River Basin.

Objective: Experience of drought mitigation through water resource management strategies based on *predominantly ground water pumping.*

(v) NGO representing Farmers' Unions and Associations for Agriculture, Agribusiness and Rural Development Professionals.

Objective: Expectations of professionals regarding existing water and drought management policies, including legislation and overexploitation of water resources, particularly groundwater.

(vi) Decision making on water planning at the national level.

Objective: How to define optimum scenario for water allocation between users under different drought situations, at national and provincial levels to resolve conflicts.

(vii) Decision making on water use in irrigated perimeters.

Objective: Understanding the difficulties of setting adequate water allocation rules in the irrigated agriculture because of competition between national interest vs individual user's interests: how to define national interest as compared to regional / individual interests. From the analysis, develop the concept of shared vision methodology to answer the above questions.

(viii) Use of remote sensing technologies for drought monitoring at national and regional / local levels (Royal Centre for Remote Sensing).

Objective: Insisting on added value of using remote sensing indices in combination with proposed Medroplan drought monitoring indices in order to improve the drought early warning systems in the Mediterranean.

(ix) Components of the National drought mitigation programme with particular focus on crop monitoring and agricultural insurance (Crop Production Division, Ministry of Agriculture).

Objective: Understanding drought development stages of field crops to improve triggering mechanisms for declaring deteriorating drought conditions, and policies to develop agricultural drought insurance schemes.

Conclusions from the Workshop

(i) Morocco, like most Mediterranean countries, frequently suffers from severe drought episodes. So far, reactive management of the drought crisis has been the rule until recently when, following the severe drought nationwide of 2000, the development of a new pro-active approach started.

(ii) The development of a Drought Preparedness Guidelines Manual has been welcomed by the stakeholders participating in the workshop for testing the Draft Guidelines, as an instrument to aid decision makers and drought managers to develop national and provincial drought plans.

(iii) The Guidelines were tested on the Oum Er Rbia Subwatershed of Tadla. The results from the drought identification and the risk analysis studies indicate that the performance of the indices used to characterize the drought events and intensities was in agreement with the participants' field truth. Thus, the Methodology Components of the Medroplan Draft Guidelines is appropriate although further improvements through integration of remote sensing indices may be necessary.

(iv) For the organizational component of the Guidelines, observations by the stakeholders participating in the workshop emphasizes the necessity of developing further the legal framework for water management under drought conditions in the case of Morocco. The participants do recognize the usefulness of the Medroplan Guidelines as an entry to such development.

(v) The Guidelines do also provide a good scientific basis for elaborating methodologies and tools for drought risk analysis, drought impact assessment and for preparing drought plans. However, these Guidelines still need further simplification for practical use by drought managers. Also, the vulnerability issue needs to be more developed by integrating information layers about soil and water resources conditions, crop development stages, rangeland status and livestock feeding conditions, economic and social indicators.

(vi) The participants insisted on the use of Medroplan Guidelines findings to develop awareness among the decision makers involved in integrated water and drought management in Morocco.

Organization of meeting, workshops and field days in some of the seven existing Regional River Basins would be a good opportunity to improve institutional capacity building for drought planning, mitigation and response.

In addition to this training activity, communication of the Medroplan Guidelines attributes among various stakeholders is felt to be an important determinant for drought preparedness, indicating the usefulness of the proposed Medroplan Web pages. For developing exchange of information, tools and methodologies between Mediterranean experts, it is proposed to add to the Web page a Discussion Forum to allow such exchanges. This will strengthen the proposed Mediterranean Drought Preparedness Network.

Spain

Testing and Revising the Drought Management Guidelines for the Spanish Case Study was conducted in Illueca, Zaragoza, 26-27 September 2006 according to the protocol described in the Guidelines.

The Ebro River Basin was selected for the purpose of testing the Guidelines for Drought Management.

Nine stakeholders participated in the workshop. They belonged to different institutions at National, Regional and Local level:

(i) ENESA (Spanish National Body for Agricultural Insurance).

(ii) Zaragoza (City Council of Zaragoza).

(iii) COAG (Farmers Trade Union).

(iv) Comunidad General de Riegos del Alto Aragón (Higher Aragón River General Irrigation Community.

(v) Comunidad General de Regantes del Canal de Aragón y Cataluña (Aragón and Cataluña Canal General Irrigators Community).

(vi) Confederación Hidrográfica del Ebro (Ebro River Water Basin Authority).

(vii) Universidad Politécnica de Madrid.

The feedback from stakeholders was collected by means of the responses to the questionnaire and group interviews during the meeting. The interviews were public and allowed the participations of all stakeholders. The structure of the interviews and the method for analysing the results and conclusions are outlined below. All interviews were tape-recorded.

First interview: Integrated water resources management

Objective: Experience of an established drought management plan.

Some questions for the interview:

(i) The action protocol established for the Ebro River Basin defines alarm thresholds based on reservoir volumes. Could you explain in more detail the use of these indicators?

(ii) Are there specific measures associated to each level? How are these measures classified? (First the most simple, avoid impact to urban supply…).

(iii) What's the priority order established for water supply?

(iv) How can be supply restricted to the different uses during a drought period?

Second interview: Economic instruments applied to drought management

Objective: Analysis of the existing and potencial proactive measures and their adoption in management policies.

Some questions for the interview:

(i) What's the role of economic instruments in drought management?

(ii) Are there new paradigms in price intervention?

(iii) Are the experiences in countries with different development levels adaptable to other cases?

(iv) How can users be involved in the design of new insurance products?

(v) How can farmers be involved in risk management?

Third interview: Users' groups

Objective: Compare the point of view of two users' groups with different priorities and vulnerability in order to determine the real existing of conflict among them

Forth interview: Groups affecting public opinion

Objective: Evaluate the reality of quantitative analysis of impacts that support the perception affecting general public opinion

Questions for all interviews:

(i) What aspects of your activity could be interesting for other stakeholders in relation to drought management? (Scientific knowledge, operational experience…).

(ii) What aspects of the methodology proposed by the Guidelines could be helpful to solve conflicts?

(iii) Are the methodology and concepts adequate to face real drought events? Suggestions.

Analysis of the results and conclusions

The main conclusions of the testing and revision of the Guidelines are outlined below.

(i) Diagnostic

– Define the situation of the watershed or region: water scarcity, aridity, drought, or desertification. It has to be clear that, in principle, Guidelines are conceived and designed only for drought situations.

– Evaluate social vulnerability, both induced by drought or by human activities.

(ii) Time for applying the Guidelines to develop drought management plans

– The time for applying the Guidelines to develop drought management plans should be during non-drought periods if possible in order to avoid costly emergency measures.

– Normal and pre-alert situations are the right moment to reduce vulnerability.

(iii) Audience of the Guidelines

The target audience of the Guidelines should be clearly indicated:

– The executive summary is targeted to all but especially to decision makers, stakeholders and the general public.

– The Technical Annexes of the Guidelines are targeted to technical experts that would implement some of the aspects of a drought management plan.

(iv) Communication and participation

– More emphasis should be made on the importance of stakeholders' participation in the process of developing a drought management plan.

– Media have to be won over to the cause.

– Messages to the general population during pre-alert and alert phases must be positive in order to reduce alarm and induce people to adopt the proposed measures.

(v) Vulnerability evaluation

– It is essential to include the vulnerability aspects form the economic and social point of view.

– Evaluate mechanisms to reduce human-caused vulnerability.

(vi) Synergies with integrated water resource management and agricultural strategies

– The permanent measures to save water or to adopt rational cropping patters have to be developed in synergy with current overall strategies.

– Water saving needs to be a permanent action to reduce vulnerability to drought.

(vii) Steps in the operational management

The operational management should include three sequential steps:

– Balancing supply and demand and improving water use efficiency. These measures are targeted to decrease vulnerability.

– Minimizing the impacts in the sector.

– Reactive measures should only be taken if the other two steps fail to avoid drought damage.

Aknowledgements

The Medroplan team acknowledge all the participants in the Workshops of Testing the Drought Management Guidelines for their disponibility, their valuable contributions and their willingness in the process of improvement the Guidelines for Drought Management.

Annex 1. Proposed questionnaire to be distributed during the meeting

Section I: Characterise the decision process in your institution/organisation

Name: Address: email:

1. Is your institution…

Public agency	
Private company	
Association of stakeholders (farmers)	
NGO?	
Another type of institution	

2. What is the level of intervention of the institution?

National		Local	
Regional		Other	

3. Which water uses are related to the institution?

Agricultural		Recreation	
Industrial		Others	
Domestic Consumption			

4. What are the objectives of the institution?

Water management		Agricultural production	
Water distribution		Promote new infrastructures	
Policy maker		Agricultural production	
Develop information systems		Industrial production	
Promote integrated management		Tourism activity	
Establish the tariff rules		Thermo-electric power generation	
Promote water resources conservation and protection (quantity and quality)		Promote a water network	
Ensure water infrastructure's maintenance and security		Research	
Promote new infrastructures		Others	

5. Is your institution a…

Policy-maker	
Other stakeholder	

6. ONLY FOR POLICY MAKERS: If it is a decision-maker, is the institution autonomous for taking decisions?

Yes	
No	
Yes, but… (please describe)	

7. ONLY FOR POLICY MAKERS: If the institution is not autonomous for taking decisions, do other levels of decision or institutions impose the decisions?

Level	Institution
National	
Regional	
Local	
Other	

8. ONLY FOR POLICY MAKERS: Are external opinions considered in this process?

Yes	
No	

9. ONLY FOR POLICY MAKERS: If external opinions are considered in this process, who gives opinion?

Consultants	
NGO's	
Media	
Other	

Section II: Characterise your role in the decision process related to drought

10. ONLY FOR POLICY MAKERS: Have you been actively involved in the decision making process undertaken in the specific case study in your country?

Yes	
No	

Explain:

11. ONLY FOR OTHER STAKEHOLDERS: Have you been actively involved in the decision making process undertaken in the specific case study in your country? Explain how:

Bilateral meetings	
Steering groups	
Advisory groups	
Consultation methodologies	
Others	

Explain:

Section III: Characterise common management practices during drought

12. Which is the extent of acceptance of the decisions and established rules related to drought management?

Entirely accepted	
Partially accepted	
Partially Contested	
Entirely Contested	

13. Are there conflicts arising from competition between different water uses?

No	
Yes	
Obs.	

Explain:

14. From your viewpoint, should inefficient use of water be penalised?

Type of inefficient use	Type of penalty

15. Are there environmental problems caused by drought?

Type of problem	Is the problem taken into account in drought management plans
Soil erosion	
Desertification	
Salinisation	
Microbiological contamination of groundwater resources	
Contamination of groundwater (please specify the kind of contamination)	
Contamination of surface waters (please specify the kind of contamination)	
Other (please specify)	

Section IV: Drought management actions

16. Your participation in drought management meetings…

Only this one	
Other Medroplan meetings	
Occasionally	
Drought management is my main professional activity	
Other	

17. Expected role of MEDROPLAN in drought management …

18. Which management actions can be implemented to manage drought with success? (please specify if these measures are related with measures of management or investment in infrastructures and if they are supported by the present national or regional regulations/laws). **Who should implement these measures?**

Action/Measure	**Who**	**Management /Infrastructure**	**National /Regional /Local**
1.		M I	N R L
2.		M I	N R L
3.		M I	N R L
4.		M I	N R L
…		M I	N R L

Section V: Interactions of the policy makers and stakeholders in the case study

19. Purpose of the interactions between stakeholders.

Explain the interactions of your institution with other stakeholders and describe the mechanism of interaction according to the following mechanisms of interaction:

Mechanism of interaction	**Group of stakeholders**
Advice	
Technical Support for specific projects	
Definition of Strategies & Spatial planning issues	
Institutional meetings	
Specific water availability issues	
Specific water quality issues	
Environmental issues	
(others, please specify)	

20. Periodicity of the interactions between stakeholders

Once in less than 1 month	
Once between 1-6 month	
Once in more than 1 year	

Section VI: Contribution to the Medroplan Guidelines

21. Your role in Medroplan

Collaborator with a partner	
Participant in this workshop only	

22. FOR COLLABORATORS WITH PARTNERS ONLY: What aspects of your collaboration with a partner are relevant for the Guidelines?

23. FOR PARTICIPANTS IN THIS WORKSHOP ONLY: What aspects of your work are related to the Guidelines?

Section VII: Suggestions and comments relevant to the Medroplan Guidelines

Chapter 15. Application of the Drought Management Guidelines in Cyprus

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SUMMARY – Cyprus is the third largest island of the Mediterranean Sea with an average area of 9,251 Square kilometers and with an intense Mediterranean climate with an average annual precipitation around 476 mm. The annual water availability is less than 500 m3/capita and so far it has developed more than 75% of the natural water resources, and has implemented sea water desalination and re-use of the treated domestic effluents. Its legal framework vests ownership of the water resources to the Government and it gives to the Government the power to construct waterworks and sell water at prices approved by the Parliament. It also gives the right to physical and legal entities to drill their own borehole and abstract groundwater and the right to organized communal entities to construct their own water works for surface and ground water development and utilization. The law is now adapted to comply with the Water Framework Directive. Cyprus prepared its water master plan in the 1970's and its implementation lasted for more than 30 years, with almost all surface water resources developed and the groundwater over-pumped. However, due to the observed climate changes and the repeated droughts the island faced serious periods of water shortages during the decade of the 1990's. To adapt to drought and minimize its adverse effects Cyprus was forced to modify its water policy by the introduction of seawater desalination, to accelerate the construction of new water projects and the recycling of the domestic effluents, to intensify the water demand management methods, and finally to develop and implement drought mitigation plans.

Key words: Southern Conveyor Project, legal framework, institutions, drought mitigation plan, drought characterization, impacts, monitoring, actions, stakeholders.

The planning framework

Defining the planning purpose and framework

Overview

Cyprus being one of the most drought prone areas in the Mediterranean area, with frequent drought events of high severity and long duration, has great experience on drought management. The authors of this Chapter have been involved in the preparation and execution of drought mitigation plans in Cyprus during the last 30 years when the worst of the drought events occurred.

Cyprus is an island in the North Eastern end of the Mediterranean Sea, with an area around 9251 square kilometers. The island has a Mediterranean climate with mild wet winters and hot summers with an average annual precipitation around 476 mm, mainly falling in the winter and spring months and geographically varying from 250 mm in the plain areas to 1200 mm on the top of the high mountains. The evapotranspiration varies from 1722 mm/year in the low lying areas to 1243 mm/year in the areas above 300 meters, 75% of which occurs in the months May to October.

Cyprus is inhabited by 802,000 people, of which 68% live in urban areas and the remaining in the rural areas. Today's economic activity is centered on the services, which contribute more than 75.6% to the GNP, the industry contributing 20% and the agriculture contributing 4.4%. About 715,000 people live in the Government controlled areas.

The natural water resources of Cyprus in the areas under Government control are very limited amounting to 307 million cubic meters (or 429 m3/capita), made up from 197 million cubic meters surface water, 110 million cubic meters from groundwater. Another 36 million cubic meters are available from non-renewable sources: 30 million cubic meters from desalination of seawater (introduced in 1997), and 6 million cubic meters from treated recycled domestic effluents.

From the total area of 9251 square kilometers, 45.8% is agricultural land, 7.5% is carob land, 19% is forest land, 9% is scrub land, 11.9% is barren land and 6.9% is build up areas. From the agricultural land 90% is dry or rainfed land, 6% is cultivated with annual crops (potatoes, onion, and vegetables) and the remaining 4% is cultivated with permanent crops mainly grapes, citrus, deciduous and olives. Agriculture consumes about 75% of the water resources, while the domestic and industrial sectors consume the remaining.

Cyprus with very limited water resources is vulnerable to droughts because it has developed most of all its natural water resources, with most of its aquifers depleted, and no perennial rivers. Due to climatic changes the water availability has decreased by as much as 40% compared to the original quantities estimated in the 1970's with all projects yielding less water, while the demand is increasing because of population increase, the population redistribution (movement of 200,000 people since 1974's Turkish occupation) and the rising of the standard of living.

Water resources development

In 1971, Cyprus started implementing a Water Master Plan, based on the Integrated Water Resources approach. Since then it has implemented five out of the six major projects included in the master plan with the sixth not being implemented because of the Turkish occupation of 37% of the island area, developing almost all its natural water resources, surface and groundwater. The remaining undeveloped water resources are very limited and expensive to develop. Since the year 1960, the capacity of the constructed dams has increased from 6 million cubic meters to 307 million cubic meters in 2002. The groundwater resources were developed early in the 1950's and 1960's, being easier and cheaper to develop, by individuals, by digging wells or drilling boreholes. Although water conservation measures were implemented early in the 1960's as soon as it was realized that their depletion was imminent, this did not avoid the depletion of the major aquifers, since water demand continues to increase at a higher rate than sustainable water resources development. Finally to keep up with the increasing growth of water demand and to face the water shortages caused by the repeated drought events, water augmentation was achieved by the introduction of seawater desalination and the recycling of the domestic effluents much earlier than anticipated in the master plan. From the implementation of the water resources development plans the available water resources now presently used are estimated at 245 million cubic meters per year as shown on Table 1 below.

Table 1. Water availability in Cyprus by source

Description	Quantity (Km^3/year)	Remarks
Renewable water resources	0.209	All internal
Surface	0.099	From dams with capacity 304 Mm^3
Groundwater	0.110	From aquifers all in the area under Government control
Non renewable water resources	0.036	Recycled and desalination
Recycled domestic effluents	0.006	Tertiary treated domestic effluents
Desalination	0.030	From two desalination plants
Total water resources	0.245	

Water use by sector

The present water demand is estimated at 245 million cubic meters per year out of which 60-70 million cubic meters are used for domestic consumption and for tourism, 5 million cubic meters are used by the industry and 170-180 million cubic meters are used for irrigation. Table 2 shows the total water consumption for the year 2002 by source, including the production of waste and the desalination water. The irrigation demand is consumed for the irrigation of permanent crops (about 40% of the total area and 55% of the total annual water demand) and for annual crops covering an area 60% of the total with 45% of the total irrigation water consumption. The wastewater discharge on the table shows the amount of domestic effluents that could be treated and recycled to be used by the irrigation sector.

Table 2. Total consumption and wastewater discharge by sector

Description	Quantity (Km^3/year)	Remarks
Consumption		
Domestic consumption	0.070	
Agricultural	0.170	
Industrial	0.005	Included in domestic
Electric power and cooling	0.000	Use of seawater
Total consumption	0.245	
Wastewater discharge		
Domestic	0.05	
Industrial	0.00	
Total wastewater (industrial + domestic)	0.05	
Discharge into continental	0.04	
Discharge directly to sea	0.04	

Case study: The Southern Conveyor Project (SCP)

The Southern Conveyor Project (SCP), one of the six identified in the Master Plan, is the largest water development project ever undertaken by the Government of Cyprus. The basic objective of this project is to collect and store surplus water flowing to the sea and convey it to areas of demand both for domestic water supply and irrigation. The project aims at the agricultural development of the coastal region between Limassol and Famagusta, as well as to meet the rising domestic water demand of the towns of Limassol, Larnaca, Famagusta, and Nicosia, of a number of villages and the tourist and industrial demand of the southern, eastern, and central areas of the island (Fig. 1).

Fig. 1. Southern Conveyor Project layout.

Hydrological structure of the SPC (Fig. 1)

The project consists from three dams, one main conveyor, two water treatment plants, two desalination plants, an irrigation distribution system and a domestic waste water treatment plant for recycling the domestic effluent.

Water availability and allocation in the SPC

The project water yield was originally estimated at 96 m^3/year, about 38% of the total annual water demand in the areas under Government Control and was allocated to the two main sectors as follow.

(i) Domestic water supply: 50 m^3, increasing annually by 2%.

(ii) Irrigation (for 13,985 Hectares): 46 m^3 for irrigation.

The Southern Conveyor Project is operating since the year 1987 and during these years it was found out that it was unable to supply the originally planned quantities because due to repeated droughts and due to climatic changes the quantities of water available from the project were by 40% less than the planned with a water deficit of 43 million cubic meters. This resulted to the implementation of water rationing in the years 1991 and 1996-2000 both on the domestic supplies and on irrigation supplies and the construction of two seawater desalination plants by almost 10 years ahead of the planned time.

Organizations, stakeholders and legal framework in the SPC

Organizations

The administrative body, which is responsible for the construction, operation, and maintenance of the Southern Conveyor Project, and generally for the supply of the available water resources, is the Water Development Department. The Council of Ministers approves the annual budget for the operation and maintenance of the project, within the Government Budget, and set the water tariffs, with the approval of the House of Representatives.

Stakeholders

The clients to the project are made of two groups, the domestic water users legal entities and the irrigators, mainly individual persons and in some cases legal entities. Since Cyprus is suffering from water scarcity there is always a conflict between the consumer groups and within the groups both at the planning stage and during the operation especially under water shortage conditions.

Legal framework

Although the existing laws do not mention specifically any action that must be taken under water scarcity conditions, the existing provisions give the right and power to the Council of Ministers to allocate the existing water resources, based on criteria and conditions with a view to minimize adverse effects. Based on the existing law the Council of Ministers approves proposals or modifies proposals for the water allocation and reallocation under water scarcity conditions. The Government usually compensates the stakeholders adversely affected by the water scarcity.

Organizational component

Legal framework

Existing legal framework

The legal framework in Cyprus has been enacted during the colonial era (1928-1950) and still remains in force by virtue of the provisions of Article 188 of the Constitution of the Republic of Cyprus, which got its independence in 1960. Additions and modifications were made to the legislation since then to take account of changes, new developments and trends, but these are very limited. The existing legal structure and content in relation to water development, management and distribution, is described below.

Water ownership

Water in Cyprus is a public good and the constitution of the Republic of Cyprus vests all powers for the management of this resource to the Council of Ministers. The ownership of the water resources at the time of the implementation of the main legislation, which is still valid, was defined as follows thus respecting private use or ownership:

(i) Surface water and groundwater ownership: All surface water running to waste and groundwater not brought to surface before 1928 (the year the Government Waterworks Law was enacted) is vested to the Government, which is acting through the Council of Ministers.

(ii) Private water rights protected: The water rights of any citizen, physical or legal are protected and riparian rights are given to those who can prove that they are entitled or own such rights.

According to the Government Waterworks Law access to any water is given to any individual for abstracting water for his own personal use, i.e. for drinking and washing purposes. The amount of water that can be taken is all that can be carried in the palms of the hands.

Powers of the Council of Ministers to develop and allocate water resources

Since the State is the owner of almost all the natural water resources on the island the existing Legislation gives to the Council of Ministers the right to manage, protect and conserve the natural water resources, and to plan, design, construct, manage, operate and maintain waterworks and the water resources and sell water at a price approved by the Parliament, and to allocate and reallocate the water resources according to the existing water availability and the needs provided the existing water rights are satisfied.

Rights of natural or legal bodies to use public water

Although almost all water resources belong to the Government the Legislator has given the right to individuals to develop and use surface or groundwater water for their own needs, i.e. for irrigation, domestic, industrial or other uses. It has also provisions allowing to legal communal entities to develop and sell or use water. In all cases, the issue of permits for the development and use of water is governed by specific laws administered by Government Bodies such as the District Administration.

Rights of water owners to develop and use their water

The laws also provide for the development and use of privately owned water resources. For this purpose a special law titled "Irrigation Associations" Law, gives the right to individuals or legal bodies, who own water rights, to form Irrigation Associations and construct, maintain and operate irrigation works for the development and use of their water. Only persons or Legal Bodies who own water rights, by title, or otherwise recognized by the Laws can form Irrigation Associations.

Water rights protection and rights of Council of Ministers

Water rights are protected but the Council of Ministers has the right to expropriate such rights and provide compensation for the public interest. So in areas where Government Waterworks are planned the Council of Ministers has the right to appoint the Water Commissioners with the specific duty to identify, evaluate and register in a Register any existing water rights. For this purpose the Commissioners have the right to carry out surveys and investigations and to make inquiries. In case the Government expropriates the water rights the owners are compensated accordingly.

Rights and obligations of the Director of the Water Development Department

The Water Development Department is a Technical Government Department belonging to the Ministry of Agriculture, Natural Resources and the Environment responsible for the Management of the Water

Resources, acting under the directions of the Council of Ministers. Accordingly this Department is given the right to carry out surveys for identifying and estimating any existing water rights for a specific water project work before the project is executed, to refuse the issue of a building permit for the construction of any structure in areas within the hydrological catchments of a project if the construction is likely to affect the water resources in the catchments, both qualitatively and quantitatively, to enter private property for carrying out surveys for the study and execution of water development projects and to refuse the issue of a permit for the sinking of well, or borehole in an area under the Special Measures Law, if such borehole or well shall affect qualitatively or quantitatively the groundwater resources.

Environmental issues

Environmental issues on water are covered by Law no 69/91-"Water pollution control" and other relevant laws, which provide for the reduction, control and abolition of water pollution for the best protection of the natural water resources and the health and the well being of the population.

Main laws

Water laws

The legal framework consists of a number of individual laws, the most important of which are: (i) the Government Waterworks, which gives the right to the Government to construct waterworks, (ii) the Wells Law, which gives the right to individuals (physical or legal entities) to apply for a permit to drill wells and abstract groundwater, (iii) the Irrigation Division Law, which gives the right to land owners to associate and construct communal waterworks, (iv) the Water Supply Law, which gives the right to communities to form water boards and develop water projects for their domestic requirements, (v) the Sewage and Drainage Law, which provides for the creation of sewage boards for the collection, treatment and disposal of the sewage effluents, and (vi) the Water Pollution Control Law, which provides for the abolition or reduction and control of water pollution.

Agricultural Insurance Law

This law, which was established in 1978 provides for the compulsory insurance of deciduous fruits against losses due to hail, frost and windstorm and due to rain only on cherries at ripening stage, of grapes against losses due to hail, frost and heat waves, of citrus against losses due to hail, frost and windstorm and due to "water spot" only on "Local and Clementine" mandarin varieties, of cereals against hail, drought and rust, of dry-land forage crops against drought and hail, of potatoes against hail, frost and flooding, of beans against hail, frost, flooding, prolonged rainfall and hot dry wind and of artichokes and loquats against hail and frost. The premium paid by the farmers equals to 3% of the total crop value and is the same for all crops covered by the scheme. The insurance is public and the Agricultural Insurance Law defines the premiums. The Government subsidizes this premium with an amount equal to the amount of premiums paid by the farmers. The ultimate aim of the Organization is the gradual improvement and expansion of the legislation and the formulation of an integrated insurance scheme, which shall cover the main crops against all the major calamities.

Legal framework under consideration

Because the existing legislation is considered inadequate to deal with the new conditions and challenges on the water resources management in relation to the socioeconomic and environmental needs with respect to the European requirements and vision and the new approaches related to the Integrated and Sustainable Management, a new law is under consideration. This law provides for the creation of a Water Entity, within the Government, to undertake the management of the water resources of Cyprus all in accordance with the integrated water resources principle and taking into consideration the EU Water Framework Directive.

Additional laws

(i) European Water Framework Directive. At the time of drafting this report, Cyprus was preparing to join the European Union. Since May 2004 Cyprus joined the EU and adopted the European Water Framework Directive. According to the decisions taken, due to its size (only 9,125 Square kilometers) the whole of Cyprus is considered as one basin and it is already mobilized to carry out the necessary studies related to the protection of the natural water resources. Under the European Water Framework Directive there are no additional laws dealing with water resources management except those related to environment. There are no any other laws or regulations relating to proactive or reactive drought policies.

(ii) Modifications of the Agricultural Insurance Law. Since the existing Agricultural Insurance Law does not cover against losses due to drought with the only exception of the cereals and dry-land forage it is necessary that this law is gradually improved and expanded to an integrated insurance scheme, which shall cover all crops against all major calamities including drought.

Need for further legal development

Although Cyprus experienced very acute water shortages due to repeated droughts, no attempts were made to introduce new legislation on drought mitigation. A few measures through legislation were promoted by submitting to the parliament the relative bills, one for enforcing the prohibition of use of hoses for car cleaning, which was approved and the second legislation providing for the installation of separate plumbing systems within the houses for enabling the use of second quality water for sanitary purposes and for the installation of separate waste-water collection systems enabling the collection of the grey water for treatment and reuse at the house level, which is not approved.

The updating, revision and/or totally new water legislation, taking into account the new trends in water management (water demand oriented), the recently approved European Water Framework Directive and the Directives on the Environment were on the agenda of the various Governments since the 1960's. During 2002 a new Legislation was drafted and approved by the Council of Ministers and then submitted to the Parliament for approval. This new legislation, which is not yet approved by the Parliament due to differences between the parties in the Parliament, provides for the creation of a Water Entity, within the Government, to undertake the management of the water resources of Cyprus all in accordance with the integrated water management principle and taking into consideration the EU Framework Directive. However the new law does not deal with the preparation of drought mitigation plans.

Water resources and drought management plans

The Water Development Department of the Ministry of Agriculture, Natural Resources and the Environment is responsible for formulating and, after approval by the Government, executing the Government's overall policy on water resources management (planning, design, construction, operation and maintenance of the projects and the management of the water resources). Plans, designs and policy proposals are prepared by the Water Development Department, which are then submitted to the Ministry of Agriculture, Natural Resources and the Environment and after approval is secured from the Council of Ministers, they are implemented.

The financing of the Government waterworks, the Irrigation Division projects, the village water supplies and the town water supplies are made either through Government funds or through loans from international financing institutions such as the World Bank, the Kuwait Fund or the European Investment Bank. In case of sewage projects constructed by the sewage boards or for works carried out by the water boards the plans are prepared and implemented by the respective organizations and their financing are done by the organizations themselves. Generally the Water Development Department, although no legally defined as the administrative authority for water resources management, acts like one, carrying out water resources balance for each project including water availability evaluation (surface and groundwater) and water demand evaluation, keeping water resources inventory and to some extent exercises control over the surface water supplies and the ground water abstraction.

Structure of the institutions, organizations and stakeholders

Water Administration relates to all non-physical measures[1] taken to provide beneficial, efficient and effective use of water resources and prevent harmful effects. Such measures include legislation,

1. Institutions: Non physical non-material, spiritual, moral, mental measures, as opposed to structural measures, such as the ones related to staff, buildings and works.

which has been dealt in the previous section and the institutional arrangements (organization), required for implementing the laws.

The organization map linking all relevant institutions, organizations and stakeholders[2] representing the existing arrangements, (as depicted in the relevant laws) for water resources administration is shown on Fig. 2. The map shows three levels of activity i.e. the policy level, the executive level and the water users[3] level.

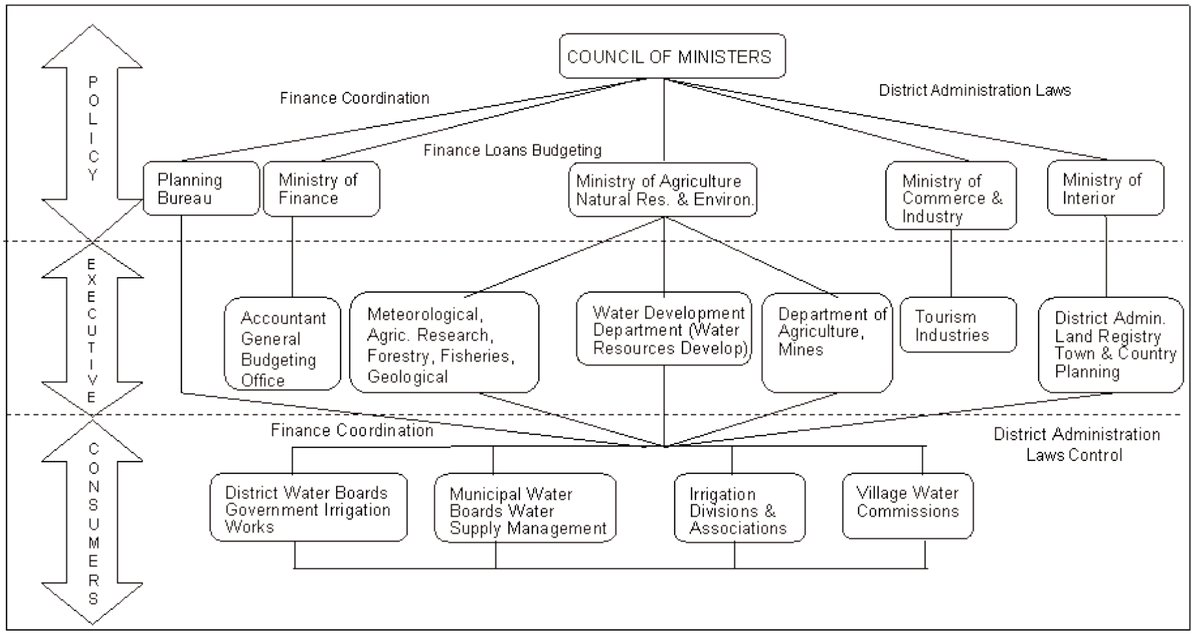


Fig. 2. Cyprus water resources management organization.

The institutions involved in drought preparedness and drought management are the same involved in the water resources management, but they are engaged in different actions for meteorological and hydrological drought preparedness planning and mitigation. This separation is made because meteorological-agricultural drought events are faced mainly within the context of the agricultural insurance scheme, while the hydrological drought is faced by a more complex setup of departments and organizations. A complete description of agricultural and hydrological drought management is included in the following sections.

Policy level – the Council of Ministers

The ultimate responsibility for all policy on water resources management and administration is within the Council of Ministers made up of eleven ministers and joined by various independent services such as the Attorney General, the Audit Office and the Planning Bureau. In formulating the water policy four ministries are involved, being the Ministry of Agriculture, Natural Resources and Environment, the Ministry of Interior, the Ministry of Finance and the Ministry of Commerce and Industry. The Planning Bureau is the coordinator of all development projects. The Ministry of Agriculture, Natural Resources and the Environment provides the technical support through the Departments of Water Development, the Geological Survey, the Agriculture and other Departments such as the Meteorological Services, the

2. Stakeholders: Water stakeholders are people, legal entities or institutions that hold any interest in the water resources.

3. Water users: Users are people or entities that continuously use water, or deal with water management and development.

Fisheries Department, and the Agricultural Research Institute, etc. The Ministry of Commerce and Industry deals with water for industries and tourism, the Ministry of Finance provides the financing for the execution of the waterworks and the Attorney General is the legal adviser.

Executive Level – Water Development Department of the Ministry of Agriculture, Natural Resources and the Environment, and the Ministry of Interior

Responsibilities for water administration at the executive level are primarily divided between the Ministry of Agriculture, Natural Resources and the Environment and the Ministry of Interior. The Ministry of Agriculture, Natural Resources and the Environment through the Water Development Department, a competent technical organization, formulates the water resources development policy. This Department is responsible for formulating and executing the Government's overall policy on water resources planning, design, and construction on the island. It also operates and maintains all of the Government Waterworks and gives advice to other local organizations with regard to the operation, maintenance and management of local projects. Other departments of the Ministry of Agriculture, Natural Resources and Environment are the Department of Agriculture and the Agricultural Research Institute, closely concerned with the efficient and effective use of irrigation water, and the Geological Survey Department dealing with ground water surveys and investigations. The Ministry of Interior has the legal power, mainly through the district officers, both at the executive and the water user levels, dealing with the supervision of the administration of the town water boards, the irrigation divisions, the village water commissions, and the town and village sewage boards, carried out by committees partly elected and partly appointed by the Government.

User Level – water boards and unions

At the water user's level we have the water boards, that manage the distribution of town water supplies and are semi-governmental organizations, the improvement boards and village water commissions that manage the domestic water supplies in small towns and villages, the municipal water supply and sewage boards that manage the town water supplies and town sewage collection treatment and disposal and are chaired by the town Mayor, the irrigation divisions and associations that manage the irrigation water supplies to small irrigation schemes and are chaired by the correspondent district officer of the Ministry of Interior. In addition to the above there are the farmers unions, that take care of the Farmer's interests including the supply of irrigation water, and the environmentalist organizations (governmental and non-governmental) which look for the interests of the environment. Cyprus does not use water for power production, where the use of water for industrial purposes is very limited.

Drought mitigation plans within the existing structure

The drought mitigation plans were prepared along with the monitoring process. Fig. 3 shows the steps followed for drought monitoring and drought mitigation plan preparation by using the meteorological, hydrological, water in storage, and water demand data. This exercise is repeated every two months starting in August, before the next hydrologic year and finishing by the end of next April. During this period the water balance sheet is prepared each time based on the actual and projected water inflows and demand under different scenarios of inflows and demands and accordingly, the probable adverse impacts on the economy, on the social life and on the environment are defined and roughly evaluated, and the Council of Ministers is informed. No levels of severity were defined but the adverse impacts were identified and preliminarily evaluated with proposals on how to mitigate such adverse effects. The final decisions on the water saving, water augmentation and compensations in the case that no technical measures were enough to mitigate the adverse impacts, are taken by the Council of Ministers based on proposals of the Water Development Department. It must be mentioned that the existing legislation does not provide anything on drought preparedness plans. Although drought phenomena hit frequently Cyprus, droughts in most instances are dealt "as crisis management phenomena" under the General Disaster Laws. In case of drought, the Government mobilizes in a proactive manner but all its actions are reactive in nature as is explained below.

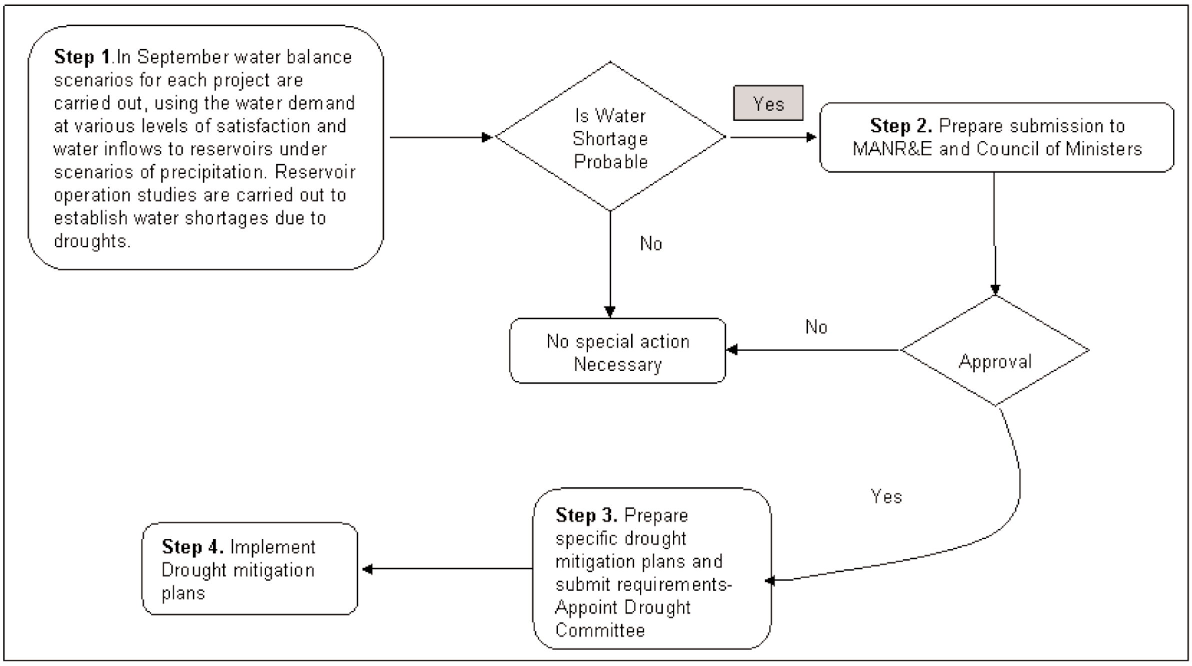


Fig. 3. Drought mitigation proactive plan steps undertaken by the Water Development Department in Cyprus.

Step 1

Early in August before the commencement of the new hydrological year, and every two months thereafter, till the end of next April (wet season), the Water Development Department prepares the water balance sheet for each project, based on the water resources available at the time, the forecasted water inflows to the dams and to the aquifers during the remaining wet season (October-May) and on the projected demand till the end of the next year. Different water supply scenarios are developed and other inflow scenarios are developed. Each water balance sheet, covering the period August to December next year, presenting one scenario depicting a different situation is a spreadsheet containing for each project the available water sources (groundwater, surface, reuse and desalinated water), existing and projected and the water supply scenario (domestic, irrigation, industrial and environmental).

For each water supply scenario (depicting different levels of satisfaction) the inflow required is estimated and the probability of having this inflow is calculated. In the water supply scenarios the losses to evaporation and seepages from the dams are taken into account and a reservoir operation study on a monthly base is carried out for finding out the additional water inflow required. The results for each scenario are then evaluated and are ranked according to the level of satisfaction and the probability of their satisfaction and a "Table of Results" is prepared. In parallel, a preliminary evaluation of the severity of the drought is made and the impacts on the economy, on the social life and on the environment are identified and preliminarily evaluated, and suggestions are made as to the actions that must be taken. The different scenarios take into account strictly technical data (i.e. hydrological, hydro-geological, agricultural, and environmental).

Step 2

The outcome of the exercise including the balance sheet, the "Table of Results", comments and suggestions are submitted to the Ministry of Agriculture, Natural Resources and Environment for consideration. Normally no actions are taken until the end of January when the two wet months (December and January) are over and the results show that a drought is more probable or is not. The scenarios are revised every two months, and scenarios that are fully satisfied are not considered further. In parallel to this the Agricultural Insurance Organization is monitoring any developments with respect to agricultural drought, which affects mainly the rain-fed agriculture.

Step 3

Based on the outcome of the revised scenarios, if a drought is already on, the most probable scenario is chosen and a detailed action plan is prepared early in February, which is referred again to the Ministry of Agriculture, Natural Resources and Environment, and then to the Council of Ministers, for decisions. The plan includes drought mitigation measures, such as water transfer, new water supply emergency schemes, water cuts, water reallocation, water saving campaigns, etc. For the implementation of the plan an *ad hoc* Drought Management Committee is formed which meets and examines the implementation of the proposed measures and take decisions concerning the implementation of the measures and the allocation of the funds, on a biweekly basis or earlier if it is necessary. The Drought Management Committee is a multidisciplinary committee with members from the Ministry of Agriculture, Natural Resources and the Environment, the Water Development Department, the Department of Agriculture, the Geological Survey Department, the Ministry of Interior (District Office level), the Planning Bureau, and depending on the occasion under consideration, with officers from other Government Organizations. The Committee does not include any water consumers or their representatives. To a certain extent, however, they are represented by the district officers.

Step 4

The implementation of the Drought Mitigation Plan starts in May and lasts until the end of the drought phenomenon or until the effects are minimized. The Drought Management Committee does not examine applications for compensations or subsidies to persons or communities suffering from the adverse effects of droughts. Any such claims are submitted to the Government in general and decisions are taken by the Council of Ministers.

The funds for financing the implementation of the Drought Management Plans are provided from the Government Budget, either from previously approved funds under the heading "Damages from Drought and Other Natural Calamities" or under the heading "Contingencies and Reserve", under the control of the Ministry of Finance.

For the meteorological drought, the Agricultural Insurance Organization mobilizes later in May-June to evaluate the damages caused by the drought and payments are made from its own resources

From the above it is seen that the action to Drought Management is not proactive but reactive and is based not on the principle of risk management but on the principle of crisis management. The above procedure has been used in the recent droughts faced in Cyprus during the period 1990-2000.

Agricultural drought management

The institutions involved in the process for facing the meteorological and agricultural droughts are the Agricultural Insurance Organization, the Department of Agriculture, the Planning Bureau, the Ministry of Finance and the Council of Ministers. Since the existing insurance scheme covers only losses against drought from cereal and dry land forage crops, losses from the remaining crops due to drought are in many cases covered by the Council of Ministers using government funds, by using the Agricultural Insurance Organization and/or the Cooperatives for transferring the funds.

The process for responding to the agricultural drought effects is reactive and involves the following steps.

Step 1: Evaluation. Upon realization of the agricultural drought effects the Agricultural Insurance Organization mobilizes by itself for the evaluation of the losses in cereals and dry land forage. For crops not covered by the Agricultural Insurance Scheme the Government usually acts by itself providing compensations to the farmers. In such situations the Council of Ministers through the Ministry of Agriculture, Natural Resources and Environment gives instructions to the Agricultural Insurance Organization or the Department of Agriculture for the evaluation of losses.

Step 2: Compensation. Upon evaluation of the losses the Agricultural Insurance Organization proceeds with the payments of losses from crops covered by the insurance plan all in accordance with the valid agricultural insurance scheme. For those crops not covered by the insurance plan the procedure is quite long since it involves further considerations before a decision is taken by the Council of Ministers and the Parliament for approval of the funds.

Model structure validation

The mapping model presented above was implemented and validated in a number of occasions during the period 1990-2000, by the author. This model is not based on a specific law or regulation but on the necessity to mitigate the adverse effects from water shortage caused by repeated droughts. Since there is no law or regulation the model was the best possible under the circumstances of acute water shortage. The model made the best use of the existing institutions and organizations and its success was based on the good will and understanding of all stakeholders.

The model, although not covering all affected sectors, is validated in recent drought situations, observing that the model current structure provided support of the following essential points:

(i) To satisfy the basic needs of water with priority in the supply of drinking water but without neglecting the needs for other sectors. This necessitated the reallocation of the very limited water resources available at the time.

(ii) To alleviate the impacts of the water shortage by promoting water saving measures and methods, and augmenting the water resources availability, where possible, by mobilizing natural water resources, by recycling domestic effluents, by introducing seawater, desalination and by using lower quality water, where possible.

(iii) To promote water savings in all sectors of the economy, indicating that water shortage is a problem concerning all consumers irrespective of the priority given to one or the other sector for satisfaction.

(iv) To raise public awareness and to educate the population on the importance of the water and how to use wisely and efficiently the limited water resources. It was also stressed and understood by all that the best method to mitigate droughts and avoid the repetitions of water shortage due to droughts was to save water when it is available.

The model was validated form the conclusions of the stakeholders' interviews that were carried out in the framework of the MEDROPLAN project, which are summarized below:

(i) Perception of drought. The perception by the professionals and the population that droughts are natural phenomena that occur periodically affecting the water resources availability and that the drought mitigations plans should be part of the water resources management plans.

(ii) Actions. The legislators and the Government understood how serious could be the impacts from the droughts and embraced all the plans that could alleviate the adverse effects and relief the consumers, domestic users, irrigators and industrialists from the difficult situation created by the shortage of water. For this purpose they approved and authorized the expenditure of funds for new projects, for promoting water saving, and for compensations to those adversely affected, mainly farmers.

(iii) Collective approach. The population understood very soon that mitigation of the adverse effects could not be undertaken individually but by all and under the direct supervision of experts, who have the expertise and the know-how.

The validation of the model does not mean that the model is the best or it is always adequate or does not have weaknesses. The main weaknesses of the model are the following:

(i) It is a reactive and not a proactive plan. Although the plan is drafted ahead of time its implementation is commencing after political decisions are taken. Water saving plans and measures included in drought preparedness plans, are abandoned once the crisis is over where other measures involving emergency plans for additional water supplies continue to operate thus increasing the water demand and depriving the authorities of a source that could be used again in the future. This occurs often with the drilling and operation of emergency boreholes, which after the crisis is over, continue to operate mainly depleting the strategic sources and increasing the permanent water demand.

(ii) Lack of legal framework. The procedure and criteria for development of the Drought Preparedness Plan and its implementation are not based on any specific law or regulation. The implementation of most actions is not based on legislative articles but on the good will and understanding of those affected, positively or negatively.

Strengths and weaknesses on current drought management plans

Legislation

Since no specific legislation exists for the preparation of drought mitigation plans no strengths and weakness can be reported, but the absence by itself is a great weakness for fighting drought. Generally the absence of laws and regulations (defining drought, the preparation of drought mitigation plans, when drought mitigation plans are to be implemented, and when drought is terminating, as well as criteria, rules and priorities for water reallocation, who shall be compensated, how much and to what extend, how economic, environmental and economic issues are mitigated, as well as defining the responsible institutions and their powers, etc.), is a serious weakness of the whole system.

In general actions on drought are left to the good will of some organizations or persons who do not have a legal responsibility or the obligation to watch and prepare plans for facing situations under drought.

Another dimension of the drought impacts is the fact that the impacts are not confined to water scarcity only but extend to a number of other activities not easily manageable under a crisis management approach.

The power of the Council of Ministers to declare "a situation of emergency" under certain conditions, requires the approval of the Parliament and contains too many other considerations which Governments usually do not exercise unless the situations is very serious and lives are at stake.

Institutions

The comments on strengths and weakness of the existing institutions dealing with drought are based mainly on the complete absence of a legal framework, on the lessons learned and the experiences gained in facing the recent drought events.

From the point of view of the collection, processing and storage of data on meteorology and water resources, the institutions do not show weaknesses. There is a good network of meteorological and hydrological stations which collect on a regular permanent basis the basic information. Although there is no provision in their duties and responsibilities to deal with drought phenomena, since such phenomena are recurrent in Cyprus the institutions and organizations are collecting and processing such data with a view to identify drought events.

The same is true with the water resources management, where the responsible institution is continuously monitoring the availability of surface and groundwater resources and prepares scenarios for future actions. The data on water availability and use, like the hydro-meteorological data are continuously updated and analyzed for the identification of droughts events and the Ministry of Agriculture, being the ministry responsible, is continuously informed. However this does not mean that the institutions are fully staffed to monitor and analyze drought events in a comprehensive manner, or to prepare drought preparedness plans or to initiate actions for drought mitigations. Knowledge and know-how are not available since nobody has the responsibility by law or regulation for acquiring such expertise or specialty. All the above weaknesses lead in many instances to the preparation of incomplete reactive plans or to reactive plans in the case of plans to mitigate the effects of drought on the social and economic sectors.

In conclusion it can be said that the weaknesses of the existing system is the total absence of legislation for drought preparedness plans, for drought definition and for definition when drought initiates and when drought terminates. Also the absence of legislation defining the obligations, duties, responsibilities and powers of institutions to act under drought conditions is a fatal weakness since neither complete monitoring systems are guaranteed, nor integrated drought proactive mitigation plans can be prepared and no organization or institution is named with the duties and responsibilities to act accordingly. The inadequate reactive drought mitigation plans usually lead to high cost measures, but ineffective in the long term. The institutions also lack experience on risk analysis and drought preparedness plans.

Methodological component: Drought characterization and risk analysis

Drought characterization

Historical drought events

During the years, 1989-2000 Cyprus has suffered from a number of severe droughts as shown on Table 3. In all cases, the events are initiated as meteorological droughts but very quickly they develop into hydrological droughts since Cyprus has no perennial rivers and the rivers length is very short. By studying Table 3 it can be easily concluded that drought phenomena in Cyprus are very frequent and severe since reduced precipitation in drought conditions is between 65-88% of the normal with runoff reduction from 17 to 52% of the normal.

Table 3. Drought events in Cyprus in the period 1989-2000

Year	Precipitation (mm)	Percentage of average precipitation	Percentage of average runoff	Remarks
1989/90	363	68.1	18	Two year drought
1990/91	282	52.9	0	39.5% deficit on precipitation
1993/94	417	78.2	35	One year drought
1995/96	383	71.9	20	Five year drought
1996/97	399	74.9	30	24.7 % deficit on the average
1997/98	388	72.8	28	per year on Precipitation
1998/99	473	88.7	52	
1999/00	363	68.1	18	

Of importance is the period 1996-2000, during which the average precipitation was only 75.3% of the long-term average and the average inflow to the reservoirs was only 24.7% of the average. This shows that meteorological droughts in Cyprus quickly develop into hydrological droughts causing acute water shortages.

The relationship between precipitation and run-off is shown in Fig. 4, which shows the actual precipitation, expressed as the percentage of the long-term average, versus the actual reservoir inflow, expressed as the percentage of the average annual. The average annual inflow is the one calculated at the planning stage of the project, which corresponds to the average normal precipitation. As can be seen in Fig. 4, the relationship is not linear due to the changing hydro-geological and other conditions prevailing in the different catchments, with runoff decreasing at a higher rate than precipitation. As an example for precipitation around 82% of the average the runoff is only 40% of the normal i.e. for precipitation reduction of 18% from the average the runoff reduction is 60%. It is also seen from Fig. 4 that the recorded percentage of inflows versus the recorded precipitation is not always the same but shows different percentages these being due to the time and space distribution of the precipitation as well to other parameters such as temperature, wind, humidity etc. Although the above is not fully studied and the relationship not scientifically defined this relationship can be used to give a measure of the severity of water scarcity in the various projects.

Meteorological drought in Cyprus

Droughts and their effects on the economy, on the social life and on the environment are very well known in Cyprus since ancient times. The frequency of drought events in Cyprus, with lower than average precipitation of varying severity, duration and scale has been changing during the last century as it is seen on Table 4 and Fig. 5, which shows the actual average annual rainfall during the period 1916-2000. In the early years of the century the droughts frequency was 2.4 years with rainfall below the average out of ten (10) years, while after 1970 the frequency of droughts increased to 6 years out of 10 and in the period 1990-2000 out of 11 years 8 years had a rainfall lower than normal.

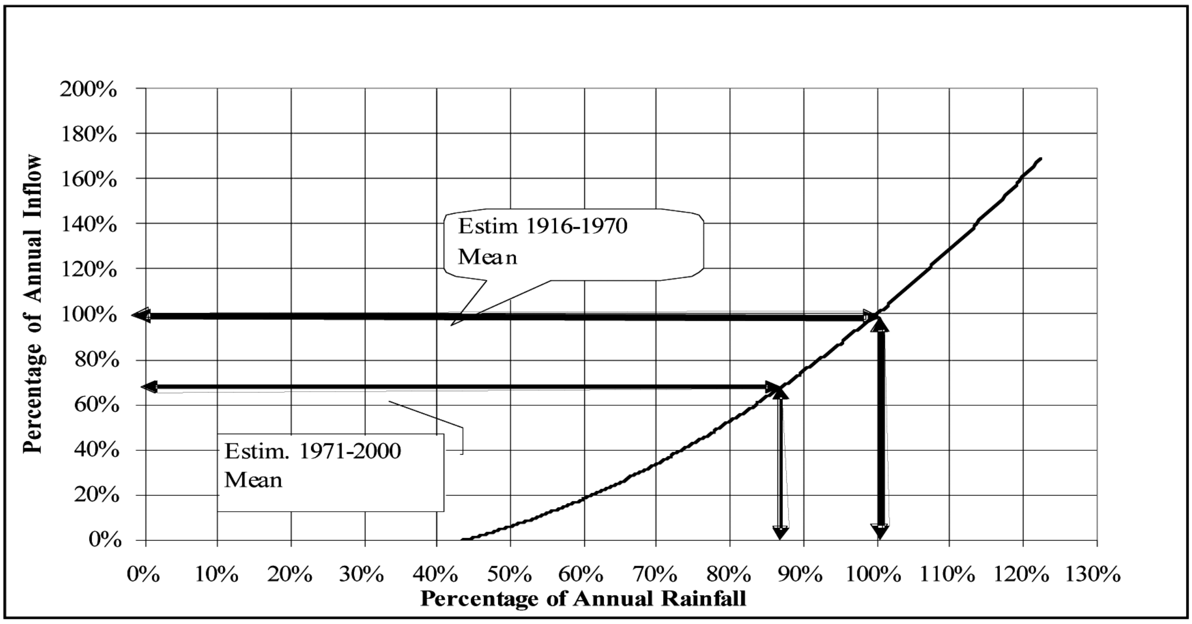


Fig. 4. Relationship between precipitation and annual inflow in Kouris dam.

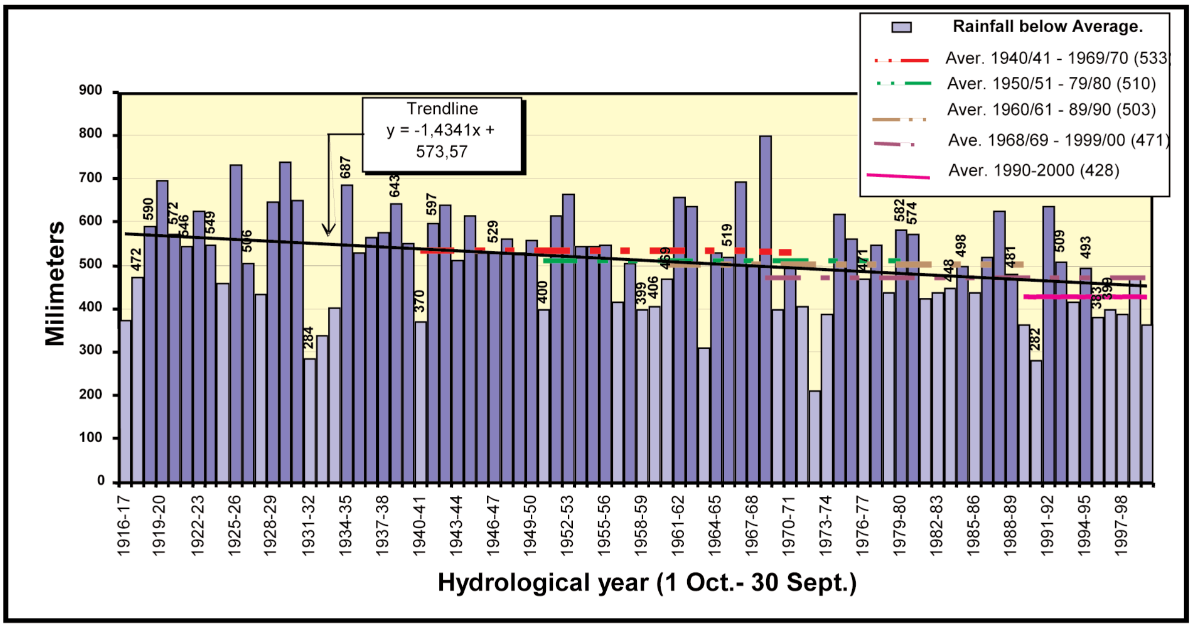


Fig.5. Average annual rainfall in the free area of Cyprus (1916-2000).

Table 4. Meteorological drought events in Cyprus (1916-2000)

No	Years	Precipitation in mm	Percent of Average	Deficit %	Remarks
1	1916/17 1917/18	373 472	70.0 88.5	30.0 11.5	Two year drought 20.6% deficit
2	1924/25	460	86.3	13.7	One year drought
3	1927/28	434	81.4	18.6	One year drought
4	1931/32 1932/33 1933/34	284 341 401	53.3 64.0 75.2	46.7 36.0 24.8	Three year drought 35.8% deficit on the average per year
5	1940/41	370	69.4	31.6	One year drought
6	1950/51	400	75.0	25.0	One year drought
7	1958/59 1959/60 1960/61	399 406 469	74.9 76.2 88.0	25.1 23.8 12.0	Three year drought 20.3% deficit on the average per year
8	1963/64	309	58.0	42.0	One year drought
9	1969/70	398	74.7	25.3	One year drought
10	1971/72 1972/73 1973/74	408 213 389	76.5 40.0 73.0	23.5 60.0 27.0	Three year drought 36.9% deficit on the average per year
11	1976/77	471	88.4	11.6	One year drought
12	1978/79	439	82.4	17.6	One year drought
13	1981/82 1982/83 1983/84	425 437 448	79.7 82.0 84.0	20.3 18.0 16.0	Three year drought 18.1% deficit on the average per year
14	1985/86	438	82.2	17.8	One year drought
15	1989/90 1990/91	363 282	68.1 52.9	31.9 47.1	Two year drought 39.5% deficit
16	1993/94	417	78.2	21.8	One year drought
17	1995/96 1996/97 1997/98 1998/99 1999/2000	383 399 388 473 363	71.9 74.9 72.8 88.7 68.1	28.1 25.1 27.2 11.3 31.9	Five year drought 24.7 % deficit on the average per year

Drought is a recurrent feature of climate that is characterized by temporary water shortages relative to normal supply, over an extended period of time. On the other hand climate, which represents the normal average state of the atmosphere for a given time of years and a given location, was considered for many years as a constant with its daily, weekly, monthly and seasonal variations with fixed means and standard variations. Climate changes are now occurring in many parts of the world because of the green house effect with noticeable changes on precipitation temperature. While temperature globally increases, the precipitation and other parameters are different in various parts of the world. Cyprus had an increase of 0.5°C in temperature during the last century, which is expected to increase the irrigation water requirements and water demand. However, from statistical analysis of the records available over the period of the hydrological years 1916/17-1999/2000, the rainfall shows that the precipitation time series displays a step change around 1970 and can be divided into two separate stationary periods. For the 1916/17-1969/70 period precipitation records do not show any trend where for the period 1970/71-1999/2000 the data show a slight decrease in precipitation but this trend is not significant compared to the variations from year to year. The mean precipitation of the recent period 1970-2000 is lower than the mean precipitation of the older period as is shown on Fig. 6.

The shift in the mean precipitation was found to be larger in the Troodos Mountains sectors that in the coastal and inland plains, and since some 80% of the runoff originates on these mountains, then the effect is comparatively more. Thus at every location of elevation higher than 500 m the mean annual precipitation in the recent period is lower by 100 mm or more than the mean in the older period resulting in 15-25% decrease of the mean annual precipitation of the older period resulting in a reduction of the mean annual inflow to the dams from 24% to 58% compared to the older mean. This means that in preparing the drought mitigation plans the climatic change that already occurred has to be taken into consideration. Thus a re-assessment of the water availability and water demands has to be made for each project before a drought mitigation plan is prepared.

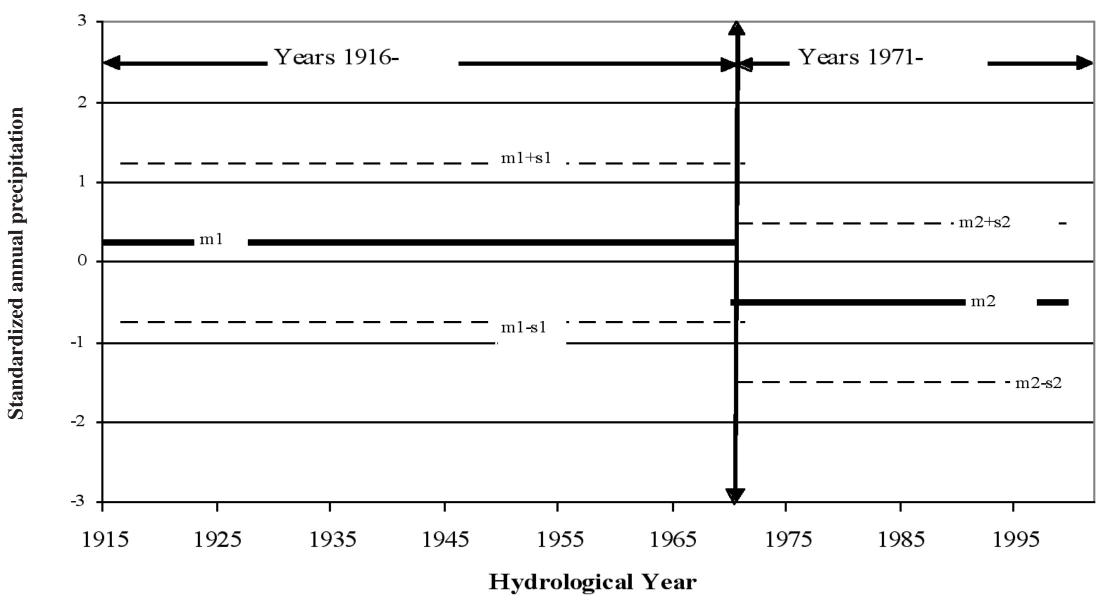


Fig. 6. Mean average precipitation. Steep reduction of precipitation after 1970. m: mean average precipitation; s: standard deviation.

Meteorological drought in the SCP

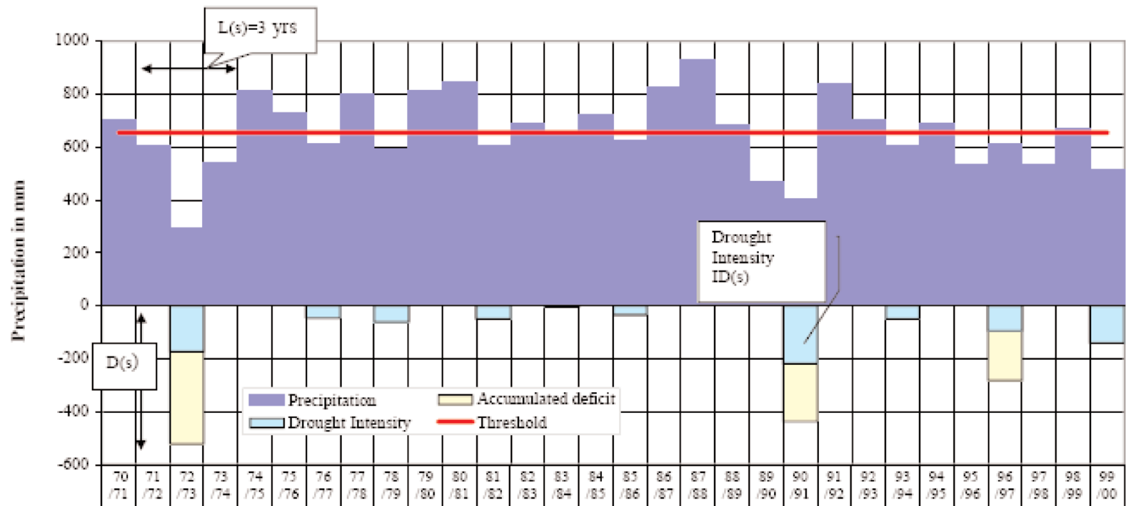
The Southern Conveyor Project supplies water to closely two thirds of the urban population and to one third of the irrigated land of the area under the Government control. Fig. 5 shows the average precipitation on the area under the control of the Government for the years of 1916-2002. Fig. 5 shows that there is a trend of reduction of precipitation with the average decreasing from 533 mm/year in the period 1940-1970 to 428 mm/year in the decade 1990-2000. On the same figure, it can be seen that the frequency of precipitation events being below the average has increased from 2.4 every 10 years to 8 out of 11 years in the period 1990-2000. Since no single indicator or index (Standardize Precipitation Index or Surface Water Supply Index or Deciles) based on the precipitation and other available data could be correlated with the hydrological drought periods or historical drought impacts, the water managers tend to rely on the precipitation, stream-flow and water in storage data variables to determine the onset and end of the water shortage situations.

Hydrological drought in Cyprus

The run analysis is an objective method for identifying the drought periods and for evaluating the statistical properties of drought events. According to this method, a "Drought period" coincides with a "negative run" defined as a consecutive number of intervals where a selected hydrological variable, in this case the precipitation, remains below a chosen truncation level or threshold. A threshold is very important since it can be chosen to be equal to the long-period mean or to a percentage of the average. The setting of threshold is based on the relationship between precipitation and runoff, which is roughly shown on Fig. 4.Three different thresholds were considered as follows: (i) drought occurs when the rainfall is below the average precipitation, (ii) drought occurs when the rainfall is equal or below 95% of the average precipitation, and (iii) drought occurs when the rainfall is equal or below 90% of the average rainfall. Based on these three thresholds, Table 5 shows the calculated number of drought events, the number of drought years, the minimum and longest period of droughts and the deficits and drought intensities for the period 1970-2000. An example of graphical presentation of the droughts identification for a threshold equal to the average precipitation is shown on Fig. 7.

Table 5. Hydrological series and drought characterization for the Kouris catchments area, for three thresholds: equal to the mean, equal to 95% and equal to 90% of the mean precipitation

	Mean	95% of the mean	90% of the mean
Droughts Characterization			
Length of analysis period (years)	30	30	30
No. of drought years	14	13	8
No. of drought events	9	8	5
Minimum duration of drought (years)	1.0	1.0	1.0
Longest period drought (years)	3.0	3.0	2.0
Average duration of drought (years)	1.56	1.63	1.60
Maximum accumulated deficit for one period (mm)	522.00	417.00	334.00
Average accumulated deficit (mm/year)	180.33	141.88	160.40
Maximum drought intensity (mm/year)	218.50	183.50	167.00
Average drought intensity (mm/year)	62.04	42.73	50.13
Percentages to mean annual precipitation			
Maximum accumulated deficit for one drought period	79.69%	63.66%	50.99%
Average accumulated deficit	27.53%	21.66%	24.49%
Maximum drought intensity	33.36%	28.02%	25.50%
Average drought intensity	9.47%	6.52%	7.65%
Percentages to length of period			
No. of drought years	46.67%	43.33%	26.67%
Longest period of drought (years)	10.00%	10.00%	6.67%



Year	70/71	71/72	72/73	73/74	74/75	75/76	76/77	77/78	78/79	79/80	80/81	81/82	82/83	83/84	84/85
Precipitation	704	607	297	539	813	731.	609	797	593	813	847	604	687	650	723
Accumulated deficit			-522.				-46.5		-61.8	0.0	0.0	-51.1	0.0	-5.1	0.0
Drought Intensity			-174.				-46.5		-61.8			-51.1		-5.1	
Threshold	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655

Year	85/86	86/87	87/88	88/89	89/90	90/91	91/92	92/93	93/94	94/95	95/96	96/97	97/98	98/99	99/00
Precipitation	622	824	931	685	472	400	837	704	604.	692	535	614	534	671	514
Accumulated deficit	-33.2	0.0	0.0	0.0		-437.			-50.2			-282.			-141.
Drought Intensity	-33.2					-218.			-50.2			-94.1			-141.
Threshold	655	655	655	655	655	655	655	655	655	655	655	655	655	655	655

Fig. 7. Drought identification using the run method.

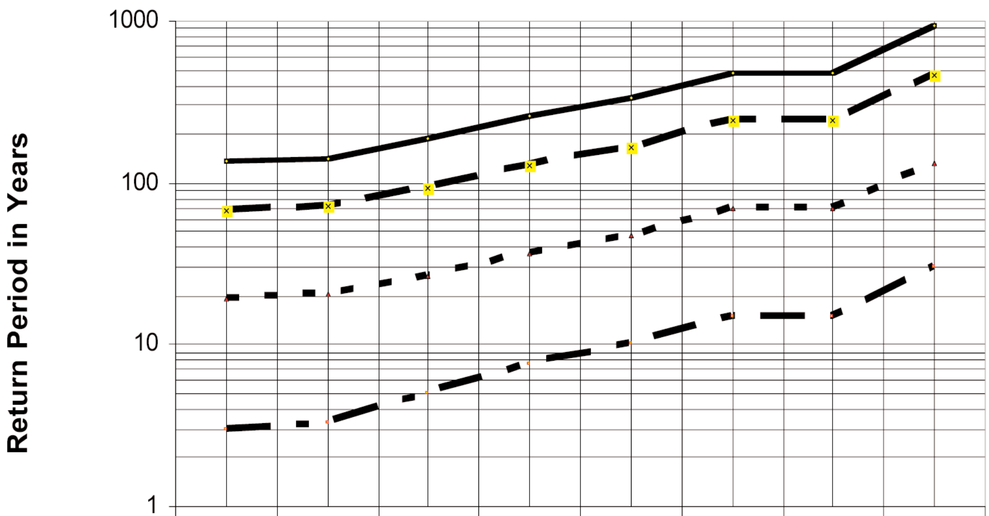
If we take a drought with a threshold equal or less than 95% of the average rainfall then the average number of drought events is eight (8) over a period of thirteen (13) years equivalent to 4.3 years every 10 years. The use of a comparatively high threshold value (very close to the mean rainfall) is due to the fact, that a meteorological drought of this intensity causes a relatively high hydrological drought as seen on Fig. 4, which shows the relationship between precipitation and surface runoff.

Probability distribution of drought characteristics and return periods

Since the probabilistic features of droughts characteristics cannot be properly carried out by fitting a parametric distribution to observed sequences of drought characteristics because of the limited number of drought events,an analytical derivation of the probability distributions of drought characteristics, based on the distribution of the hydrological series has been proposed by a number of researchers. Such analytical expressions have been derived for the marginal distribution of the accumulated deficit and for the bivariate distributions of duration and accumulated deficit and drought intensity.

The return period of droughts is defined as the expected value of elapsed time or inter-arrival time between occurrences of critical events. In evaluating the return period of multiyear droughts it is necessary to consider their duration and their severity, i.e. the accumulated deficit or intensity in order to derive analytical expressions for its estimations.

The probability of occurrence and the return periods of drought identified are shown on Table 6 and Fig. 8.



	0,0%	4,6%	7,6%	15,3%	30,5%	45,8%	61,1%	76,3%
One Year Duration Drought	19	20	27	37	48	69	69	133
Two Years Duration Drought	135	143	188	260	333	482	482	931
Three Years Duration Drought	68	71	94	130	167	241	241	466
Any Drought	3,00	3,33	5,00	7,50	10,00	15,00	15,00	30,00

One Year Duration Drought — Two Years Duration Drought

Fig. 8. Return periods in year of droughts deficit equal to or more than to a certain amount (percentage of mean average precipitation) and for drought duration of one, two or three years for catchments area and threshold equal to mean average precipitation.

Table 6. Drought characterization (Accumulative Deficit>Do and duration L = 1, 2, 3 years) and return periods probability of occurrence

Kouris catchment-Threshold equal to mean average								
Accumulated deficit mm	0-30	30-50	50-100	100-200	200-300	300-400	400-500	500-600
Percentage to mean average (Do)	0.0%	4.6%	7.6%	15.3%	30.5%	45.8%	61.1%	76.3%
Probability of occurrence of D>Do	33%	30%	20%	13%	10%	7%	7%	3%
Return period in years								
A.1: One year period drought	19	20	27	37	48	69	69	133
A.2: Two years period drought	135	143	188	260	333	482	482	931
A.3: Three years period drought	68	71	94	130	167	241	241	466
A.4: Totals	3.00	3.33	5.00	7.50	10.00	15.00	15.00	30.00
Kouris catchment- Threshold equal to 95% of mean average								
Accumulated deficit mm	0-30	30-50	5-100	100-200	200-300	300-400	400-500	500-600
Percentage to mean average (Do)	0%	5%	7.6%	15.27%	30.53%	45.80%	61.07%	76.34%
Probability of occurrence of D>Do	27%	13%	13.3%	13.33%	6.67%	6.67%	3.33%	0.00%
Return period in years								
B.1: One year period `drought	31	52	52	52	96	96	186	0
B.2: Two years period drought	153	260	260	260	482	482	931	0
B.3: Three years period drought	77	130	130	130	241	241	466	0
B.4: Totals	3.75	7.50	7.50	7.50	15.00	15.00	30.00	
Kouris catchment -Threshold equal to 90% of mean average								
Accumulated deficit mm	0-30	30-50	50-100	100-200	200-300	300-400	400-500	500-600
Percentage to mean average (Do)	0.0%	4.6%	7.6%	15.27%	30.53%	45.80%	61.07%	76.34%
Probability of occurrence of D>Do	16.7%	17%	10.0%	6.67%	6.67%	3.33%	0.00%	0.00%
Return period in years								
C.1: One year period drought	72	72	111	161	161	310	0	0
C.2: Two years period drought	108	108	167	241	241	466	0	0
C.3: Totals	6.00	6.00	10.00	15.00	15.00	30.00		

The calculations of the probability distribution of drought characteristics and return periods were carried out as outlined in Tsiourtis (2005b).

The probability of occurrence of any drought event with accumulated deficit greater than zero (threshold equal to mean average precipitation) is 33.3%, with recurrent period 3 years.

The probability of occurrence of any drought event with accumulated deficit greater than zero (threshold equal to 95% of mean average precipitation) is 26.67%, with recurrent period 3.75 years.

The probability of occurrence of any drought event with accumulated deficit greater than zero (threshold equal to 90% of mean average precipitation) is 16.67%, with recurrent period 6 years.

The return period of a drought event with accumulated deficit greater than zero (Threshold equal to the Mean Average Precipitation) and drought period duration equal to 3 year is 68 years.

Generally the return period for any drought with accumulated deficit above zero is 3 years, for accumulated deficit above 7.6% of the mean is 5 years, for accumulated deficit above 15.3% of the mean average precipitation is 8 years and so on. Fig. 8 shows in graphical form the return periods for any drought and for specific droughts.

Conclusions on model validation

Threshold is set arbitrarily or can be based on the observations and findings the selected hydrological or meteorological variables have on the droughts. In the case of rainfall it was observed that even a small reduction causes a big reduction in stream flow and in the groundwater recharge. This is due to the typical Mediterranean climate with relatively high potential evaporation, and high potential transpiration. The resulting surface runoff is not directly proportional to the rainfall reduction but reduces drastically with small reduction of the rainfall this being the result of satisfaction first of the relatively constant evaporation and transpiration demand. The precipitation-runoff relationship has been studied in the Re-Assessment Study of Water Resources and Demand in Cyprus (Klohn, 2002) for the Kouris Dam and it is shown on Fig. 4. A reduction of 13% of the precipitation causes 35% deduction of the average of the runoff. Therefore an annual precipitation below the average precipitation is always a drought condition since the runoff is reduced drastically. In view of the above the threshold should be fixed equal to the average mean annual precipitation.

Impacts of drought

Droughts have adverse impacts on agriculture, on the water supply economy, on the environment and on the social life. A number of potential impacts, for each sector, were identified and ranked according to their importance, from five down to one. The drought impacts selected were characterized taking into account the area extent, the social distribution, the public priority, the historical trend and where possible the estimated cost of damage. The characterization of impacts is made for each of the years 1990-2000, for each of the project areas (catchment, Akrotiri area and Kokkinochoria area) in a qualitative (see Table 7) and quantitative manner (Tsiourtis, 2005b, Tsiourtis, 2005c).

Correlation of drought indices with impacts

The Standardized Precipitation Index (SPI) and the Surface Water Supply Index (SWSI) were calculated on a yearly base for the years 1970-2000 and were correlated with the economic impacts identified and ranked in the Risk Analysis Study carried out by the MEDROPLAN project. From the analysis, some conclusions, that follow, can be issued (Tsiourtis, 2005c).

There is a high correlation between Standardized Precipitation Index (SPI) and the Surface Water Supply Index (SWSI), ranging from 0.75 to 0.887.

There is a high correlation between SPI and the gain/loss in the rainfed agriculture, which varies from 0.6306 in the Akrotiri area to 0.7124 in the Kokkinochoria Area. Kokkinochoria area is the most representative area since it covers the largest part of the area under rainfed crops. This relationship is

Table 7. Checklist and ranking of potential impacts

No.	Impact	Rank	Remarks
	ECONOMIC: AGRICULTURE		
A.1	Loss of farm income	5	Mainly for rainfed
A.2	Decrease in Farm Income	4	This includes crop and livestock
A.3	Decrease in crop production	4	Valid only on crop production
A.4	Decrease in livestock feed quantity and quality	3	Valid only for livestock
A.5	Increase of farm subsidies	3	This concerns Government subsidies
A.6	Increase of unemployment of the agricultural sector	3	Affects both family farm and hired workers
A.7	Decrease in pasture production	2	This is affected by meteorological drought
A.8	Decrease crop quality	2	Mainly on crop production
A.9	Increase in crop prices because fixed costs remain the same	2	Due to reduced supply of crops and
A.10	Loss of income of industries dependent on agriculture	2	Because of less product available
A.11	Loss of income from agricultural exports	2	Because of less product available
A.12	Losses in financial institutions related to agricultural activities	2	Because the lending capacity of the farmers decreases where their needs increase
A.13	Increase in crop imports	1	To cover needs not covered by local production
A.14	Increase of soil erosion	1	Due to the loss of plant roots and the winds
A.15	Loss of Value Added Tax	1	Less product, lower value, lower VAT
	ENVIRONMENTAL		
B.1	Biodiversity loss in land based ecosystems	4	Less moisture, less vegetation
B.2	Biodiversity loss in ecosystems associated with water	3	Less water or lack of water in water systems, animals and fish migrate to other areas
B.3	Deterioration of visual and landscape quality	3	Wetlands, riparian animals and plant life are displaced or die
B.4	Groundwater depletion	3	Water levels drop because of less recharge and over pumping
B.5	Increase stress to endangered species	3	Endangered species are very vulnerable to droughts
B.6	Increase in number and severity of fires	3	Drier land and mountain slopes increase vulnerability of the forest
B.7	Water quality effects (salt concentration in soil)	3	Less quantities of infiltrating water to groundwater and seawater intrusion due to falling water levels
B.8	Groundwater quality deterioration	3	Same as above plus higher waste water infiltration
B.9	Decrease in reservoir and lake levels	1	Less inflow from rivers
B.10	Increase erosion of soil by wind	1	Less moisture less roots
	ECONOMIC: WATER SUPPLY		
C.1	Decrease revenues of water supply firms	4	Less water to sell
C.2	Decreased revenues of Government	4	Less water to sell
C.3	Additional cost of supplemental water infrastructures	3	Construction of emergency water projects
C.4	Increase in water treatment costs	3	While fixed costs remain the same treated Water volumes decrease

C.5	Additional cost of water transport	2	Water has to be transported from long distances
C.6	Increased cost of groundwater extraction	2	Water levels are falling, yields are decreasing, water is pumped from deeper levels and from more boreholes
C.7	Reduced service quality	2	Lower pressure, lower flow rates do not serve All consumers
	SOCIAL		
D.1	Conflict between the Government and affected groups	5	The inability to provide full supply of water
D.2	Deterioration of the overall well-being of rural people	5	Less water input less product lower income
D.3	Social inequality	5	Social inequality deepens since rural inhabitants suffer most
D.4	Danger to public safety from fires	4	Fires are more frequent because of droughts
D.5	Increase migration from rural to urban areas	4	Less work opportunity in rural areas People move to towns for work
D.6	Public health related problems	3	Reduced water supply, with reduced water quality may endanger public health
D.7	Conflict in decision-making by different government authorities	2	Because of water scarcity and different priorities set by different departments
D.8	Decrease in the visits to recreational areas	2	Because of deterioration of the environment
D.9	Damage in cultural heritage sites	1	Not in Cyprus
D.10	Decreased nutrition quality in rural areas	1	Not in Cyprus

correct since rainfed agriculture production depends entirely on the precipitation falling during the year of growth and production. Soils in Cyprus are not such to carry over year moisture.

There is no high correlation between SPI and irrigationor water supply dependent activities economic impacts. The correlation varies from -0.164 to -0.334 for the SPI in the catchments area, from -0.4099 to -0.422 for the SPI of Akrotiri and around -0.3 for the Kokkinochoria SPI.

There is no correlation at all between SPI and the losses of financial institutions and industries dependent on irrigated agriculture. It is also seen that the correlation is slightly high in the opposite direction which means that in cases of drought events these institutions do not suffer from losses but instead increase their activities.

The correlation of SWSI with the different impacts is the following:

– Losses in crop production: Correlation coefficient -0.6627

– Losses of water supply firms: Correlation coefficient -0.6354

– Losses of Government from domestic water: Correlation coefficient -0.6959

– Losses of Government from irrigation water: Correlation coefficient -0.5689

– Extra cost to Government in water treatment: Correlation coefficient -0.5307

– Total economic cost: Correlation coefficient -0.6810

– Rainfed crop gain/loss: Correlation coefficient 0.9002

– Water supply: Correlation coefficient 0.2228

From the above the following can be concluded:

(i) The Surface Water Supply Index reflects in a more representative manner the relationship between droughts and economic impacts

(ii) The SPI index correlates highly with the rainfed agriculture losses, which indicates that the meteorological drought affects directly the rainfed agriculture.

(iii) There is no correlation between the SWSI and SPI with the water supply quantities. In both cases this is because of the role the reservoirs play in the water supply management. The role of the surface, over-annual storage reservoirs is to regulate the greatly varying inflow to the reservoirs to a steady outflow thus providing a dependable safe annual supply, which is based on the overall average yield of the reservoir. With the right management of the reservoirs, it is possible to achieve satisfaction of the basic water demands even under severe drought conditions something, which happened in Cyprus during the years 1990/91, and 1996/2000. The uniformity of water supply achieved by the proper use of the over-annual storage reservoirs definitely distorted the correlation coefficient and finally showed that there is no correlation between SWSI and water supply volumes, which under normal conditions should be very high.

A study aiming to estimate the economic effect of drought from the reduction on agricultural production was carried out by the Economics Research Unit of the University of Cyprus within the framework of the MEDROPLAN Project (Soteroulla *et al.*, 2005). For carrying out the study, the agricultural production was divided into seven categories for which data could be found on all variables of interest for the years 1975-2000, which categories are: potatoes, grapes, citrus, fruit, vegetables, olives and wheat. Wheat and grapes are the only products, which depends solely on rainfall. The aim was to estimate the effect of drought, measured with the annual or semi annual or as a moving average Standardized Precipitation Index (SPI) and the regressions are estimated for the standardized production of each agricultural product, since SPI is a standardized variable.

From the mentioned analysis the following can be summarized:

(i) There is no clear relationship between potatoes production and SPI. This is due to the fact that groundwater has been used extensively to supplement the deficient surface water supply, where surface reservoir reserves were used to compensate supplies during drought periods. The potatoes are winter crops and under normal conditions most of their water demands can be satisfied from the rainfall. In case of drought a relatively small supply of water from surface reservoirs or from groundwater can secure full production. The role of surface reservoirs and groundwater aquifers is very important in eliminating water shortages during droughts if used properly.

(ii) There is clear relationship between grapes production and SPI. This is because grapes are fully rainfed and SPI expresses the meteorological drought.

(iii) There is clear relationship between wheat production and SPI. This is because wheat is fully rainfed and SPI expresses the meteorological drought.

(iv) The relationship between citrus and SPI is varying, being originally negative and then becoming positive. This can be explained by the fact that during the 1970's 1980's droughts there was an alternative water supply from groundwater to compensate the short supplies from surface water. However with repeated droughts and with the continued over-pumping, the groundwater reserves have been adversely affected thus at the end not being able to supplement the surface water supplies. Ground water depletion and increased water demand on the surface water sources, and acute water shortage on the surface water supply system in drought events, result to the inability of the supply system to supply water to the citrus plants, indicating finally a direct relationship between SPI and citrus production.

(v) The relationship between vegetables production and SPI is similar to the one of citrus for the same reasons.

(vi) Generally there is a direct relation between rainfed agriculture and SPI although this sometimes depends on the rainfall distribution during the rainy season. Reduced rainfall in the winter months might not affect the rainfed crops but reduced rainfall in the autumn and spring months may have an adverse effect. With regard to the irrigated crops the relationship is not so direct because the surface and groundwater reserves play an important role in the supply of water. From the analysis carried out it can be seen that the duration of drought, expressed by SPI, starts to have an effect on irrigated agriculture since prolonged drought causes depletion of the reserves (surface or groundwater). Unfortunately not enough data was available to examine the relationship with the Surface Water Supply Index.

Operational component

The great variability of rainfall during the decade 1990-2000 with two periods of drought one lasting for two years and the other for five years, have created acute shortage of water. During these periods the Government was forced to change its water policy and to implement a number of drought mitigation measures thus avoiding devastating effects on the economy, on the social life and on the environment. The short and long term measures were aiming to increase the water availability, to reduce the demand and to minimize the impacts. The best measures under the prevailing hydro-meteorological, social, economic and environmental conditions were the water rationing, the raising of the public awareness and education of the consumers on how to use and save water at the consumers' level, the introduction of desalination and the use of improved irrigation systems for irrigation. Cyprus does not have the necessary legal framework for the preparation of drought preparedness plans of the risk management type and all the drought mitigation plans that were implemented were of crisis management type.

Permanent monitoring

The basis for the drought management plans in the past during the decades 1970-2000 was the selection of actual meteorological data, the hydrological data (inflow and outflow from dams) the actual use of water by sector and by user and the actual amount of water in storage in real time. Early before the commencement of the hydrologic year (in August) an assessment of the available water resources (surface, groundwater and other) was made, and the projected demands and most probable inflows were estimated in an effort to prepare a balance sheet of the water resources by the end of the coming hydrological year. This exercise was continuously updated through the winter months until the end of March, at the end of the rainy season. By analyzing the results of the water balance sheet, the water situation was initially forecasted but as time was passing by, the situation whether a drought was coming or not was becoming clear. The monitoring was not based on any index but clearly on meteorological, hydrological and water demand data that were collected on a daily basis and utilized to run water supply simulation models to establish water deficits if any.

Fig. 9 shows the actual water supply, the normal water demand and the deficit that occurred during each of the years 1987-1999 of the Southern Conveyor Project. The figure shows acute water shortages in the years 1991-1993 and the years 1996-2000 created by the drought events of the years 1990/91 and of the years 1996-1999 (one year drought and a four year duration droughts).

Examples of drought management

The drought events in the early 1970's and 1980's were easier to mitigate because the level of water utilization was lower and the water demand was lower. Their adverse effects were avoided by mobilizing non-mobilized water, by transferring water from non-developed river basins and by accelerating the rate of project construction and to a lesser extent by imposing small water cuts. However the droughts of the 1990's were very difficult to mitigate and the only way to mitigate them was by water rationing to both domestic and irrigation consumers and by cutting water supplies by more than 20% to domestic users and up to 70% to the irrigators. The inability of the water managers to mitigate these droughts was caused by the fact that all natural water resources were developed and the water demand has reached a level equal to the average annual supply. It is obvious that the only way to minimize the adverse impacts on the economy, the social life and the environment, generated by the water shortages caused by droughts, is through a Drought Preparedness Plan.

Cyprus adopted and applied practices which were chosen from a variety of practices available or proposed at the time. There are long term, medium term and short term measures, and each measure

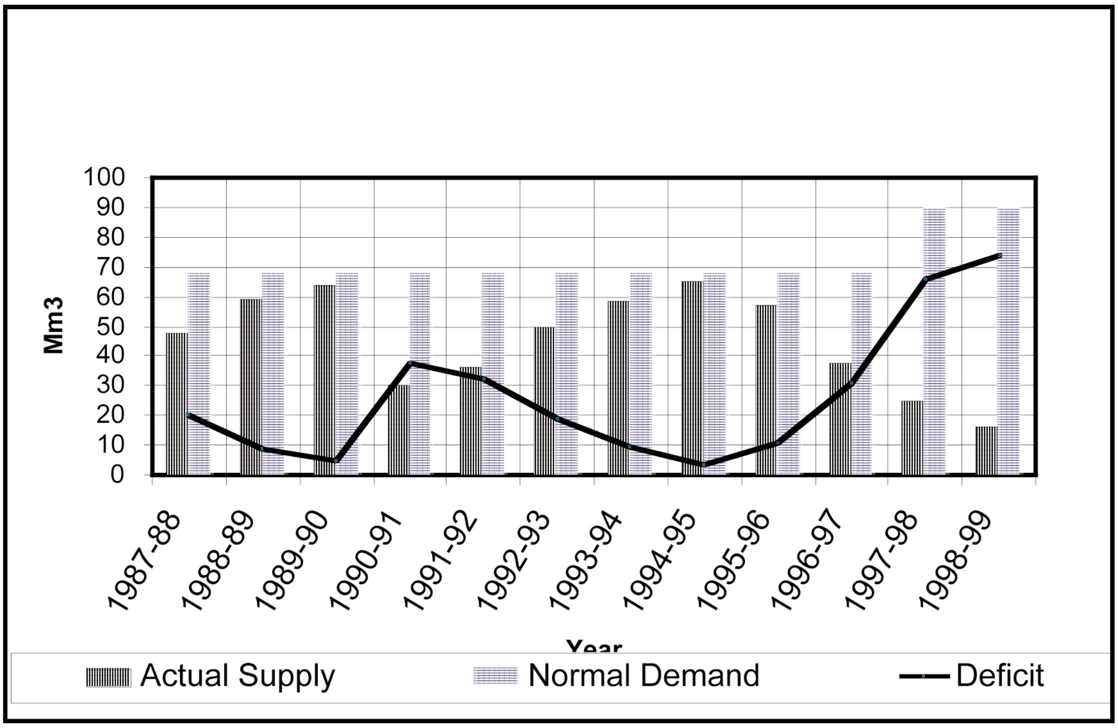


Fig. 9. Southern Conveyor Project water supplies, normal demand and observed deficit (dams only).

includes a number of practices. It has been found out that the best practices are those that are very effective and efficient (give results), are just and simple, are understood by the affected consumers, give immediate results and are applied as long as they are needed.

From all the measures adopted and applied the following can be considered as the best practices.

Water rationing

Although it is a painful measure, it is the most effective since it generally enables the water mangers to overcome the great water crisis. There were difficulties to find the golden rule as to how much water should be rationed to the individual irrigators and how to achieve equal distribution to the domestic consumers. This measure was effective (reduction in water consumption, reduction in wasteful use) and a lot of water was saved. It requires cooperation and understanding from the side of the consumers and generosity, patience and quick action from the part of the water managers. The water rationing was imposed by water cuts but its success is based on the acceptance and cooperation of the users.

Water saving

The consumers were "educated how to use water" and how to avoid over-consumption and were assisted to achieve this by the provision of the means (modernization of on-farm irrigation systems, toilet flashing water saving mechanisms, flow regulators in taps, avoid use of hoses for car and floor washing and cleaning, etc.). Domestic water distribution systems improvement, by the use of leakage detectors and repairs and the installation of high accuracy water meters were also very effective.

Use of brackish water

The use of second quality water for gardening and flashing is a common best practice.

The Government subsidized the drilling of boreholes, installation of pumping units and connection to the toilets in urban areas, thus enabling the saving of almost 50% of the domestic consumption. In some areas without groundwater the Government subsidized the installation of grey water treatment and recycling water systems.

Desalination

This measure is very efficient and effective since it increases the water availability, increasing the system reliability, and it gives results within short time compared to other alternatives which require longer periods to materialize and are dependent in many case on the weather conditions and the will of the consumers.

Awareness

Creating water awareness and, promoting the education of the consumers on water was effective and efficient directly and indirectly since it helped the population to accept the measures and also to save water.

Compensations

The provision of compensations to the most affected solved a socioeconomic problem and on the other side it helped the population to be responsive and accept the implementation of the drought mitigation measures.

Improved irrigation systems

Since agriculture consumes more than 70% of the total water resources a small saving on water for irrigation is contributing a lot in the effort to save water. The Government of Cyprus started very early in the 1960's to promote the use of modern efficient on farm irrigation systems, with efficiencies around 85-90%. Now almost 100% of the irrigated area is served from pressurized distribution systems are irrigated with modern on-farm irrigation systems.

Stakeholder analysis

Five stakeholders were interviewed to validate the organizational and operational mental model and to enhance the understanding of droughts and water scarcity problems in Cyprus. Below is a summary of the role each stakeholder plays in water and the information provided in the interviews relevant to the drought definition and understanding and to the validation of the reactive model applied in Cyprus during the period 1990-2000.

The five stakeholders were the following: Water Development Department, Meteorological Service, Department of Agriculture, water boards and farmer union organizations.

Water Development Department

This Department is the technical adviser to the Ministry of Agriculture, Natural Resources and the Environment and to the Government in general and contributes mainly to the formulation of the Government's water policy. This Department is also the main contractor who under the direction and authority granted by the Council of Ministers undertakes to plan, design, construct the waterworks and implements in general the Government's water policy.

Meteorological Service

This Service is a Government Department belonging to the Ministry of Agricultural, Natural Resources and the Environment and it is in charge of collection, processing and storing of all the meteorological data and preparing the weather forecasts for the civil aviation, travelers, agriculture and for any other users.

Department of Agriculture

This Department belongs to the Ministry of Agriculture, Natural Resources and Environment and it is responsible for the implementation of the Agricultural Policies of the Government. It also participates to the formulation of the policies.

Water Boards

These are semi-governmental organizations charged with the responsibility of distribution of domestic water in towns and cities. A Board of Directors made of a varying number of members, three of which are appointed by the Government and the rest being elected members from the municipalities govern the Water Boards.

Farmers Union Organizations

The farmer's union organizations are non governmental organizations whose objectives are to promote and protect the interests of the farmers. There are four such organizations in Cyprus representing the various political fractions of the constituent.

Summary of the interviews with stakeholders

(i) *Drought definition.* Droughts constitute a permanent feature of the Cyprus climate and are recognized by all by the lower than normal precipitation, lower flow in rivers and inflows to dams, and by reduced moisture in the plants root zones. No indices or other specific parameters are used to identify drought. It is also recognized that Droughts cannot be avoided but can be mitigated through proactive planning and actions.

(ii) *Water value.* Water is a socioeconomic good and as such it must be valued and priced accordingly. Although almost all water belongs to the Government, the irrigators' and other users' rights to use the water cannot be totally removed. In cases of droughts water is reallocated according to the priorities set by the Government. The Government through its agencies monitors the climatic and hydrological parameters and keeps records enabling its agencies to intervene in cases of droughts.

(iii) *Trends.* During the last 30 years it has been observed that droughts are occurring more frequent with longer periods than before. It is also recorded that there is a climate change with reduction in rainfall by 1 mm/year and increase of the ambient temperature by 0.5° C. per 100 years. During the 1990-2000 decade Cyprus has faced successfully the 5 year severe drought, because the measures adopted were accepted by the public and were just and not one sided. The Government also provided limited compensation to those that were severely affected.

(iv) *Management.* Cyprus is very vulnerable to droughts because it has developed most of its natural water resources and the existing legislation does not provide for drought preparedness plans and no specific actions for drought mitigation. The exiting Agricultural insurance plan against droughts is inadequate and cannot be considered as a drought mitigation measure. It does not cover losses suffered by the irrigated agriculture due to droughts and in case of rainfed agriculture it provides cover for a very limited type of crops.

Acknowledgements

The drought identification and the risk analysis studies were carried out on meteorological and hydrological data of the Southern Conveyor Project, which supplies domestic and irrigation to more than 60% of the population of Cyprus, using the procedures outlined in the Terms of Reference of the MEDROPLAN Project. A lot of data and information were provided by the Water Development Department, the Meteorological Department and the Agricultural Department to whom we express our sincere thanks and gratitude.

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Annex 1. Data and information systems

For the preparation and implementation of water development and water management plans, including drought management plans, it is necessary to collect record, process and provide accessibility to a number of variables of Biophysical and Socioeconomic nature. Table 1.1 outlines the type of data, the Institutions that collect record and process the data, how the data is acquired, the accessibility, the data reporting and the data users. Most of the information and data on drought can be acquired by request from the Departments that collect and use it, where a smaller portion can be required from published statistics or census reports.

Table 1. Characteristics of the biophysical and socio-economic data and information in Cyprus

Type of Data	Data and information System Description
Climate	Supplier: Meteorological Service Governmental Office Acquisition: Meteorological Stations manned or unmanned spread all over the island. Data include precipitation, temperatures (min, max, average), humidity, wind speed, evaporation, solar radiation, etc. Accessibility: Hard Copies, free of charge Reporting: Not published. Data kept in database Files in soft or hard copies Users: Civil Aviation, Department of Water Development, Dept of Agriculture and other organizations
Soils	Supplier: Department of Agriculture Acquisition: Surveys and investigations, soil type, soil potential, soil classification Accessibility: Purchase of Maps from Land and Surveys Department Reporting: On Maps by the Land and Surveys Department Users: Department of Agriculture, Town and Rural Planning Department, Farmers, Others
Water	Supplier: Water Development Department Acquisition: Continuous measurement of stream-flow, and water levels in aquifers Accessibility: Official request to the Water Development Department. Hard copy, digital form Reporting: Not published. Data kept in database Files in soft or hard copies Users: Water Development Department
Land	Supplier: The Land and Survey Department is responsible to register all lands in Cyprus Acquisition: Compulsory registration of land ownership Accessibility: Purchase of the Land Registry Maps Reporting: Land Registry Maps Users: Government Offices and Individuals

Agriculture	Supplier: Department of Agriculture, Department of Statistics Acquisition: Surveys, Census and Investigations Accessibility: Purchase of Agricultural Statistics Publications of the Department of Statistics from Government Printing Office Reporting: six monthly, yearly statistics Users: Government Offices and others
Water Supply and Use	Supplier: Water Development Department Acquisition: Continuous measuring of sales of water to communities and individuals. Accessibility: Requesting data Reporting: Hard copy upon request Users: Water Development Department
Land Use	Supplier: Department of Agriculture Acquisition: Land use surveys or by Agricultural Census Accessibility: Purchasing of Census Reports or Agricultural Statistics Reports from Printing Office Reporting: Annual Statistic Reports or Census Reports Users: Department of Agriculture, Water Development Department, Land Consolidation Department
Water Demand	Supplier: Water Development Department Acquisition: Measuring consumption by various users Accessibility: Requesting Data Reporting: Hard copy upon request Users: Water Development Department
Economic Indicators	Supplier: Department of Statistics Acquisition: Department of Statistics on a regular basis Accessibility: Purchasing Economics Statistic Publications from Government Printing Office Reporting: Official Government Statistic Publications Users: Ministry of Finance, Economic and financing Planners in general
Demographic Indicators	Supplier: Department of Statistics Acquisition: Ministry of Interior vital statistic Department Accessibility: By purchasing Demographic and Population statistics of the Department of Statistics fro the Printing Office Reporting: Hard Copy Users: Economic and social Planners

Chapter 16. Application of the Drought Management Guidelines in Greece

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SUMMARY – Greece is often affected by recurrent drought. The study includes analysis of two watersheds, Nestos and Mornos, selected to represent drought episodes and management in Greece. The study focuses on the methodologies for the drought characterisation and the analysis of the hydrological and agricultural impacts of drought. Furthermore, it analyses the interrelations between the drought indices derived for certain return periods and the impacts on the socioeconomic system and the environment. The operational component reviews the procedures of previous drought events, in order to formulate proposals for successful mitigation actions. Although the Greek organisations have not developed concrete strategies concerning droughts, they have dealt with this phenomenon as a case to case basis, to a certain extent. However, from a review of the existing institutional structure, it can be concluded that the country needs a comprehensive effort to rationalise the entire drought analysis, monitoring and mitigation system. There is an obvious lack of scientific organisations, legal framework and operational capabilities to combat the effects of drought. It is also absolutely necessary to devise preparedness plans for achieving pro-active defence against drought. Needless to say that an operating mechanism should be instituted for an effective application of rational measures resulting from a scientific analysis. During drought, water restrictions are imposed mainly for domestic water consumption. However, the 84% of the water used in the country is consumed in the agricultural sector. It is logical therefore to re-direct water restrictions, giving emphasis to agricultural use, which is the principal consumer of water. Last but not least, it should be noted that there is a severe gap in the measures for combating drought, i.e. the lack of insurance of people and property in the event of a drought occurrence. However, it should be pointed out that following the Law 3199/2003 and the subsequent presidential decrees, scientific and technical commissions are established in order to analyse the occurrence and mitigation of droughts. The current framework in Greece is characterised by changes. The new law was approved by the Parliament in November 2003 to comply with the obligation of the member states to harmonise their legal system with the water Direct 2000/60.

Key words: Nestos Basin, Mornos Basin, legal framework, drought characterisation, risk analysis, drought plan.

The planning framework

Drought events in Greece

Due to its climatic conditions, Greece is a country often affected by droughts. Although the Greek organisations have not developed concrete strategies concerning droughts, they have dealt with this phenomenon as a case to case basis, to a certain extent. However, from a review of the existing institutional structure, it can be concluded that the country needs a comprehensive effort to rationalise the entire drought analysis, monitoring and mitigation system. There is an obvious lack of scientific organisations, legal framework and operational capabilities to combat drought. It is also absolutely necessary to devise preparedness plans for achieving pro-active defence against drought. Needless to say that an operating mechanism should be instituted for an effective application of rational measures resulting from a scientific analysis. It should be noted that during drought, water restrictions are imposed mainly in domestic water consumption. However, 84% of the water used in the country is consumed in the agricultural sector. It is logical, therefore, to re-direct water restrictions, giving emphasis to agricultural use, which is the principal consumer of water. Last but not least, it should be noted that there is a severe gap in the measures for combating drought, i.e. the lack of insurance of people and property in the event of a drought occurrence. However, it should be pointed out that following the Law 3199/2003 and the subsequent presidential decrees, scientific and technical commissions are established in order to analyse the occurrence and mitigation of droughts. The current framework in Greece is characterised by changes. The new law was approved by the Parliament in November 2003 to comply with the obligation of the EU member states to harmonise their legal system with the Water Framework Directive 2000/60.

The Nestos and Mornos Basins

Drought characterisation and operational management are analysed in the Nestos and Mornos Basins (Fig. 1). The Nestos watershed (Fig. 2) is located in northern Greece. The total catchment area, which is 5184 km^2, belongs partially to Bulgaria (2872 km^2) and partially to Greece (2312 km^2 or 45% of the catchment). The topography of the main part of the Nestos catchment is an alternating sequence of valleys and ridges, except of the Nestos Delta plain, which is flat. As far as the geology of the catchment area is concerned, the mountainous part of the Nestos watershed consists of metamorphic rocks (marbles, gneisses, schists), igneous rocks and deposits of quaternary to recent age. The study presented here in a concise form covers only the Greek part of the basin.

The hydrological drought was not examined for the purposes of this report because the three dams that exist in the site started to function in the year 1997. The meteorological time-series at our disposal finishes at 1998. Therefore, the two types of data could not be correlated, even if they existed. Besides, the data of the reservoir of the dams belong to the Public Power Corporation, whose policy is very strict in sharing its data.

Mornos watershed (Fig. 3) is located in the central Greece. The entire watershed occupies an area of 1025 km^2, while the study area covers 571 km^2. At the Mornos River, a dam has been constructed in the late 70's to supply potable water to Athens greater area. Most of the study area is very mountainous. The altitude of the Mornos dam is 320 m, while most of the peaks of the mountains are higher than 2000 m and the mean altitude of the basin is 1020 m. The parent rock is flysch and limestone, and the soils are clay-loam and loam. Analysis was performed on data collected all over the Mornos Basin. Monthly precipitation data were collected at 8 stations across the basin with a record length of 39 years.

Fig. 1. Nestos and Mornos Basins in Greece.

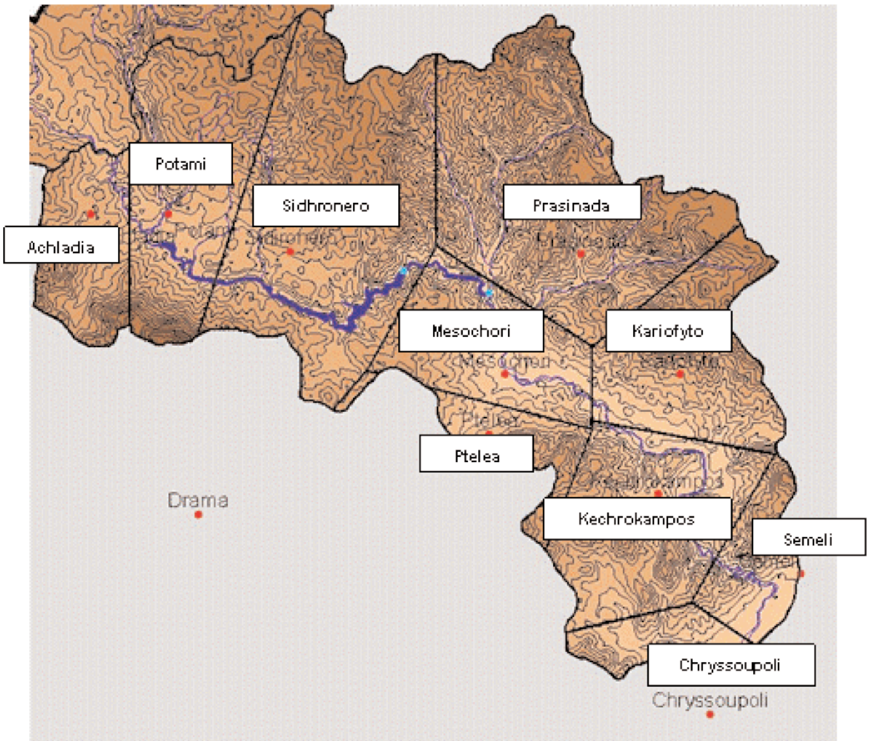


Fig. 2. The Greek Nestos Basin.

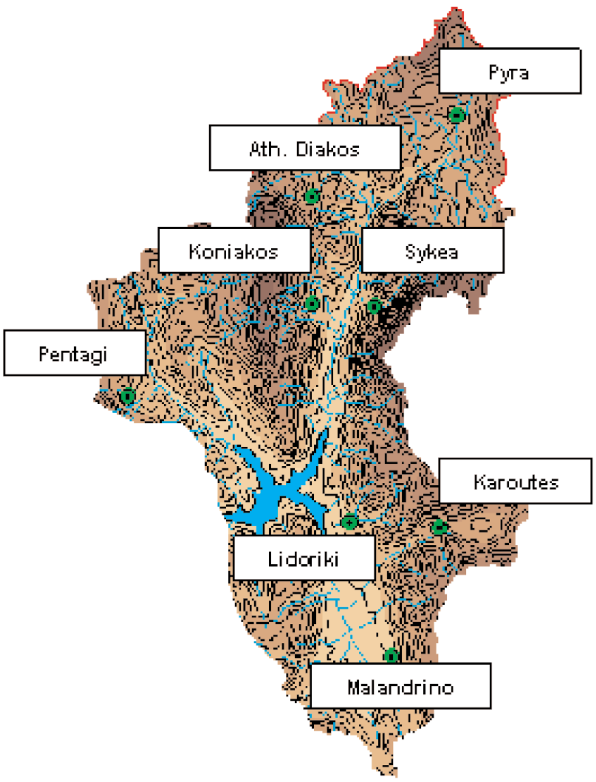


Fig. 3. The Mornos Basin.

Organisational component

Legal framework

The key legal actions in Greece related to water and drought management are:

(i) The Law 1739/1987 "for the Management of Water Resources".

(ii) The Law 1650/1986 "for the Protection of the Environment", regarding the quality of water

(iii) The European Framework Directive 2000/60/EU.

(iv) The Law 3199/2003 of "Protection and Management of Water".

(v) The legal implications of the UNCCD (94) convention.

The Law 1739/1987 "For the Management of Water Resources" covered all issues related to water policy (research, organisation, planning) by establishing procedures and structures that permitted water management on a national and a regional scale.

However, the lack of presidential decrees covering specific aspects of the application of this Law resulted in a fragmentary and incomplete application. Nevertheless, the Law 1739/1987 served as a framework for the management of the water resources in Greece for the last 15 years.

This statutory framework for Water Resources Management exists for 14 years. It includes the Law 1739/87 "management of water resources and related provisions", regarding water use and management of water quantity, and the Law 1650/1986 "for the protection of the environment", regarding water quality.

The Law 1739/87 defines, inter alia, the River Basin Districts, the responsible Authorities according to the type of water-use, the cardinal role of the Ministry of Development, an Intra-ministerial Water Committee, Regional Water Committees, Regional Water Resources Management Authorities, programs of water resources development, research on surface and ground-water, works of water resources development, water use-permits, the preservation and protection of water resources, the disposal of waste water, the disposal of industrial waste and the disposal of low-quality water to aquatic recipients according to the Law 1650/1986. According to the Law 1739/87, the regional administrative authorities will be responsible for the water supply system and the arrangement of conflicting uses.

The Law 1739/87 sets as primary goal the reservation of adequate water supply to satisfy the present and future demand for different water uses.

However, there are some points that led to the unsuccessful implementation of the Law 1739/87, such as: the multiple distributions of authorities to different Ministries, which have hampered integrated actions, the fact that water resources management was not incorporated in the environmental policy, and the allocation of water quality and quantity issues within the same area to different authorities.

The Law 1739/87 institutes the concept of planning for the development of water resources (preparation of water resources development programs). However, the planning focuses only on satisfaction of water demand, without dealing with the adaptation of the demand on the available water resources.

Integrated management of aquatic ecosystems was hampered by the distinction between management of water resources and environmental policy.

Several problems arose during the process of transfer of authorities from the Ministry to the districts, mainly because the overall infrastructure and specifically the operational infrastructure in the districts is inadequate to respond to the present demands.

Water management is assigned to the Ministry of Development which is deprived of the adequate infrastructure, human resources, knowledge and material, and especially of the political will needed in order to apply water policy.

Incapability to perform the appropriate water authorities satisfactorily has been created from the complete assignment of the water authorities to the state sector and the lack of autonomy and self-reliance.

According to the Law 1739/87, as far as the water permits are concerned, every person has the right to use water. In order to use this right, the person should be supplied with a permit, issued by the responsible ministry. Permits for multiple water use are issued only in special cases. The water permit defines the quantity and the conditions of water use. A water permit is not required for the satisfaction of personal or family needs; still this use should never be expanded in productive activities for product or service sharing and exploitation. The water supply is of first priority compared to any other water use. The permit of water supply for domestic use can neither be abolished nor limited.

The European Directive 2000/60/EC "Establishing a Framework for Community Action in the Field of Water Policy" imposed the need for adopting a new framework for water, fully compatible with its content.

On November 12th, 2003 the Law for the "Protection and Management of Waters" was adopted by the Parliament of Greece. The Law 3199/2003 is based upon the principles of the European Directive. This Law establishes a framework for the achievement of a sustainable water policy and, as a consequence, of a sustainable development of the Country and aims at:

(i) The creation of a contemporary and effective institutional/legislative framework.

(ii) The development of long-term planning.

(iii) The decentralisation of responsibilities and the strengthening of regional structures.

(iv) The creation of national laws with the UE Framework Directive 2000/60.

(v) The implementation of the objectives of the Directive taking into account local specificities of the Country.

The Law 3199/2003 contains the following chapters:

1. Chapter A: Application field and definitions (Articles 1 and 2).

2. Chapter B: Institutions and Authorities (Articles 3, 4, 5 and 6).

3. Chapter C: Management plans, programs of measures (Articles 7, 8, and 9).

4. Chapter D: Use of water, financial regulations (Articles 10, 11 and 12).

5. Chapter E: Penalties (Articles 13 and 14).

6. Chapter F: Repeals, transitional and final provisions, (Articles 15, 16 and 17).

Provisions of the Water-Directive 2000/60 and of its Annexes, not included in the Law 3199/2003, were embodied in Presidential Decrees.

According to the Law 3199/2003, apart from the central authorities, decentralisation is attempted by establishing water directions in all regions of the country. The Law also establishes regional water councils in which most of the stakeholders take part. The water councils are bodies of social discussion and of consultative type. The decisions on water resources for each basin are taken by the region in the territory in which they belong. In case that a river basin belongs to more than one regions, the ensemble of the regions co-operate for the water resources management of the river basin.

Regarding the water permits for water supply or the construction of a water project, they are issued, following a prescribed procedure by the general secretary of the corresponding region.

Finally, several penalties in case of violation of the Law are described in the last articles. Most of the articles of the Law 1739/87 are replaced by the Law 3199/2003.

Although there are no specific articles regarding drought mitigation, it is implied that the bodies responsible for the water resources management will be also responsible for drought issues.

Although the major framework of bodies responsible for the water resources management according to the Law 3199/2003 has been decided, further elaboration is needed in order to render this Law functional. For this purpose a series of ministerial decrees should be issued, in order to customise the various directions provided in this framework Law. At the same time, several actions have been taken for testing the proposed structure at a pilot scale.

Specific measures of drought mitigation have not been legislated in the past in Greece. However in 1994 Greece signed the Desertification Convention of the United Nations, which was ratified by the Greek Parliament in 1997. Desertification may be considered related to drought. The implementation of this Convention the National Committee to Combat Desertification (NCCD) has been established and in 2002 the Greek National Action Plan (NAP) for Combating Desertification was developed. The Greek Government accepted officially the National Action Plan in July 2001, through a Common Ministerial Decision (CMD) of six involved Ministers.

Structure and linkages among the relevant Institutions, organisations and stakeholders

The Law 3199/2003 establishes and defines the institutions and authorities responsible for the water protection and management. The NGOs can express opinion and, from time to time, they are invited to make proposals to the responsible Ministries. However, it is left totally to the Minister to decide whether the proposal will be accepted or not. The institutional structure is depicted in Fig. 4.

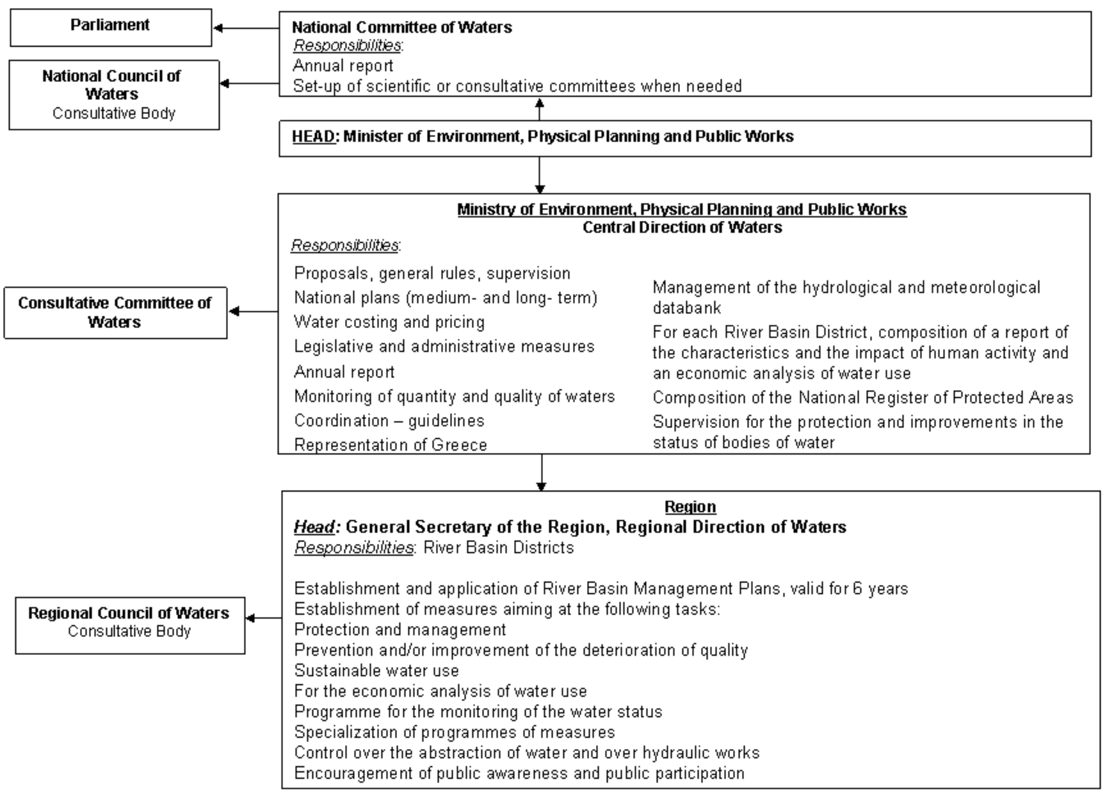


Fig. 4. Organisation chart of services concerning water resources management in Greece.

The River Basin District was first introduced in Law1739/87. Greece was divided into 14 river basin districts, including: West Peloponnesus, East Peloponnesus, North Peloponnesus, West Central Greece, Epirus, Attica, East Central Greece and Evia, Thessaly, West Macedonia, Central Macedonia, Thrace, Crete and Aegean Islands.

It is estimated that the existing river basin districts will be changed and limited in number. Within this concept, it is suggested to divide Greece into 7 to 9 river basin districts.

National Committee of Waters and National Council of Waters

A National Committee of Waters is constituted, chaired by the Minister of Environment, Physical Planning and Public Works. This Committee is responsible for: (i) planning of the policy for the protection and management of waters; (ii) supervision and control of the implementation of the aforementioned policy; and (iiI) approval of the national plans for the protection and management of the water potential of the Country.

Members of the National Committee of Waters are the Ministers of Economy and Finance, of Interior Affairs, Public Administration and Decentralisation, of Development, of Health and Welfare and of Agriculture. Other Ministers may participate when issues of their responsibilities are in the agenda. The Minister of Foreign Affairs participates when issues about international waters are discussed.

The National Committee of Waters may form consultative-scientific committees when needed. The National Committee of Waters submits an annual report to the Parliament and to the National Council of Waters.

A National Council of Waters is constituted, presided also by the Minister of Environment, Physical Planning and Public Works. Members of this Council are representatives of stakeholders, i.e. political parties represented in the Parliament, prefecture representatives, municipal unions and companies, unions of workers, scientific organisations and two non-governmental organisations. The National Council of Waters is a consultative body and reports to the National Committee of Waters.

Central Direction of Waters and Consultative Committee of Waters

A Central Direction of Waters is constituted as a unified administrative sector in the Ministry of Environment, Physical Planning and Public Works, having the following responsibilities:

(i) Working out of national medium –and long– term plans for the protection and management of waters.

(ii) Drawing up of the annual report mentioned above.

(iii) Coordination of the various state departments and public sectors and representation of Greece in the official bodies of the European Union.

(iv) Proposal of the general principles for water costing and pricing and supervision of their implementation.

(v) Proposal of legislative and administrative measures for the protection and management of water.

(vi) Management of the hydrological and meteorological database on a national level and care for updating.

The Central Direction of Waters is responsible for the economic analysis of the water use for each River Basin District, the composition of the National Register of Protected Areas, the surveillance for the protection, upgrade and restoration of surface, artificial or heavily modified water bodies, etc. In the Central Direction of Waters the Consultative Committee of Waters is constituted.

Regional Direction of Waters, Regional Council of Waters

Regions are responsible for the protection and management of each River Basin District. In each Region the Regional Direction of Waters is constituted, which has the following responsibilities:

(i) The specialisation of the appropriate measures that have to be taken for the integrated protection and management of the River Basin Districts.

(ii) The specialisation and application of medium- and long- term programs for the protection and management of the River Basin Districts.

(iii) The establishment of measures necessary for the economic analysis of water use.

(iv) The control over the abstraction of fresh surface water and groundwater and over hydraulic works developed for the exploitation of water.

(v) The establishment and application of River Basin Management Plans.

(vi) The encouragement of public participation.

In each Region, the Regional Council of Waters is constituted, presided by the General Secretary of the Region. This is a consultative body and acts as a link for the promotion of public involvement and participation in the protection and management of waters.

Methodological component: Drought characterisation and risk analysis

Intensity, frequency and duration of drought

Intensity, frequency and duration of drought were calculated for the Nestos and Mornos river Basins. Multiple indices were applied to estimate the optimal indicator to be used in a monitoring system. Two well-known indices, the Deciles and the Standardised Precipitation Index (SPI), and a new index, the Reconnaissance Drought Index (RDI), were evaluated. The results obtained by each index, as well as the correlations of the Deciles and SPI with the RDI are presented in Annex 1. The "run method" was applied to further characterise the statistical properties of drought.

Monthly precipitation data were collected at 10 stations across the Greek Nestos Basin with an average record length of 32 years (1964 to 1996), and at 8 stations across the Mornos Basin with an average record length of 39 years (1962 to 2001). The stations and periods used for the analysis are shown in Table 1.

Table 1. Meteorological stations in the Nestos and Mornos Basins

Sites in the Nestos Basin	Period	Sites in the Mornos Basin	Period
Achladia	1964 - 1996	Pyra	1962 - 2001
Chryssoupoli	1964 - 1996	Ath. Diakos	1962 - 2001
Kariofyto	1964 - 1996	Sykea	1962 - 2001
Kechrokampos	1964 - 1996	Koniakos	1962 - 2001
Mesochori	1964 - 1996	Pentagioi	1962 - 2001
Potami	1964 - 1996	Lidoriki	1962 - 2001
Prasinada	1964 - 1996	Karoutes	1962 - 2001
Ptelea	1964 - 1996	Malandrino	1962 - 2001
Semeli	1964 - 1996		
Sidironero	1964 - 1996		

The Nestos Basin

In general, all indices in all stations show a severe drought period during the years 1989-1993, a period that is documented as the most severe drought period over the last decades in Greece. The correlation among indices during this extreme drought period is high. Results show that the RDI is a very reliable index that could be more widely used than the other two indices tested, since it is correlated with both of them. The RDI has a mean correlation coefficient equal to 0.9509 when it is correlated to Deciles and a mean correlation coefficient equal to 0.9785 when it is correlated to SPI.

In order to characterise the statistical properties of drought, we considered the following parameters: duration, frequency and intensity. Drought frequency was estimated as the probability of non-exceedance for each precipitation station. We chose to calculate the probability of non-exceedance for the SPI, since its threshold is much more evident that the one of Deciles. We established a threshold of "severe drought" event when the SPI was equal or less than -1. Table 2 shows the frequencies calculated with this criterion. The intensity of the drought periods is also presented in Table 2. The intensity of each drought episode, calculated as the value of the SPI in each period is summarised in Table 3. Data in Table 2 show that apart from duration, the drought spell of 1989-93 was also relatively severe for almost all the stations of the Nestos Basin. Furthermore, the northern part of the basin (stations Mesochori, Potami, Prasinada) passed an important drought period during the hydrological year 1984-85.

Table 2. Frequencies of drought spells calculated when the SPI is equal or less than -1 and duration of drought spells in the Nestos Basin

Site	Number of droughts	Calculated return period (years)	Practical return period (years)	Drought periods (hydrological years)[†]
Achladia	8	4.05	4	1967 - 68 (1), 1973 - 74 (1), 1986 - 87 (1), 1988 - 90 (2), 1991 - 94 (3)
Chryssoupoli	7	4.75	5	1975 - 76 (1), 1984 - 85 (1), 1988 - 93 (5)
Kariofyto	4	7.11	7	1973 - 74 (1), 1988 - 89 (1), 1991 - 93 (2)
Kechrokampos	7	4.70	5	1965 - 66 (1), 1969 - 70 (1), 1973 - 74 (1), 1990 - 93 (3)
Mesochori	6	5.13	5	1984 - 85 (1), 1988 - 90 (2), 1991 - 94 (3)
Potami	5	6.17	6	1973 - 74 (1), 1984 - 85 (1), 1988 - 90 (2), 1993 - 94 (1)
Prasinada	4	7.45	7	1973 - 74 (1), 1984 - 85 (1), 1988 - 89 (1), 1992 - 93 (1)
Ptelea	6	4.98	5	1967 - 68 (1), 1984 - 85 (1), 1988 - 92 (4)
Semeli	6	5.01	5	1984 - 87 (3), 1989 - 90 (1), 1991 - 93 (2)
Sidironero	6	5.14	5	1975 - 78 (3), 1980 - 81 (1), 1984 - 85 (1), 1992 - 93 (1)

[†] (The number in the parentheses indicate the number of consecutive years of drought).

The threshold of the run method was calculated based on the Deciles index. As in many cases, the lowest 40% of the average precipitation occurrences was considered as the threshold in order to apply the run method.

Figure 5 shows for each Thiessen polygon, the diagram that describes the droughts identified on hydrological series and their characteristics. Figure 6 shows the diagram that sums up the influence of each polygon to the whole river basin throughout the hydrological time series. Table 4 summarises the characteristics of drought on each Thiessen polygon for the hydrological series that were studied.

The A_{crit} (critical area) is considered equal to 25% based upon the following reasoning. In the Greek part of the Nestos Basin, there are three dams. The sub-basin of the biggest one of them covers about 40-45% of the total Greek basin. We consider that having even 1/3 of the flow from the dams lost during a drought spell has undesirable results in agriculture, water supply and energy production. Therefore, it was considered that A_{crit} should be taken equal to the 25% of the basin. Based on the above, a diagram (Figure 6) that shows the water deficit along the entire river basin was produced, according to the theory of the runs.

Table 3. Drought periods and values of annual SPI for each period at the Nestos Basin

Site	Drought period 1 (SPI)	Drought period 2 (SPI)	Drought period 3 (SPI)	Drought period 4 (SPI)	Drought period 5 (SPI)
Achladia	1967 - 68 (-0.57)	1973 - 74 (-0.21)	1986 - 87 (-0.20)	1988 - 90 (-0.77)	1991 - 94 (-0.33)
Chryssoupoli	1975 - 76 (-0.60)	1984 - 85 (-0.56)	1988 - 93 (0.61)		
Kariofyto	1973 - 74 (-0.88)	1988 - 89 (-0.50)	1991 - 93 (-1.05)		
Kechrokampos	1965 - 66 (-0.31)	1969 - 70 (-0.01)	1973 - 74 (-0.28)	1990 - 93 (-0.56)	
Mesochori	1984 - 85 (-0.96)	1988 - 90 (-0.66)	1991 - 94 (-0.28)		
Potami	1973 - 74 (-0.66)	1984 - 85 (-1.51)	1988 - 90 (-0.45)	1993 - 94 (-0.23)	
Prasinada	1973 - 74 (-0.35)	1984 - 85 (-1.41)	1988 - 89 (-1.11)	1992 - 93 (-0.85)	
Ptelea	1967 - 68 (-0.28)	1984 - 85 (-0.39)	1988 - 92 (-0.67)		
Semeli	1984 - 87 (-0.43)	1989 - 90 (-0.19)	1991 - 93 (-0.58)		
Sidironero	1975 - 78 (-0.50)	1980 - 81 (-0.46)	1984 - 85 (-0.25)	1992 - 93 (-0.66)	

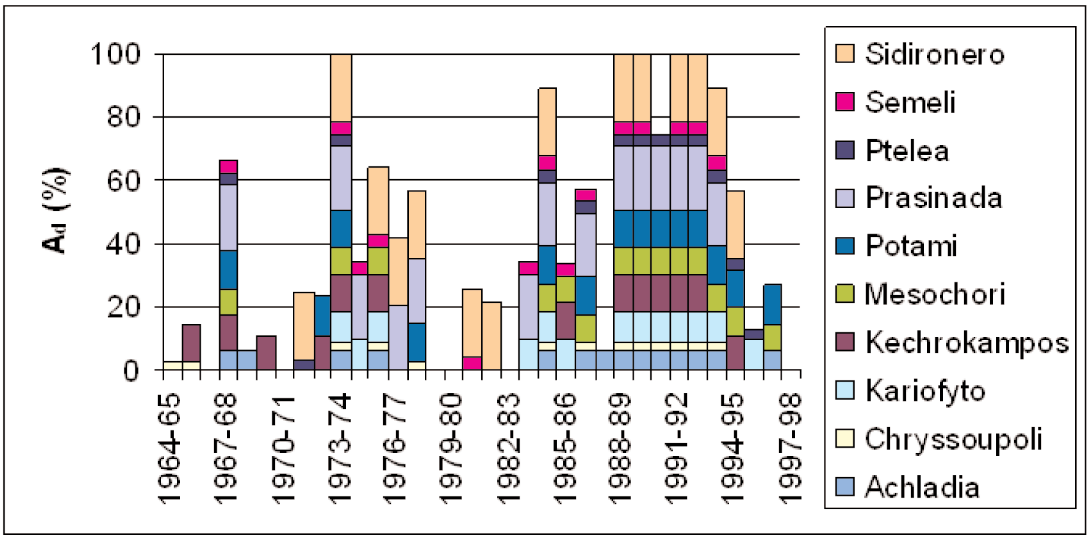


Fig. 5. Regional drought identification - influence of Thiessen polygons in the Nestos Basin. Ad: Affected area.

Table 4. Characteristics of drought spells among the Nestos Basin

	Duration (years)			Water deficit (mm)			Intensity of drought (mm/year)			Total number of droughts
	Min	Max	Average	Min	Max	Average	Min	Max	Average	
Achladia	1	8	2.33	12	952	239.59	12	128	84.07	14
Ptelea	1	8	2.17	9	948	235.47	9	158	90.19	13
Semele	1	4	2.33	56	538	294.21	56	156	118.89	14
Sidironero	1	4	2	3	363	131.80	3	121	56.02	14
Chrisoupoli	1	6	1.86	13	1137	263.41	13	211	121.34	13
Kariofyto	1	6	3.25	8	1068	453.19	8	178	107.88	13
Kehrokampos	1	5	1.63	11	894	193.69	11	179	90.62	13
Mesohori	1	7	2.6	7	680	172.85	7	97	47.96	13
Potami	1	7	2	4	703	203.66	4	262	104.15	14
Prasinada	1	6	2.33	3	712	226.21	3	155	80.21	14

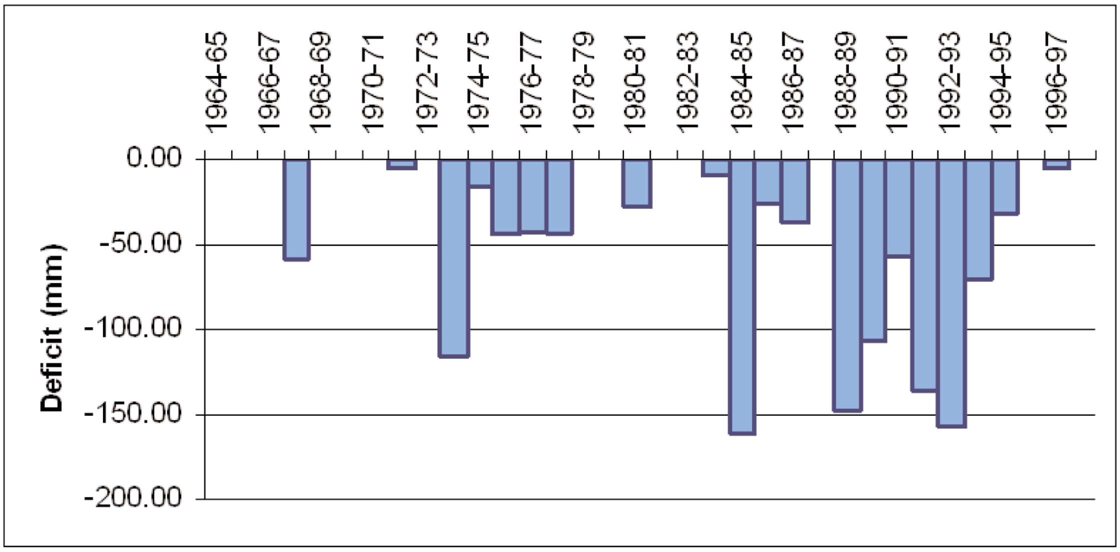


Fig. 6. Water deficit along the Nestos Basin.

The Mornos Basin

The analysis of the hydrologic regime of the Mornos Basin in Central Greece was conducted for 39 hydrological years. The main result is that drought is a recurrent phenomenon since 1987: in most of the years since then the Mornos watershed suffers from drought in almost every station.

The RDI correlates relatively well with the deciles and the SPI. It has a mean correlation coefficient equal to 0.8924, when correlated to Deciles and a mean correlation coefficient equal to 0.9812, when correlated to the SPI. In order to characterise drought and its statistical properties, we also considered the following parameters: duration, frequency and intensity. The results for the Mornos Basin are synopsised in Tables 5-7.

For the calculation of the frequency of drought, the probability of non-exceedence was calculated for each precipitation station. The probability of non-exceedence was calculated for the Standardised

Precipitation Index, because its threshold is much more evident that the one of Deciles. Therefore, the threshold to consider a severe drought event was considered equal to -1, and the following frequencies (summarised in Table 5) were computed.

For the drought periods presented in Table 6, the different intensities for each drought spell of all the meteorological stations were calculated. Table 7 summarises the characteristics of drought on each Thiessen polygon for the hydrological series that was studied.

Table 5. Frequencies of drought spells calculated when the SPI is equal or less than -1 and duration of drought spells in the Mornos Basin

Site	Number of droughts	Calculated return period (years)	Practical return period (years)	Drought periods (hydrological years)†
Pyra	6	6.50	7	1976 - 1977 (1), 1987 - 1988 (1), 1989 - 1990 (1), 1991 - 1992 (1), 1997 - 1998 (1), 2000 - 2001 (1)
Ath. Diakos	5	7.80	8	1975 - 1976 (1), 1982 - 1985 (3), 1991 - 1992 (1)
Sykea	5	7.80	8	1989 - 1990 (1), 1991 - 1993 (2), 1995 - 1996 (1), 2000 - 2001 (1)
Koniakos	4	9.75	10	1976 - 1977 (1), 1991 - 1993 (2), 2000 - 2001 (1)
Pentagioi	8	4.88	5	1982 - 1983 (1), 1987 - 1993 (6), 2000 - 2001 (1)
Lidoriki	6	6.50	7	1974 - 1976 (2), 1984 - 1985 (1), 1989 - 1990 (1), 1991 - 1992 (1), 1995 - 1996 (1)
Karoutes	4	9.75	10	1984 - 1985 (1), 1988 - 1990 (2), 1991 - 1992 (1)
Malandrino	6	6.50	7	1982 - 1983 (1), 1984 - 1985 (1), 1988 - 1990 (2), 1991 - 1993 (2)

† (The number in the parentheses indicate the number of consecutive years of drought).

Table 6. Drought periods and values of annual SPI for each period at the Mornos Basin

Site	Drought period 1 (SPI)	Drought period 2 (SPI)	Drought period 3 (SPI)	Drought period 4 (SPI)	Drought period 5 (SPI)	Drought period 6 (SPI)
Pyra	1976 - 1977 (-0.92)	1987 - 1988 (-0.08)	1989 - 1990 (-0.62)	1991 - 1992 (-0.63)	1997 - 1998 (-0.82)	2000 - 2001 (-0.52)
Ath. Diakos	1975 - 1976 (-0.29)	1982 - 1985 (-1.43)	1991 - 1992 (-0.55)			
Sykea	1989 - 1990 (-0.08)	1991 - 1993 (-1.13)	1995 - 1996 (-0.25)	2000 - 2001 (-0.84)		
Koniakos	1976 - 1977 (-0.17)	1991 - 1993 (-1.25)	2000 - 2001 (-0.71)			
Pentagioi	1982 - 1983 (-0.00)	1987 - 1993 (-0.62)	2000 - 2001 (-0.75)			
Lidoriki	1974 - 1976 (-0.34)	1984 - 1985 (-0.19)	1989 - 1990 (-0.56)	1991 - 1992 (-1.23)	1995 - 1996 (-0.59)	
Karoutes	1984 - 1985 (-0.02)	1988 - 1990 (-0.70)	1991 - 1992 (-1.82)			
Malandrino	1982 - 1983 (-1.02)	1984 - 1985 (-0.15)	1988 - 1990 (-0.24)	1991 - 1993 (-0.90)		

Table 7. Characteristics of drought spells among the Mornos Basin

	Duration (years)			Water deficit (mm)			Intensity of drought (mm/year)			Total number of droughts
	Min	Max	Average	Min	Max	Average	Min	Max	Average	
Pyra	1	3	1.77	29.1	457.6	245.57	29.0	325.0	150.99	16
Ath. Diakos	1	4	2.00	3.9	1801.8	432.88	3.9	450.4	157.63	16
Sykea	1	7	2.28	3.5	1512.7	345.5	3.5	224.6	112.71	16
Koniakos	1	2	1.77	0.2	1524.2	304.55	0.2	357.8	139.81	16
Pentagioi	1	8	3.16	105.7	3448.8	825.23	75.1	431.1	272.15	19
Lidoriki	1	3	1.33	1.8	418.6	138.69	1.8	260.9	100.65	16
Karoutes	1	4	2.00	8.4	576.2	259.83	8.4	286.8	116.14	16
Malandrino	1	3	1.60	25.7	475.7	158.14	12.8	252.9	101.72	16

The threshold of the run method was decided upon the deciles index. According to the deciles theory, a value equal to 4 may be considered as below normal. Therefore, the lowest 40% of the average precipitation occurrences was considered to be the threshold in order to apply the run method.

In Fig. 7, the diagram that describes the droughts identified on hydrological series and their characteristics for each Thiessen polygon is constructed. The diagram that sums up the influence of the polygons to the entire river basin through the hydrological time series is also presented in Fig. 8.

The A_{crit} (critical area) was considered equal to 25% of the basin, based upon the following theory. We consider that having even 1/4 of the area under drought and consequently 1/4 of the flow from the dam lost during a drought spell has undesirable results in water supply, agriculture, as well as in energy production. Therefore, it was considered that A_{crit} should be taken equal to 25% of the basin. Figure 8 shows the water deficit along the whole water basin, according to the theory of runs. During the most serious drought occurrence in Greece, throughout the period 1989 - 1993, the deficit stroke 400 mm of annual deficit out of a normal of 1245 mm per year. In August 1992, Mornos reservoir had water to supply to the Athens greater area only for 40 days.

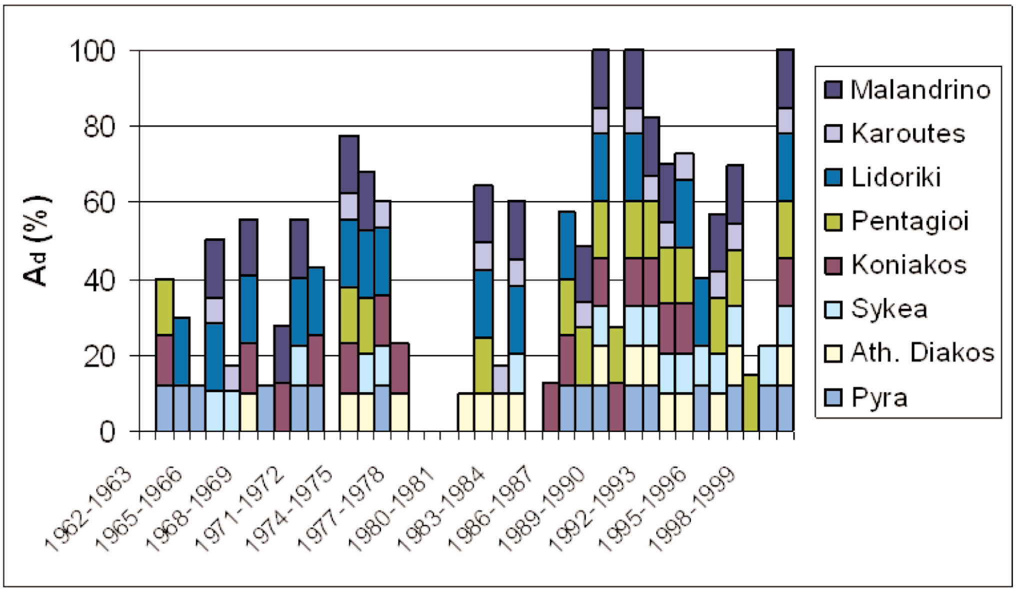


Fig. 7. Regional drought identification - influence of Thiessen polygons in the Mornos. Ad: Affected area.

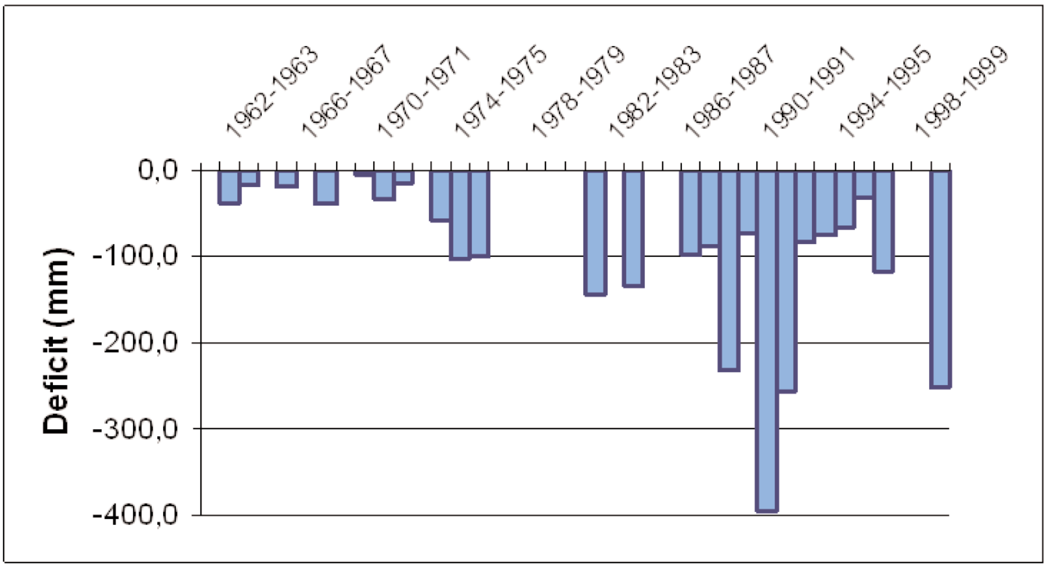


Fig. 8. Water deficit along the Mornos Basin.

Drought effects on runoff

Medbasin software was used for the assessment of the reduction of runoff for the two case studies. Medbasin was developed at the Laboratory of Reclamation Works & Water Resources Management and it includes two conceptual rainfall-runoff models, on daily and on monthly basis, respectively. Moreover, there are many additional tools, which can be used to simulate various conditions of the hydrological system. One of these tools was used in this study in order to simulate the several levels of drought and investigate the response of the system.

The methodology is based on the formulation of several climatic scenarios, derived from the alteration of the normal climatic conditions of the study area. For this task, a period of years with normal or near normal climatic conditions was defined (e.g. using a drought index). By applying the climatic scenarios for this period in the rainfall-runoff model, the percentage of the change of runoff compared to the normal value was estimated. It should be mentioned here, that the results of this method can be reliable only in annual or multi-year basis.

A detailed description of the Medbasin software and of the theoretical background is presented in the Chapter "Tools and models" of this publication.

The Nestos Basin

The selected area for the Nestos case study is a zone of 500 km^2 upstream of the river delta, between the hydrometric stations of Temenos and Paskhalia (Fig. 9). The geological structure of the part of Nestos valley from Temenos dam to Paskhalia is solid with a high runoff coefficient. The altitude varies from 100 to 1500m having a sharp terrain and a sparse hydrographical network. Data from four meteorological stations were used; three of them (Prasinada, Ptelea and Mesohori) are located within the study area, while Kariofyto station is outside the area, a few kilometres to the south (Fig. 9). Using the Thiessen polygons method, it was calculated that for the period of 1964-96 the mean annual precipitation is around 740 mm and the mean annual potential evapotranspiration is 710 mm (Fig. 10).

For the formulation of the climatic scenarios, the RDI was used in order to define the climatic conditions of the area (Fig. 11). A period of eight years (1971-1979) having near normal conditions was selected in order to run the rainfall-runoff simulation. Since only monthly data were available, the monthly rainfall-runoff model was used. The input data were the average precipitation and potential evapotranspiration of the area, while for the calibration of the model the measured runoff data at Temenos and Paskhalia stations were used.

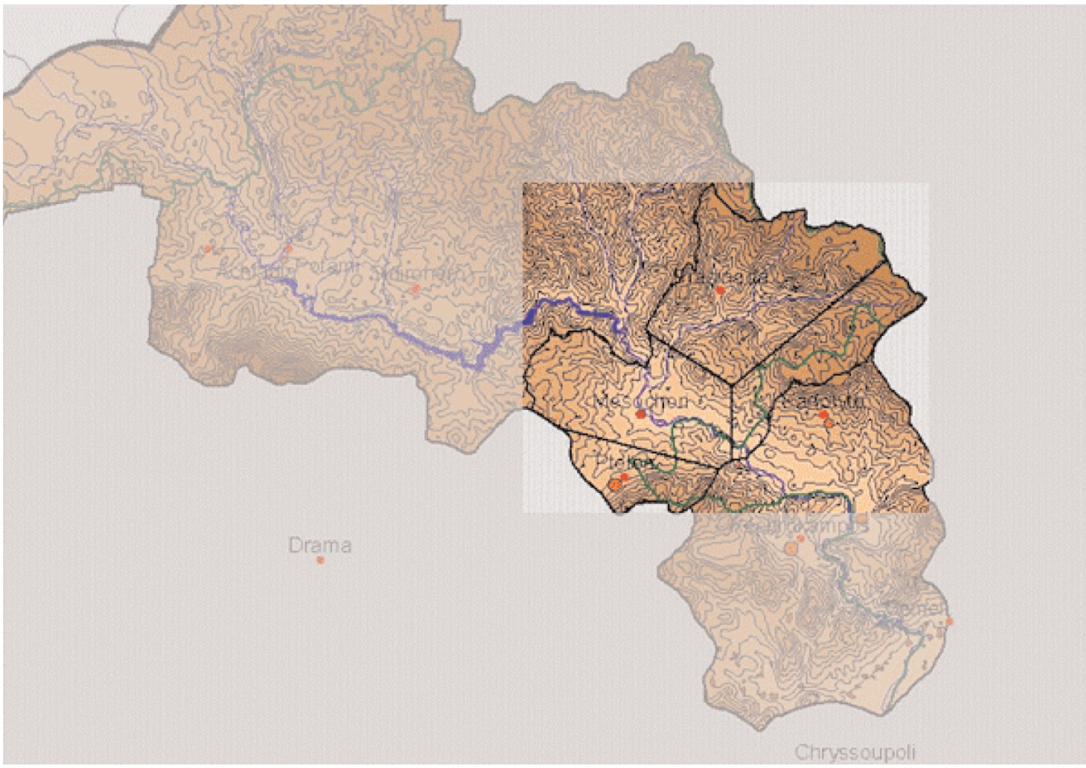


Fig. 9. Nestos Basin: Area of study.

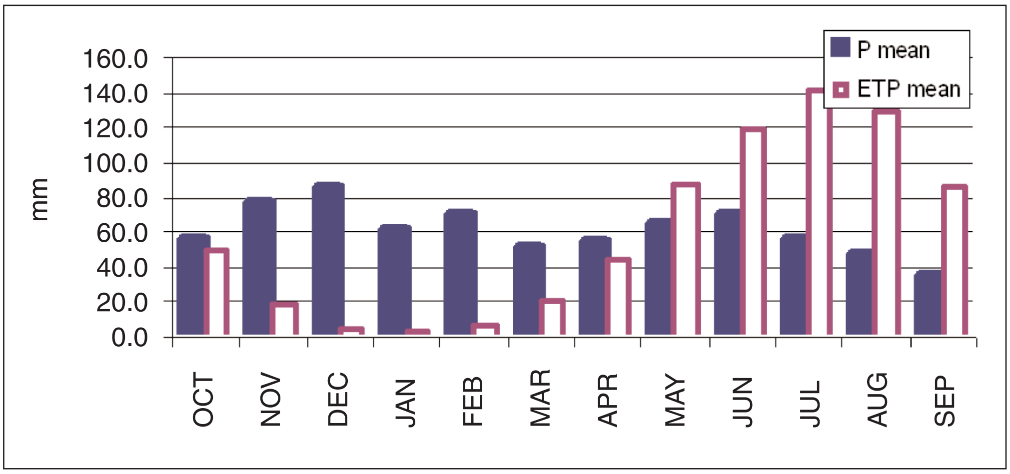


Fig. 10. Mean annual precipitation and potential evapotranspiration for the study area (period 1964-96).

About 120 climatic scenarios were created by altering the original precipitation and potential evapotranspiration data by different percentages up to -40% and +24%, respectively. The results of the rainfall-runoff simulation of these scenarios are presented graphically in Fig. 12 with two-dimensional and three-dimensional diagrams.

On the 2D diagram, some values of the RDI_{st} are presented together with the percentage of the runoff deviation from the normal value. As it can be shown, the runoff reduction is 20-35% for moderate drought conditions, 35-50% for severe droughts and it can be up to 65% for extreme drought conditions. In order to check the accuracy of these estimations, the actual values of runoff reduction for the dry period of 1990-95 were compared (Table 8). It can be observed that for the first

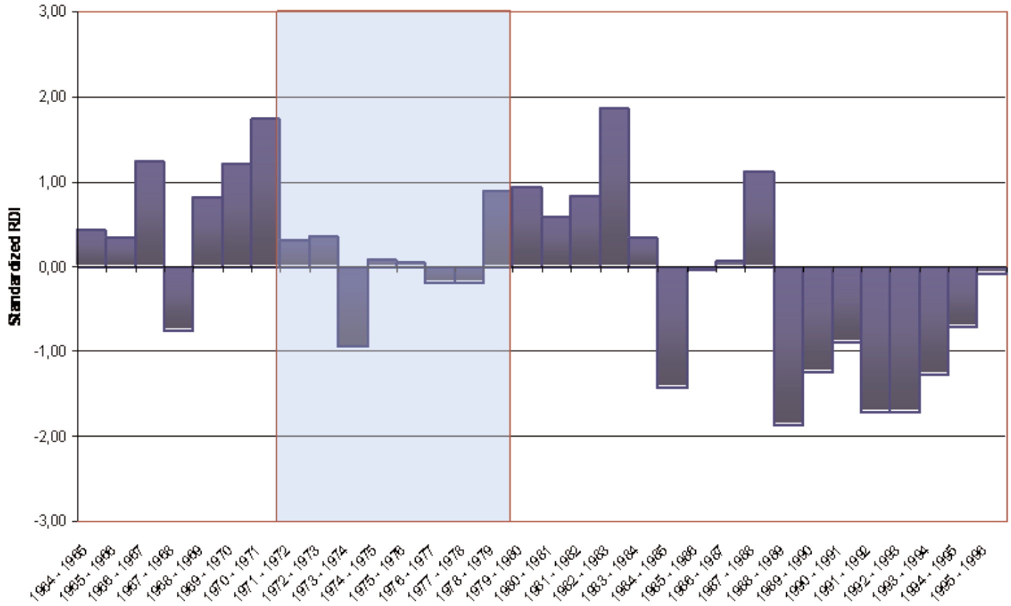


Fig. 11. Standardised RDI (RDIst) values for the study area of Nestos Basin. The period 1971-79 was selected for the rainfall-runoff simulation.

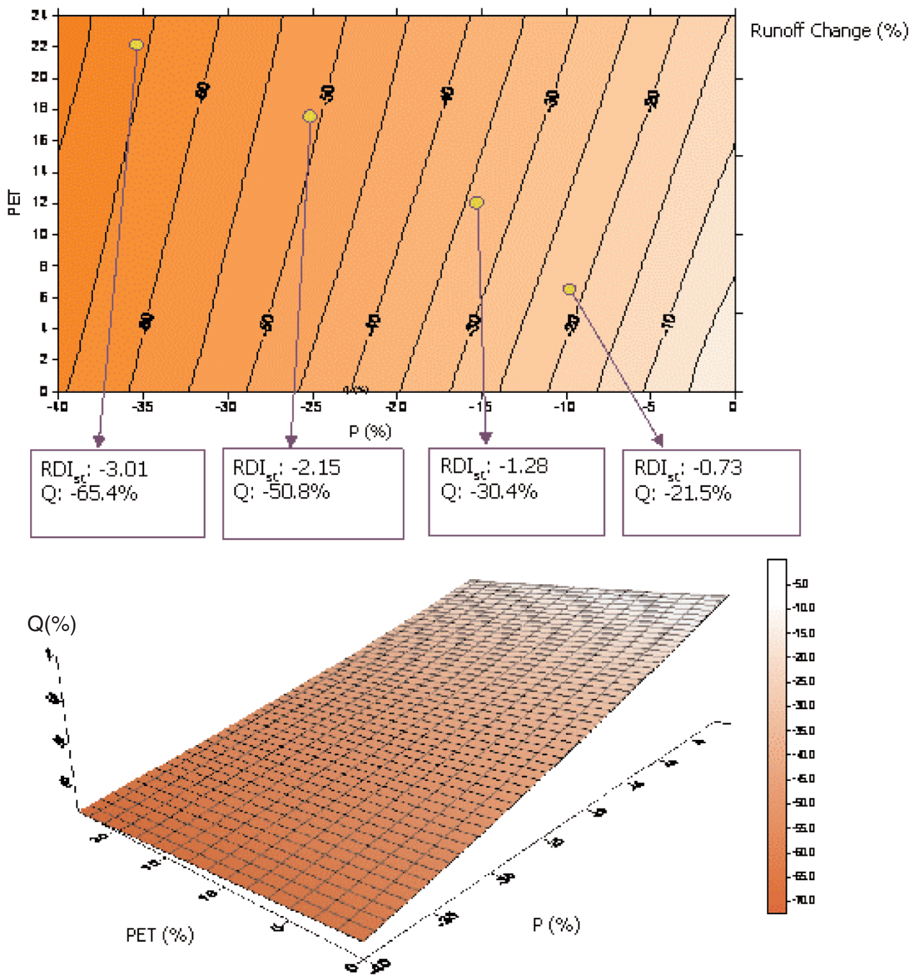


Fig. 12. Results of the rainfall-runoff simulation of the climatic scenarios for the Nestos study area. Q%: percentage of runoff change.

three years the estimation is good, while for the last two the actual runoff reduction is greater than the estimated. This may be caused by the cumulative effect of the sequence of the drought events, which is not taken into account in this approach.

Table 8. Actual and estimated runoff reduction for a period of 5 dry years in the Nestos Basin

Hydrological year	RDIst	Actual runoff reduction (%)	Estimated runoff reduction (%)
1990-91	-0.89	19.2	23.0
1991-92	-1.72	45.1	47.7
1992-93	-1.71	52.8	47.6
1993-94	-1.27	53.4	33.3
1994-95	-0.72	39.6	22.5

The Mornos Basin

The applied methodology for the Mornos case study is similar to the Nestos case. Eight years were selected for the rainfall-runoff simulation (1967-1975, Fig. 13). For this case daily data were also available, therefore the daily and the monthly model were both utilised. For this analysis, which is based on annual values, the results of the monthly model are similar to the daily one.

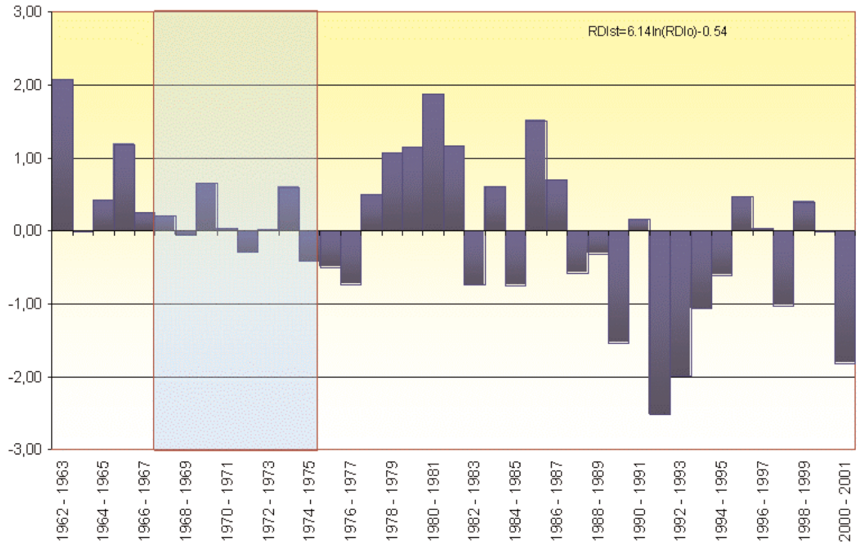


Fig. 13. Standardised RDI values for the study area of Mornos Basin. Years 1967 to 1975 were selected for the rainfall-runoff simulation.

The climatic scenarios were formulated by altering the original data of precipitation and potential evapotranspiration by various percentages up to -40 and +14%, respectively. About 170 scenarios were simulated and the results are presented in Fig. 14. The comparison of the results with RDI_{st} shows that the reduction of runoff for moderate drought conditions is 8-20%, for severe droughts from 20-30% and for extreme droughts can be up to 50%.

Potential impacts of drought

The potential impacts of drought in the Nestos and Mornos Basins are summarised in Table 9. The importance of each impact represent the responses to the interviews of major stakeholders in drought and water management in the basins. The full responses are included in Annex 3.

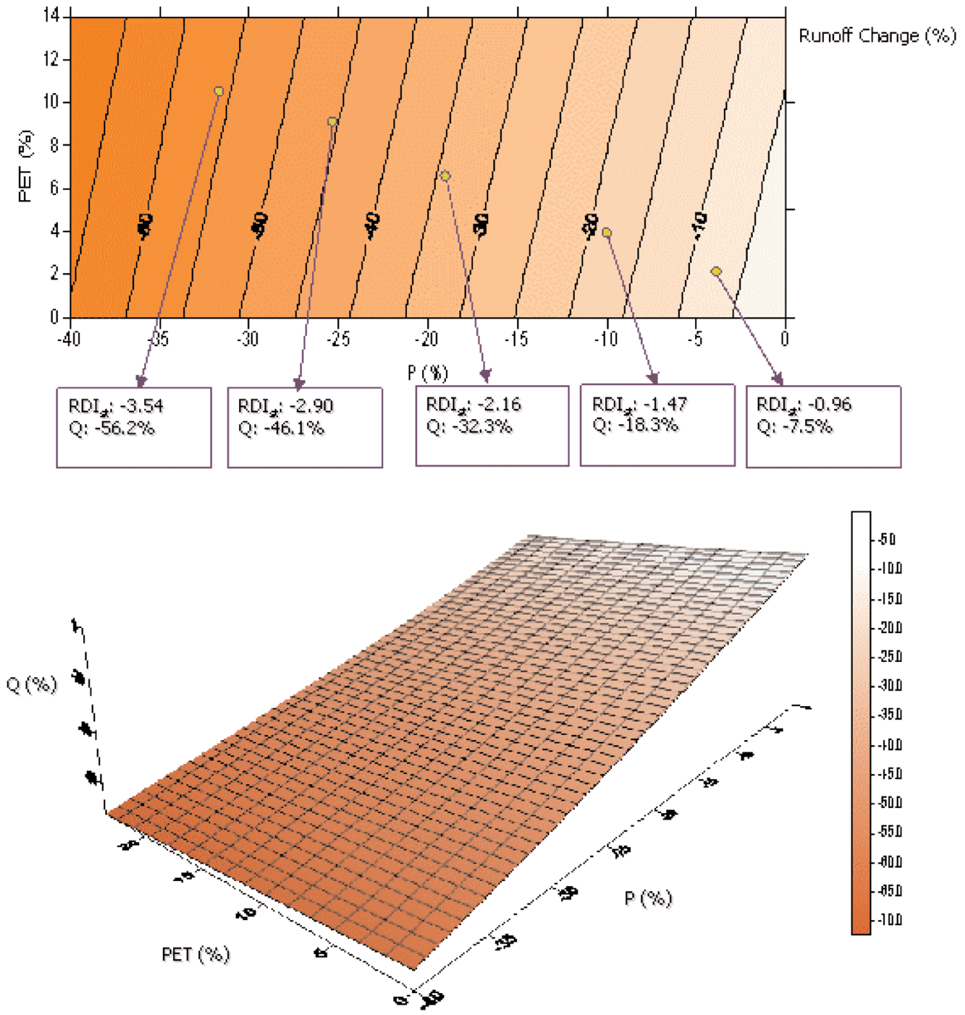


Fig. 14. Results of the rainfall - runoff simulation of the climatic scenarios for the Mornos Basin. Q%: percentage of runoff change.

In general, the most significant impacts of drought in the Nestos and Mornos Basins refer to runoff reduction and reduction in agricultural production. In addition, in the Nestos water basin it is important the wetland ecosystem affection and biodiversity loss. In the Mornos water basin the pressure on water supply system of the city of Athens (capital of Greece) and the tensions to government are key issues.

Operational component

Combining the above reported procedures and the lessons learned from previous actions at the national, regional and local level during significant drought events of the past, a set of actions was devised. In the case of drought, the experience from the past, regarding the Greek area, was mainly attained through two periods of extreme drought that stressed the metropolitan area of Athens. The urban water supply system, which was used in this study along with the drought events considered, and the actions that were taken, regardless of their success, are presented below.

Lessons learned from the Athens urban water supply system study, mainly focus in drought mitigation actions and plans. The success of these actions and plans will be enhanced with the use of a monitoring system that will give us information on when and where various measures should be applied. Since a monitoring system is essential for the success of the measures, a brief introduction on how a monitoring system can be of assistance is also presented.

Table 9. Summary of the potential impacts of drought in the Nestos and Mornos Basins based on responses of stakeholders

Impact	Nestos Basin	Mornos Basin
Increase of farm subsidies	Very important	Very important
Conflict appearance in water use	Very important	Very important
Increase in number and severity of fires	Very important	Important
Decreased crop production	Very important	Not very important
Increase in crop imports	Very important	Not very important
Increased soil erosion	Important	Very important
Conflict appearance in political decisions	Important	Very important
Public dissatisfaction with government regarding drought response	Important	Very important
Decreased water in farm ponds for irrigation	Important	Important
Increase in insects, pests, and crop diseases	Important	Important
Loss of farm income	Important	Important
Biodiversity loss in ecosystems associated with water	Important	Important
Increased cost of ground water extraction	Important	Not very important
Decrease in farm income	Important	Not very important
Decrease of agricultural labour	Important	Not very important
Increase in food prices	Important	Not very important
Increased unemployment of the agricultural sector	Important	Not very important
Increased stress to endangered species	Important	Not very important
Conflict appearance in management	Important	Not very important
Decrease in hydroelectric power generation	Important	Not very important
Additional cost of water transport or transfer	Important	Not very important
Increase in water tariffs	Not very important	Important
Decreased crop quality	Not very important	Important
Additional cost of supplemental water infrastructures	Not very important	Very important
Decreased revenues of water supply firms	Not very important	Very important
Decrease in reservoir and lake levels	Not very important	Important

In order to mitigate the drought consequences there are two major axes that should be followed. These two axes refer to the long term and the short term actions that have to be taken. In the long term, a preparedness master plan should be deployed and applied, while in the actions in the short term, predetermined actions could be devised and implemented. Table 10 summarises the operational actions.

Preparedness master plan

Regarding the preparedness plan, four are the main aspects that have to be considered along with other aspects of less importance or ones that are applied according to the local conditions of the application areas. These main aspects are:

The *technocratic perception* (refers to the knowledge on what should be done and of course in what time). This knowledge should be concrete and widely respected since there is no space for experiments during the implementation. Though a drought monitoring system can help in identifying the correct time of actions implementation, thresholds between the different levels of drought severity should be clarified and accepted for local conditions, so all the authorities involved in the implementation of the plans will act accordingly. Measures that should be taken shall be concordant with the international practice, though local deviations should also be considered.

The *administrative and organisational matters*. It should be clear who is responsible for every action that should be taken. Organisational disorders can lead to devastation. Certain control centres that may not decide upon an action, in the thought that it is not their responsibility, may affect the entire plan implementation. Though it seems that this is an aspect of minor importance, this step has to be planned in advance and given the respective credit. It is a known fact (at least in Greece) that

Table 10. Summary of the components of the drought planning and operational actions to manage drought in Greece

Component of drought planning	Operational actions
Preparedness master plan (ongoing)	1. Ongoing based on monitoring and early warning 2. Definition of the responsible officials for the action to be taken 3. Definition of the time to implement the action 4. Ensure laws are in place to take action 5. Ensure public participation
Actions in the short term (actions taken when drought is occurring)	1. Reduction of water demand – prohibition of use – pricing (not effective) – incentives to save water – advertising to raise public awareness – agricultural practices that save water 2. Increment of water supply 3. Monitoring
Practical examples	1. Improvement of the operational management of the water system 2. Use of emergency and auxiliary water resources 3. Emergency water transfers 4. Changes in rights of water use 5. Monitoring 6. Concrete applications in the city of Athens and in the Mornos Basin

when a situation is dealt successfully, all authorities involved are trying to gain the credit of this success, while no one accepts the responsibility when something goes wrong.

Time and space actions. The time sequence of the actions as well as the spatial scale of the plan should be carefully scheduled. If the actions are not applied in the right order a prominent loss of resources may occur. This step focuses mainly in planning the actions in advance, in an acceptable detail level, regardless of the final implementation.

Public awareness and participation. Public has to be involved in the plan. Not only because the citizens will be the receivers of the actions but because they have to be fully aware of what is going to happen. This will help the smoother implementation of the plan and will give the civilians the potentiality of making the appropriate proposals for changes in the plan in order to be more adaptive to them. Non governmental organisations (NGOs) have to play an important role in the interaction between the public and the authorities. Since their communication with the citizens is guaranteed and most of the times they are spread among different community levels they can reassure an important feedback to the stakeholders.

Actions in the short term

Two directions can be followed: Reduction of the water demand and increment of the water supply. In an urban environment, this may be achieved through the administrative actions along with new and sometimes even strict laws and essentially through the stimulation of public awareness. Specific acts of this type are for example the prohibition of excessive use together with a legal framework for a more rational water use. Pricing policy regarding higher costs per unit for higher water consumptions may be also applied. In European countries, though, this measure was used in the past and was not very successful.

A more successful measure could be the use of economic incentives from the water companies in order to lead the people in less water consumptions. Advertising and other means of public announcement is always essential in not only informing the people for the water shortage situation but also helping them to consume water in a more rational way in the long term. Public awareness information may be diffused through mass media or leaflets distributed to the citizens, but an important aspect is to pass this information to young people through schools (or any kind of educational campaigns), in order to shape a life style that includes rationality in water use. Regarding the rural environment, changes in agriculture will mainly lead to the desired results. Such changes may be the selection of less water consuming crop varieties, the control of evapotranspiration by artificial means, the optimisation of agronomic techniques and actions that are even more complicated (e.g. the soil enhancement).

Emergency water transfers and diversions is another auxiliary solution from the same point of view, with the advantage that the source will not remain connected to the supply network after the crisis and the disadvantage of being a more expensive solution since appropriate infrastructure should be constructed just for a short period of time.

Diversions between different purposes of water consumption that should be listed hierarchically in advance may be also implemented during an emergency situation.

Measures and actions to minimise the impacts of drought should be also considered. Minimisation of water supply impacts should be made through water supply system adjustments. The same implies for the agricultural sector, while in the economic sector impacts may be minimised with direct and indirect public aid and the use of insurance policies.

Monitoring systems

The actions planed for drought mitigation will not be very efficient unless information on drought incidents in temporal and spatial scale are available or can be acquired. Such information can be obtained from monitoring systems. In brief, a monitor system can give information of when a drought period started, how long it lasted, how severe it was and which were its spatial limits. Moreover, a monitoring system applied on historical data series can give us the opportunity to identify drought prone areas. Identification of drought prone areas helps in a more efficient application of drought mitigation plans, since areas that are affected by drought more frequently than their surroundings should be monitored in detail and the authorities should respond faster in the mitigation of an extreme situation. Monitoring systems though, can mainly supply information on past events. A warning system of extreme situations is a more useful tool, since it can provide the authorities with enough time in order to apply measures to prevent the situation. A warning system can be the result of a combination between a monitoring system and a weather prediction system and it is obvious that its accuracy is based on meteorological predictions.

Operational monitoring in the Mornos Basin and the Athens water supply system

The best practices for drought mitigation that are presented in this study are mainly derived from what we have learned from past actions and mainly from the measures that were taken during drought events in the one of the most important water supply networks of Greece, the Athens metropolitan water supply network. This network is important not only because it supplies an urban area with almost half the population of the whole country but, as shown in Fig.15, because it comprises a number of rivers, artificial lakes, reservoirs, pipelines and other infrastructures that covers about one fifth of the whole area of Greece.

There are two main historical droughts, which occurred in the past, which affected Athens and consequently the water supply system and all the areas that are connected to this system. The first drought took place during the years 1976 to 1977 and led to a significant urban water shortage. Though there are not detailed data available from this period regarding the incident and the solution applied, it is known that the pressure for water was so high that even brackish water was used to cover part of the needs. It is important that this specific drought and its consequences led the authorities in an extension of the water supply system with the addition of the Mornos reservoir.

The Mornos dam (which can be shown in the left part of Fig. 15) was finally constructed in 1980 and it is a part of the metropolitan water supply system since then. The second major drought took place in the years 1989 to 1993. The pressure on the urban water supply system was again extremely significant even though new reservoirs were already added to the system. It should be mentioned that the reservoir levels were low and that the prediction of water availability, even with the measures applied, was that the stored water would cover the needs only for the remaining 33 days.

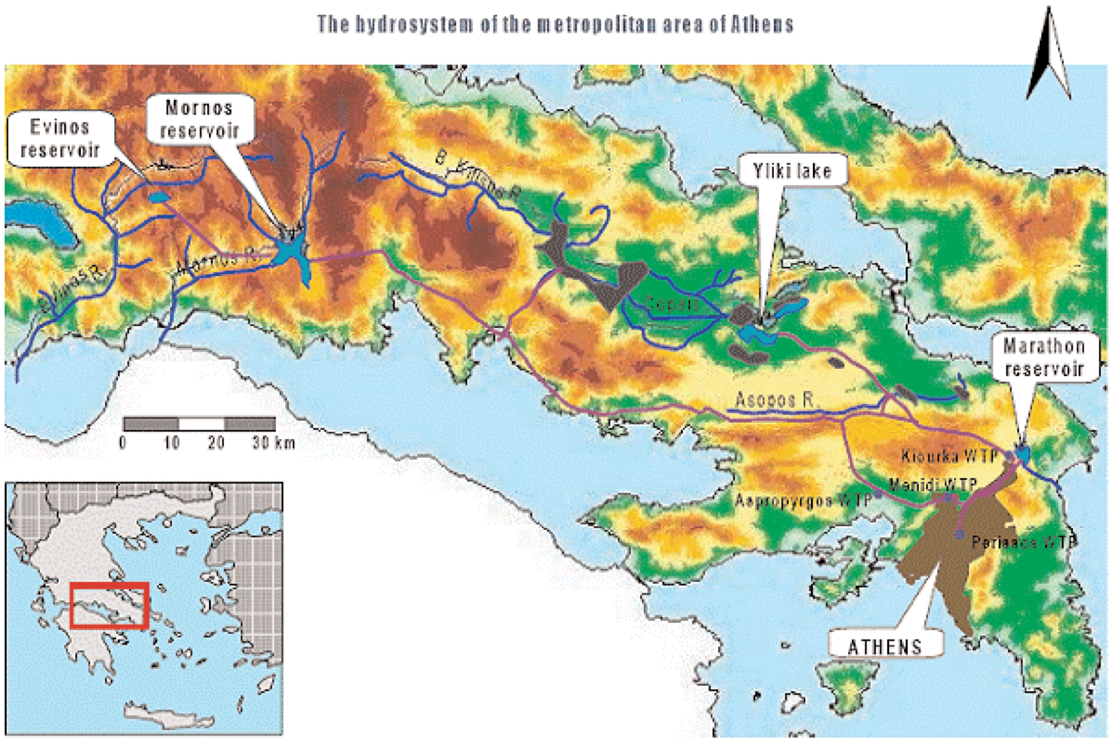


Fig. 15. Water supply network of Athens.

Another important issue, from an environmental point of view, was that the specific drought affected the rural areas, which support the system. The Kopais valley (in the centre of Fig. 15), which is one of the main agricultural sites in the outskirts of Athens, suffered a major problem regarding irrigation water scarcity, since the Yliki Lake, which provides water for irrigation in the area, was used to cover the urban needs of the metropolitan area. In order to solve this problem, the authorities agreed to provide the farmers with a certain amount of water for irrigation regardless of their real needs. This example shows, not only the pressure of drought in all the areas that are involved in the water supply network of Athens, but also an involvement of politicians in the situation providing non scientifically based solutions. The lack of systematic plans for extreme events mitigation led to the use of actions that were not sustainable and viable and could produce even larger problems in the future.

A number of actions were proposed during the second drought period. Some of them were finally implemented, though a lot of them were rejected on a second thought. An example of a rejected action was the water transport with tankers. It was a rather expensive solution that proposed the transport of water from a remote site, without taking into account the capability of this area in providing the specific amount of water. The addition of new resources to the system was another rejected solution. According to this proposal, Trihonis Lake, a natural lake at the west of the Evinos River was examined to reinforce the water system. Of course, adding new resources every time a problem occurs has nothing to do with a systems stability and moreover with any sense of sustainability. The proposal for new infrastructure was also rejected as an expensive and unsustainable solution.

Actions that were finally taken marginally assisted in overcoming the difficult situation, though some of them are not considered useful worldwide nowadays. Water supply cut-offs according to a schedule was one of them. Since water was not available for all the sections of the metropolitan area, a scheduled distribution was designed. Water was distributed to different sections for only a few hours each day according to a time table that was publicised through mass media. Citizens had to schedule their own activities according to a broadcasted time table or they had to collect water in small reservoirs at their house for daily use.

Pricing policy was used along with the cut-offs. The pricing policy was mainly based in the set up of high penalties for high consumptions in order to force citizens to consume only the necessary amount of water. Though this measure may have led to social inequality forcing poor people to lower consumptions, it was a useful solution in the water supply system of Athens during the past droughts.

Public information mainly through mass media campaigns has also been used during past droughts successfully. Citizens were informed about the water storages, the distribution schedules and they adopted the measures proposed by the authorities in a very rational way.

Finally, an important measure taken from the authorities was the irrigation water reduction from Yliki reservoir to over 50%. This measure helped in gaining water for urban use, which was considered at the time as more important, but created a significant problem in the irrigated areas since the reduction was not based in a schedule and it could not be easily adopted by the farmers.

Proactive and reactive plans and actions

The most recent regional drought episode in Greece was experienced during the period 1989-1993. According to the data of that period, this multiple-year drought had caused severe problems in most areas of Greece. The situation was so difficult that for the last six months of the drought period, several non-conventional scenario and solutions were proposed for securing water supply for domestic use in the major cities of the country. The most characteristic case was the case of the municipality of Athens, which derives its water from Mornos River as well as Yliki and Marathon Lakes, and a battery of boreholes from Viotikos Kifissos basin. (Recently Evinos River is also one of the contributors for fulfilling the water resources demands of Athens).

Some of these scenarios referred to massive transport of water by vessels from various areas, the construction of a new aqueduct connecting Trichonis Lake with Mornos reservoir, construction of water supply networks from other areas of Sterea Hellas and Peloponnese.

The most amazing of all was that Athens, at the end of September 1993, had water only for one more month. The solution which was at that time decided was given by applying demand reduction measures, which were assisted by the change of the climatic conditions soon after.

Gradually after October 1993, the reservoirs of the system started to be filled and after a lag of three years, the situation was again normalised.

Within this Plan, the institutional and legal measures related to water resources and more specifically the mitigation of drought, are covered by the EU Directive 2000/60 and the Law 3199/2003. Particularly, measures taken or planned that are compatible with the NAP are:

The implementation of the plans for developing water resources at all levels, the establishment and operation of the regional water management services, the issue of regulation decisions by prefectures to protect water resources per river basin and the exertion of effective checking on infringement of the law and infliction of the respective penalties are ensured by the respective laws, and the support for more efficient operation of Local Land Reclamation Organisations.

The reparation and renovation of the irrigation networks, the application of integrated irrigation systems, the water recycling and re-usage is implemented through the plans of the Land Reclamation Directorate for facing drought as well as the Local Land Reclamation Organisations.

The actions for combating drought are being realised by the construction of dams and off-stream reservoirs in drought prone areas. So far, twenty dams and twenty-nine reservoirs have been constructed. Also, technical studies for eleven dams and four water reservoirs have been prepared. Both the Greek government and the European Union fund the plans. Additionally, the Ministry of Agriculture has continued an activity initiated in 1994 for facing the drought problem, by funding works like drilling (where sufficient ground water resources exist), harvesting of spring waters, repairing the irrigation networks and other land reclamation projects. Recycled water has been used, at a relatively small scale, to satisfy irrigation needs. Other actions include: The refilling of artificially drained lakes and the planned diversion of the Acheloos River towards the Thessaly plain, which is threatened by desertification; The development and expansion of the National Data Bank of Hydrological and Meteorological Information; and The support of research for increasing available water supply. Several reports are being prepared for the support and pilot application of the EU Directive.

Given that agriculture uses 84% of the water resources of Greece, most pro-active and reactive plans and actions concerning the effects of droughts were taken in the past by the Ministry of Agriculture.

Proactive actions

The most relevant proactive actions in Greece include: Small earth dams for collection of rainwater, canal rectification to reduce water losses, and modernisation and improvements of irrigation networks.

In more detail, all proactive measures have the same aim to enhance the storage, the conveyance and distribution of water. In this context, it should be mentioned that important contribution to water saving is the gradual change from conventional surface irrigation systems to modern sprinkler and trickle irrigation systems. Therefore, application efficiency is enhanced if farmers follow this tendency.

Reactive actions

The most relevant reactive actions in Greece include: Constraints in water consumption, intensification of the use of groundwater resources, reallocation of water resources, use of saline and brackish waters, and Water transfer.

During drought, the reactive actions follow two categories of measures: the allocation of new sources of water, such as saline and brackish waters and also intensive pumping of existing ground waters. In some cases, water is also transferred from agricultural users to the towns and cities for municipal consumption. If possible, in some cases, water transfers and reallocation of water resources is attempted. The reallocation of water resources of Viotikos Kifissos from the irrigation area of Viotia, in order to serve the Athens greater area during the drought 1989-1993 is the most profound example of this category of reactive actions. In the future, pro-active and reactive plans and actions for drought mitigation will be based on the Law 3199/2003.

During this period, several Water Resources Management Studies are prepared for most regions of the country under the supervision of the Ministry of Development. Although these studies have their roots on the previous legal system (Law 1739/87) by which the coordination of water resources management was responsibility of the Ministry of Development, they can produce important results for the implementation of the Law 3199/2003.

It is expected that these studies will organise the hydrological and other data in a systematic way and they will provide useful information about the drought-prone areas of the country. However, it should not be anticipated that these studies will produce proactive or even reactive plans to combat drought. According to the Law 3199/2003, proactive and reactive plans related to the mitigation of drought will be adopted by the Central Direction of Waters (proposals, general rules, medium-term and long-term national plans) and by the Regional Direction of Waters for each River Basin District.

Although reallocation strategies seem to be a very effective measure to combat drought in the agricultural sector, very little work has been done at operational scale. It is expected that at least in some areas prone to drought experimental studies on changes of cropping patterns will be applied. For example, Thessaly plain has been proposed for these cropping pattern changes, where one of the major crops is cotton.

During the period of 1989-1993, several measures for the confrontation of drought were taken by the ministries involved and the perfectural and municipal services. Most of these measures, which have been presented elsewhere in this text, were taken with little co-operation and co-ordination. However, in most of the cases (and although there are some conflicts reported) the results were in the same direction, namely the reduction in water consumption and the use of some extra water resources wherever possible. Conclusively, it should be said that during the last drought there was no systematic approach and sufficient co-ordination.

Stakeholder analysis

The Public Power Corporation S.A. (Hydroelectric Power Plants Operations Department)

Public Power Corporation (PPC) supplies Greece with electric energy. A percentage of 6% of the total energy is supplied by hydroelectric plants. The dams of PPC form reservoirs-artificial lakes that are used for power production irrigation and water supply purposes.

The interviewee –director of the sector of exploitation of hydro-electrical stations– perceives drought as a comparison between the mean value of precipitations during a long time series and the mean value of precipitations of the current year. He also believes that mankind cannot easily control but only influence drought, because this is related to the quantity of precipitations. Agriculture is the most sensitive sector affected by drought (80% of the total water consumption is used in agriculture), while tourism seems to be the most insensitive sector.

Ordering the factors of uncertainty, which affect irrigation farmers, the climate may be considered as having the highest level of uncertainty, because in the interviewee's opinion it is not influenced by man. In a second rang, the economic value of agricultural products should also be considered, because they are related to the climatic conditions. On the other hand, in the interviewee's opinion, agricultural policies are rather insensitive to uncertainty.

The interviewee believes that only a small part of users is holding a water permit in Greece. The whole issue is complicated and has many aspects: financial, social, developmental and legal. According to the Law 3199/2003, many sectors are represented and participate in organisations/committees that are responsible for the definition of water allowance during drought periods. The problem focuses in the fact that such numerous bodies do not easily make decisions.

The number of users related to a certain water allowance influences decisions, due to the political power of the vote. There is also greater ability to make decisions concerning the definition of water allowance for representatives of the public sector (ministries, etc.).

There is no formal procedure to declare a "drought situation". As far as the management of inflows in reservoirs of hydroelectric plants is concerned, the "drought situation" is considered by taking into account the current meteorological and hydrological information, in comparison with previous conditions, the volume of the reservoirs, the snows existing in the basin district, etc.

According to the interviewee, in the case of drought, highest priority for the water supply should be given obviously to the domestic use of water and lowest priority to tourism, with the exception of the Aegean islands. These priorities correspond also to the priorities that the administration should defend.

The Public Power Corporation does not have a specific policy that is followed in the case of drought. Nevertheless, during past periods of water scarcity, pressure has been applied on farmers for the reduction of the quantity of water used for irrigation (informal measure) and a report has been sent to the prime minister. In drought periods, a pro-active measure adopted by the Public Power Corporation is the construction of reservoirs managed by the Corporation itself and which are multi-purpose projects.

A reactive measure taken by the Public Power Corporation, related with the drought management, is the appropriate management of water outflows from the reservoirs for domestic use and irrigation purposes, in addition to the energy production. According to the interviewee, creation of reservoirs may be considered as the most important measure to be carried out for the management of drought, because rainfalls are few in Greece and unevenly distributed during the year. Desalinisation of water is considered to be an expensive way for water supply. Measures should be adopted separately for the various districts of the Country because they have different weighting conditions of water use.

The interviewee considers as measures not accepted by the public: The substitution of high water-demanding crops with low water-demanding crops, the reallocation of water, the inter-basins transfers, and the conversion of some irrigation surfaces to dry farming.

The interviewee expresses the opinion that water cannot be treated in a way similar to other natural resources (oil, gas, etc.) because the property of water cannot be easily controlled, i.e. who the owner of water is and how the water will be sold. The water management should be carried out by public organisations and the users should pay the cost according to social criteria.

There are two distinct parts in Greece: (i) The Eastern part and the Aegean islands, characterised by water scarcity and consequently a considerable number of users that would probably buy water; and (ii) the western part, with adequate quantities of water and, therefore, less inclined to buy water.

Water is a good of first priority, essential for the human life. Buying and selling water would result in the interest of some people or companies dealing with the water marketing and a high cost for the water itself. The establishment of institutions, which would deal with water buying and selling seems to be unfeasible for the time being.

The Greek National Committee for Combating Desertification

The interviewee –president of the Committee– perceives drought as a naturally occurring phenomenon that takes place when precipitations have been significantly below normal recorded levels, causing serious hydrological imbalances that adversely affect land resource production systems. He also believes that agriculture is the most sensitive sector affected by drought (80% of the total water consumption is used in agriculture), while tourism seems to be rather insensitive.

According to the interviewee, the agriculture sector is the major consumer in Greece and therefore this is the one whose responsibility is to cope with the effects of drought.

Ordering the factors of uncertainty that affect irrigation farmers, climate may be considered as having the highest level of uncertainty, as it is often related with severe consequences. On the other hand, in the interviewee's opinion the work market is rather insensitive to uncertainty.

According to the interviewee, in the case of drought, the highest priority for water supply should be given obviously to the domestic use of water and second to agriculture. The lowest priority should be given to the recreational use of water. These priorities correspond also to the priorities that the administration should defend.

The Committee's proposal with regard to proactive measures generally adopted in drought periods includes the construction of reservoirs, the enforcement of the artificial groundwater recharge and the improvement and repair of the water supply systems. Concerning the reactive measures generally adopted in drought periods, it is suggested to discourage wasteful use of irrigation water and to use agricultural methods limiting evapotranspiration.

According to the interviewee, increase in the regulation capacity for irrigation purposes and creation of reservoirs may be considered as the most important measures to be carried out for the management of drought (management of supply). Inter-basin transfers of water and use of brackish water are considered by the interviewee as being of lowest priority measures for water supply (least important).

The interviewee expresses the opinion that it is possible to treat water in a way similar to other natural resources (oil, gas, etc.) but at the same time, there should exist an intervening state policy to preserve public interest. The option to buy and sell water would possibly involve users from the whole country.

The interviewee considers as possible negative effects of buying and selling water, the increase of the price of water, the profits without control to companies selling water and the various environmental consequences of such a policy. Simultaneously with the creation of water banks, controls for the protection of the public interest should exist.

Ministry of Agriculture - Hellenic Agricultural Insurances

The interviewee –director of the branch of Patras– perceives drought as an extended deficiency in water caused by lack of precipitation in a particular area. The interviewee believes that man can significantly limit the consequences of drought by applying an appropriate planning, organisation and a national policy of drought confrontation that will control the malign consequences.

The interviewee believes that the agricultural production of non-irrigated crops is exclusively dependent of precipitation. For the irrigated crops, any pause of irrigation can be disastrous. Therefore, he considers that the domain most affected by drought is agriculture, whereas domestic use is not that sensitive as a provision for water reserves is often ensured. It is evident though, that the domain responsible to confront the drought consequences is the agriculture domain.

Sorting the factors of uncertainty that affect irrigation farmers, climate may be considered as having the highest level of uncertainty, since it cannot be controlled. On the other hand, the interviewee believes that the work market is rather insensitive to uncertainty.

The interviewee believes that the current legal framework defines clearly the rights of the water permit holders, but that compensations due to users are not clearly defined in the current legal framework.

The interviewee expressed the opinion that the agriculture sector should be better represented in the legal framework and that the groups that have the greater ability to make or influence decisions concerning the definition of water allowances are mainly the different Scientific and Technical Chambers. According to the interviewee, a "drought situation" is undefined as far as time is concerned; however, it could be related to the end of the last rainfall.

In the case of drought, the highest priority for water supply should be given to agriculture, because it is the domain most affected and also affects every other activity. The lowest priority should be given to recreational use of water. However, those priorities do not correspond to the priorities that the administration defends, as the current legal framework does not prescribes this strategy.

In previous drought situations, the Department followed a pilot programme of precipitation increase in the highlands of Central Greece with the method of seeding clouds with hygroscopic substances. Unfortunately, the programme was not accepted by the government. Emphasis should be given in the fact that no proactive neither reactive measures are taken by this department in order to combat drought.

The interviewee believes that the most important measure to be taken is the creation of reservoirs in order to ensure the water sufficiency. He also considers an increase in the regulation capacity for irrigation purposes as an important measure to be followed, as well as the improvement of irrigation efficiency. He regards the reallocation of water from irrigation to urban uses as an unnecessary measure as it will induce social problems.

The interviewee believes that measures acceptable by the public are the creation of reservoirs, the regulation capacity for irrigation purposes and the improvement of irrigation efficiency, whereas a measure not acceptable by the public is the reallocation of water from irrigation to urban uses. In general, more accepted are the measures concerning the creation of infrastructure and sound management principles, while less acceptable are considered the measures concerning modification in agricultural uses.

The interviewee expressed the opinion that it is possible to treat water in a way similar to other natural resources (oil, gas, etc.) under the condition that the utilisation cost will be limited to low levels and will be spread according to the user's intentions. Water metering would involve a considerable number of users and could possibly reduce the total consumption.

A negative effect for buying and selling water is that the consumption would be disproportional to the real needs of each user, and that the users to be aggrieved would be the ones whose needs would be the greater, and in particulate the irrigation farmers. The establishment of water banks is considered to be a necessary measure, but it should be governed by a well-planned Water Management and Utilisation Rule and its application should be very well monitored.

Strengths and weaknesses of the current structure

It is understandable that the interviewees face the drought phenomenon and the corresponding results from their interest and the interest of the people they represent. Obviously, the big majority of people agree that recreational uses (e.g. pools, fountains, etc.) have the last position hierarchically in the list of uses. However, according to the Law 3199/2003, municipal water consumption is considered as the first priority. Regarding the other uses, there are specific interests in each area, which to some extent define the priorities.

The main strengths of the Greek institutional framework that stand out from the above analyses are:

(i) A National Data Bank of Hydrological and Meteorological Information (NDBHMI) has been established. Various software applications are linked to the central database of the NDNHMI supporting the analysis and synthesis of the data and the elaboration of secondary information. A GIS subsystem was developed to support the spatial analysis of hydrological data.

(ii) There are sufficient socio-economic data concerning water users, with the exception of incomplete information on farmers and irrigation water.

(iii) According to the existing situation, all institutions involved in drought preparedness and mitigation, have a good experience concerning recent drought episodes. Although there are no specific plans for drought mitigation in Greece, many governmental institutions and other institutions are dealing with the effects of drought in a case to case basis.

(iv) There is a sufficient number of reservoirs that are being used in drought situations and therefore the water reserves of the country are well managed.

(v) The domain of agriculture seems to have enough influence with the government and whenever irrigation farmers are affected by drought, the pressure exercised on the authorities has good results in order to combat drought.

(vi) The Law 3199/2003 has been recently adopted. According to this law, all sectors affected by drought are represented in the National Council of Waters and the Consultative Committee of Waters.

The main weaknesses of the Greek institutional framework that stand out from the above analyses are:

(i) Up to now there is neither insurance nor compensation policy provided by the legal framework for the rainfed or irrigated agriculture.

(ii) No systematic monitoring of drought occurrence and regional extent has existed in Greece in the past. This work will be hopefully carried out by the commissions instituted according to the law 3199/2003 on Water Resources Management.

(iii) In the past, decisions concerning droughts were taken in a case to case basis. This approach is considered unsatisfactory and it is therefore necessary to elaborate a plan for drought mitigation, based on the structures described in the law 3199/2003 on Water Resources Management. The only positive conclusion regarding the case by case action against drought is that it is an indication of local creativity and the readiness of the local organisation to act independently and find quick and acceptable solutions.

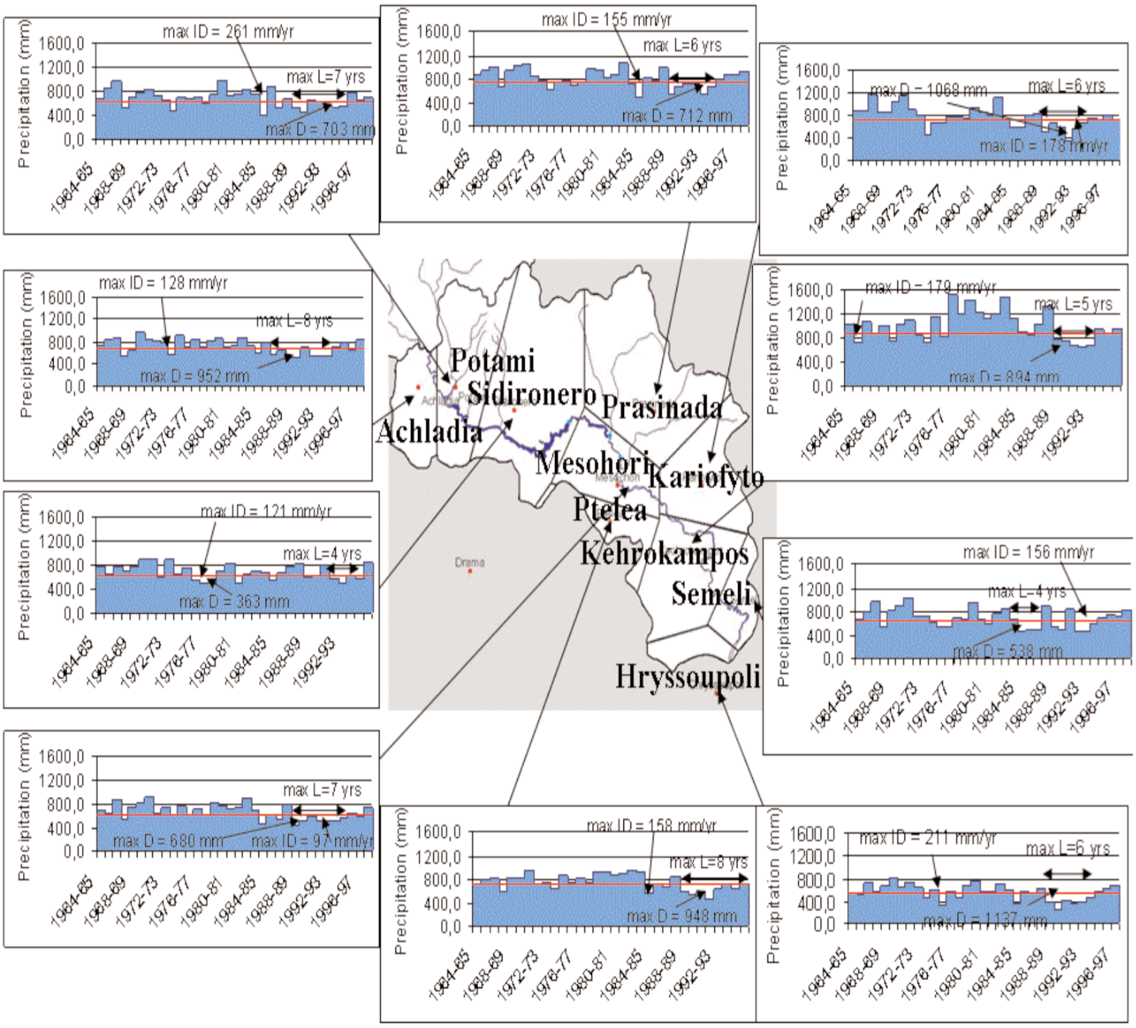
(iv) Up to now, there is a lack of information concerning the consumption of irrigation water by individual farmers. Although there are institutions and organisations with experience on the subject, there is no coordination among them and there is no managerial policy in a higher level from a central administration.

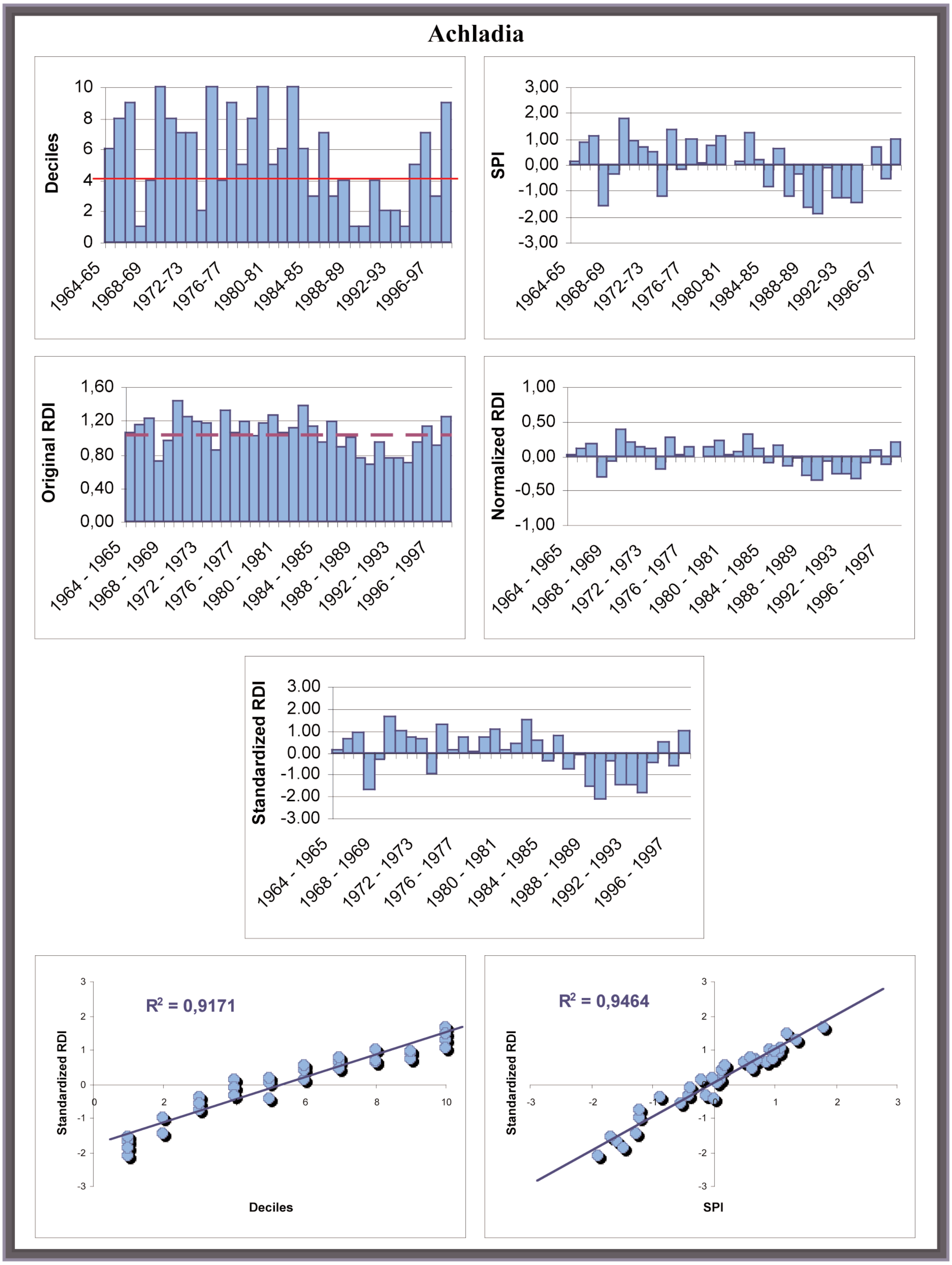
(v) In Greece, little research was carried out in the past for defining droughts for different sectors of the economy, i.e. agriculture, power production, domestic use, etc. Similarly, drought indicators have not been examined with respect to their feasibility on Greek conditions.

(vi) There are no drought indicators or any other scientific objective indices used in order to detect crisis situations.

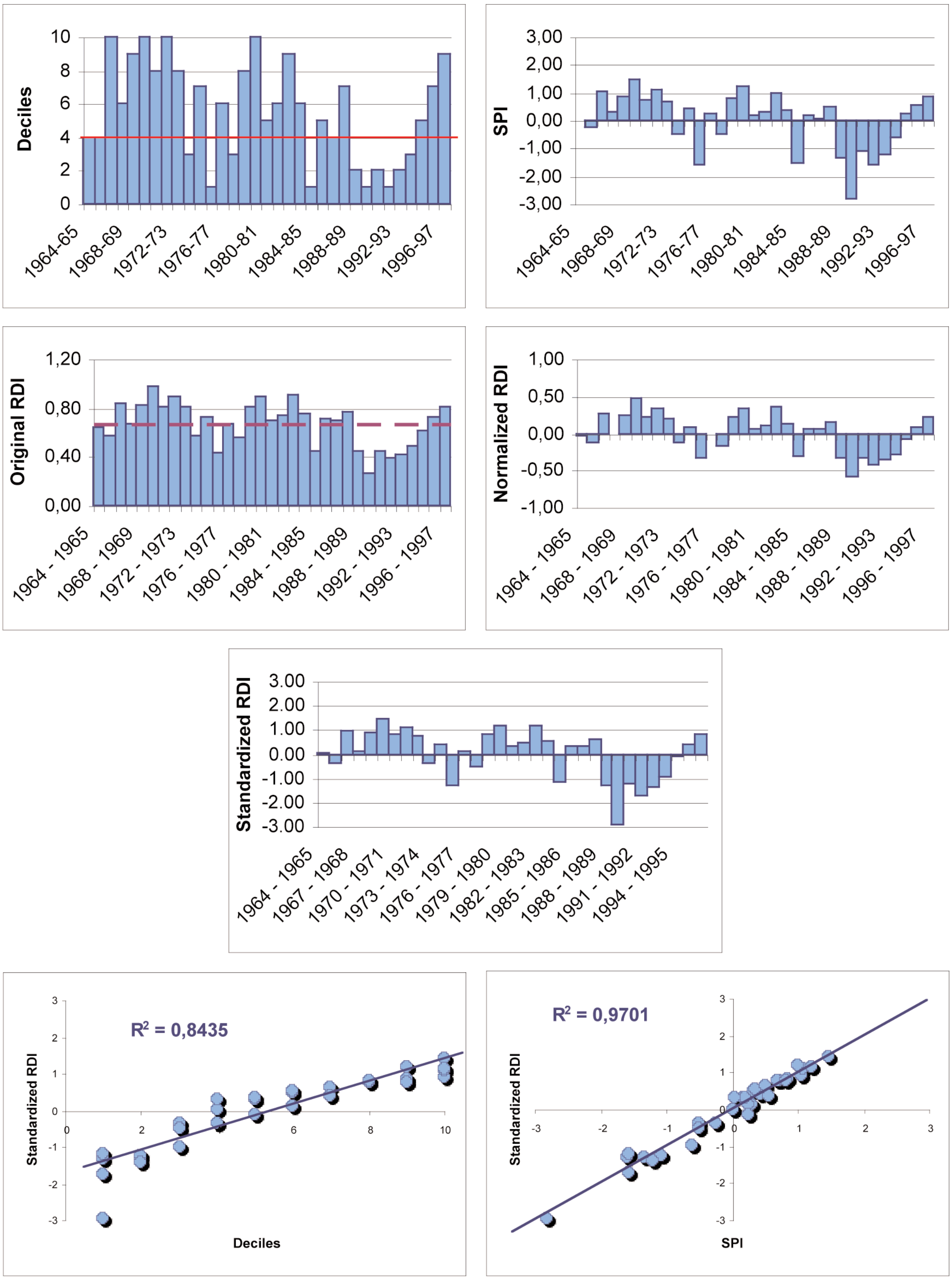
Annex 1. Drought characterisation

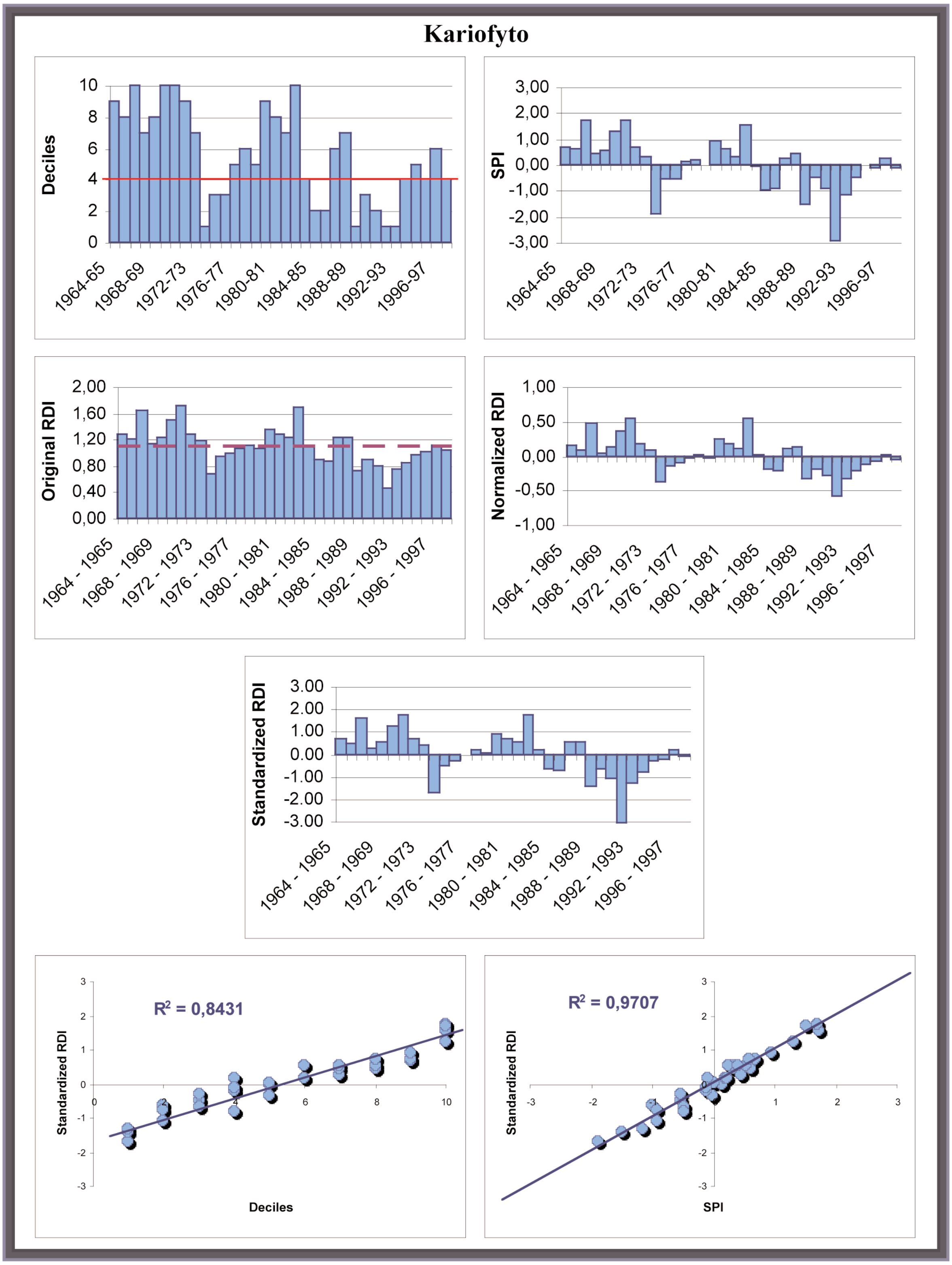
Nestos River Basin



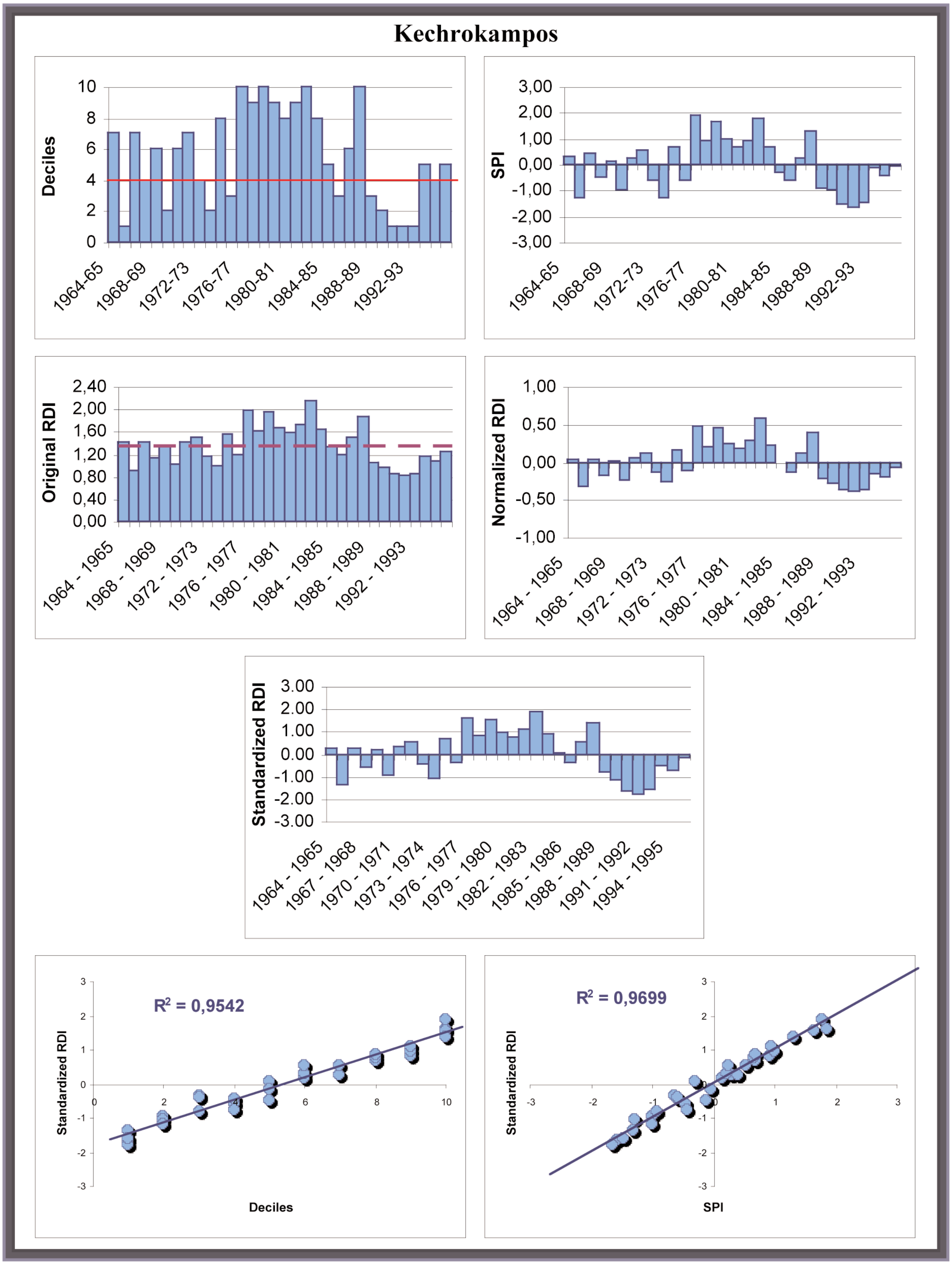

Achladia
Deciles
1964-65
1968-69
1972-73
1976-77
1980-81
1984-85
1988-89
1992-93
1996-97
SPI
Original RDI
1964 - 1965
1968 - 1969
1972 - 1973
1976 - 1977
1980 - 1981
1984 - 1985
1988 - 1989
1992 - 1993
1996 - 1997
Normalized RDI
Standardized RDI
R² = 0,9171
R² = 0,9464
Deciles
SPI

Chryssoupoli

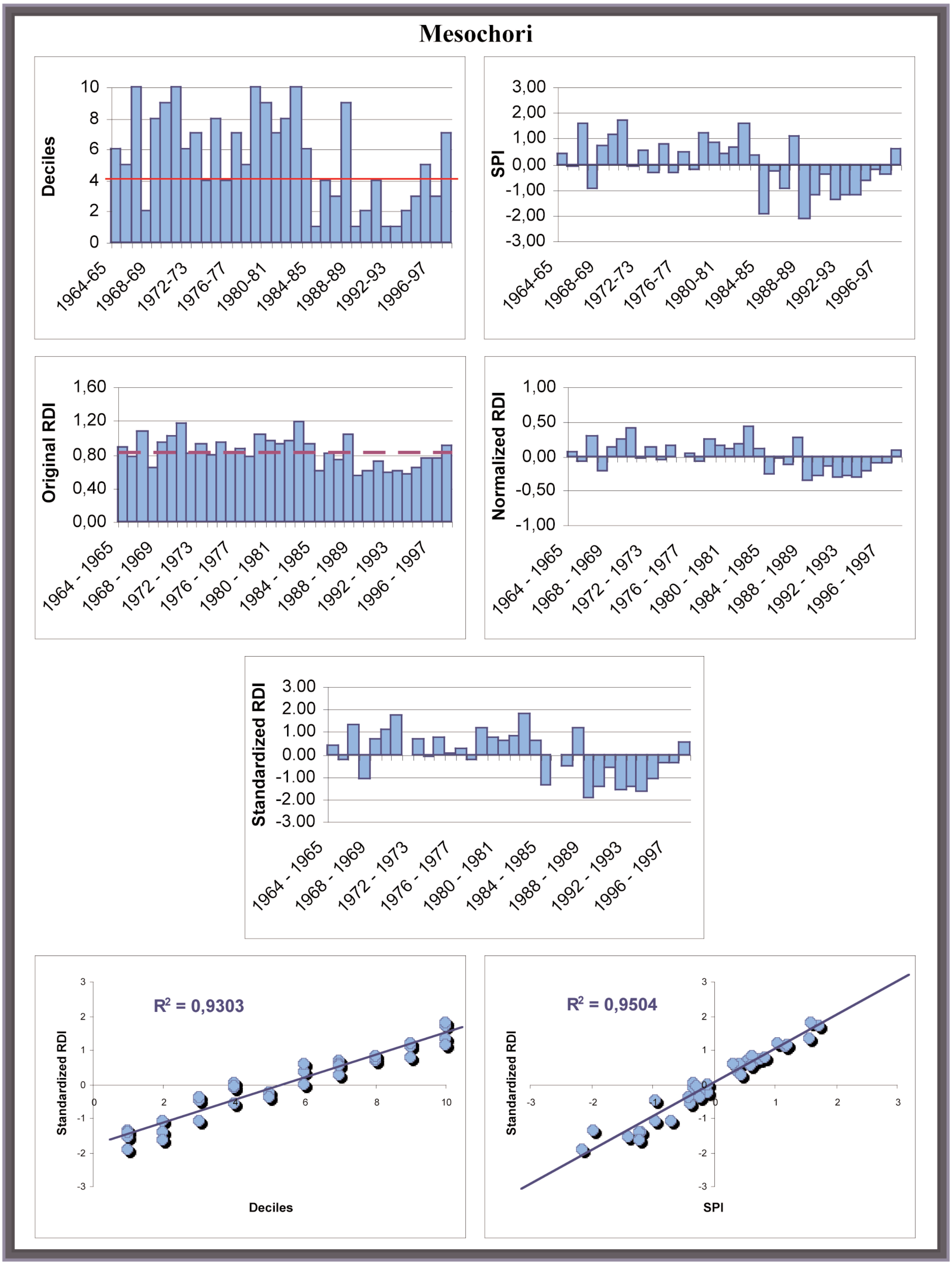




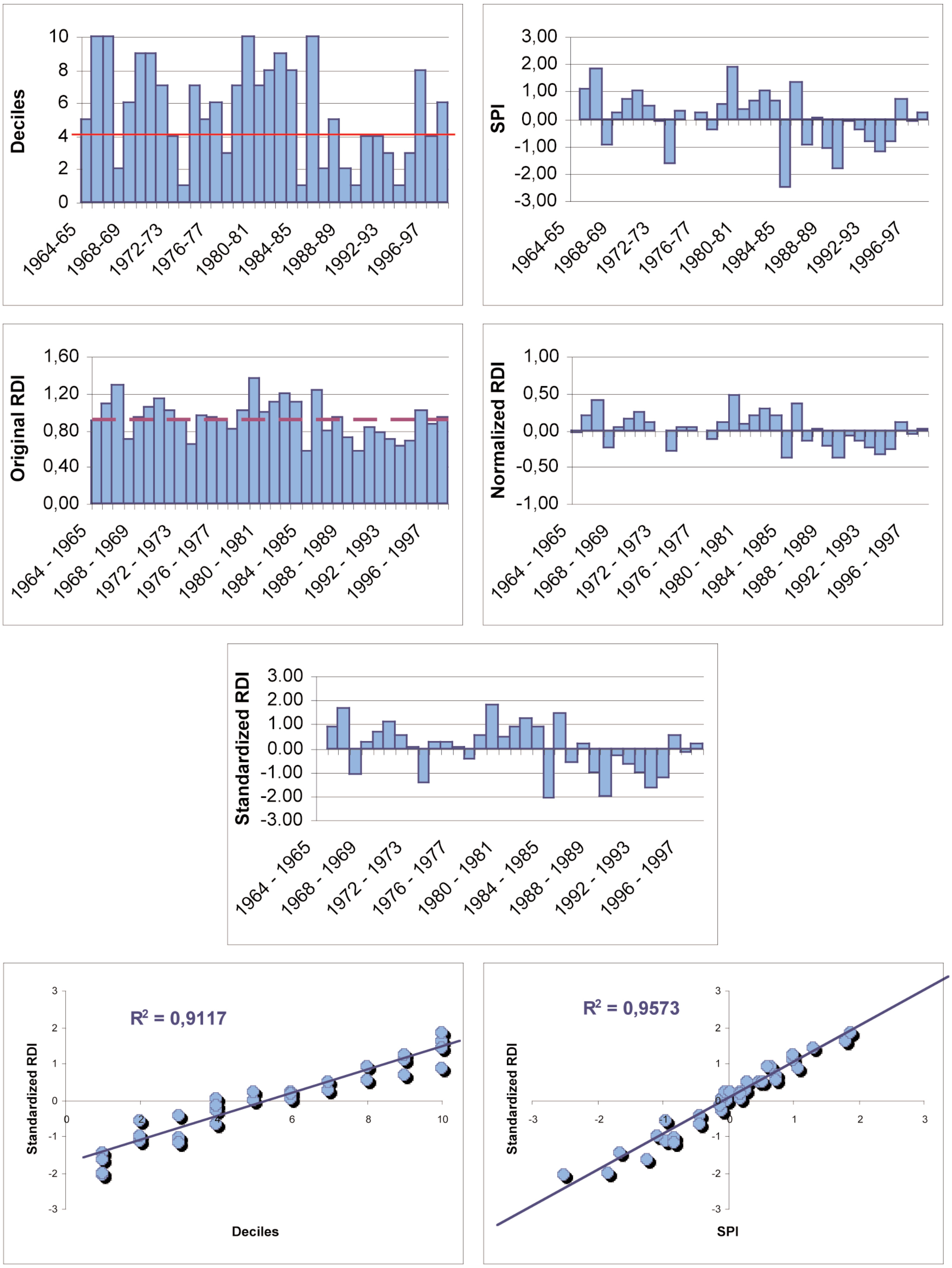
Kariofyto
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,8431
R² = 0,9707

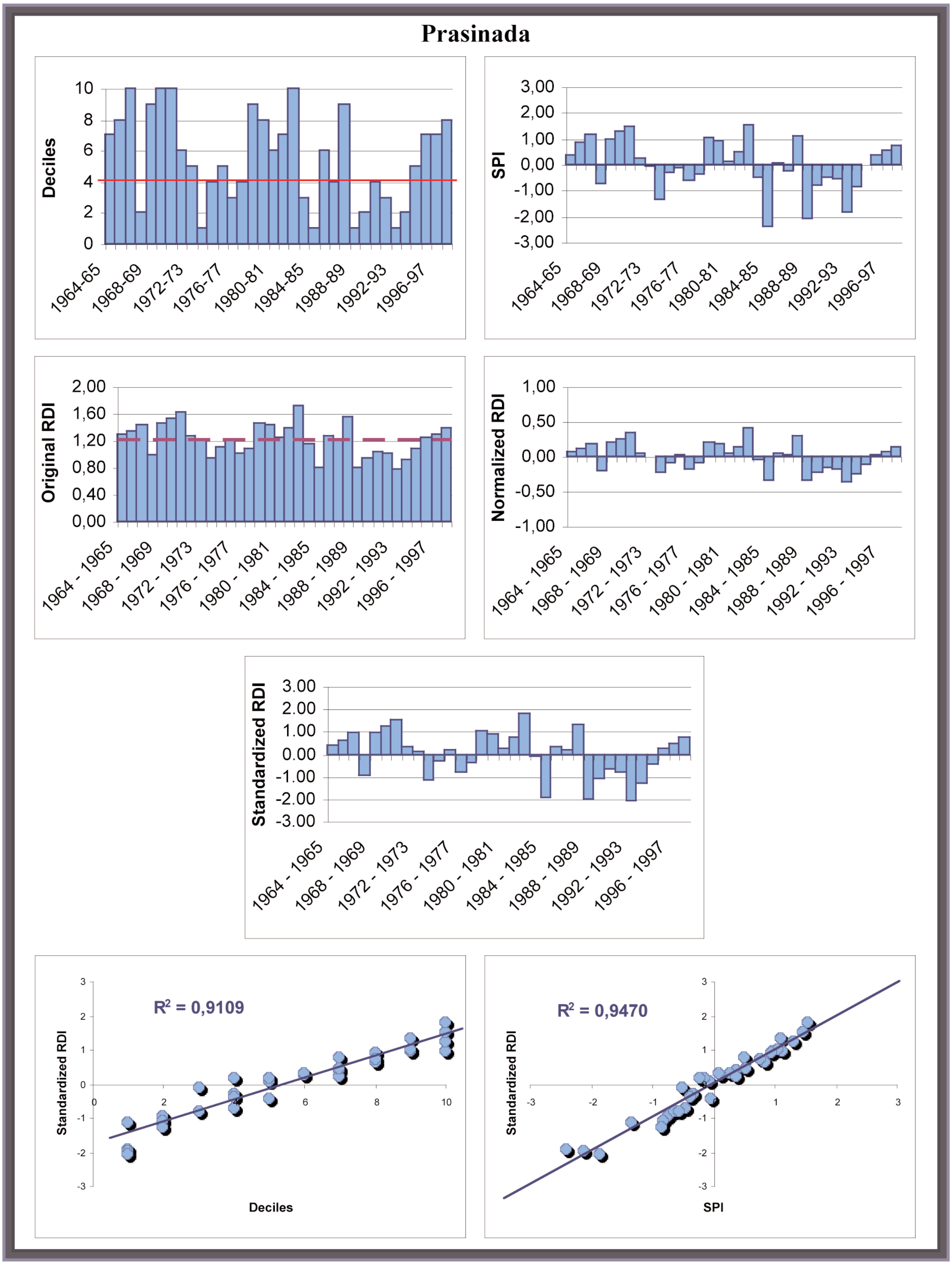


Kechrokampos
Deciles
1964-65
1968-69
1972-73
1976-77
1980-81
1984-85
1988-89
1992-93
SPI
Original RDI
1964 - 1965
1968 - 1969
1972 - 1973
1976 - 1977
1980 - 1981
1984 - 1985
1988 - 1989
1992 - 1993
Normalized RDI
Standardized RDI
1964 - 1965
1967 - 1968
1970 - 1971
1973 - 1974
1976 - 1977
1979 - 1980
1982 - 1983
1985 - 1986
1988 - 1989
1991 - 1992
1994 - 1995
R² = 0,9542
Standardized RDI
Deciles
R² = 0,9699
Standardized RDI
SPI

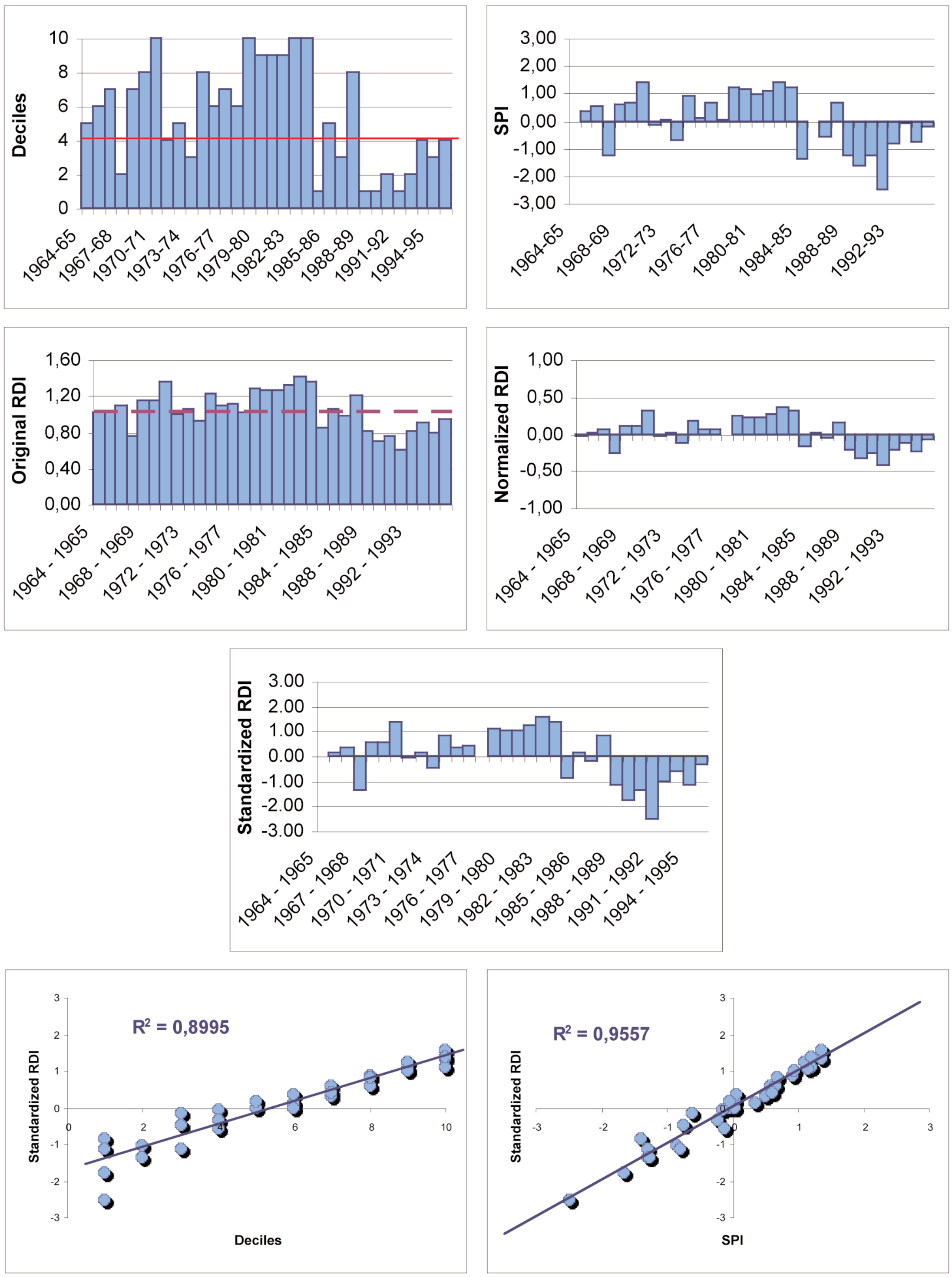

Mesochori
Deciles
1964-65
1968-69
1972-73
1976-77
1980-81
1984-85
1988-89
1992-93
1996-97
SPI
Original RDI
Normalized RDI
Standardized RDI
1964 - 1965
1968 - 1969
1972 - 1973
1976 - 1977
1980 - 1981
1984 - 1985
1988 - 1989
1992 - 1993
1996 - 1997
R2 = 0,9303
R2 = 0,9504
Standardized RDI
Deciles
SPI

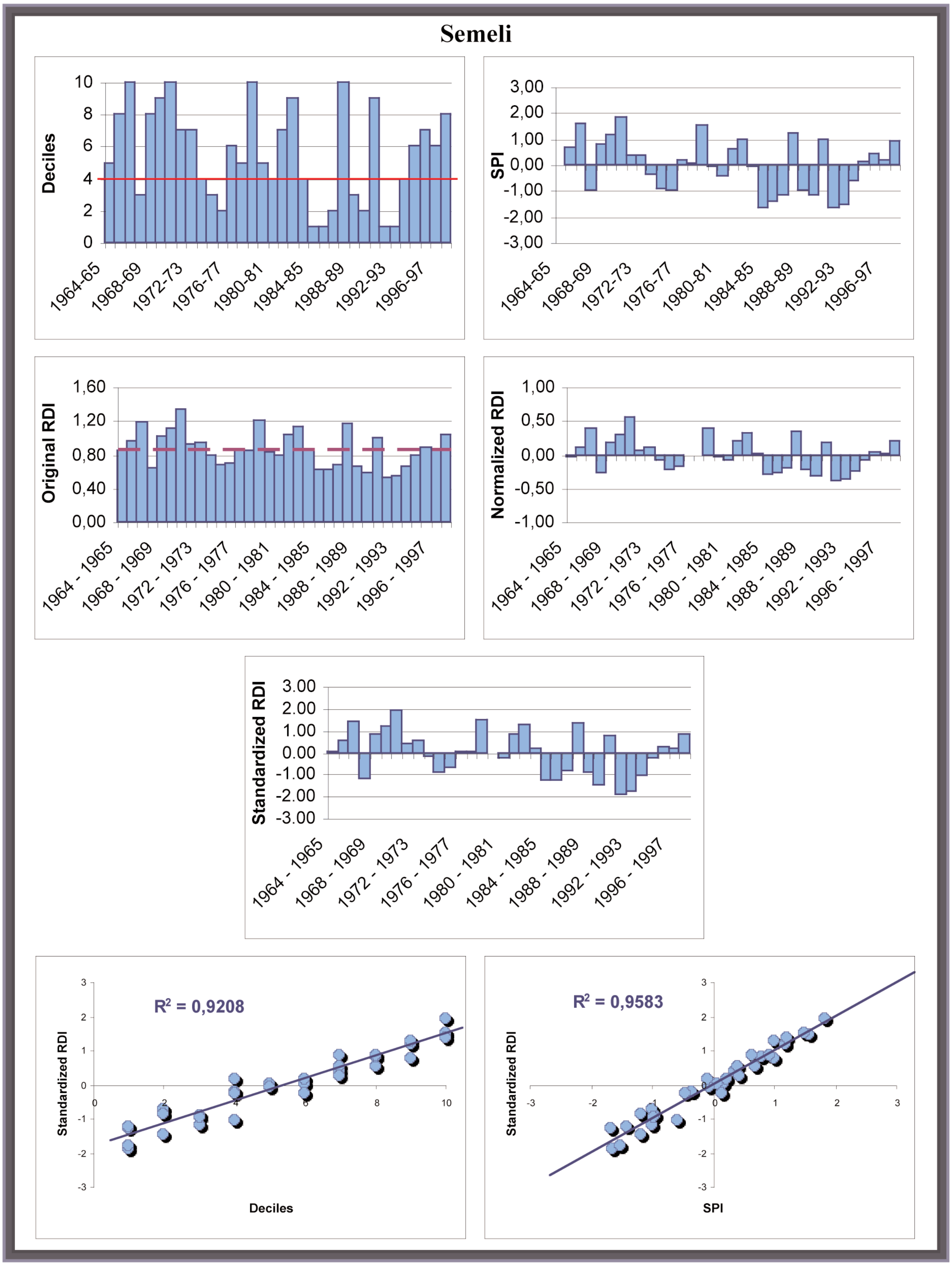
Potami


Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9117
R² = 0,9573
Standardized RDI
Deciles
Standardized RDI
SPI

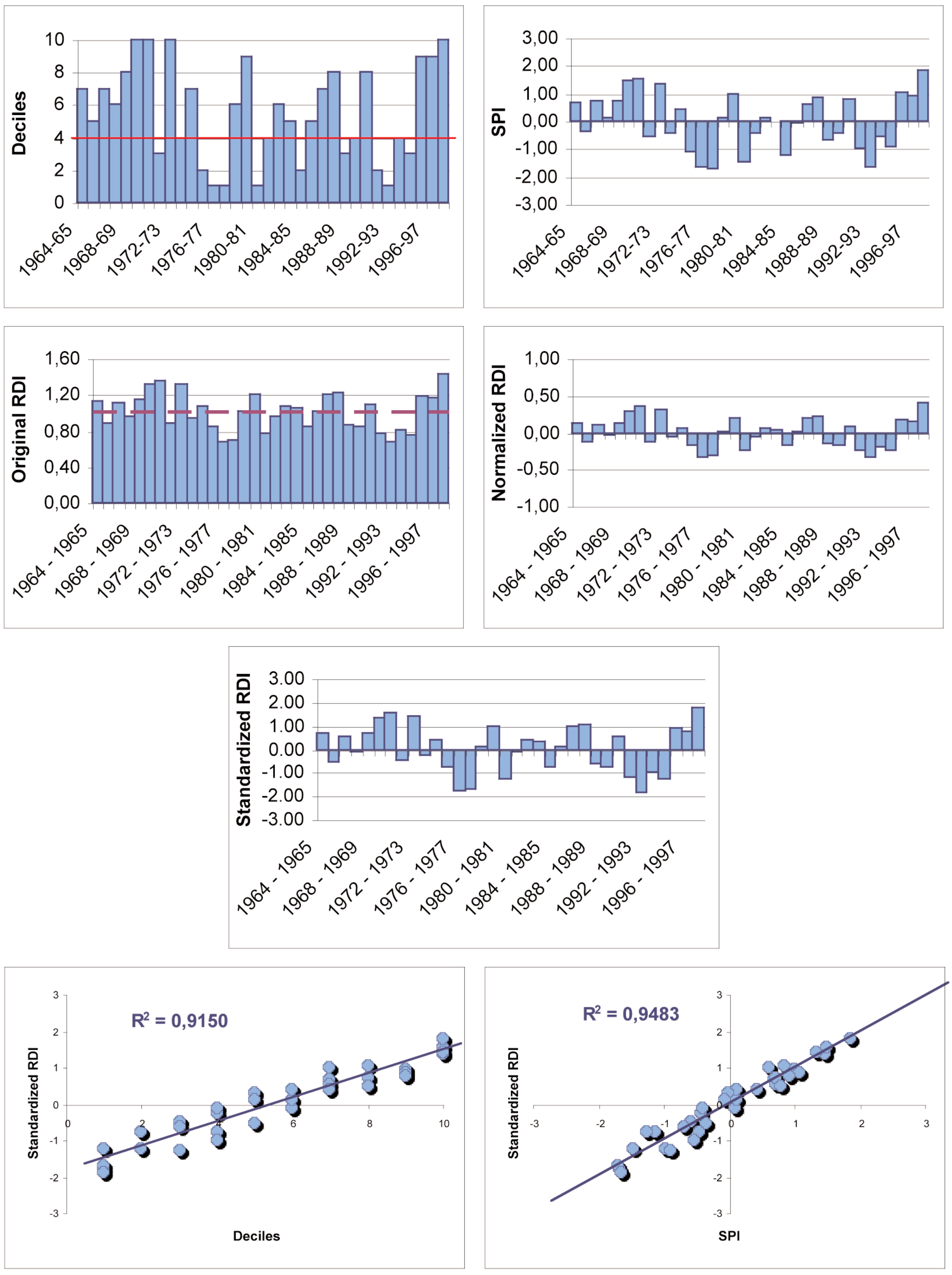

Prasinada
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9109
R² = 0,9470
Standardized RDI
Deciles
Standardized RDI
SPI

Ptelea

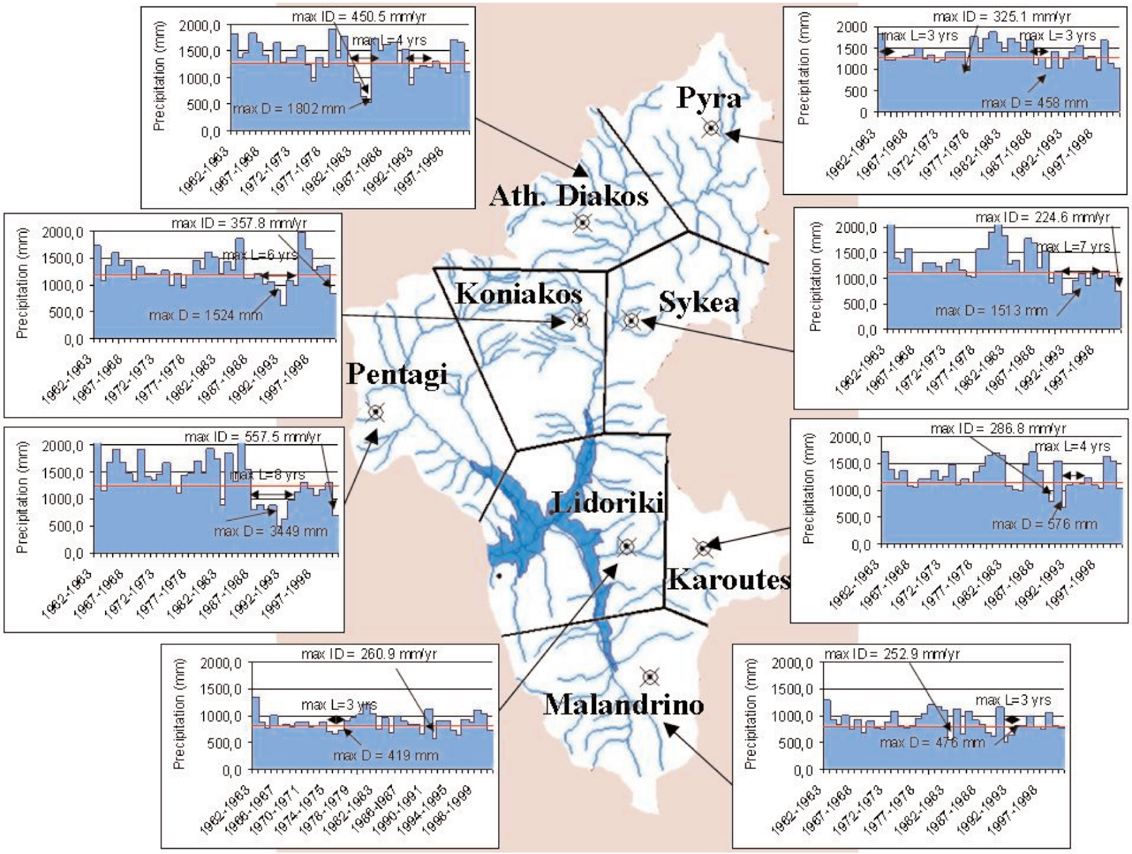

Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,8995
R² = 0,9557
Deciles
SPI

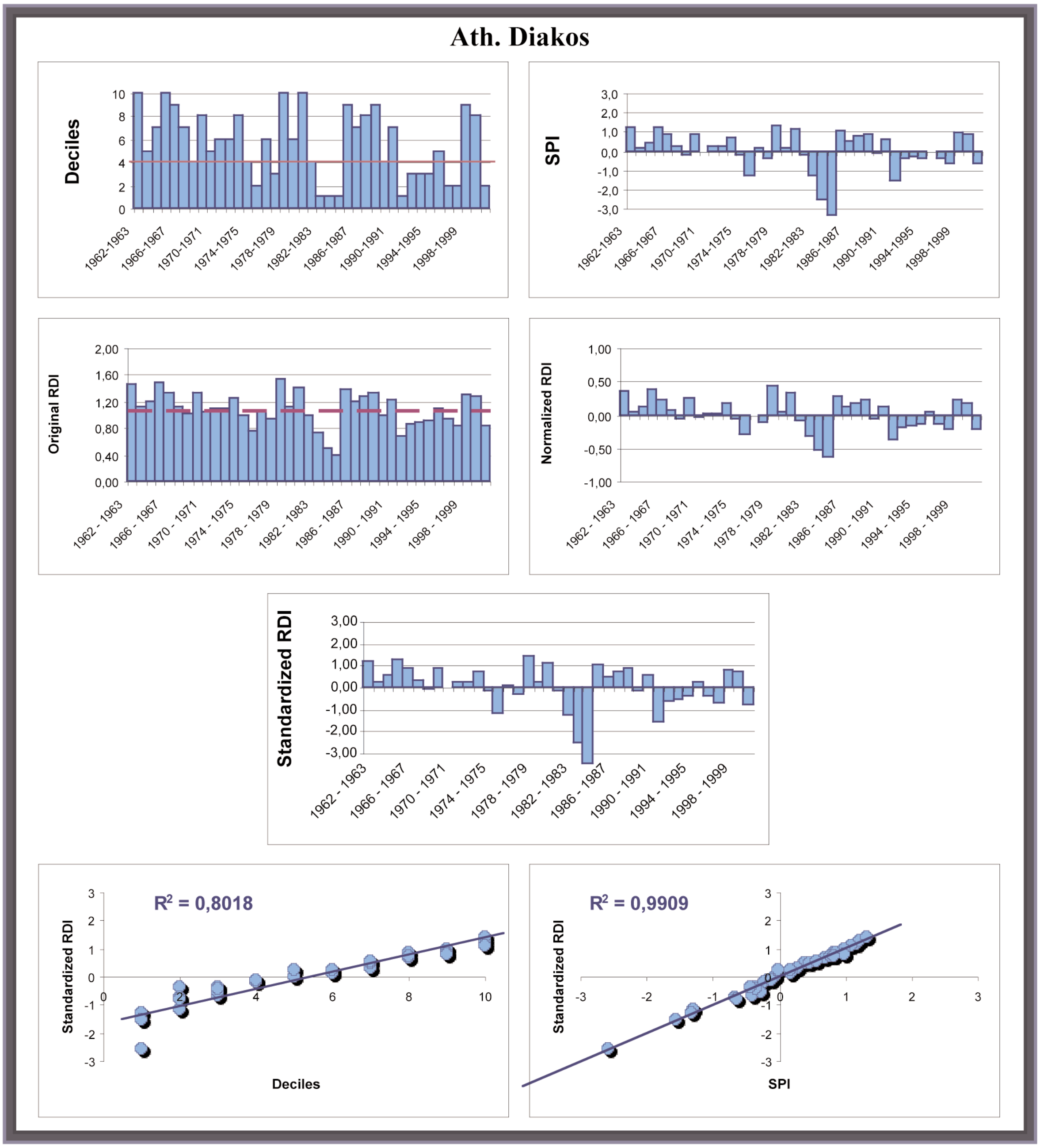

Semeli
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9208
R² = 0,9583
Deciles
SPI

Sidironero

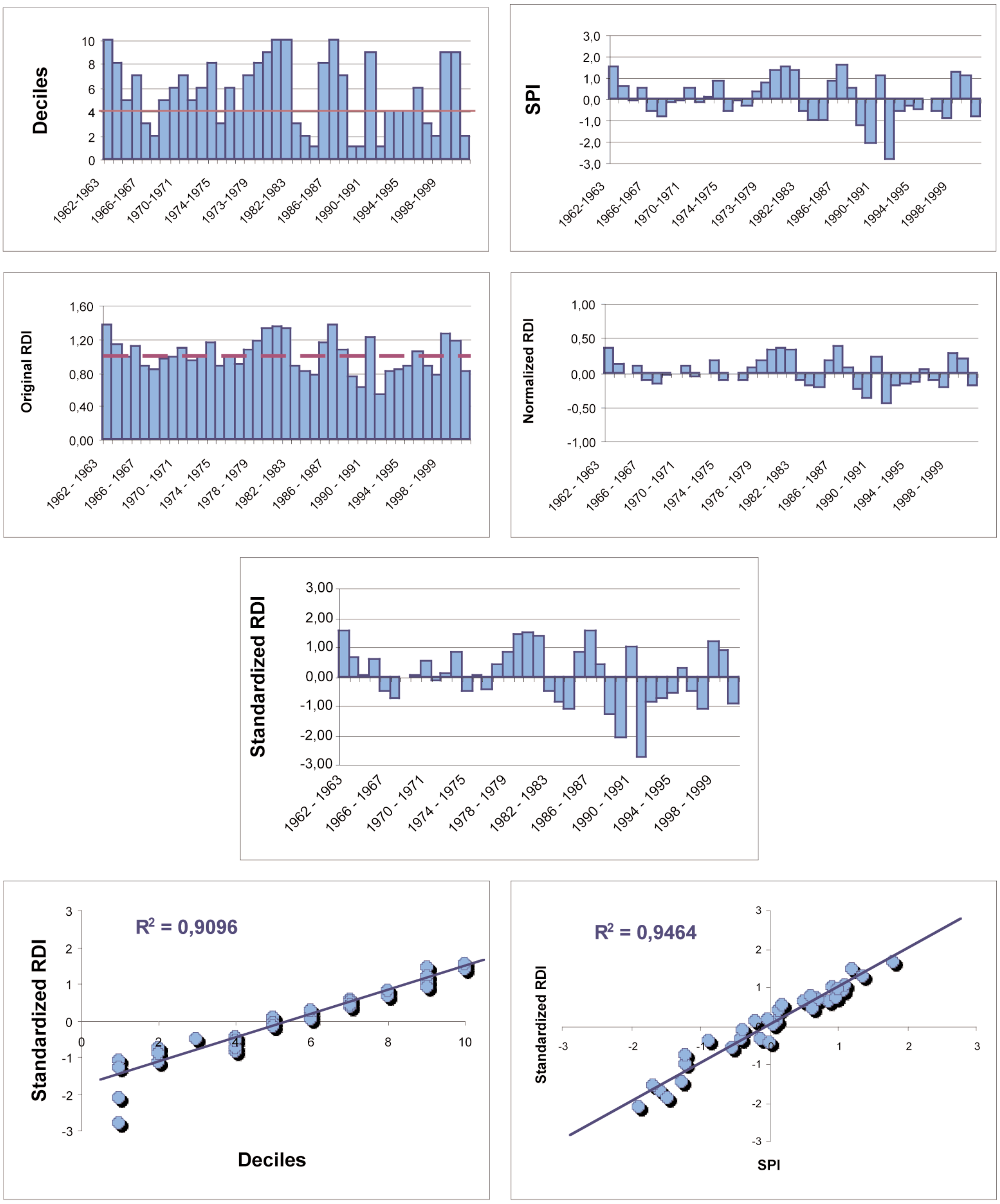

Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9150
R² = 0,9483
Standardized RDI
Deciles
SPI

Mornos River Basin

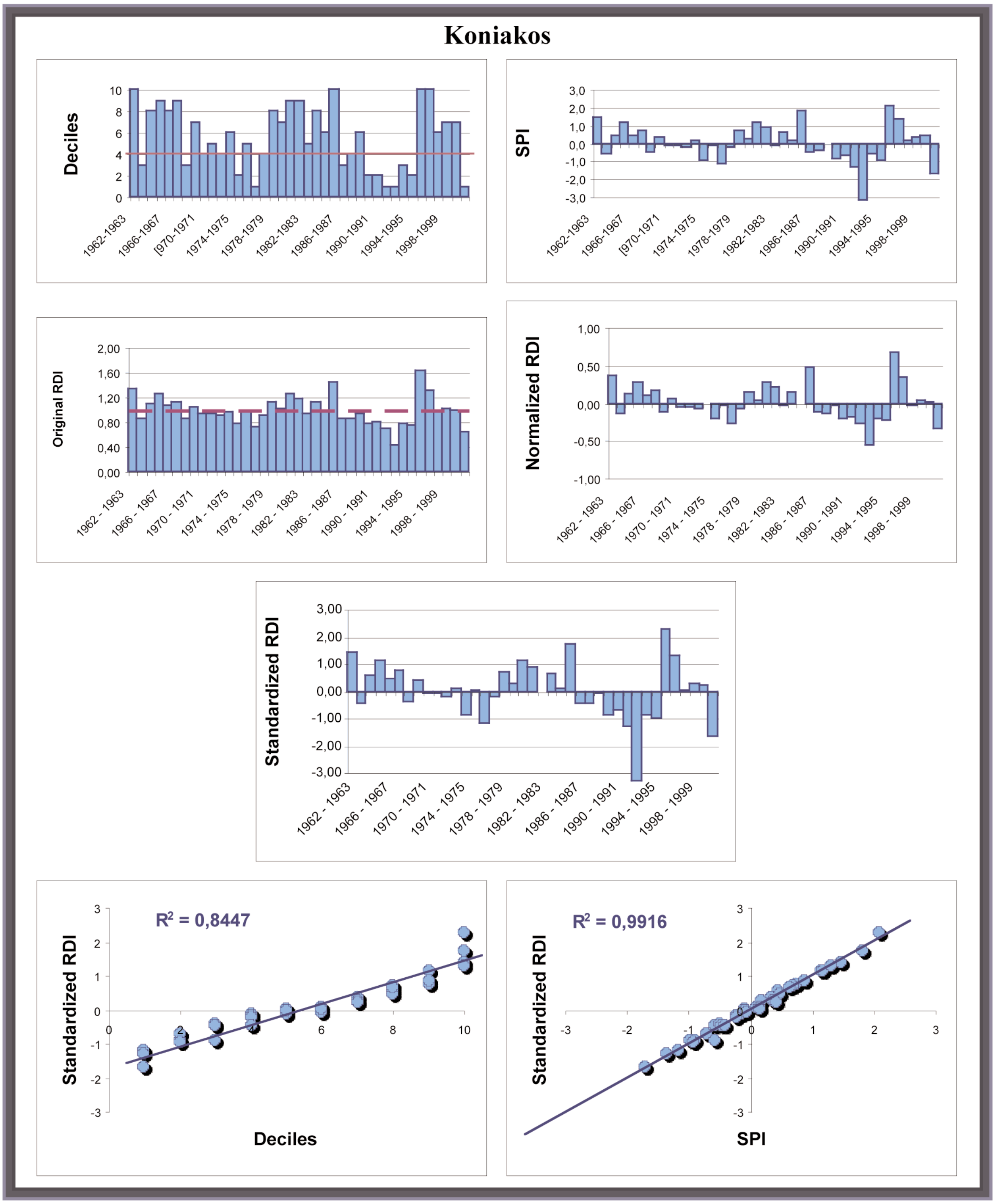


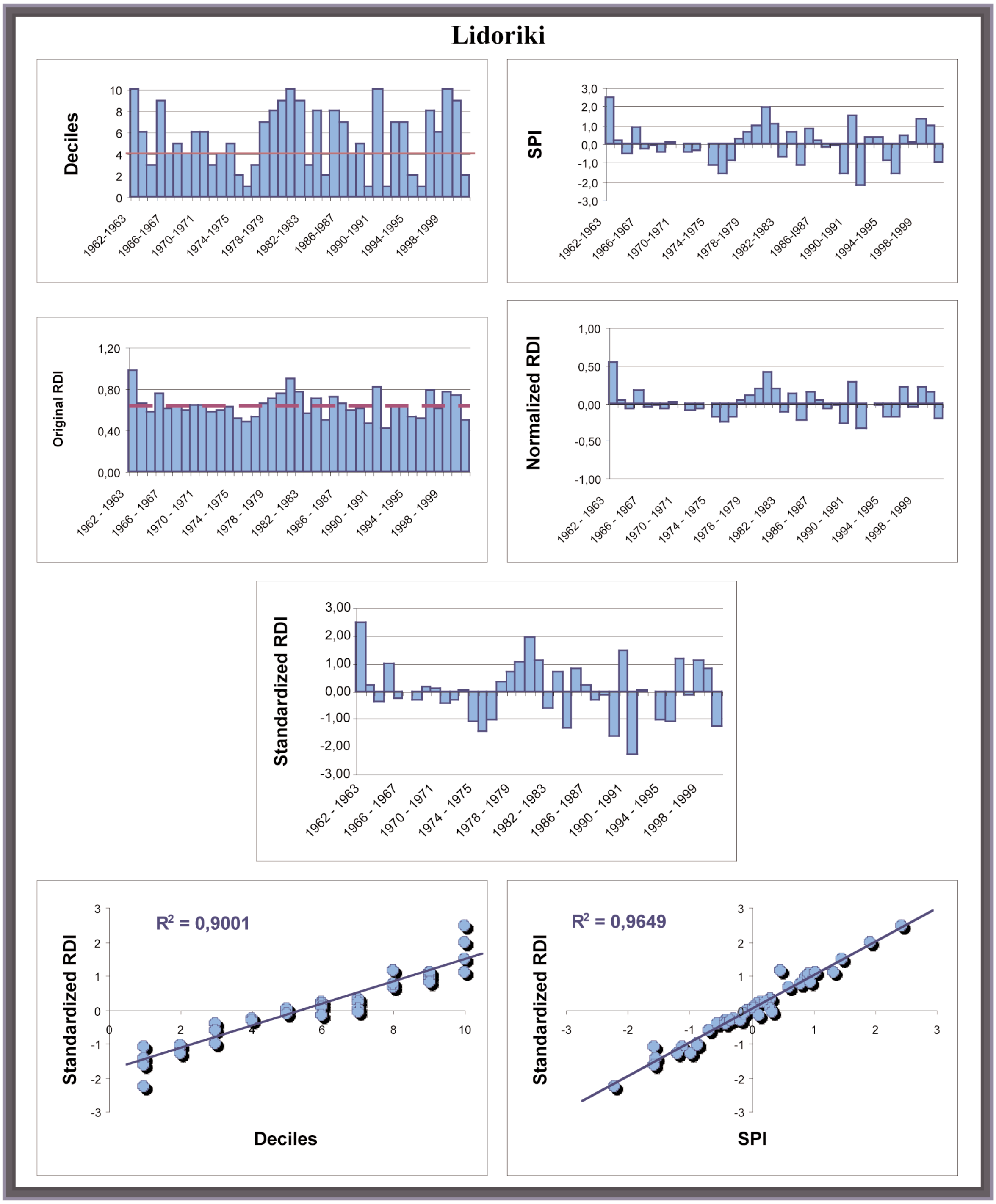

Ath. Diakos
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,8018
Standardized RDI
Deciles
R² = 0,9909
Standardized RDI
SPI

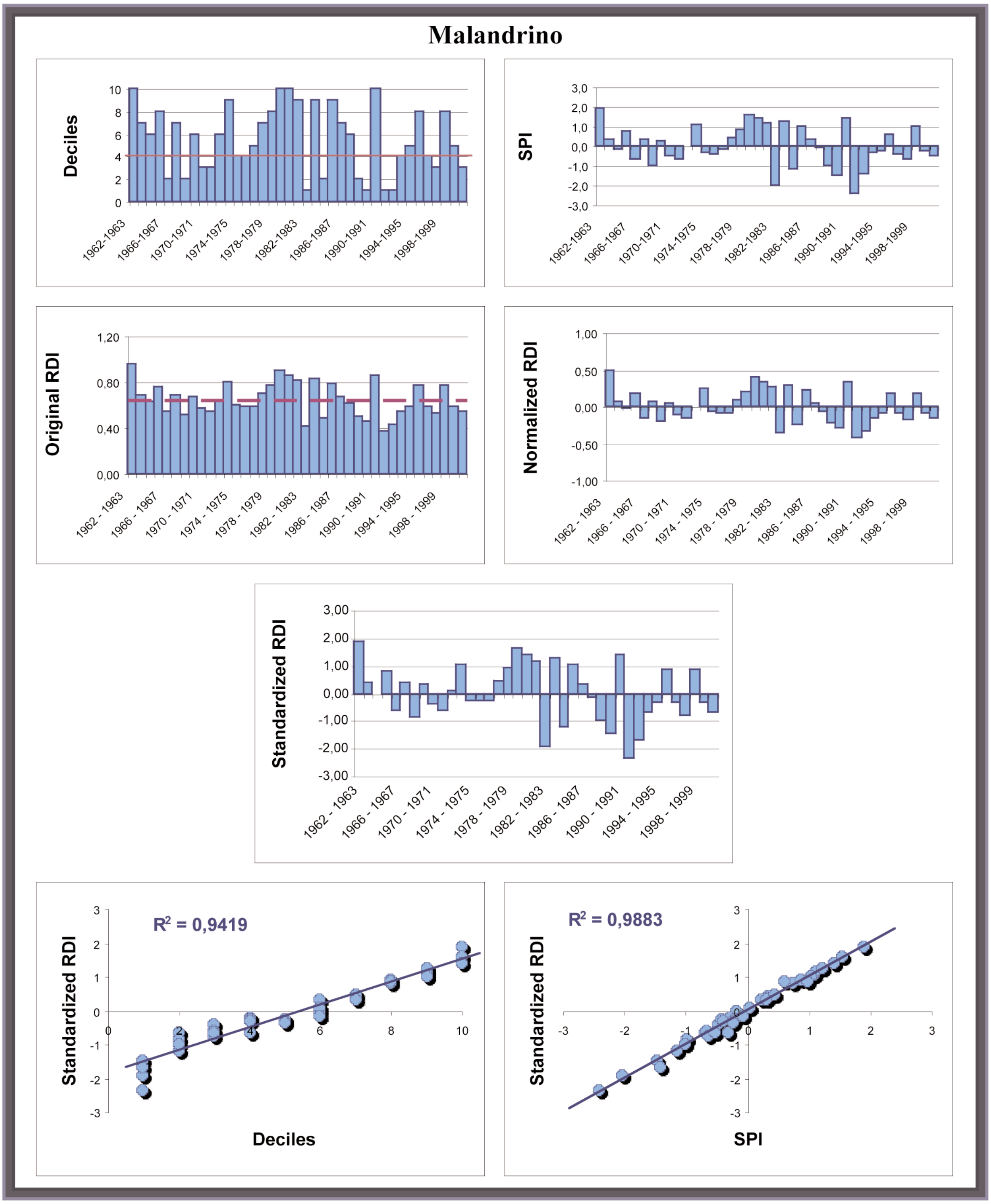
Karoutes



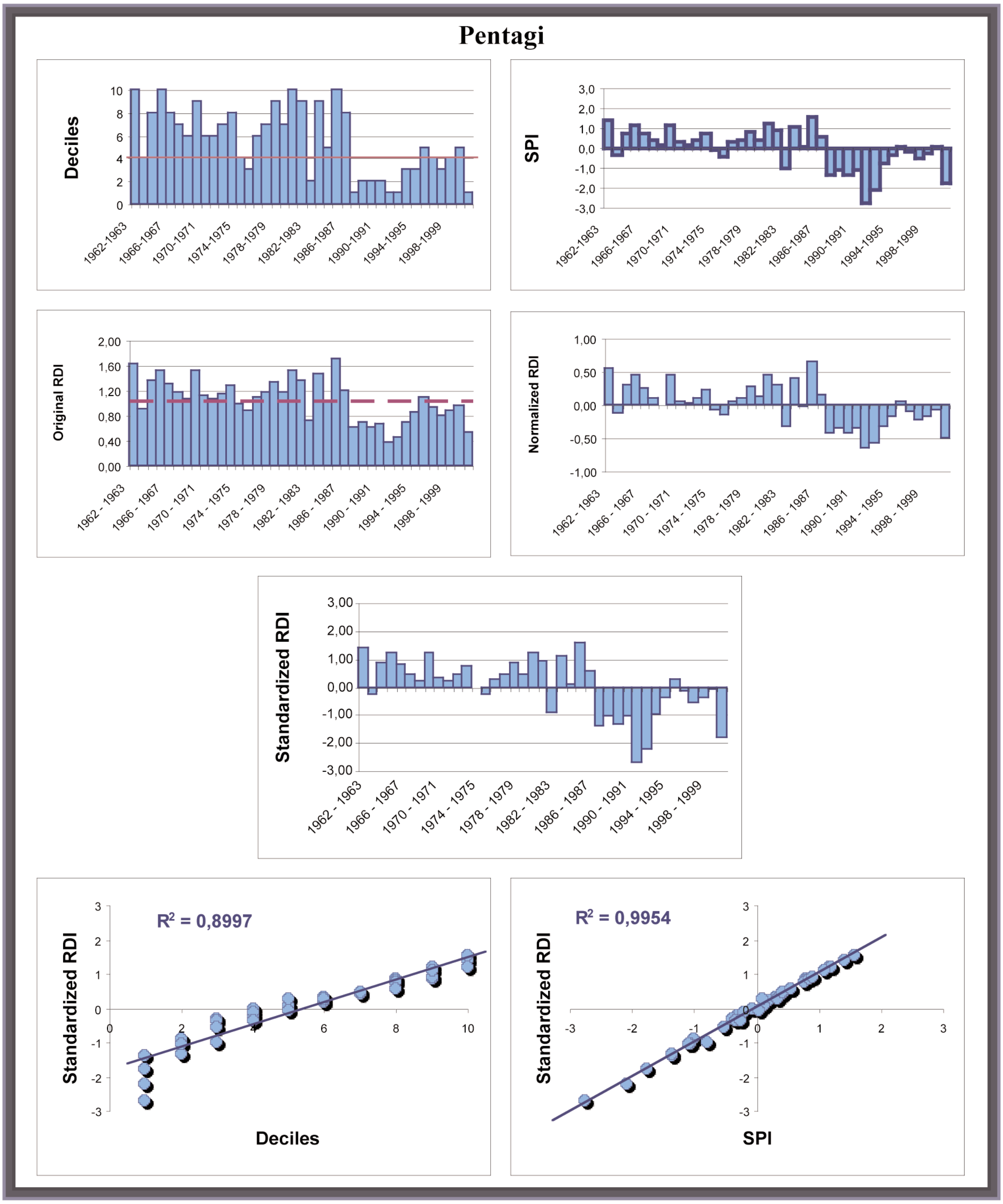
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R^2 = 0,9096
Standardized RDI
Deciles
R^2 = 0,9464
Standardized RDI
SPI

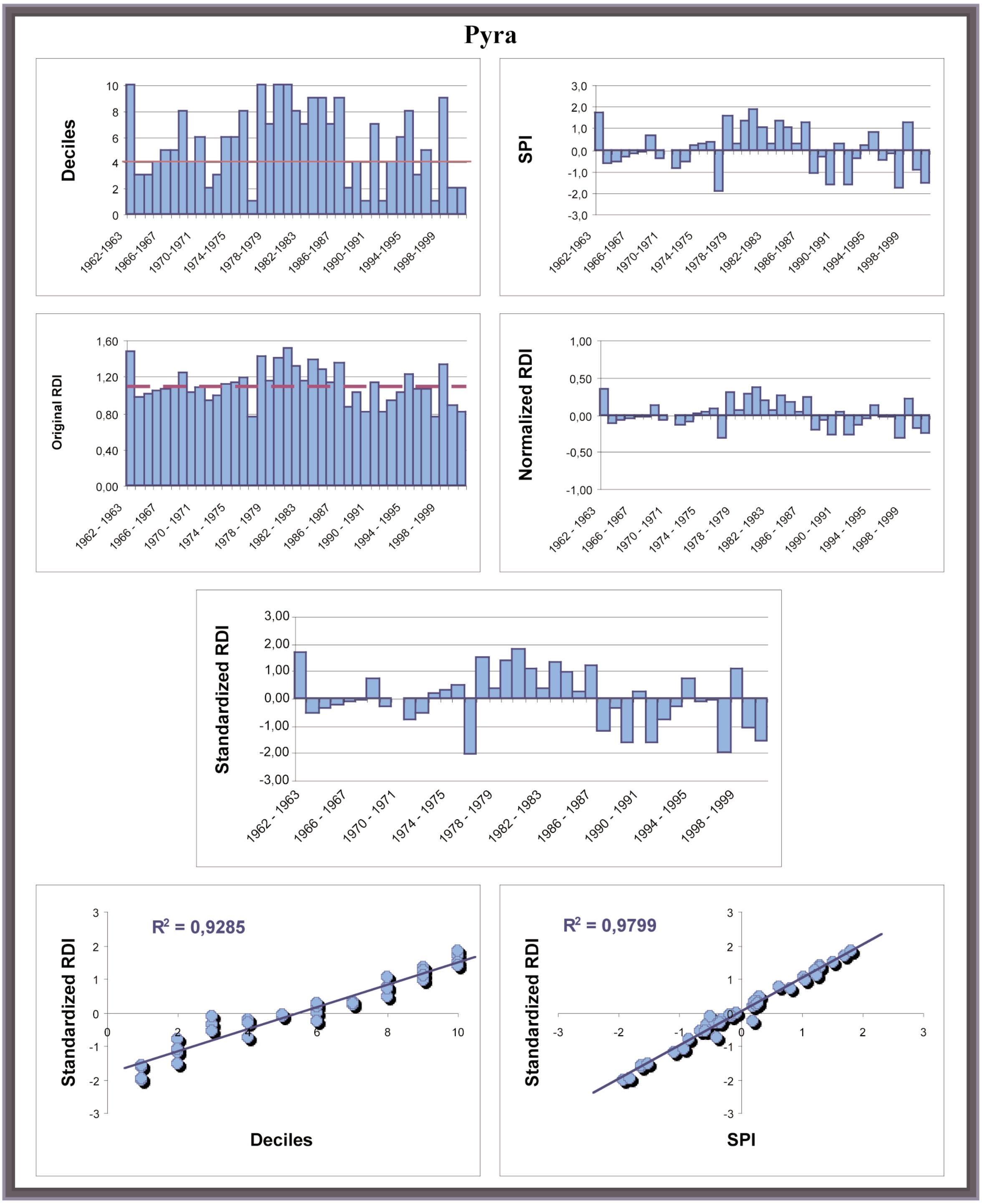

Koniakos
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R2 = 0,8447
R2 = 0,9916
Standardized RDI
Deciles
Standardized RDI
SPI


Lidoriki
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9001
R² = 0,9649
Deciles
SPI

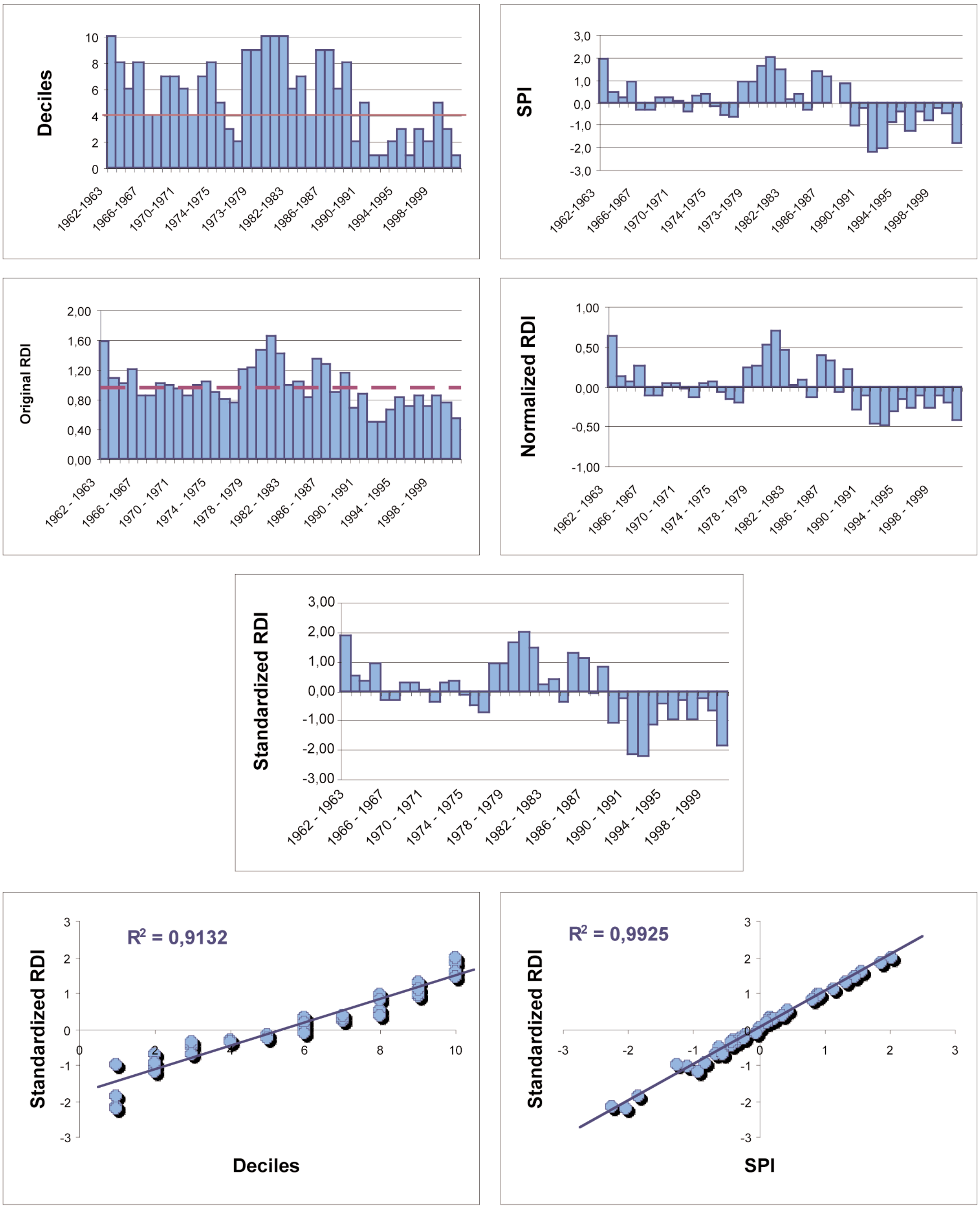


Malandrino
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R^2 = 0,9419
R^2 = 0,9883
Deciles
SPI


Pentagi
Deciles
10
8
6
4
2
0
1962-1963
1966-1967
1970-1971
1974-1975
1978-1979
1982-1983
1986-1987
1990-1991
1994-1995
1998-1999
SPI
3,0
2,0
1,0
0,0
-1,0
-2,0
-3,0
Original RDI
2,00
1,60
1,20
0,80
0,40
0,00
Normalized RDI
1,00
0,50
0,00
-0,50
-1,00
Standardized RDI
3,00
2,00
1,00
0,00
-1,00
-2,00
-3,00
1962 - 1963
1966 - 1967
1970 - 1971
1974 - 1975
1978 - 1979
1982 - 1983
1986 - 1987
1990 - 1991
1994 - 1995
1998 - 1999
R² = 0,8997
Standardized RDI
Deciles
R² = 0,9954
Standardized RDI
SPI


Pyra
Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9285
R² = 0,9799
Standardized RDI
Deciles
Standardized RDI
SPI

Sykea



Deciles
SPI
Original RDI
Normalized RDI
Standardized RDI
R² = 0,9132
R² = 0,9925
Deciles
SPI

Annex 2. Data and information systems

The Institutions that collect, record and process data that provide a representation of natural processes and socio-economic patterns directly or indirectly related to droughts are outlined in Table 1.

Table 1. Summary of institutions that collect and process data related to drought in Greece

Institution	Type of Data
The Ministry of Environment	Water quality, Water use, Geographical data, Land use
The National Meteorological Service	Meteorological data
The Public Power Corporation	Energy consumption
The Ministry of Agriculture	Meteorological data, Water quality, Water use, agricultural census
The Ministry of Interior	Municipal water consumption
The Ministry of Development	Land use, Populations, Groundwater
The National Observatory of Athens	Meteorological data
The Water Supply Companies	Water quality, Water use
The Army	Geographical Agency Maps, Topography, Land use, GIS
The Centre of Planning and Economic Research	Socio-economic indicators
The Institute of Geology & Mineral Exploration	Groundwater, Land use, Geology
The National Statistical Service	Statistics, Macroeconomic indicators

The major institutions, which play a role in combating drought are the three ministries:

(i) The Ministry of Agriculture, the Ministry of Interior and the Ministry of Environment. These Ministries are responsible for the use of water in Agriculture, in Municipalities and in the Industry domain.

(ii) The National Data Bank of Hydrological and Meteorological Information (NDBHMI), which has been established using information provided by the first six Institutions mentioned in Table 1, contains hydro-meteorological and hydro-geological data covering the entire country. Up to now, only the institutions that have contributed in the creation of this data bank have access to the data, but soon the data will be also accessible to other institutions and research organisations. The NDBHMI provides the required infrastructure for the implementation of the EU Water Framework Directive for the protection, rational management and exploitation of the water resources at the national level.

(iii) Various software applications are linked to the central Database of the NDNHMI supporting the analysis and synthesis of the data and the elaboration of secondary information. The distributed form of the database allows a continuous online operation and exchange of data between the participating organisations.

(iv) A GIS subsystem was developed to support the spatial analysis of hydrological data. The GIS applications were designed and implemented in such a way to allow both independent processing of data as well as interaction with the database and the different software packages.

(v) Given the large number of organisations measuring rainfall in Greece, a rationalisation plan was devised, creating a unified meteorological network.

(vi) Together with the National Network of Gauging Stations, the project team studied the development of network of 15 high resolution gauging stations in Attica, the greater area of Athens. These stations will automatically transfer data to the main database of NDBHMI at programmed intervals. The selection of the location of the stations was made, taking into account the geographical distribution as well as the security of each location. The main equipment in these stations consists of the following: Auto-recording meteorological stations Data - transfer equipment Customised software for the automatic transferring of recordings to the database This network will work in parallel with meteorological radars that the National Technical University of Athens (NTUA) is in the process of buying. This system will constitute an integrated storm prediction system in the wider area of Athens.

Annex 3. Potential impacts of drought

Table 1. Summary of the potential impacts of drought in the Nestos and Mornos Basins based on responses of stakeholders. Impact range from 0 (not important) to 5 (most important)

Impact	Nestos Basin rank	Mornos Basin rank
ECONOMIC: WATER SUPPLY		
Additional cost of supplemental water infrastructures	2	5
Additional cost of water transport or transfer	4	0
Decrease in hydroelectric power generation	4	2
Decreased revenues of water supply firms	2	5
Increase in water tariffs	3	4
Increase in water treatment costs	3	3
Increased cost of ground water extraction	4	3
Reduced service quality	3	3
Other (please specify)		
ECONOMIC: AGRICULTURE		
Decrease in farm income	4	3
Decrease in land prices	2	2
Decrease in livestock feed quantity and quality	3	2
Decrease in rangeland and pasture production	3	3
Decrease of agricultural labour	4	3
Decreased crop production	5	3
Decreased crop quality	3	4
Decreased water in farm ponds for irrigation	4	4
Increase in consumer credits in rural areas	3	3
Increase in crop imports	5	2
Increase in food prices	4	3
Increase in insects, pests, and crop diseases	4	4
Increase in livestock diseases	3	2
Increase of farm subsidies	5	5
Increased crop insurance premia	3	3
Increased soil erosion	4	5
Increased unemployment of the agricultural sector	4	3
Livestock production: water quality and quantity	3	3
Loss of farm income	4	4
Loss of income of industries dependent on agriculture	3	3
Losses in financial institutions related to agricultural activities (e.g., credit risks)	2	1
Revenue losses to state and local governments (from reduced tax base to farmers)	2	3
Other (please specify)		
ECONOMIC: FISHERIES		
Decrease production of fishery	1	0
Other (please specify)		
ECONOMIC: FORESTRY		
Decreased production of forests	2	2
Other (please specify)		

ECONOMIC: INDUSTRY		
Changes in the energy cost (e.g., due to changes in hydroelectric by oil)	1	0
Electric power unbalance (Increased energy demand and reduced supply)	3	2
Income loss of manufacturers and sellers of recreational equipment	0	0
Other (please specify)		
ENVIRONMENTAL		
Biodiversity loss in ecosystems associated with water	4	4
Biodiversity loss in land based ecosystems	2	2
Changes in estuarine areas (e.g., salinity levels)	3	2
Changes in the migration and concentration of animal species (loss of wildlife in some areas and too many species in others)	3	2
Decrease in reservoir and lake levels	2	4
Deterioration of visual and landscape quality (e.g., dust, vegetative cover, etc.)	1	2
Deterioration of air quality (e.g., dust, pollutants)	1	1
Ground water depletion and land subsidence	3	2
Increase erosion of soils by wind and water	2	2
Increase in diseases in animals (e.g., due to low quality of water or poor feed)	3	2
Increase in diseases in plants (e.g., due to low quality of water)	3	3
Increase in invasive weeds and algae	3	3
Increase in number and severity of fires	5	4
Increased stress to endangered species	4	3
Reduction of the wetland areas	3	2
Water quality effects (e.g., salt concentration, increased water temperature, pH, dissolved oxygen, turbidity)	3	2
Other (please specify)		
SOCIAL		
Appearance of human health related problems (from water and air quality deteriorations)	2	2
Conflict appearance in management	4	3
Conflict appearance in media or science	3	3
Conflict appearance in political decisions	4	5
Conflict appearance in water use	5	5
Damage in cultural heritage sites	1	2
Danger to public safety from forest and range fires	3	3
Decrease in the visits to a recreational area	2	2
Decreased nutrition quality in subsistence farm areas	2	2
Deterioration of aesthetic values	2	2
Increase in the poverty level in rural areas	3	3
Increased migration to urban areas form agricultural areas	3	2
Public dissatisfaction with government regarding drought response	4	5
Other (please specify)		

Chapter 17. A paradigm for applying risk and hazard concepts in proactive planning: Application to rainfed agriculture in Greece

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SUMMARY – The concepts of risk and hazard have been used with different meaning in a wide spectrum of disciplines. Even in the area of natural hazards such as the floods and droughts the definitions used for all the related terms are still confusing the scientific community and the stakeholders. The objective of this chapter is to attempt to clarify some of these terms and propose a methodology for risk assessment. Emphasis is given to the estimation of risk of the affected areas due to the occurrence droughts and the proposed methodology. Simplified examples are presented for illustrating the use of these terms. Particular attention is given to the concept of vulnerability mainly in relation to proactive planning.

Key words: Hazard, vulnerability, risk, annualized risk, droughts, rainfed agriculture, proactive planning.

Introduction

Several concepts have been used over the past decades to describe the potential threats from natural phenomena and the capacity of the various structural and non-structural systems to protect people, properties and the environment from these threats.

Concepts such as hazard, risk and vulnerability are the most commonly used terms although they have different meaning for different people. In some cases there is also a lack of understanding between scientists and engineers who attempt to quantify these concepts, and the stakeholders who are asked to apply them in the real world.

Furthermore quantification is not an easy task. It is possible that some parameters affecting the above concepts are beyond quantification. However even so it is necessary to find a way for analyzing these parameters and assess their importance in the final impact (Brauch, 2005; Thywissen 2006).

From the above it is understood that a wide systematic effort should be undertaken in order to clarify all these concepts and propose a practical and understandable methodology for calculating them in the various disciplines and specialised applications (Klein, 2003).

Towards this initiative this chapter is attempting to address these concepts and give practical algorithms for calculating them in the area of droughts, and their effect on agriculture (Tsakiris, 2006). The approach used however is to build a general framework in which several natural hazards could be incorporated and analyzed. For this purpose drought hazards are analyzed following the proposed general algorithm.

Hazard

The term "hazard" due to a natural phenomenon may be defined as: (i) a source of potential harm, (ii) a situation with the potential to cause damage, and (iii) a threat or condition with the potential to create loss or damage to lives or to initiate any failure to the natural, modified or human systems.

The causes of hazard may be external (e.g. flooding) or internal (e.g. defective section of protection levees). Also under a different categorization hazards may be natural, meaning that the cause is natural (e.g. storm), or human-induced (e.g. deforestation). Although this distinction may be unclear for certain cases it applies to the majority of applications.

Hazard according to the above general definition should be treated as a type of threat to lives, environment, cultural heritage and development. However this threat should be quantified somehow. This quantification may remain at a qualitative level by describing the people, the properties, the affected area, etc. being under threat or by estimating the frequency of a certain level of threat derived from the existing historical events. Therefore, although the numerical assessment is difficult and may be subjective, the hazard can be assessed in a more soft way by characterizing it as small, moderate or high.

In a more structured way, hazard may be quantified by two ways:

(i) The probability of occurrence of the hazardous phenomenon (e.g. an area is flooded once in five years).

(ii) The sum of potential consequences of the affected area provided no protection system is in operation (e.g. in case of a catastrophic drought the damage to the rainfed agricultural area due to the loss in crop yield is 10M€). The calculation of the potential consequences could be performed having in mind that a sort of basic protection mainly for low severity events can be found in most of the systems. However this could be regarded as the reference level corresponding to the "totally unprotected" area.

Under certain conditions the first or the second way can be considered as more appropriate. In general it can be said that natural hazards caused mainly by external causes can be quantified by probabilistic approaches. On the contrary, human-induced phenomena caused by mainly internal causes are better quantified through deterministic approaches by calculating the potential consequences from a very "critical" scenario of failure. Obviously the critical scenario selected represents the basis for designing any protection system.

Concentrating on the natural hazards in which the cause of initiating the failure mode is natural it can be supported that only the frequency is not sufficient to describe the level of hazard. In a more comprehensive way natural phenomena may be described by their magnitude (and therefore their potential consequences) together with the frequency of these hazardous events.

Since the magnitudes of the phenomenon (and therefore the anticipated consequences) follow, in most of the cases, a certain probability distribution, the following equations may be written:

$$F(x) = P(D \leq x) = \int_{-\infty}^{x} f_D(x)dx = \int_{0}^{x} f_D(x)dx \quad (1)$$

$$\text{or} \quad 1 - F(x) = P(D > x) = 1 - \int_{-\infty}^{x} f_D(x)dx \cong 1 - \int_{0}^{x} f_D(x)dx \quad (2)$$

in which x is the sum of potential consequences of each hazard event of the phenomenon, $F(x)$ and $P(D \leq x)$ are the cumulative density functions, $P(D > x)$ is the exceedance probability, and $f_D(x)$ is the probability density function.

It should be noticed that for the calculation of $f_D(x)$, the relationship between $F(x)$ and x should be known. In general, this type of relationship may be any curve, not necessarily following a certain probability distribution. The F-x curve is produced from a table linking cumulative frequencies to magnitudes of the phenomenon and the estimated potential consequences.

The figure which gives a representative measure of hazard is the expected value $E(D)$ which considers both the potential consequences and their probability of occurrence:

$$E(D) = \int_{0}^{\infty} x \cdot f_D(x)dx \quad (3)$$

Since $E(D)$ is a measure of "average" (annualized) expected hazard it would be useful to calculate the variance [$Var(D)$] as a complimentary figure for estimating not only the most expected outcome but also the range of this outcome.

$$Var(D) = \int_0^\infty (x-\mu)^2 \cdot f_D(x)\,dx \tag{4}$$

in which μ is represented by *E(D).*

$$\text{or}\quad Var(D) = E(D^2) - (E(D))^2$$
$$Var(D) = \int_0^\infty x^2 \cdot f(x)\,dx - (E(D))^2 \tag{5}$$

Applying the above equations, an important assumption should be met. That is the function relating the potential consequences to the magnitudes of the phenomenon to be an 1 – 1 function. These functions are usually of geometric type and are called "loss functions".

A numerical example is provided for illustrating the procedure to estimate annualized hazard. Table 1 provides the data linking return periods of magnitudes of the hazardous phenomenon to the potential consequences anticipated.

Table 1. Return periods and anticipated potential consequences

Return Period T (y)	Potential consequences D (M €)
2	0
10	400
50	800
100	1170
1000	3000
>1000	3000

Further from the above table another table (Table 2) is produced relating the frequency of each class of magnitude to the mean potential consequences of the class.

Table 2. Frequency vs mean potential consequences of each class

Frequency $F(x_{i+1}) - F(x_i)$	Mean potential consequences $\frac{x_i + x_{i+1}}{2}$
0.40	200
0.08	600
0.01	985
0.009	2085
0.001	3000

Based on the latter table the (mean) expected value of potential consequences is calculated representing the average hazard of the phenomenon.

$$E(D) = \sum_{i=1}^{n} \left(\frac{x_i + x_{i+1}}{2}\right) \cdot \left[F(x_{i+1}) - F(x_i)\right] = 80 + 76.6 + 28.6 + 18.8 + 3 = 207$$

$$Var(D) = \sum_{i=1}^{n} \left(\frac{x_i + x_{i+1}}{2}\right)^2 \cdot \left[F(x_{i+1}) - F(x_i)\right] - (E(D))^2 = 37414.75 - 48849 = 24565.75$$

The standard deviation is then:

$$SD = \hat{\sigma} = \sqrt{Var(D)} = 156.73$$

That is the average hazard is estimated as 207 M€/y with a standard deviation of 156.73 M€/y.

Vulnerability

Vulnerability of a certain system is generally defined as the degree of susceptibility to damage from a hazardous phenomenon or activity. In most of the cases quantification of vulnerability is a very difficult task. However some kind of assessment of vulnerability is required in order to estimate the real threat from an existing source of hazard. Therefore in most of the cases quantitative approaches could be implemented for assessing vulnerability.

A common characterization of vulnerability is with the scale "low, moderate, high".

In a more detailed approach vulnerability may be characterized as related to the anticipated damages as follows:

(i) Negligible or slight damage

(ii) Moderate damage

(iii) Substantial to heavy damage

(iv) Very heavy damage

(v) Destruction

As it can be easily understood vulnerability of a system comprises of two components: the coping capacity of the system to withstand the hazardous event and the exposure of the system to this event. The assessment of vulnerability based mainly on the capacity of the system has a meaning only if the system is exposed to the hazardous event.

In general vulnerability of a system related to a hazardous phenomenon is dependent upon a large number of factors most of which are listed below:

(i) Exposure

(ii) Capacity of the system

- Infrastructure
- Condition of the system
- Institutional set-up
- Quality of governance
- Motivation to react
- Skills and education of people
- Resources available
- Preparedness status
- Monitoring capabilities
- Existance of an emergency plan
- Development status
- Resilience / time of recovery
- Initial conditions of the system
- Interaction of interrelated components

(iii) Hazardous event

- Magnitude of the event
- Duration of the stress

– Timing of the event
– Conditions which may influence the destruction capacity

Under a different categorization the above factors may be grouped in four categories:

(i) Exposure of the System (E)

(ii) Capacity of the System (S)

(iii) Social Factor (SF)

(iv) Severity of the event (Qmax)

(v) Conditions and interrelated factors (I)

In mathematical terms:

$$V = V(E, S, SF, Q_{max}, I) \tag{6}$$

In more simplistic terms, vulnerability could be considered as a function ranging between 0 and 1.

In general terms, vulnerability may be related to the entire system or it may be necessary to disaggregate the system into a number of components and perform a detailed analysis on each of them. The aim of reclamation and protection works is to reach a lower level of the system's vulnerability. A comprehensive measure of the improvement of a system is the ratio of anticipated consequences after the improvement divided by the initial potential consequences. A graphical representation of vulnerability and its reduction presented versus the magnitude of the hazardous phenomenon appears in Fig. 1. As can be seen the improvement of the capacity of the system is represented by a shift to the right of the vulnerability curve.

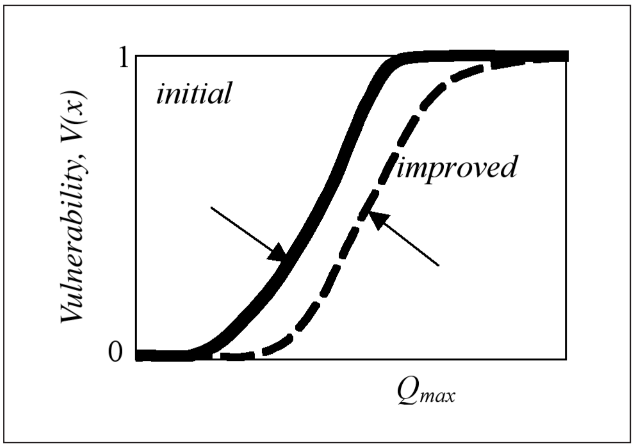

Fig. 1. Vulnerability vs magnitude of the phenomenon for the initial and the improved capacity of the system.

The routes for reducing vulnerability may follow the main items, which it is dependent upon. That is:

(i) Improving the coping capacity of the system

(ii) Mitigating the magnitude of the phenomenon (and its potential consequences)

(iii) Improving social capacities to deal with the phenomenon (capacity building)

(iv) Controlling internal and external factors and their interrelations

(v) Changing the exposure of the system

Risk

Risk may be defined as an existing threat to a system (life, health, properties, environment, cultural heritage) given its existing vulnerability. In a metaphor hazard could be viewed as a source with a beam of rays, vulnerability as the filter and risk as the beam of penetrating rays through the filter affecting the system.

Risk is similar to hazard, but it is not a potential, it is a real threat. It is customary to express risk (R) as a functional relationship of hazard (H) and vulnerability (V).

$$\{R\} = \{H\} \square \{V\} \tag{7}$$

in which the symbol □ represents a complex function incorporating the interaction of hazard and vulnerability. A simple example of such a function is the simple product of hazard and vulnerability.

$$\{R\} = \{H\}\ x\ \{V\} \tag{8}$$

Since vulnerability is a dimensionless quantity risk could be measured in the same quantities as hazard. That is risk could represent the probability of harmful consequences or the expected damages resulting from interactions of hazard and vulnerable conditions.

Following the methodology for calculating average (annualized) hazard, the average risk can be calculated as follows:

$$R(D) = \int_0^\infty x \cdot V(x) \cdot f_D(x)\, dx \tag{9}$$

in which x is the potential consequence caused by the phenomenon of the corresponding magnitude, the probability density function of which is $f_D(x)$ and $V(x)$ is the vulnerability of the system towards the corresponding magnitude of the phenomenon.

Important issues when calculating the risk are the characteristics of the cause of initiating the failure mode and causing damage. These causes may be natural or due to human error or human involvement. If the triggering event can be caused by human intervention or activity, then this process cannot be described by probabilities.

Therefore, to assess the risk threatening a certain area ("area at risk") or population ("population at risk") the worst conditions should be considered. For example, the breach of levees protecting an area can occur in the night under adverse conditions instead of midday on a sunny day. The assumption of the "critical" scenario could be the worst scenario in case lives or important properties or heritage are at risk.

If risk is calculated on the basis of probabilities of extreme events or processes, care should be taken on the possibility of two or more causes of failure to occur at the same time. Then the total damage might be higher from the damage caused by the two causes occurring independently from each other.

The above analysis is based on the assumption that the system under risk is a uniform entity which is exposed to a certain hazard. If this system is considered as an element of a much more wide and non-uniform system then the total risk could be calculated by integration over the sum of elements at risk. It might be also useful to distinguish exposure from vulnerability. In this case exposure could be represented by a similar function ranging from 0 to 1.

Application of drought hazard to rainfed agriculture

An agricultural is cultivated with cereal crops. No irrigation or other drought protection system is in operation. Analyzing a long historical record the frequency of a number of drought severity classes was associated with the crop production losses in monetary units. The severity of drought was calculated by a general drought index, the Reconnaissance Drought Index (RDI) on an annual basis. (Tsakiris and Vangelis, 2005, Tsakiris *et al.*, 2006). According to the thresholds adopted for this index four classes of severity were used. The results of this analysis are represented in Table 3.

Table 3. Drought frequency and crop yield losses from the agricultural area under study

Severity of annual drought	Probability of occurrence	Anticipated Losses (k€)
0 > RDI > -1	1 : 3	20
-1 > RDI > -1,5	1 : 7	150
-1,5 > RDI > -2	1 : 12	400
RDI < -2	1 : 25	900

Based on Table 3 the following Table 4 is produced:

Table 4. Average losses from each class of drought severity vs frequency

$\bar{x}_{i,i+1}$ (k€)	$F(x_{i+1}) - F(x_i)$
20	0.333
150	0.142
400	0.083
900	0.040

The average (annualized) hazard due to droughts can be calculated from the above table as follows:

$$E(D) = \sum \left(\frac{x_i + x_{i+1}}{2} \right) \cdot \left(F(x_{i+1}) - F(x_i) \right) \text{ or} \tag{10}$$

$$E(D) = 6.66 + 21.3 + 33.2 + 36 = 97.16 \text{ k€/y}$$

To protect the area from the above hazard several measures were taken. For example, the existing irrigation system was put into operation only during the most sensitive period of the growing season by using water conveyed from outside of the affected area. The cost of the water transferred is covered by the state. By applying these measures, the following results concerning vulnerability are expected (Table 5).

Table 5. Average yield losses and expected vulnerability of the improved system for each class of drought severity

$\bar{x}_{i,i+1}$	$F(x_{i+1}) - F(x_i)$	$V(\bar{x}_{i,i+1})$
0	0.333	0
100	0.142	0.667
300	0.083	0.750
850	0.040	0.944

The vulnerability of the system is therefore reduced, compared to the vulnerability of 1 of the initial system. The vulnerability is presented for each level of $\bar{x}_{i,i+1}$ (column 3 of Table 5). In Fig. 2 the vulnerability of the initial and the improved systems is plotted against the severity of drought represented by RDI.

The average risk is therefore calculated for the improved system as:

$$R(D) = \sum \left\{ \bar{x}_{i,i+1} \cdot V(\bar{x}_{i,i+1}) \cdot f(\bar{x}_{i,i+1}) \right\}$$

$$= 0 + 14.2 + 24.9 + 34 = 73.1 \text{ k€/y}$$

Therefore due to the improvement of the system the risk is reduced from 97.16 to 73.1 k€/y or about 25%.

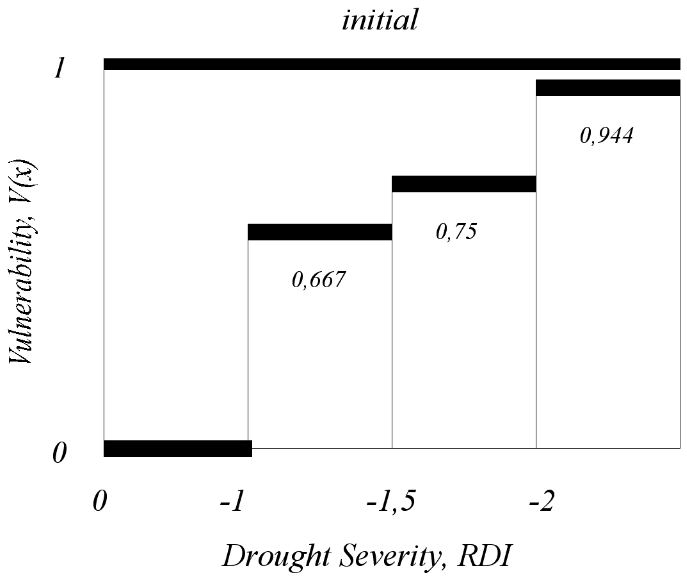

Fig. 2. Vulnerability of initial and improved system plotted against the drought index RDI.

Concluding remarks

An attempt to clarify some of the parameters associated with the assessment of hazard and risk due to natural phenomena was made. Particular emphasis was given to droughts which affect rainfed agricultural areas.

It was concluded that the most difficult task in the process of calculating risk is the assessment of vulnerability of the affected system. In regard to drought risk, the average (annualized) risk is proposed incorporating both the frequency of each class of drought severity (expressed by drought indices) and the consequences measured as loss in crop yield.

Although rainfed agriculture was used as a simplified example for calculating the average risk, irrigated agriculture inserts various difficulties for assessing vulnerability. Similar difficulties may be encountered in case the vulnerability of other systems affected by extreme natural phenomena is assessed. It is a challenge for researchers to investigate methodologies for assessing vulnerability of the various systems affected by droughts such as agricultural areas, municipalities, industry, tourism and environment.

Since natural phenomena may be of different magnitude and frequency for the future as compared with the events of the historical record some sort of modification in the proposed probabilistic methodology is required. That is, climatic changes could be introduced so that the calculated average risk is more representative of the future than of the past.

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Chapter 18. Application of the Drought Management Guidelines in Italy: The Simeto River Basin

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SUMMARY – The present report summarizes the results of the application of the proposed methodologies for Drought Identification and Characterization, Risk Analysis and Risk Management for Water Supply Systems to the Italian Case Study, namely the Simeto River Basin in Sicily. In particular, after a general description of the case study (Section 2), the results of the drought identification study, carried out by means of several indices and methods such as SPI, Palmer indices and run method, are presented (Section 3). The application of a methodology proposed for the assessment of the return periods of drought events identified on the historical annual precipitation series is also presented. In Section 4, after a general classification of drought mitigation measures, the drought mitigation measures historically adopted for the Simeto River Basin to reduce drought impacts in urban and agricultural sectors are described. Then, in Section 5, the methodology for risk analysis presented in Chapter 6 is applied to the Salso-Simeto water supply system, which is a part of the larger system of the Simeto river. In particular, a Montecarlo simulation of the system, making use of synthetically generated hydrological series and a water supply system simulation model, is carried out in order to assess both unconditional (long term) and conditional (short term) drought risk. Finally impact assessment on rainfed agriculture is presented.

Key words: Water supply system, characterization, risk analysis, shortage, conditional, unconditional, simulation.

The Simeto Basin

The Italian case-study of the Medroplan project is the Simeto River Basin (see Fig. 1), located in Eastern Sicily. The mean annual precipitation over the basin is about 600 mm. The climatic conditions are typical of a Mediterranean semi-arid region, with a moderately cold and rainy winter and a generally hot and dry summer.

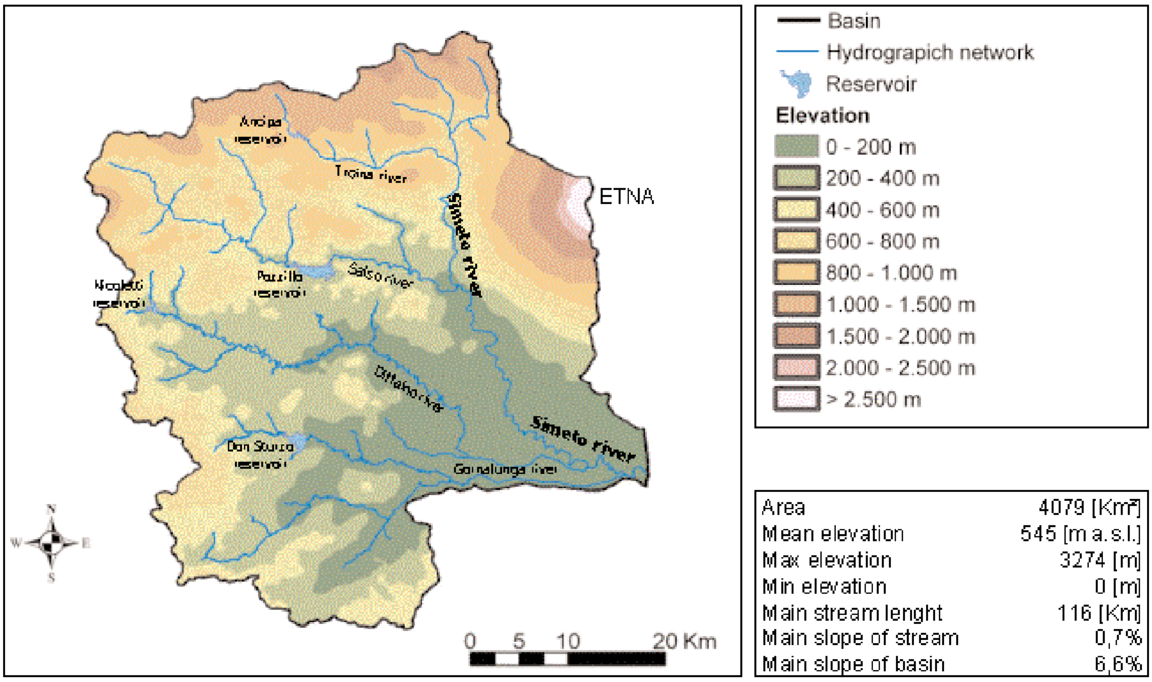


Fig. 1. The Simeto River Basin.

The basin includes various agricultural, municipal and industrial uses and is mainly supplied by a set of multipurpose plants for regulation and diversion of streamflows. As shown in Fig. 2, the current water supply system can be divided in two sub-systems: the Salso-Simeto system and the Dittaino-Gornalunga system.

The Salso-Simeto system has been built during the 50's. It includes two dams, Pozzillo on Salso River and Ancipa on Troina River, three intakes located on the Simeto River (S. Domenica, Contrasto and Ponte Barca), and five hydropower plants operated by the Electric Energy Agency (Enel). The Ancipa reservoir has a net design capacity of $27.8 \cdot 10^6$ m^3, which is currently limited, due to structural problems, to $9.35 \cdot 10^6$ m^3. A small portion of the its releases are used to supply several municipalities in central Sicily, whereas the remaining portion is used for hydropower generation and irrigation purposes. The Pozzillo reservoir, which is mainly devoted to irrigation, has a current storage capacity of $123 \cdot 10^6$ m^3. Most of the releases are routed for hydropower generation and irrigation of the main district of Catania Plain (irrigated area is about 18,000 ha), whose water conveyance and distribution network is operated and managed by the Land Reclamation Consortium no. 9 (LRC 9).

In addition, the Lentini reservoir is connected to the system via the Ponte Barca intake on Simeto River. It has been recently built in order meet the demands of the irrigation districts managed by LRC9 and LRC10 (Siracusa city) and industrial areas of Siracusa and Catania. It was designed for a net storage capacity of $127 \cdot 10^6$ m^3.

The Nicoletti and Don Sturzo reservoirs, in the Dittaino-Gornalunga system (Fig. 2), have been built during the 70's either for regulating streamflows and for irrigating the Dittaino valley. The Nicoletti reservoir has a storage capacity of $17.4 \cdot 10^6$ m^3, whereas the Don Sturzo reservoir has a storage capacity of $110 \cdot 10^6$ m^3. The Dittaino-Gornalunga water supply system is operated and managed by the Land Reclamation Consortium no. 7 of Caltagirone (LRC 7).

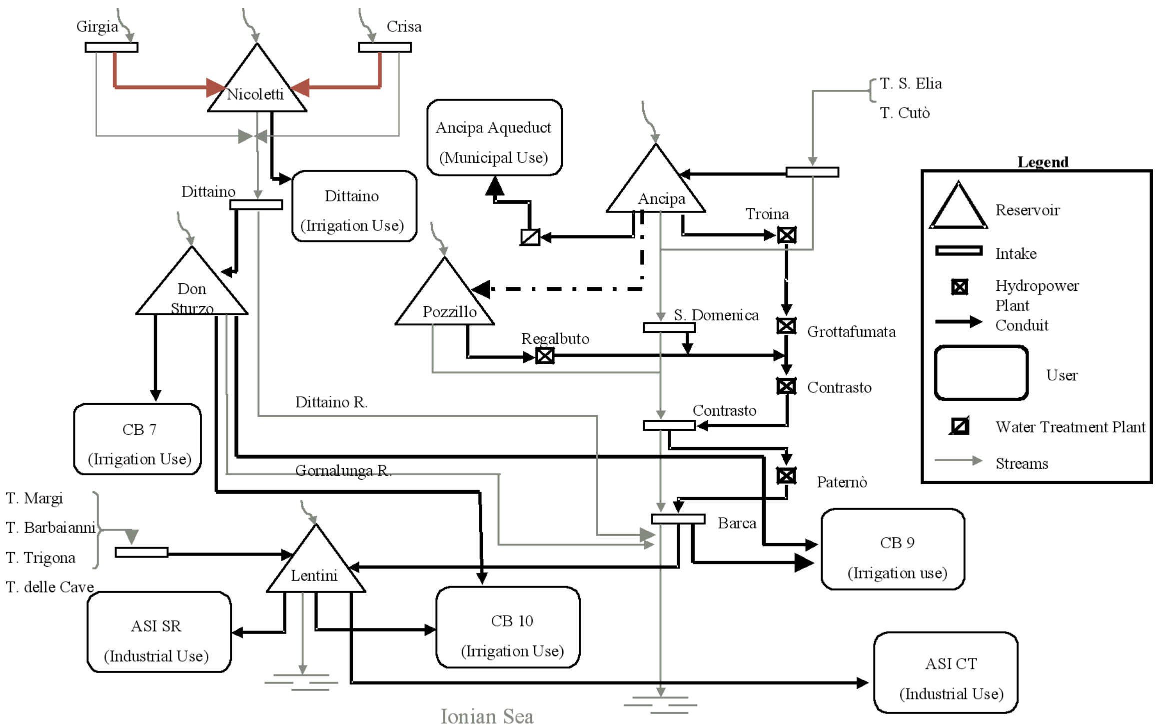


Fig. 2. The water supply system of the Simeto River Basin.

The main features of the reservoirs of the Simeto water supply system are summarized in Table 1.

Table 1. Reservoirs storage capacities, watersheds and annual average inflows of Simeto water supply system reservoirs

Reservoir	Surface (km^2)		Storage capacity (10^6 m^3)	Annual average inflows (10^6 m^3)
	Direct basin	Tributaries basins		
Ancipa	51	58	27.8 (9.3†)	52.8
Pozzillo	577	–	123	92.3
Lentini	16	1086 + 431	127	96.4
Don Sturzo	171	285	110	31.58
Nicoletti	49.5	13 + 42	17.4	22.73

† Operational constraint.

Available hydrological data include monthly series of precipitation at 22 rain gauges (from 1921), of temperature at 4 stations (from 1926) and streamflow at 10 hydrographic stations (from 1923). For the purpose of investigating the hydrological features of the basin, the whole basin has been divided in 9 sub-basins, which roughly coincide with sub-basins upstream of a diversion or of a reservoir or of a merging of two rivers. For each sub-basin, average seasonal precipitations, average mean temperatures and historical series of different drought indices have computed.

In order to promote Medroplan activities, stakeholders operating within the selected case-study have been invited to take part in the Risk Analysis Committee (RAC). In particular, besides the scientific experts in hydrology, hydraulic plants, water resources management, irrigation and agricultural economy from DICA-University of Catania, the RAC includes representatives from the following institutions:

(i) Land Reclamation Consortium no. 9 (Catania)

(ii) Agricultural Provincial Office (Enna, Catania, Siracusa)

(iii) National Electric Agency (ENEL)

(iv) Enna Optimal Territorial Unit (ATO, in charge of municipal supply)

(v) Regional Office for Water Emergency

(vi) Sicily Hydrographic Service

Drought identification and characterization

SPI

The SPI (McKee *et al.*, 1993) is one of the most widely applied tool for drought identification and monitoring. The dimensionless and standardized nature of the index allows to compare droughts among regions with different climates, as well as droughts occurring during different seasons of the year.

According to the commonly adopted classification (see Table 2), negative values of the index describe drought conditions, while positive values indicate wet conditions.

The SPI has been applied on the available monthly precipitation series aggregated at various time scales k, corresponding to the time intervals at which the different hydrological components are more sensitive to a significant reduction in precipitation. Also a similar procedure has been applied to the available streamflow series in order to obtain a Standardized Streamflow Index (SSI). SSI is an index, based on the same structure of SPI, by using monthly streamflow data. Figures 3 and 4 represent the time series respectively of the SPI and the SSI at Salso at Pozzillo reservoir. It can be observed that in both cases, the most critical droughts occurred between the end of the '80s and the beginning of the '90s, and during the last two years. Besides, droughts periods identified by the SSI look much severe and longer than those captured by the SPI.

Table 2. Wet and drought period classification according to the SPI index, provided by National Drought Mitigation Center (NDMC, http://www.ndmc.unl.edu)

Index value	Class
SPI ≥ 2.00	Extremely wet
1.50 ≤ SPI < 2.00	Very wet
1.00 ≤ SPI < 1.50	Moderately wet
-1.00 ≤ SPI < 1.00	Near normal
-1.50≤ SPI < -1.00	Moderate drought
-2.00 ≤ SPI < -1.50	Severe drought
SPI < -2.00	Extreme drought

Another application of the SPI is presented in Fig. 5. In this case, the time series of the SPI at k=12 months are represented for each sub-basins of Simeto reported in vertical axis according to a geographical order, namely from North to South. A general coincidence of dry and wet periods can be observed among the different sites, which confirms that the climatic conditions are rather homogeneous over the whole basin, with a few exceptions.

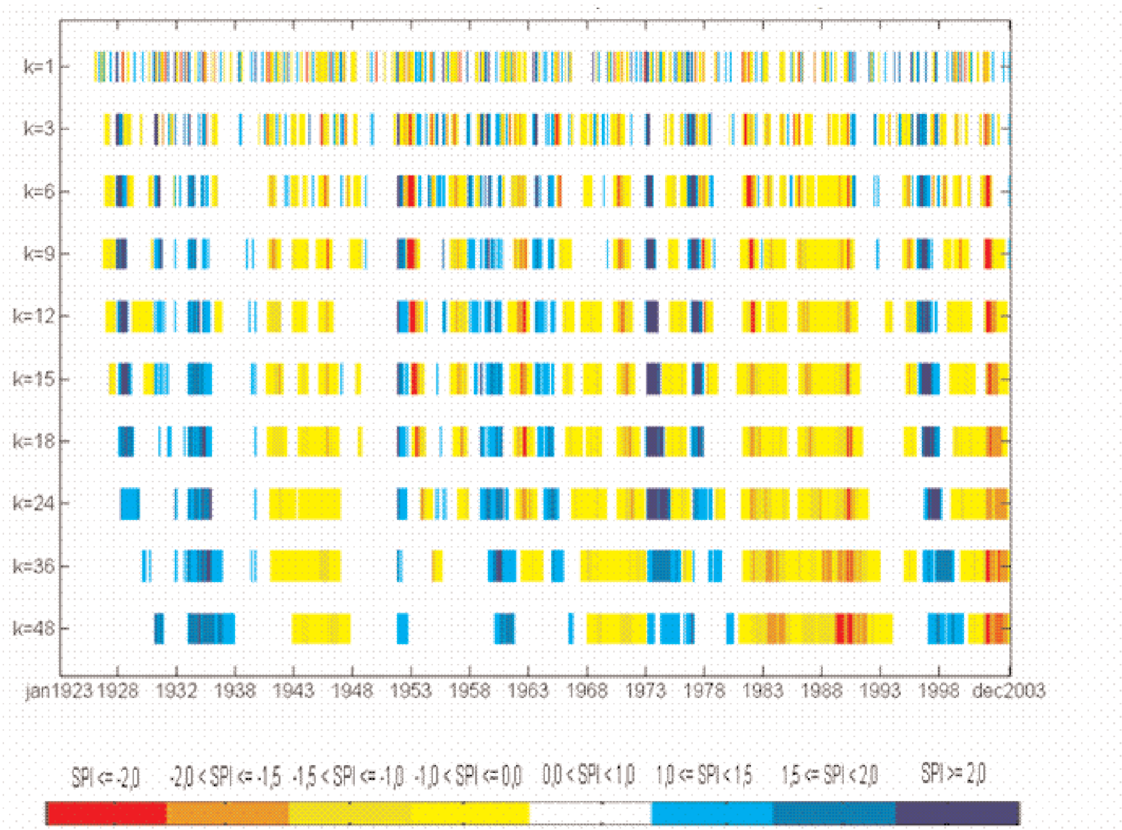


Fig. 3. Time series of the SPI for different time scale k of Salso at Pozzillo reservoir.

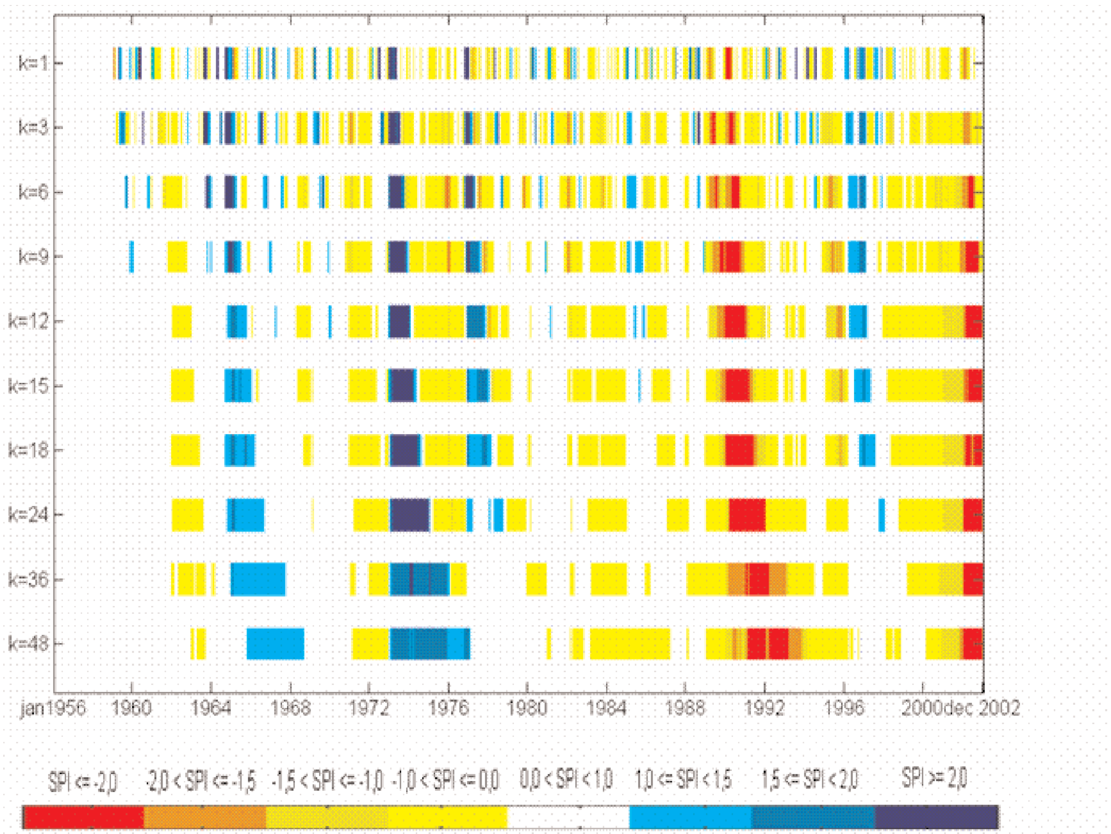


Fig. 4. Time series of the SSI fordifferent time scale k of Salso at Pozzillo reservoir inflows.

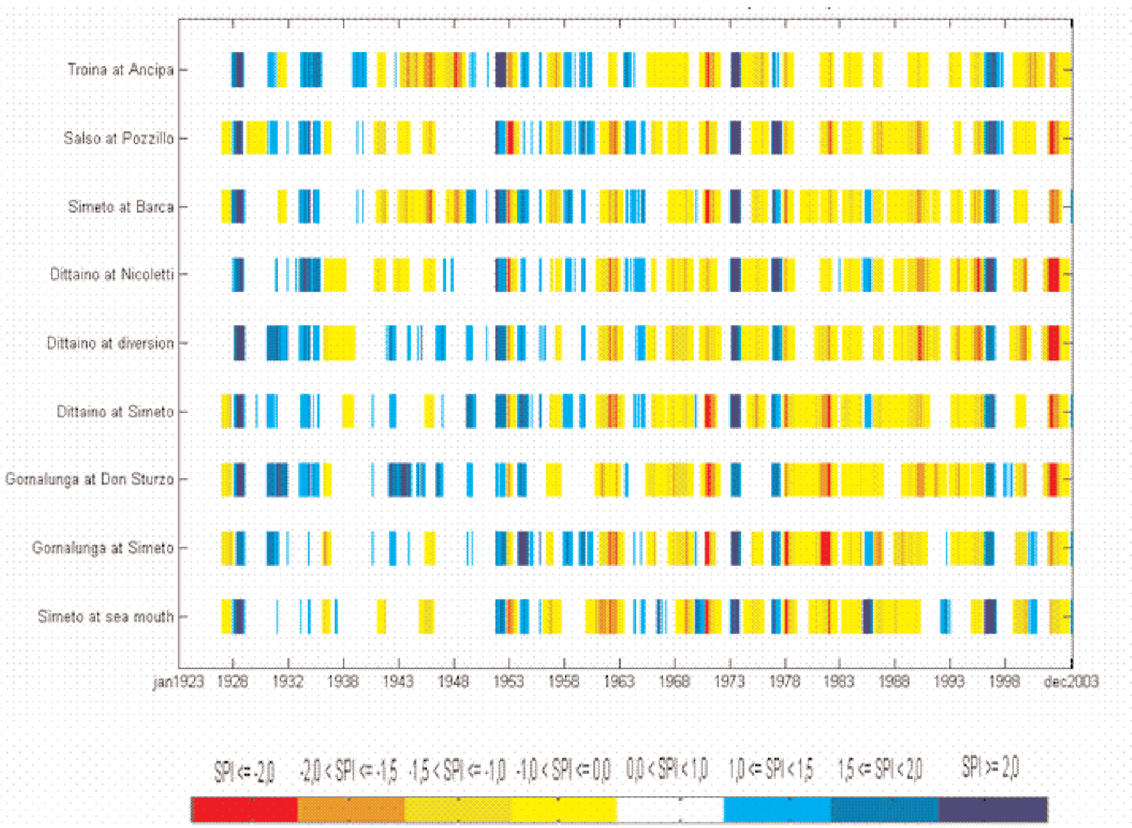


Fig. 5. Time series of the SPI over the sub-basins of Simeto (k=12 months).

PHDI Index

The Palmer Hydrological Drought Index (Palmer, 1965) is based on a water balance model between soil moisture supply and demand for a two layer soil on a monthly time scale. In order to evaluate such an index, precipitation and temperature series are required. Table 3 indicates the classification of dry and wet periods related to the Palmer Index.

Table 3. Wet and drought period classification according to the Palmer Index (PHDI)

PHDI	Class
<- 4	Most severe drought
- 4 to -3	Severe drought
- 3 to -2	Medium drought
- 2 to –1	Nearly drought
-1 to 1	Normal
1 to 2	Nearly wet
2 to 3	Medium wet
3 to 4	Severe wet
> 4	Most severe wet

In Fig. 6 the time series of the PHDI are represented for each sub-basins of Simeto. The results reported for the PHDI are generally in agreement with those presented in Fig. 7, although the PHDI seems to describe much longer and severe drought conditions.

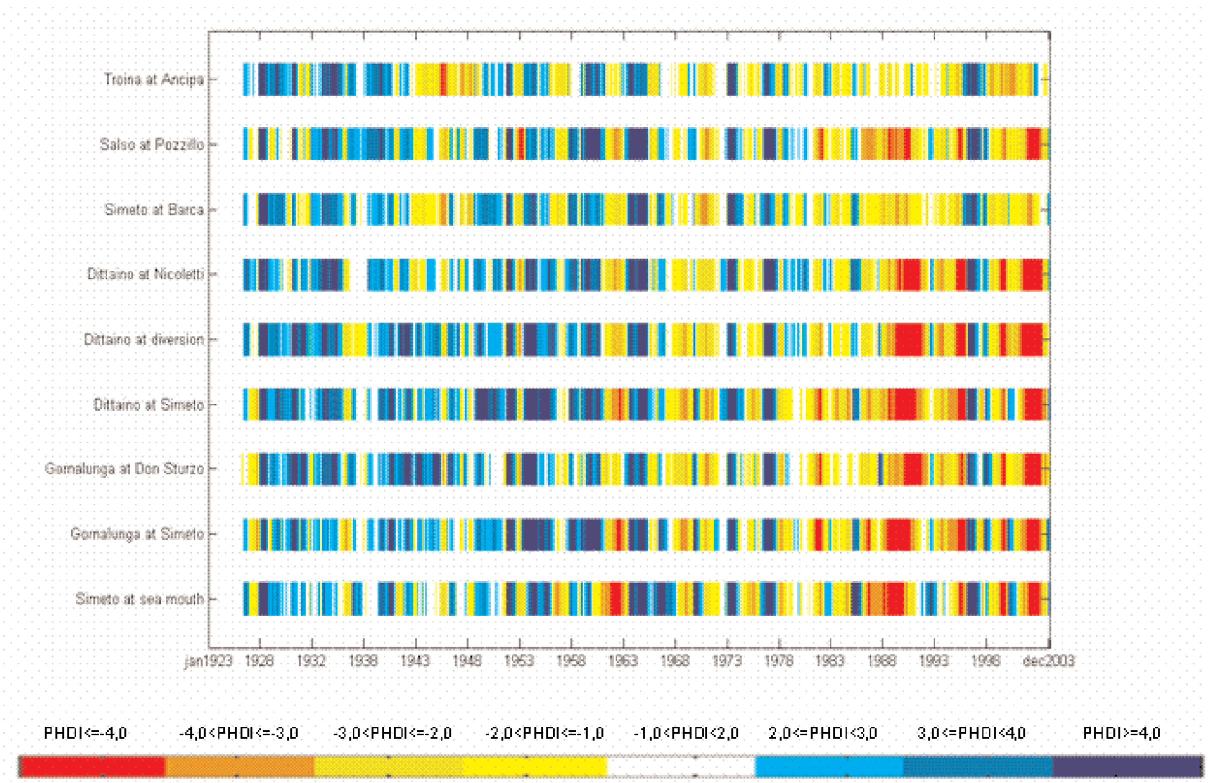


Fig. 6. Time series of the PHDI over the sub-basins of Simeto.

Run method

The run method (Yevjevich, 1967) allows an objective identification of drought periods and it can be applied for evaluating the statistical properties of drought. According to this method a drought period coincides with a "negative run", defined as a consecutive number of intervals where a selected hydrological variable remains below a chosen truncation level or threshold. For each drought event, the following characteristics can be derived:

(i) duration *L*, defined as the number of consecutive intervals where the variable remains below the threshold;

(ii) accumulated deficit *D*, defined as the sum of the negative deviations, extended to the whole drought duration;

(iii) intensity of drought *I*, defined as the ratio between accumulated deficit and duration.

The above analysis can be extended to the case of regional droughts, i.e. droughts which affect large regions, by considering several series of the variable of interest and selecting, besides the truncation level at each site, an additional threshold, which represents the value of the area affected by deficit above which a regional drought is considered to occur.

A possible application of the run method is illustrated in Figs 7 and 8, where respectively the time series of the percentage of deficit area and the areal deficit obtained by considering three different threshold levels $x_0 = x_m\text{-}a\cdot s$ at each site are shown. The most critical drought can be recognized by the fact that the whole basin is under drought condition independently of the considered threshold level.

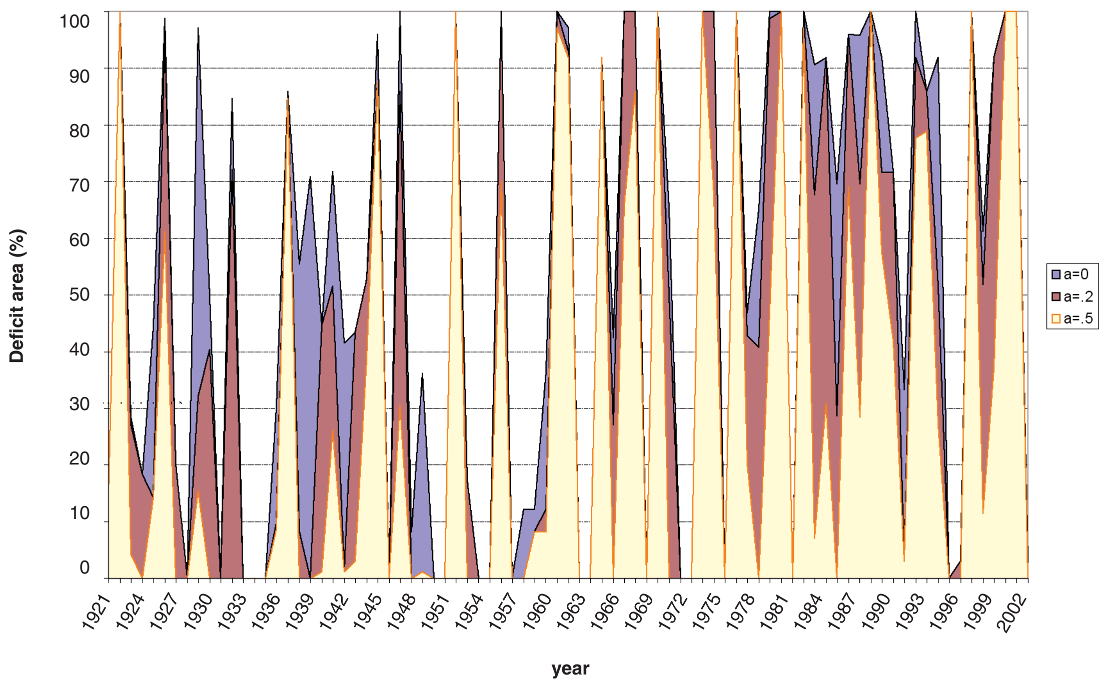


Fig. 7. Time series of the deficit area over Simeto Basin for different threshold levels.

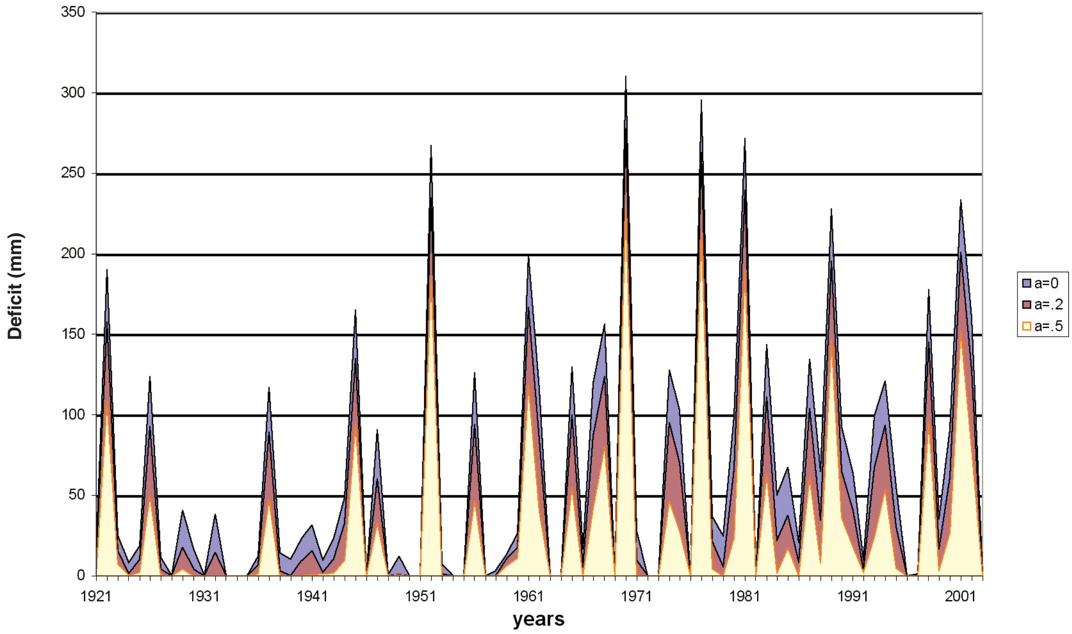


Fig. 8. Time series of the areal deficit over Simeto Basin for different threshold levels.

Assessment of drought return period

The return period of droughts can be defined as the expected value of elapsed time or interarrival time between occurrences of critical events (Shiau and Shen, 2001). With reference to the generic critical drought event identified on stationary (annual) and serially independent series, the return period can be written as:

$$T = \frac{1}{p_1(1-p_1)}\frac{1}{P[\mathrm{A}]}$$

where p_1 is the probability of observing a surplus (i.e. P[$h(i) \leq h_0$]) and P[A] is the occurrence probability of a drought event A.

The following cases have been applied to the case study:

1. Drought event A with duration L equal to l, i.e. A = {$L = l$ (l = 1, 2,...)};

2. Drought event A with duration L greater than or equal to l, i.e. A = {$L \geq l$ (l = 1, 2,...)};

3. Drought event E with cumulated deficit D greater than a specified quantity d, i.e. A = {$D > d$};

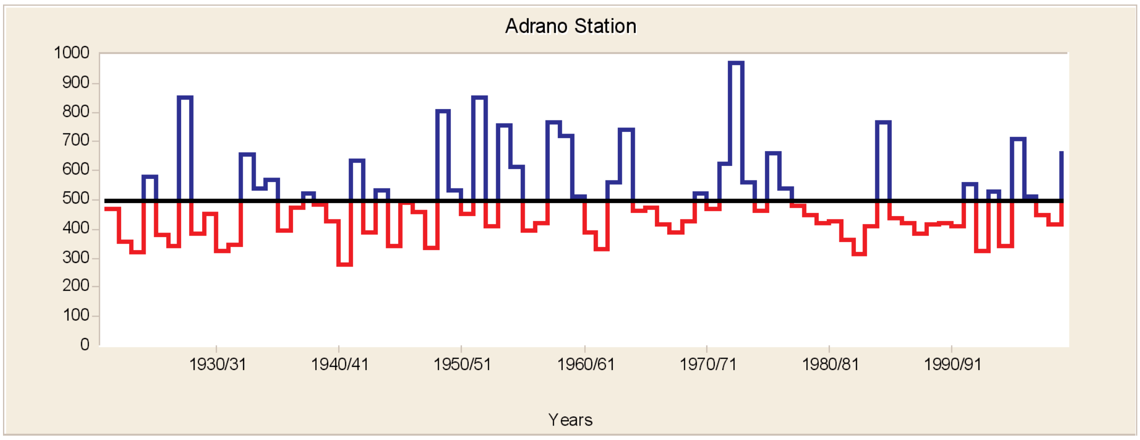
4. Drought event A with cumulated deficit D greater than a specified quantity d and duration L equal to l, i.e. A = {$D > d$ and $L = l$ (l_0 = 1, 2,...)};

5. Drought events A with cumulated deficit D greater than a specified quantity d and duration L greater than or equal to l, i.e. A = {$D > d$ and $L \geq l$ (l_0 = 1, 2,...)}.

The probability distributions of drought characteristics above considered can be derived based on the distribution of the underlying hydrological series and the threshold (Bonaccorso *et al.*, 2003; Cancelliere *et al.*, 2003; Salas *et al.*, 2005). In particular, the gamma distribution has been fitted to the precipitation series of the selected stations.

Such procedure has been implemented in the software for drought analysis REDIM, developed by DICA University of Catania. An example of the application of REDIM for at-site drought analysis at Adrano station is hereafter presented in Fig. 9.

Drought Identification – at site analysis



Station name: Adrano
Hydrological variable: Precipitation
Aggregation time scale: year

Initial month: September
From year: 1921 To: 2000
Threshold (Average 50%): 495,35 mm

Drought Characteristics

Number of drought periods: 19

N	Begin.	End	Durat. *l*	Accum. def *d*	Drought Int. *i*	Tr(L=*l*)	Tr(L≥ *l*)	Tr(D>*d*)	Tr (L=*l*,D>*d*)	Tr (L≥ *l*,D>*d*)
	[year]	[year]	[years]	[mm]	[mm/year]	[years]	[years]	[years]	[years]	[years]
1	1921	1923	3	342.06	114.02	30.05	25.69	18.06	78.40	22.13
2	1925	1926	2	271.71	135.85	16.20	13.85	12.69	65.32	13.89
3	1928	1931	4	469.41	117.35	55.74	47.66	34.82	160.58	44.30
4	1935	1936	2	125.71	62.85	16.20	13.85	6.36	20.12	8.26
5	1938	1940	3	303.06	101.02	30.05	25.69	14.84	59.43	19.36
6	1942	1942	1	105.75	105.75	8.73	7.47	5.83	20.95	5.76
7	1944	1947	4	355.91	88.98	55.74	47.66	19.38	84.31	31.77
8	1950	1950	1	41.75	41.75	8.73	7.47	4.52	10.47	4.37
9	1952	1952	1	88.35	88.35	8.73	7.47	5.41	16.86	5.30
10	1955	1956	2	176.31	88.15	16.20	13.85	8.01	27.39	9.52
11	1960	1961	2	273.11	136.55	16.20	13.85	12.78	66.30	13.97
12	1964	1968	5	312.27	62.45	103.39	88.41	15.54	110.27	49.24
13	1970	1970	1	25.15	25.15	8.73	7.47	4.27	9.37	4.16
14	1974	1974	1	33.15	33.15	8.73	7.47	4.39	9.83	4.25
15	1977	1983	7	604.17	86.31	355.79	304.21	70.89	464.39	190.01
16	1985	1990	6	490.12	81.69	191.80	163.99	38.81	239.56	99.62
17	1992	1992	1	168.55	168.55	8.73	7.47	7.72	51.02	7.86
18	1994	1994	1	156.15	156.15	8.73	7.47	7.29	42.37	7.38
19	1997	1998	2	127.71	63.85	16.20	13.85	6.41	20.31	8.30

General Characteristics of Drought Periods

	Values			Years of max characteristics	
	Mean	Min	Max	Begin.	End
Duration *l* [years]:	2.58	1	7	1977	1983
Cum. Def. *d* [mm]:	235.28	25.15	604.17	1977	1983
Drought Int. *i* [mm/year]:	92.52	25.15	168.55	1992	1992

Fig. 9. Drought identification – at site analysis – and characteristics. Adrano station. Results of the analysis with the REDIM software.

The first application concerns the run analysis with the derivation of drought return period. In particular, the figure illustrates drought events identified on the annual precipitation series, by fixing a threshold equal to the long term mean. It is worth observing that the considered time interval is the hydrological year, defined as the period during which the hydrological cycle takes place (conventionally starting in September for Sicily region). Thus, the period of observation is September 1921 – August 2000 (79 years).

Drought mitigation measures for the Simeto River Basin

The measures to be implemented to mitigate drought impacts can be classified in several ways (Rossi, 2000; Rossi, 2003). A first classification (Yevjevich *et al.*,1978) refers to three main categories: (i) water demand oriented measures, (ii) water supply oriented measures, and (iii) drought impacts oriented measures. In particular, the role of the three mentioned categories of drought mitigation measures is highlighted. It is apparent that the first two categories of measures, by increasing water supply or by reducing water demand, aim to reduce the risk of water shortage due to a drought event, while the third category is oriented to minimise the environmental, economic and social impacts of drought.

A second classification focuses on the type of response to drought problems, distinguishing between a *reactive* and a *proactive* approach. The *reactive* approach consists of measures adopted once a drought occurs and its impacts are perceived. It includes measures implemented during and after a drought period finalized to minimise the impacts of the drought itself. It can be indicated as the "crisis management" approach because it is not based on plans prepared in advance. The *proactive* approach consists of measures conceived and prepared according to a planning strategy (Yevjevich *et al.*, 1983), which are implemented before, during and after a drought event. In particular, measures undertaken before a drought event aim to reduce the vulnerability of the system to droughts and/or to improve drought preparedness.

Within the proactive approach, a further classification can be made according to the time horizon of the measures, namely:

(i) Long-term actions, oriented to reduce the vulnerability of water supply systems to droughts, i.e. to improve the reliability of each system to meet future demands under drought conditions by a set of appropriate structural and institutional measures.

(ii) Short-term actions, which try to face an incoming particular drought event within the existing framework of infrastructures and management policies.

Finally, for a more specific analysis of the various measures, the identification of the affected water use sector is necessary. Therefore, measures regarding at least 4 main categories, urban, agricultural, industrial, recreational and environmental, should also be distinguished. Thus, a specific drought mitigation measure can be classified according to a three-dimensional plot, as shown in Fig. 10.

Among the main actions undertaken at regional level, it is worth mentioning the activities carried out by the Regional Hydrographic Service of Sicily (UIR). In particular, a real time hydro-meteorological network, which also includes 40 gauges to measure the water level in the aquifers and 23 gauges to monitor the storage volumes in the most important Sicilian water supply reservoirs, has been developed in 2000.

Besides, an web-based monthly bulletin for drought monitoring has been developed by the Department of Civil and Environmental Engineering of Catania University for the Regional Hydrographic Service of Sicily, with the aim to provide the agencies in charge of water management in Sicily, with the information necessary in order to adopt appropriate drought mitigation measures and to improve the preparedness to drought of water supply systems. In Fig. 11, the home page of the drought bulletin for Sicily is shown.

Finally, campaigns for increasing population awareness to water saving, either at municipal level and regional level (see Fig. 12), have been promoted by the Sicilian Regional Government.

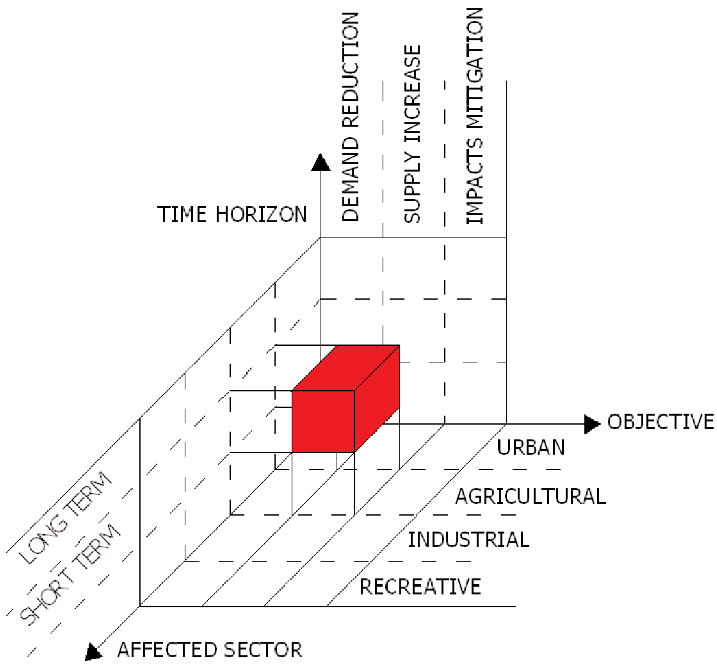


Fig. 10. 3D representation of drought mitigation measures.

Fig. 11. Home Page of the Drought Bulletin for Sicily.

Fig. 12. Water saving campaign sponsored by Sicily Region.

About past actions to mitigate drought impacts in urban sector, during the last drought events, the Sicilian Aqueduct Agency, who manages reservoirs and main aqueducts in Sicily, and the Municipal Water Supply Departments have implemented water supply increase measures, such as:

(i) diversion and reallocation of surface water resources (stored in Ancipa reservoir) normally devoted to irrigation use;

(ii) increase of groundwater withdrawal by wells for municipal use;

(iii) use of groundwater withdrawal by private wells (normally devoted to irrigation use).

With reference to the actions adopted to mitigate drought impacts in agriculture, it is possible to distinguish between actions undertaken by Land Reclamation Consortia and by private farmers.

The main actions undertaken for the Simeto River Basin by Land Reclamation Consortia of Catania, Caltagirone, Siracusa and Enna, have been:

(i) Priority allocation of available resources for agricultural use in Ancipa and Pozzillo reservoirs to perennial crops (i.e. citrus trees) and restriction of water supply to annual crops.

(ii) Maintenance of canal networks for reducing water losses.

(iii) Projects to transform the canal network (conveyance and distribution) in pipelines.

(iv) Projects of emergency pumping plants of surface water stored in Lentini reservoir (currently not operational).

(v) Projects of public ponds to improve operation of irrigation system.

The mitigation of damages in agriculture (rainfed) is principally linked to the dry-farming practices applied at farm level:

(i) Collecting and saving rainfall (deep labour in summer, minimum tillage and weeding during the crop cycle, optimal planting and sowing, etc.).

(ii) Using water efficiently (low water consuming crop species, fertilization adapted to the water availability, selection of varieties able to accomplish their cycle within the length of the climate growing period, etc.).

Private farmers have implemented two different types of mitigation measure to cope with drought in irrigated agriculture:

(i) Measures to increase preparedness to water scarcity

– Introduction of more efficient irrigation techniques (micro-irrigation);

– Construction of farm ponds (to be filled by water delivered by consortium before the irrigation season start and/or by private wells);

– Reduction of irrigated areas for annual crops.

(ii) Measures for coping with drought

– Deepening of existing wells;

– Construction of new wells;

– Water transfer by trucks (in extreme cases and for small farms).

Also financial benefits for the farmers related to the "*natural disaster declaration*" by the national or regional government are to be mentioned. It should be mentioned however that such benefits have been insufficient to cover the actual damages during the past drought periods (see Table 4).

Table 4. Past actions to mitigate impacts in agriculture at State/Regional level (financial measures to the farmers)

Province	Grant			Lan with 40% of grant			Five years Loan		
	Amount requested (Million €)	Amount provided (Million €)	%	Amount requested (Million €)	Amount provided (Million €)	%	Amount requested (Million €)	Amount provided (Million €)	%
Catania	50.378	0.743	1.47	No data					
Siracusa	34	4.282	12.6	14.818	3.611	24.3	9.915	2.512	25.3
Enna	31.169	6.475	21.8	14.20	5.364	37.6	12.640	2.163	17.19

Risk analysis for Salso-Simeto water supply system

System identification

The methodology for the unconditional and conditional risk assessment has been applied to the Salso-Simeto water supply system depicted in Fig. 13. In Fig. 14, the scheme of the system is shown from which it can be inferred that the system includes two dams, Pozzillo on Salso River and Ancipa on Troina River, and one intake located on the Simeto River. In addition, the Lentini reservoir is connected to the system via the Ponte Barca intake on Simeto River.

Fig. 13. Simeto River Basin at Barca diversion.

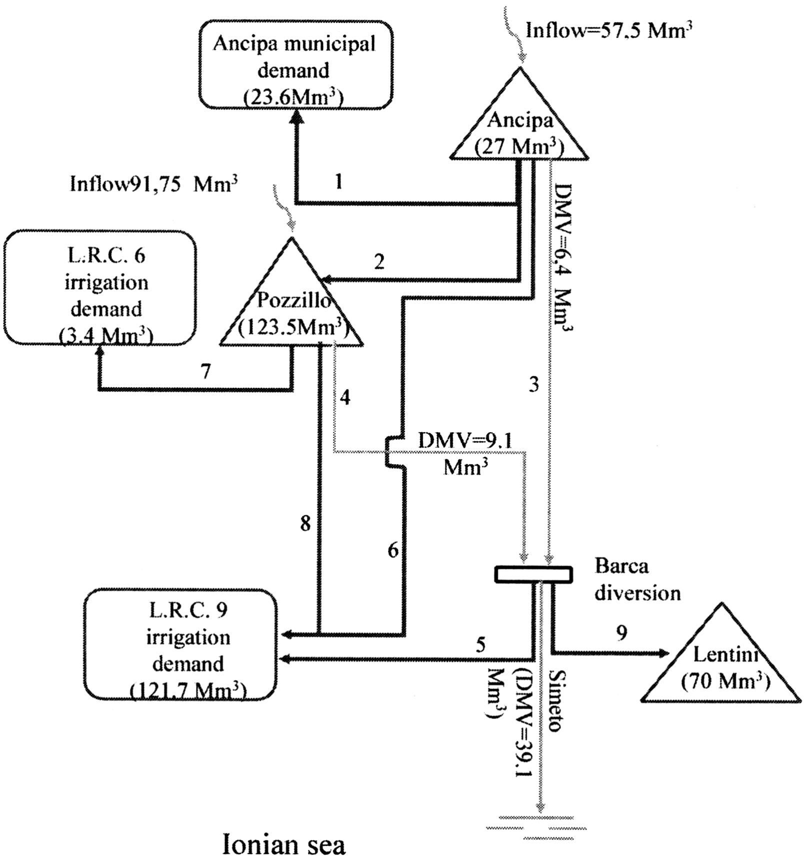


Fig. 14. Salso-Simeto water supply system.

Streamflow data include more than 40 years of reconstructed streamflows at Ancipa and Pozzillo reservoirs and Barca diversion (see Figs 15, 16 and 17). The annual demands have been estimated as follows: municipal demand from Ancipa reservoir 23.5 10^6 m^3/year (see Fig. 18), irrigation demands 121.4 10^6 m^3/year and 3.4 10^6 m^3/year for Catania Plain (LRC9) and Enna (LRC6) (see Fig. 19). Furthermore, instream flow requirements (indicated by DMV in Fig. 4) equal to 9.1, 6.4 and 39.1 10^6 m^3/year downstream of Pozzillo and Ancipa dams and Barca diversion respectively have also been considered.

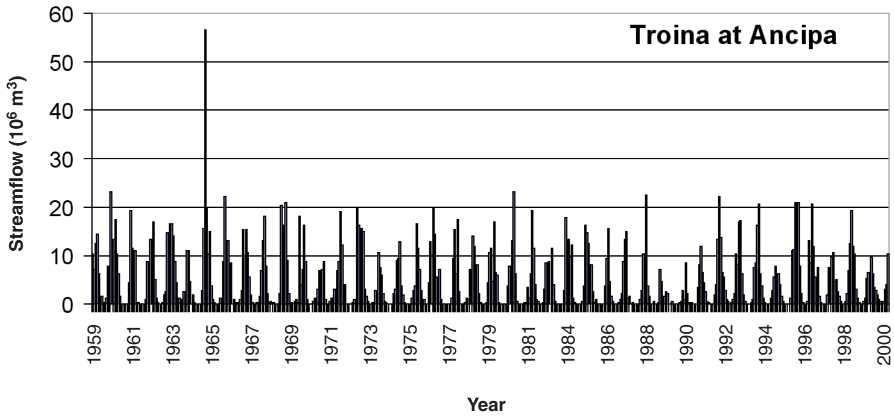


Fig. 15. Streamflows of Troina River at Ancipa.

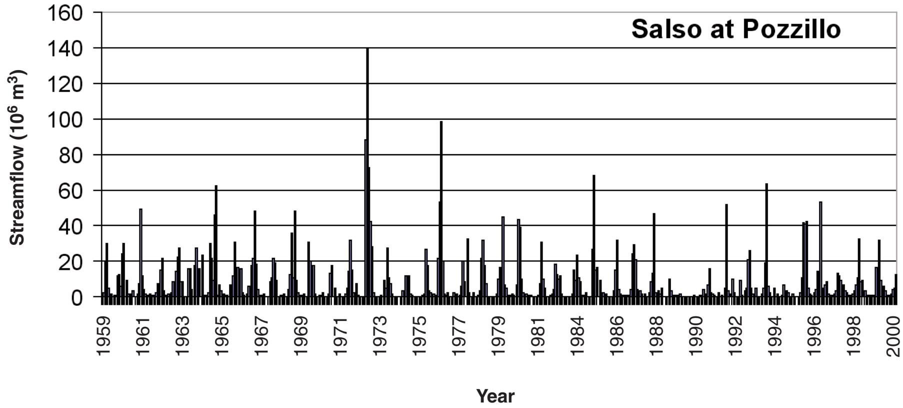


Fig. 16. Streamflows of Salso River at Pozzillo.

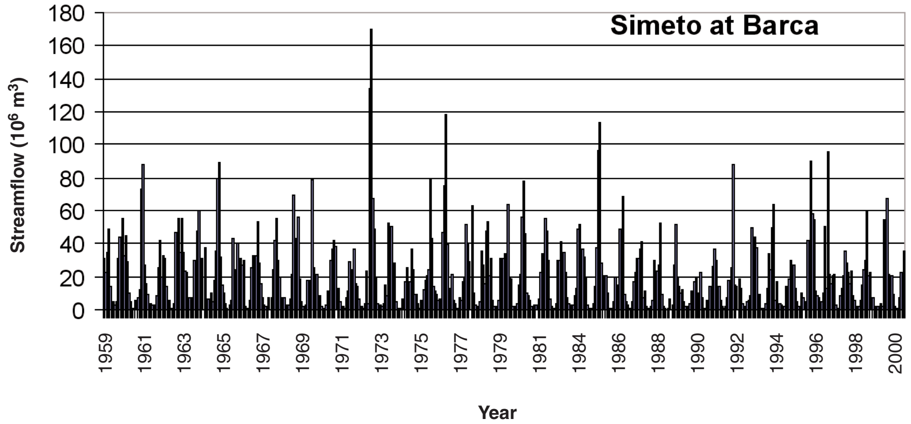


Fig. 17. Streamflows of Simeto River at Barca.

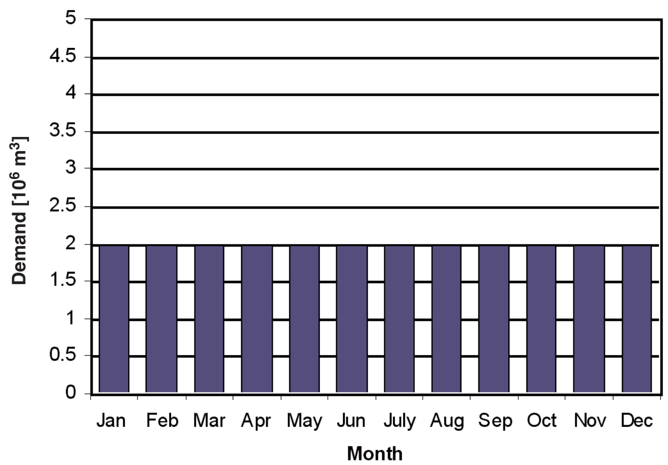


Fig. 18. Municipal demand (Ancipa Aqueduct).

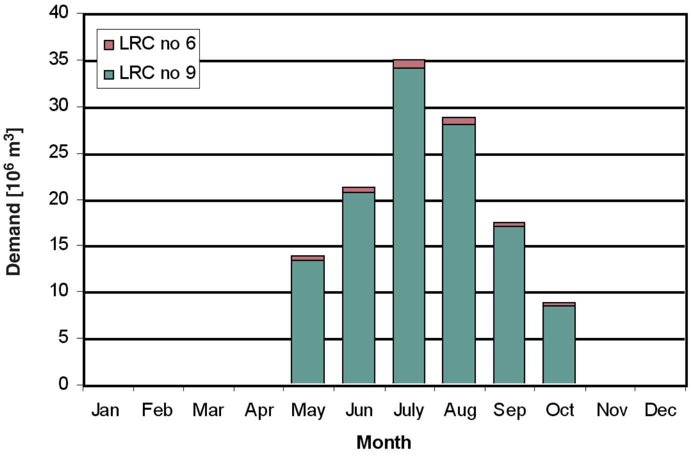


Fig. 19. Agricultural demand (LRC no. 6 and no. 9).

Stochastic generation of streamflow series

Generation of synthetic streamflow data has been performed by means of the sofware SAMS (Sveinsson *et al.*, 2003). In Fig. 20, the lag 0 monthly cross correlations between the three streamflow series (Pozzillo inflow, Ancipa inflow and Barca streamflows) are shown. From the figure, where the confidence limits under the no correlation hypothesis according to Anderson are shown by dashed lines (Salas, 1993), it can be inferred that in several months the series exhibit a significant cross correlation, while in other such cross correlation is negligible. Thus, the stochastic modeling of the three series must be carried out by means of a seasonal multivariate model, able to take into account the cross correlations, as well as their seasonal variability from month to month.

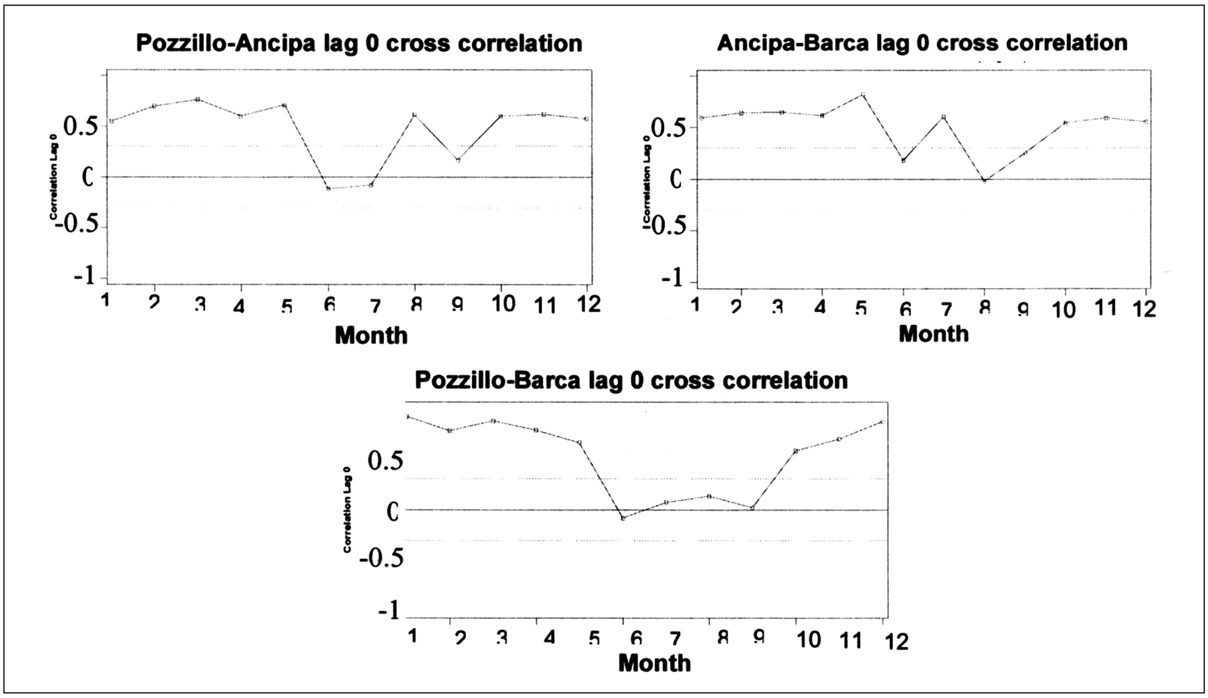


Fig. 20. Lag 0 monthly cross correlations between the three investigated series.

Then, the proposed generation scheme is as follows:

(i) First, annual and monthly data have been transformed, in order to reduce skewness, by means of the relation:

$$X_v = (X^*_{\upsilon} + a)^b$$

where X^*_{υ} is the original (untransformed) data at year *n*, X_{υ} is the transformed data, approximately normally distributed, and *a* and *b* are parameters, obtained by imposing the minimization of the skewness of the transformed data.

(ii) Then, annual data are generated by means of multivariate autoregressive model:

$$\underline{X}_v = \underline{GX^*}_{v-1} + \underline{L}\varepsilon_v$$

where $\underline{X}_{\upsilon}$ is the vector of the values at year υ at the three sites, *G* and *L* are square matrices (in our case 3x3), and ε_v is a vector of white noise;

(iii) Finally, monthly data are generated by means of a disaggregation scheme (Salas,1993):

$$\underline{Y}_v = \underline{AX}_v + \underline{B}\zeta_v + \underline{C}\ \underline{Y}_{v-1}$$

where $\underline{Y}_{\upsilon}$ is the vector of the monthly values at year υ at the three sites, $\underline{Y}_{v-1}$ is a vector of values from the previous year, ζ_v is a white noise vector and *A, B* and *C* are matrices of parameters.

In Table 5, the comparison between historical and generated annual statistics at the three sites is shown. It can be inferred that the model is able to preserve the main statistics of the observed series and therefore it is suitable for data generation.

Table 5. Comparison between statistics of historical and generated annual streamflow series at the three sites

	Pozzillo		Ancipa		Barca	
	Historical	Generated	Historical	Generated	Historical	Generated
Mean (10^6 m^3)	92.06	91.83	57.54	57.50	231.50	231.30
StDev (10^6 m^3)	56.57	53.78	18.99	18.91	68.59	66.98
CV	0.61	0.59	0.33	0.33	0.30	0.29
Skew	1.57	1.06	0.52	0.21	1.01	0.79
Min (10^6 m^3)	8.50	0.00	13.30	0.00	109.20	61.12
Max (10^6 m^3)	295.10	540.40	116.20	155.90	438.50	728.90
Acf(1)	-0.03	0.06	0.13	0.15	-0.08	0.01
Acf(2)	-0.16	-0.08	0.02	-0.06	-0.04	-0.05

Simulation of the system

Simulation of the system has been carried out by means of the software SIMDRO, specifically developed to simulate the implementation of drought mitigation measures according to a specified plan.

SIMDRO simulates the system through a node-link network. Sources and demands are represented by numbered nodes whereas system connections are represented by links characterized by origin node (source) and final node (source or demand).

System configuration is defined specifying in a input ASCII file number of sources (reservoirs, diversions, wells), number of demands, number and type of links (source to source or source to demand connection). Each node representing a reservoir has to be defined also in terms of maximum storage capacity, dead storage and initial stored volume. Coefficients of storage-area relationships (assumed well represented by a law of the type y = *a* + *b*x + *c*x^2 with y = area and x = storage) and monthly evaporations has to be defined as well.

Hydrological inputs to the system are managed by means of inflow-nodes (not coincident with source nodes and characterized by a different numeration) associated with hydrological series through an inflow name linked to an external file containing the data. These files can be supplied both in a free text format or in a tabular form. Each source node has to be associated with its inflow node otherwise the source will present a null input.

In order to take into account diversion to dams, for each inflow node it is possible to define a minimum volume Q_{min} and a utilization coefficient c_{ut}. Under the minimum volume Q_{min} input to the source node is considered null whereas c_{ut} is used to take into account the effective water that can be diverted at the source node related to its technical features.

Demands have to be defined in terms of their yearly amount and monthly pattern.

Simulation of the system is carried out in a monthly timescale respecting for each reservoir node the following mass-balance equation:

$$V_{t+1} = V_t + I_t - E_t - R_t - Sf_t \pm Tr_t$$

Where:

– t is the current step defined as [$t = \tau + 12 * (\upsilon - 1)$ with $1 \leq \tau \leq 12$ month of the υ year;

– V_t is the stored volume at the beginning of the month t;

– I_t is the net streamflow to the reservoir at month t;

– E_t is the evaporation at month t;

– R_t is the release at month t;

– Sf_t is the spill at month t occurring when volume V_{t+1} is greater than the maximum capacity of reservoir;

– Tr_t is the transfer between two sources at month t;

In addition the constraints, such as minimum and maximum storages, are implemented.

Net streamflow to reservoirs is computed as the difference between the total inflow from direct basin and from linked basins (expressed as a function of utilization coefficient c_{ut} and minimum volume Q_{min}) and an in-stream ecological releases. In normal conditions, if total inflows to a given reservoir for a particular month is less or equal than in-stream ecological requirements no net runoff will be available at that particular reservoir.

Monthly evaporation losses are computed considering monthly evaporation heights times an average area function of the areas obtained by the storage-area relationship for the beginning and the end of the current timestep. Due to the fact that stored volume at the end of the timestep is unknown an iterative procedure till convergence is carried out.

One of the most important features of SIMDRO is that it is specifically oriented at the implementation of drought mitigation measures. In particular the software is able to simulate the system behaving differently in dependence of different hydrological states to which correspond different possible drought mitigation measures defined by the user.

Three different hydrological states namely normal, alert and alarm can be defined by the user as a function of the available storage in reservoirs as well as of the expected flows.

Drought mitigation measures for each hydrological state are triggered when the total volume stored in the system is not enough to meet the total demand of the next dry season computed as a weighted (c_c, c_{ir} and c_{in}) sum of different demands (municipal *Dc,* irrigational *Dir,* industrial *Din*). Such total demand Dr_t is computed for each month of the dry season as sum of a percentage of demands of the next *k* months. Water demand reduction levels change in correspondence of municipal, irrigation and industrial demands and *k* is a function of the current month of the dry season in a way that makes easy to take into account demands for the months that come before the beginning of water year (i.e. October):

$$Dr_t = \sum_{m=t+1}^{t+k(\tau)} \left(c_c Dc_m + c_{ir} Dir_m + c_{in} Din_m \right)$$

Water availability in the system ($Disp_t$) is assumed equal to the sum of the volumes stored on reservoirs plus net runoffs for current time step *t* at reservoirs and runoffs with a fixed non-exceedence probability for the *k* following months.

$$Disp_t = \sum_{f=1}^{z} \left(I_{tf} + V_{tf} \right) + \sum_{t=t+1}^{t+k(\tau)} \sum_{f=1}^{z} I_{tf}(P)$$

If in a given month water availability is less than the trigger defined for the hydrological state characterized by normal conditions the system will switch from normal condition to alert conditions behaving as defined previously by the user making effective the implemented drought mitigation measures. The measures can consist in demand rationing, release reduction to the water demand according to different reduction levels for each type of demand, fulfilment of municipal demand before other uses, etc. The aim is to impose small deficits in the present in order to reduce the risk of larger deficits in the future.

If in a given month water availability is less than the trigger defined for the hydrological state characterized by alert conditions the system will switch from alert condition to alarm conditions again behaving as defined previously by the user for this particular condition implementing stricter drought mitigation measures consisting for example in breaking the constraints related to the minimum storage on reservoirs and/or relaxing instream flow requirements.

The system will remain in alert or alarm conditions performing in accordance with the drought mitigation measures specified for the particular condition (alert or alarm) for a period of time defined formerly by the user. At the end of this pre-defined period SIMDRO will compare the water availability in the system with the predefined thresholds for the hydrological states. If water availability is more than the threshold defined for normal condition it will switch automatically to this condition otherwise it will continue to perform in alert or alarm conditions until water availability is above the threshold defined for normal conditions.

The drought mitigation measures to be set by the user varying from normal to alert and alarm conditions are listed below:

(i) priority of demands;

(ii) priority of sources to meet a specified demand;

(iii) maximum release in a given month;

(iv) maximum in-stream ecological release for a given month;

(v) minimum stored volume on reservoirs under which not consider low priority demands; and

(vi) demands and their monthly distribution.

In the italian case study the simulation of the system in normal conditions has been performed according to the following operating rules:

(i) Target storages are imposed at Pozzillo and Ancipa reservoir, such that no water is released if the stored volume is below the target, with some exceptions. In Fig. 21, the monthly target storages at Pozzillo and Ancipa are shown.

(ii) Municipal demand has the highest priority over the other demands and up to a percentage equal to 90% is not affected by target storages (i.e., 90% of the demand will be released regardless of the target storages).

(iii) A water transfer of up to 8 10^6 m^3/month from Ancipa to Pozzillo is activated during the winter months if the volume stored in Ancipa is greater than 85% of net storage (24 10^6 m^3).

(iv) Instream flow requirements are released from the reservoirs and the diversion, unless the upstream inflow is less. In this case, the whole streamflow is released.

(v) During the winter months, a water transfer from Barca to Lentini is activated up to 11.7 10^6 m^3.

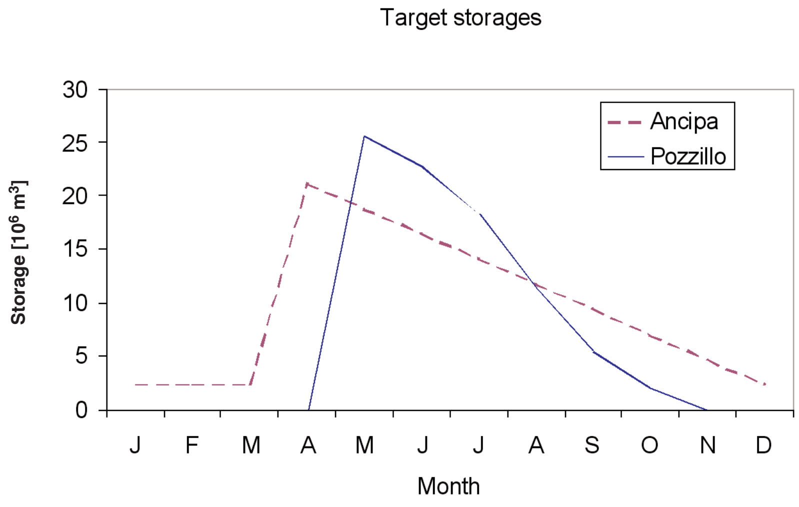


Fig. 21. Target storages at Pozzillo and Ancipa reservoirs.

Alert and alarm conditions are activated by comparing the total storage in Pozzillo and Ancipa with triggering levels, shown in Fig. 22. In particular the following measures are adopted, according to the conditions:

Alert conditions

– Relax target storage requirement for municipal
– Restrictions on irrigation
– No irrigation release from Ancipa

Alarm conditions

– As Alert + relax instream flow requirement

Fig. 22. Triggering levels for normal, alert and alarm conditions.

Unconditional risk analysis

Unconditional risk assessment of the Salso-Simeto water supply system has been carried out through two sets of simulations. In the first case, no mitigation measures have been considered, i.e. the system has been assumed to be always in normal conditions. In the second case mitigation measures have been activated as mentioned previously. Simulations have been carried out with reference to 500 generated series with the same length of the historical one (42 years).

In Table 6 and Table 7, the performance indices obtained by simulating the system using the generated series are shown, with reference to the two main water uses of the system, Enna municipalities and LRC 9 irrigation respectively. From each table, the comparison between the system performances with or without mitigation measures can be inferred.

Table 6. Performance indices for municipal use. Simulation on generated series, Enna Municipalities

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
No mitigation measures	96.8	97.4	4.0	2.0	12.9	47.7
Mitigation measures	88.1	96.9	3.2	1.0	9.5	21.1

Table 7. Performance indices for irrigation use. Simulation on generated series, LRC9 irrigation

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
No mitigation measures	71.4	81.9	3.1	34.1	104.0	7264
Mitigation measures	73.0	82.9	3.0	33.2	98.6	5920

In particular, with reference to the municipal supply, both temporal and volumetric reliability show a reduction due to the mitigation measures of about 9% for temporal reliability and less than 1% for volumetric reliability. The reduction in the just mentioned indices is fully balanced by the gain of about 20% for the average shortage period length index (from 4.0 to 3.2 months), 50% for the maximum monthly shortage index (from 2.0 to 1.0 10^6 m^3), 26% for the maximum annual shortage index (from 12.9 to 9.5 10^6 m^3) and about 56% for the sum of squared shortage index (from 47.7 to 21.1 10^6 m^3). Better values of the latter performance indices have to be ascribed to the implementation of mitigation measures such as restrictions on irrigation and no irrigation release from Ancipa.

Table 7 shows that basically average shortage period length and maximum monthly shortage indices are not affected by the implementation of the drought mitigation measures while temporal and volumetric reliability show very slight increase, on the contrary maximum annual shortage and sum of squared shortage indices show increases (5% for the first and about 18% for the latter) likely due to the relaxation of the target storage requirements for municipal implemented as mitigation measure both in alert and alarm conditions that makes more water available for irrigation use.

Figure 23 shows monthly frequencies of shortages for Enna municipalities as results of the simulation on generated series without mitigation measures. In this case shortages of more than 75% of the municipal demands appear for the whole period within March to August with probability of about 0.05 with a peak for April of about 0.1 but there are almost no shortages for the period within September to February.

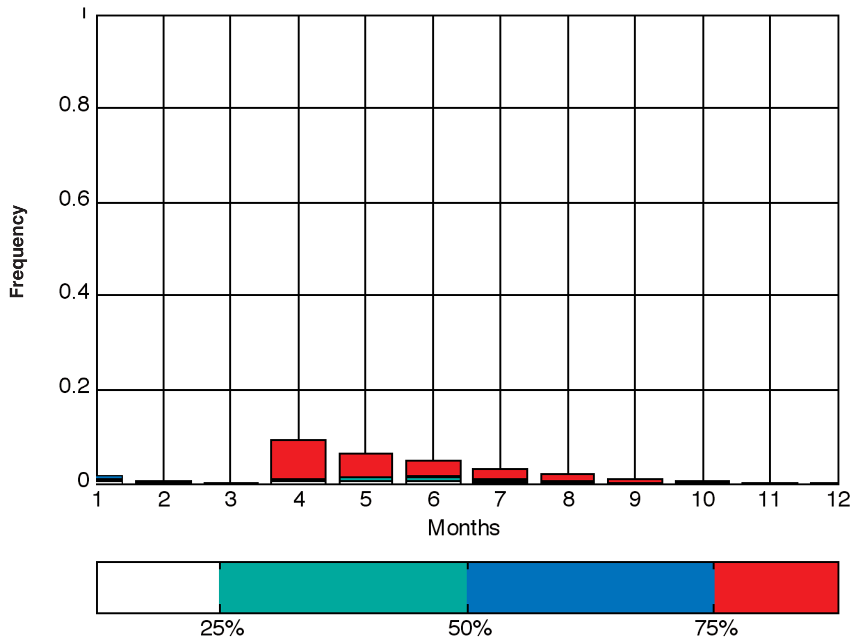


Fig. 23. Monthly frequencies of shortages for Enna municipalities (simulation without mitigation measures).

Figure 24. shows the same type of results of Fig. 23 but for the simulation implementing drought mitigation measures triggered by the defined hydrological states. The occurrence probabilities of shortages in the period within March to August is increased in comparison with the simulation without mitigation measures (on average 0.1 with a peak for August of about 0.3) but the entity of the shortages is reduced to the class of shortages less or equal than 50% of the municipal demand. The period within September to February shows shortages belonging to the class of less than 25% and only occasionally less than 50% of the municipal demand while almost no shortages in the simulation without mitigation measures appeared.

As expected the implementation of mitigation measures produces more frequent but slighter shortages making a given drought event more tolerable for the particular demand.

Figure 25 and Fig. 26 show the frequencies of shortages for LRC9 irrigation demand, presenting the same kind of behavior obtained for the municipal demand. Implementation of mitigation measures produces almost the same monthly occurrence probabilities of shortages of the simulation without mitigation measures but decreasing the class of shortage. For almost the entire irrigation season, indeed, Fig. 25 shows shortages also belonging to the class of shortages greater than 75% of irrigation demand while Fig. 26 shows less occurrence probability of shortages belonging to this class. Globally implementing mitigation measures helps to reduce the amount of shortages during the irrigation season.

Figures 27 and 28 show sample frequencies of monthly shortages for the municipal demand as result of simulations using generated series with and without mitigation measures. As depicted in Fig. 27 simulations without mitigation measures produce almost the same probability for shortages of large or small entity whereas Fig. 28 shows that, implementing mitigation measures, monthly shortages of more than 50% of municipal demand are very unlikely even if shortages of smaller entity are more frequent than the case without mitigation measures.

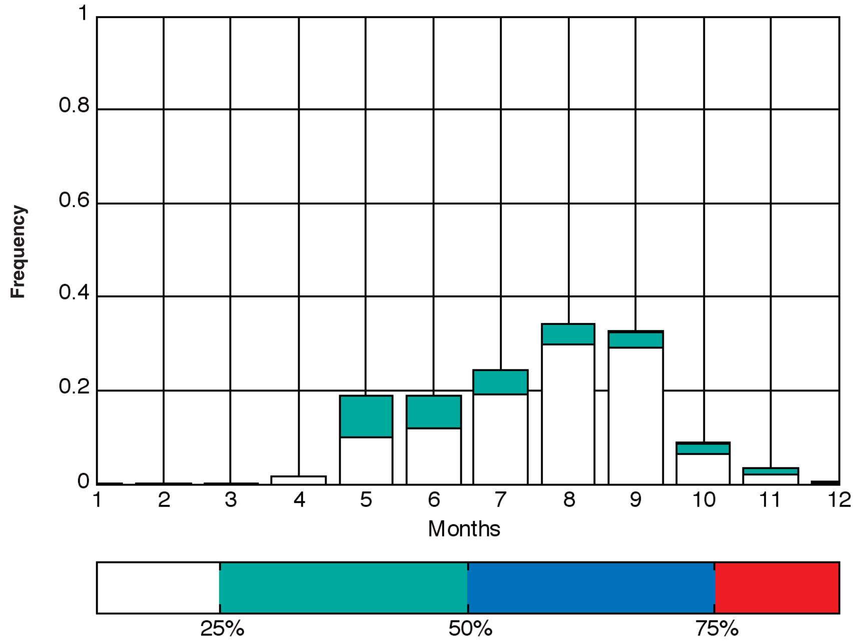


Fig. 24. Monthly frequencies of shortages for Enna municipalities (simulation with mitigation measures).

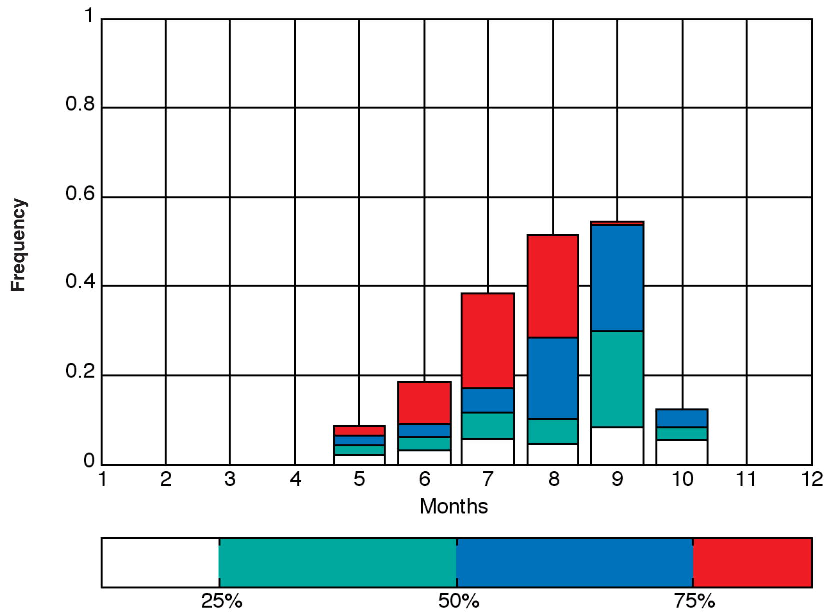


Fig. 25. Monthly frequencies of shortages for LRC9 irrigation demand (simulation without mitigation measures).

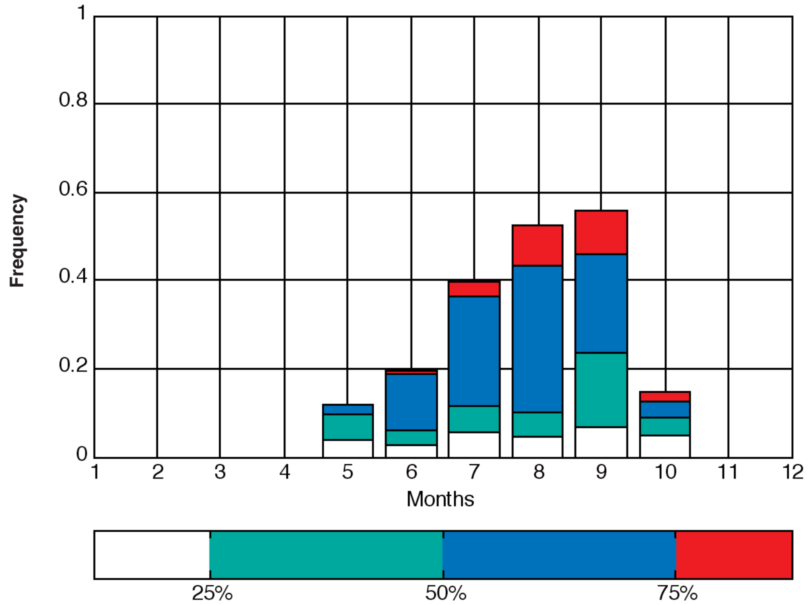


Fig. 26. Monthly frequencies of shortages for LRC9 irrigation demand (simulation with mitigation measures).

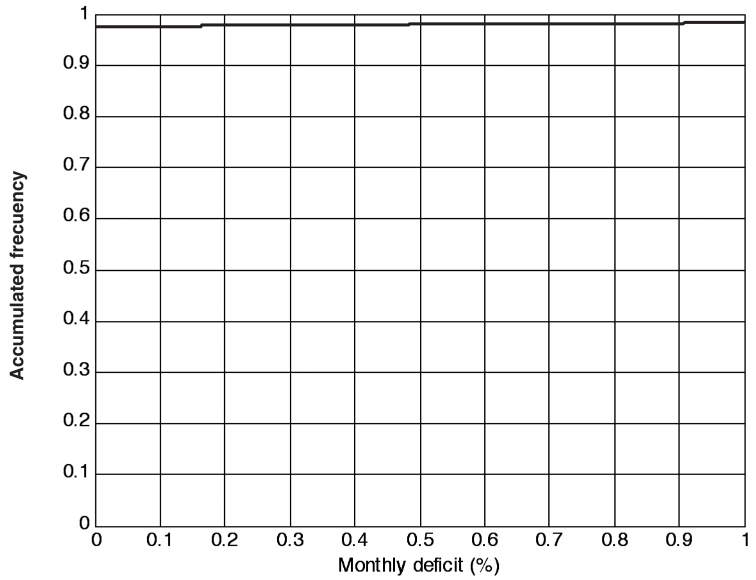


Fig. 27. Sample frequencies of monthly shortages for municipal use (simulation without mitigation measures).

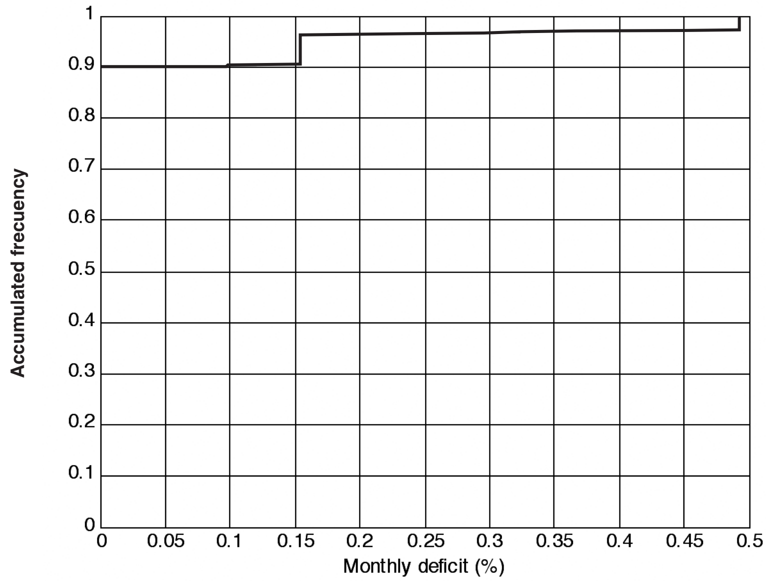


Fig. 28. Sample frequencies of monthly shortages for municipal use (simulation with mitigation measures).

Sample frequencies of monthly shortages for irrigation demand (LR9) reported in Fig. 29 and Fig. 30 respectively for simulations without and with mitigation measures show almost the same pattern except for a step for shortages of about 67% of irrigation demand that goes from a non exceedence probability of about 0.91 to 0.97 for the case with mitigation measures. Again implementation of mitigation measures has reduced the occurrence of large shortages leaving substantially unchanged non exceedence probabilities of smaller shortages.

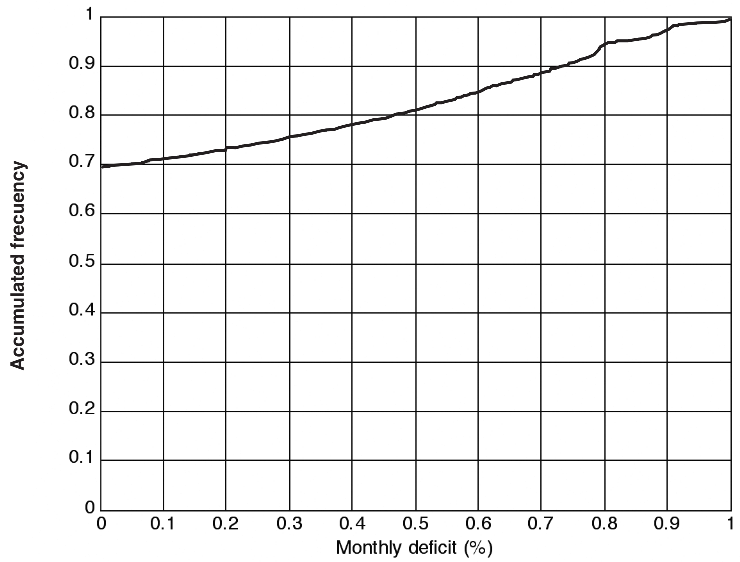


Fig. 29. Sample frequencies of monthly shortages for irrigation demand (simulation without mitigation measures).

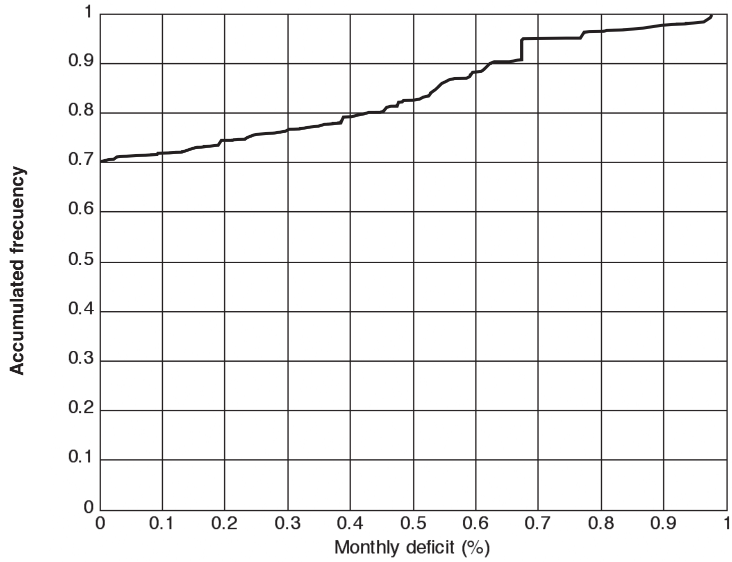


Fig. 30. Sample frequencies of monthly shortages for irrigation demand (simulation with mitigation measures).

The two curves of Fig. 31 show return period of annual shortages in municipal demand for simulations performed with and without mitigation measures. The curves are very close to each other for shortages less than 30% of municipal annual demand then start to depart from the same pattern showing, for example, differences of about 33% (from about 140 to about 210 return period years) for shortages of 50% of the municipal demand. The curves show a more than linear direct relationship between percentage of shortage and return period that becomes more relevant for the simulations with mitigation measures.

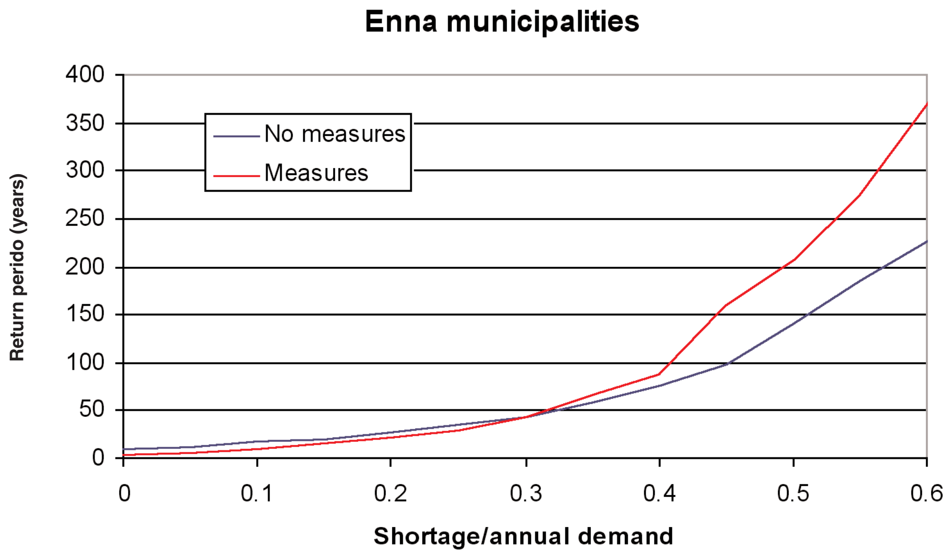


Fig. 31. Comparison between return period of annual shortages for municipal use simulating without or with mitigation measures.

Conditional risk analysis

Conditional risk assessment of the Salso-Simeto water supply system has been carried out by means of 500 synthetically generated series of 36 months starting from the initial condition that the system presented in correspondence of March 1989.

This particular condition has been chosen as consequence of the analysis performed over the whole available historic period. The historic simulation, indeed, shows that a significant period of drought on LR9, LR6 and Enna municipalities demands started in 1989 as depicted in Fig. 32.

In order to perform the conditional risk assessment and to verify the goodness of the proposed mitigation measures, four different management criteria have been used. The first criterion considers the system managed as it was in *normal condition*, i.e. no activation of mitigation measures is implemented regardless the actual state of the system. The second and the third management criteria consider always the system managed respectively in *alert* and in *alarm* condition. The forth simulate the system following a possible drought mitigation plan providing triggers based on the actual volumes stored on the reservoirs of the system to activate the different state condition and the relative mitigation measures (see Fig. 22).

Shows the probability of shortage in municipal use for 36 months ahead starting by the condition of the system of March 1989 for the four above mentioned management criteria. From the figure can be inferred that if the system is managed following the policy typical of *normal* condition greater and more frequent shortage appear respect to those obtained in the case of management criteria for *alert* and *alarm* conditions.

Figure 34 shows the probability of shortage on irrigation demand for 36 months ahead starting by the condition of the system of March 1989. Better results obtained for municipal demand respect to those obtained on irrigational varying management conditions are due to the fact that mitigation measures are particularly devoted to the satisfaction of municipal demand as required by the law. In particular, during alert conditions, the absence of irrigation releases from Ancipa reservoir to the Land Reclamation Consortium 9 makes more water available for municipal demand. Similar considerations can be drawn for the alarm conditions case. On the contrary mitigation measures activation gives results not as good for irrigation demand as shown by Fig. 34.

Goodness of chosen mitigation measures is confirmed by the general reduction of the probability to have deficits during the 36 months of the future under investigation and from the fact that in general the probability to have large deficits is decreased.

The analysis done "forcing" the system in a particular operational condition (normal, alert or alarm) is useful to confirm correctness of the chosen mitigation measures. However a real management of the system should consider the possibility to switch between the different operational conditions.

To simulate the real behavior of water managers it’s necessary to consider the simulation with triggers to activate the different operational conditions.

Results obtained by operating with triggering levels are better than those obtained by the simulation of the system always in normal condition representing a good trade-off between a management that doesn’t consider any mitigation measure and a continuous management in alert or alarm conditions. Indeed, the overall probability of deficits and their amount is less for both demands if the system is operated with triggering levels activating mitigation measures based on the provide thresholds.

The following Tables 8, 9, 10 and 11 report performance indices of the system calculated for the simulations in the three operational conditions and for simulations with triggering levels. All indices, calculated as mean of indices obtained for each one of the 500 simulation done, are better switching from normal conditions to alert and alarm for municipal demand and for irrigation demand at LR9. Satisfaction of irrigation demand at LR6 is penalized by the mitigation measures in comparison to the larger LR9 irrigation demand because it can rely on alternative sources that are insufficient for LR9.

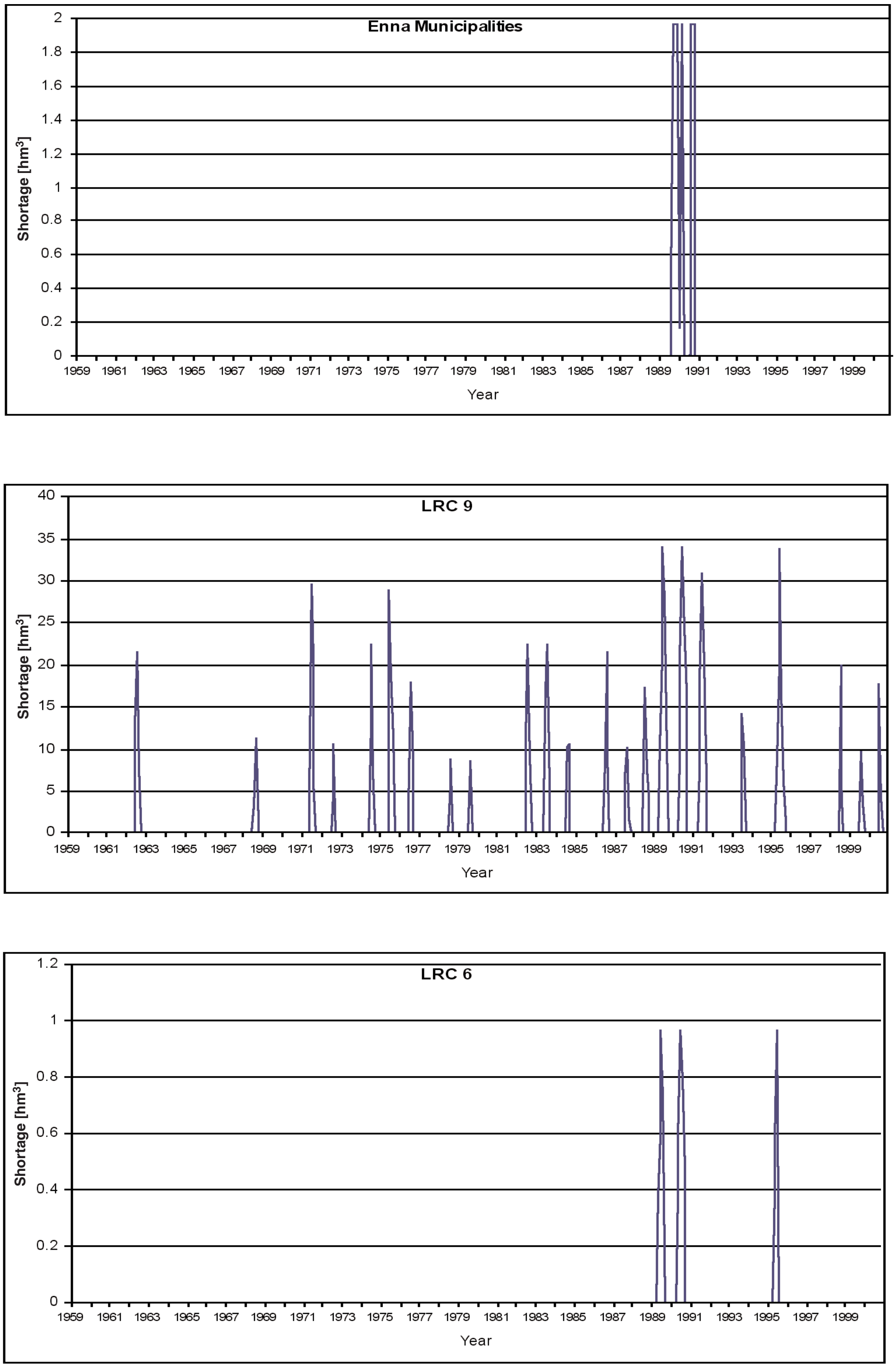


Fig. 32. Water shortage obtained by historical simulation (1959-2000) using normal condition operating policies.

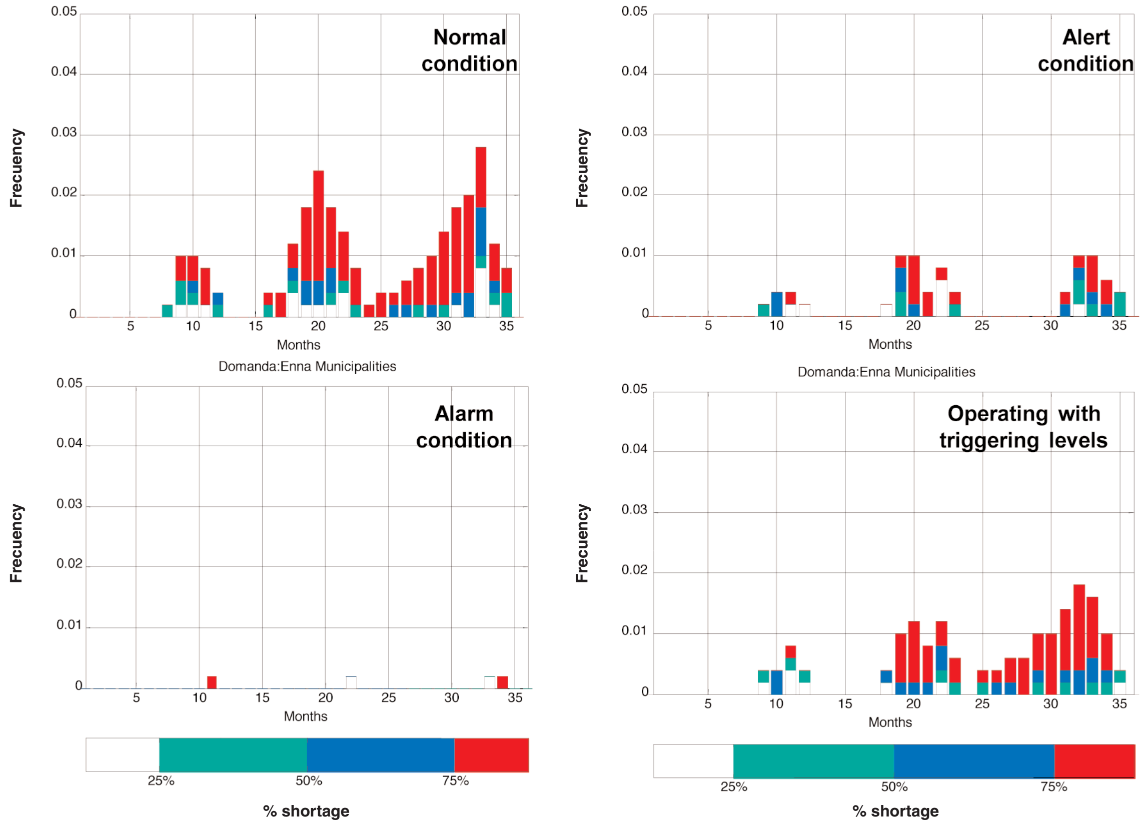


Fig. 33. Frequency of shortage in municipal use in the 36 months following March 1989.

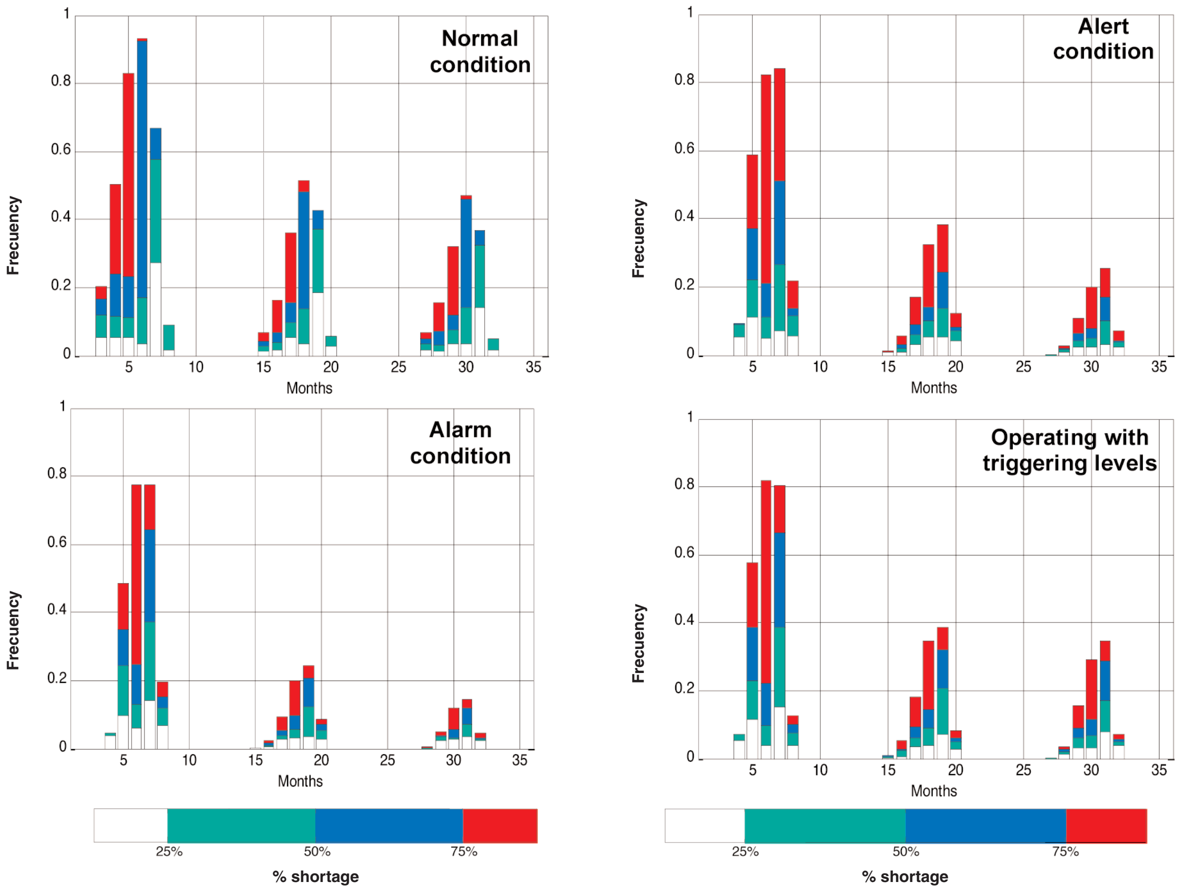


Fig. 34. Frequency of shortage in irrigation use (LRC9) in the 36 months following March 1989.

Table 8. Performance indices of the system operated in normal conditions

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.2	99.4	0.21	0.09	0.33	0.5609
LR9	65.3	75.5	2.90	16.97	36.33	756.22
LR6	96.3	96.5	0.55	0.11	0.21	0.0970

Table 9. Performance indices of the system operated in alert conditions

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.7	99.8	0.07	0.04	0.09	0.1294
LR9	76.1	81.9	2.51	14.99	30.7	597.73
LR6	88.4	91.5	1.27	0.28	0.43	0.2030

Table 10. Performance indices of the system operated in alarm conditions

	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.9	99.9	0.008	0.006	0.006	0.0101
LR9	81.8	87.6	2.245	12.724	23.432	383.21
LR6	91.7	94.6	1.068	0.213	0.2986	0.1185

Table 11. Performance indices of the system operated with triggering levels

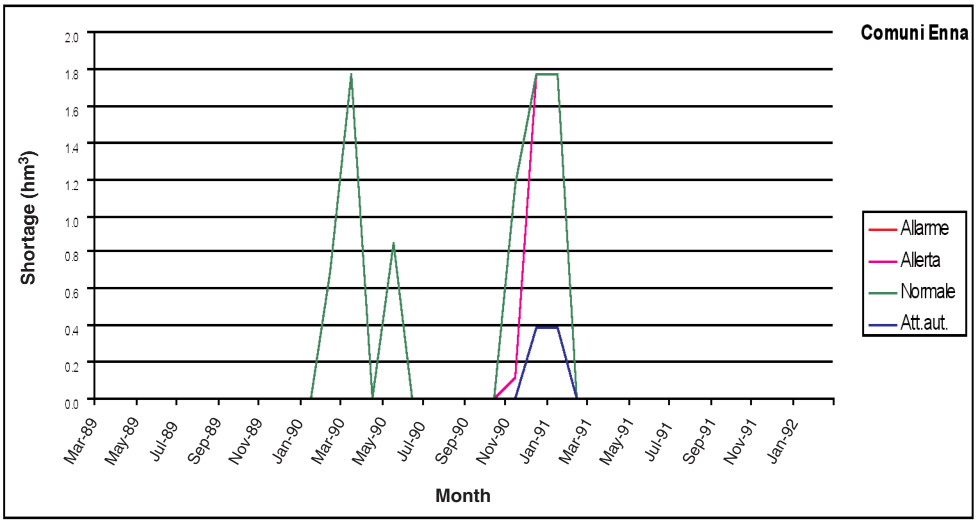
	Temporal reliability (% month)	Volumetric reliability (%)	Average shortage period length (months)	Max monthly shortage (10^6 m^3)	Max annual shortage (10^6 m^3)	Sum of squared shortage (10^6 m^3)
Enna municipalities	99.5	99.6	0.136	0.06	0.21	0.33
LR9	75.8	82.4	2.42	14.8	29.0	570.25
LR6	86.8	91.5	1.36	0.28	0.42	0.18

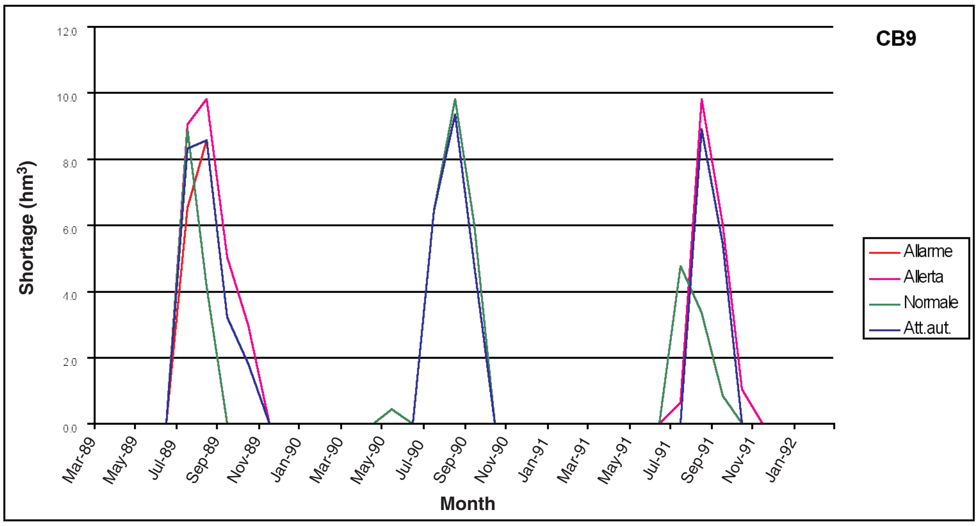
Indices calculated in correspondence of the system operated with triggering levels are always between those calculated for simulation with no mitigation measures and those obtained operating the system as it was always in alarm condition. Indices obtained operating the system with triggering levels have to be considered as the most meaningful because represent the performance obtainable following the behavior of the water managers that tend to adapt the managing to real conditions of the system and not follow pre-constituted operating rules.

The methodology aids water managers to choose management criteria in order to contain the risk of shortage over the immediate future constituted by the 36 months successive to the time in which the decision about the right management criterion has to be done.

In order to evaluate actual effects of the proposed management criteria a new simulation was performed considering to operate the system with triggering levels starting on march 1989 till February 1992 using the historic 36 streamflow to the system (Fig. 35).

Operating with triggering levels contributes to reduce risk of deficit both for municipal and irrigational demands resulting in worst results only for irrigational demand during the third year fully compensated by the gains obtained on municipal demands during the previous two years.





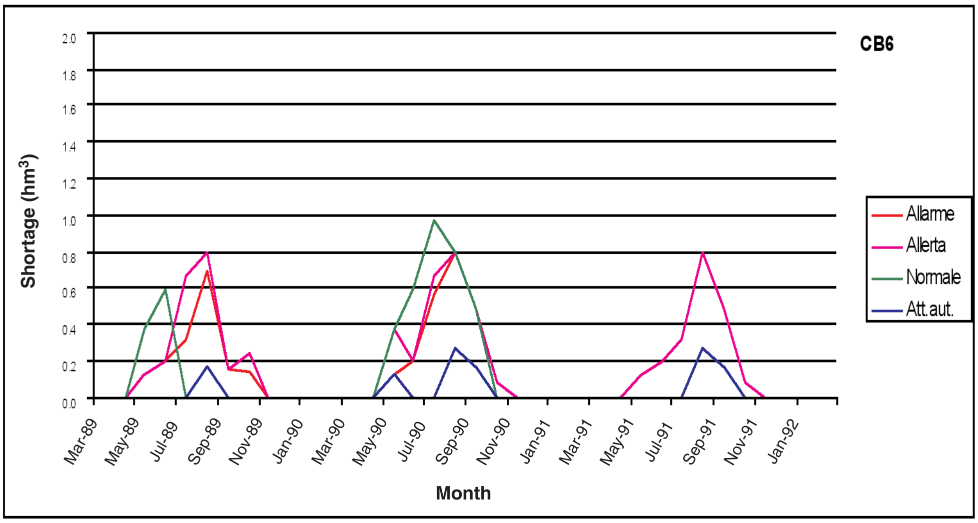


Fig. 35. Simulation using 36 months historic records starting from March 1989.

Drought damage in rainfed agriculture

Drought impacts in the agricultural sector strictly depends on the type of agriculture practiced in a specific area: rainfed or irrigated. Indeed, in rainfed agriculture drought impacts are usually very serious and often all or part of the crop production is lost. Sometimes farmers are unable to produce spring and summer crops and they have few defense tools.

Irrigation, of course, is the best way to cope with the climatic variability, although in the farms or districts supplied by surface water the impacts of severe droughts can be also very serious. In the farms supplied by groundwater, the impacts of droughts are almost non-existing, if the short term is considered. For long drought periods, the impacts are related to the decreasing of water tables level. In this case the farmer is forced to change the operating rules of the wells and/or of the irrigation system. In the farms supplied by an irrigation district or a land reclamation consortium, the impacts are related to water resources availability existing during the drought period both at farm and district level. When water resources are limited, the district/consortium gives priority to the fruit orchards and change the irrigation scheduling with a longer turn of water delivery.

In order to evaluate the risk associated to drought events in agriculture, an analysis of the expected social and economic impacts has to be carried out. The main difficulty related to this issue is to collect all the possible data about drought damages and express such data in economic terms. Among these data, damages caused by drought either to rainfed and irrigated agriculture, expressed as production losses, are generally assessed by specific institutions that control agriculture activity. For instance, in Italy, the damages consequent to drought events, are assessed by the Provincial Agricultural Offices, on their own initiative or solicited by farmers or by social and categories organizations. In particular, for each crop cultivated in the target area, the percentage of Gross Sale Production (GSP) corresponding to the economic loss is evaluated, then the whole damage is computed as a weighted average. Only when the damage reaches a given percentage (30% according to the L. Decree 102/2004, 35% according to the previous law) of GSP of the whole crops production of the target area, it is possible to request the "natural disaster declaration". In Fig. 36 the institutional framework to cope with drought emergency in agriculture is illustrated. The declaration of natural calamity is requested by the Regional Government, through the Regional Agricultural Department, to the Ministry of Agricultural Affairs. Once that the extreme nature of the occurred drought event, in terms of impacts on agricultural production, is ascertained, the status of natural calamity is declared and funding to cover income losses or to stipulate insurance is supplied to the Regional Government and then to Provincial Agricultural Offices, which are in charge to build new infrastructures and/or to allocate funding to the farmers for insurance.

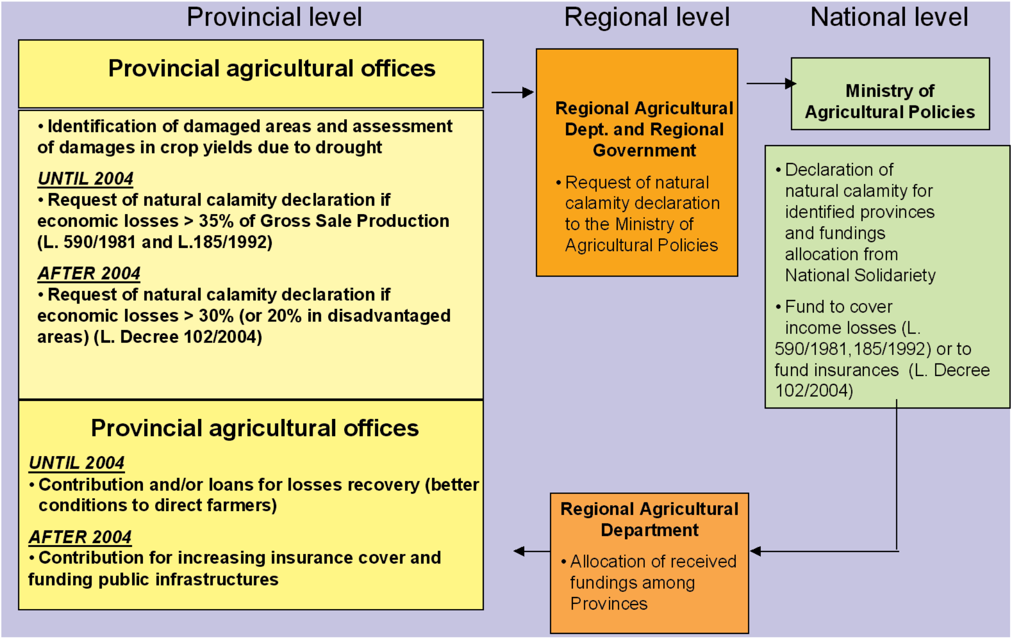


Fig. 36. Institutional framework in Italy to cope with drought emergency in agriculture.

With regard to the examined case-study, data related to losses in crop production during the recent drought events, as estimated by the Provincial Agricultural Offices, have been collected in the Offices of Catania, Siracusa and Enna. For these provinces the soil use, together with the location of the considered rain gauges, is reported in Fig. 37.

The sample series of the areal rainfall with respect to the cultivate areas in each province has been computed, based on monthly precipitation data observed in the selected rain gauges during the period 1921-2000, by using the Thiessen polygons methods. Rainfall values for each kind of soil use has been determined by considering a weighted average among the intersections between cultivate areas and relative polygons (see Fig. 38). Finally, fixing the time scale, the corresponding SPI series have been calulated.

In Fig 39 and Fig. 40, as an example, a preliminary comparison between the values of SPI and the contemporary percentage of damages on cereals and fodders for Catania and Siracusa is presented. The SPI has been calculated by considering an aggregation time scale *k* equal to the crop cycle (from seeding to harvesting) and/or to the critical phenological phases of the different crops. For instance, if cereal is the kind of the crop, the rain during the months October, November and December is essential for the sowing, as well as the rain on the period March to May, during which the plants are not able to complete the crop cycle. Therefore, for this case, it can be useful considering SPI values on May with time scales of 7 or 8 months, or on January with 3 or 4 months. It is easy to observe that, even if there is a certain agreement, however there is no direct proportionality between percentages of damages and SPI values. This can be partially due to the fact that drought impacts on agriculture are roughly assessed, and in some cases they might be artificially increased in order to overcome the threshold for getting refunds according to current legislation. Further investigations are still in progress regarding this issue.

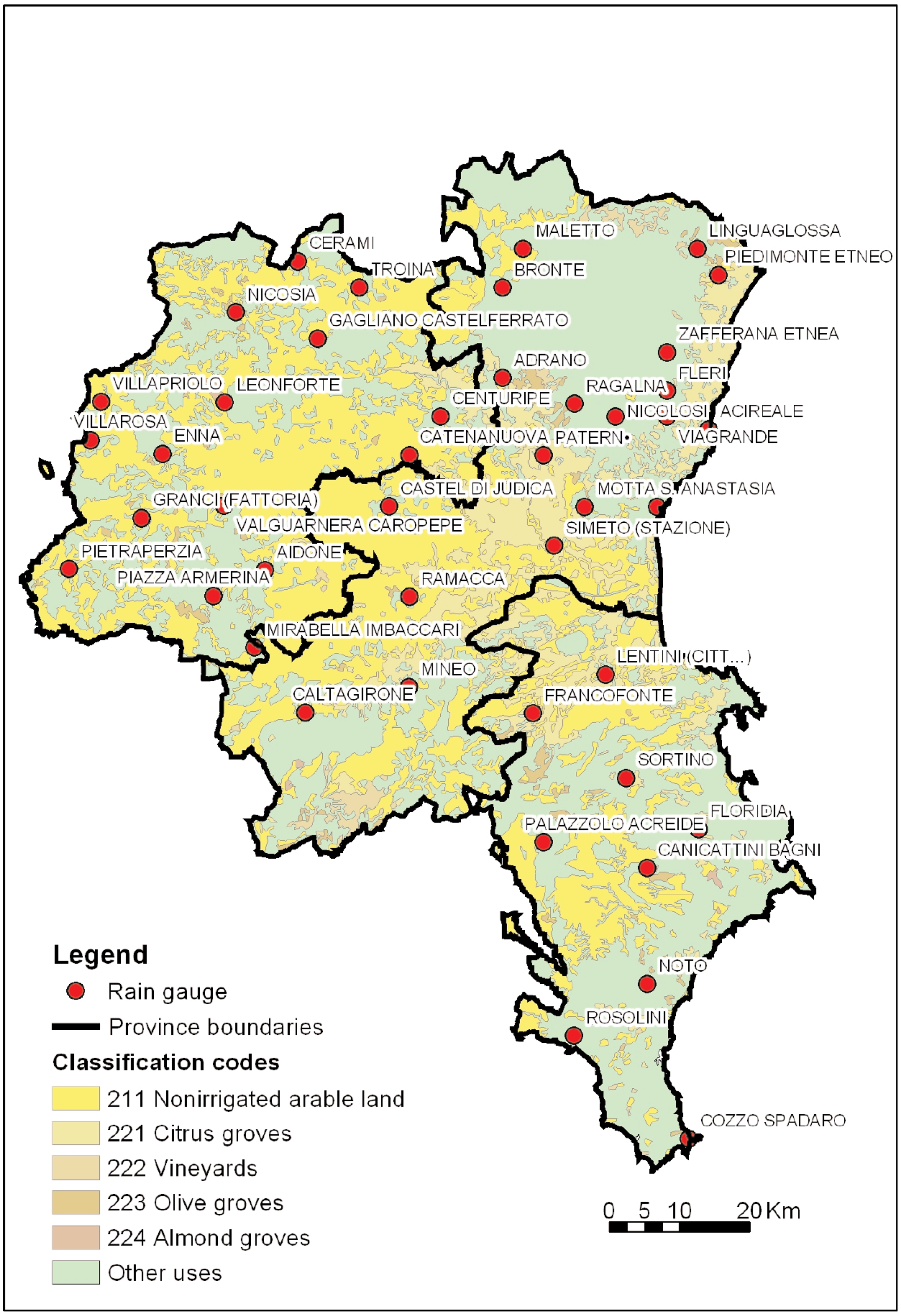


Fig. 37. Rain gauges and soil use for the 3 provinces of Catania, Siracusa and Enna.

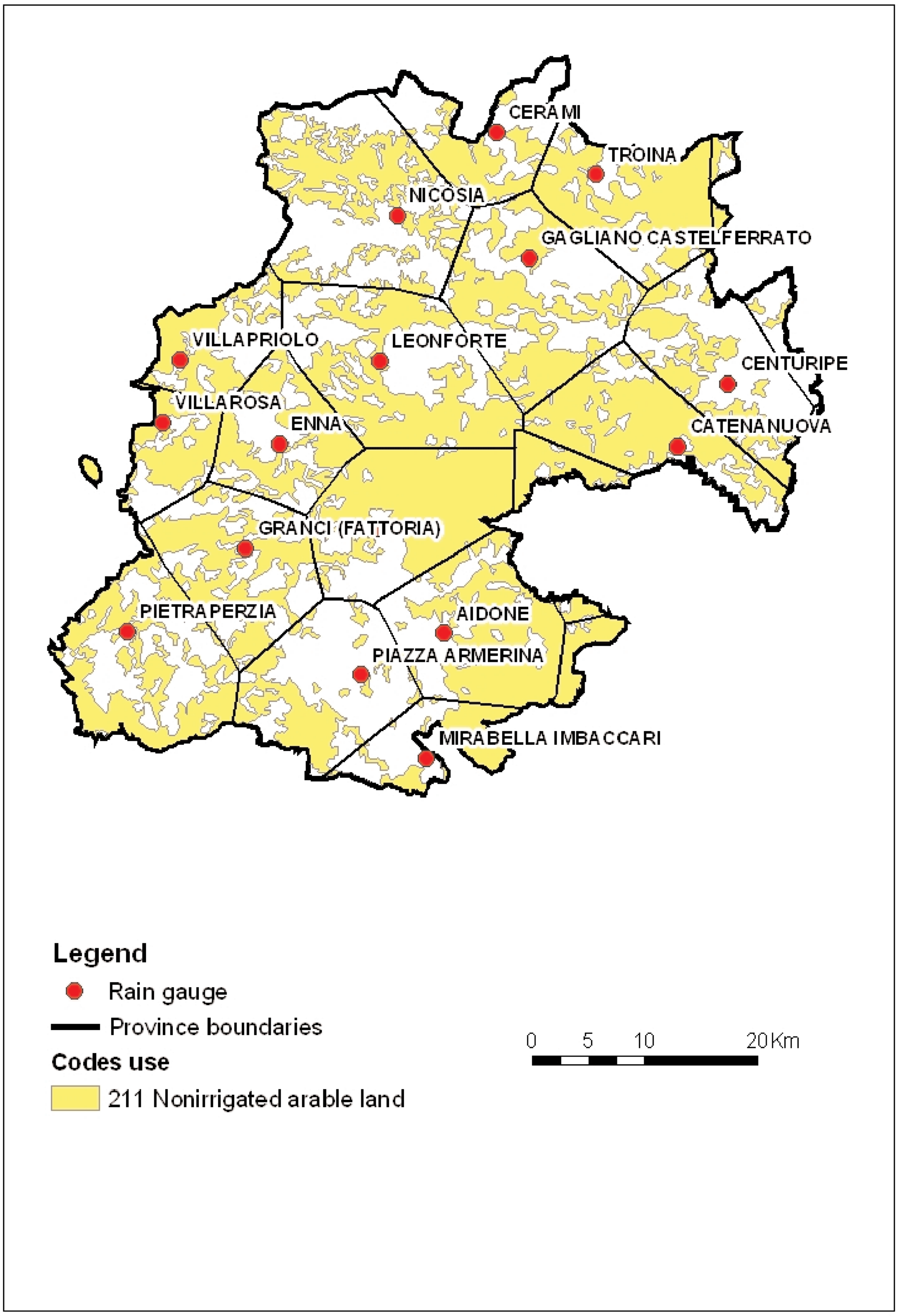


Fig. 38. Thiessen polygons and soil use for the province of Enna.

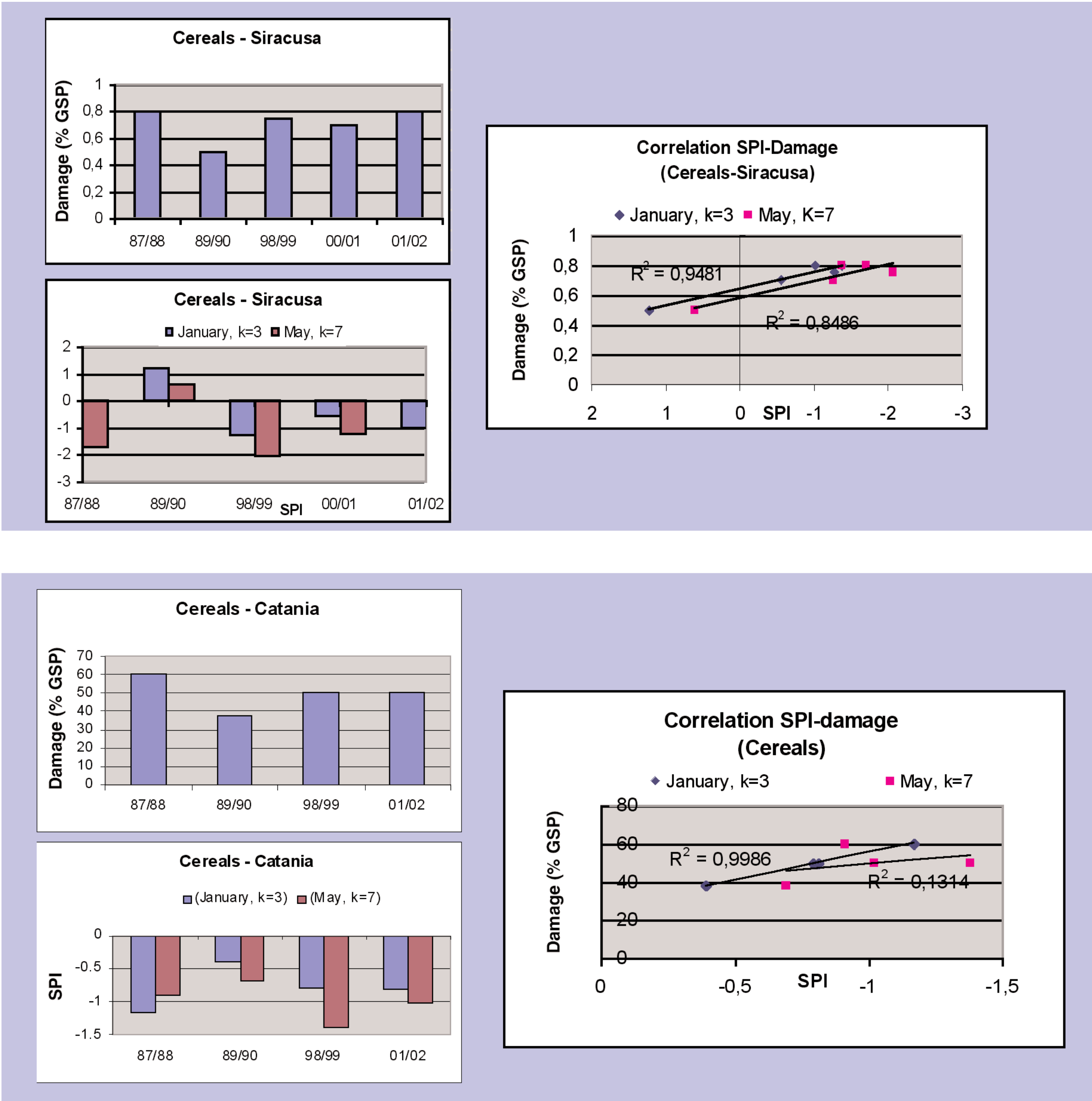


Fig. 39. Comparison between SPI and drought impacts on cereals for the provinces of Catania and Siracusa.

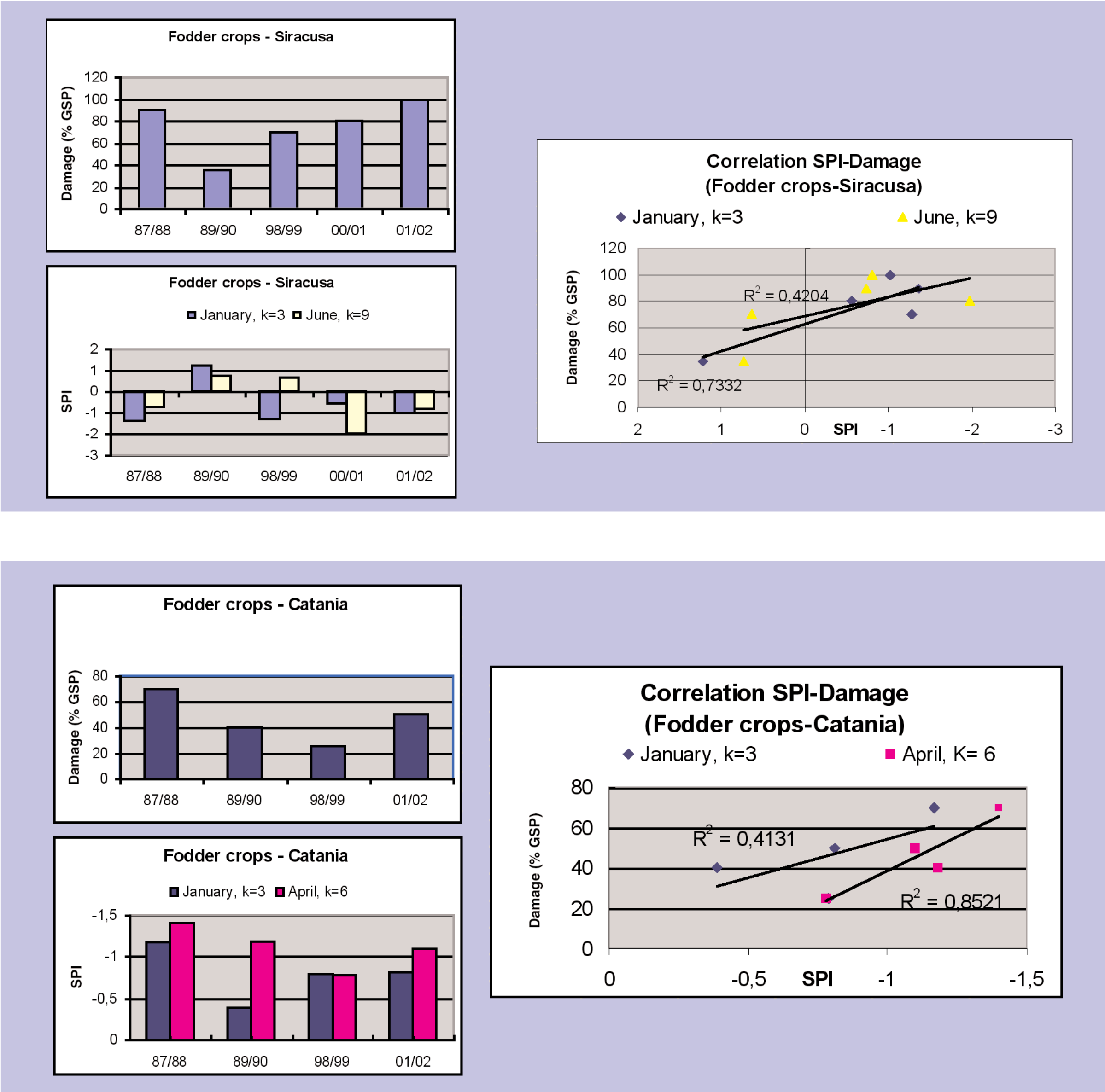


Fig. 40. Comparison between SPI and drought impacts on fodder crops for the provinces of Catania and Siracusa.

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Chapter 19. Application of the Drought Management Guidelines in Morocco

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SUMMARY – The laws with regard to water management were seriously reviewed in 1995. The Administration is still largely in charge of the formulation of water policies. The consultative institutions issue recommendations and approve plans; while the stakeholders control over municipal water through the Local Authorities, which work under the supervision of the Ministry of Interior. However, slow change is taking place. When the drought cycle is over, the activity of the national inter-government committee is abandoned. Should the drought recur, the same procedures are reproduced regardless the results of the previous drought episode. There is however a renewed political will to move away from this crisis management to a more proactive drought management approach. This has been activated in 2001 by the creation of the National Drought Observatory in the form of an institutional network of representative stakeholders working on drought issues; the support of the insurance policy plans; and water saving operations. A methodology of drought characterization, risk analysis and vulnerability assessment in agricultural system is presented for Oum Er Rbia river basin.

Key words: Drought, legal framework, characterization, Oum Rbia Basin, agriculture, management.

The planning framework

Situated in the North Western part of Africa, Morocco is subject to the influence of highly diverse climatic conditions. The North is characterized by Mediterranean influences, the South is part of the arid Sahara, the West is subject to Atlantic influences and in the East the high Atlas has its own microclimates. Average annual precipitation levels vary from 750 mm per year in the Mediterranean region of Loukkos to under 100 mm in the Saharan regions of Ouarzazate and Tafilalet. Total precipitation levels for Morocco average 150 billion m^3 per year, 29 billion of which replenishes surface and groundwater flow, the remainder being lost to evaporation. About 20 billion m^3 of freshwater resources are available for mobilization, of which 16 billion m^3 as surface water and 4 billion m^3 as groundwater (Fig. 1).

The challenges associated with the uneven geographical distribution of Morocco's water resources are compounded by the uneven and erratic nature of rainfall. Most precipitation falls between October and April. Morocco is highly susceptible to long periods (one to six years) of drought. This creates highly variable surface flows and threatens water supplied to households and farmers alike. According to official figures of Secretary of State for Water (MATEE, 2004), and with renewable freshwater availability, per capita water resources are estimated at only 700 m^3/person/year. Morocco is well below UNDP's scarcity criterion of 1,000 m^3/person/year. Moreover, water is becoming scarcer due to demographic and economic growth pressures, limited potential for increased resource mobilization, and periodic long droughts. By 2025, about 35 percent of the population will be below the absolute scarcity threshold of 500 m^3/person/year; so that Morocco is to become a "chronically water-stressed" country (Bzioui, 2000).

Economic development in Morocco has always been dependent on the development of water resources which has facilitated agricultural and urban growth and played a vital role in poverty alleviation. Because agriculture provides a livelihood to 43 percent of the economically active population, and contributes around 15 percent of GDP, changes in output due to variations in weather and drought episodes have a multiplier effect on overall economic activity, with serious consequences for incomes.

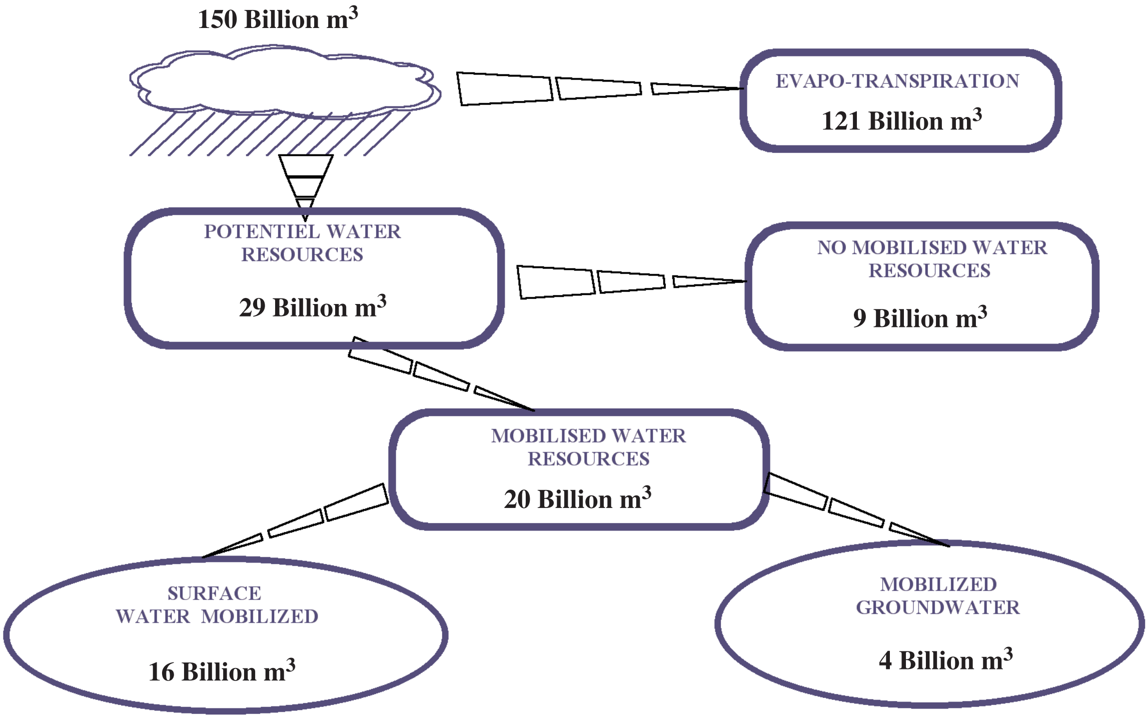


Fig. 1. Characterization of water resources in Morocco (DGH, 2004).

Of Morocco's 71.5 million hectares, 21 million are classified as rangeland and 9 million as cultivable land. Due to cropping patterns that include fallow periods, actual area cultivated in any year averages 7 million hectares. Irrigated agriculture is an essential pillar of economic and social development in Morocco. Morocco's 1.4 million hectares of irrigated crops consume, on average, 85% of available water resources (as low as 60 to 70% in a dry year), while 12% and 3% of resources are used for public water supply and industry, respectively. The National Irrigation Plan aims at raising the efficiency of agricultural water use, through upgraded infrastructure, improved practices, and lower-demand crops (Yacoubi, 2000).

The Moroccan Government has recently redefined the irrigation objectives as: (i) contributing to food security by efficiently producing strategic food products; (ii) increasing agricultural incomes and employment by improving on-farm productivity and upstream and downstream linkages; (iii) conservation of natural resources; and (iv) encouraging the integration of agriculture into international and local markets. To achieve these objectives, it recognizes that greater attention needs to be paid to the conservation and protection of water resources and to increasing on- and off-farm water efficiency. Since the introduction of 1995 Water Law, the legal framework for achieving these new orientations has been in place. The 1995 Water Law marked a paradigm shift in the Government's water policies, from supply to demand management. With the new law, the emphasis changed from heavy investments in water resources development, which was almost complete, to better water use efficiency, resource allocation practices, and protection of water quality.

Organisational component

Legal framework

Legal aspects and history

Due to the nature of the climate in Morocco, irrigation has been introduced very early and rules on property, conflict resolution and ways of managing and realizing collective works for implementing irrigation networks have been defined, debated and written in the 9th century, after Islam was introduced in Morocco. The institutional setting was shaped by the laws inherited from Islam as interpreted by

Moroccan Ulema (Arabic word for jurist that interpret the tenets of Islam in order to complete and explain the rules derived from the Revelation), by the customs and rules developed in pre-Islamic Morocco.

A turning point occurred in 1912, with the Protectorate and the introduction of a "modern" legal system and juridical concepts. Thus, in Morocco, the first text concerning modern water legislation goes back to 1914 (Decree of l July 1914) recognizing water resources as a public good. That created a mixed system due to the prevalence of private appropriation based on the interpretation of Moroccan Ulema of Islamic Chariaa.

The legislation on water was further codified in 1925, with the adoption of the law on "Régime de l'Eau" (Water Rules) that develops on the public ownership of water and defines the conditions of water use and water access. It is completed by a decree stating the conditions for recognizing water rights. Beside the corpus on public ownership, the Protectorate issued a law regarding water users associations in order to formalize the implementation of a private irrigation network. The ASAP (Associations Syndicales Agricoles Privilégiées, 1924) were allowed to intervene on the public domain in order to realize irrigation infrastructure and received privileges in order to implement the network.

In 1995, a new legislation was voted by the parliament and adopted by the government.

The 1995 Water Law

The 1995 law called "Loi sur l'Eau" (Water Law) constitutes the main actual water legal frame. This law recognizes that all water resources are a public good and water should be managed at a river basin level. The law is authorizing the creation of river basin agencies, which, when fully established, will result in a more decentralized and participatory water management program. It also introduced a lot of new considerations about the management of water at the national, regional and local level.

The content of the 1995 Water Law is organized around the following points:

(i) An extension of the public ownership of water and the imposition of a time limit of 5 years to any claim on private water rights.

(ii) The introduction of the "Agence de Bassin" (Water Basin Agency), as the main entity in charge of water issues at the water basin level.

(iii) The official recognition of planning by the State of mobilization and allocation as the main instrument of decision about public infrastructure, water allocation and water transfer. The Water Basin Master Plan is to be prepared by the Agence de bassin and to be submitted to the Conseil Supérieur de l'Eau et du Climat (Superior Council for Water and Climate) for formal adoption. Once adopted, the master plan for an integrated management of water resource at the hydrological basin level becomes the main document to decide water allocation by sectors, abstraction agreement and concessions. It includes goals in terms of quality.

(iv) The introduction of new taxes, "redevance de bassin" based on water abstraction, and pollution taxes based on the contribution to the stream pollution. These taxes will cover subsidies in investment to reduce pollution, expenditures related to the network of observation in the basin, the definition of the master plan of water mobilization and allocation at the basin level and management of the agency.

(v) The introduction of new instruments to deal with pollution and drought: Fees for polluters, subsidies for investment to reduce pollution and exceptional power to the administration for dealing with drought. In the case of acute drought, a decree defines the area where the administration receives such powers that allow for reduction in abstraction, and obligation of use of underground resources.

(vi) The formal introduction of the National Hydrological Plan was to be presented to the Superior Council for Water and Climate, to solve allocation conflicts and make recommendations.

Stakeholders and their participation

In the board of the River Basin Agencies, a third is composed from the administration; a quarter from public enterprises and the rest (42%) represents users. In conducting irrigation projects, it is very recently within the framework of AUEA (Water Users' Associations) Law, 1990) that users have a say on the project.

Reforms and changes

In the current setting, stakeholders do not have always a proper say on water issues, except locally by the control over municipal water through the local authorities (collectivities locales), which work under the supervision of the Ministry of Interior. However, slow change is taking place. This change will be supported because NGOs and civil society are more active in this field, and water user associations are gaining more autonomy in their dialogue with the administration.

Institutional drought management

Water resources management overview

The main institutional stakeholders in the water sector are represented by the key ministerial departments including agriculture, water and environment, local authorities (Ministry of Interior), Health, Energy and Mines, and Finance Departments (Fig. 2). NGO's such as water user associations, and natural resources / environment protection associations are also actively operating in the country in response to civil society's needs.

MAIN ADVISORY AUTHORITIES

Superior Council for Water and Climate (SCWC)
National Council for Environment (NCE)
Council for Agricultural Development (GCAD)
Permanent Inter-Ministerial Council for Rural Development (PICRD)
National Drought Observatory (NDO)

EXECUTIVE ADMINISTRATION AUTHORITIES

Ministry of Territorial Administration, Water & Environment (MTAWE)
- Secretariat of SCWC
- Directorate General of Hydraulics (DGH)
- National Meteorological Office

Ministry of Agriculture and Rural Development (MARD)
- Water & Ag – Engineering Administration (AGR)

High Commissariat of Water, Forest and Fight against Desertification
Ministry of Interior (MI)
- Directorate General of Local Collectivities
- Directorate of Régies & Conceded Services

Ministry of Finance (MF)
Ministry of Health (MH)
Ministry of Energy and Mines (MEM)
Ministry of General Affairs (Prices Directorate) (MGA)

PUBLIC OFFICES, AGENCIES & PRIVATE OPERATORS

River Basin Agencies (MTAWE)
Directorate General of Hydraulics (MTAWE)
National Water Drinking Office (ONEP - MTAWE)
Regional Office for Agricultural Development (ORMVA - MARD)
Autonomous companies and private operators (REGIES – MI)
National Office of Electricity (ONE – MEM)

WATER LOCAL

Water Provincial Commission
Local Collectivity Representatives
Water Users Associations (AUEA)

Fig. 2. Main stakeholders in water sectors in Morocco.

The current institutional setting does not clearly define the scope of intervention of each ministerial department. However, it addresses the issue of coordination through consultative institutions at the national, regional river basin and local levels, and through the executive central administration authorities. The overall coordination is the role of the Directorate General of Hydraulics (DGH, State Secretary for Water) with a strong involvement of the Water and Agricultural Engineering Administration (AGR, Ministry of Agriculture). Decisions related to water resources management are implemented by the Public Offices and Agencies which operate under the supervision of their respective ministries: ONEP (National Office for Drinking Water) for drinking water, ORMVA (Regional Reclamation land Offices) for irrigation and ONE (National Office for Electricity) for hydropower. The general model for water management in terms of decision making, coordination and implementation at the national, regional and local levels includes advisory bodies and the executive authorities at the different levels (Fig. 3).

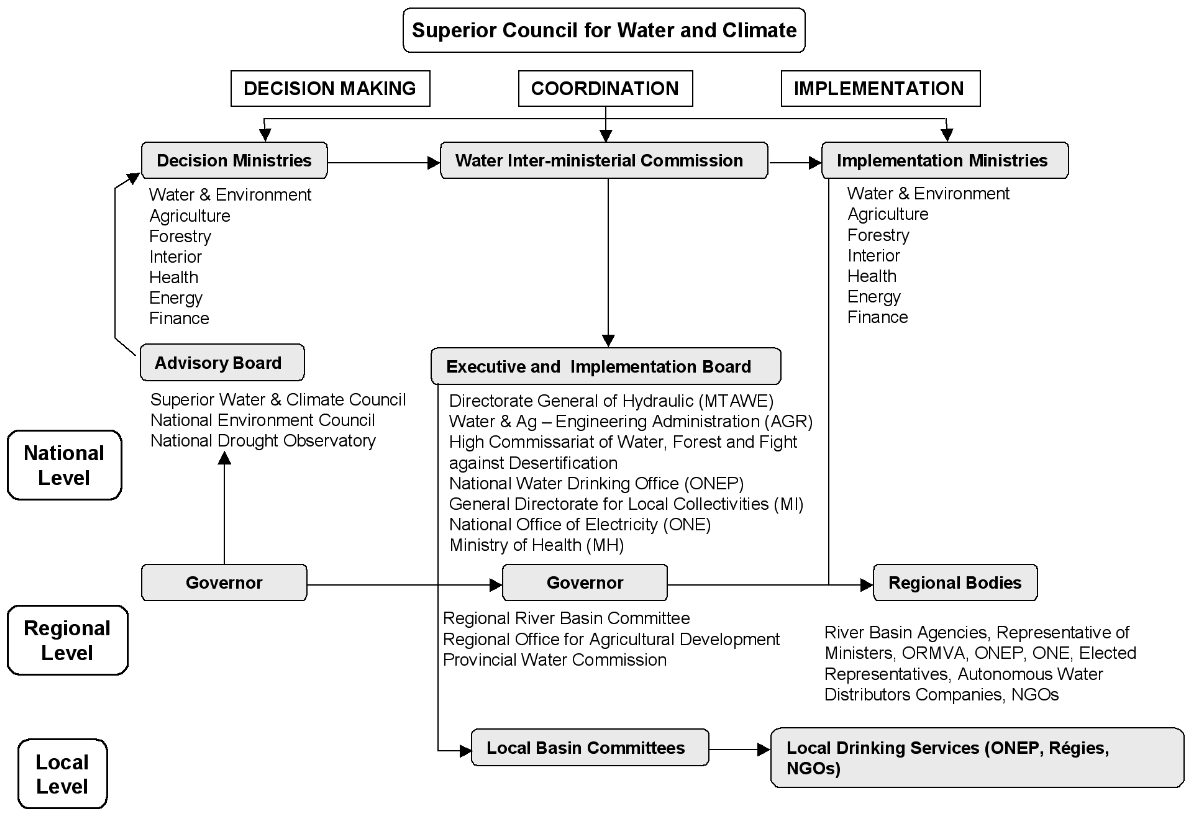


Fig. 3. Water resources management in Morocco.

Consultative institutions and bodies

The Superior Council for Water and Climate (SCWC)

The main consultative body, the Conseil Supérieur de l'Eau et du Climat (Superior Council for Water and Climate, SCWC) includes all administrations involved in the water sector, representatives of the parliament, of users and nominated experts that have competencies on the water issues. The SCWC convenes to address issues of national importance and formulate recommendations on the options of planning, mobilization and management of water resources.

The National Council for Environment (NCE)

The National Council for Environment (Conseil National de l'Environnement, CNE) was created in 1981 but has been reactivated only in 1995 in order to advise the Government on all environmental issues. On water issues, the NCE contributes to define guidelines that limit conflicts between institutions and promote environmental awareness and education.

The Permanent Interministerial Council for Rural Development (PICRD)

The Permanent Interministerial Council for Rural Development (Conseil Interministériel Permanent du Développement Rural, CIPDR) was created in 1999 following the severe drought episodes in Morocco. The main activities of the Council relate to the declaration of drought onset, the preparation of the National Drought Plan, the supervision of the planned drought actions and the elaboration of rural development strategies for Morocco.

The National Drought Observatory (NDO)

The National Drought Observatory was created in 2001 as an entity attached to the General Secretary of Ministry of Agriculture and Rural Development and based at the Institut Agronomique et Vétérinaire Hassan II (IAV), as a result of a ministerial decision to locate it physically in an academic institution allowing multidisciplinary collaboration, and giving it certain neutrality with regard to policy pressures. The main mission of the Observatory is to provide decision makers with decision support tools for drought management and to advise on strategic drought planning, preparedness, mitigation and response.

The General Council for Agricultural Development (GCAD)

The main role of the General Council for Agricultural Development (Conseil Général du Developpement Agricole, CGDA) is to make studies and recommendations pertinent to policies for agriculture development including contributions to policies on sustainable use of water and other natural resources, economic policies and social development issues.

National Executive Institutions

The Executive institutions in charge of advising the various line agencies and ministries, issue recommendations and approve plans. These institutions are the following:

Ministry of Water (State Secretary for Water, within MTAWE)

The ministry has an organization related to water, as follows:

(i) The Directorate General of Hydraulics, DGH (Direction Générale de l'Hydraulique) is in charge of policy formulation and implementation in planning, mobilizing, managing and protecting quality of water resources. It is also responsible for the all large infrastructure projects, in terms of implementation, management and maintenance.

(ii) The National Office for Drinking Water (Office National de l'Eau Potable, ONEP) is an autonomous institution which has more operational duties. It is in charge of planning all operations related to potable water and to implement the investments needed.

Ministry of Environment (as State Secretary for Environment within MTAWE)

The main attribution of the State Secretary for Environment is to prepare a strategy for the preservation of the natural environment. The Ministry contributes to the master plans on water resources and is in charge of water quality issues.

Ministry of Agriculture and Rural Development

The Ministry of Agriculture and Rural Development has two main duties in terms of water management: irrigation and watershed management. Two Administrations define and implement its policies in the Water sector:

(i) *The Water and Ag-Engineering Administration (Administration du Génie Rural, AGR)* plans and realizes all projects related to irrigation and drainage. It supervises the ministry regional structures for water management, the "Office Regional de Mise en Valeur Agricole" (ORMVA) (Regional Land Reclamation Office) which implements, operate and manage the Large Scale Irrigated (LSI) projects and all the Small and Medium Scale Irrigated (SMSI) projects.

(ii) *The Water and Forest Administration (Administration des Eaux et Forêts et de la Conservation des Sols, AEFCS)* prepares watershed management plans and projects and regulates access to continental fishing. Late in 2003, this Administration was transformed into the High Commissariat of Water, Forest and Fight against Desertification (Haut Commissariat aux Eaux et Forêts et pour la Lutte contre la Desertification, HCEFLCD).

Ministry of Interior

The Ministry of Interior is involved in the water sector as the tutor of local collectivities (Communes, provinces and regions). It is directly involved in the management and supervision of municipal water distribution and sewage.

Ministry of Health

The Ministry of Health is responsible for mineral water agreement and control, and is also in charge of all health issues related to water projects and water quality.

Ministry of Energy and Mines

The Ministry, through the National Office of Electricity (Office National de l'Electricité, ONE), is in charge of all hydropower projects and operations. As a user, it has a say on the planning of water resources, and water management especially during drought periods.

Regional and Local Institutions

In order to deal locally with the issues of implementation, management and coordination, a set of line agencies and consultative bodies were progressively set up. This policy has led to the creation of the Regional River Basin Agencies as autonomous public institutions which group all the water stakeholders and users in the region. The Regional River Basin Agencies (Agences de Bassin) are the most important institutions at the regional level; they are charged to manage the water resources at the basin level and monitor quantity and quality of surface and underground water. They also contribute to drought management and adjust water allocation according to available resources. Their effective implementation is, however, yet to come. Figure 4 shows the hydrological basins of Morocco.

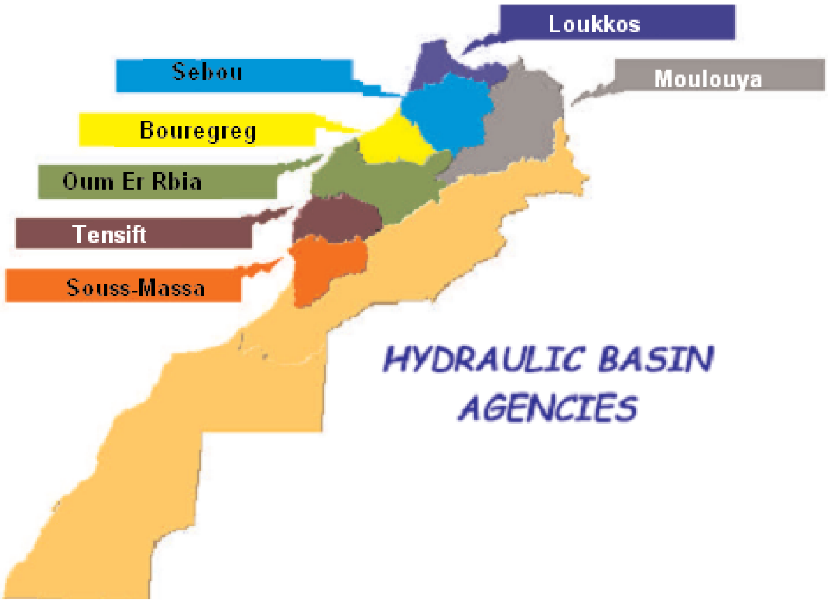


Fig. 4. Hydrological basins of Morocco.

The local authorities are fully responsible for water distribution and sewage system in their commune, under the supervision of the Ministry of Interior, since the adoption of the commune regulation "Charte Communale", in 1976 (recently revised), the cornerstone of the Moroccan decentralization policy.

The Offices Régionaux de Mise en Valeur Agricole (ORMVA) implement the irrigation projects, manage the network, enforce the water police and promote good agricultural practices through extension.

The Conseils Régionaux de l'Environnement (CRE) are to inventory regional environmental issues, including those related to regulation and implement recommendation of the CNE, the National Environment Council. They group representatives from the local administration, the local authorities and elected members of the local collectivities.

Water users associations

The water users associations (WUA or AUEA) constitute a very important institution in dealing with coordination problems at the irrigated perimeter level. Traditional water user associations, informal with regard to the current legislation, played an important role in coordinating efforts to realize collective infrastructure and irrigation water management particularly at the canal level ("Seguia") Informal water user associations still manage the operations of drought and the newly created legal status of AUEA is largely used by AGR in order to promote Small and Medium Scale Irrigation perimeters or to realize new projects with more flexibility than in the past.

Methodological component

Before performing the drought risk characterization and risk analysis for the case study of Oum Er Rbia River Basin, important features of meteorological, hydrological and agricultural droughts are presented for Morocco as a hole and compared for main agro-ecological zones including Oum Er Rbia region. Both historical and recent droughts are considered.

The national drought context

Meteorological drought

Historical droughts and long term drought frequency

Preliminary analysis of some of the longer and more climatically sensitive Moroccan tree-ring series (Ambroggi, 1988; Stockton, 1988) suggest the appearance of a periodicity of about 20 years in drought recurrence.

The long term drought frequency as determined by tree ring techniques is summarized in Table 1 which traces back ten centuries of drought history in the Col Zad area of central Morocco. Drought is defined as tree-ring values of 70 percent of normal or less.

Table 1. Number of droughts occurring in north central Morocco during the period 1000-1984 as inferred from the Col Zad tree-ring series

Drought length	Number of occurrences	Time interval between occurrences (years)
1 to 6 years	89	11.0
2 to 6 years	35	28.5
3 to 6 years	9	113.7
4 to 6 years	6	182.0
5 to 6 years	4	303.3
6 years	3	455.0

Source: Adapted from Chbouki (1992) by Ameziane and Ouassou (2000).

Recent droughts at the national level

An investigation by Chbouki (1992) completed with recent observations showed that Morocco often knew in the past periods of intense drought, and allowed to identify, since 1896, twelve main very dry periods that were generalized in the major parts of the country and had moderate to strong intensities: 1904-05; 1917-20; 1930-35; 1944-45; 1948-50; 1960-61; 1974-75; 1981-84; 1986-87; 1991-93; 1994-1995 and 1999-2003. The other, less generalized ones are the years 1906-07; 1910-14; 1924-53; 1965-67 and 1972-73.

The agricultural seasons of 1944-45, 1982-83, 1994-95 and 1999-00 were among the driest years of the recent climatological series as their rainfall deficits were generalized and very important.

Hydrological drought

In Morocco dams reserves are generally for multiple purposes such as drinking water, irrigation and hydro-electricity power. The dam's role was particularly highlighted during the recent droughts which the country has experienced. Without the water stored in dams, the water supply of the main cities of the country and of agricultural perimeters would have been disrupted in a considerable way. The most recent striking droughts from hydrological point of view were those of episodes from 1980-81 to 1985-86; 1991-92 to 1994-95 and 2000-2001 to 2002-2003 (Fig. 5).

These dry years profoundly aggravated the chronic deficit of the water flow. Average surface water inflow estimated to about of 19 billions of m^3, were reduced to values of 10 billions of m^3 for the period 1980-85 to 4.9 billion in 1992-93 and 5.3 billion in 1994-95. The year 1991-92 registered a contribution of 10.8 billions of m^3.

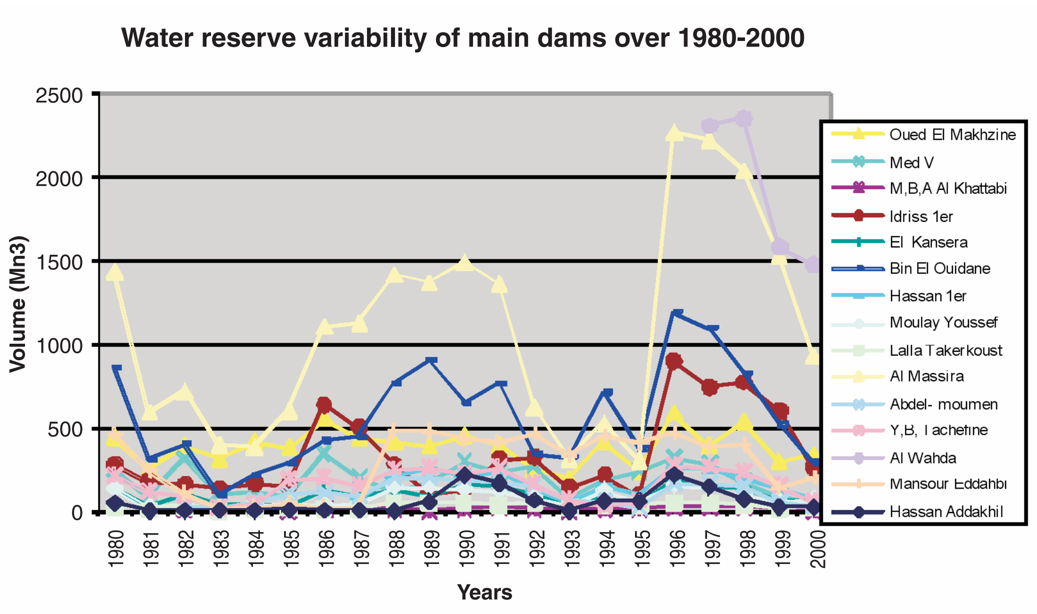


Fig. 5. Water reserve variability of the main Moroccan dams from 1980-2000.

Impacts of recent droughts

The recent drought episodes from 1980-81 to 1985-86, 1991-92 to 1994-95 and 2000-2001 to 2002-2003 engendered net declines of dam's water reserves and of the underground water levels, limitation in drinking water and irrigation water supply. Drought effects resulted also in the degradation of water quality in terms of increased water pollution leading to fish death, dysfunction or break service of drinking water treatment plants, and increase of waterborne disease. Hydraulic production underwent drought impact because of water stocks decline and fall height of all dams. Finally, drought episodes greatly affected agriculture production, livestock and their contribution to overall gross domestic production (GDP).

Drought characterization and risk analysis in the Oum Er Rbia Basin

The MEDROPLAN project team selected the Oum Er Rbia River Basin, Tadla region, as the main geographical unit for drought characterization, drought impact evaluation and risk analysis studies.

The Oum Er Rbia Basin

The Oum-Er-Rbia Basin, situated in the center of Morocco, extends over a surface of 35,000 km^2 (Fig. 6). The Oued Oum Er Rbia River, 550 km in length, takes its origin in the Middle Atlas 1800 m of altitude, crosses the chain of the Middle Atlas, the plain of Tadla and the coastal Meseta and sheds into the Atlantic Ocean in about 16 km of El Jadida city. Streams of the area of study are constituted with the main Oum Er Rbia River and the main secondary rivers: Tessaout, Lakhdar and El Abid. Average water flow is approximately of 3400 Mm^3/year (period 1939/40-2002/03) with a maximum of 8300 Mm^3 and a minimum of 1300 Mm^3/year.

The basin also contains numerous superficial and deep water-tables. Water potential of these water-tables is estimated at 330 Mm^3/year and is used mainly for the private irrigation and in small and average hydraulics and for drinkable and industrial water supply. The contributions of numerous sources associated to the snow melting guarantee to the Oum Er Rbia River to be a very steady and the most regular stream of the country.

The basin knew an important hydraulic development from the years 1920-1930 with the realization of 5 big dams reservoirs (Dchar El Oued on high Oum Er Rbia, Bin El Ouidane on Oued El Abid, Moulay Youssef on Oued Tessaout, Hassan I on Oued Lakhdar and Al Massira on the low part of Oued Oum Er Rbia River) to satisfy the water requirements of the basin and the need for the northward transfers to satisfy the drinkable and industrial water supply (AEPI) of Casablanca and southward transfers for the irrigation in Haouz and Doukkala perimeters as well as the AEPI of Marrakech, Safi and El Jadida and for the hydroelectric production (Fig. 6).

The total surface irrigated, at present, with big hydraulics is of 280,500 ha. The water demand for irrigation of this surface is closely about 2500 Mm^3/year.

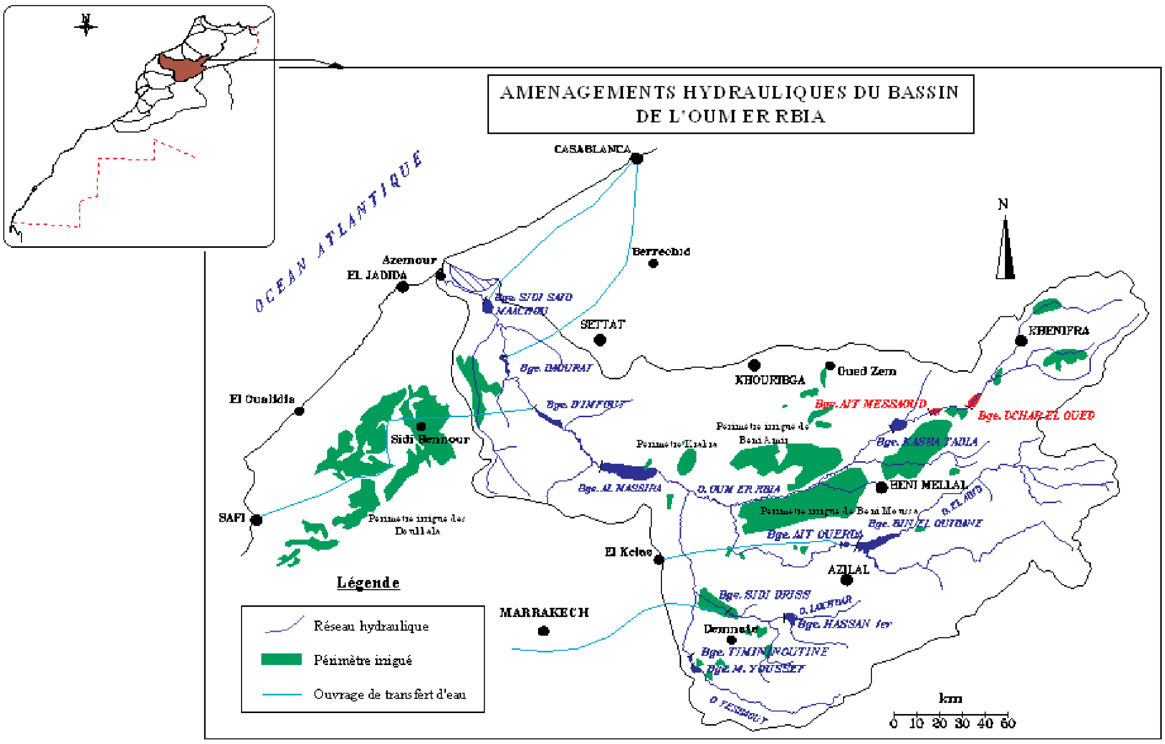


Fig. 6. Oum Er Rbia Basin (provided by the DGH of Morocco).

Drought characterization using drought indices and modeling tools

Several drought indices are used in Morocco to analyze drought patterns at the national and regional levels. Emphasis on drought risk analysis has been given at the level of Oum Er Rbia Basin.

Deviation from normal precipitation

The normal year retained for the purpose of risk analysis study relates to the period 1970-2001. The distribution of normal year precipitations among the main regions of Morocco is shown in Fig. 7.

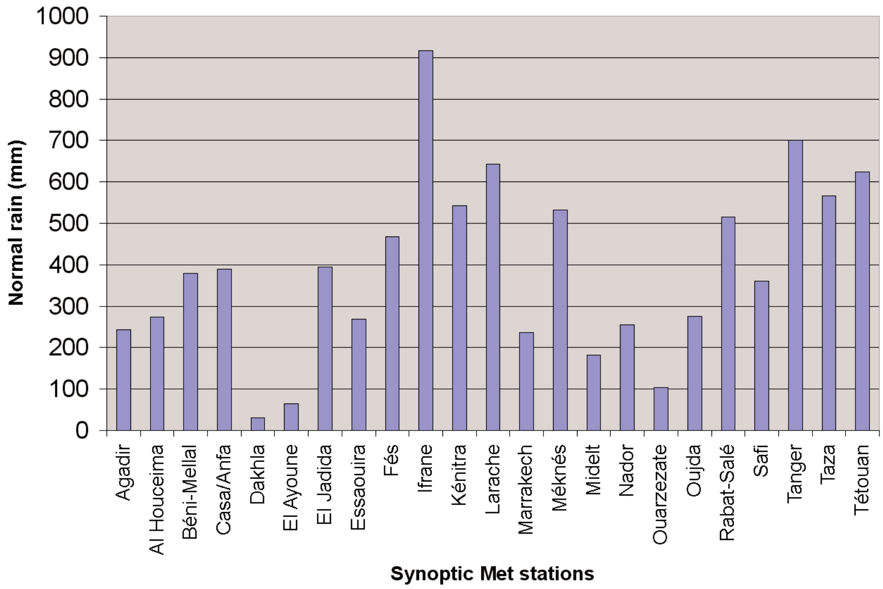


Fig. 7. Distribution of normal year precipitations among the main regions of Morocco (Period considered 1970- 2001).

Deciles analysis

Deciles analysis was performed for the period 1970-2001 at the national and regional levels. Deciles Indices (DI) are grouped into five classes, two deciles per class. If precipitation falls into the lowest 20% (deciles 1 and 2), it is classified as "much below normal". Deciles 3 and 4 (20 to 40%) indicate "below normal" precipitation; deciles 5 and 6 (40 to 60%) give "near normal" precipitation; 7 and 8 (60 to 80%) give "above normal" precipitation; and deciles 9 and 10 (80 to 100 %) are "much above normal" precipitation. The probability of occurrence of an expected level of cumulative annual rainfall for synoptic meteorological stations in Morocco is shown in Table 2; and Table 3 provides deciles analysis for selected stations. These data indicate that one year out of ten is expected to have a cumulative annual rain less or equal to 263 mm which is less than normal water requirements for a wheat crop.

Table 2. Deciles values for the synoptic meteorological stations in Morocco

Deciles	Decile1	Decile2	Decile3	Decile4	Decile5	Decile6	Decile7	Decile8	Decile9
Probability level	0.1	0.2	0.3	0.4	0.5	0.6	0.7	0.8	0.9
Expected rainfall (mm)	263	309	353	371	394	427	447	495	551

Table 3. Deciles values for selected meteorological stations in Morocco, including the Tadla (Oum Er Rbia) region under the risk analysis study of the MEDROPLAN project. Units: mm/year

Station	Normal	Decile1	Decile2	Decile3	Decile4	Decile5	Decile6	Decile7	Decile8	Decile9
Settat	367	70	140	210	280	350	420	490	560	630
Khemisset	431	87	174	261	348	435	523	610	697	784
Taza	625	123	247	370	493	617	740	864	987	1110
Tanger	737	139	278	417	557	696	835	974	1113	1252
Safi	367	69	139	208	277	347	416	485	554	624
Oujda	313	63	126	189	252	315	378	440	503	566
Ouarzazate	120	22	44	66	88	110	132	153	175	197
Méknes	562	112	225	337	450	562	675	787	900	1012
Marrakech	240	48	96	144	192	240	288	336	384	433
Marchouch	406	77	154	230	307	384	461	538	614	691
Larache	675	127	255	382	510	637	765	892	1020	1147
Fes	525	106	213	319	426	532	638	745	851	958
Aoulouz (Agadir)	253	51	101	152	202	253	303	354	404	455
Azilal (Tadla)	526	101	202	303	404	506	607	708	809	910

Standardized precipitation index (SPI)

SPI is based on the probability distribution of precipitations and is reported to be able to monitor emerging droughts. The use of different time scales under the umbrella of the same index allows the effects of a precipitation deficit on different water resources components (groundwater, reservoir storage, soil moisture, streamflow) to be assessed. Positive SPI values indicate greater than median precipitation and negative values indicate less than median precipitation. The "drought" part of the SPI range is arbitrary split into near normal conditions (0.99 < SPI <-0.99), moderately dry (-1.0 < SPI < -1.49), severely dry (-1.5 < SPI <-1.99) and extremely dry (SPI < -2.0). A drought event starts when SPI value reaches -1.0 and ends when SPI becomes positive again. The positive sum of the SPI for all the months within a drought event is referred to as "drought magnitude".

SPI to date is finding more applications than other drought indices due to its limited input data requirements, flexibility and simplicity of calculations. The determination of SPI values for selected regions of Oum Er Rbia Basin was performed for different time steps and a summary is given by Fig. 8.

Surface water supply index (SWSI)

SWSI integrates reservoir storage, streamflow and two precipitation types (snow and rain) at high elevations into a single index number. SWSI is relatively easy to calculate and it gives a representative measure of water availability across a river basin or selected region/province. It is however unlikely that it could be successfully used for large regions with significant spatial hydrological variability. A modification of SWSI (Svoboda, 2004) was used for Morocco as in Fig. 9, namely:

$$SWSI = (P - 50) / 12$$

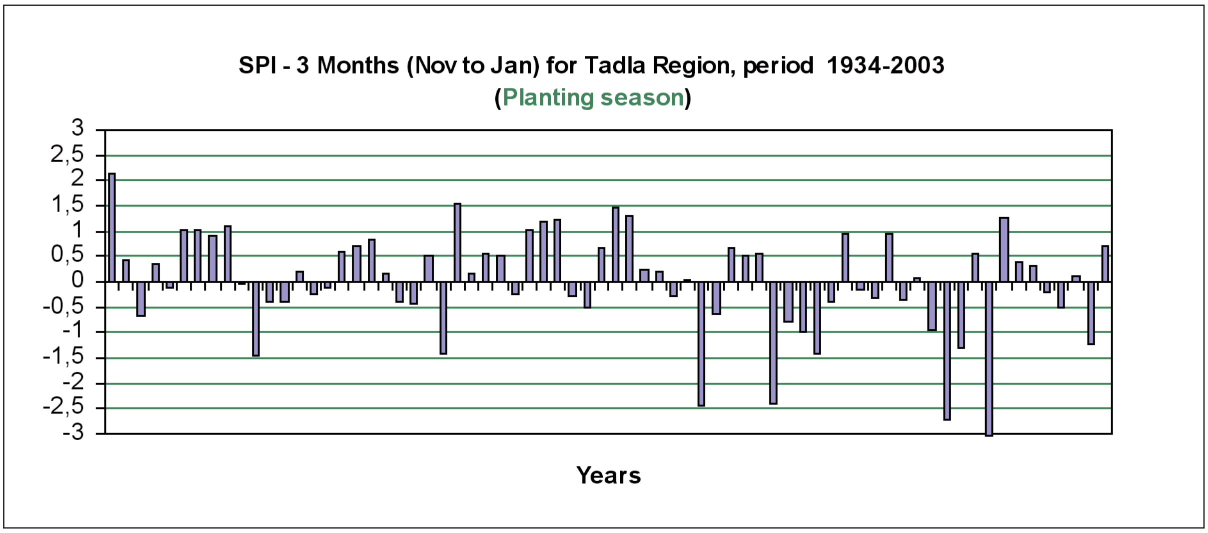
where P = non exceedence probability (%) of reservoir storage + streamflow,

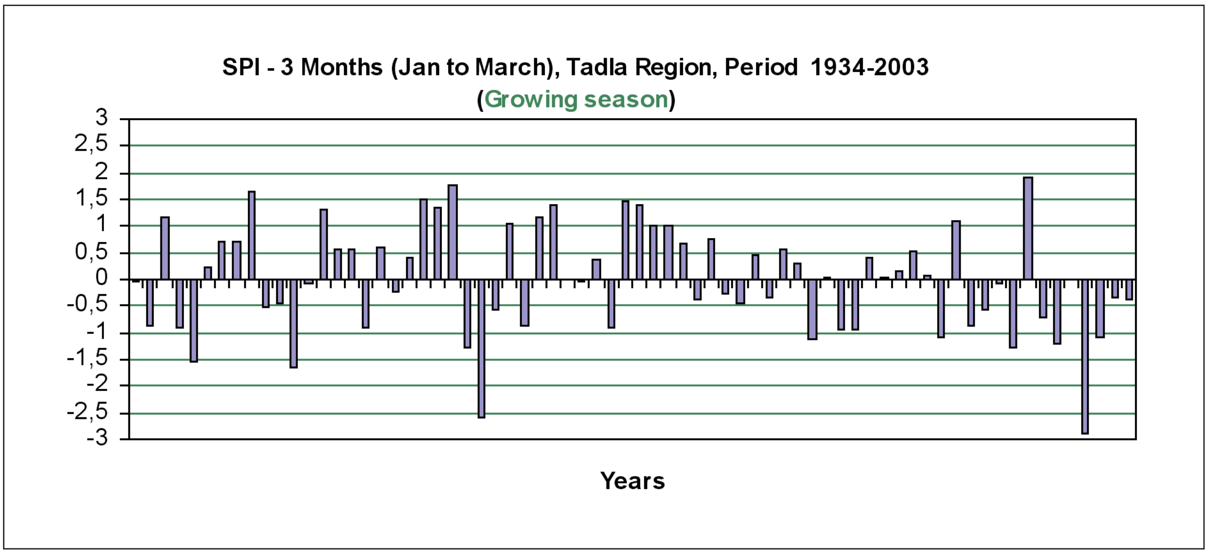
50 = centers the distribution on zero and,

12 = scales to existing ranges from -4.1 to + 4.1 for drought indices.

Use of RIBASIM Model

RIBASIM (River Basin Simulation Model) is a generic model package for analyzing the behaviour of river basins under various hydrological conditions (Delft Hydraulics, 2006).





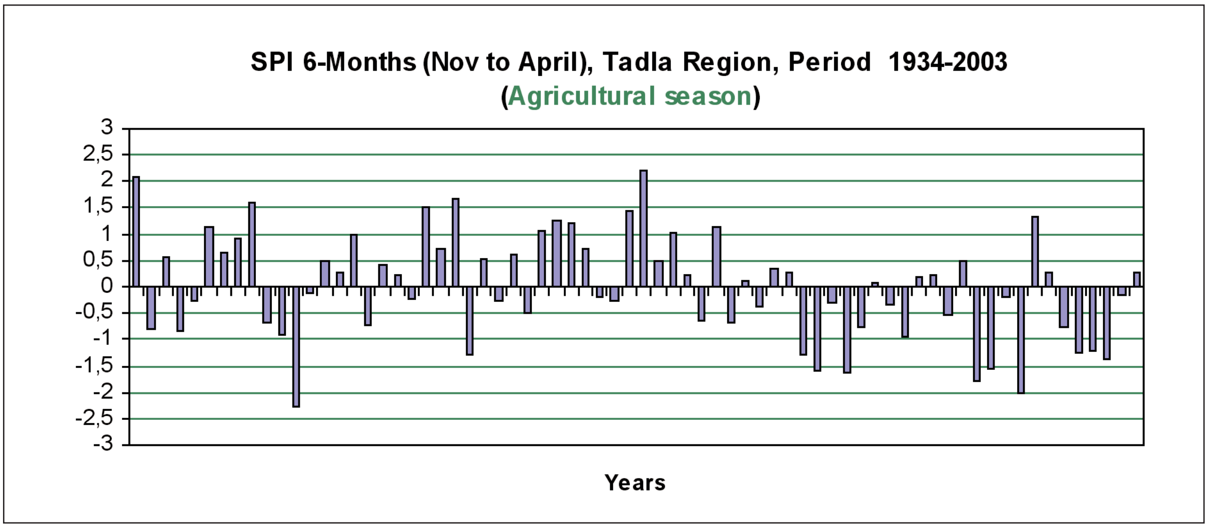


Fig. 8. Determination of SPI values at different time steps of cereal agricultural season for Tadla (Oum Er Rbia Basin).

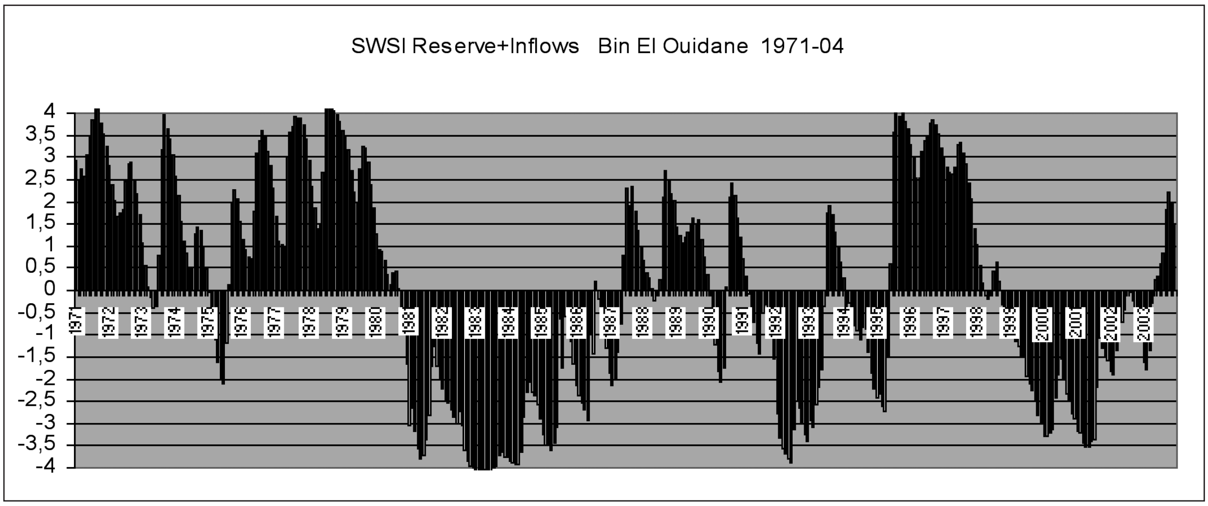


Fig. 9. SWSI values in the Oum Er Rbia River Basin over the period 1971-2004 for the Bin El Ouidane Dam.

RIBASIM enables the user to evaluate a variety of measures related to infrastructure, operational and demand management and the results in terms of water quantity and water quality. The RIBASIM model is currently used by water planners and managers within different big reservoirs in Morocco. It considers large number of variables to produce decision making tools at the river basin level. The inputs to the model are: water inflow; climatic data; dam reservoir characteristics; data from hydropower plants; data from water user sectors; and management rules. The outputs of the model are global basin water inflow, demand and supply in relation to probabilities of exceedence, and dam storage management curves which indicate different thresholds in relation to the water volume of the reservoir.

An example of such outputs is given in Fig. 10 for Bin El Ouidane reservoir in Oum Er Rbia Basin.

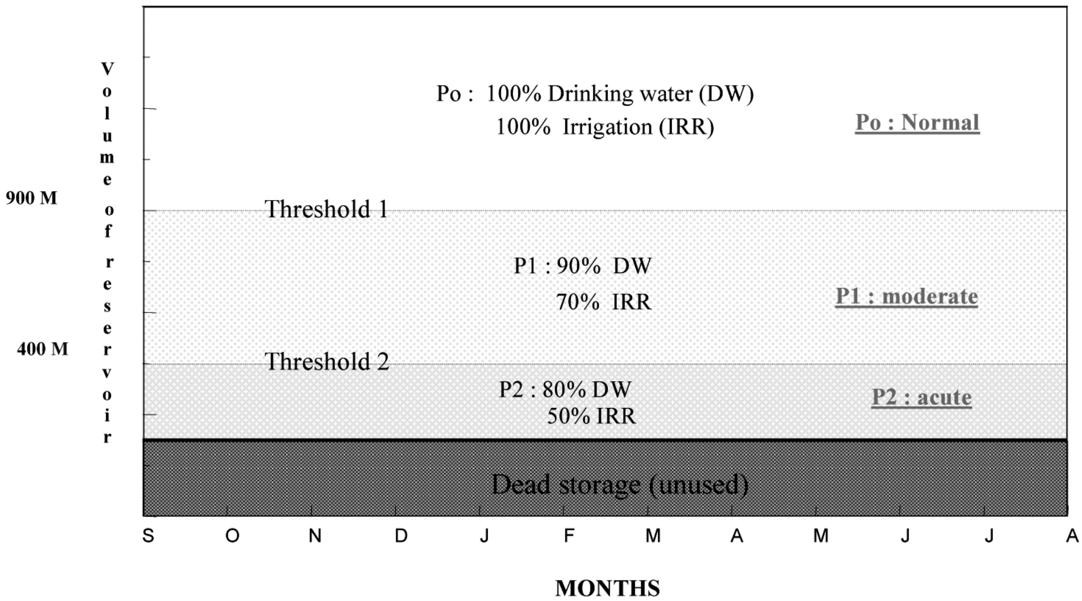


Fig. 10. Oum Er Rabia Dam storage management curve using Ribasim model.

Risk analysis in agricultural systems: Case Study of Oum Er Rbia Basin

A methodology is proposed to evaluate drought impacts and vulnerability and assess drought risks in agriculture. The analysis is applied at river basin scale by considering the case study of Oum Er Rbia Basin.

Methodology for Agricultural drought risk analysis and vulnerability assessment

Drought risk in agriculture is a product of both exposure to the hazard and the vulnerability of cropping practices in drought conditions. Therefore, the first step is to characterize drought hazard and then to assess the vulnerability of the agricultural system to the degree of exposure to this hazard. Impacts vary depending on type of production systems: rainfed systems, irrigated systems, and rangelands and livestock systems. Because of this diversity of impacts and vulnerabilities, adapted risk analysis methodologies and tools should be developed for each of these production systems. Here, focus is made on rainfed cereal production system in the river basin.

For this methodology, three steps have to be followed: (i) Characterization of drought hazard, (ii) Spatialization of drought hazard; and (iii) Drought vulnerability assesment

Step 1: Characterization of drought hazard in rainfed agricultural systems

In rainfed systems, cereals are the dominant crop and cereal yields are appropriate drought indicators. To characterize drought years, and their impact on cereal yields, two methods are used. The first is based on the yield threshold for profitability which is supported by field surveys and consists of defining a minimum yield level to cover the production charges for the crop to be profitable. The second method is based on the cereal production regression line over time which considers official recorded cereal yields to calculate the trend and its confidence intervals.

Once the dry years have been identified, several drought indices were tested for their predictive value of dry years. Among the tested drought indices, Deviation from Normal Rainfall, Deciles and Standardized Precipitation Index have proved to be simple and very useful for drought managers.

The relationship between the tested drought indices and cereal yields of dry years in different provinces within Oum Er Rbia River Basin is given in Table 4. The results clearly indicate the performance of SPI over the traditionally used indices for drought risk characterization. However, deciles analysis is also useful as complementary tool to characterize the extent of seasonal rainfall variability in order to make appropriate decisions, for example on crop planting in a given region.

Table 4. Correlation coefficients between cash a drought indices and cereal yield in different provinces of the Oum Er Rbia River Basin

Index	El Jadida	Khouribga	Settat	ElKalla	Safi	Azilal	Beni Mellal	Khenifra
SPI	0.74	0.76	0.73	0.65	0.75	0.58	0.63	0.65
% Deviation from normal	0.65	0.72	0.64	0.66	0.71	0.52	0.61	0.60
Deciles	0.65	0.72	0.64	0.66	0.71	0.52	0.61	0.60

Step 2: Spatialization of drought hazard

Drought spatialization is important for determining the vulnerable areas to drought over the entire basin. Mapping of drought risks can be performed by using any available drought index. However, for an adequate interpretation of the extent of drought within a given region and /or comparison of drought intensities between regions, SPI is best suited because of its standardised structure. SPI was used to map drought intensities over the Oum Er Rbia Basin, during the 1994-95 dry years and the 1995-96 wet years (Figs 11a and 11b).

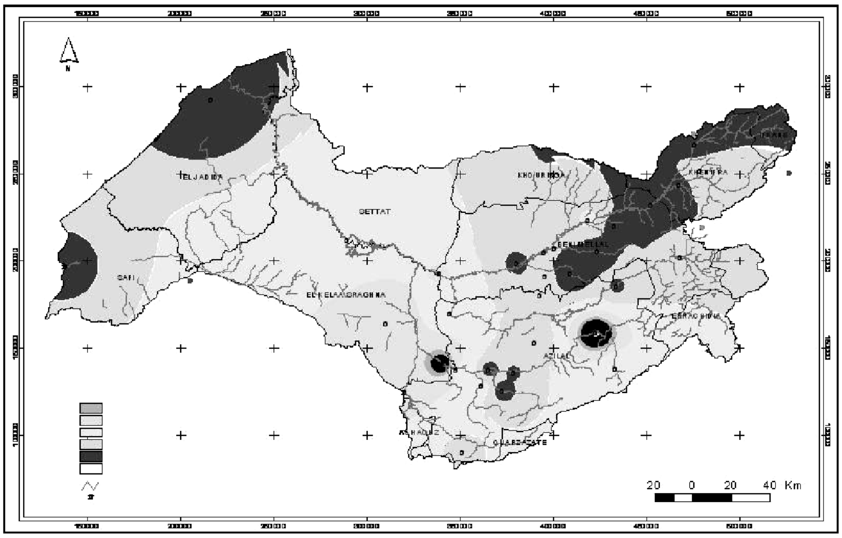


Figure 11a. Spatial drought characterization by SPI of the dry year (1994/95).

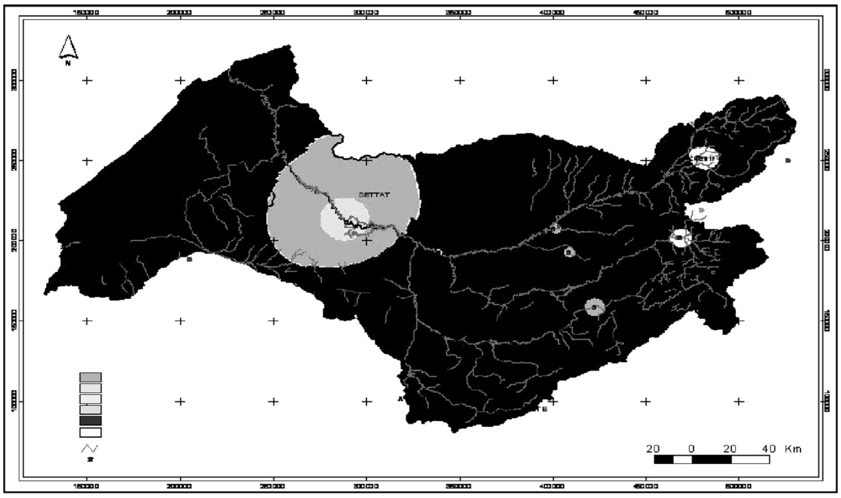


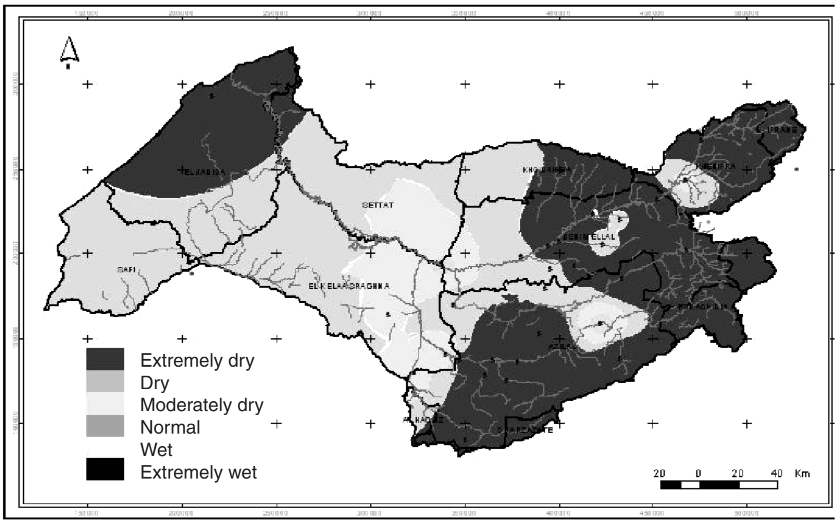
Figure 11b. Spatial drought characterization by SPI of the humid year (1995/96).

For the dry year 1994-95, the SPI was also used to map seasonal drought intensities for characterizing early season drought, mid-season drought and late season drought over the growing cereal crop cycle. The results are shown in Figs. 12a, b and c. The characterization of seasonal drought risk is important for farmers to select adapted crop species and appropriate planting dates, and for decision makers to decide whether or not to import cereal grains to meet domestic needs.

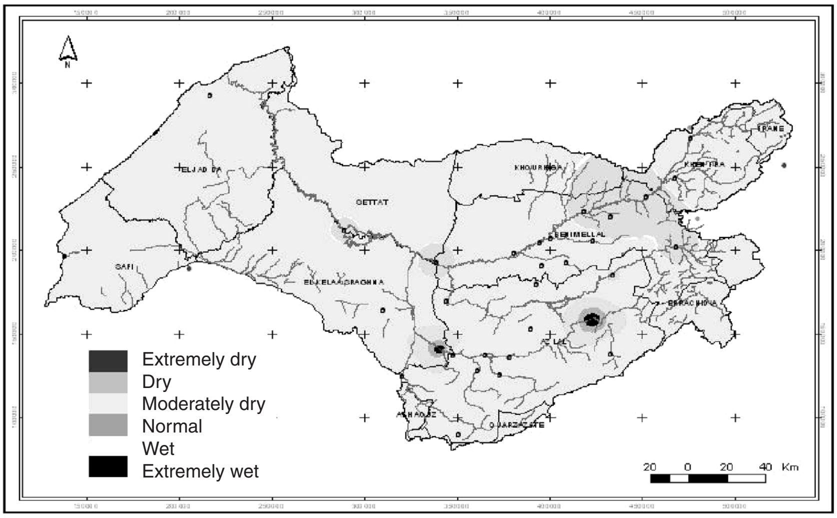
Step 3: Drought vulnerability assessment of agricultural systems

This method is aimed at establishing regional probabilities of crop vulnerability to agricultural drought following the methodology described by Wilhelmi (1999). A fundamental assumption underlying this approach is that the best characterization of the climatology of the basin from the agricultural drought vulnerability perspective is the probability of seasonal crop moisture deficiency. The agricultural drought begins when available stored water in the soil cannot meet the evaporative demands of the atmosphere. In order to determine the critical seasonal crop moisture thresholds for sustainable crop development and growth, seasonal crop-specific evapo-transpiration values were estimated.

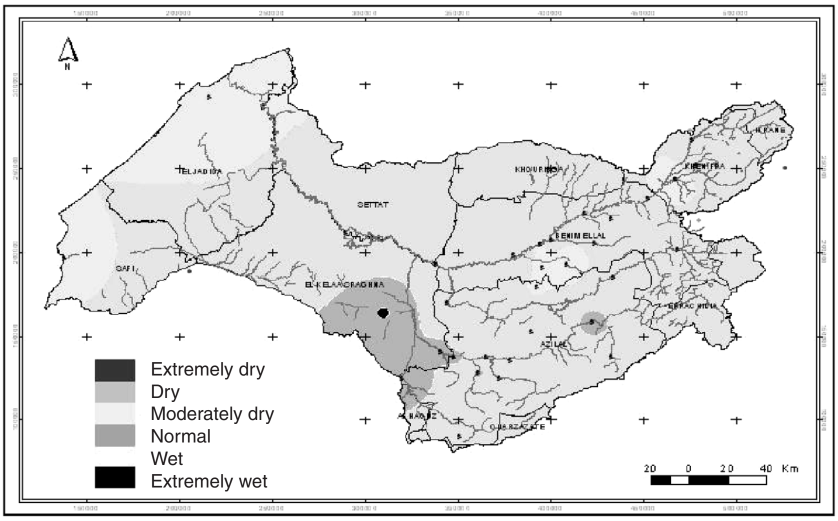
Droughts have spatial and temporal dimensions. The use of GIS for superposing data from different sources is found essential in many drought studies. The identification of key vulnerability



(a) Drought extent early in the season (Oct-Dec) as assessed by SPI.



(b) Mid season drought development (Jan-Feb) as assessed by SPI.



(c) Late season drought (March-May) as assessed by SPI.

Fig. 12. Seasonal drought characterization by SPI for the dry season 1994/95 in Oum Er Rbia Basin.

factors is based on their significance for agricultural sector. Analysis of drought in the Oum-Er Rbia Basin showed that biophysical factors, climate and soils, social factors, land use and irrigation, and socio-economic data such as sources of income, and the percent of acreage insured under crop insurance are the most significant factors of agricultural drought vulnerability.

Following Wilhelmi (1999), probability of seasonal crop moisture deficiency, soil root zone available water-holding capacity, and land use types maps were combined to produce an agricultural drought vulnerability map; GIS was used to determine the area extent of combinations of classes present. A numerical weighting scheme was used to assess the drought vulnerability potential of each factor. This approach is similar to those described for food security mapping (Eastman *et al.*, 1997) and drought proneness mapping (Thiruvengadachari and Gopalkrishna, 1993). Each class of four vulnerability factors has been assigned a relative weight between I and 4, with 1 being considered least significant in regard to drought vulnerability and 4 being considered most significant (Table 5).

Table 5. Weighting scheme for assessing agricultural drought vulnerability

Agricultural drought vulnerability factor	Vulnerability class	Drought vulnerability classes score (weight)
Land use types	Forests and bare land	1
	Rangeland	2
	Rainfed cropland	3
	Irrigated cropland	4
Soil root zone available water holding capacity (mm)	More than 150	1
	100-150	2
	50-100	3
	Less than 50	4
Probability of seasonal crop moisture deficiency (%)	Less than 20 (low)	1
	20-40 (moderate)	2
	40-60 (high)	3
	More than 60 (very high)	4

The final result of the combination of factors was a numeric value calculated by simple addition of the weights. A high numeric value within each category was assumed to be indicative of an area that is likely to be vulnerable to agriculture drought. The resulting map is reclassified into 4 classes identifying geographic areas with "low", "low to moderate", "moderate" and "high" vulnerability (Figure 13).

Most rainfed cropland is assigned to the "moderately" vulnerability class because large part of the land receives enough rainfall for cereal production, combined with soil types and cropping patterns. However, during drought events, the crop can be significantly damaged and farmers' income reduced. While the rangeland area is assigned of "high-to-moderate" vulnerability class; most of it is located in area of low rainfall and shallow or sandy soils which significantly affect, during drought events, livestock forage production and water supply. With proper drought management, such as keeping appro-priate stocking rates and storing above-average levels of forage for livestock when rainfall is sufficient, vulnerability can be lessened.

The identification of agriculture drought vulnerability can be a step in reducing the impacts associated with drought; it will lead to adjustment in agriculture practices and incomes loss during drought years. The map of vulnerability can help decision makers visualize the hazard and take actions. However, drought vulnerability should also include socio-economic data such as sources of income, percent of acreage insured under crop in-surance.

The map of drought vulnerability can help decision makers visualize the hazard and communicate the concept of vulnerability to agricultural producers, natural resource managers and others to adjust agricultural practices and select more appropriate cropping patterns in order to alleviate reduction in crop yields and income loss during drought years. Vulnerability maps are also important tools to orient policies, strategies and actions at national, regional and local levels.

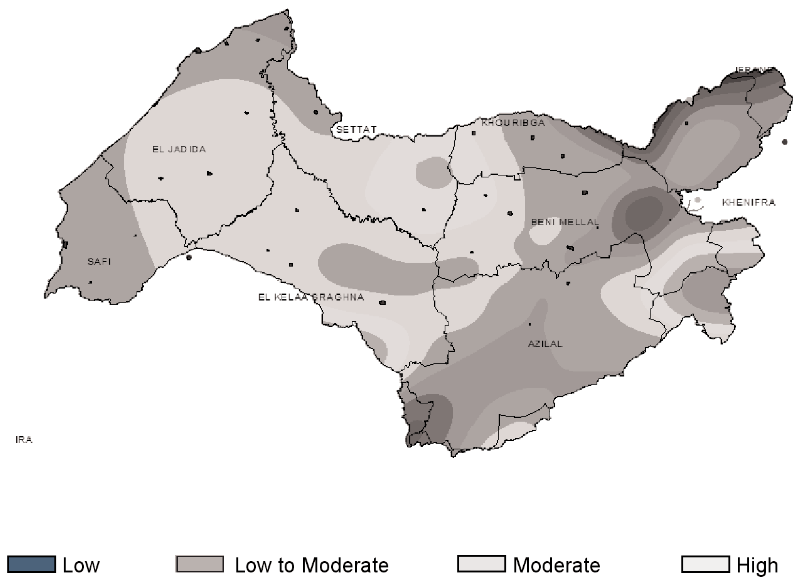


Fig. 13. Agricultural drought vulnerability of Oum Er Rbia Basin.

Operational component

Overall model of drought management in Morocco

This section describes the overall model for drought management in terms of decision making, coordination and implementation processes (Fig. 14). Overall coordination of drought management issues is the responsibility of the Permanent Interministerial Council for Rural Development (PICRD), which has ability to officially declare the onset of drought. The technical secretariat of this Council is under Ministry of Agriculture and Rural Development which heads the weekly periodic meetings of the Interministerial Technical Commission once a drought episode is declared.

National advisory board

In addition to the political board represented by the PICRD, the other members of the national advisory board on drought are the National Drought Observatory, the National Meteorology Office, the Superior Council for Water and Climate and the National Environment Council. The first two structures have advisory role to their respective ministry on a continuous basis while the last two others have much less frequent consultative role on drought issues.

National executive board

The Interministerial Technical Commission (ITC) is the basis of the executive board at the national level. It includes ministry representatives of Agriculture (MADR), Forestry (HCFWFD), Water (DGH, ONEP), Energy (ONE), Interior (MI), Health (MH), Finance and Credits (MF, CNCA). The ITC meets weekly to report to the Permanent Inter-Ministerial Council for Rural Development which, based on the Commission report and the information provided by the advisory bodies, may or may not declare drought and drought affected regions. If drought is declared nationwide, then the National Drought Mitigation Plan is set for execution. This is basically the reactive relief dimension of the plan that has to be implemented and supervised at the national, regional / provincial and local levels.

Regional and local setting of drought management

The Regional Drought Committee is headed by the Wali of the Economic Region. The regional drought committee is responsible for all decisions pertaining to the national drought mitigation plan related measures and actions to be implemented in the region. This committee includes representatives of key ministries (ONEP, ORMVA, DPA) and elected members of the rural and urban collectivities of the region, in addition to active NGO's operating in the region.

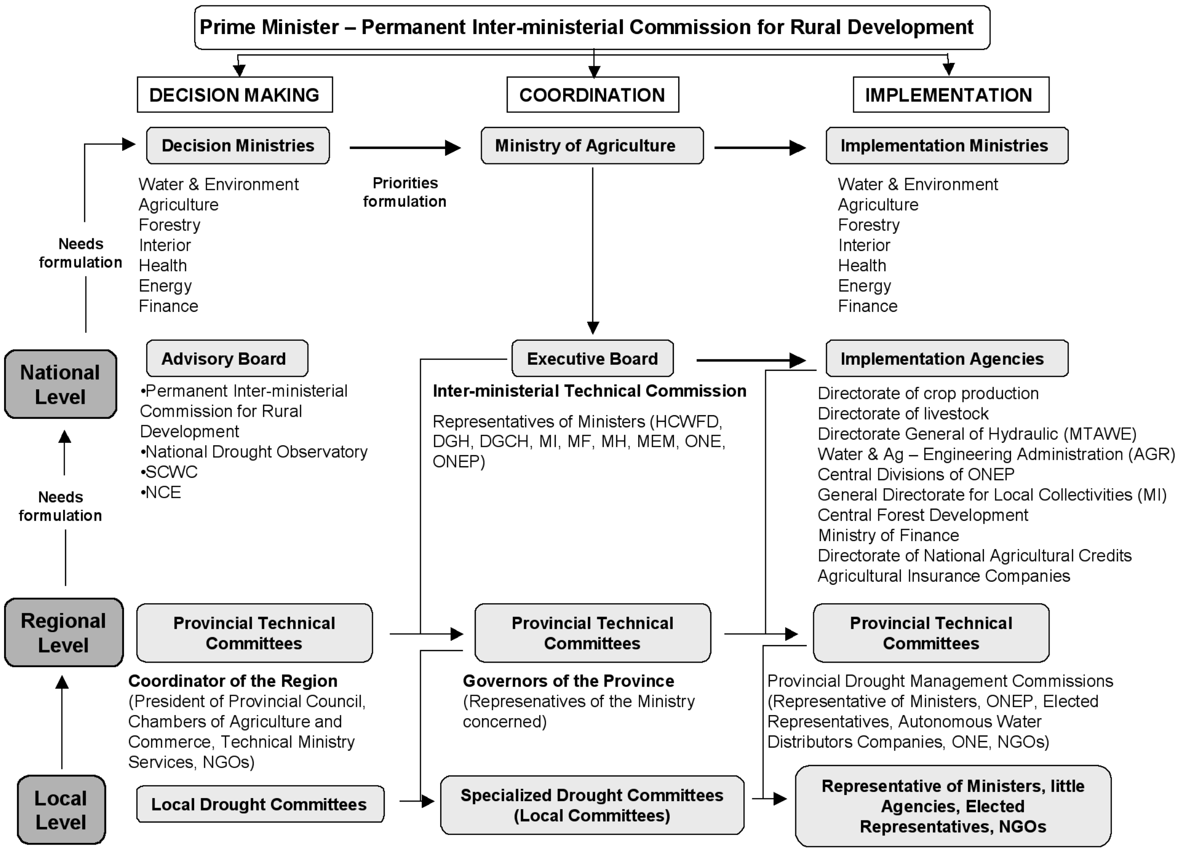


Fig. 14. Drought management in Morocco.

Current status of water and drought management and recent evolution

Actually, the State plays a major role in water resources management and is in charge of:

(i) Water mobilization

(ii) Irrigation water allocation

(iii) Water distribution

(iv) Water pricing

(v) Water allocation

(vi) Conflicts resolution

(vii) Registration of water rights

These multiple interventions have a huge cost to the State budget and have forced the Government to reconsider its options. It was estimated that the overall budget accounts for more than 90 % of total investment cost for irrigation. All the cost of water mobilization is also paid by the public budget. The cost of current policies explains the shift in favour of more involvement of the private sector and a change in cost sharing between the State and the water users.

Reactive and proactive action plans

Because of the severe droughts which dominated much of the country during the 1980's and occurred more frequently during the 1990's, the Government adopted in 1985 a reactive action plan to mitigate the drought effects in the form of relief operations which initially focused on population drinking water and livestock relief. However, the more dramatic subsequent development of the droughts and the growing awareness from the scientific community and civil society led the policy makers to adopt a more pro-active approach to this recurrent problem. As a result, the National Programme for Drought Mitigation has now two clear orientations, (i) an operationally oriented short term reactive programme with relief operations as the main focus, and (ii) a structurally oriented drought planning programme focusing on the long term pro-active approach to drought mitigation.

Consequently, a National Drought Observatory was proposed in 1999, and officially created in 2001 as a coordinating structure and also as a link between the scientific community working on various drought issues and the decision makers in charge of the drought mitigation activities.

National reactive plan for alleviation of drought effects

When a drought occurs nationwide, the policy so far applied consists of setting up a National Drought Programme. To implement the planned activities, funds are made available to combat the deleterious consequences of drought and to assist rural populations in solving the problems associated with, (i) drinking water, (ii) livestock protection, (iii) jobs creation, and (iv) agricultural credit debt relief. This is typically a crisis-management oriented approach whose cost is tremendous in terms of public money investment, time and human resource needs. For example, during the 1999 drought year, a total of MDH 3.18 billion (approximately USD 318 million) was allocated to the national drought relief programme, including 332 million dirhams for the drinking water component, 300 million dirhams for the livestock component, 1.91 billion dirhams to create job opportunities in rural areas, and the remaining was to cover the agricultural credit sub-programme.

Simplification of administrative procedures was proposed to speed up the execution of proposed drought mitigation activities and to improve their implementation efficiency. The procedures have been simplified with regard to: (i) definition of programme of activities to be undertaken to alleviate the drought impacts, (ii) visa and signing of the programme, and (iii) spending and payment regulations. For illustration purposes, the setting up of the programme of actions to be implemented is as follows: Description of detailed activities including clarifying the nature of operations, their locations, their costs, the schedules of realization and the budgetary lines for imputations. The programme must be established before the middle of April for urgent operations and before the end of April for the remaining activities to be realized between April and June. The proposed programmes of activities are then transmitted to the Prime Minister Cabinet and to the Ministry of Economy and Finances (Budget Directorate, General Control of the Spending and General Finance).

Meteorological drought and weather forecasts

Morocco has some 40 complete weather stations (called synoptic stations) operated by the Direction de la Météorologie Nationale (the National Meteorology Office). The Met Office has full-time meteorologists who monitor rainfall patterns and weather forecasts in relation to drought events, using different models and publishes a monthly newsletter on drought trends. Meteorological drought can be described in terms of reactive and proactive responses (Fig. 15). A series of triggers are used by Ministry of Agriculture for monitoring crop stage and the state of livestock and pasture, by Ministry of Water (as State Secretary) for monitoring and managing available water, and by Ministry of Communication for public awareness about development of the drought situation.

Agricultural drought – crop production and livestock

The reactive response to agricultural drought includes drought triggers, ministries involved to produce a national drought plan of action, the components of that plan and its implementation. The organization structure for implementation is shown in Fig. 16. Actions are of two kinds. A first series of measures concerns the financing of agricultural activities affected by the drought. Among these measures, a system of farmer insurance for cereal production failure, in case of drought, was also launched. A second series of measures concerns seed supplies, the objective being to increase seed availability for the next agricultural campaign.

The Crop Production Directorate collects information mainly through its regional structures. Every week during the drought period, a campaign document is prepared summarizing main events observed by province particularly on cereal growth and phenology development. This information –in addition to that provided by the Meteorological Office– is used to monitor the drought process during the growing season. Monitoring of dysfunction of market prices for basic commodities and agricultural inputs, along with pricing policies and subsidies during drought period is the responsibility of the Programming and Economic Affairs Directorate. Lack of a continuous recording system and of quantitative assessment of drought development in the different regions on a real time basis may be considered as the main weakness within the Ministry of Agriculture and Rural Development. Coordinating mechanisms for water management issues with the newly established Secretary of State for Water have yet to be reshaped.

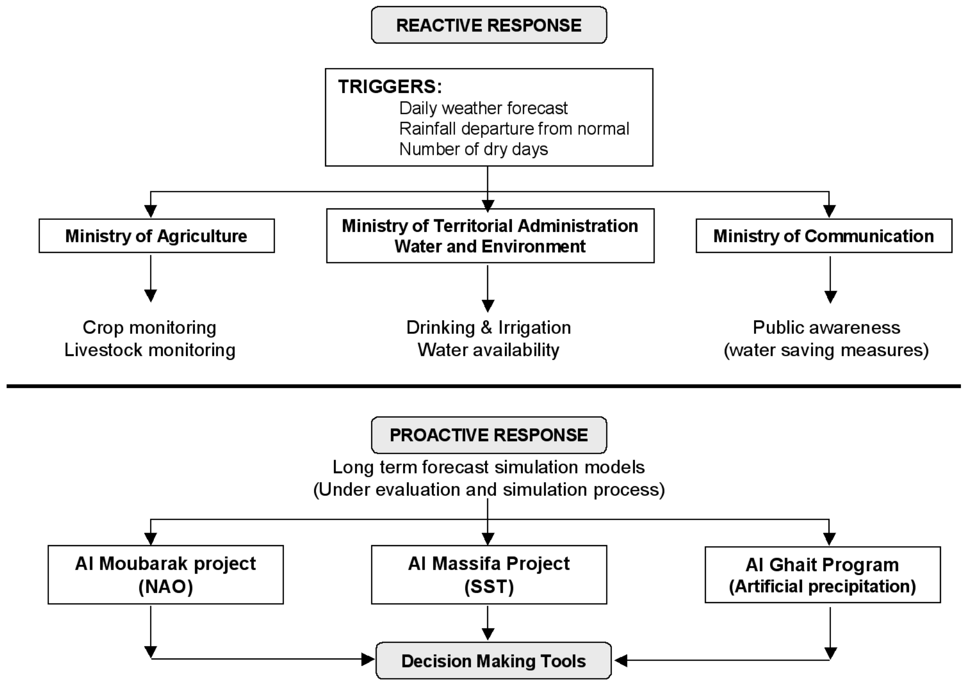


Fig. 15. Meteorological drought response in Morocco.

The Livestock Directorate receives information from Agriculture Provincial Directorates (rainfed areas) and from Agricultural Development Offices (irrigated areas), about the state of cattle feed supply, prices for animals and for feed, state of watering points for livestock, grazing land availability and herd sanitary states. Also, this Directorate closely monitors the animal feeding balance, and the imports of animals and animal products which are communicated by sanitary services control at country border. The livestock numbers surveillance system allows to control herd reduction during drought and to maintain a minimal population for reproduction. Collected information is analyzed by the services of this Directorate to elaborate necessary scenarios for decision-makers regarding livestock safeguard and protection. A weekly report is established on the drought impact situation and severity on animal productions. The main objective of the livestock safeguard and protection programme is largely to fill part of the fodder deficit to enable herders to overcome their financial incapacity to face important feed purchases to protect their herds. Under drought conditions, activation of the livestock safeguard plan is considered to be operational enough but independent evaluation of its impacts in different regions of the country is still to be carried out.

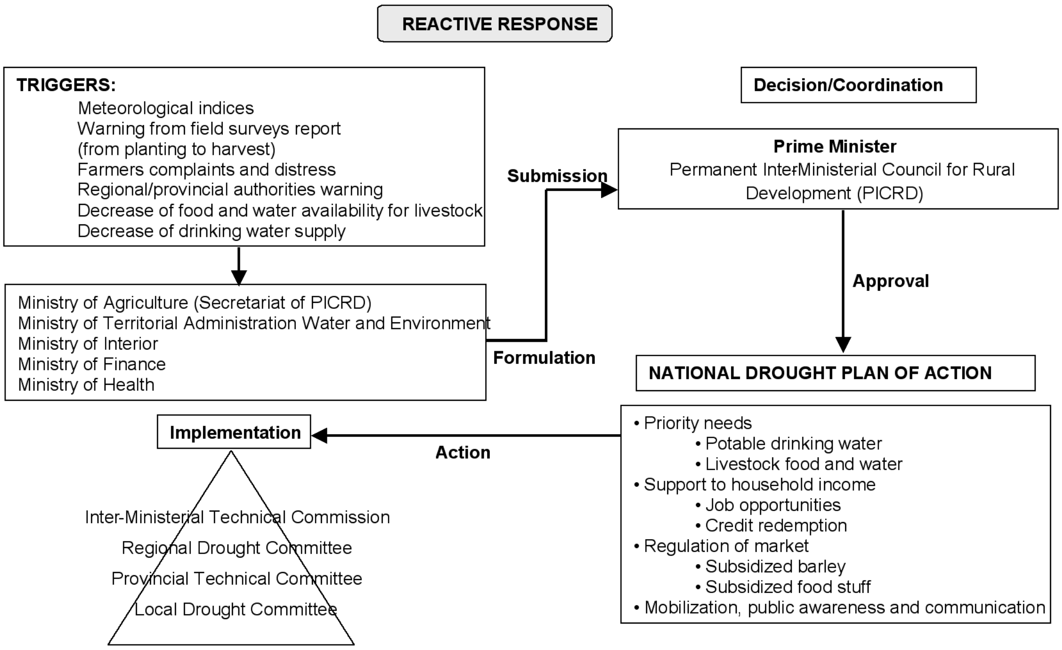


Fig. 16. Agricultural drought response in Morocco.

Hydrological drought and water management

The General Hydraulic Directorate has the responsibility of surface and underground water resources mobilization, water storage in the dams, and evaluates with the relevant structures of agricultural sector (mainly the Administration du Genie Rural, AGR) and other users the water needs throughout the drought period (Fig. 17). The evaluation is regularly made in joint meetings on the basis of indicators concerning the average rainfall deficit across the country, the amount of water stored in dams and the situation of the main groundwater tables. The outcome is a number of scenarios for water allocation by sectors (irrigation water, domestic, industrial). For each scenario, estimates are proposed to activate the water supply programme including: (i) Drinkable water supply of the urban and rural zones mostly affected by drought; (ii) Mobilization of water resources from groundwater by creation of additional water sources; (iii) Water supply for livestock in rural areas; and (iv) Water economy package including public awareness campaigns to adopt hygienic and water saving measures envisaged under drought conditions.

Responsibility for implementing the proposed measures is shared with other ministries departments and institutions, mainly Ministry of Agriculture and Office National de l'Eau Potable (National Office for Drinking Water, ONEP). The newly promulgated participation of the regional water basin agencies to decentralize decisions and to consider specific needs at the regional / local levels is an important element of equity. The participatory approach to decision taking with regard to water allocation under drought conditions is certainly a strengthening factor of the overall functioning of the system. However, conflicting views between the hydraulics and agriculture decision makers may alter the decision process with sometimes negative impacts on irrigated agriculture. This is particularly true when the level of stored water in the dams is not enough to have the right water allocation compromise between irrigation and other users.

Socio-economic drought

One of the major impacts of drought is the considerable loss of agricultural seasonal jobs and the risks of rural migration to urban areas which result from it. In order to maintain populations in rural zones, the Government has included in the national drought relief program job creation activities such as organization and construction of country roads, operations of land improvement like land stone clearing, and irrigation management operations of small and average hydraulic structures.

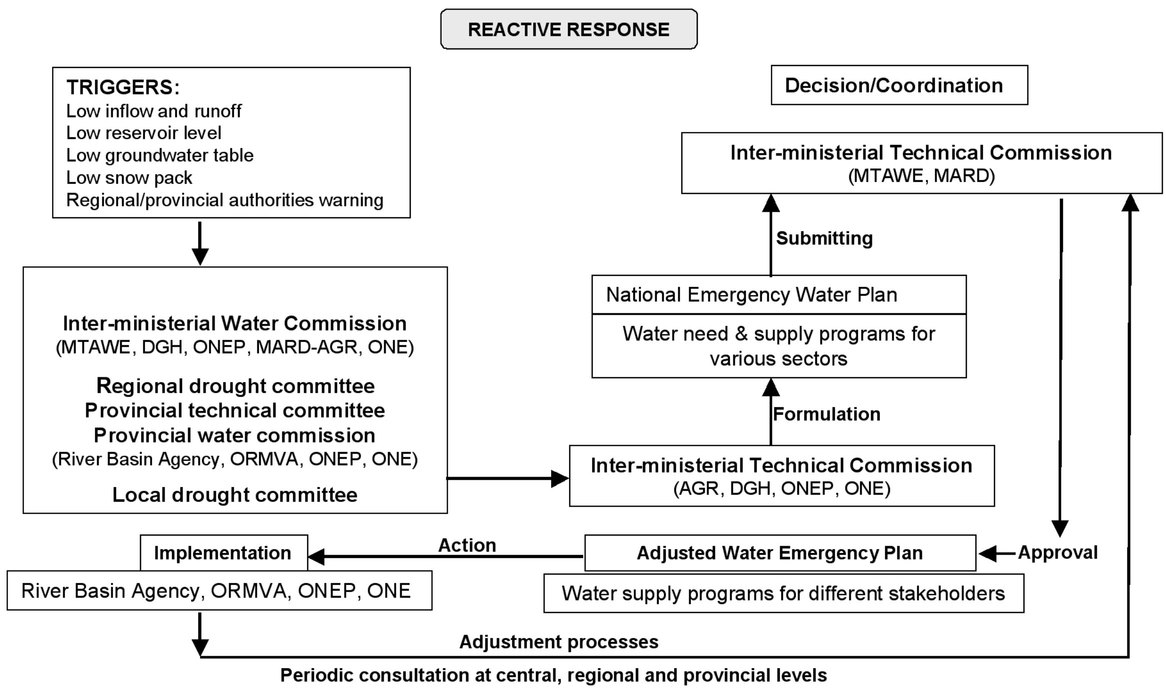


Fig. 17. Hydrological drought response in Morocco.

Proactive drought management

Following the severe drought episodes of the 80's, and the rising awareness among decision makers and the large public, the Government decided to set up a strategic drought planning and to move from the prevailing crisis management of the drought. In 1995, preliminary guidelines for a new approach to drought based on risk management principles provided the basis for a more proactive drought management approach in the country. The process is outlined in Fig. 18.

Working towards further development and implementation of this proactive approach, the Ministry of Agriculture and Rural Development and the Ministry of Public Works organized in 1999, in close collaboration with the Institut Agronomique et Vétérinaire Hassan II, an international workshop on "Drought management strategies in the Mediterranean". The purpose of this workshop was to gather information on the state of the art of drought planning and management by considering not only the local experience but also foreign experiences, with particular reference to Australia, South-Africa, Andalusia in Spain and to the US experience. The workshop recommended that promotion of risk management principles should be a key component of any strategy of drought management. It was also shown that drought risk management can be achieved by encouraging development of reliable climate forecasts and prediction, comprehensive early warning systems, preparedness plans, and mitigation policies and programs that reduce drought impacts and population vulnerability.

However, there are still weaknesses to overcome, the most important being:

(i) Institutional constraints associated with the major restructuring of the ministry departments dealing with water management.

(ii) Lack of availability of data and of clear mechanisms for the circulation of information as required by the proactive approach to drought management.

(iii) Lack of internal financial resources to meet the recurrent cost of the proposed activities for institutional capacity building in proactive drought management.

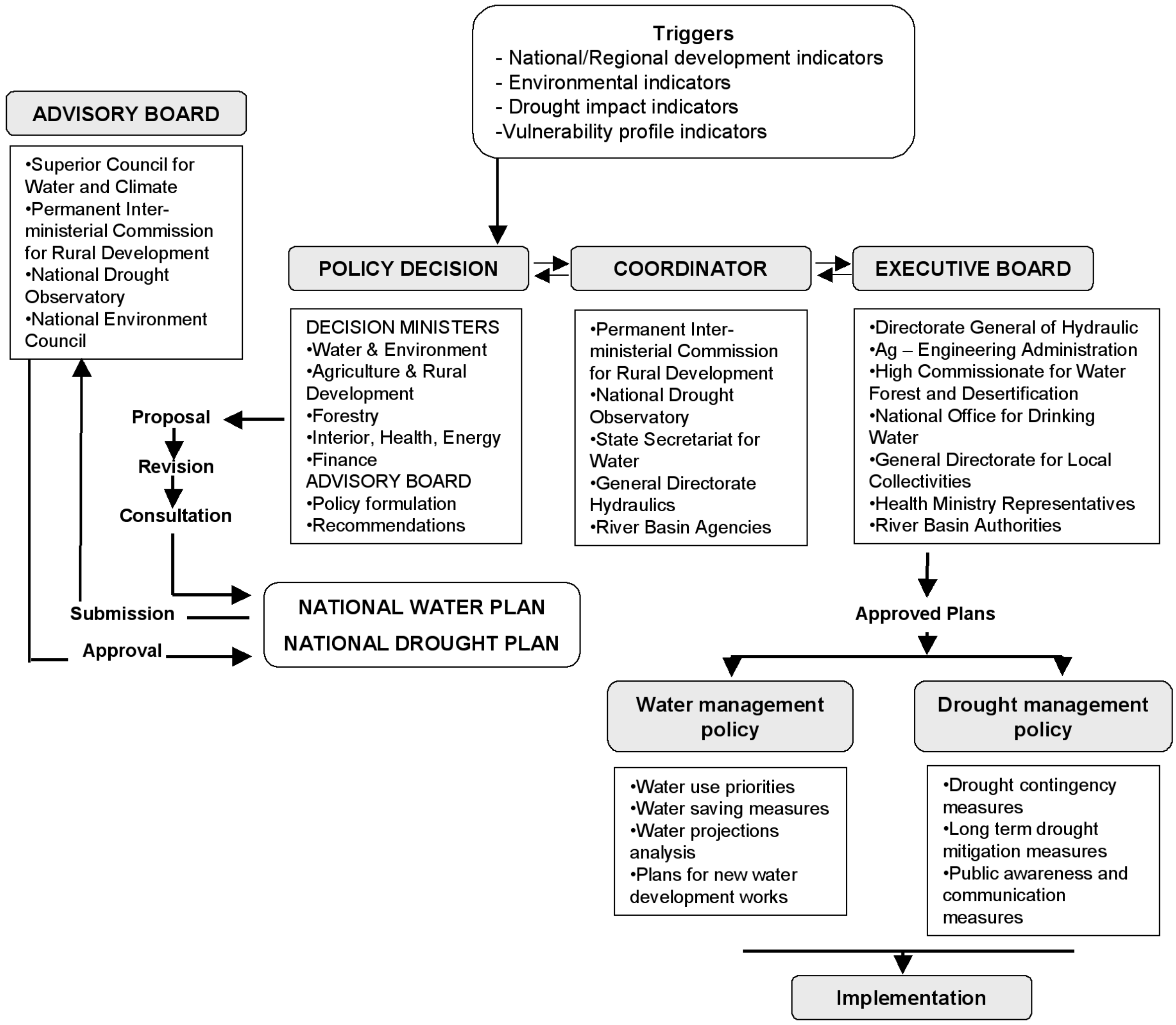


Fig. 18. Proactive responses in agricultural and hydrological drought in Morocco.

The National Drought Observatory

In 2001, the National Drought Observatory was created within the Ministry of Agriculture and Rural Development, and located on the campus of Institut Agronomique et Vétérinaire Hassan II (IAV), as a mean of building institutional capacity to cope with drought in Morocco.

The National Drought Observatory Center's specific objectives are to:

(i) Collect, analyze and deliver drought related information in a timely systematic manner.

(ii) Characterize drought and define reliable indicators that can provide early warning or emerging drought conditions.

(iii) Conduct vulnerability assessments to determine those sectors most at risk from the occurrence of drought.

(iv) Establish criteria for declaring drought and triggering mitigation and response activities.

(v) Ensure timely, accurate assessment of drought impacts.

(vi) Establish procedures to evaluate the effects and impacts of drought programs.

At the national level, the Observatory is managed by the Ministry of Agriculture and Rural Development, through a central management unit located at IAV Hassan II. In addition to the involvement of the central administrations of the Ministry, its regional structures are also involved in the proposed operational activities during implementation of the National Programme for Drought Mitigation. The Observatory has indeed to work with the Centre Royal de Télédetection Spatiale (Royal Centre for Remote Sensing), and has to develop links with the other ministerial structures and institutions, basically the National Meteorology Office and the Hydrology Administration (Water Department), the Department of Environment, the Department of Forestry, and the Ministry of Higher Education and Scientific Research through university centers. Other national partners may join the network as activities around drought management develop.

At the international level, the National Drought Observatory is supported by the US National Drought Mitigation Center, University of Nebraska, Lincoln, and by USDA. The Observatory has also organized a joint workshop with the US Corps of Engineers on the shared vision methodology for water management under drought conditions. Further developments of scientific links are being established with other institutions and centers. Since its creation in 2001, the Observatory has developed training programmes on proactive drought management approaches to meet the needs of national professionals and has organized an advanced course at IAV Rabat with Mediterranean Agronomic Institute of Zaragoza (IAMZ) on drought management strategies in the Mediterranean. On this occasion, the need to create a Mediterranean Network on Drought Preparedness was highlighted and discussed. This development led to the creation of the NEMEDCA Network with FAO, ICARDA, and CIHEAM / IAMZ. Of direct relevance to the MEDROPLAN project, the National Drought Observatory organized the Regional FAO Workshop on ''National Capacity Building for Drought Mitigation in the Near East Countries" which was held in Rabat, 1-5 November 2002, and where the latest developments on water management policies and drought preparedness issues in 14 countries of North Africa and the Middle East were presented and discussed.

Conclusions

The major lesson from the analysis of the previous situations is that drought is a structural of the Moroccan climate and that the fight against the drought cannot be improvised. It has on the contrary to be written down in a way perfectly integrated into the national strategies of water resources development and management. This is evident all the more as the hydrological context is fragile in consideration of the frequency of drought, the irregularity of the climate and the steady pressure exercised on water resources by more and more conflicting demands.

The consultative institutions in charge of advising the various line agencies and ministries regarding water and drought management do not have regulatory powers. They issue recommendations and approve plans. The regulatory functions over water utilities, in irrigation as well as in municipal water distribution, are usually mixed with operational duties as planning, project financing and supervision, and supervision of line agencies. The list of ministerial bodies involved in the sector shows very clearly the shortcomings of the actual setting, although improved by the consultative bodies.

In the current setting, stakeholders do not have always a proper say on water issues, except locally by the control over municipal water through the Local Authorities, which work under the supervision of the Ministry of Interior. However, slow change is taking place. This change will be supported because NGOs and civil society are more active in this field, and water user associations are gaining more autonomy in their dialogue with the administration.

The dispositions relative to the sensitization of the populations for water economy and on water resource use rules allowed easing in a significant way the effects of water shortage. However, the analysis a posteriori of the past management showed the lack of preparation of the country to face this kind of situation. It followed in certain cases a delay in the decision-taking to engage the necessary capacities for the drought management.

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Annex 1. Data and information systems

Summary of Institutions that collect, record, and process data that provide a representation of natural processes and socio-economic patterns related to drought in Morocco.

Category	Institutions	Type of data
Climate Water	DMN, Forestry, ORMVA, DPA, SCWC DGH, AGR, DPV, ONEP, SCWC, River Basin Agencies, Autonomous state-controlled companies, ME/Water	Meteorological Surface water, Groundwater, Water quality control Water use and allowances
Land	DAF, DPV, ANCFCT, CRTS, MI, DCL, ME	Land use, topography, land census, administrative and ecological zoning
Agriculture	MADR, DPAE, DPV, DE, AGR, CGDA, DEPAP, CNCA, MAMDA, ONICL, INRA, IAV, ENA, CRTS, ME,	Agricultural census, statistics (area, type of farms, labor, production, prices, export and import), Research and development activities
Forestry	CFLD, DDF, DREF, ENFI, IAV, ME	Forestry (areas, products, prices)
Socioeconomic	DPAE, MI, IAV, ENA, INRA,	Population, macroeconomic indicators, Universities and NGOs production costs
Energy & Mine	MEM, MC, ONE	Statistics by activity, energy consumption
Finance	MF	Statistics by activity, Studies reports, Outlook report

Annex 2. Potential impacts of drought

Summary of potential drought impacts in the Oum Er Rbia Basin based on responses of stakeholders. Impacts range from 0 (not important) to 5 (most important).

Impact	Oum Er Rbia Basin rank
ECONOMIC: WATER SUPPLY	
Additional cost of supplemental water infrastructures	1
Additional cost of water transport or transfer	1
Decrease in hydroelectric power generation	2
Decreased revenues of water supply firms	3
Increase in water tariffs	2
Increase in water treatment costs	3
Increased cost of ground water extraction	3
Reduced service quality	3
Other (please specify)	
ECONOMIC: AGRICULTURE	
Decrease in farm income	4
Decrease in land prices	2
Decrease in livestock feed quantity and quality	4
Decrease in rangeland and pasture production	4
Decrease of agricultural labour	4
Decreased crop production	4
Decreased crop quality	3
Decreased water in farm ponds for irrigation	4

Impact	Oum Er Rbia Basin rank
ECONOMIC: AGRICULTURE	
Increase in consumer credits in rural areas	1
Increase in crop imports	2
Increase in food prices	3
Increase in insects, pests, and crop diseases	4
Increase in livestock diseases	3
Increase of farm subsidies	3
Increased crop insurance premia	1
Increased soil erosion	4
Increased unemployment of the agricultural sector	5
Livestock production: water quality and quantity	3
Loss of farm income	4
Loss of income of industries dependent on agriculture	3
Losses in financial institutions related to agricultural activities (e.g., credit risks)	3
Revenue losses to state and local governments (from reduced tax base to farmers)	3
Other (please specify)	
ECONOMIC: FISHERIES	
Decrease production of fishery	0
Other (please specify)	
ECONOMIC: FORESTRY	
Decreased production of forests	2
Other (please specify)	
ECONOMIC: INDUSTRY	
Changes in the energy cost (e.g., due to changes in hydroelectric by oil)	0
Electric power unbalance (Increased energy demand and reduced supply)	2
Income loss of manufacturers and sellers of recreational equipment	0
Other (please specify)	
ENVIRONMENTAL	
Biodiversity loss in ecosystems associated with water	4
Biodiversity loss in land based ecosystems	2
Changes in estuarine areas (e.g., salinity levels)	2
Changes in the migration and concentration of animal species (loss of wildlife in some areas and too many species in others)	2
Decrease in reservoir and lake levels	4
Deterioration of visual and landscape quality (e.g., dust, vegetative cover, etc.)	2
Deterioration of air quality (e.g., dust, pollutants)	1
Ground water depletion and land subsidence	3
Increase erosion of soils by wind and water	2
Increase in diseases in animals (e.g., due to low quality of water or poor feed)	3
Increase in diseases in plants (e.g., due to low quality of water)	3
Increase in invasive weeds and algae	3
Increase in number and severity of fires	4
Increased stress to endangered species	3
Reduction of the wetland areas	2
Water quality effects (e.g., salt concentration, increased water temperature, pH, dissolved oxygen, turbidity)	2
Other (please specify)	

Impact	Oum Er Rbia Basin rank
SOCIAL	
Appearance of human health related problems (from water and air quality deteriorations)	2
Conflict appearance in management	3
Conflict appearance in media or science	3
Conflict appearance in political decisions	4
Conflict appearance in water use	5
Damage in cultural heritage sites	2
Danger to public safety from forest and range fires	3
Decrease in the visits to a recreational area	2
Decreased nutrition quality in subsistence farm areas	2
Deterioration of aesthetic values	2
Increase in the poverty level in rural areas	4
Increased migration to urban areas form agricultural areas	4
Public dissatisfaction with government regarding drought response	5
Other (please specify)	

Chapter 20. Application of the Drought Management Guidelines in Spain

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SUMMARY – The Spanish case study presents the drought planning process carried in the Tagus Basin. The presentation is structured in four parts: organizational, methodological, operational and public review components. The organizational component presents the framework and specific legislations and the organizations and institutions in Spain that work on drought preparedness and mitigation. The methodological component presents the analytical techniques used for drought risk analysis and management. The operational component describes the proposed structure for the drought management plan and presents the specific actions that are contemplated in it. The process review component identifies stakeholders that are involved in the decision making process and presents their views on the process.

Key words: Tagus Basin, regulated systems, water supply, agricultural, urban, probabilistic, deterministic.

Organizational component

Legal framework

Embid Irujo (2003) recognizes two main legal sources of the Spanish water codes and statutes: derived from the Spanish Constitution and from the European Union Water Framework Directive. These two legal bodies are on top of the hierarchy of laws and statutes pertained to water and droughts. Three instrumental laws are identified as the main precursors of drought preparedness and planning: The Water Law, the Law of the National Hydrological Plan and the Agricultural Insurance Law.

The Water Law (WL) was approved in 1985, reformed in 1999, and consolidated in 2001 in a Royal Decree (Real Decreto Legislativo 1/2001, 20 July 2001) with slight amendments with respect to the 1999 version. The Spanish Water Law can be considered a modern and comprehensive water code, covering all issues and aspects related to water policies, organization, procedures, finance, civil works, planning, and public participation. Among the key Water Law provisions that pertain to droughts are:

(i) Water-rights holders can make use of their rights insofar Basin Authorities approve them and issue concrete management plans detailing all possible uses for the current hydrological year (Articles 55 and 58).

(ii) Water use plans and reservoir release decisions are taken by the Basin Authorities, as proposed by the Reservoir Release Commissions and Management Boards (Articles 32 and 33). Droughts are considered exceptional circumstances.

(iii) The formal declaration of a "drought" allows the Government to initiate any project, work, or action under fast track approval procedures.

(iv) Right-holders are allowed to freely exchange their water use rights, but the transfer requires approval of the Basin Authority and is subject to various regulatory provisions (Articles 67-70). Works and projects needed to solve emergent scarcity problems are considered works that promote the general interest (Article 46), and as such, their approval procedures and financing enjoy preferential treatment.

(v) Basin Authorities can create Water Exchanging Centres, through which right holders can offer or demand use rights in periods of droughts or severe water scarcity situations (Article 71). The initiative to create these Centres must be proposed by the Environment Ministry and be approved by the Ministerial Cabinet. If the exchanges centres or the water rights transfers involve two different basins they must be explicitly approved by the Environment Ministry.

All Spanish Hydrological Basin Plans were approved by the Royal Decree 1664/1998 (Real Decreto 1664/1998, of July 24th). In compliance with Article 60 of the Water Law, reliability criteria were established that guarantee minimum allowances for the irrigation and urban sectors for the medium and long term. The criteria are specified by a range of probabilities of supply failure during one, two, or ten consecutive drought years.

The Law of the National Hydrological Plan (Ley 10/2001, of July 5th, de Plan Hidrológico Nacional) consolidates all planning decrees pertained to each of the inter-regional basins, and lays down the basic principles of the Water Planning at the national level. Droughts are explicitly mentioned in Article 27 establishing:

(i) The Environment Ministry will establish a system of hydrological indicators to support the formal declaration of alert situation and droughts by Basin Authorities.

(ii) Basin Authorities should develop special action plans for alert situation and droughts, including the management rules and the programme of measures to be applied on the water public domain under these situations.

(iii) All public administrations that are responsible of supplying urban water services to cities with more than 20,000 inhabitants must develop an Emergency Plan. This Plan must be approved by the relevant Basin Authority and take into account the special action plans mentioned in the previous point.

The Agricultural Insurance Law (Ley 87/1978, 28 December 1978, de Seguros Agrarios Combinados) lays the framework and institutional organization of the Spanish system of agricultural insurance policy. Droughts are mentioned among the risks recognized in the law to be covered by the insurance policies (Article 3). The specific development of various insurance policies covering yield losses caused by droughts (and other abnormal natural events) has given rise to a menu of options that are currently available to most crops grown under dry-land regimes. Some of these will be described below.

In addition to the above, there is also extensive legislation and normative related to water management and water policy. In general the laws, statutes, and norms focus on reactive drought management, providing conditions for emergency actions. In the case of the insurance normative, the laws from 2001 to present have a pro-active character.

Institutions involved in water and drought management

River Basin Authorities

The administrative body that is responsible for providing public service regarding water management in the basin is the Basin Authority, with competence on inland water and groundwater. The Basin Authority is an autonomous public organization that depends from the Ministry of the Environment. The River Basin Authority structure is the following:

Chairman, appointed by the Council of Ministers at the proposal of Ministry of Environment, for inter-regional basins, and at the proposal of the Autonomic Communities the when is an intra-regional basin.

Management Board ("Junta de Gobierno"). Headed by the Chairman, includes representatives of the Ministries of Environment, Agriculture, and Energy; and regional governments whose territories are part of the basin and users (at least 33% of the board members). It is in charge of: financial matters, general action plan, definition of aquifer depletion and groundwater protection, and drought by creating an ad-hoc Permanent Committee.

Operation Boards ("Juntas de Explotación"). Co-ordinate the management of hydraulic works and water resources in specific areas. The Waters Act establishes composition of the Board according to the importance of each user group in the basin, but it includes the administration, public and private water supply companies, irrigation associations, hydropower companies, and industrial users.

Assembly of Users ("Asamblea de Usuarios"). Headed by the Chairman, includes all users that are part of the Operation Boards. Co-ordinates the management of hydraulic works and water resources throughout the basin.

Dam Water Releases Commission ("Comisión de Desembalse"). Headed by the Chairman, and members selected by the Assembly of Users. Responsible for proposing the system for releasing water from reservoirs, and flood measures (through the creation of a special Permanent Committee).

Water Basin Council ("Consejo del Agua de Cuenca"). Headed by the Chairman, and includes representatives the central and regional governments, technical services, and users including NGOs and professionals (at least 33%). It approves the Basin Hydrological Plan, which is then referred to the central Government.

Hydrological Planning Office ("Oficina de Planificación"). Defines, monitors, and reviews the Hydrological Basin Plan, and provides technical support to the Water Basin Council.

Other institutions

The Ministry of Agriculture is responsible for irrigation planning, the implementation of publicly funded water schemes and the development of irrigation improvement schemes.

The Agricultural Insurance Agency (ENESA), that has the character of an Autonomous Agency dependent on the Ministry of Agriculture, Fisheries and Food through the Under-Secretariat of the Department, acts like a coordination organization and link on behalf of the Administration for the development of Agricultural Insurances. The Institution is headed by the Undersecretary of the Ministry of Agriculture, Fisheries and Food and has a Director that is designated by the Minister of Agriculture, Fisheries and Food.

The Insurance Compensation Consortium acts as an essential re-insurer of the system and has been entrusted the monitoring of the consultancies and taking on the percentage of co-insurance not covered by the insurance institutions.

The Permanent Office for Adverse Climate and Environmental Situations depends from the Ministry of Agriculture, Fishing and Food, General Secretariat of Agriculture and Food. It is directed to an agricultural environment, and acts through the generation, execution and monitoring of measures undertaken to mitigate drought effects.

Methodological component: Drought characterization and risk analysis

Challenge to water management in Spain

Water resources in Spain are limited, scarce, and difficult to predict from year to year. The average annual potential water availability per capita considering the total freshwater resources is 2,700 m^3 compared to 3,807 m^3 in the EU-15 and 7,000 m^3 worldwide (Aquastat, 2005), but some Spanish regions have less than 1000 m^3 per capita and year, such as the Southeast regions and the Islands. In addition, real available water resources in Spain are less than half of the total freshwater resources.

Regulated water resources account for 40% of the total natural resources, compared with 8% worldwide, since the potential use of surface water under natural regime is only 7% (Garrote *et al.*, 1999). Groundwater use is intensive in many areas of the country contributing to an additional 10% of the total available resources. With limited and scarce water resources and demand rising due to demographic shifts, economic development and lifestyle changes, water management problems are significant even without drought events, due to the imbalance between availability and demand. Water use in the country is mainly for agriculture (irrigation accounts for 68% of the water demand), nevertheless the other economic and social water demands are rapidly increasing, such as tourism (current urban demand is 13%) and ecosystem services (Aquastat, 2005).

Storage and regulation by reservoirs do not always solve the problem of water scarcity in areas where dry periods are particularly damaging to the natural and human wellbeing. Eutrophication is a major problem in southern areas of Spain, where 40% of the reservoirs show biological oxygen demand, conductivity, and nitrogen and phosphorus concentrations well outside the adequate range (Estrela *et al.*, 1995). These water quality parameters usually get worse during dry periods due to the depletion of reservoir storage. This factor may play a significant role during crises since water from certain reservoirs may not be acceptable for human consumption.

In Spain, groundwater resources play a vital role in meeting water demands, not only as regards quality and quantity, but also in space and time, and are of vital importance for alleviating the effects of drought (Garrido *et al.*, 2000; Llamas, 2002). However, groundwater pumping should be controlled because excessive use of the aquifers can cause overexploitation problems with the consequent negative environmental, social and economic impact. Direct use of groundwater in Spain is currently estimated at 5 km^3/year, mainly for irrigation use (80%), but the water quality is easily deteriorated due to point-source pollution or diffuse pollution caused by agricultural and livestock activities (Estrela *et al.,* 1995).

Wetland area in Spain has decreased from over 1200 km^2 in the 1970s to less than 800 km^2 in the present time (excluding the Guadalquivir marshlands). This decrease may be in part related to recurrent drought episodes and surface water scarcity, and amplified by the excessive groundwater pumping to compensate for these problems.

The case study: Tagus Basin

The Tagus Basin is located in the central part of the Iberian Peninsula. The main river runs on east-west direction, with a contributing area of 83,678 km^2, of which 55,870 km^2 are located in Spain and the rest in Portugal. Due to the transboundary nature of the basin, a certain amount of water has to reach the river in Portugal, determined by the Albufeira agreement. The Tagus Basin also supplies water to the Segura Basin, a water scarce basin in eastern Mediterranean area of Spain. Table 1 outlines the water balance of the Tagus Basin.

Table 1. Hydrological balance in the Tagus Basin

Water balance	Water use	Sector	Mm^3/year	Mm^3/year
Total available water resources				12180
Demands				5780
	Inside the basin	Urban	740	
		Irrigation	1780	
		Refrigeration	1390	
		Environmental	1440	
	Outside the basin	Transfer to the Segura Basin	430	
Losses	Consumption		1650	2210
	Evaporation		560	
Water leaving the system	Transfer to the Segura Basin			430
	Water to Portugal			9540

Water resources in the Tagus Basin are dominated by irregularities of the hydrologic regime that originate frequent and severe drought episodes. There is a long tradition of water use in the Basin, with 12 main water supply systems equipped with well-developed infrastructure for regulation, transportation and distribution of water resources (Table 2). In some of these systems, water demand is a large fraction of average resources. Due to the imbalance between water availability and demand in drought years, there is an extensive experience in hydrological management, but recent drought events have questioned the capacity of some systems to meet increasing demands with the available water resources.

Table 2. Characteristics of the main water supply systems in the Tagus Basin

System	Mean flow (Mm^3/yr)	Coeff. of Variation	Min. flow (Mm^3/yr)	Storage (Mm^3)	Demand (Mm^3/yr)
Cabecera	1200	0.48	350	2400	980
Tajuña	51	0.59	12	68	30
Henares	150	0.56	15	240	110
Sorbe	170	0.46	20	53	50
Madrid	750	0.42	200	900	500
Alberche	650	0.51	110	250	180
Toledo	62	0.73	1	32	12
Tiétar	900	0.52	155	115	170
Alagón	1300	0.48	312	911	510
Árrago	267	0.51	45	125	110
Salor	32	0.66	0.57	14	11
Trujillo	6.4	0.59	0	1.5	1.5

Streamflow regulation in the Basin

The diverse characteristics of regulation systems in the Tagus basin are illustrated in Fig. 1. The figure presents the simulated time evolution of water storage in three systems under current conditions of demand and infrastructure for the period 1940-1993: Alberche, Madrid and Cabecera. The Alberche system consists of two main reservoirs with maximum storage capacity of 250 Mm^3. The system supplies a local demand of 180 Mm^3/yr with average inflows of 650 Mm^3/yr, with a coefficient of variation of 0.51 and a minimum of 110 Mm^3/yr. It also supplies a maximum of 120 Mm^3/yr to Madrid in drought periods.

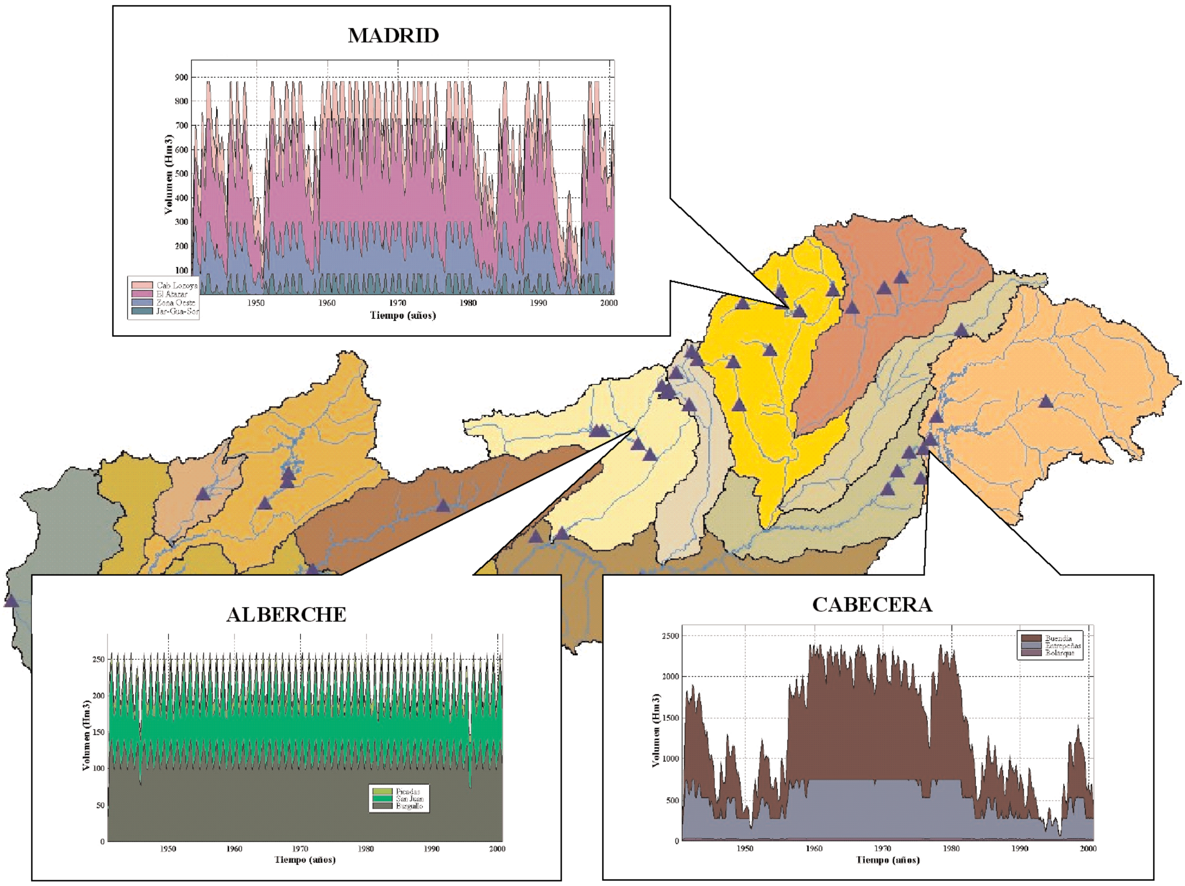

Fig. 1. Different regulation systems in the Tagus Basin.

Regulation in the Alberche system is based on an annual cycle. Storage is depleted significantly only in very dry years, and it usually returns to normal levels in the following year. The Madrid water supply system consists of 17 reservoirs in the Jarama and Guadarrama basins with total storage capacity of 900 Mm^3. The average inflow to the reservoirs is 750 Mm^3/yr, the coefficient of variation is 0.42 and the minimum of the historic series is 200 Mm^3/yr. Regulated surface waters supply an urban demand in Madrid of 500 Mm^3/yr, although the system has other alternative sources, such as groundwater or transfer from the Alberche basin. The regulation cycle in Madrid is normally annual, but persistent droughts can affect reservoir levels during two or three consecutive years. The Cabecera regulation system consists of two reservoirs with total storage capacity of 2,400 Mm^3. Mean annual flow is 1,200 Mm^3/yr, with a coefficient of variation of 0.48 and a historic minimum of 350 Mm^3/yr. In this system, the regulation cycle is hiperannual, with long dry and wet periods. Over-the-year storage is crucial to supply demands in dry periods, which may last one decade or more.

Meteorological and hydrological drought

No single indicator or index can identify drought. Many efforts have been made to characterize drought by using a range of indices (Rossi *et al.*, 2003; Wilhite, 2000, Vogt and Somma, 2000). Classical drought indices, such as the Standardized Precipitation Index (SPI), (Hayes *et al.*, 1999) or the Palmer Drought Index (Palmer, 1965), are widely used to characterize meteorological drought. These indices do not correlate well with hydrological drought periods or historical drought impacts, due to the effect of storage (Flores-Montoya *et al.*, 2003). Many of the more complex indices that take storage and management into account are not easily interpreted across regions and cannot be validated with the data available over wide geographical areas. Therefore, managers of water resources tend to rely on precipitation and streamflow variables to determine the onset of drought.

Figure 2 shows the time series of aggregated precipitation in Spain defining meteorological drought episodes, and the SPI calculated at 24 month intervals, defining hydrological drought. The two variables are correlated (correlation coefficient = 0.75) and a threshold value of the SPI index of -1.0 may be taken as an alert indicator of drought (Hayes *et al.*, 1999). Many studies have characterized comparable precipitation patterns at different geographical scales (De Luis *et al.*, 2000; Estrela *et al.*, 2000). The Figure also shows the extremely large variability characteristic of Spanish precipitation and the recurrent multi-year drought episodes. The Figure shows at least two periods with different precipitation trends, highlighting the importance of choosing the adequate reference period for developing indicators for management. Precipitation in the latest period, from the 1960s has clearly decreased.

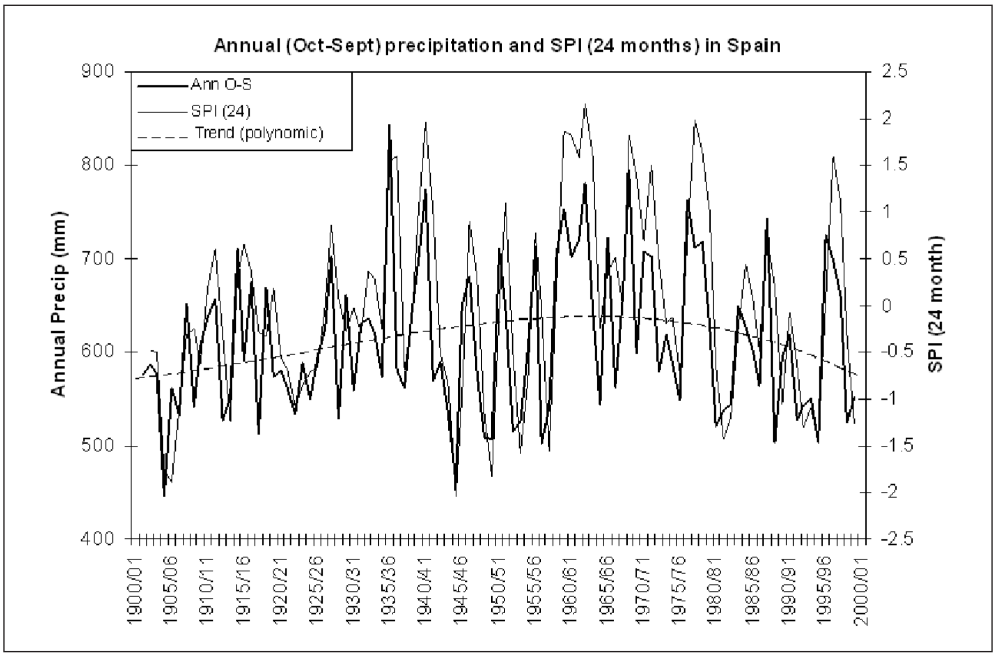

Fig. 2. Time series of aggregated annual precipitation and SPI values (24 month time scale) in Spain. (Data source: The Tyndall Center database TYN CY 1.1).

The very low precipitation of the 1940s defined the historical drought during that period, with severe consequences for the economy. The structural water deficit of many areas in the country has been aggravated during three severe drought episodes (1975-76, 1981-82, and 1992-95), each more severe than the previous one. During these droughts, besides the collapse of irrigation water supply, urban water supply series were affected significantly.

Drought characterization in highly regulated systems is complex and calls for multiple indicators. The slope of accumulated deviation of precipitation from the mean (Fig. 3) is an indicator that highlights drought patterns relevant to hydrological management. The Figure highlights the recurrent multi-year characteristic of drought periods in Spain and the value of continuous monitoring for preparedness. Also, this indicator is related to other variables that are more difficult to monitor, such as groundwater levels.

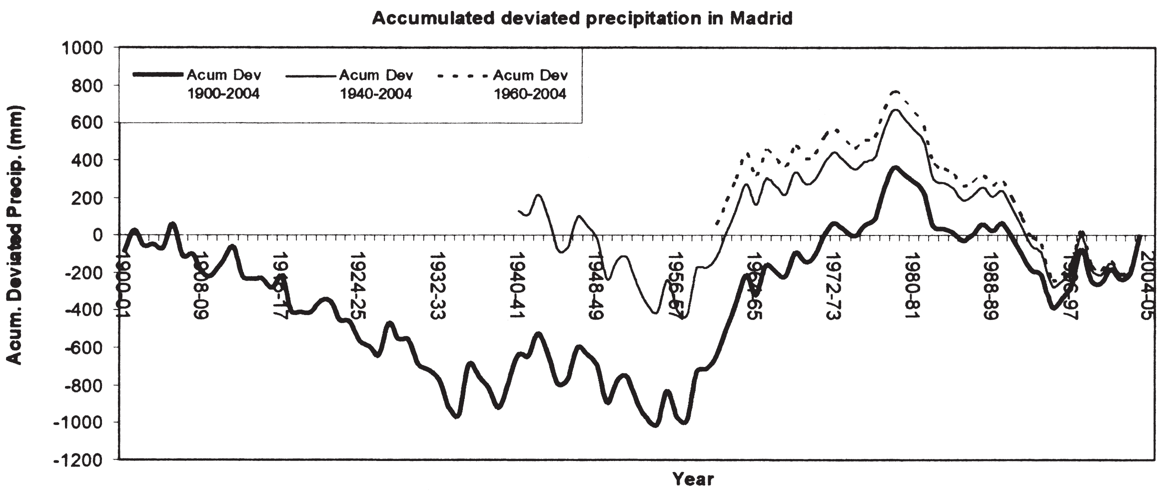

Fig. 3. Accumulated desviated precipitation in Madrid. (Data source: Tagus River Basin Authority).

Components of hydrological drought monitoring systems

The basis of any drought management plan is a robust system of indicators that can identify and diagnose anomalies in water availability and can provide the basis for early detection of drought episodes. A comprehensive study of hydro-meteorological time series and drought indices in the Basin (Flores-Montoya *et al.*, 2003) led to the definition of a drought indicators system. The system is in continuous revision, taking into consideration the availability of new information and the progress in knowledge of the hydrologic behaviour of the Basin.

Variables used as early warning levels to predict droughts are grouped in two categories: informative and executive. Informative variables provide information on the development of the drought, and are used as a monitorization tool. Executive variables are objective indicators that are used to trigger specific actions in an operational context.

Drought is a complex phenomenon that evolves slowly in time and may affect different regions with varying levels of intensity. No single indicator can encompass the complexity of drought development (Hisdal and Tallaksen, 2000). Effectiveness is greatly enhanced if multiple indicators are used to describe drought extension and severity. Values used in the Tagus Basin are: significant departure from normal values in cumulative precipitation or streamflow during the hydrologic year in representative rain and stream gauges, reservoir levels, classical drought indices, like the Standardized Precipitation Index or the Surface Water Supply Index (Garen, 1993), abnormal thickness of snow pack during winter months and depletion of piezometric levels in aquifers.

The combination of the above indices and indicators can provide decision makers with enough information to understand the drought phenomenon and estimate its effect. Although these informative indicators are very useful to understand and characterize droughts, management of a multidimensional array of indicators can limit the effectiveness of decision making. In the drought management plan, the monitoring system should be linked to specific actions through a limited set of indicators that can be used as triggers of drought mitigation measures. For this reason, a subset of indicators has been selected as executive variables, which are used as thresholds to trigger specific actions.

Water managers are ultimately concerned by drought if it affects water supply. A robust indicator of hydrological drought is reservoir storage. Figure 4 shows the time series of inflow in Bolarque, a reservoir near Madrid with a contributing area of 7,420 km^2. The behaviour of this series appears to be non-stationary, or, at least, highly variable with a period between wet and dry spells clearly beyond the possibilities of regulation for water supply (Flores-Montoya *et al.*, 2003). Data show a possible intensification of drought conditions in recent years, during the decades of 1980's and 1990's. If a linear trend is fitted to the data, the slope is clearly negative, with a decrease of more than 8 Mm3/yr every year.

However, since droughts were also important during the 1940's and 1950's, the question arises as to whether recent droughts are a consequence of man-induced climate change or there is a multi-annual cycle of wet and dry conditions with a period of about 40 years over the time period analyzed. Classical drought indices, such as the SPI, have limitations for analyzing regulated systems. Although the correlation between streamflow and SPI over the time series is 0.54, the SPI threshold of -1 does not capture severe water shortages such as the one of the mid 1990s that led to emergency actions (see below: Supporting legislation).

The variability of streamflow at Bolarque reservoir in the high course of the Tagus Basin was not completely understood when a water-transfer facility was planned. The Tajo-Segura aqueduct diverts water from the Tagus river at Bolarque and transports it to South-East Spain. The aqueduct was designed during the wet period using data that, at that time, seemed to be reliable, but the subsequent evolution of streamflow showed a significant reduction of mean flows and forced a change in the planned exploitation of the infrastructure. The Bolarque example also represents the complexity of the indicators that need to be included in a drought characterization system. In the case of water for irrigation, indicators for drought risk extend to water allocation options (Gomez-Ramos and Garrido, 2005).

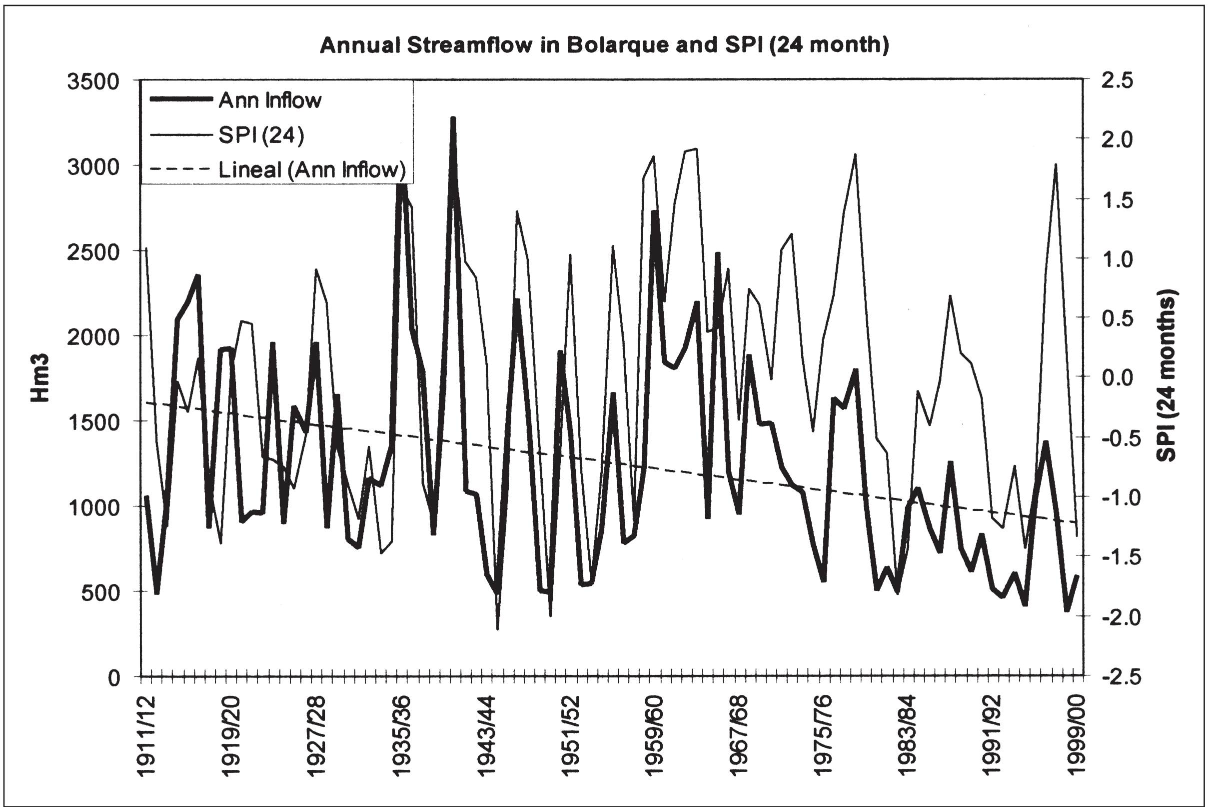

Fig. 4. Time series of inflow in Bolarque and SPI calculated for a 24 month time sale in Madrid (data source: Tagus River Basin Authority).

In some cases, the indicators do not reflect the real impact of drought. Figure 5 shows results from the simulation model used in the Tagus Hydrological Plan for the Henares Basin (sub-basin of the Tagus Basin, east of Madrid), compared to SPI index in the Basin. Shortages of water supplied to the demands of the Henares Basin are poorly correlated with SPI due to the effect of reservoir storage. The fact that the system has enough regulation capacity to supply the demand with high reliability and relatively scarce failures is probably one of the reasons for this low correlation. When the demand exceeds the available water resources, as in Southern Spain, drought episodes may result in failures in demand supplied (del Moral and Giansante, 2000).

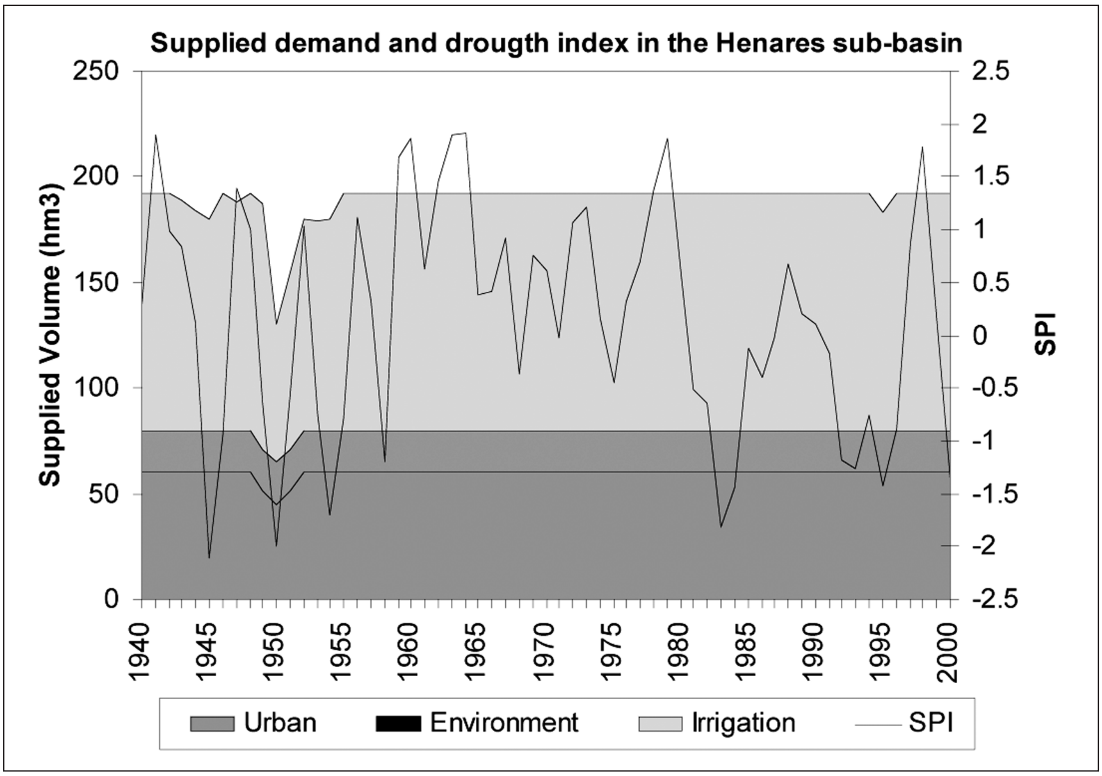

Fig. 5. Demand supplied in the Henares Sub-basin (Tagus Basin) and historical droughts calculated with the SPI.

The value that best describes water scarcity in regulated systems is the reduction of water stored in strategic reservoirs below critical levels. Whenever the development of a meteorological drought is being discussed, water managers check for stored water in the reservoirs in order to decide whether there is a significant risk of water deficit. Reservoir storage complies with most of the requirements proposed by (Steinmann *et al*., 2005) for drought indicators and triggers and are ideal for decision making, because they can be interpreted in terms of risk of failure of the systems.

Therefore, from the operational perspective, the executive set of variables that have been selected to link with actions in the drought plans are the sum of volumes stored in the reservoirs in every system. These values are readily available through the hydrographic service, and are of public domain, so users can have easy access to them.

Hydrological risk analysis

The proposed methodology for hydrological risk analysis is based on two main requirements: objectivity and simplicity. Objectivity is unavoidable, since drought management actions affecting users rights will be based on the results of the analysis. The requirement for simplicity is justified by the necessity to submit the results of the analysis to discussion and approval by all stakeholders in the Basin Water Council. Complex models based on sophisticated analyses are difficult to understand and may not be trusted by affected users. It is expected that once the drought plan is approved and put into operation, the simplicity requirement may be relaxed progressively, as users become more familiar with the methodology.

Probabilistic analysis

The objective of the analysis is to define the thresholds for the declaration of the pre-alert, alert and emergency scenarios. 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 droughts, the vulnerability of the demand to deficits of a certain magnitude, etc.

The basic tool is the development of a simplified model of the water resources system. The model considers only a single reservoir, with storage capacity equal to the sum of all reservoirs in the system. Inputs to the system are the regulated flows, which are flows in the contributing basin to the reservoirs, and non-regulated flows, which enter the system downstream of the reservoirs. The model simulates the operation of the reservoir considering losses to evaporation and restrictions imposed by environmental constraints.

The model was initially used to estimate the volume that is required every month to satisfy 100% of the demand during different time horizons. The results for the three representative systems in the basin (Alberche, Madrid and Cabecera) are shown in Fig. 6. These results show the different nature of regulation in the three systems, although the hydrologic regime of natural resources is similar in all of them. Droughts in the Alberche have impacts during more than one year only occasionally. In the Madrid water supply system the effects are seen during three and even four years. In the Cabecera system the effects of droughts have longer persistence, spanning several years. Variations in demand and reservoir volume compared to natural resources explain these differences.

By analyzing the results produced by the model, graphs like those presented in Fig. 7 can be obtained. The graphs on the left show the cumulative probability distribution for every month of required storage volumes to supply 100% of the demand during a time horizon of 1 year with a given amount of storage. In a probabilistic sense, these may allow to estimate the probability of satisfying 100% of the demand during 1 year given the volume stored in the reservoir in a certain month. The graphs shown on the right represent the required storage volumes corresponding to different quantiles (0.5, 0.75, 0.9, 0.95 and 1).

The graphs shown in Fig. 7 and similar graphs generated by changing model parameters (the time horizon or the fraction of the demand that is satisfied) may be used as a basis to declare pre-alert, alert and emergency scenarios.

The definition of parameter values to declare drought scenarios in every system is currently under discussion. There are two main factors to be considered in this discussion: The vulnerability of demands and the effects of drought declaration.

The characteristics of demands in every system are the first factor to assign values to model parameters. Demands having only one single source of supply are more vulnerable and require stricter parameter values than those having alternative sources. In this group, demands having such sources available exclusively to themselves are less vulnerable than those sharing them with other demands. The Alberche system provides water supply for urban, irrigation, hydropower, and recreational uses, and is the major source of emergency water supply to Madrid. Although local demands in the Alberche system have good reliability, the drought situation in Madrid can affect all uses in the Alberche system significantly.

The expected effects of drought declaration should also be balanced versus drought risk. In systems where demands are close to average natural resources, like, for instance, the urban water supply to Madrid, there is little margin for action, and drought declaration may have very important social and economic impacts. Most emergency measures for Madrid imply having to alter existing

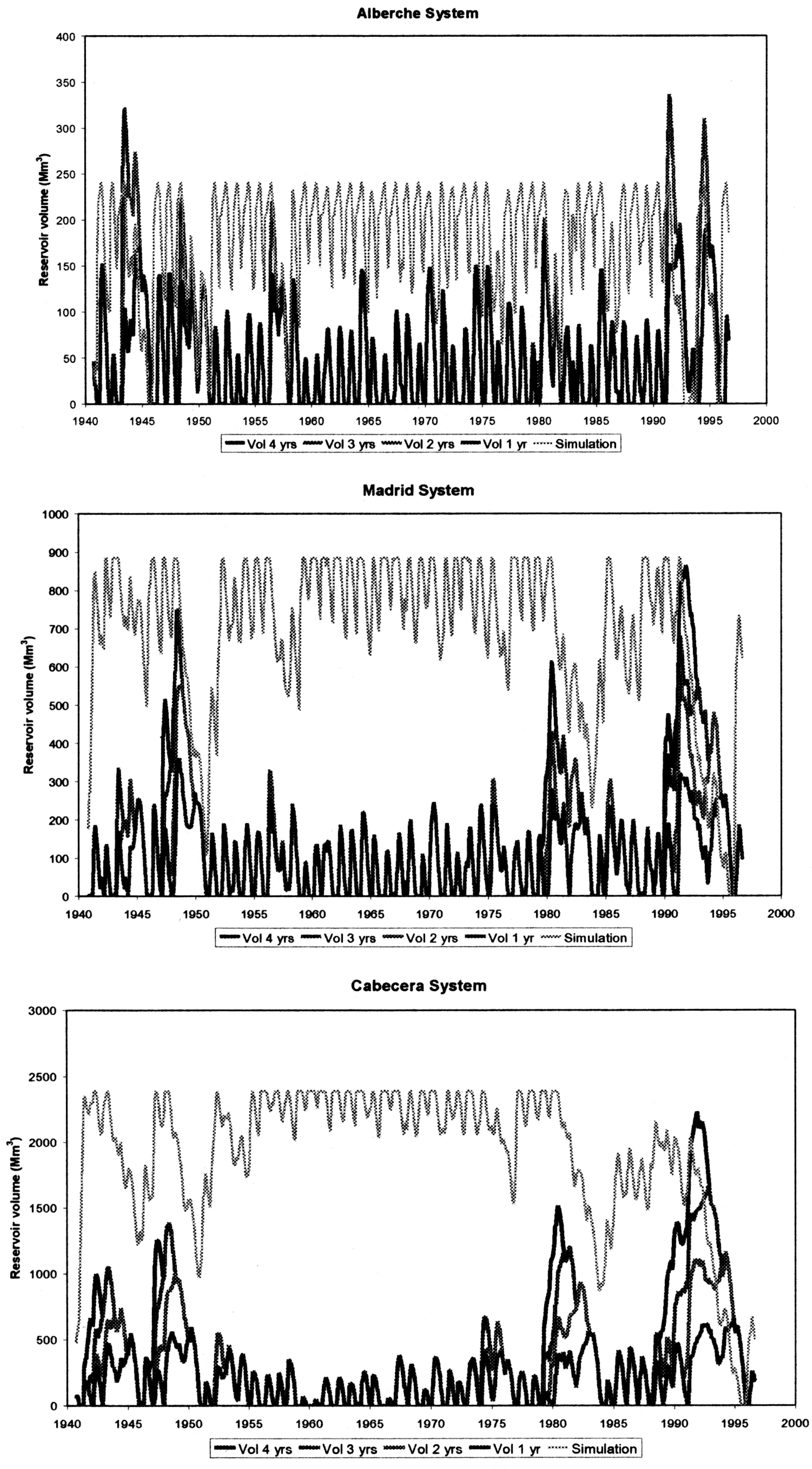

Fig. 6. Required storage volumes to supply 100% of the demand compared to simulated storage for the three representative systems of the Tagus Basin.

water rights, face the development of new transport or storage facilities under great social pressure or impose stronger rules and penalties and more strict control. If the drought situations are declared very frequently, the global effects may be even worse than the no-action approach.

One of the issues raised by technical staff in charge of water resources management in the Basin Authority was the situation of regulated systems for irrigation use at the end of the hydrological year. Normal operation of irrigation systems usually depletes reservoir storage at the end the irrigation campaign. This is a normal feature of annual regulation systems. However, according to the graphs shown in Fig. 7, there is a significant probability of not being able to satisfy demands during the next year if reservoirs are almost empty in October. But declaring drought in November is not perceived as a good management policy. If the following autumn and winter are normal, the reservoirs will fill again, and there will not be a scarcity situation. If autumn and winter are dry, farmers cannot do anything to react to drought until spring. So for these systems based on annual regulation for irrigation use, declaration of drought might only make sense at the beginning of the irrigation campaign, when farmers are making decisions regarding their crops.

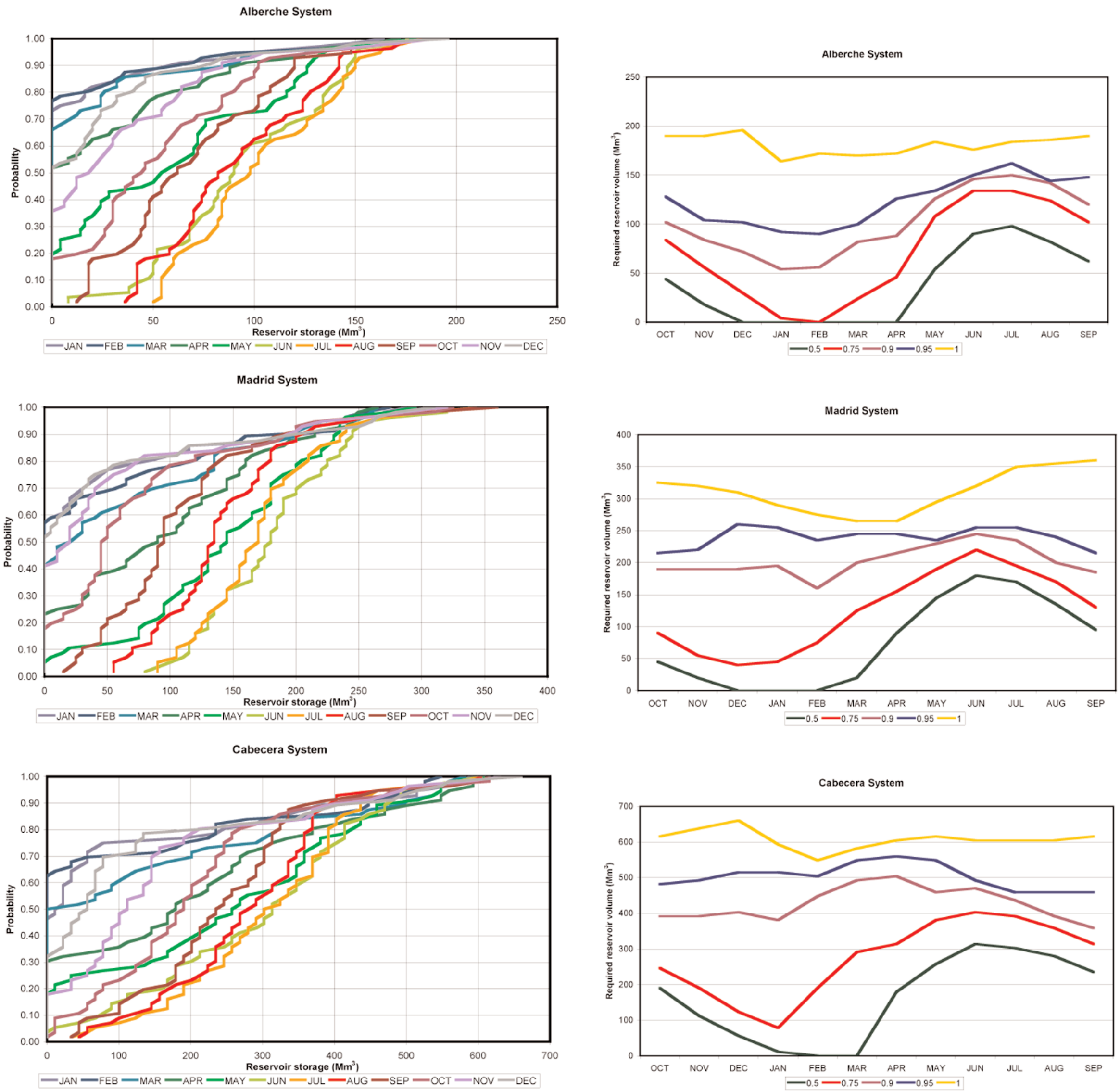

Fig. 7. Cumulative probability distribution of required reservoir storage to supply 100% of the demand for 1 year and monthly distribution for selected quantiles in the three representative systems of the Tabus Basin.

Deterministic analysis

The probabilistic analysis presented in the previous section is a good approach for decision making within the Basin Authority. However, from the perspective of user involvement in the process, the presentation of probabilistic results is always faced with reluctance. Unless they have a formal education in water resources engineering, users are not willing to accept restrictions based on a probability of failure, especially if that probability is not close to one. Implementation of measures usually takes time, and if the activation of the drought situation is delayed until there is almost a certainty of deficit, it is very difficult to avoid important impacts. For that reason, a simplified version of the procedure was developed for the purpose of dissemination and negotiation with users. Rather than using a probability distribution of required storage volumes, the decisions are based on a set of droughts, which are selected as representative of droughts of different severity occurred in the past in the system. The methodology is structured in three phases, which are described as follows.

The process begins by the characterization of the distribution of annual and monthly flows and the evaluation of the minimum values in historic record for different lengths of time, obtaining sample deciles and fitting the sample values to a theoretical probability distribution. In most systems the normal probability distribution provided an acceptable fit, while in others the gamma probability distribution was selected. The characteristic drought is defined by an annual volume and a monthly distribution. The annual volume is selected from the fitted distribution of annual flows, considering a probability of exceedance depending on the nature of the demand of the system. The monthly distribution of the annual volume was taken from the deciles of the sample monthly distributions, using a probability of exceedance equal to that of the annual volume.

The second step is the definition of the values of reservoir storage that are associated to every drought scenario. The simplified system model was used to estimate the storage volumes that are required to supply a given percent of total demand for a certain period of time during the characteristic drought. Different values of demand percentage, length of time period and probability of occurrence of the characteristic drought were used in every system. The figures finally adopted were the result of a feedback process with system managers during the validation phase.

The final step is the validation of the model. System behaviour was simulated with the simplified model for the period of historic record, implementing a set of measures in every drought scenario. The measures were simplified assuming a reduction of a fraction of the demand in every drought scenario. This reduction means either a real demand reduction by water conservation measures, or the activation of an additional supply source that supplies water to a fraction of total demand. Values were fitted by trial and error with the goal of avoiding complete depletion of reservoir storage and considering the possibilities of demand reduction and resource mobilization in the system.

This scheme was applied to all systems in the basin, adapting parameter values to the particular circumstances in every system. To illustrate the process, results obtained for the Alberche system are presented in Figs. 8 to 11. The cumulative distribution of annual flows in the system is shown in Fig. 8. The sample has been fitted to a normal probability distribution. The characteristic drought was chosen as the minimum value in historic record, 117.91 Mm^3/yr, which corresponds to a probability of exceedance in the normal fit of 95%. Threshold values for the pre-alert, alert and emergency drought scenarios are shown in Fig. 9, together with the maximum conservation volume in the reservoirs of the system, which is limited by hydropower and flood control. Threshold values were obtained as the reservoir storage that is required to supply the following fractions of the demand during the characteristic drought:

(i) Pre-alert scenario: 90% of the urban water supply demand and 80% of the irrigation demand during at least 1 year.

(ii) Alert scenario: 80% of the urban water supply demand and 60% of the irrigation demand during at least 1 year.

(iii) Emergency: 70% of the urban water supply demand and 40% of the irrigation demand during at least 1 year.

Model validation was performed by simulating the system with and without the implementation of drought management rules. The results of system simulation without rules are shown in Fig. 10. There are three severe drought episodes in the historic record in which the reservoirs of the system are

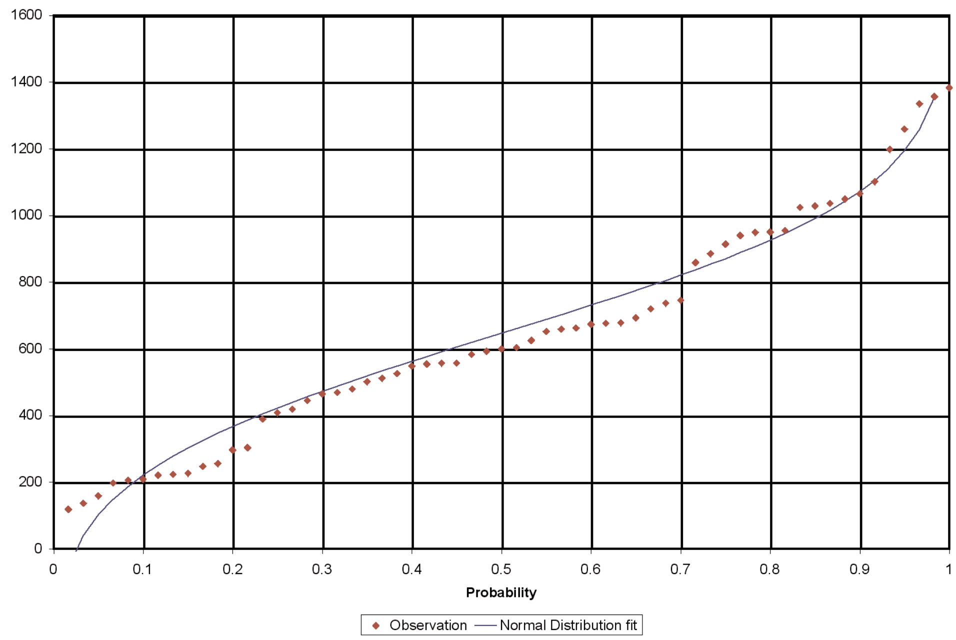

Fig. 8. Distribution of annual flow values in the Alberche system.

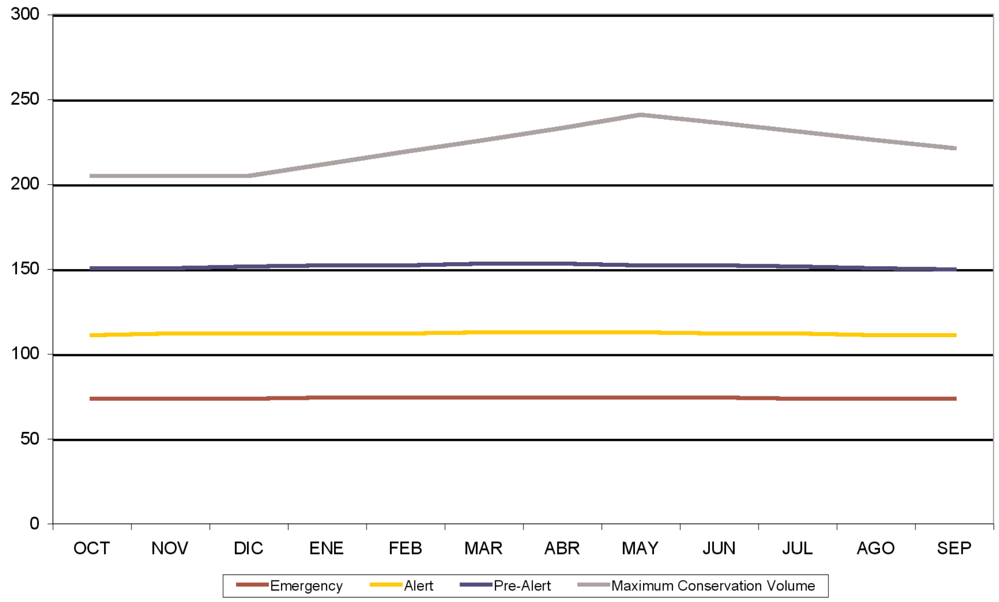

Fig. 9. Drought definition thresholds in the Alberche system.

completely empty, and there is a deficit of 100% of the demand during several months. This situation is catastrophic, and should be avoided by defining drought management rules that conserve water in the system. As a first approximation, these rules have been simulated as reductions of the demand supplied by the system in every drought scenario. These rules are defined as follows:

(i) Pre-alert scenario: no specific demand reductions. Only awareness measures are contemplated.

(ii) Alert scenario: reduction of 15% of the demand, which corresponds to a reduction of 35% in supply to irrigation and no reduction in supply to urban demand. Irrigation can be supplied using waters from the nearby Tagus River, although farmers do not want this option, due to the lower quality and the pumping costs.

(iii) Emergency scenario: reduction of 50% of the demand, which corresponds to no supply to irrigation and 15% reduction in supply to urban demand. Urban demand can use alternative water supplies, like in the case of the cities of Madrid, Talavera and Toledo, but this possibility depends on the situation of their own water supply systems.

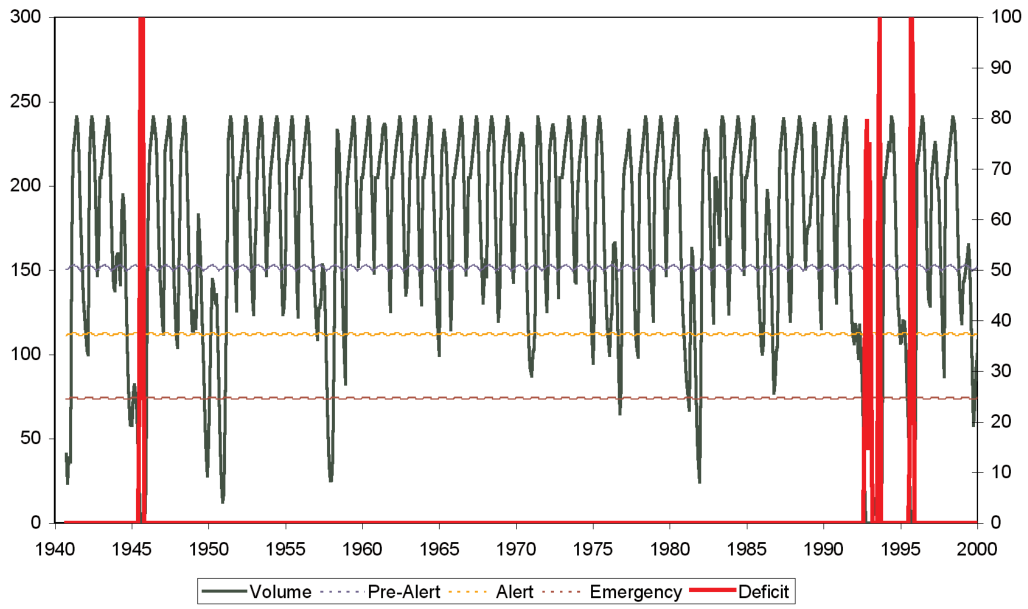

Fig. 10. Simulation of the Alberche system without implementing drought management rules.

Results of this simulation are shown in Fig. 11. The proposed rules can reduce maximum deficit in the system to 50% of total demand, but at the cost of more frequent restrictions. There is always this trade-off between water conservation measures and drought risk. Early response to drought risk implies producing restrictions that could have been avoided, but it can also avoid important deficits of catastrophic consequences.

The results of the simulation can be analyzed to assess the frequency of drought declarations. A comparison of drought thresholds and the cumulative distribution of simulated reservoir storage is shown in Fig. 12. The probability of reservoir storage being below the drought thresholds in the Alberche system is presented in Table 3. These values are relatively higher for the autumn and winter months. This is due to the fact that autumn and winter flows are much higher than spring and summer flows. Dry winters can fill the reservoir, while even the wettest of summers cannot contribute much to reservoir storage. This feature of the methodology is currently under discussion, and will probably be revised before the plan is implemented.

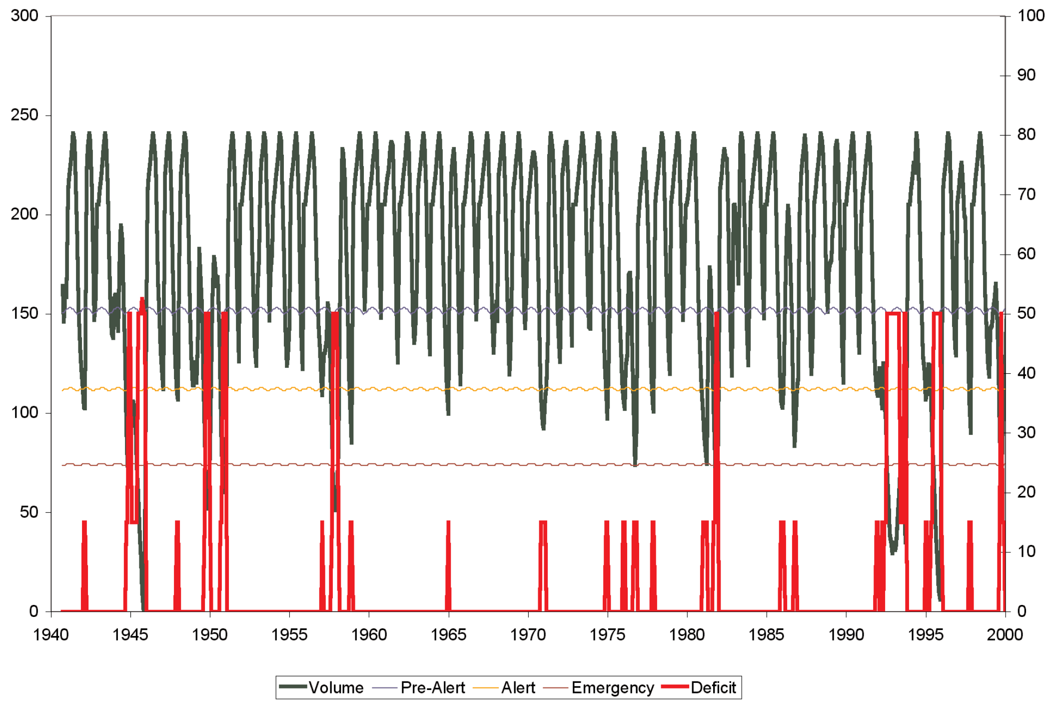

Fig. 11. Simulation of the Alberche system alter implementing drought management rules.

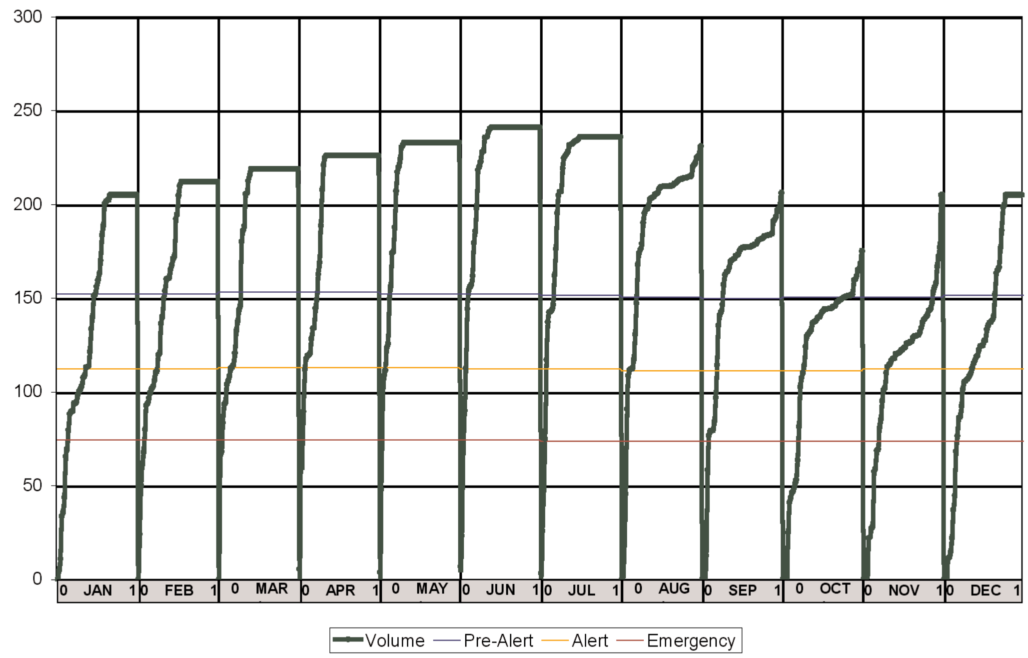

Fig. 12. Monthly cumulative probability distribution of reservoir storage in the Alberche Basin.

Table 3. Probability that the reservoir storage is below the drought thresholds in the Alberche system

Month	Pre-alert	Alert	Emergency
October	0.77	0.25	0.20
November	0.87	0.28	0.20
December	0.63	0.35	0.15
January	0.48	0.35	0.12
February	0.33	0.23	0.07
March	0.28	0.15	0.05
April	0.22	0.08	0.05
May	0.13	0.07	0.03
June	0.10	0.07	0.05
July	0.17	0.07	0.05
August	0.20	0.10	0.07
September	0.27	0.18	0.08

Operational component

Proactive measures

The institutional process and the context of the pro-active responses to hydrological and water scarcity drought is mapped in Fig. 13. Triggers and motivations include general trends of the economy, demographics, environment, or land planning policies. Pro-active responses may also be motivated by force of complying with National and European Union legislation. In this situation the River Basin Authorities operate at three levels: Governing Bodies, Management Bodies and Planning Bodies (Stage 1), who draft the Basin Hydrological Plan (Stage 2). The decision process follows the phases of proposal, consultation, revision and submission to the Ministry of the Environment (Stage 3). The Ministry of the Environment can approve or reject the proposed Basin Hydrological Plan. If the Plan is rejected, the decision process is reinitiated (Stages 4 and 5).

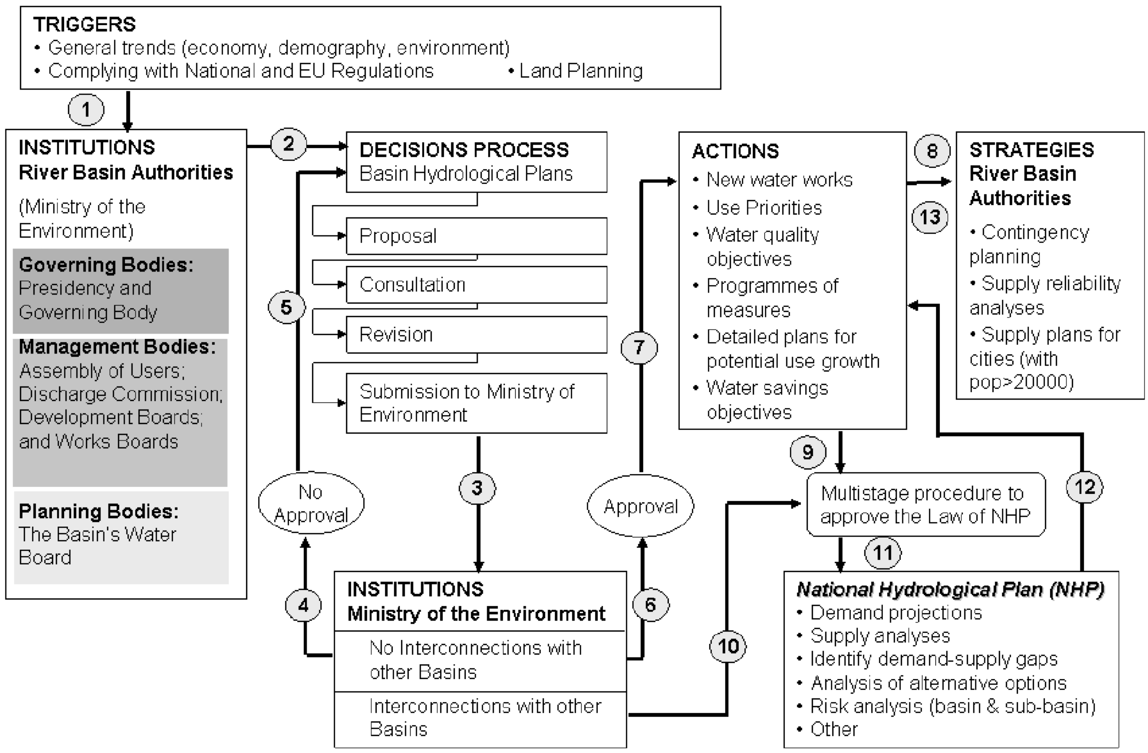

Fig. 13. Processes and institutional linkages in the pro-active responses to hydrological drought and water scarcity in Spain.

If the plan is approved, two alternative roadmaps follow, depending on whether or not the Plan envisions any inter-basin transfer, according to the following structure:

(i) If the Plan does not foresee connections with other basins, it is approved (Stage 6). In this case, a few of the included measures can be qualified as pro-active, such as new water works, defining use priorities, water quality objectives, programmes of measures to solve scarcity issues, setting water conservation targets, and detailed plans for potential use growth (Stage 7). From this action some strategies to mitigate drought are derived which are related to contingency plans, supply plans for cities or supply reliability analyses (Stage 8). Finally, these actions and strategies are included in a multistage (Stage 9) that will likely integrate some of the proposed actions, measures, works and policies included in the Basin Plan (Stage 11).

(ii) If the Plan envisions inter-basin transfers (from or towards other basins), strategies are designed and drafted within the multistage procedure to approve the Law of National Hydrological Plan (NHP) (Stage 10). These plans take into account some outcomes from the NHP like demand projections, supply analyses, identify demand-supply gaps, and analysis of alternative options and risk analysis (basin and sub-basin) (Stage 11). From this procedure final actions and strategies return to the Basin Plan for development and execution (Stages 12 and 13).

Reactive measures

Figure 14 summarises the institutional reactive responses to hydrological drought or water scarcity. As a result of permanent monitoring, some indicators of scarcity such as reservoir levels, low water tables in groundwater, or low runoffs may be warning signs to River Basin Authorities (Stage 1), whose response will depend on the relative severity of the perceived risks. Under non-emergency conditions, the Reservoir Release Commission will meet in ordinary session (Stage 2) and will define some actions relative to reservoir management, onset of Right Exchanging Centres, revision of ecological flows and ground water abstraction and definition of precautionary water allocation schemes (Stage 3). All these measures affect farmers, hydropower units, environment, urban users, and others.

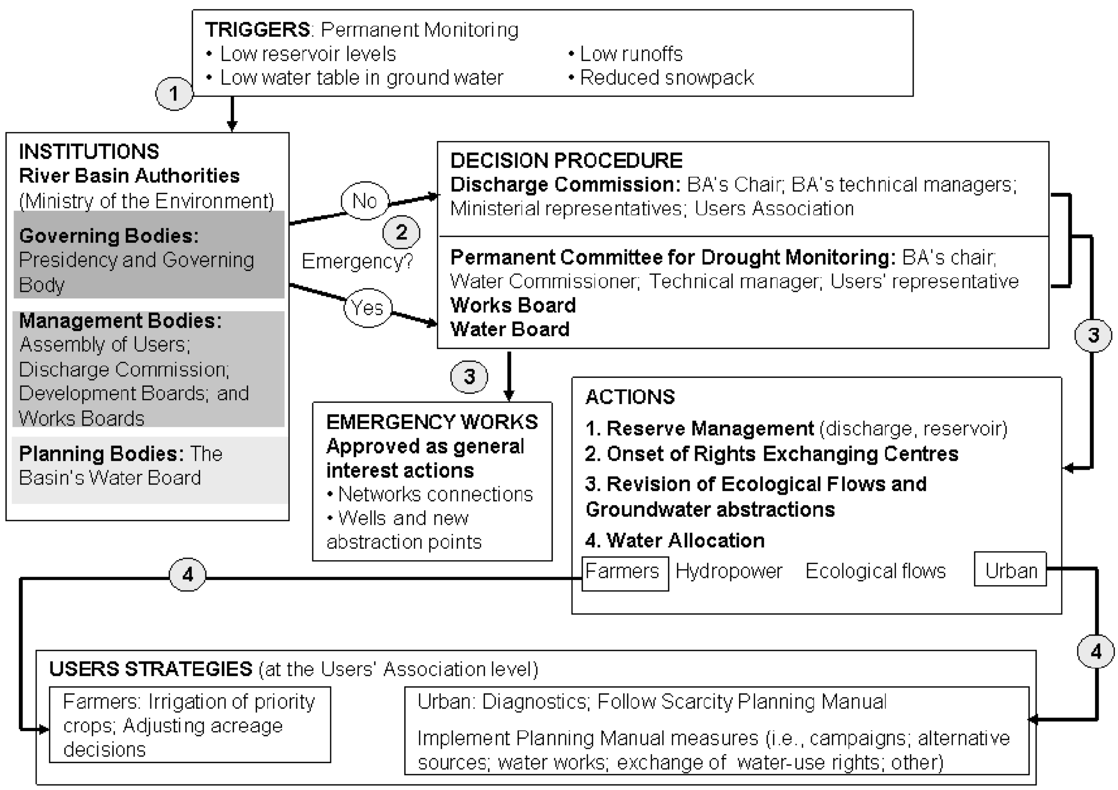

Fig. 14. Processes and institutional linkages in the pro-active responses to hydrological drought and water scarcity in Spain.

If the monitored indices worsen, entering a pre-emergency stage, a Permanent Committee is established within the Basin Authority for drought monitoring. This committee can adopt exceptional measures such as extraordinary releases or establishing special strategic reserves in the Basin's reservoirs. In this situation the Works Board and the Water Board, in addition, can file applications to have emergency works approved as "initiatives of general interest action" (networks connections, wells and new abstraction points) (also Stage 3).

Based on these River Basin Authority initiatives and in coordination with them, users strategies will be planned and carried out. These responses are usually drafted and decided by water users associations. For instance, irrigators can consider priority crops to be irrigated or perform exchanges of water use (Stage 4). Urban users in turn will follow their Water Scarcity Planning manuals or protocols, implementing measures like saving campaigns, alternative uses, water works, exchanges of water use, demand management provisions and so on. In general, these reactive responses will be applied only during drought periods. Examples of these are the revision of ecological flows and a better coordination of releases for hydropower generation with the timely demands for consumptive uses, such as irrigation.

Meteorological and agricultural drought

Pro-active responses

The degree of development of the Spanish agricultural insurance, as it covers most climate risks, stands out as the main pro-active response to droughts. Being a major drought policy in Spain, and one that complements other types of policies, it deserves specific attention. Therefore, we first concentrate on the institutional landscape of the agricultural insurance policies, since this is a guide for describing the institutional framework of the other reactive responses. The institutional mapping of meteorological and agricultural droughts is completed with the description of the reactive responses to drought risks.

Figure 15 describes the institutional process of the agricultural insurance system to illustrate a key pro-active response to drought in Spain. The Figure illustrates the framework for developing new agricultural insurance premia as a result of emerging risks. This process includes seven key stages (1 to 7 in Fig. 15).

The trigger (Stage 1) is the realization that a new potential insurable risk(s) is sufficiently concrete and specific, so that demand to develop new premia to cover it is expressed by formal and informal means. In some cases, the result is coverage expansion of premia already in the market based on past and accumulated experience for increased risk. In others cases, farmers associations demand that certain risks should be covered. Occasionally, local and regional political pressures take on sufficient strength so that the Ministry of Agriculture elects to initialize new studies, and provide the required research and development (R&D) funds.

Under Stage 2 budget is allocated and approved for concrete research and development activities to analyze the new product. A research team is formed, which tentatively includes officials from ENESA (The Spanish State Insurance Agency), representatives of farmer associations, insurance companies, and external research institutes. If the research and development results recommend to generate marketable premia, all its details are defined in Stage 3, including rates, geographical scope, and other technical characteristics. Under Stage 4, the Finance Ministry, and the Reinsurance public agency will review the proposed new premia, and approve or reject them. In this process, the pool of insurance companies is consulted. Their approval is necessary to continue the process.

Stage 5 gives rise to final marketable policies that are added to the menu of insurance premia and are commercially offered to eligible farmers. In addition, the level of rate subsidization requires the approval of the Ministry of Agriculture, which also makes budgetary allocations (Stage 6). The process ends in a standard feed-back relation, described by Stage 7. New and old premia are permanently evaluated, giving rise to amendments, removals, or impulse to broaden existent insurance lines.

In conclusion, the institutional framework encompasses all sectors –from farmers to insurance companies– and various Administrative branches. In the past 25 years (i.e., from the declaration of the Agricultural Insurance Law mentioned above) this process has given rise to a wide and broad set of insurance policies, being the ones covering drought risks the most important from the point of view of farmers' responses and agricultural areas covered.

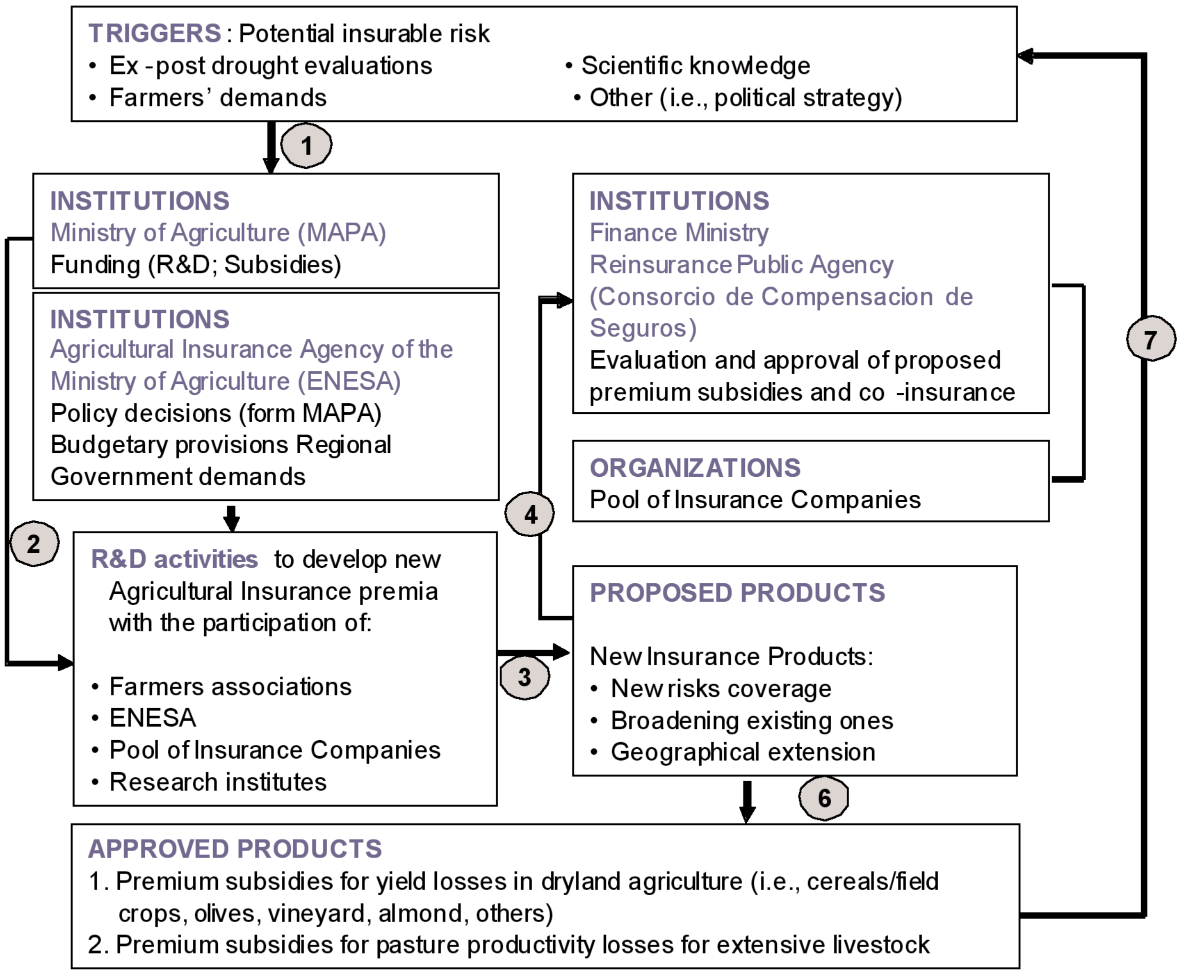

Fig. 15. Processes and institutional linkages in the pro-active responses to drought in the agricultural sector in Spain.

Reactive responses

Figure 16 illustrates the reactive responses to meteorological and agricultural drought, outlining the organizations and institutions involved in the processes, their hierarchical linkages, and the sequential time stages of the process. This process complements the pro-active responses described above. In general, the triggers of the reactive responses are dispersed and diffused: social tensions, social unrest, or warning signals that originate from regional and local Governments (Stage 1). These triggers originate primarily from the agricultural sector, particularly from dry-land farmers and extensive livestock farms.

In Stage 2, the Ministry of Agriculture calls for a meeting of the Permanent Office for Drought (entirely composed by officials serving in the Ministry). In Stage 3 the Permanent Office analyses the situation focusing almost exclusively on the risks for which no insurance was available. Among the most vulnerable sub-sectors subject to non-insurable risks are a few marginal crops, such as saffron or nuts orchards, and animals raised under extensive husbandry threatened by drinking water scarcity.

Under Stage 4, the Permanent Office will table specific proposals to alleviate the drought effects on the identified vulnerable sectors. These proposals are translated into the final programme measures to be developed and approved (Stage 6). The programme includes taxation abatements or deferrals and requires the approval of the Ministry of Finance (Stage 5), agricultural policy, agricultural insurance, and water policy. The EU Commission may also take measures to help farmers hit hard by droughts, bringing forward direct CAP payments or permitting cattle to graze on set-aside land. The most common response in water policy is a reactive response related to the authorization for drilling wells for animal drinking and it has to be approved and financed by the River Basin Authorities with urgent character (Stage 7).

The most salient characteristics of this mapping are: (a) that it focuses explicitly in the agricultural sector; (b) that the executive committee is formed only by officials of the Ministry of Agriculture; and (c) that its scope and concerns are limited to the vulnerable sectors or sub-sectors whose risks are not insured.

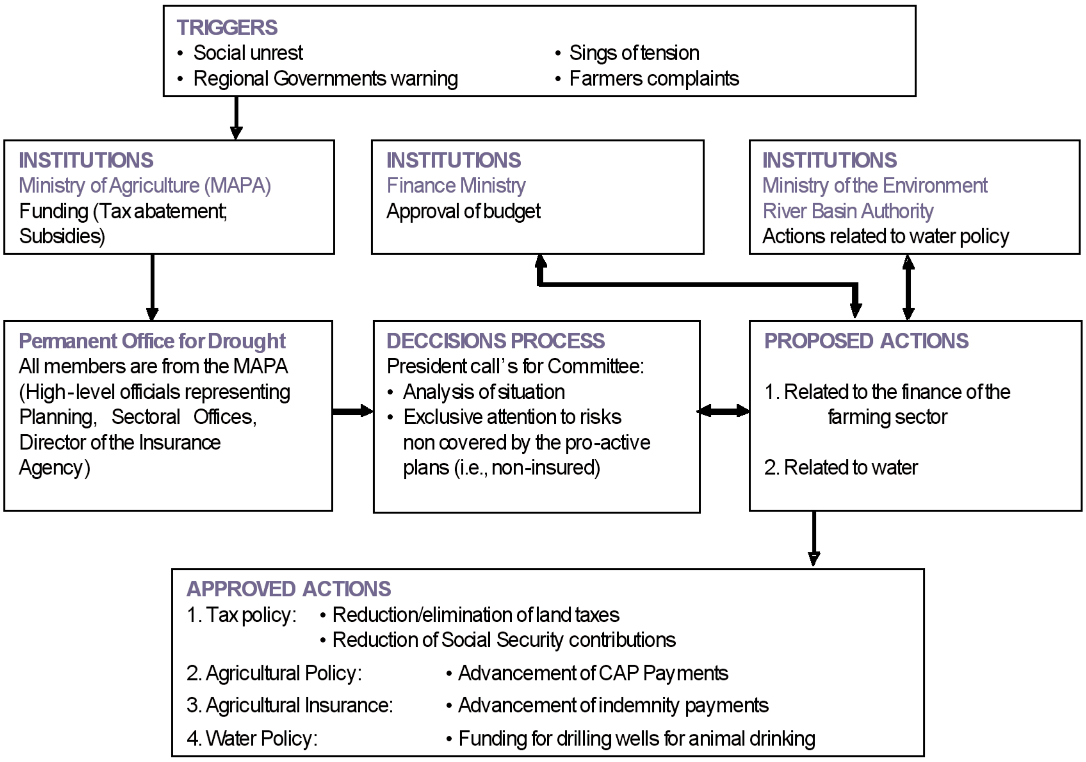

Fig. 16. Processes and institutional linkages in the reactive responses to drought in the agricultural sector in Spain.

Conceptual model for drought management

Specific drought management plans have been developed at different administrative levels. Figure 17 shows a conceptual model elaborated from the range of operational management actions observed and supported by the institutional and legal framework existing in Spain.

Possible operational actions

The Basin drought policy can be summarized as a list of possible actions to be taken in case of drought. The catalogue of possible actions is restricted by the legal competences that are attributed to the organism, but the resulting list includes a great number of actions of very diverse nature, like the examples presented in the following categories.

Internal operation: Within the Basin Authority, most frequent measures include intensification of monitoring, inspection of facilities to prevent leaks or revision of rules for the operation of infrastructure.

Water uses: Regarding water uses, demand management measures include: information dissemination and user involvement, promotion or enforcement of water savings, prohibition of certain uses, temporary exemption of environmental obligations, etc.

Water resources: Regarding the water resources, drought measures focus on conservation and protection of stored resources, activation of additional resources or monitorization of indicators of water quality.

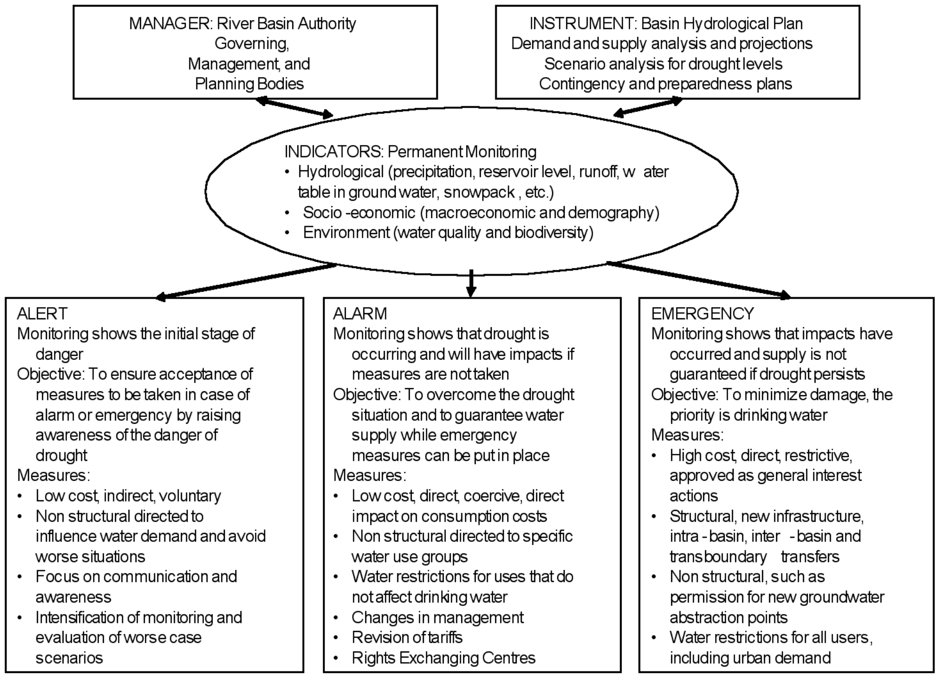

Fig. 17. Drought management at the basin level: Indicators and measures for different levels of drought intensity.

Institutional: From the institutional perspective, the President of the Basin Authority may appoint committees or task forces to address specific issues, usually in conjunction with affected users, or enhance cooperation with other organizations or stakeholders.

Legal: In the legal framework, there are a number of legislative measures that can be adopted, ranging from the official declaration of emergency due to drought, to a long list of possible palliative measures with different objectives: subsidy, restrictions, emergency works, etc.

These options are very diverse in nature, have different effectiveness and imply multiple economic and social impacts (Wilhite, 1997). In every practical case, only a number of measures are feasible and potentially effective at a reasonable cost.

Drought severity levels

The operational effectiveness of the drought management plan is greatly enhanced if the selected measures for every system are grouped in packets, which are applied if certain conditions are met. In the Tagus Basin Plan (BOE, 1999), drought management strategies are grouped in three scenarios, corresponding to increasing levels of severity: Pre-alert, alert, and emergency scenarios.

Pre-alert scenario

The pre-alert scenario is declared when monitoring shows the initial stage of drought development, which corresponds to moderate risk (i.e. greater than 10%) of consuming all water stored in the system and not being able to meet water demands. The management objective in the pre-alert scenario is to prepare for the possibility of a drought. This means to ensure public acceptance of measures to be taken if drought intensity increases by raising awareness of the possibility of societal impacts due to drought. The kinds of measures that are taken in the pre-alert situation are generally of indirect nature, are implemented voluntarily by stakeholders and are usually of low cost. The goal is to prepare the organism and the stakeholders for future actions. Regarding the Basin Authority, main actions are intensification of monitoring, usually through the creation or activation of drought committees, and evaluation of future scenarios, with special attention to worst case scenarios. Regarding the stakeholders, the focus is communication and awareness. Generally, non structural measures are taken, aimed to reduce water demand with the purpose of avoiding alert or emergency situations.

Alert scenario

The alert scenario is declared when monitoring shows that drought is occurring and will probably have impacts in the future if measures are not taken immediately. There is a significant probability (i.e. greater than 30%) having water deficits in the time horizon. The management objective in the alert situation is to overcome the drought avoiding the emergency situation by enacting water conservation policies and mobilizing additional water supplies. These measures should guarantee water supply at least during the time span necessary to activate and implement emergency measures. The kind of measures that are taken in the alert situation are generally of direct nature, are coercive to stakeholders and are generally of low to medium implementation cost, although they may have significant impacts on stakeholders' economies. Most measures are non structural, and are directed to specific water use groups. Demand management measures include partial restrictions for water uses that do not affect drinking water, or water exchange between uses. This may be a potential source of conflict because user rights and priorities under normal conditions are overruled, since water has to be allocated to higher priority uses.

Emergency scenario

The emergency scenario is declared when drought indicators show that impacts have occurred and supply is not guaranteed if drought persists. The management objective is to mitigate impacts and minimize damage. The priority is satisfying the minimum requirements for drinking water and crops. Measures adopted in emergency are of high economic and social cost, and they should be direct and restrictive. Usually there has to be some special legal coverage for exceptional measures, which are approved as general interest actions under drought emergency conditions. The nature of the exceptional measures could be non structural, such as water restrictions for all users (including urban demand), subsidies and low-interest loans, or structural, like new infrastructure, permission for new groundwater abstraction points and water transfers.

Examples of response actions in historical droughts

Pro-active plans: Insurance policies for winter crops

Upon the approval of the Law of Agricultural Insurance in Spain in 1978, the initial policies offered to farmers for winter crops covered only fire and hailstorm risks. Since then, these crop producers have been given an increasingly broad choice to cover all natural risks in a broad range of crops, including droughts. For the fiscal year 2003-04, growers of rainfed winter crops can select one of the insurance premia listed in Table 4.

Table 4. Summary of the insurance premia for winter crops (2003-2004) in Spain

Premia	Hailstorm	Fire	Freeze	Drought	Wind	Rain	Floods	Pests & diseases	Climatic Adversities
Integral	x	x	x	x	x	x	x	x	
Combined	x	x				x	x		
Yield	x	x	x	x	x	x	x		x

During the period 1993-2001, insurance uptake has ranged from a low of 59% of all eligible land to a maximum of 78%. Presently, about 75% of the eligible land is covered by an insurance policy. In 2001, 42% of the total insured production was covered by integral, 18% under the combined premia and 12% with yield premia. Purchasing insurance represents a small cost percentage for the growers. The most expensive premia represent about 4% of all direct production costs, whereas the least expensive policies represent about 0.5% of direct crop production costs.

Total premia subsidies of insurance lines applicable to winter crops amount to €18 million in year 2001 year, which represents about 1.4% of the value of the insured crops. Subsidies range from 35 to 42 percent of the market rates for integral insurance and yield insurance respectively. These extremely large values data demonstrate that the Government policy aims to induce farmers to purchase insurance with the largest risk coverage.

Yield insurance is the latest addition to the choices, and it was offered for the first time in 2000. Individual risk premia for yield was developed by using historical records of individual farmers' yields. During drought years, the individual yields are adjusted according to the records of yield loss caused by drought (other hazards are also included in the database). Individual risk premia and loss adjusting is possible because ENESA (The Spanish State Insurance Agency) has kept and updated a database of 160,057 individual farmers, with 12 years of yield data.

The 20-year experience of insuring rainfed extensive crops has made a significant progress in facing drought risks in about 45% of all Spanish agricultural land. In addition, the cumulative results of years of Research and Development, ex-post evaluation and data collection and analysis, ensures that each farmer idiosyncratic risks can be evaluated, so that premia can be tailored to each farmer at actuarially fair prices.

An indirect by-product of the insurance process is the research opportunities that ENESA's databases and experience offer to carry out risks analyses. Unfortunately, very little academic work has been conducted in this area. The evaluations carried out so far indicate that:

(i) Farmers tend to develop habits regarding their insurance strategies. The ones at greater risk tend to insure more often than those characterized as being expose to lesser risks.

(ii) Yields respond positively to higher than expected prices and to lower than expected prices variance. As a result of this and the previous findings, price support mechanisms seem to provide clearer incentives to increase cereal yields than the various insurance policies available for Spanish cereal growers during the 1990 to 1998 seasons.

Reactive plans: Actions at the Tagus Basin Authority

All relevant pro-active responses fall within the planning and administrative institutions. There are several examples that document the reactive actions taken during critical drought conditions with the aim of increasing water resources availability, such as new wells, conduits for water transfer, and desalination plants, or for reducing water losses in conveyance and distribution network. Here we document, as example, the actions taken in the Tagus River Basin that involved the agreement of four key stakeholders: Two partners in MEDROPLAN –the CYII and the Tagus Basin Authority (CHT)–, a hydropower company (Unión Fenosa) and an association of irrigation farmers (Comunidad de Regantes del Alberche).

During 1991 to 1993, prolonged meteorological drought resulted in hydrological drought, and the regulated water storage systems that serve Madrid Metropolitan Area (over 5 million people) were under critical conditions. As response to the situation a number of emergency measures were taken. One of the actions was to establish an agreement to use water from the river Alberche for water supply in Madrid. An emergency work was constructed to link the source (San Juan dam in the Alberche River) to the urban distribution system in Madrid. The water supply service provider for Madrid, CYII (Canal de Isabel II), did not hold a permit to use water from the Alberche for urban water supply in Madrid at that time. Water use priorities in the San Juan dam were and continue to be, recreation and ecological services, and water in the Albeche river was legally allocated to hydropower and irrigation. The hydropower company was entitled to turbine freely while the water level at the San Juan reservoir was above a certain minimum required to satisfy the irrigation demand. Since there was a drought situation, water in the San Juan reservoir was below the minimum level for hydropower operation. The irrigation association of the Alberche river was affected by the decision to derive water for Madrid. The agreement among the irrigation association and CYII was reached after legally changing the priorities of water use in the San Juan dam to allow for urban use in Madrid. In exchange for the loss of water rights, the irrigation association was given the right to irrigate with water from the nearby Tagus River. A pumping station was built to pump water from the Tagus River to the Alberche irrigation canal. The State Administration (CHT) paid for the facility, and CYII paid for the energy costs of the action. As a side effect, irrigators complained that water from the Tagus River had worse quality than that from the Alberche River and could contaminate the aquifer that was used for urban water supply to several municipalities. An existing water supply line, used for the nearby city of Talavera, was used to supply water for three municipalities at risk of contamination. Eventually, all problems were solved, and water from the Alberche could finally reach Madrid, although the critical drought conditions were already over.

It is remarkable to note that, although this infrastructure was built under pressure due to the emergency conditions, it has been used ever since to supply water for Madrid. A legal action had to be taken to concede a permanent water use permit to CYII to divert the Alberche water. The negotiations involved the agreement with the hydropower company to establish an economic compensation for the loss of hydropower production, to be paid by CYII. This action highlights the implicit value of some of the emergency works during severe drought in the cases that drought is the detonating point to undertake a structural work that was necessary for the system. Nevertheless, structural works undertaken under emergency conditions often result in a higher total cost than if they were planned with sufficient time.

Combination of reactive and pro-active plans: Programme for improving urban water use efficiency in Zaragoza

Background. The impact of drought in 1991-1995 in Spain stimulated Fundación Ecología y Desarrollo (ECODES), to develop a pilot project focused on improving urban water use efficiency. Spanish water use efficiency in cities has a great potential for improvement as documented by the World Water Council. ECODES launched a program of actions in Zaragoza (Zaragoza: The Water Saving City) that is outlined in Fig. 18.

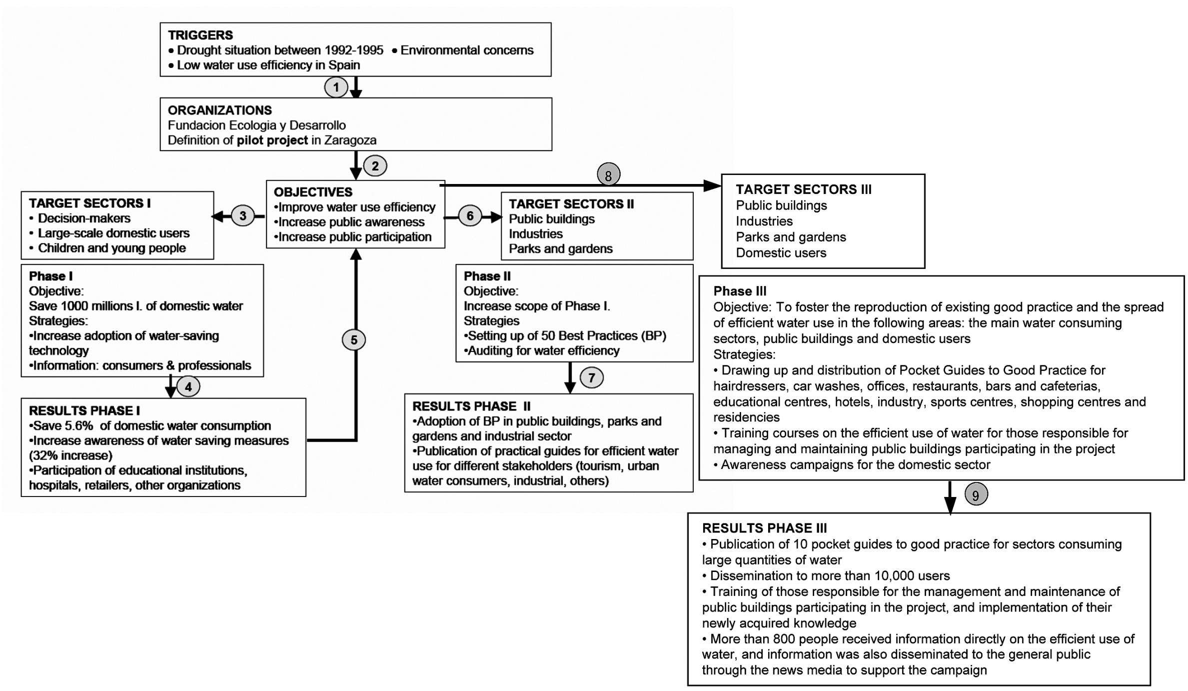

Fig. 18. Summary of the NGO Fundación Ecología y Desarrollo (ECODES) program to save water in the city of Zaragoza, Spain.

Objective and strategies. The main strategy was to save 1 million m^3 of domestic water per year.

This objective was met by:

(i) promoting demand for water-saving technology among consumers;

(ii) stimulating water-saving technology markets; and

(iii) training and informing professionals in this sector.

Specific actions were directed to:

(i) professionals linked to domestic water use (i.e. manufacturers, distributors, retailers, plumbers);

(ii) large-scale domestic users (i.e. hotels, restaurants, gymnasiums, etc.);

(iii) young people; and

(iv) the general public.

The program took place in parallel to other initiatives taken by the city, the Regional Government, the River Basin Authority, and the National Government.

Results. The results were positive and 1.176 million m^3 of water were saved (5.6% of annual domestic consumption). The number of people aware of water-saving measures increased (from 40% to 72%). The participation in the project was large: 69% of educational centres; 65% of health care centres; and 150 diverse organizations that collaborated by disseminating information about water savings.

Although the results were positive, it was considered necessary to extend the scope of action of the project. A new objective was the development of 50 best practices for efficient water use in public buildings, industries, and parks and gardens. A program of free audits was created and implemented in voluntary centres willing to adopt the best practices guides. These pilot centres served and continue to serve as role model for others in the city.

In this second phase, the main results of the project include:

(i) participation by 100% of the city's nurseries and garden centres;

(ii) adoption of best practices in public buildings, in parks and gardens and in the industrial sector; and

(iii) publication of practical guides for efficient water use. These guides include: practical eco-audit guides for hotels, offices, industry, hospitals and educational institutions; practical guide to dryland gardening; and practical guide to water-saving technology for households and public services.

The third phase of the project centered on the spread of good practice to sectors consuming large quantities of water. To this end Pocket Guides to Good Practice were produced for hairdressers, car-washes, offices, restaurants, bars and cafeterias, educational centres, hotels, industry, sports centres, shopping centres and residencies, and these were delivered to more than 10,000 users.

The Guides contain information on Good Practices identified during the previous phase of the project in the sector in question, and resulting from contacts made with institutions and companies. The guides also include a section of general information concerning habits and technologies for the efficient use of water in the sector. Agreements have also been drawn up with professional associations in each sector to ensure their collaboration in the distribution process of guides to their members.

The aim of the guides is to ensure the same type of consumers can benefit from experience gained from each good practice identified in the project. For example, using experience gained from one shopping centre in all the other shopping centres in the city. The goal is to ensure the reproduction of existing good practices and the spread of efficient water use. The involvement of professional associations linked to the range of sectors means the message reaches the professionals concerned through a medium they are familiar with and with which they identify because of their professional activity.

During the third phase specific activities were also carried out to foster efficient water use in the public sector. For example, training courses in efficient water use for those responsible for the management and maintenance of public buildings participating in the project, or for the general public, such as a public awareness campaign use and on efficient water saving technologies undertaken in a shopping centre in the city. Water saving devices were on offer at a subsidized price for washbasins (aerators) and water meters were given away with them so savings achieved in comparison to traditional taps could be checked. Those interested could also receive information free on other savings options explained in the Good Practice Guides on the Efficient Use of Water at Home, drawn up in the previous phase of the project.

A new phase began in November 2006 the objective of which is to obtain *100,000 commitments* from at least *25,000 citizens and organizations* to save water and consume it efficiently. The commitments will then be put on display at the *Zaragoza International Exhibition 2008.*

The commitments concern actions taken to save water and/or to spread the word, which citizens or organizations declare publicly as already underway or soon to be implemented. Savings actions include all those day-to-day activities that result in major water savings. Spreading the word refers to actions that foster good practice and water saving in others.

The above-mentioned aims are however ambitious and can only be achieved if thousands of citizens actively participate by undertaking savings actions and consuming water efficiently in their homes, at work, at school, in common sectors of consumption (shopping centres, leisure centres) and in public areas (libraries, civic centres, administrative buildings, etc.).

Public review component: Stakeholder participation

This section identifies stakeholders whom have been and are involved in the decision making process. The primary stakeholder is the Tagus Basin Authority that has competences for water management at the national, regional and local levels by implementing the Basin Hydrological Plan. The River Basin Authority includes users groups and representatives of different central and regional government bodies. The Basin Authority defines the Basin Hydrologic Plan, controls the public water domain, designs, develops and manages the hydraulic works, granting of licenses and permits for the use of water resources and the public water domain and hydrological monitoring (gauging, floods, quality). The responsibility of the Hydrological Planning Office (Oficina de Planificación) is to define, monitor, and review the Hydrological Basin Plan, and to provide technical support to the Water Basin Council.

Historically, three groups of users have been in conflict over water use in the Tagus basin: the urban water supply companies, the irrigators and the hydropower companies. They compete for their established rights to water use within the framework established by national, regional and local authorities. Recently, environmental groups are playing an important role in protecting the natural resources. The conflicts are solved within the Assembly of Users of the Tagus Basin Authority.

Stakeholder validation and proposals

Six key stakeholders have been interviewed to validate the mental model and to enhance the understanding of droughts and water scarcity problems in the country. This Section includes an outline of the information provided by them relevant to model validation.

Tagus River Basin Authority

The River Tagus is the longest river on the Iberian Peninsula and the third with regards to total contributing area (about one ninth of Spain) and in amount of water carried (about one tenth of Spain). The Tagus Basin is the one that has the largest population weight in Spain and in the Iberian peninsula (over 6 million people). The volume of water that provides to other basins is a concern, since the Tagus is the one that provides the largest share to other basins. The Tagus Basin is the most regulated one (about one fourth of the regulated water in Spain is from the Tagus Basin). Drought is viewed as a situation in which available resources are insufficient to meet regular demands, or when tensions arise attempting to meet the system's demands. Meteorological droughts are considered secondary events, as they affect soil moisture and runoff coefficients. As a result, meteorological droughts increase the left tails of the probability distribution of runoffs as they feed the systems reservoirs. Basin Authorities take decisions in collective bodies, although the executive responsibility is held by the Chairman of the Basin's Authority. Reservoir Release Commissions are responsible for the continuous management of reservoirs. Under severe scarcity conditions, a Permanent Committee is appointed to manage the situation. As in any other River Basin Authority, the planning process is exposed to public scrutiny. Concerned individuals and social or political groups can make allegations that affect the planners' decisions. The drought mitigation measures considered take into account all economic and social costs, at the regional and local levels. At the present time, the exchange of water rights may not be the most adequate strategy in many areas of the Basin. The main impediment is that some water right holders do not exhaust their current rights, and therefore if they are offered an interesting price, they will sell their rights to buyers who would put the purchased waters into use, deteriorating the Basin's water balance. Some of the current water concessions could be revised and reduced if evidence of under-utilization is found. A fundamental issue that determines the actions related to risk management in a large basin arises from the available data series. In general data series are too short to consider accurately extreme events, such as droughts or floods. This may be partially solved by the use of synthetic series.

Ebro River Basin Authority

The Ebro Basin provides in general sufficient water for its users, although conflicts are manifested in certain years and/or locations. Nevertheless, the basin includes several areas of endemic drought where supply is not enough and others where there is a recurrent problem but not endemic. Eighty percent of the water use is for irrigation and the future of it is linked to the future water scenarios and Common Agricultural Policies of the European Union. The data provided by the extensive data system SAIH (Sistema Automático de Infomación Hidrológica) in real time, and water extractions metering are an essential tool in the planning process. Spain is a Pilot experiment for the use of these data. Agricultural water use data are provided by farmers willing to collaborate; at the moment 15 irrigation districts are already engaged in an experiment that monitors real time data on agricultural water use. The Ebro River Basin Authority provides these data on-line. The legal framework for the planning process is complete. However, the Basin Authority may benefit from a fuller capacity of decision during crisis situations. At the present time the Basin Authorities depend on the Council of Ministries for drought declaration and water rights revisions. It is important to highlight that planning for drought should be performed during non-crisis times. Drought impacts appear in the Basin under certain conditions. When irrigation supply is below 90%, conflict among users in the basin arises. This may even give rise to additional conflicts between users of other basins if inter-basin water exchanges occur. Full cost recovery in the farming community cannot assume the cost of improved irrigation structures, part of these costs may have to be assumed by the State if they are recognized as positive for Basin's conditions and for other users along the Basin. Information, water allocation, and allocation of priorities are essential components of adequate management. Participation is consolidated in the Management Board. The meetings of the Board have incorporated a large number of stakeholders to conciliate interests. The Pilot projects with farmers have shown positive results. Priorities in water allocation should be, as established in the Water Law, for domestic water supply. In many cases conflicts arise with water permits of the farmers. In case of crisis, it is necessary to agree on economic compensations to the water rights holders in exchange for their rights. In general this was not necessary in the Ebro Basin as stakeholders reach agreement without compensations. In the agricultural sector the priority is irrigation of orchards since the lack of water causes long term effects.

National Association of the Water Supply Companies

The National Association of Water Supply Companies (AEAS) includes the most relevant companies that supply urban water. The interviewed believes that water supply companies are passive actors for most possible pro-active responses since they are severely constrained. A main constraint is that the companies are not responsible for reservoir management, therefore it is difficult, if not impossible, to take an active role in reducing water scarcity risks. An exception is the water company of Madrid (Canal de Isabel II, a partner in MEDROPLAN), which has a protocol for both reactive and pro-active responses to water scarcity risks. An additional constraint is the regulatory regime for Local Governments ("Real Decreto legislativo 781/1986, de 18 de Abril por el que se aprueba el Texto refundido de las Disposiciones legales vigentes en materia de Régimen Local") that limits the water companies in the scope of actions to obtain new tariffs approval based on the costs of implementing future contingency plans. A final constraint is the non-accumulative nature of technical efficiency improvements, from the abstraction point to the customer connection. As a result, improvements on the leakage ratio, or the unaccounted losses have an incremental effect that cannot be accounted for in long-term planning, unless the reduced demands can be maintained and projected in the future. Therefore improvement of technical efficiencies, demand management, and other measures taken by water companies, may not be as effective to reduce water scarcity risks. In contrast, the interviewed expressed that water companies have a role in reactive planning and must also coordinate actions and initiatives with the Basin Authorities and local Governments. Contingency plans and stable agreements (i.e., for water allowances exchange) are perceived as critical elements for effective performance in case of drought. Nonetheless, market arrangements for sharing water use rights must be agreed through negotiations, with the mediation of the Basin Authority.

Water Supply System

The CYII (Canal de Isabel II) is responsible for water supply to 5 million people and is the most important user of the water in the Tagus River Basin. The company has a comprehensive Manual of Water Supply. The manual has had significant public relevance and its aim is to provide rational arguments and rigorous risk analysis of actions before, during or after water scarcity situations. By rationalizing all processes and strategies, the company seeks to shelter itself from mismanaged allegations and uninformed public scrutiny. The main concern of CYII is the frequency or probability associated with each level of insufficient supply to meet water demands. In the view of the interviewed, droughts cannot be controlled, but water scarcity can be controlled to a certain extent. The CYII does not establish priorities among users during water scarcity, reflecting a political choice of free decision of the users. The Manual provides a special water levy for water scarcity situations, and it is systematically used in operations with preventive character. In real situations, water scarcity affects the environment and agriculture in the first place. The water company has a prevalent position within the River Basin Authority (Tagus) and an influential role among other competing users. Drought policies are included in long term planning, but are also dependent of the short term (i.e., operational) planning. In the long term, planning for scarcity consists of defining scenarios, evaluating probabilities and identifying effects and strategies, and in general these actions are not influenced by political or media pressures. Sources of uncertainty for future planning arise from:

(i) The uncertainty of the climate patterns;

(ii) land and urban development; and

(iii) changing demand factors, such as seasonality or consumption patterns.

The main challenge is to maintain current reliability levels, despite the significant changes appearing from demographic and socio-cultural change (i.e., expansion to the peri-urban space, and single family homes). The measures include:

(i) Water metering;

(ii) full cost recovery rates;

(iii) demand management; and

(iv) water right exchanges with irrigators, making use of the provisions of the 1999 Water Law amendment. The CYII considers that the water rights are sufficiently clear and envisions purchasing water rights currently in the hands of irrigators, as one possible strategy to meet moderate risks of water scarcity.

Economic instruments are viewed as a main tool for implementing measures. Reasonable expectations are based on market allocation mechanisms, by which water companies can acquire permanently or temporarily use rights currently in the hand of the farmers. If these measures result in cost increases, the company would pass them on to its final consumer.

Agricultural Insurance

ENESA is an autonomous body under the umbrella of the Ministry of Agriculture. The General Director of ENESA is also a member of the Permanent Office for Drought. The interviewed expressed that meteorological and agricultural drought risks are perceived as identical. The Permanent Office for Drought meets when the signs of stress or difficulties arisen from meteorological droughts are perceived by affected groups. No particular index or set of indices of droughts are used to set off alert signs or justified a call for a Permanent Office meeting. All members are Senior Officials of the Ministry of Agriculture. In crisis situations, attention is focused on the agricultural sub-sectors with no agricultural insurance available that experience difficulties related to crop water stress or unavailability of animal drinking water. Alleviation measures include tax reductions or subsidies for wells construction for animal drinking. The Permanent Office is also concerned with insurable production inasmuch financial support can be secured by advancing insurance indemnities payments, Common Agricultural Policy subsides, and occasionally filling applications to the Finance Ministry to condone land taxes or social securities contributions.

Non Governmental Organization

The Fundación Ecología y Desarrollo is an NGO that plays a role in public water saving programs in urban environments. The interviewed considers drought a recurrent process that depends mainly on management actions. In his view, man can anticipate drought and be prepared to minimize its impacts. The identified roles of NGO's in water management are: (i) to mobilize and rise awareness; and (ii) to force Public Administrations to introduce some topics in the political agenda that otherwise will not be attended. Through these actions, FED has contributed to raise awareness in society of the need of rational water use together with implementation of actions targeted to reduce consumption using best available technology. The program started in a pilot experience in households, and has expanded to the commercial sector. FED has introduced and developed a set of ideas for improving Water Management, including:

(i) Demand management versus supply management. Modifications in the current legal framework to increase flexibility at crisis time (i.e., revision of water permits) and establishment of different crisis levels with measures target to each level. Increased participation in the River Basin Authority, since environmentalists, consumers, neighbourhood associations are currently under-represented.

(ii) Include Better Water Management in the political agenda by increasing efficiency in the system (i.e., reforms in the sewage system, water metering, etc.), and by incorporating anticipatory measures (i.e., pro-active management).

(iii) Promote cultural changes that will result in water use reductions (i.e., Mediterranean gardens with lower water consumption plants).

Lessons learned

Meteorological and agricultural droughts

The mapping for reactive responses shows that triggers originate from widespread and diffused signs that reach the Ministry of Agriculture. The call of a meeting of the Permanent Office for Drought is the origin of all reactive responses for drought alleviation. However, the types of signs and collected evidence are based on costs, damages, and difficulties, as they are already occurring across the agricultural regions.

By limiting their attention to non-insured risks, the Permanent Office assumes that insured risks do not deserve concern. The implication is that the drought effects that go beyond the farm gate are properly handled by agricultural markets, both of inputs and outputs. As a result of this, the spanning chain of effects that droughts create in related industries and perhaps in the urban areas is mostly disregarded. As a result, the whole family of indirect effects beyond the farm gate is left unattended in the institutional mappings.

Consider of a severe drought, and the supply reductions of many basic commodities. Eventually, consumer prices will start rising, affecting the Consumer Price Index and the economy as a whole. This example, and many others that could be thought of, illustrates the reductionists concerns of the competences of the Permanent Office

Some of the consequences resulting from this view are:

(i) That drought indirect effects are not considered, nor corrected.

(ii) Many vulnerable farms do not purchase insurance.

(iii) Risks associated with water supply could also be insured against, provided they are based on natural and objectively measurable indices, such as runoffs or precipitation indices.

(iv) While the agricultural insurance system is quite complete and innovative, some of the policies that are based on satellites images, such as the pastures drought insurance, are purchased by a very limited number of farmers.

The above points indicate that there are significant gaps both in terms of geographical scope and in the number drought vulnerable sectors and productive activities that may not receive sufficient attention.

Hydrological droughts and water scarcity

The development and revision of Basin Hydrological Plans are slow processes, constrained by legal formalities, and some data or results may become outdated in the process. In addition, the Plans will have to be amended to comply with the EU Water Framework Directive, especially with the new notions enshrined in this European legislation.

At the basin levels, contingency planning is still in very early and immature stages. Groundwater resources, as a strategic supply source, is not sufficiently controlled and valued. It is also a source of conflicting views among Basin agencies and water suppliers that rely on them for very specific situations.

Water quality deterioration is threatening the regulation capacity of eutrophic reservoirs to service urban customers. This reflects that proactive measures should include water quality issues in order to preserve the adequacy of current water supply sources.

Although users' and public participation is secured within the various bodies of the Basin Authorities, risk analyses performed by executive bodies may encroach the rights of the lowest value users.

Public awareness of the value of secure water sources at the basin level is extremely limited. While most users across the basin are largely dependent on the Basin Authority reactive and pro-active plans, the general public may disregard this fact and assume that their water supply security is managed by the retailers that service the water. This is the most uncommon case, except for the urban water supply to Madrid.

The water market and exchanging options, as envisioned in the Water Law, is perhaps too naïve to facilitate the kinds of agreements that water companies are interested in reaching with the irrigation sector. In particular, sharing mechanisms that are based on objectively measurable conditions may have a more promising future than the rights lease-out contracts that are defined in the law.

With reference to the previous point, water companies are demanding legal security and enforceable long-term contracts with irrigators. These will significantly reduce the negotiation costs that impede and retard lease-out contracts sometimes needed urgently.

Strengths and weaknesses of current drought plans

In this section we identify the strengths and weaknesses of the institutional mappings that have been described in the Organizational Component Section, contrasted by personal interviews and validated in our discussion in the previous part of this section. The section is organized in coherence with our previous structure, focusing first on agricultural and meteorological droughts, and then on hydrological droughts and water scarcity risks.

Meteorological and agricultural droughts

The main strengths of the Spanish institutional framework that stand out from the above analyses are:

(i) The Spanish agricultural insurance system has solid bases, and grows year by year expanding its coverage and new premia specifically targeted to cover drought risks. This has given rise to an important capital of knowledge regarding site-specific drought risks and the development of premia individually tailored to all eligible farmers.

(ii) In some rainfed crops, such as cereals, olive trees and other field crops grown, farmers can elect from a wide menu of insurance premia, that cover an increasingly range of risks from fire and hailstorms all the way to yield losses caused by any natural event.

(iii) In addition to the well-developed and dynamic agricultural insurance system, there exists a Permanent Office with clear missions and means to address stressful situations caused by droughts and other climatic and environmental hazards. The Permanent Office members are appointed in advance, and its president can call for a meeting whenever signs of stress are received. All Permanent Office members are senior officials of the Ministry of Agriculture, and are likely to be especially receptive to agricultural strains. The Office's attention is primarily focused on the agricultural sub-sectors and farmers, which are not eligible for any of the agricultural insurance premia.

The main weaknesses are the following:

(i) The combination of all eligible productions for insurance and the non-insurable areas or production is far from complete. In some products and production systems, the subscription rates are below 20%. This includes premia for pastures, olive trees and vineyards which in total make up more than 4 million hectares. The fact the Permanent Office does not address drought hazards as they affect insurable production results in significant area and sector gaps, which the present insurance framework does not cover.

(ii) Fundamental problems hinder the prospects for higher subscription insurance rates. This is because many agricultural areas are subject to significant risks, which the insurance system can cover only with unaffordable premium rates for the farmers. This is not going to be solved by the insurance system, and does not seem to be properly addressed either by the Permanent Office's services.

(iii) The Permanent Office's primary attentions do not go beyond the agricultural sectors, nor does it pay attention to indirect effects of the vulnerable agricultural sectors. This implies that non-agricultural effects are basically disregarded and left to be attended by other income-smoothing and counter-cyclical instruments such as the tax and social security systems.

(iv) The Permanent Office does not use currently drought indicators or any other scientific objective indices to call for crisis situations.

(v) As a risk reducing strategy, insuring irrigated crops is presently disregarded on the basis of potential moral hazard and adverse selection problems. While there are unquestionable difficulties in developing insurance premia that are based on human-made decisions, such as water allocation among sectors and crops, index rates could be developed that are based on runoffs or other fully natural events/variables. This possibility is fully disregarded, though does not differ dramatically from other policies that are already in the market, such as pastures insurance based on indices computed from satellite images.

Hydrological droughts and water scarcity risks

The main strengths of the Spanish institutional setting are:

(i) Basin agencies are experienced organizations in managing basins' water resources. They have adopted modern technologies to monitor all systems in real time and are capable of collecting and processing hydrological data and analyze it for risk analyses and projects' evaluations.

(ii) Basin agencies, albeit public institutions, encompass by statute all users, governmental branches and stakeholders in all decision bodies both for pro-active and reactive responses. It is customary to favour their active participation and influence most decisions in planning and managing tasks.

(iii) Entities responsible of retailing water to final customers participate actively in the basin agencies' decisions and have seats in their planning and executive bodies. In times of scarcity, water is assigned through collective decisions taking into account the priorities enshrined in the approved Hydrological Plans or, by default, as the Water Law dictates. The allocation process is transparent, at least with regards to the most immediate consequences as they result in costs and benefits accruing on water right holders.

(iv) The Spanish Water Law is modern, well adapted to the country's water conditions, and fairly well enforced in most basins for surface resources. The 1999 Law amendment foresees water rights lease-out contracts and water banking schemes, as a means to mobilize valuable resources to be made available for demanding agents through voluntary responses.

(v) Planning documents both at basins' and national levels are legally approved, detailing priorities, specific plans, works and actions. These plans have gone through multi-layered consultation processes, and been subject to very thorough scrutiny by the political parties, various administrations, the general public, the media and the scientific community.

(vi) As a legal mandate, Basin agencies must develop contingency plans for drought situations and develop strategic plans for cities with 20,000 population or larger.

(vii) Lessons drawn during recent drought experiences have been incorporated and used to shift the focus on pro-active responses and preparedness capacity. The Madrid Water company is currently in its second generation "strategic contingent planning" and has specific staff devoted to these tasks working on risk analyses.

Some of the main weaknesses of the institutional framework to face hydrological droughts and water scarcity are the following:

(i) Although the Planning documents described above result from intense consultations, scrutiny and analyses, they may lack the flexibility to be amended to accommodate social, environmental and economic trends. In particular, the planning concept and the programmes of measures as they are conceived in the EU Water Framework Directive represent a significant departure from the traditional planning techniques as they have been practiced by basin agencies in the past. Among the most significant difference is perhaps the focus on the "ecological status of the heavily modified water bodies", and how restoring the ecological water quality is integrated in the planning strategies.

(ii) While Basin agencies, in coordination with the Environment Ministry, are adapting their methodologies, objectives and constraints at a reasonable speed, the needed changes are far from simple and direct. So it remains to be seen how Spanish Basins manage to comply with these new challenges.

(iii) The Water Law enforcement levels show a number of grey areas, particularly in the area of groundwater resources. Although key water suppliers internalize them as key strategic supply sources, the Basin agencies are in charge of managing and controlling its use and exploitation regimes. Inconsistencies in these are have been identified, showing that much more is needed to protect these key resources and secure accessibility when they are urgently needed.

(iv) The steps taken to let economic incentives allocate scarce resources during stressful situations are laid down in the Law, yet they have to be put into practice under real conditions. In particular, while these market arrangements to mobilize water resources and transfer them to highly valued uses are recognized by urban suppliers as promising, at the Basin agencies level there is much more scepticism. This gives rise to some inconsistencies between the drafters of the 1999 Law amendment, the expectations of some of the active parts of these market agreements, and the reluctance and reserves expressed by those Basin agencies' officials, who act as notaries and controllers of such agreements.

(v) Water quality problems endanger strategic resources and threaten the quality of high water quality sources. These problems evolve slowly and silently, but are not properly framed in the menu of pro-active measures.

(vi) Emergency actions, mainly in the from of works approved and built under urgent conditions, often take much larger costs and efforts than would be the case had they been planned for regular time frames. Occasionally, these works become operative when scarcity is no longer a problem, although they are certainly available for subsequent drought periods.

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Chapter 21. Drought management in the urban water supply system of Canal de Isabel II

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Introduction

Canal de Isabel II's commitment to the efficient use and management of the water resource is the best contribution to the quality of service to the citizens and environmental sustainability of the Community of Madrid. The materialization of this commitment is supported in the establishment of protocols for the better development of all the assurance processes of water supply.

The Supply Manual developed by Canal de Isabel II falls under these protocols and its main objective is to establish the general planning and operation guidelines of the Supply System, to ensure water supply to urban centers in compliance with all established standards. All this is in the context of sustainability in the maintenance of the ambient conditions of all the bodies of water related to the supply system, and following the principles of efficient management of the water resource.

The supply standards should reflect the need for flexibility and adaptation of management to a high risk of insufficiency of resources to handle the present or immediate needs of each situation in areas with a broad climatic variability. These situations, usually generated by the occurrence of periods of low precipitation, constitute the main element of the dimensioning of the hydric systems and require specific management guidelines. Guidelines which should consider the worst meteorological records known as those which involve the occurrence of the most severe episodes, due to natural causes or those induced by man.

Among the outstanding objectives of the Supply Manual is the fulfillment of Law 10/July 5, 2001, of the National Hydrologic Plan, which in Article 27.3 establishes that for urban supply systems which serve a population in excess of 20,000 inhabitants, an "Emergency Plan in Case of Drought Situations" should be provided. Although the operation of this Emergency Plan is conditional to that drawn up by the corresponding Basin Agency ("Special plan of action in situations of alert and possible drought") to which the Emergency Plan should adapt, the Supply Manual of Canal de Isabel II reflects the prevention and management proposals of situations of scarcity in the strict context of the supply system of Canal de Isabel II. The definition of the identification and management guidelines of the scenarios of scarcity constitute a significant section of the Supply Manual, which represents a complete revision of the Drought Management Manual of Canal de Isabel II, edited in 1999 and updated in an annual basis.

The proposals of this Manual, in case of a drought of a high severity, will fall under the competencies of the Basin Agency (Tagus River Hydrographic Confederation, "Confederación Hidrográfica del Tajo", CHT), established in Article 55 of the rewritten text of the Water Act, as well as, if applicable, in the exceptional measures approved by the Government, under the coverage of Article 58 of the same law.

With the considerations related to the fulfillment of the requirements of the water quality supplied being of prime importance in the all supplies, the scope of the Supply Manual does not cover these points, since it is considered that the water quality requirements, established by the standards in effect, will be satisfied through the use of available installations in the Canal de Isabel II system, under normal conditions in the operation and availability of resources, as well as in the scenarios of scarcity of little seriousness.

The document does not attempt to carry out a diagnosis of the Canal de Isabel II supply system or of the actuation requirements to handle medium- and long-term future scenarios. Nor does it attempt to determine and evaluate possible alternatives to guarantee an appropriate balance of resources and demands. Notwithstanding, in that related to short-term planning, the potential risk situations are made known and the conditions to manage these are established.

The presentations of the Supply Manual cover from the resource planning criteria up to the establishment of operating procedures with a clear orientation toward ensuring the sufficiency of the system to handle demands. The appraisals have been carried out from the consideration of global volumes, with a breakdown according to the different catchment sources and the main demand areas. The operating guidelines considered are based on monthly intervals of decision, consequently, excluding the weekly or daily scale of operation.

In summary, the Supply Manual of Canal de Isabel II expresses the protocols and good practices to:

(i) Establish the risks of scarcity and incapacity of the supply system to satisfy all demands.

(ii) Establish efficient management policies of the resource and water demand.

(iii) Ensure an integrated and sustainable management of resources.

(iv) Establish guidelines to operate the supply system handling short-term outlook.

(v) Integrate the satisfaction of environmental constraints and sustainability of related ecosystems into the operation of the supply system.

(vi) Manage the supply under conditions of drought and scarcity of resources.

(vii) Manage the supply system in case of large-scale contingencies and anomalies, such as floods.

(viii) Plan actions to guarantee the water supply in the medium and long term with the established risk level.

Basic principles of water supply in Canal De Isabel II

The Suppy Manual of Canal de Isabel II outlines the Basic Principles of water supply for its system, which are:

(i) The main mission of the water supply in Canal de Isabel II is to ensure the supply to all its users, according to the conditions stipulated by the regulations in effect.

(ii) The use of natural resources necessary for carrying out the function of a water supplying body to urban centers will be carried out within the framework of sustainability of ecosystems linked to the bodies of water whose conditions are affected as a consequence of the activity of the supply system.

(iii) All hydric resources in the supply system will be used under the principles of integrated management.

(iv) The guarantee of equilibrium between the availability of natural resources and the total consumption demanded in the supply system, for present and future scenarios, will be handled by giving particular priority to efficient management solutions of all the components of the supply and demand cycle.

(v) The assurance strategies of the supply for future scenarios will be established in the corresponding planning studies, within the frameworks established by the National Hydrologic Plan and the Tagus Basin Plan.

(vi) All the actions considered for the assurance of the availability-demand equilibrium will be calculated with the evaluation of its social, environmental and economic implications.

(vii) Droughts, understood as periods with low precipitation patterns, are a normal phenomenon although of little frequency in the scope of availability of resources of the Community of Madrid.

Droughts, understood as a climatic phenomenon triggering episodes of high-risk of nonfulfillment of the service standards, constitute a main part of the planning and management work of the supply of Canal de Isabel II.

(viii) In a combined consideration of efficient utilization of resources and recognition of adjusted balances between availability and consumption, in present scenarios and those of the immediate future, it is assumed the need to possibly resort to the temporary reduction of consumption. In spite of this, the commitment to always satisfy 91% of demand is established, within the historically recorded climatic context[1]. The reference objective for the need to introduce reductions in consumption is established at 4% of the years[2]. These assumed reductions do not require savings rates in excess of 9% of the average normal annual volumes, and under all circumstances will have an extent of less than one year.

(ix) The ecosystems dependent on the management of the CYII supply system will also be affected by the conditions of scarcity of resources triggered by drought episodes. In these cases, the need to restrict the fulfillment of the conditions for normal assurance, on a subsidized basis with urban supply, will be assumed.

(x) The assurance of the supply in the CYII also considers episodes of greater severity than those planned. Within the principles of risks and contingencies management, the encountering of episodes of prolonged scarcity of resources for supply, as a consequence of the occurrence of one or more of the following situations is considered:

- Periods of higher climatic severity than that recorded.
- Consumption increases in excess of those forecasted.
- The occurrence of eventualities which limit and condition the normal use of the infrastructure which forms the supply system.

Scenarios of possible climatic changes have been outlined within these planned risk strategies.

Scenarios of risk of scarcity of resource in the supply system of Canal de Isabel II

Canal de Isabel II establishes three degrees of risk of scarcity or insufficiency of resources to handle all its demands:

(i) Risk of severe scarcity

(ii) Risk of heavy scarcity

(iii) Risk of emergency scarcity

The process followed to integrate the risk management in the supply assurance process is that of characterizing each of these possible *scenarios* of *scarcity* under the terms of risk related to them, and from this characterization, determine the *levels* which identify the commencement of the scenarios, and establish its corresponding management procedures.

1. The acceptance of the need to reduce consumption 9%, based on voluntary savings, by the citizens for a limited number of years, forms part of the integrated planning practices and efficient management of the resource in all scopes subject to occasional periods of scarcity, since it is feasible with a slight incidence on society, according to that justified in the Manual. These reduction amounts have been maintained in the policies of the supply management in Canal de Isabel II, and particularly in its Drought Management Manual, whose first version is dated 1992.

2. This figure is that which has been maintained for longer than a decade in the planning criteria of the supply of Canal de Isabel II in its search to fine-tune with the general criteria of National Hydrologic Planning and most accepted guidelines in the water supply of western cities.

Usually, the concept of *risk* is understood as the product of the probability of occurrence of an event by the consequences deriving from this. According to this concept, the impact or consequences of each risk scenario has been mainly characterized by the implications they would have in the quality of service, with this being understood to be reductions in the supply of the volumes of normal demands. These reductions will have a different scope according to the risk scenario involved and, in reality, will correspond to that established a priori to handle and resolve each scenario. In regard to the other component of the risk calculation, the probability of occurrence has been based on the volume of reserves stored in the system in each month of the year, since the probability that the reserves are below a determined value is the parameter which best reflects the capacity of the system to handle its immediate demands, and its value in each month of the year implies a specific probability of occurrence of runoff in the prior time intervals.

So, for each scenario it is considered:

(i) The probability of occurrence that the level of reserves is below an established value.

(ii) The consequences, the impact on the supply, in the form of consumption reductions of a different intensity, implemented to solve each situation and prevent the occurrence of a scenario of greater severity.

In reality, with the management of each scenario, reducing the consumption and seeking temporary augmentation of inflow of resources, what is being sought is to reduce the probability of occurrence of a risk of worse consequences. Or, in brief, reduce the total risk of nonfulfillment of the supply requirements.

In the context described previously, the *scenarios* are related to the characteristics of the situation, and particularly to the impact related to this and the indicative *levels* of the commencement of the scenario, of stored reserves and, consequently, the probability of occurrence.

Following, the scenarios of scarcity and their consequences are described and, subsequently, the levels of commencement of these scenarios.

Scenarios of scarcity

The impacts corresponding to each scenario of scarcity will be variable and proportional to the severity of the considered scenario. These impacts have been calculated from the basic principle of the management guidelines of this type of risk, which is to ensure the surmounting of the episode identified in the risk, together with the prevention of incurring the following scenario of greater severity.

The surmounting and prevention guidelines and the objectives considered for each type of action have been established from rigorous evaluations of feasibility of implementation of the management measures of the risk situations, in regard to the time required for obtaining the proposed objectives, and in regard to the amount of the proposed demand reductions.

The calculation of these scenarios has been carried out departing from the identification of severe scenarios, to be avoided through risk management procedures associated with each less severe situation.

Consequently, the method consists in beginning to consider the worst possible situation and, from this, determine the conditions under which it would be necessary to act and with which to prevent that this situation materializes, always in a context of a specific probability.

On the other hand, and as has been indicated, on listing the scenarios of scarcity considered, a graduation of three scenarios is presented, whose main differences are:

(i) *Emergency scarcity:* Critical situation, which does not reach the total lack of supply, but would have certain dramatic effects of consumer rationing.

(ii) *Heavy scarcity:* This is the neatest scarcity scenario, with little probability of occurring, whose main management objective is to prevent the occurrence of an emergency scenario. It involves restrictions in the supply.

(iii) *Severe scarcity:* This is that of the lowest consequences for the users of the supply, and with little probability of occurrence, with impacts generally accepted by the citizens and assumed in the hydrologic planning criteria and efficient and sustainable use of resources.

Due to that indicated previously, the scarcity scenarios described in the following sections, beginning with those of the greatest severity. Each scenario describes the main characteristics, the related impact for surmounting these and the hypothetical conditions under which it is assumed that its management will be carried out.

Scenario of emergency scarcity

The point of departure could have been the consideration of an episode of absolute absence of reserves in any of the storage elements of the storage system, as the most dramatic situation imaginable to be avoided, but this referent is unfeasible when applied to an urban population of more than five million inhabitants. Instead, an emergency scenario has been established, in which the situation would be more dramatic due to the social and economic implications that the simple fact of facing it in a set of large communities, as is the case of the Community of Madrid.

Notwithstanding, within the preventive measures of this scenario, the precautions against the hypothesis of the total absence of reserves has been considered.

This emergency scenario, which should be considered as a referent of a dramatic situation, which will correspond to an extremely low probability of occurrence, would present a balance of surmounting with the following main parameters:

(i) *Impacts on supply:*

– Demand rationed to the basic needs of the population, estimated at 80 l/inhabitant per day for domestic use, and 50% of the normal water duties for remaining activities.

– The quality conditions of the water supplied could not be guaranteed with the same degree of commitment as in situations of less severity.

– The environmental constraints of surface fluvial runoff cannot be fulfilled to any degree.

– Only urban tree species of special value and interest would be provided with irrigation.

– Anticipated maximum duration of 12 months.

– The socioeconomic costs would be enormous in implementing a rationing system.

(ii) *Scenario management conditions:*

– Surface runoff corresponding to that defined as extreme hydrologic drought.

– Reduced availability of underground reserves as a consequence of the continued use during scenarios of scarcity which, by necessary would have occurred prior to this dramatic situation. An average extraction of 1.50 m^3/s is estimated.

– Runoff complement of 70 hm^3 from the Alberche River.

– Supply complement of 40 hm^3 obtained through the reuse of recycled water and exchanges from other concessionaires who may assign their rights.

– The maximum duration of continuation in this dramatic situation should be 12 months, which it is understood would be the duration in providing the population with an extraordinary solution to alleviate the situation.

– Notwithstanding, it is necessary to point out that the fulfillment of the conditions of inflow of resources and demands indicated would render a balance which would result in a prolonged continuation beyond that indicated.

Scenario of heavy scarcity

This scenario is of a transitional nature among the situations of severe scarcity, anticipated and assumed as part of the cyclical management of demand and the emergency scenario described previously.

This is an authentic *drought* situation, with significant social, environmental and economic impacts, which will be associated with the occurrence of climatic episodes of a greater severity than those recorded up to the date, and will occur as a consequence of the prolongation of a period of scarcity. Its solution will require forceful restrictive measures.

(i) *Impacts on the supply:*

– Would correspond to average reductions of demand of 26%.

– Anticipated maximum duration of 24 months, including in case of the occurrence of one of the worst recorded hydrologic periods.

– It is not possible to comply with the fluvial environmental constraints and an attempt would be made to maintain the urban tree species of value and interest and of the highest fragility. Loss of seasonal plant species.

– The socioeconomic costs would be significant as a consequence of the water consumption restrictions in commercial and industrial activities.

(ii) *Management conditions of the scenario:*

– The reduction values will be reached as a consequence of restrictive and support measures. The distribution of these demand reductions in the different types of use will be adapted.

– Surface runoff equivalent to those of a heavy hydrologic drought.

– Resource runoff complement by an amount of 192.5 hm^3, of which, 60 will originate from strategic reserves, 101 from the Alberche River, and the rest from the reuse and use exchanges.

Scenario of severe scarcity

This scenario corresponds to that of a moderate impact on users, considered within the cyclical management policies of demand, to adjust on an elastic basis the demands to the hydrologic irregularity and to the real supply capacities of the supply system. Its establishment may be imposed by policy-setting plans in the hydrologic plans, supply standards, preferential and acceptance studies on the part of the users, or otherwise, in situations of imbalance between resources and demand, as the only way to adjust the resource availability to existing global demands.

In the case of Canal de Isabel II, this scenario has formed part of the efficient management policy for longer than a decade, is included in the basic principles and is in line with that established as general criteria to appraise the availabilities in the basin hydrologic plans (Technical Instructions and Recommendations for the Drawing Up of the Intercommunity Basin Hydrologic Plans).

(i) *Impacts on the supply:*

– An average reduction of demand of 9% and a maximum duration of 12 months are considered.

– The environmental impacts would translate into a reduction of the environmental constraints to only 25% of the discharges established for El Vado and El Atazar reservoirs, from March to September.

– The socioeconomic costs would be very low.

(ii) *Scenario management conditions:*

– The reduction values in the consumption will mainly be reached as a consequence of voluntary changes of the individual user's habits and attitudes, and in the temporary conservation from all public centers and institutions. The distribution of these demand reductions in different types of use will be adapted.

– The surface runoff is the same as those of a severe hydrologic drought.

– Inflow of resources complement for an amount of 263 hm^3, of which 79 will originate from strategic reserves, 169 from the Alberche River, and the rest from the Sorbe River and the Almoguera Mondéjar system.

Levels of commencement of scenarios of risk of scarcity

As was indicated previously, risk management is made from the identification and typification of certain scenarios of very little frequency, and a measurement of the probability that this occurs. With both factors it is necessary to conclude in a series of values related to each risk scenario which identifies these situations and serves as reference for the commencement of the corresponding corrective action.

The probability of occurrence of the risk scenarios indicated in the previous section will be a consequence of the combination of the following factors:

(i) Present or short-term forecasted consumption.

(ii) Capacity of the supply system infrastructures.

(iii) Reserve volumes stored in the different components of the system.

(iv) Probability of a certain hydric runoff being produced.

The presentation followed is that of identifying the values of stored volumes which will determine, for an established hydric runoff pattern, the commencement of each of the risk scenarios. The hydric patterns used have been those typified in the situations of drought and scarcity of resources section, and specifically those corresponding to hydrologic droughts.

The patterns considered and the resulting scenario commencement values are described below:

Level of commencement of risk of severe scarcity

This would be the series of volumes stored monthly corresponding to the occurrence of a severe hydrologic drought or to any of the consecutive monthly sequences (from 1 to 48 months) to which a probability of occurrence equal to or less than 4% applies.

These values correspond to the distribution of consumption considered for the immediate future, but these values would be reached with a higher probability, as a consequence of demand growth in excess of that considered in the establishment of the operating policies of the system for the short term.

The commencement level of this risk scenario has been determined as the monthly reserve volumes in which only 4% of the years would be incurred. The extension of the scenario covers up to the monthly values which could be reached in case of the worst hydrologic sequence recorded (which is the border between the severe and heavy hydrologic droughts) and which, in addition, would ensure a minimum precautionary period of 12 months before incurring the scenario of heavy scarcity, even in case of the occurrence of the worst monthly sequences. The highest value is adopted each month, of those obtained with each of the criteria. This commencement level of the scenario of risk of severe scarcity corresponds to that which will be defined as the beginning of the drought situation in the supply system.

The values of monthly volumes of reserves which determine the commencement of this scenario are indicated in Table 1 below and are reflected in Fig. 1.

Table 1. Monthly reserve volumes (in hm^3), for the commencement of the different risk scenarios

	Level of severe scarcity	Level of heavy scarcity	Emergency level
October	345.2	169.6	69.9
November	311.9	148.0	67.7
December	305.7	138.5	66.9
January	314.5	138.5	66.5
February	309.3	127.6	67.6
March	328.4	156.3	69.2
April	358.5	194.1	70.7
May	348.6	226.4	74.4
June	383.4	255.9	78.9
July	401.7	248.0	80.4
August	391.6	221.5	77.7
September	369.8	198.0	73.9

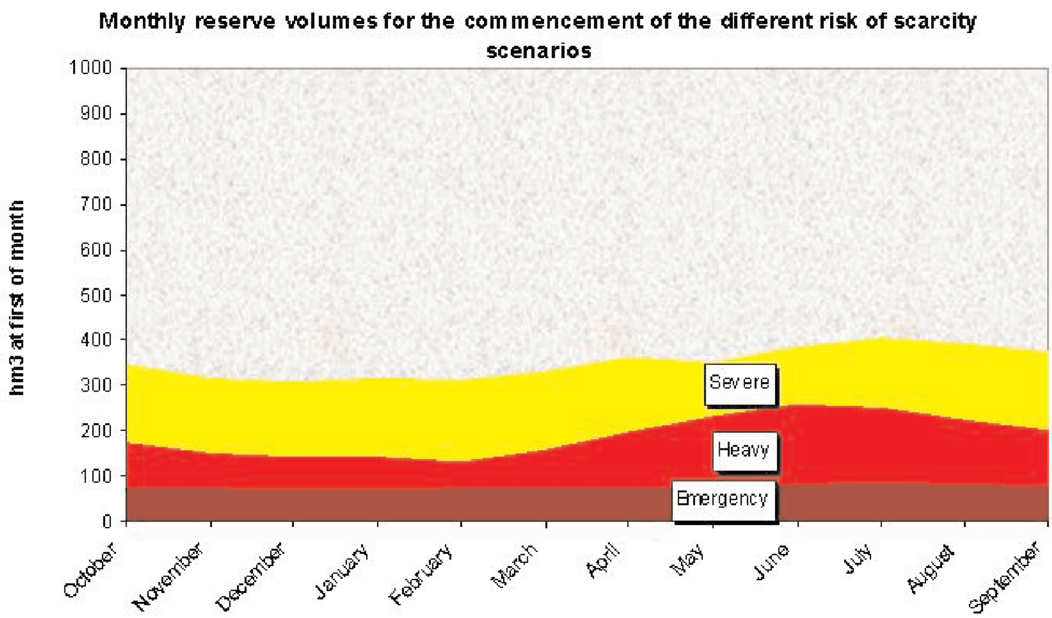

Fig. 1. Monthly reserve volumes for the commencement of the diferent risk of scartity scenarios.

Level of commencement of risk of heavy scarcity

This will be the set of monthly values of surface storage corresponding to the occurrence of a hydrologic sequence of less runoff than the severe hydrologic drought (periods of less runoff than that historically recorded of a duration of less than six months should not trigger this scenario).

This scenario may also be incurred as a consequence of the nonfulfillment of the consumption reduction objectives, or inflow of resources to the system, considered for surmounting the scenario of risk of severe scarcity.

The commencement levels of this scenario have been determined as those which would be incurred only in case of the occurrence of hydrologic droughts with lower runoff than those historically recorded. In addition, they would ensure a minimum precautionary period of 24 months before incurring the scenario of emergency scarcity, even in case of the occurrence of the worst consecutive monthly sequences of runoff corresponding to that typified as a heavy hydrologic drought, once immersed in this scenario.

This commencement level of the scenario of risk of severe scarcity corresponds to that which will be defined as the commencement of a heavy drought situation in the supply system.

The values of monthly reserve volumes which determine the commencement of this scenario for the 2003 period are listed in Table 1 and reflected in Fig. 1.

Level of commencement of risk of emergency scarcity

This would be the set of monthly values of surface storage corresponding to the occurrence of a hydrologic sequence of less runoff than the heavy hydrologic drought (periods of less runoff than that typified as heavy of a duration of less than six months should not trigger this scenario).

This scenario may also be incurred as a consequence of the nonfulfillment of the consumption reduction objectives, or inflow of resources to the system, established for scenarios of risk of heavy or severe scarcity.

The commencement levels of this scenario have been determined as those in which only in case of the occurrence of hydrologic droughts with runoff less than that typified as heavy and which in addition ensures a minimum precautionary period of 12 months to find an emergency solution which permits to recover scenarios of a lesser severity, even in case of the occurrence of the worst consecutive monthly sequences of runoff corresponding to that typified as an emergency hydrologic drought.

In spite of the theoretic positive balances of runoff and consumption established in the management of this scenario, it is assumed that the volume of surface reserves should be equivalent to two months of consumption under these rationing conditions at all times, in order to handle temporary irregularities of the minimum runoff forecast and the distribution of uses among the different reservoirs of the system.

This level of commencement of scenario of risk of emergency scarcity corresponds to that which will be defined as the commencement of the emergency drought situation in the supply system.

The values of monthly volumes of reserves which determine the commencement of this scenario for the 2003 period are indicated in Table 1 and reflected in Fig. 1.

Normal scenario

Levels of surface reserves over the commencement values of a situation of severe scarcity. Harnessing of resources according to the normal guidelines and according to the priorities established.

The mission of this scenario, in relation to the risks of scarcity indicated previously, is to ensure the integrated and efficient use of the different sources of resources, under conditions of abundance, in order that the probability of occurrence of scenarios of scarcity is that initially established on defining the risk scenarios. This probability, which in previous sections is exclusively related to the hydrologic runoff pattern, will evidently be conditioned by the operating guidelines during the normalcy scenarios.

Chapter 22. Application of the Drought Management Guidelines in Tunisia

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SUMMARY – This Chapter summarizes the analysis of the Tunisian organizations and institutions related to drought. First, the Chapter provides an overview of the rainfall and water resources in Tunisia. Second, mapping of the different National organizations and institutions involved in water management and drought mitigation, and also those not working on water management but, due the emergency of drought circumstances and regarding the importance of their contribution, they are associated when the drought is upon. The International organizations working on water resources management in Tunisia and eventually on drought mitigation are also described. The Chapter analyses the interaction between the different organizations and institutions involved in the process of the water management and drought mitigation as well as in the linked data and information collection and processing system. The Chapter includes a description of the water resources data and information systems, which have an important role in the water management and drought mitigation. The Tunisian water resources and drought policy and the related legislation are described. Finally, the drought preparedness and management system in Tunisia and its coping with drought proficiency is outlined.

Key words: Institutions, legislation, risk analysis, reservoir, Siliana, drought management.

The planning framework

Tunisia is located in the South of the Mediterranean basin, therefore climatic conditions and consequently the rainfall, the origin of renewable water resources and principal factor for rainfed (dry) farming systems, are influenced by the Mediterranean climatic perturbations from the north and also by the desert effects from the south. In other hand, in Tunisia, drought periods could be restricted for one or some regions and could be generalized. The drought duration could be one season or one year and more, but with a variable intensity. The probability to have 3 successive dry years is so small (one time in the north and 2 to 3 times in the centre and the south during 1 century), like the drought occurred during 1999-2002.

According to FAO (1994), especially the southern Mediterranean countries are among those that will face severe water resources scarcity in the near future. Regarding the demographic evolution of those countries, the great challenge for the coming decades will be the task of increasing food production with limited water resources, and unfortunately under global climatic changes (Sakiss *et al.*, 1994). For this reason, Tunisia focused its policy on the water mobilization, that is conceived with inter annual volume regulation approach and with inter-basins and within-basin water transfer system, and implemented an integrated water resources management system (IWRM). In the Tunisian IWRM process, the drought is considered as a climatic reality, which is taken in to account in Development Plan Programs. The planning for drought for moving from crisis to risk management dates only from the end the eighties. Before, drought was erroneously considered for several years as temporary and rare climatic event, and consequently its management was "a forced reaction" to respond to immediate needs. A drought management system have been developed, used for the drought events occurred during 1987-1989 and 1993-1995, and showed the performance of the hydraulic system. In 1999, Tunisia elaborated its first drought mitigation guideline (Louati *et al*., 1999). The later, applied during the drought upon during 1999-2002, were qualified as moderately sufficient, and could be improved; the lessons learned should be established in order to update the system (the guideline). The output and deliverable of MEDROPLAN will have certainly a high importance in the updating process of the drought management system in Tunisia.

Organizational component

Organizations and institutions

According to Article 2 of the updated Decree No. 2001-419 dated on 13 February 2001 (Journal Officiel de la République Tunisienne, JORT), the Ministry of Agriculture, and Water Resources (MARH, Ministère de l'Agriculture et des Ressources Hydrauliques) is entrusted with the water management. The MARH duties are carried out by its different directions and departments defined in the updated Decree No. 2001-420 (13 February 2001, JORT).

The complexity of the Tunisian water system results in an intricate institutional water management framework, where the water competencies and responsibilities are spread among several organizations and institutions. Consequently, all those institutional bodies are linked to drought mitigation processes. Moreover, several departments in the MARH and in other Ministries, which are not working in water management, are associated in the drought management (Table 1).

The principal organizations and institutions, which are involved in the water mobilization, management and planning as well as in the drought management are the MARH, especially the BPEH (Bureau of Water Planning and Hydraulic Equilibriums, Bureau de la Planification et des Equilibres Hydrauliques) department, the central directions, and the regional services (Departments). In addition the organizations supervised by MARH, such as the NGOs (Collective Interest Associations/Groupement d'Intérêt Collectif, GIC), which are professional and users associations. Finally, the are some institutions non relevant to MARH.

BPEH (Bureau de la Planification et des Equilibres Hydrauliques: Bureau of Water Planning and Hydraulic Equilibriums)

BPEH is directly attached to the cabinet (departmental staff) of the MARH Minister. The competencies assigned to this bureau are:

(i) Mapping the conventional and non conventional water resources.

(ii) Identifying the different socio-economic water needs (demands).

(iii) Collecting the available and exploitable water resources information.

(iv) Collecting and analysing all data related to the water demand.

(v) Proposition of plans and programmes on the water resources allowance for all users, according to the supply and demand.

Regarding its important role within the MARH, the BPEH is continually in relation with all organizations and institutions involved in water resources management in the country. Consequently, an important database on the water resources is continually collected and updated.

Central Directions of MARH

Central Directions, that have extensive competencies in the water resources management field, are the General Direction of Dams and Large Hydraulic Works (DGBGTH, Direction Générale des Barrages et Grands Travaux Hydrauliques), the General Direction of Water Resources (DGRE, Direction des Ressources en Eau) and the General Direction of Rural Engineering and Water

Table 1. Organization and institutions involved in water resources management and/or drought mitigation in Tunisia (see text below for acronyms)

Ministry	Institution	Water Management	Drought Mitigation Phases
MARH	BPEH (Cabinet)	X	(1-2-3)
MARH	DGBGTH	X	(1-2-3)
MARH	DGRE	X	(1-2-3)
MARH	DGGREE	X	(1-2-3)
MARH	DGACTA	X	(1)
MARH	CRDA (Water Departments)	X	(1-2-3)
MARH	CRDA (Vegetal and Animal Departments)		(1-2-3)
MARH	BIRH (DGRE)	X	(1)
MARH	SONEDE	X	(1-2)
MARH	SECANDENORD	X	(1-2)
MARH	IRESA	X	(1-2-3)
MARH and other Ministries	CNE	X	(1-2-3)
Advised by MARH	NGO association	X	(1-2-3)
MESD (Environment and Sustainable Development)	DGEQV	X	–
MESD (Environment)	ONAS	X	–
MESD (Environment)	ANPE	X	–
MESD (Environment)	CITET	X	–
MTCT (Meteorology)	INM	X	(1-2)
MPH	DHMPE	X	(2-3)
MARH	DGPA	–	(1-2-3)
MARH	DGSV	–	(1-2-3)
MARH	DGPCQPA	–	(1-2-3)
MARH (Budget)	DGEDA	X	(2-3)
MARH (Budget, Finance)	DGFIOP	X	(2-3)
MARH	DGF	–	(1-2)
MARH	OC	–	(2-3)
MARH	OEP	–	(2-3)
MARH	AVFA	–	(2-3)
Prime Ministry	Media	–	(2-3)
NGO	UTAP	–	(2-3)
Ministry of Finance	Ministry	–	(1-2-3)
Ministry of Economic Development	Ministry	–	(1-2-3)
Ministry of Public Health	Ministry	–	(1-2-3)
Ministry of Interior	Ministry	–	(1-2-3)
Ministry of Commerce	Ministry	–	(1-2-3)
Ministry of Communication Technologies and Transport	Ministry	–	(1-2-3)

Exploitation (DGGREE, Direction Générale du Génie Rural et de l'Exploitation des Eaux). On the other hand, the General Direction of Planning, Management and Conservation of Agricultural Lands (DGACTA, Direction Générale de l'Aménagement et de Conservation des Terres Agricoles) is involved in the natural resources evaluation and preservation as well as in the hydrological and hydro geological aspects linked to the water resources. Those directions have their legal framework defined in the updated Decree No. 2001-420 dated from 13 February 2001 (JORT).

DGBGTH

Responsibilities in water resources planning and management are shared by DGBTH through the following competencies:

(i) Elaboration of the hydraulic studies.

(ii) Elaboration of mastering surface water resources planning.

(iii) Elaboration of water mobilizations studies.

(iv) Making up the dams and lakes building studies.

(v) Elaboration of important water planning studies for surface water resources mobilization (big dams, water transfer…).

(vi) Control and maintenance of dams.

(vii) Realization of the planning and large hydraulic works related to the rural and agricultural zones protection against floods.

(viii) Ensuring a platform to encompass all the areas of flood prevention and disaster management.

(ix) Supervising the drought management system.

DGRE

The DGRE is responsible for:

(i) Setting up and managing of measurement and observation networks related to all country water resources components (water data and information system and flood early warning, etc.).

(ii) Elaboration of basic and applied studies on the water resources evaluation and setting their general balance.

(iii) Drawing the principal and specific methods for the water resources management, according to the supply and the demand.

(iv) Promotion of the research and experimentation activities related to the conventional and non conventional water uses.

(v) Finalizing and perfecting the different ground (basics) of water mobilizations planning and their exploitation.

BIRH

The Hydraulic Inventory and Research Bureau (BIRH, Bureau de l'Inventaire et des Recherches Hydrauliques) was created by the Law No. 80-100 (31 December 1980, JORT), has a financial autonomy and it is under the DGRE administrative authorities. BIRH participates, by using advanced technological instrumentations, in the mounting and management of measurements and observations networks related to all country water resources components (surface and ground water). BIRH is loaded by the realization of the following duties:

(i) Establishment and updating of the national surface and groundwater resources inventories and development of prospecting for new water resources identification.

(ii) Mounting and management of measurement and observation networks related to all the country water resources components (surface and ground water).

(iii) Realization of pumping operations in order to determine the technical aquifers characteristics.

(iv) Computation and optimization of water information and data base management.

(v) Dissemination of water data and information recorded and analysed, by publishing bulletins and technical yearbooks (annuaires).

DGGREE

The attributions of the DGGREE are:

(i) Realization of strategic studies and elaboration of political plans related to rural engineering and agricultural water exploitation.

(ii) Attending and evaluation, planning, equipping, soil sweetening and drainage of irrigated areas, management of irrigation water exploitation, maintenance of hydraulic works and equipments, and conceiving the appropriate technical and economic management of the irrigated areas.

(iii) Optimizing the water use and valorisation of the reclaimed used water, attending all NGO (GIC), and implementing the management and the balance of the water demand and supply in the agricultural sector.

(iv) Coordination of rural and urban domestic (drink) water programmes, and elaboration of water supply planning and projects and attending them.

(v) Coordination of rural infrastructures and basic equipments, and studying the technological and economic aspects related to the agriculture mechanization promotion.

DGACTA

DGACTA is involved in the natural resources management by realizing the following missions:

(i) Elaboration of plans and orientations related to natural resources (soil, plant and water).

(ii) Proposition, elaboration and promotion of measures ensuring the optimization of natural resource utilization.

(iii) Soil resources evaluation (vocation and agricultural aptitude). The GIS and remote sensing technique are used.

(iv) Realization of research on soil sciences, using advanced techniques and equipped soil and water analysis laboratories.

(v) Control of soil evolution under the different exploitation modes, and their protection against salinity, degradation, and desertification.

(vi) Coordination between all parties working on the soil and water conservation.

(vii) Elaboration of the basins planning, and drawing out the anti-erosive studies and implementing them.

(viii) Control and attending the soil and water conservation projects realization.

(ix) Evaluation of the soil and water conservation planning and programmes.

(x) Setting and promotion of approaches targeted on the natural use optimization and preservation and associating all operators in the preservation process.

(xi) Ensuring the valorization and exploitation of the soil and water conservation infrastructures and planning works realized.

DGPA

The General Direction of Agricultural Production (DGPA, Direction Générale de la Production Agricole), is a central direction and is responsible for the promotion of agricultural production (cereal, forage, horticulture, arboriculture, fruit and olive trees particularly, industrial crops, biological agriculture, animal production). This DG is subdivided into 5 directions:

(i) Direction of Cereal and Forage Crops.

(ii) Direction of Fruit and Olive Trees and Horticultural Crops.

(iii) Direction of Agricultural Production Diversification (biologic agriculture, production diversification).

(iv) Direction of Forage Resources and Rangelands.

(v) Direction of Animal Production and the Livestock Promotion (meat, milk, productions, genetic amelioration, etc.).

DGPA is not involved in water management but it is associated in the drought mitigation system and contributes through its central and regional services ("Arrondissements") in the CRDAs in the different steps of drought management.

DGSV

The General Direction of Veterinary Services (DGSV, Direction Générale des Services Vétérinaires) defines the national programmes and policy in the animal health sector and all components related to the livestock preservation and safeguard. This General Direction is associated in the drought mitigation process by its central directions and regional services in the CRDAs.

DGPCQPA

The General Direction of Agricultural Products Quality Control and Protection (DGPCQPA, Direction Générale de la Protection et du Contrôle de la Qualité des Produits Agricoles), has several attributions related to the sustainability and the promotion of the agricultural quality production. It controls the quality of several products and attests their conformity with the norms: (seeds, plants, chemical treatment products, the imported and exported agricultural products, etc.). This direction establishes the products quality control when the importation programme is scheduled.

DGEDA

The General Direction of the Agricultural Studies and Development (DGEDA, Direction Générale des Etudes et du Développement Agricole), has to realize the following duties:

(i) Realization of studies and analysis for the agricultural development.

(ii) Elaboration and attending the development plan execution with the collaboration of the different MARH departments.

(iii) Identifying the agricultural development plan components and evaluation of related programmes and projects.

(iv) Elaboration of the MARH budget, realization of economics-related research topics, establishing statistical data analysis on the agricultural activities for future utilization in the economic planning programmes.

(v) Attending the evolution of the agricultural circumstances, notably during the drought events.

(vi) Elaboration of economic analysis related to the agricultural development policy.

By its Directions (Studies and Plans, Statistics and Agricultural Circumstances, Development Programs and Projects), DGEDA contributes on drought management by analysing its different phases and evaluating the social and economic impacts.

DGFIOP

The General Direction of Financing, Investments and Professional Institutions (DGFIOP, Direction Générale du Financement et des Investissements et Organismes Professionnels) prepares the MARH budget with the collaboration of DGEDA, and draws up all operations related to the financial support for the agricultural activities as well as for the drought management.

DGF

Forest General Direction (DGF, Direction Générale des Forêts), is not involved in water management but contributes in the forest lands management and acts against forest fire, especially during drought events. DGF manages several rangelands that are open for farmers during drought. DGF has numerous forest lands data and maps containing numerous water resources information.

DGAJF

The General Direction of Juridical and Land Property (DGAJF, Direction Générale des Affaires Juridiques et Foncières), within its duties, ensures the legal advisory service for the MARH, notably in water legislation field.

Regional Commissaries of Agricultural Development or Regional District Department of MARH (CRDA, Commissariats Régionaux au Développement Agricole)

Within the framework of the Tunisian decentralization policy, the MARH central direction, involved in all the agricultural activities (natural resources, food production, vegetal and forestry domains, economic aspect…) are represented in each governorate (24 governorates), by regional services or district departments. It is an administrative and technical structure, called CRDA. The CRDAs are created by a law that was successively updated in March 1989 (Law No. 89-44, JORT) and in October 1992 and October 1994.

CRDAs are entrusted with numerous responsibilities targeted on the realization of all operations related to the regional agricultural development and natural resources valorizations, particularly:

(i) Application of the legislation and regulation related to soil protection, forest and water management, supervising plant protection, and caring for animal health.

(ii) Ensurance of forest resources development and protection, soil land water conservation and agricultural land and basin planning.

(iii) Regional hydraulic system and forest domain management. Conservation of the natural resources.

(iv) Realization of hydraulic planning and hydro agricultural infrastructure valorization.

(v) Hydro agricultural infrastructure management and maintenance. Achieving the water supply network management.

(vi) Encouraging farmers' initiatives for adequate structure creations that are targeted on the regional agricultural development process.

Each CRDA supervises the agricultural activities and their promotion by technical, administrative, legislative, and financial issues and by diffusion of new agricultural technologies enhancing the related regional domain. CRDA has technical and administrative services ("Arrondissement"), which are the representatives of the central directions and realize their duties at the regional level. The principal services "Arrondissements" involved in the water management and producing linked data and information are: (i) Water Resources Service (A/RE, Arrondissement des Ressources en Eau); (ii) Public Irrigated Areas Exploitation Service (A/EPPI, Arrondissement de l'Exploitation des Périmètres Publics Irrigués); (iii) Maintenance of Equipments Service (A/ME, Arrondissement de la Maintenance des Equipements); and (iv) Rural Engineering Service (A/GR, Arrondissement du Génie Rural).

On the other hand the Soil and Water Conservation Service (Arrondissement de la Conservation des Eaux et des Sols) that is relevant to the Afforestation and Soil Protection Division (Division de Reboisement et de la Protection des Sols), is linked to the water management process.

Institutions supervised by MARH

SONEDE

Created by the Law No. 68-33 (2 July 1968, JORT), the Water Exploitation and Distribution National Company (SONEDE, Société Nationale d'Exploitation et de Distribution des Eaux) is an autonomous institution under the umbrella of the MARH authorities, and ensures the management of the domestic water and also the industrial and other (non agricultural) uses in the country. Organized by several directions, SONEDE is responsible for the quantitative and qualitative fresh water management. It has to realize the water network exploitation, maintenance, transportation (transfer and canalization), and all activities related to the area of drinking water such as water treatments for normalized qualities (physical, chemical, biological and bacteriological) and its equitable distribution. SONEDE establishes the population water needs, realizes the infrastructure required, and draws up a statistical data related to the evolution of the domestic, industrial and tourist water demand, production and treatment operations required, and establishes the yearly fresh water provision for the different users. SONEDE collaborates with DGBGTH, DGGREE, DGRE and SECADENORD.

SECADENORD

The Company of Exploitation, Canalization and Adduction of the Northern Canal and Waters (SECADENORD, Société d'Exploitation du Canal et des Adductions des Eaux du Nord), was created by the Law No. 84-26 (14 May 1984, JORT), has a financial autonomy and is under the MARH authorities. It ensures the management and maintenance of the North West part of the network of water transfer (pipes and channels) from the extreme North West to the users located in the North East, Centre and South of the country were there is a fresh water shortage. The water adduction and interconnection network hydraulic components are the following: (i) Canal Medjerda Cap Bon (from Laroussia to Belli); (ii) transfer of Sejenane and Joumine waters; (iii) Kalaat El Andalous hydraulic complex; (iv) El Herry hydraulic complex; (v) Nebhana hydraulic complex; (vi) Barbara dam waters transferring; and (vii) Sidi Barrak dam waters transferring.

The water quality is controlled by several analyses, and water pollution risk during transferring is monitored.

IRESA

Decree No. 90-72 (30 July 1990, JORT) assigned to the Agricultural Research and Higher Education Institution (IRESA, Institution de la Recherche et de l'Enseignement Supérieur Agricoles) the supervision of agricultural research and higher education institutes. IRESA has to sit up, to keep awake and to supervise the agricultural research programmes, and to promote the agricultural higher education in order to enhance the agriculture sector.

Decree No. 91-104 (21 January 1991, JORT), related to the organization and the attributions of IRESA, specifies the attributions of the Direction of the Scientific Information Processing (DTIS, Direction du Traitement de l'Information Scientifique). The DTIS is the linkage organ between the agricultural research and education institutions and the development departments, and ensures the internet service supply for the agricultural sector (Authorization No. 1002, 30 December 1997), by mean of AGRINET National network (www.agrinet.tn). DTIS is entrusted notably with conservation, elaboration, and processing of scientific databases (e.g. implementing of an information system on the agricultural water research, WATER 2000) for research and planning uses purposes, and also in order to establish a simplified Decision Support System (DSS). Moreover, DTIS identifies and manages the databases (national and international) connections.

Furthermore, IRESA establishes an international collaboration and cooperation related to its field of activities (notably with ICARDA, CIHEAM, FAO, IDRC, GTZ, ACSAD, IRD, EC, AIEA, foreign Universities and numerous other institutions and organizations). Actually, by using GIS, attending the irrigated areas project is in process and is conducted by DTIS and DGGREE and Italian cooperation. On the other hand, water management and drought mitigation are within the priority research programmes of IRESA.

CNE

According to the Tunisian Water Code, the National Water Committee (CNE, Comité National de l'Eau) is supervised by MARH (Law No. 75-16, 31 March 1975, JORT). The Tunisian Water Code attributes to CNE several competencies on water resources in the country. The CNE examines and evaluates the general issues related to the water planning and management. Data on supply and demand, population, natural characteristics, etc., are used in the evaluation process. The CNE is composed (Law No. 78-419, 15 April 1978) by the MARH Minister as President and as members are the representatives of the Ministries linked to water resources management (Justice, Interior, Finance, Equipment, Development and International Cooperation, Public Health, Industry Energy, and Communication Technologies and Transport), representatives of the MARH technical direction entrusted with water management, the directors of public water institutions such as SONEDE and the National Service of Used Water Cleansing (ONAS, Office National de l'Assainissement), representatives of several water resources users public and private bodies. The regional authority is associated when the subject discussed is related to its region.

OEP

The Animal Husbandry and Pasture Agency (OEP, Office de l'Elevage et de du Pâturage) is entrusted with the management of all tasks related to animal husbandry and pasture.

OC

The Cereal Agency (OC, Office des Cereals) is in charge of the promotion and the management of the cereal production.

AVFA

The Agricultural Extension and Training Agency (AVFA, Agence de Vulgarisation et de la Formation Agricoles) is responsible for the attending the farmers to promote agricultural practices and to transfer the new agricultural technologies.

GIC (Groupements d'Interêt Collectif, NGOs)

GIC associations are a group of users in the rural areas that have to manage their demand on water (domestic and agricultural use). They are created by MARH and advised by DGGREE. The number of drinking water associations is more than 1500 and they supply (with fresh water < 1.5 g/l) around 117,000 families (1.3 million inhabitants) and the several regional schools and hospitals. In the rural areas not covered by the national agricultural hydraulic system, 550 agricultural GIC (irrigation and agricultural land management operations) are organized around the waterholes, sources and intakes from dams, hill dams in order to irrigate their farms. They ensure the management of about 30% of the total irrigated areas (DGGREE, 2002).

The GIC associations have a legal framework defining their duties and their legislative code (several decrees and laws dated from 1985 until now, where the legal framework is continually updated and almost completed, depending on the water demand evolution).

UTAP

The Tunisian Farmers Association (UTAP, Union Tunisienne de l'Agriculture et de Pêche) is a professional association, which represents the Tunisian farmers and their interests, and is supported by MARH.

Environmental Institutions supervised by MESD (Ministère de l'Environnement et du Développement Durable)

Environmental institutions do not have any role in water resources and drought management but they are indirectly involved by their competencies and duties since they care and share the environment quality, were water quality is an important component.

DGEQV

DGEQV (Direction Générale de l'Environnement et de la Qualité de la Vie: General Direction of Environment and Life Quality) has to: (i) formulate the general political aspects related to the environment; (ii) coordinate and attend the state operations and measures for the environment protection; (iii) campaign against pollution and its nuisance; and (iv) improve the life quality. It is involved in environment aspects related to water resources.

ONAS

(i) Created in 1974, ONAS (Office National de l'Assainissement: National Service of Used Water Cleansing) is involved in water management by the following activities:

(ii) Avoiding water pollution in the urban, industrial and touristy zones.

(iii) Management, exploitation, maintenance and construction of the network town cleansing.

(iv) Realization of studies projects related to the individual rural water cleansing.

(v) Management of water purifying station (used water reclamation), and supplying the reclaimed water for the specified irrigation uses.

(vi) Collecting data on the rejected water and setting all information's about the industrial effluents. Information related to the mapping of the industrial unities are organized in "Cadrin" database.

ANPE

The financial and administrative organization of ANPE (Agence Nationale de Protection de l'Environnement: National Environment Protection Agency) is defined by the Decree N° 93 – 335 (8 February 1993, JORT).

Within its missions the ANPE realizes the environmental protection and preservation operations. ANPE controls the polluting throwing out (liquid and solid) in the natural systems and also their treatment stations, attends the legislation application, and sensitizes the population to environment protection and preservation. Every new project related to agricultural, touristy, industrial, urban fields is submitted to this agency in order to identify its environmental impacts. Data information on water, air and all environmental components are monitored by ANPE. In other hand, by a special PNUD support, the OTED (Observatoire Tunisien de l'Environnement et du Développement: Tunisian Observatory for the Environment and the Development) was created in 1994, just after the Rio de Janeiro conference held in 1992 were Agenda 21 was adopted.

CITET

CITET (Centre International des Technologies de l'Environnement: International Centre of Environment Technologies) dates from. March 1996 (Law N° 96 - 25).

The CITET activities are hinged on 3 axis:

(i) National and international trainings, notably on the urban cleansing, solid and liquid rejections management, industrial pollution control, urban management systems, environmental impacts studies, campaign against desertification.

(ii) Conducting a research related to industrial effluents treatments, and purifying water stations, air quality, etc. …

(iii) Technologies transferring, as desalinization of saline and sea waters and industrial water physical and chemical treatments.

Other Institutions not related to MARH

INM

Within the Ministry of Communication Technologies and Transport framework competencies, the National Institute of Meteorology (INM, Institut National de la Météorologie) was created in 1974 (Law No. 101-74, JORT). INM ensures the meteorological observations, particularly weather forecasting, climatology, and applied meteorology by managing the nationwide meteorological observation network that comprises synoptic, agro-meteorological, climatologic, rainfall, marine and upper-air observation stations. Its mission is namely:

(i) Meteorological observations.

(ii) Seismic recording and location.

(iii) Astronomic observation and calculation of ephemeris.

(iv) Weather prediction.

(v) To provide meteorological, astronomy, and geophysical data to various national economic sectors.

(vi) Technical coordination of all activities related to meteorological and geophysical aspects.

(vii) To do technical and economic studies relevant to its field of activities.

(viii) To conduct theoretical and applied research for the development of meteorological and geophysical sciences.

(ix) Preparation and implementation of international agreements related to matters of skill and technical cooperation with international centres and specialized organizations.

DHMPE

The Direction of Environmental Hygiene and Environment Protection (DHMPE, Direction de l'Hygiène du Milieu et de la Protection de l'Environnement) is relevant to Public Health Ministry (Ministère de la Santé Publique) and involved in the water management system by the control of drink water quality, attending the network town cleansing and campaigning against pollution. DHMPE database target on the qualitative aspects of drink, recreation, and reclaimed used waters.

Ministries associated in the drought mitigation system

Treasury or Finance Ministry (Ministère des Finances), Ministry of Economic Development and International Cooperation (Ministère du Développement Economique et de la Coopération Internationale), Public Health Ministry (Ministère de la Santé Publique), Ministry of Communication Technologies and Transport (Ministère des Technologie de la Communication et du Transport), Interior Ministry (Ministère de l'Intérieur) and Commerce Ministry (Ministère du Commerce) are involved in the measures for coping with drought.

Linkages among institutions

Under the supervision of MARH, institutions involved in water resources and drought management are invited to periodical coordination meetings in order to specify the major decisions related to water resources allocation and management. Emergency sessions are conducted depending on the weather extremes situations (flood and drought).

In every water management plan that is realized and supervised by one institution, numerous institutions are associated in the relevant study as well as in the realization process. Coordination is already consolidated by the representatives of the institutions linked by the water resources management programmed. On the other hand, linkages between institutions are shown in water resources information and data exchange. Figure 1 summarizes the linkages among the institutions.

Most of the communications between institutions are organized through a network supervised by IRESA which is the same time the Internet provider of MARH.

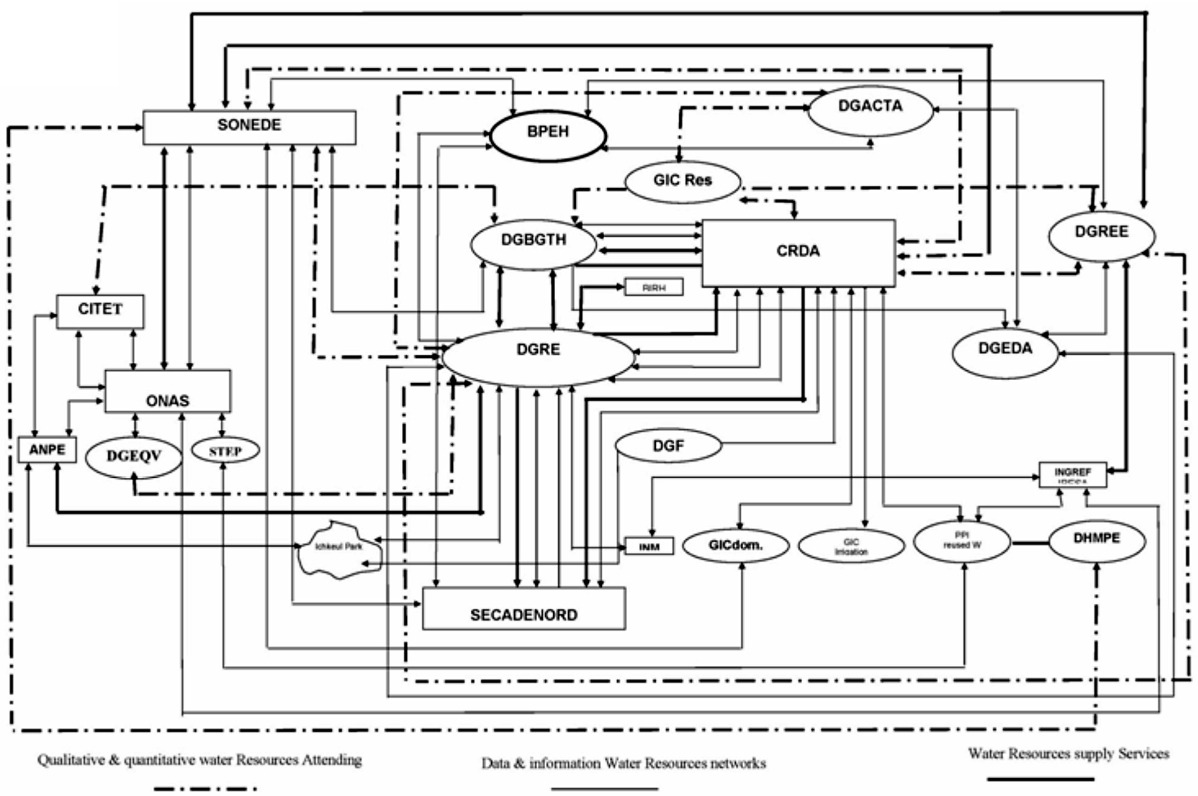


Fig. 1. Map of the organizations and institutions involved in water management in Tunisia.

International Organizations associated in water resources management in Tunisia

The Integrated Water Resources Management in Tunisia is continually viewed and updated by mean national studies and also by international cooperation programs. DGBGTH (1992) achieved the "Water 2000 project / EAU 2000" with the collaboration of KFW (German Bank). This project established planning study linked to water investment and mobilization until 2010. A study on the Natural Resources Management Policy was achieved and has as objective the sustainable natural resources management until 2025 (DGPDA, 1996; WB, 1997). In 1998, a long-term identification of water resources was defined (Khanfir *et al*., 1998). A Water sector study was elaborated in 1999, were diverse subject to water sector were analyzed as the demand, supply, cost, legislative and institutional water management system, pollution and different water origins and uses. Later, GEORE project has been achieved (DGBGTH/GTZ, 2001). GEORE Project is target on the establishment of an integrated Water Resources Management Policy.

By the World Bank support, the PISEAU project (Projet d'Investissement dans le Secteur de l'Eau: Water Sector Investment Project) is conducted in Tunisia. The objectives of PISEAU project are namely:

(i) The participative water demand management.

(ii) The integrated water resources management.

(iii) The sustainable natural resources management.

(iv) Enhancing the governmental structure capacities, promoting the NGO and (GIC) associations, and the private water users in order to sustain the water resources management.

(v) Promotion of the natural resources conservation and protection of the environment.

(vi) Training and research.

(vii) Establishment of a national information system on water resources (SINEAU).

Water resources and drought legislation

Water legislation history

The water legislation history in Tunisia could be subdivided by 4 principal periods:

(i) From the first millenary BC until the arrival of Islam, especially during the Roman civilization, where water resources have been managed by the building of aqueducts for domestic and agricultural uses.

(ii) During the Islamic empire, especially the Hafsides (1236-1574), the water was considered as "God's Gift", and consequently it was considered as public property and the free access was promulgated.

(iii) The French colonization period (1881-1956), that was characterized by the first water decrees targeted on favours attributed to the colonists. The Decree of 24 September 1885, defined the public surface water domain, without any reference to the groundwater resources. In 24 May 1920, a Water Committee was appointed. Decrees appeared in 1933, 1935, 1936 and 1938 instituted a water use regulation and fixed the dues for the water use; Decrees of 30 July 1936, 11 January 1945 and 17 March 1949 instituted the regulation related to the NGO organizations involved in water use.

(iv) The fourth period, started with the independence of Tunisia, is characterized by an evolutionary water legislation, that is related especially to the resources mobilization, exploitation by different users (urban, agricultural, industrial and tourist uses) and focused on water quality and environmental problems. In order to satisfy the different water demands, the socio-economic development national programs realized large hydraulic works. With the evolution of hydraulic planning, a legislative system was established, whose main objectives were to identify the competencies of all operators and users in the water field, to preserve the water resources and to ensure the equitable allocations. In 1975, all legislative water texts were updated and promulgated in the Water Code (Law No. 75-16, 31 March 1975).

Since 1975, the water code is continually updated by modification of some legislation and adding of new ones, that concern socio-economic development, the water demand evolution, and the environmental issues required to preserve the natural resources.

Water Code

Water Code goals

The Water Code of Tunisia was created in 1975 and was last updated in November 2001. The benefits provided by the Water Code are numerous and are the result of the increased awareness that politicians and decision makers acquired for the water importance in the country's economy and development, the need to manage the demand for water according to the availability and having as objective the sustainability of the natural resources, where water is coming on the head. Because successive drought events occurred in Tunisia, a deep awareness for the water problems and improving of water use efficiency in all sectors became the first priority in the water management policy of Tunisia. The Water Code prioritises drinking water supply. Sensitive measures were taken for saving water in agriculture, as the grants ranging from 40 to 60% of the farmers investments who adopted the irrigation techniques allowing water saving in their fields. The objective is to save around 25% of the water consumption by 2010.

Water Code Clauses

The water code is composed by nine Chapters, which rule the water resources regulation.

Drought Circumstances Legislation

The drought management system in Tunisia is based on drought announcement and MARH Minister decisions to cope with drought and the duties loaded to the National Commission, which is charged by the supervision of the execution of all the operation actions related to the 3 drought management phases: (i) before –drought preparedness; (ii) during– drought management; and (iii) after –subsequent drought management–. This process has a strong collaboration of the regional and sectorial or specialized committees (details will be stated in the next section of the present report). The Minister of MARH, promulgates several decisions related to the different drought committees and the operations programme for the drought mitigation instead of its crisis management. The Tunisian Central Bank (BCT, Banque Centrale de Tunisie), delivers a circumstance circular establishing easiness in the credits delivery for farmers. Special decisions are taken in order to exempt the importation from the custom duties.

Methodological component: Drought characterization and risk analysis

Water resources in Tunisia

Rainfall in Tunisia is characterized by a spatiotemporal variability. Around 1500 mm/year is basically received in the northwest and dropped to less than 50 mm/year in the southern desert zone (Fig. 2), resulting in a wide spatial variability as illustrated in Table 2. Tunisia is submitted to drought periods that could be restricted for one or some regions and could be generalized. The drought duration could be one season or one year and more, but with variable intensity. Figure 3 points out the regional minimum rainfall observed during the 20th century in Tunisia.

Table 2. Water resources distribution and quality in Tunisia. Source: Ministry of Agriculture and Water Resources-DG/RE

Element	North Region	Center Region	South Region	Total Tunisia
Area of the region (%)	17	32	51	100
Rainfall (%)	41	29	30	100
Surface water (Million m^3)	2,190	320	190	2,700
Surface water (%)	78	38	19	58
Shallow aquifers (Million m^3)	395	222	103	720
Shallow aquifers (%)	14	26	10	15
Deep aquifers (Million m^3)	216	306	728	1,250
Deep aquifers (%)	8	36	71	27
Total water resources (Million m^3)	2,801	848	1,020	4,670
Total water resources (%)	60	18	22	100
Resources with salinity < 1.5 g/l (Million m^3)	1796	153	6	1955
Resources with salinity < 1.5 g/l (%)	82	48	3	72
Resources with salinity > 3 g/l (%)	37	49	86	
Sallow aquifers with salinity < 1.5 g/l (%)				3
Deep aquifers with salinity < 1.5 g/l (%)				22
Sallow aquifers with salinity 1.5-3.0 g/l (%)				11
Deep aquifers with salinity 1.5-3.0 g/l (%)				57

From the rainfall temporal variability results receiving 90,000 million m^3 during the wet year that could decrease during a drought event to only 11,000 million m^3/year. The global mean allows 36,000 million m^3/year (Khanfir *et al.*, 1998). Within this quantity, 2700 million m^3/year are the potential surface renewable water resources and represent the capacity of dams and lakes, and also a part that is collected by several traditional water catchment techniques (this volume was dropped to 780 million m^3 during the drought event of 1993-1994). 720 million m^3/year is the renewable water stored in the shallow aquifers. One part flowed out to the sea by runoff as well as lost by evaporation from bare soil and the rest allows the sustainability of the natural ecosystems and allocates rainfed farming systems, that cover around 93% of agricultural lands (total agricultural lands is 5 million ha). On the other hand, deep aquifer

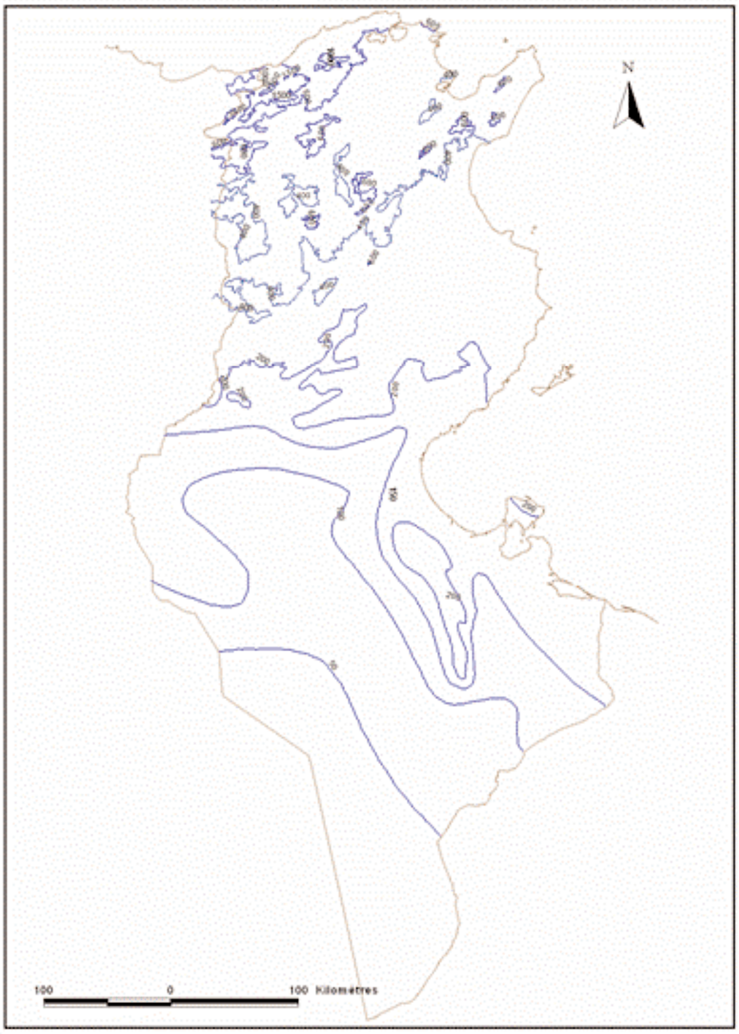


Fig. 2. Rainfall Spatial distribution in Tunisia (Source: DGRE).

resources ensure around 1250 million m^3 of non renewable water. Hence the total conventional water resources are estimated at 4670 million m^3, of which about 90% is actually mobilized (Fig. 4 and Table 2). On the other hand, the percentages of water resources with less than 1.5 g/l are 72%, 3 and 22% respectively for the surface water resources, shallow and deep aquifers (Table 2).

The total area under irrigation by conventional and non conventional water covers actually 368,500 ha (7% effective agricultural are) and it's expected to rise to nearly 400,000 ha by 2010 (Table 3). This sector consumes about 80% (Table 4) of the total water resources and provides 32-40% of the mean value of the total agricultural production. In the near future, 50% of the agricultural production should be provided by this area.

The analysis of water resources in Tunisia situation shows the importance of rainfall in the irrigated and rainfed agricultural production systems and also in the water supply for the other sectors. The water resources spatial variability is so important that the ecosystems and their responses to drought are different. When drought is upon, the natural water resources availability displayed a substantial deficit, and consequently, the irrigated area as well as the rainfed lands are strongly affected, and the other water demands are evenly subjected to some restriction. For coping efficiently with the drought period, Tunisia established a drought management system which demonstrated its capacities in drought mitigation during 1987-1989 and 1993-1995. Latter, the first guideline of drought management "Guide pratique de la gestion de la sécheresse en Tunisie" has been elaborated by Tunisian competences (Louati *et al.*, 1999).

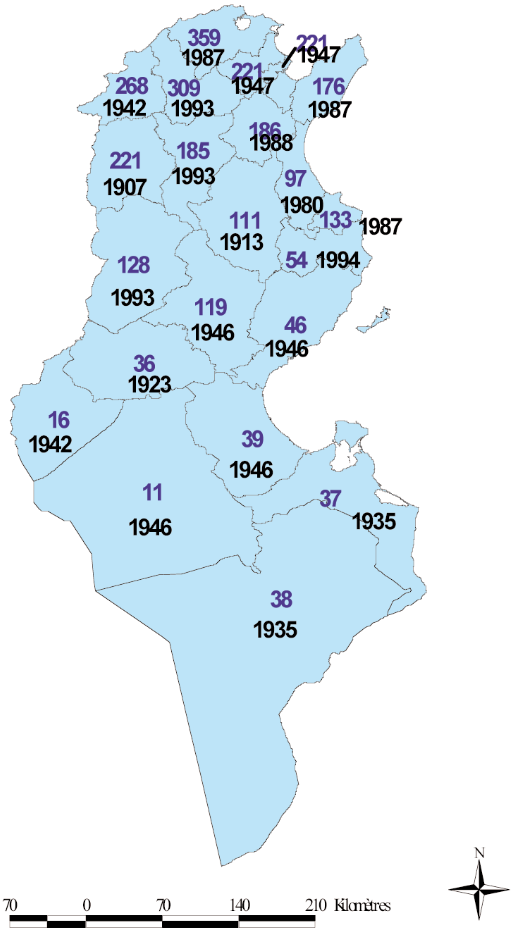


Fig. 3. Minimum regional rainfall during the 20th Century in Tunisia (Source: DGRE).

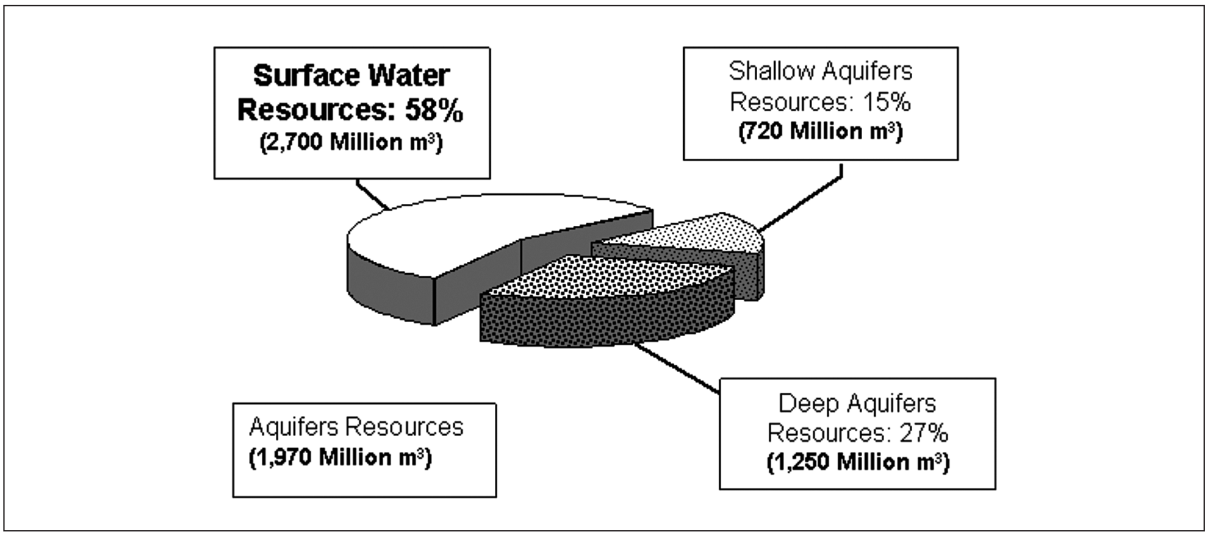


Fig.4. Water Resources in Tunisia (Total: 4,670 Million m^3).

Table 3. Irrigation schemes and water resources (2000) in Tunisia. Source: Ministry of Agriculture and Water Resources

Water resources	Area (ha)	%
Large dams & hillside-dams and lakes	127,000	34.5
Deep aquifers	85,000	23.0
Shallow aquifers	136,000	36.9
Springs and intermittent streams	14,000	3.8
Reclaimed Water (non conventional water)	6,500	1.8
Total	368,500	100

Table 4. Water demand in Tunisia. Source: Ministry of Agriculture and Water Resources – DGRE

Water Use	%
Irrigation	82
Domestic and Municipal	13
Industry	4
Touristy	1
Total	100

Water resources management units

In most Mediterranean countries, water management planning is based on "Waters Master Plans (Plans Directeurs des Eaux)". In Tunisia, these plans depend on basin boundaries. As a consequence, the water resources planning process has been compelled to balance between two main constraints. First, the target water use regions are generally different than those where mobilization has been realized, resulting in an imperative water transfer, that reaches 300 km. Second, water resource management planning is conducted on a basin scale contrary to their supply programmes which are planned, in the social and economic development national plans, depending on the administrative units (governorate and departments) (Fig. 5). Nevertheless, basins and administrative units did not have common boundaries. Consequently, the precise evaluation of Water Master Plans is hampered by such structural divergences.

In order to overcome the above constraints, the hydraulic units concept has been adopted as an approach in water resources planning and management. Since water resources (surface and aquifers) were identified, quantified, and mobilized or to be mobilized, their management became linked to "stocks management" and not as "random resources". This is the main strength of the water resources system in Tunisia. The management of each reservoir or a group of reservoirs could be realized in a normal period as well as with interaction with the remainder system components, particularly during extreme situations (drought or floods). The Geographical Information System (GIS) allowed the water balance establishment at administrative as well as at hydraulic unit scales. Every hydraulic unit is characterized by its own, imported and exported resources.

Challenges to risk management

Regarding the geographical position of Tunisia in the south of the Mediterranean Basin, climatic conditions and consequently the rainfall are influenced by the Mediterranean climatic perturbations from the North and also by the desert effects from the South. On the other hand, drought periods in Tunisia could affect one or several regions and could be generalized. The drought duration could be from one month or season to one year and more, with a variable intensity. The probability to have three successive dry years is too small (one time in the north and from 2 to 3 times in the center and the South during one century).

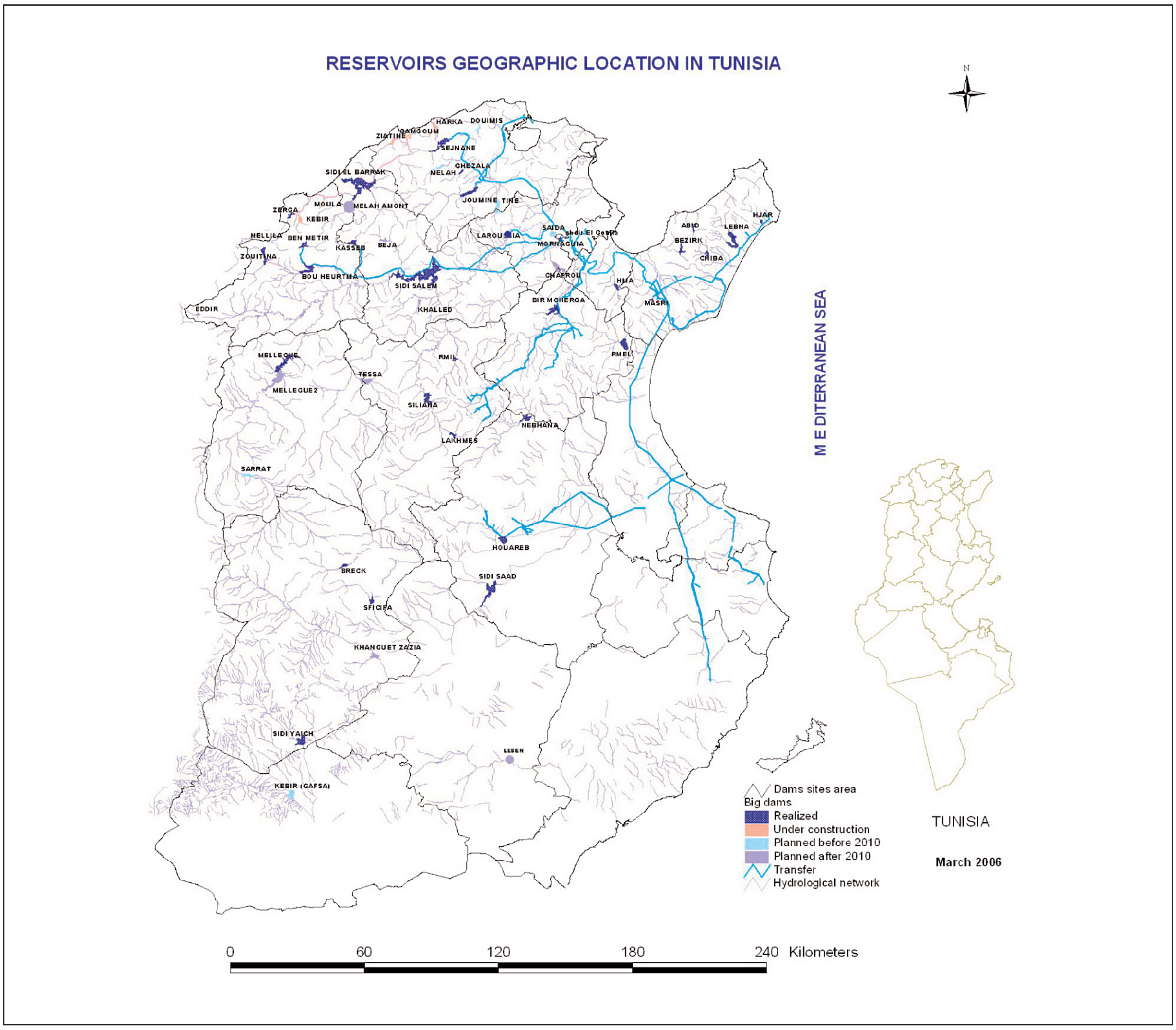


Fig. 5. Geographical location of dams in Tunisia.

There are considerable differences between the climate in the North and the South of Tunisia (Table 5). The North's climate is typically Mediterranean, with hot dry summers and mild wet winters. In the south, the proximity to the Sahara increases the aridity of the landscape, and makes an unpleasant summer climatic combination of high humidity and high temperatures.

Table 5. Rainfall distribution in Tunisia

	North	Center	South
Rainfall (%)	41	29	30
Area (%)	17	32	51

Source: Ministry of Agriculture and Water Resources – DG/RE, 1998.

Tunisia focused its policy on the water mobilization, that is conceived with inter annual volume regulation approach and with inter-basins and within-basin water transfer system, and implemented an integrated water resources management system (IWRM). In the Tunisian IWRM process, the drought is considered as a climatic reality, which is taken into account on the Development Plan Programs. The planning for drought for moving from crisis to risk management dates only from the end of eighties. Before, drought was erroneously considered for several years as temporary and of rare climatic event, and consequently its management was "a forced reaction" to respond to immediate needs. A drought management system has been developed and put into practice during the drought events occurred along 1987-1989 and 1993-1995 and showed the performance of the hydraulic system. In 1999, Tunisia elaborated its first drought mitigation guidelines (Louati *et al.*, 1999). The latter, applied during the drought during 1999-2002, was qualified as moderately sufficient, and could be improved; the lessons learned should be established in order to update the system (Louati *et al.*, 2005).

The Case study area: Siliana watershed

Siliana watershed, object of the case study, is characterized by a semi arid climate. The average rainfall is around 400 mm. Winter is usually wet, summer is hot and autumn is characterized by stormy rain with high intensity and short duration often causing floods.

Various structures were built (dams, hill dams, small lakes) to mobilize those resources. The total storage capacity in the region is around 80 Mm^3. To minimize water losses on one side and satisfy all the demands on the other side, the whole components are considered (watershed, hydraulic structures, irrigated areas) as a complex one which should be managed taking into account all stakeholders.

The case study for drought characterization and risk analysis is carried out according to the observed data in the region.

Land topography in the region presents high slopes and a low vegetative cover out of the rain period. Siliana watershed is crossed by an intensive rivers network (Fig. 6).

Drought characterization in Siliana

The system designed to alert of a drought situation depends on a complex set of interdependent and organized institutions. The drought is considered as an extreme climatic event and qualified as natural risk. However, the prolonged drought entails a water shortage in some regions, being so much heavy of consequences on a local zone than for a whole region. The capacity to manage the impact of the drought also varies from a region to another. To understand the vulnerability to drought, it is essential to protect the natural resources and to consider the policies that are linked with their management programs. In the present work, an analysis of meteorological drought in the semi-arid area of Makthar plain located in Siliana Basin in Tunisia is presented. Annual and monthly rainfall series observed at the station of Makthar were used to characterize droughts at a local scale by using run concepts (Yevjevich, 1967). The revealing drought indexes constitute the basis of the methodological approach presented in this case study. It is proposed to analyze the observed rainfall data and determine meteorological drought characteristics. (Bergaoui med. & al., 2001).

Rainfall

Hydrological phenomena can occur both at the local level and at a larger spatial scale. Drought is generally characterized by its severity, defined by its duration and the occurred deficit. Therefore drought varies in time. This temporal change is in part explained by the climatic changes due to atmospheric perturbations and environmental problems.

The rainfall records, which were collected and analyzed, were originated from the station of Makthar. Table 6 shows the main characteristics of the station, namely the location coordinates, the altitude and the corresponding area of influence. Data were obtained mainly from the hydrological services.

Table 6. Identification of the measuring site

Station	Latitude	Longitude	Altitude (m)	Area (km^2)
Makthar PF	N°:39G 84 00	E°:7G 63 00	910	483

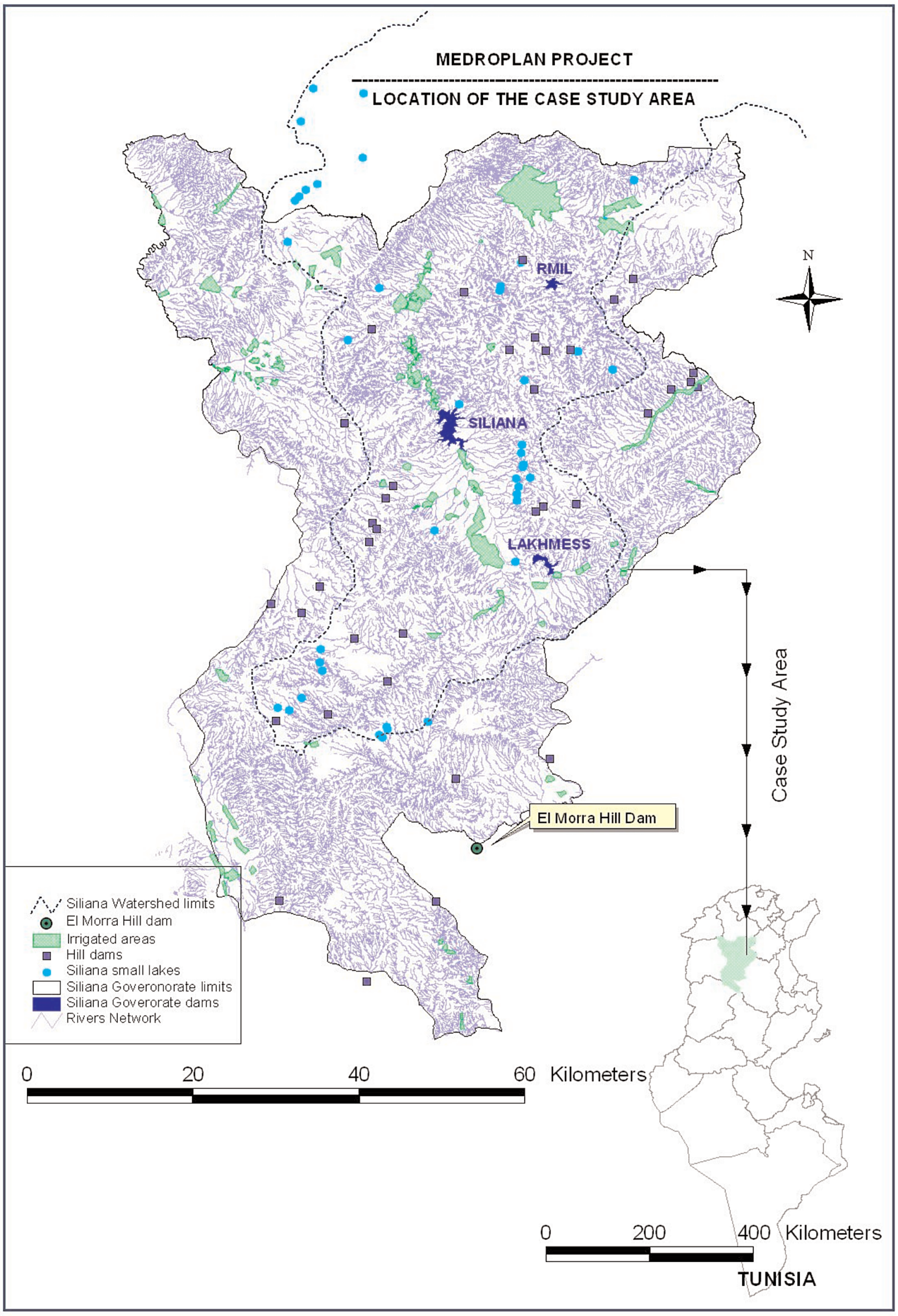


Fig. 6. Location of the case study.

The observation period for this station is ranged from 1972 to 2002; those 30 years series is believed to be long enough to reflect the validity of the analyzes to be carried out. The basic statistical characteristics of the annual and monthly rainfall series (location and dispersion parameters) are reported in Table 7. The location parameters (average and median) are quite different which indicates the presence of skewness in the series. The parameters of position and scattering show the existence of an important variability of rains quantities.

The coefficient of variation is equal to 0.22. It permits to appreciate the degree of variability in a set and the scattering of the values with regard to the average.

Table 7. Location and dispersion parameters

Characteristics	Sept	Oct	Nov	Dec	Jan	Febr	March	April	May	June	July	Aug	Annual
Average (mm)	45.9	42.2	49.9	43.6	58.0	49.3	57.3	45.5	41.0	18.2	8.6	25.9	485.4
Maximum (mm)	147.8	148.8	139.2	123.8	178.4	133.9	225.2	110.8	124.0	86.8	73.5	72.1	810.6
Minimum (mm)	0.0	2.5	0.0	0.0	5.0	0.0	4.0	8.5	0.0	0.0	0.0	0.0	317.0
Median (mm)	37.7	34.5	41.1	37.0	47.9	49.5	50.5	38.9	32.1	13.6	0.0	22.0	472.0
Standard deviation	34.7	31.8	37.5	34.0	45.3	33.3	39.5	28.7	30.8	19.4	16.5	21.9	109.7
Coefficient of variation	0.76	0.75	0.75	0.78	0.78	0.68	0.69	0.63	0.75	1.1	1.9	0.85	0.22

Stationary analysis

A time series is considered as stationary if there is no systematic change in mean (no trend), if there is no systematic change in variance, and if strictly periodic variations have been identified. The time series analysis is important both to describe data and to help in formulating a prevision or prediction model. A visual examination of a time series graphic is sufficient to see that it is not random. It is recommended to test the stationary time series for randomness. Several tests exist for this purpose and they are described by Kendall (1973). For details see (Rossi G. *et al.*, 2003).

The stationarity analysis of the series was carried out for Makthar station and applied to the catchment's area, considering calendar year, hydrological year and monthly time scales. Three tests have been applied, namely the student t-test for linear trends, and the Kendall t-test and the turning points test for randomness. The results of the three tests for the analysis of the observed rainfall series at study station are given.

Series aggregated at calendar year and hydrological year generally present a negative linear trend, with the significance level of 5%. For Kendall test, the null hypothesis is accepted, by using the test of the turning point, the null hypothesis is accepted with the significance level of 5%.

Drought identification and characterization has been carried out by means of run concepts, using the software REDIM (DICA, 2000). The drought characteristics are identified by using two annual time scales (hydrological year and calendar year) and monthly time scale. Further, two thresholds have been selected, namely the average and the median. It can be concluded that using the calendar year, the number of drought periods is equal to or higher than that found while considering the hydrological year as a time scale.

On the other hand, deficits and drought severity are generally higher when hydrological year time scale is applied. Also, the characteristics of the drought periods, identified by considering the mean as threshold, are higher than those found for the median threshold, as expected due to the difference of the two thresholds (see Tables 8, 9 and 10).

Table 8. General characteristics of drought periods; Makhtar station

Calendar year	Mean	Max	Min
Duration (years)	2	4	1
Cumulated deficit (mm)	182	440	30
Drought Intensity (deficit/years)	96	185	30

Table 9. Characteristics of drought periods

Hydrological year	Mean	Max	Min
Duration (years)	2	4	1
Cumulated deficit (mm)	194	434	34
Drought Intensity (deficit/years)	64	108	17

Table 10. Characteristics of drought periods

Time Scale: month	Mean	Max	Min
Duration (months)	2	10	1
Cumulated deficit (mm)	50	354	0
Drought Intensity (deficit/months)	19	51	0

An analysis of rainfall series observed and covering the period from 1972 to 2002 in Makthar station is presented. In particular stationarity analysis of the series has been carried out by means of three statistical tests. Stationarity analysis indicates a significant decrease of precipitation in the last years, both at calendar and hydrological year time scale. The results of general characterization of drought periods are affected by the time scale adopted. In particular, when hydrological year is applied, drought characteristics duration, deficit and intensity or severity are generally higher that those computed by applying calendar year time scale.

The normal precipitation

The objective of this analysis is to visualize the yearly rains versus the normal of 30 years observations. During the period of 01/09 to 30/10 the variation of rain is normal. The period ranging from 01/11 to 30/03, can be considered as rainy period. The total yearly precipitation is greater than the normal. There is 220 mm more than the normal. Thus, the analysis of rains for one year given in relation to the normal allows the identification of the dry or wet periods as well.

The comparison of the cumulated monthly rain for a year scale, during 2002-2003, with the normal shows that this year (2002-2003) is wet, since the cumulated value was grater than the normal one (Fig. 7). This method shows a good accuracy to identify the dry or the wet periods with a finer time scale.

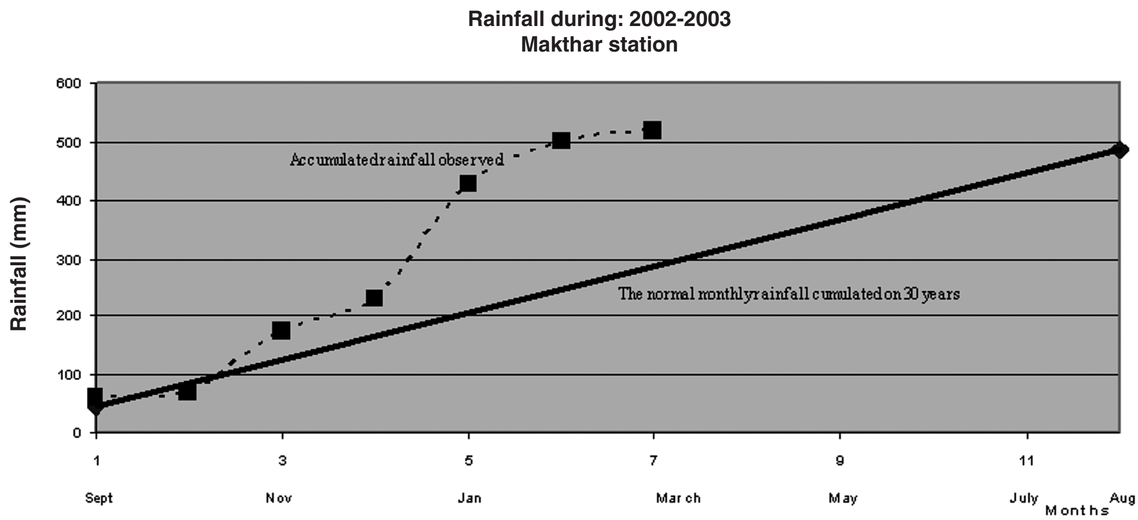


Fig. 7. Cumulated rainfall observed during the hydrological year (2002-2003).

Scale impact on drought characterization

Time scale is an important issue that needs to be accounted for when characterizing drought. Depending on the objectives of the study it will be interesting to use one scale or the other. The following examples show the importance of an analysis at a monthly scale due to the differential effects of precipitation distribution along the year for agricultural purposes.

Figure 8, for example, shows a deviation around (- 200 mm) during 1993: Consequently the year is considered as dry, however, during 2002, deviation reaches (+ 200 mm): Consequently the year is considered as wet.

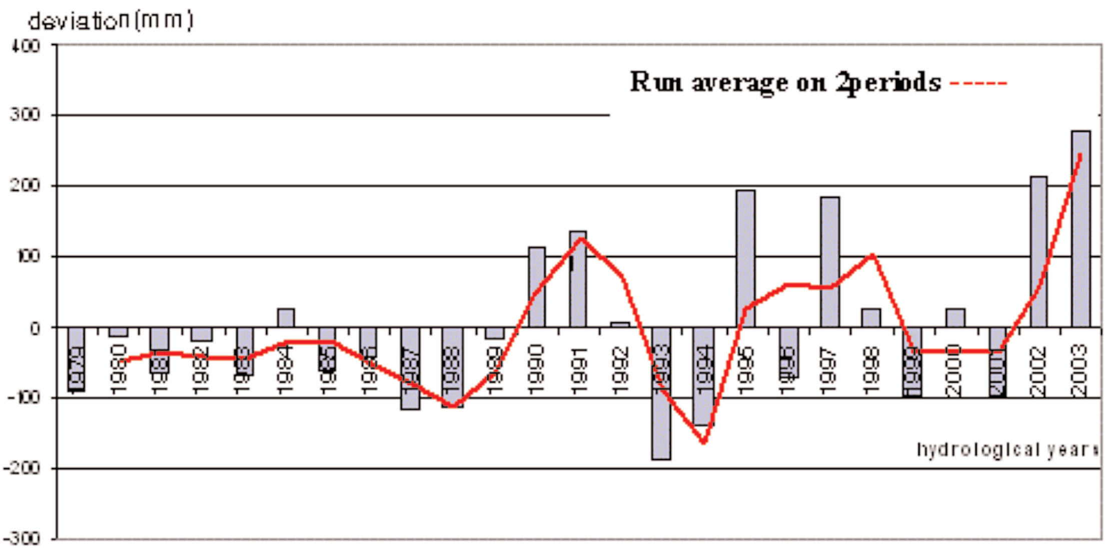


Fig. 8. Variation of the mean deviation of the annual precipitation.

Figure 9 shows that during 2002, March was significantly dry, although the year 2002 has been characterized as wet year as shown in Figure 8.

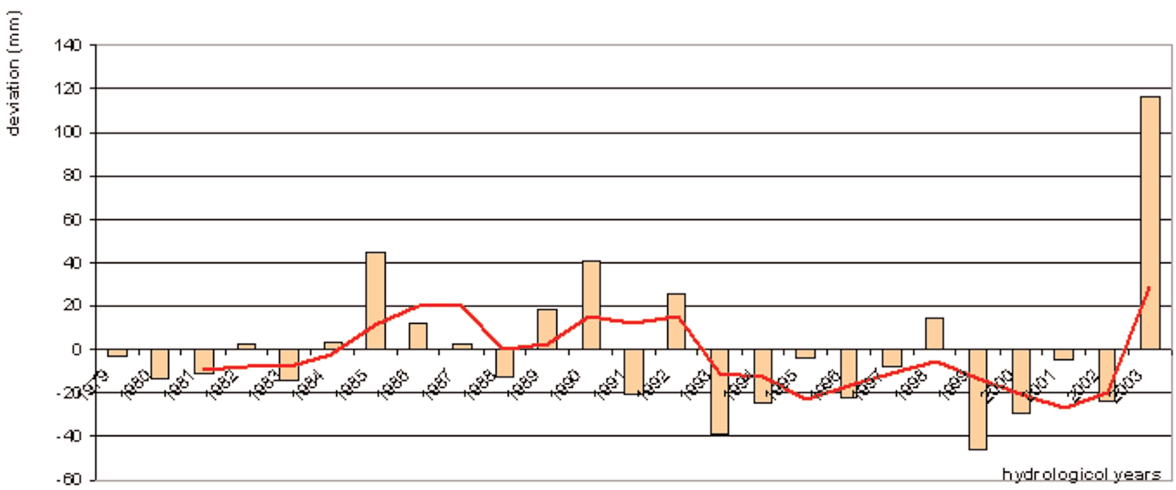


Fig. 9. Deviation of monthly mean during March in Siliana station.

The drought characterization method based on the mean deviation allows identifying the percentage of dry years. The current case study shows 60% of dry years. Drought characterization is more precise when the monthly scale is taken in account in the identification. This is illustrated by the case of Siliana region where drought characterization showed that the year 2002 was wet when the yearly scale was applied. March of the same year (2002) appears as dry month. This is very important since March rainfall is critical for agricultural production.

Risk analysis of the El Morra reservoir in the Siliana watershed

El Morra Reservoir (hill dam) is located at the boundary of Siliana watershed. Its main objective is to supply an irrigated area.

In average, the inflows are sufficient to satisfy agricultural demands, but the inter-annual variability is very high. The agricultural demand is less than the average inflow but we can observe a risk of dryness in the summer when the highly water consuming cultures of melon and watermelon are very developed (Fig. 10). The reservoir is developing a double function as agricultural water supplier from March to August, and also as a flooding regulator during autumn and spring. Therefore there is a conflict between keeping enough water for agricultural productions and having enough regulating capacity for eventual flooding.

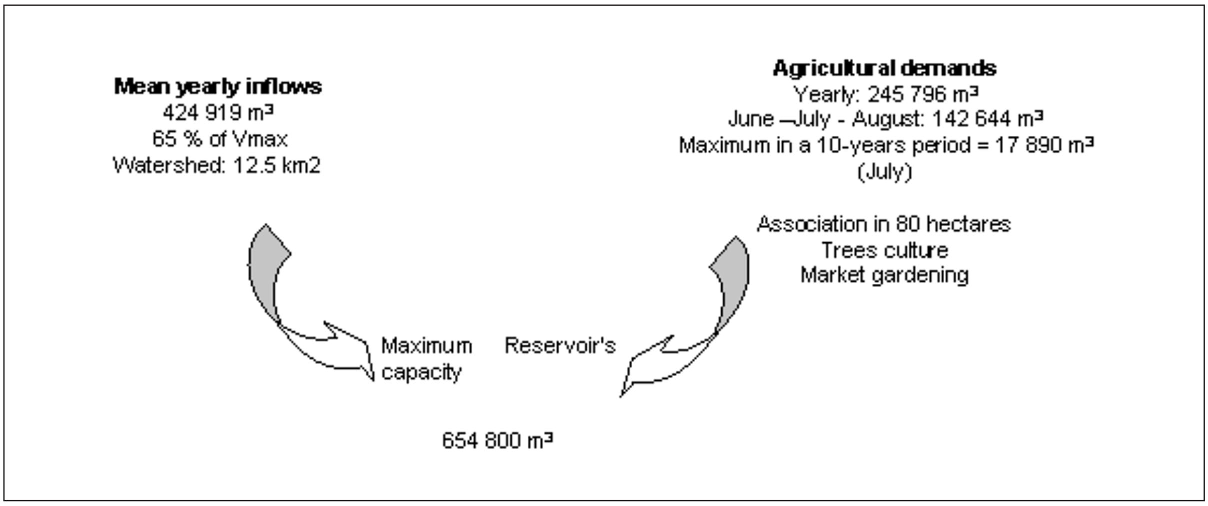


Fig. 10. El Morra reservoir characteristics.

Water balance in the reservoir

A run off-rainfall station was installed in the reservoir in March 1996 to collect daily evaporating data, rainfall and water levels in the reservoir.

Height-volume and height - surface curves

Only one bathymetry was done to the reservoir during its construction in 1992. The surface of the reservoir was deducted from the height (H) by the linear interpolation between two values. The volume (V in m^3)-height (H in m) relation is fixed by order 3 polynomial smoothing:

$V = 87.7*H^3 + 2882.1*H^2 + 22429*H + 52000$

Balance equation in the reservoir assessment: In a given period of time, the general equation of water balance is formulated as:

$$\Delta V = (V_r + V_{ecs} + V_p) - (V_{ev} + V_d + V_{inf} + V_u)$$

ΔV: the storage variation is known from the gauging records data.

V_r: inflows by streaming. It's the first variable unknown of the assessment because there isn't a gauge station controlling the gate. Its estimation is based on the floods' reconstitution.

V_{ecs}: inflow coming by underground's run off. It's the third unknown of the assessment.

$V_{p:}$ inflows are known from pluviometer saved data and the height-surface curve in the reservoir.

V_{ev}: evaporation is estimated from the daily saved backs' data and the mean surface in the same day. This estimation contains some errors due to the corrective coefficient from back evaporation to reservoir evaporation.

V_d: the spilling (the reservoir didn't spill yet).

V_{inf}: seeped volume, which is in function of the reservoir's hydraulic charge and the stored volume. It's the second unknown of the assessment.

V_u: bottom discharge, known from reading levels before and after operation.

Inflows reconstitution

In semi arid climate, the floods are violent and occur in a short duration. With a daily time step (the streaming still exist), the infiltration and evaporation are too slight compared to the streaming. The water balance formula is then simplified. Volumes records are smoothed for controlled floods.

Evaporative flux reconstitution

The evaporation in the area of the reservoir is estimated from the Colorado back in situ, taking into account a corrective coefficient equal to 0.8 (windy zone). The evaporative flux is deducted from an observed time series set with daily average during three years. These values are correlated to the stored volume (V) in the reservoir using a linear expression:

$$V_{ev} = a\,V + b.$$

Infiltration reconstitution

It can be estimated by droughts reconstitution, so we have:

$$V_{inf} = \Delta V - V_{ev}$$

In order to optimize the operating rules, a long set of inflows is needed to apprehend better the hydrological risk. Considering rainfall, inflows are reconstituted by using a GR3 rain fall-run off model from CEMAGREF. This software is calibrated on the basis of inserting three years measures on the site. An inflow generation is made to extend a 24 year's set of rainfall to a long one reconstituted from bordering stations and the rainfall-run off model.

The operation reconstitution is realized on three years-observation on the reservoir and gives good results for 10-years periods (Fig. 11).

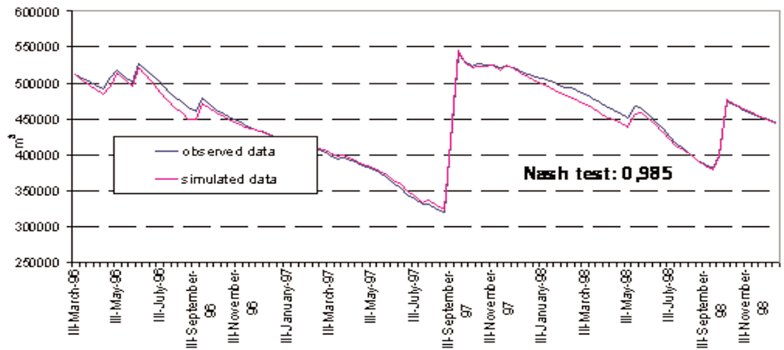


Fig. 11. Reservoir volume simulation per decade.

Operating reservoir rules optimization

Optimization of operating reservoir rules is based on the assessment of water balance equation which reflects the real hydrologic system behavior. The model's development is based on the state variables identification, decision variable and on the formulation of hydraulic constraints and the objective function. The optimization model formulation is defined by:

System states

The state variables concern the water balance variables (inflow, evaporation, etc.) and reservoir storage at the beginning of all the operating period.

The commands

The decision variable is the release executed at t time which is L(t).

Evolution function

It depends on time and use the water balance expression in the reservoir, taking in account L(t). It expresses the dynamic operation character.

Constraints

It presents the maximum and minimum values of the reservoir storage and the transit capacity of release.

$$V_{min} \leq V(t) \leq V_{max} \quad \text{and} \quad L_{min} \leq L(t) \leq L_{max}$$

The objective function

While the optimization operating rules optimization, the criterion formulated is applied, with low-objectives weighting. It consists on a simultaneous and weighted minimization of the deficit with regard to the target storage and the deviation from the water demands. That means a part of the criterion consists on storing water during a maximum of time in the reservoir and the other part consists on the satisfaction of water demands on the downstream side of the reservoir. The mathematic formulation is written as:

$$MIN \sum_{t=1}^{11} \left[\alpha \left(\frac{S_{t+1} - S_{consig}}{S_{max}} \right)^2 + (1-\alpha) \left(\frac{u_t - B_t}{B_{max}} \right)^2 \right]$$

S_{t+1}: Final storage at the end of each operating period.

S_{max}: Maximum exploitable storage (useful reservoir's volume).

S_{consig}: Target storage.

a: Weighting coefficient between 0 and 1.

u_t: Release to be optimized between i and (i+1).

B_t: Water demand presented at the beginning of an operating period.

t = 0: It corresponds to the beginning of September.

Therefore it doesn't mean to conduct the optimization from of economic benefit point of view, to respond automatically to the operator desire. The compromise to realize is based simply on the distribution of relative weight of each objective (demand satisfaction downstream of the reservoir and the guarantee of security storage for exceptional events). This operation is simulated by using synthetic series, we compare the optimal rules for each a value (weighting of each objective) and to choose the acceptable values according to the operator desire (expressed by the objective function and the constraints).

Pareto diagrams are drawn to represent performance indicators corresponding to the damageable events that could exist during time. This facilitates the optimal a value selection, which gives a better compromise between the two-operating objectives.

The operating model is naturally stochastic and the inflows are not known for each time step. Thus, for each storage level at a time (t+1) corresponds an inflow and an occurrence probability for this value. And thus for each storage level at a time (t), the system evolutes at least to "n" final states, with n, the number of the possible inflows values. According to MORAN, a simple scheme of storage levels and inflow classes' distribution, in a finite number of n equal classes, permits to apply optimization algorithms such as stochastic dynamic programming.

Optimization by stochastic dynamic programming (SDP)

Optimization process by SDP is based on a recursive equation presenting the possibility to optimize the objective criterion defined before taking in account inflows probabilities for a given time horizon:

The horizon time chosen for computation is the year because the reservoir does not have a sub-year regulation function.

The time step for computation is 10 days. It is the minimum period to simulate correctly the reservoir operation and where the different 10-days inflows are independent (Wald-Wolfowizt autocorrelation test).

The inflows and the volumes stored in the reservoir are distributed in 3000 cubic meters classes. This volume corresponds to the minimum agricultural demand per decade which is considered as base unit for calculation.

For each iteration and in the optimization procedure, the optimal desired winning is calculated for each state of the system. When the winning becomes constant from a period to another, the convergences criterion, by function stabilization increases, is fulfilled (Louks *et al.*, 1981) (Fig. 12).

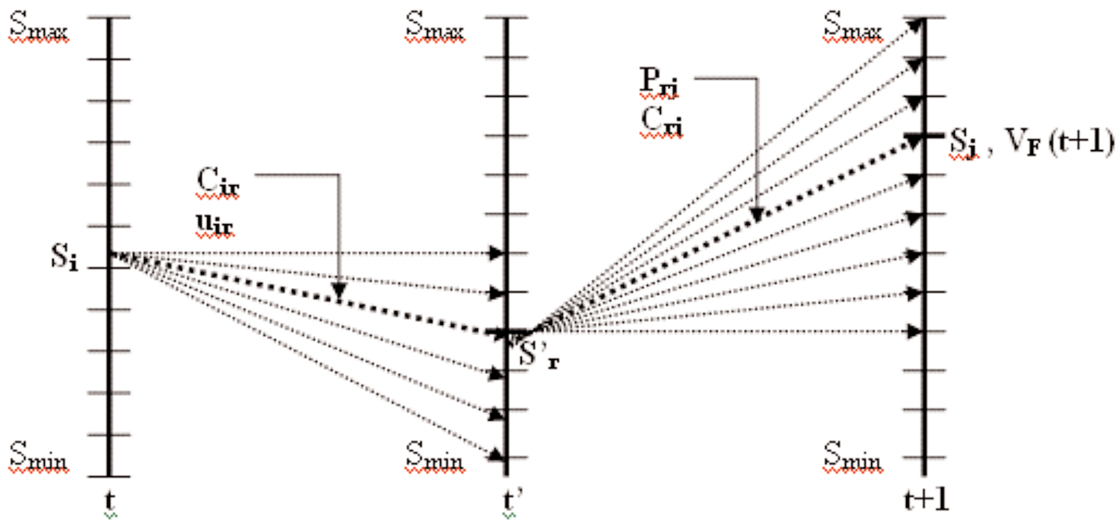


Fig. 12. Optimization scheme decision / hazard. C_{ir}: Cost of the transition between S_i and S_j. P_{rj}, C_{rj}: transition probability from S_i to S_j and C_{rj} is the transition value.

Incidents definition and selection - System performance indexes

By defining a damageable event and performance indexes, it is possible to judge the opportunity of an operating rule based on the same parameters. Incidents linked to storage shortage are also taken in account.

It is important to separate an objective weighted with a minimum of filling or a target storage to reach at each end of operating period, from eventual damageable event occurrence, when climatic conditions can't satisfy the objective indicated for the selected operating rule. The events are probable and real and can be integrated one by one into the reservoir operation. These ones are amounted when the optimal operating rule selected for a fixed a and they are used in the measure of the operating rule performance.

(i) Storage shortage: before the end of the operating period, the reservoir is empty. This situation depends on hydrologic risks and the water management policy selected until that date (Parent, 1992).

(ii) Demand not satisfied: for a given time, the available storage in the reservoir can't satisfy different partial objectives.

(iii) Spilling: it is not really an incident but it's a useful parameter, because it's the logical complement for the first incident.

For each of those incidents, and for a given operating rule, different performance indications are associated. These indicators are:

(i) The risk: it is the probability to realize, for a given time, the indicated event.

(ii) Resilience: it means estimation for medium time in which the system returns to a normal state when an incident has occurred (Fig. 13).

(iii) The vulnerability: it measures risks fullness. That means the medium importance of an incident for the resources' users (Fig. 14).

(iv) Duration of staying into a failure state.

(v) The steady probability of being in a failure state.

(vi) The time of the first transit to a failure state.

(vii) The average time between two states: full satisfaction and failure.

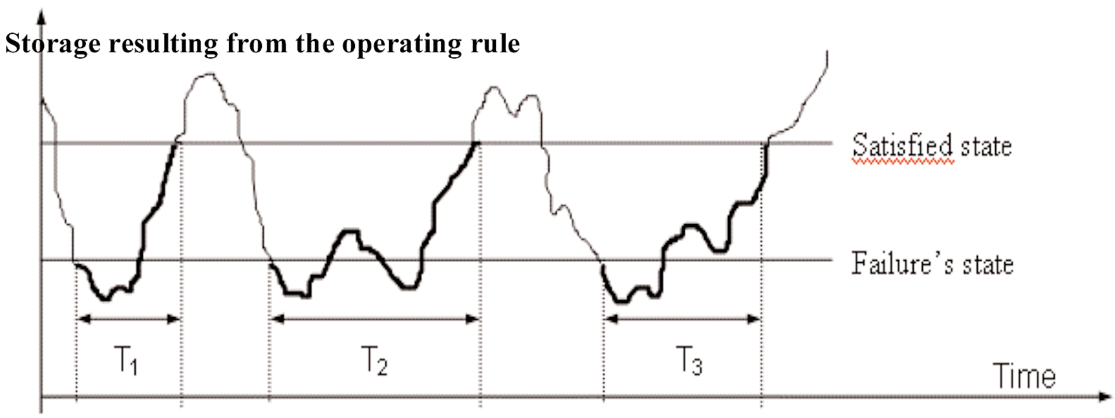
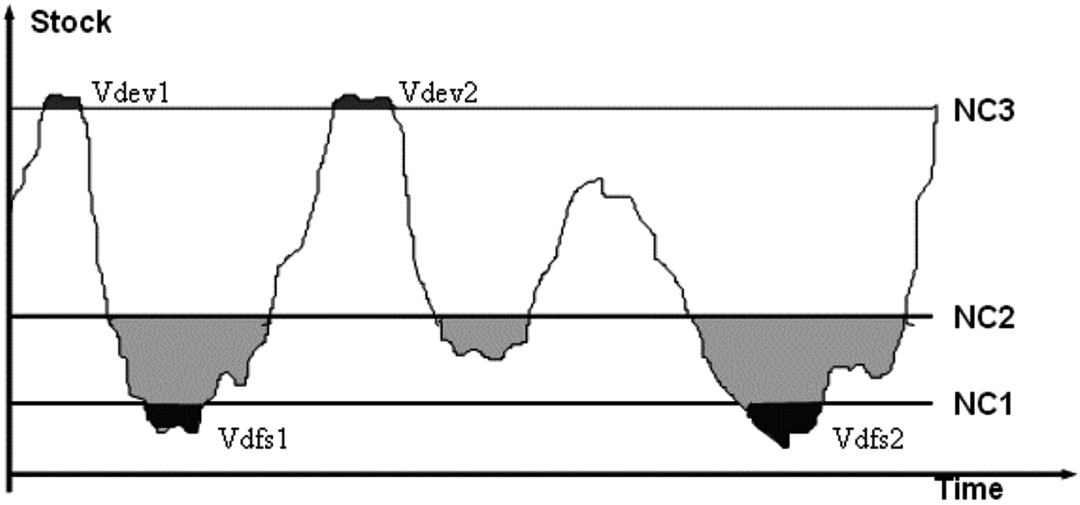


Fig. 13. System's resilience representation.

According to the resilience definition, we can write:

$$\text{Resilience} = \frac{T_1 + T_2 + T_3}{3}$$

Figure 14 represents the system's evolution in relation to time:



$$Vdfs = \frac{1}{N}\sum_{t=1}^{n}\left(S(NC1) - S_t\right)$$ for $S_t \leq S(NC1)$

$$Vbns = \frac{1}{N}\sum_{t=1}^{n}\left(S(NC2) - S_t\right)$$ for $S_t \leq S(NC2)$, N: number of simulation's years and

$$Vdev = \frac{1}{N}\sum_{t=1}^{n}\left(S_t - S(NC3)\right)$$ for $S_t \geq S(NC3)$

Fig. 14. Vulnerability or deficit representation.

The performance of an operating rule with regard to another is estimated by a comparison between values of the same performance indicator calculated for each rule, and for two damageable events.

Simulation by criteria for risk analysis

In this case study, the following indicators are selected by simulation of optimal rules on 24 years of generated hydrological data (Fig. 15):

(i) Risks of failure (RDF), spilling (RDV), and the non demand satisfaction (VBN).

(ii) Vulnerability of failure (VDF), spilling (VDV) and the non demand satisfaction (VBN).

(iii) Resilience of failure (RESDF), and spilling (RESDV).

(iv) Overshooting (unused volumes): VSUP.

All the indexes are normalized between 0 (very good performance) and 1 (very bad performance) by an acceptation threshold and they are grouped as the following:

Normalized index = (index – acceptable threshold) / (unacceptable index + acceptable threshold).

In order to simplify the results interpretation, the following graphic (Fig. 16) presents: alpha, the indexes and their values. When the rule has a normalized index > 1, it is rejected. Therefore two optimized rules are acceptable in regard to the fixed indexes thresholds (alpha = 0.2 and 0.3).

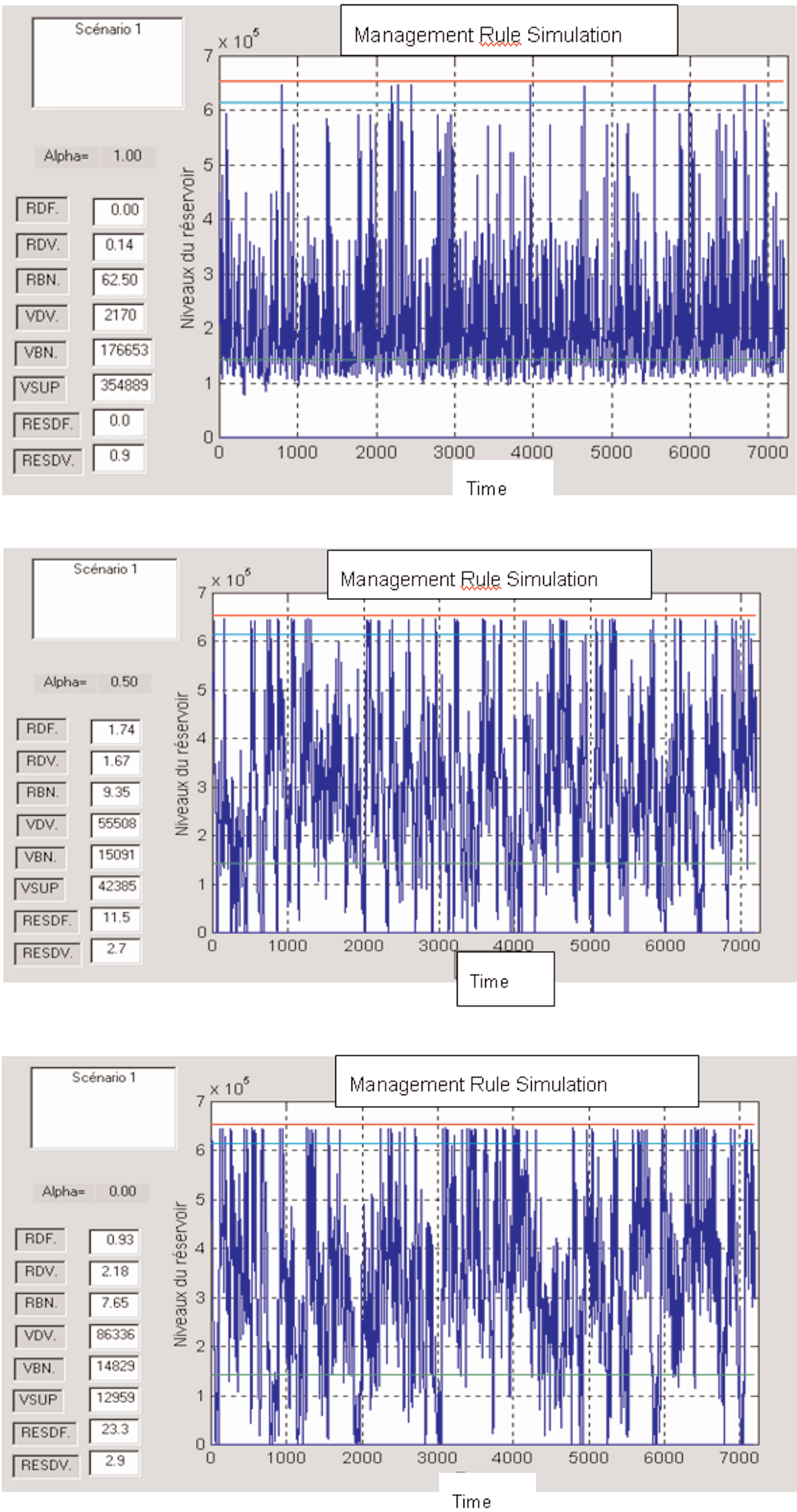


Fig. 15. Managements rule simulation.

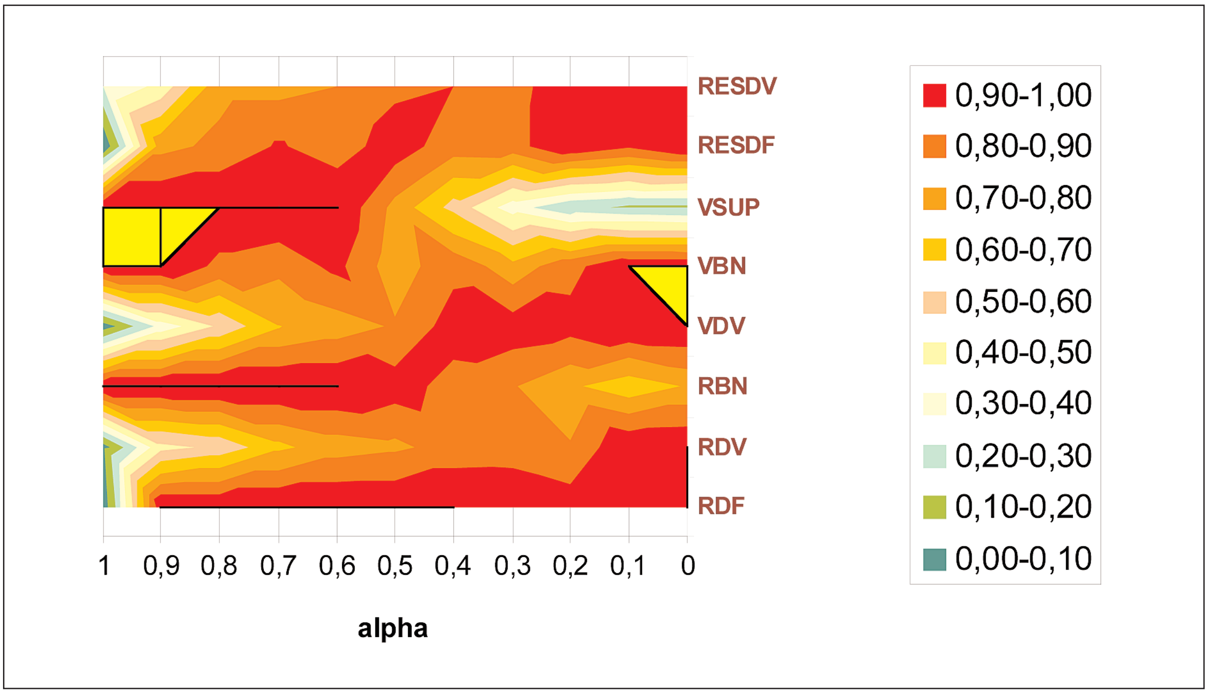


Fig. 16. Alpha values.

Results and perspectives

According to these results, the operator has in hand only a few possibilities to avoid events judged unacceptable (alpha = 0.2 and 0.3) (Fig. 17).

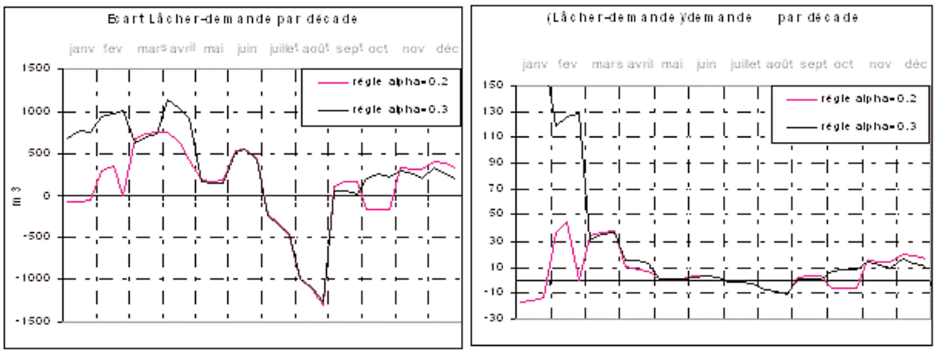


Fig. 17. (Release – Demand) deviation per decade.

In the two cases, the failures of supply are slight and the selection of those coefficients shows that the operator should give a preference for the agricultural demands to satisfy the double objectives already fixed. From May to August, the two operating rules (a = 0.2 and a = 0.3) satisfy the demand by the same way. But from January to April, the rules are different. The rule (a = 0.3) gives always exceeded volumes (overshooting), except for the dry months (July, August). The (a = 0.2) rule gives a near from a null deficit (less exceeded water) and presents a little deficit in October. However, this deficit has a slight absolute value (≤ 300 cubic meters per decade), that is 12.5 cubic meters per hectare and per day, so 0.125 mm per day (≤ limit of demands water values precision). The choice between the two rules is not trivial. We should be oriented to rule which presents less penalties (less deficit per decade, sum of minimal normalized indexes). It means the (a = 0.3) rule.

The fulfillment curve determination

The selected operating rule (Fig. 18) is based on an objective function giving a weight of 0.3 to the guarantee of a minimal storage in the reservoir (213000 m^3) and a weight of 0.7 to the demand's satisfaction. The inflows and storage distribution make the releases having a class unit equal to (3000 m^3). When the release is null and the storage level is greater than the fixed objective level to 50% of the inflow's median (23000 m^3), a correction should be operated to bring the release to the slight values of water's volumes eventually demanded. This correction is omitted when the storage level is lower than the minimum one corresponding to the demand volume of the peak period (142600 m^3). Thus, the matrix corresponding any decade to the stock level for an out let decision's value makes an objective's line (called fulfillment matrix) which delimits the storage levels per decade in which the demand is totally satisfied.

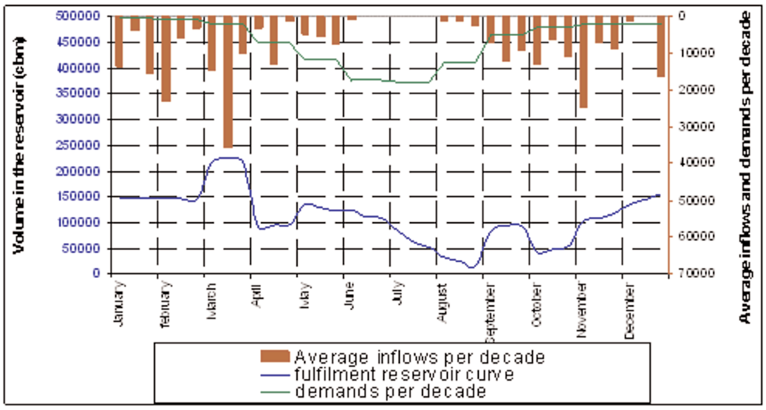


Fig. 18. Optimized operating results for El Morra reservoir.

The maximum risk of failure is 1.41%, the spilling risk is 2.12% and the unsatisfied demand risk to a 60% height of a value of 11.1%. The maximum release vulnerability is 70000 m^3, the unsatisfied demand vulnerability is 6000 m^3 and the unused releases vulnerability is 42000 m^3.

In these results there are some errors of data's incertitude caused by: reconstituted inflows with errors' tolerance, estimated demand's water fixed per decade, the optimization and the operating rules simulation.

All these approaches are concentrated either on the production and the water resources constitution or on its variability. However the demands are considered as data determined by scenarios already made and usually almost satisfied.

When the deficit offer/demand is structural, the resource operating becomes dryness operating and in this case, the proposed solutions previously calculated are no more available even in the domain of water agriculture's demand.

Operational component

Overall strategies

In most Mediterranean countries, water management planning is based on "Water Master Plans". These plans depend on basins boundaries, and as a consequence (in Tunisia), the water resources planning process has been compelled to balance between some constraints as:

(i) The target water use regions are generally different than those were mobilization has been realized, resulting in imperative water transfer, that reached 400 km.

(ii) Water resources management planning was conducted in the basins scale contrary to their supply programs which are planned, in the social and economic development national plans, depending on the administrative units (governorate and departments). Nevertheless, basins and administrative units didn't have common boundaries.

In order to overcome the above constraints, the hydraulic units concept has been adopted as approach in water resources planning and management. Since water resources (surface and aquifers) were identified, quantified, and mobilized or to be mobilized, their management became linked to "stocks management" and not as "random resources". This is the headmaster strength in water resources system in Tunisia. The management of each reservoir or a group of reservoirs could be realized in normal period as well as with interaction with the remainder system components, particularly during extreme situations (drought or floods). The Geographical Information System (GIS) allowed the water balance establishment at administrative as well as at hydraulic unit scales. Every hydraulic unit is characterized by its own, imported and exported resources.

Generally, drought is upon in Tunisia once every 10 years. In order to reduce the resulting effects of the drought in Tunisia, a related management system was developed and adopted for the drought events occurred during 1987-1989, 1993-1995 and 2000-2002. During 1999, Tunisia published the first guideline of drought management "Guide pratique de la gestion de la sécheresse en Tunisie" (Louati *et al*., 1999). The guideline was elaborated by referring to the drought management system and by analyzing the data and information recorded during the drought periods of 1987-1989 and 1993-1995. This guideline, consisting on methodological approaches, identifies the principal drought indices, describes the drought preparedness and management process, and maps the intervening parties.

The drought management system in Tunisia process in 3 major successive steps (Fig. 19):

(i) *Drought Announcement.* Referring to meteorological, hydrological and agricultural indicators as observed in the different regions affected by drought and transmitted by the agricultural, economic, and hydrologic districts relevant to MARH, a drought announcement is established by mean a circumstance memorandum.

(ii) *Warning.* This announcement, qualified as warning note, is transmitted to MARH Minister, who proposes scheduled operations plan to the National Commission (committee), which is composed by decision makers and beneficiaries.

(iii) *Action implementation*. The National Commission is loaded by the supervision of the execution of all the operation actions, with strength collaboration of the regional and specialized committees. The National Commission supervises also all operations when the drought is over.

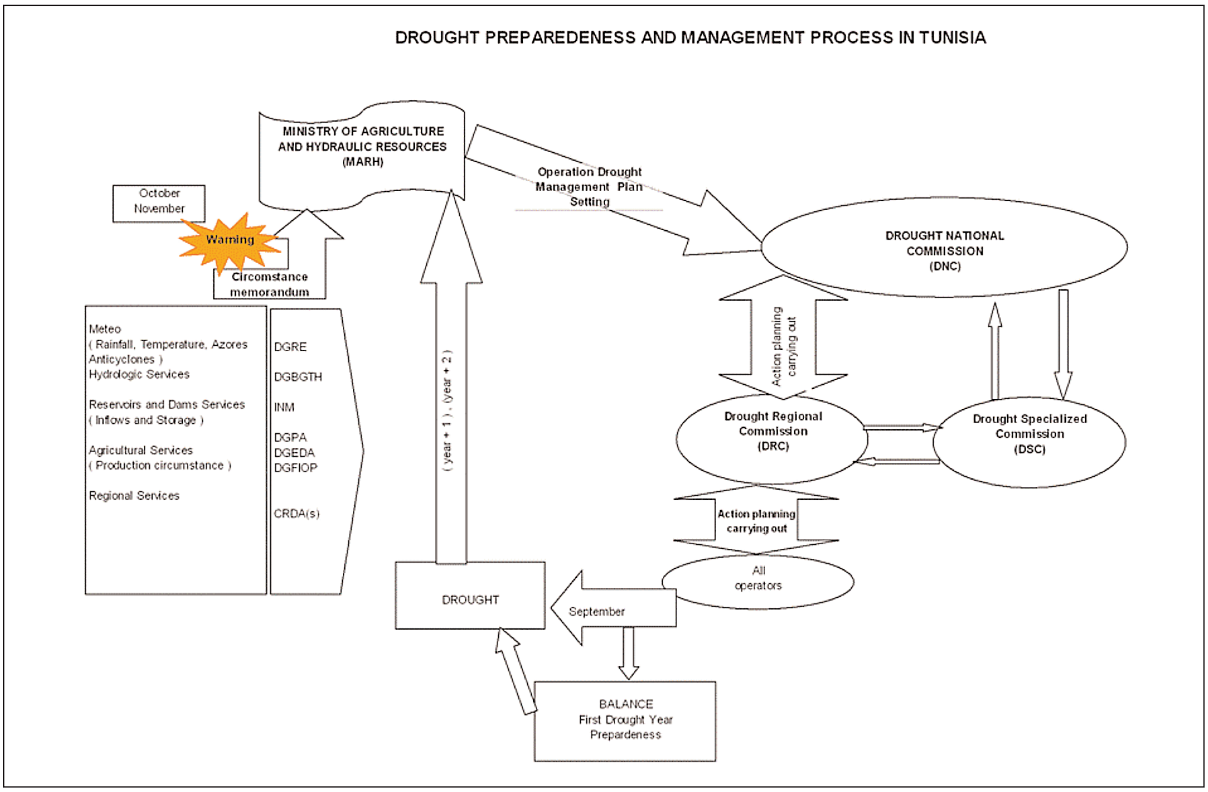


Fig. 19. Drought management plan in Tunisia.

Phases of the drought management system

The drought management system in Tunisia is based on three phases: (i) Before drought (preparedness and early warning); (ii) Drought management (Mitigation when drought is upon); and (iii) Subsequent drought (when drought is over). During each of the three phases different measures are applied and carried out (Louati *et al.*, 2005)

The Drought Management Phase is characterized by the execution of the planning programs of drought mitigation. Depending on the type, intensity and duration of the drought event, different scenarios are adopted.

The year is considered dry when the precipitation deficit is beyond 50% of the mean historically established value. The probability to have a dry year is 7 to 23% in the North and between 25 to 30% in the Centre and the South. From such situation results a substantial shortage in the available water resources, a production falling and range shortage, and some problems related to the domestic water supply appear in the drought sensitive regions. Livestock sickness could be observed, because of diet change and unbalanced nutrition regime. In order to attenuate those problems a mitigation program is executed:

(i) For Livestock safeguard, the identification of the animal nutriments stocks is established and an importation planning is fitted in order to gap the deficiency.

(ii) Prevision of vaccination campaigning on the livestock against the sickness related to drought.

(iii) To satisfy the domestic water demand, in urban as well as in rural areas, a program of aquifers uses is adopted, the use of the surface water resources is avoided or minimized. Particular attention is given to water transportation until the rural drought sensitive regions.

(iv) Establishing reservoirs' water management plan regarding the evolution of the climatic conditions. The eventuality of a second dry year is specially taken in account.

(v) Intensification of the preparedness operations related to the next year up going (short loans, soil tillage, seeds distribution, etc.).

(vi) Subsequent Drought Phase.

When drought is over, several measures are taken:

(i) Intensification of the vulgarization program related to the soil tillage and farming practices in order to maximize the valorization of the precipitation coming during the subsequent drought wet year.

(ii) Available water resources evaluation. (reservoirs and aquifers).

(iii) Reconstitution of the aquifers water reserves by the artificial recharging.

(iv) Evaluation of the mitigation program efficiency and estimation of their cost.

Analysis of historical drought periods: 1987-1989 and 1993-1995

The hydrological drought

During 1987-1989 and 1993-1995 drought was characterized by "two subsequent dry years". The drought management system that is described above has been applied. It was based on reactive decisions. Data and information related to the drought incidences were recorded and used in the elaboration of the drought management guideline in Tunisia (Louati *et al.*, 1999).

The hydrological drought in Tunisia, including the water resources reservoirs management under drought and the resulting water supply conditions, is presented in this report section.

Firstly it is important to underline that water resources reservoirs management involving the application of water supply rationing depends on water storage at 30 April. Rainfall deficit during the period between the 1st September and 30th April is an important index indicating the water resources availability situation. This period is the most determining of the hydrological drought and its impact on the reservoirs storages.

During 1987-1989 drought was severe in the whole country, where NE, CW, SE and SW were the more sensitive regions. During this period the water catchments (input) in the reservoirs has been less than 50% of dams capacity.

During 1993-1995 drought was similar to the former event described above. Rainfall deficit was ranged between 33 to 56% and was around 35% on the national scale. During this drought, data on the water catchments recorded in 8 dams within the 18 that were under exploitation in this date (actually 26 dams are already realized) are presented in Table 11.

Table 11. Minimal water input recorded in the 18 dams under exploitation in Tunisia.
Source: DGBGTH, 1996

Dams	Use starting date	Minimal water input (Mm^3)	Year
Mellegue	1954-1955	36.6	1993-1994
Joumine	1983-1984	17.9	1993-1994
Ghezala	1984-1985	0.5	1993-1994
Siliana	1987-1988	3.5	1993-1994
Bir M'Cherga	1971-1972	3.4	1993-1994
Nebhana	1967-1968	3.1	1993-1994
El Houareb	1989-1990	7.5	1993-1994
Bezirk	1961-1962	0.2	1993-1994

Statistical study on the dams (since their use starting), showed that the minimal water input has been recorded during 1993-1994, in 8 dams within the 18 under exploitation (Table 11).

Tables 12 and 13 show that 1993-1994 and 1994-1995 were characterized by a severe hydrological drought. Consequently, the water volumes stored in the dams were strongly affected as shown in Table 11. In January 1995 the stored water volumes were in their minimal quantities.

Table 12. Water catchments (inflows) in dams in Tunisia between 1st September and end of August (Mm^3)

Dams	Mean	1992-1993†	1993-1994	1994-1995
North West (10 dams)	1108.1	566.1	318.3	466.2
Centre (4 dams)	210.8	119.4	36.7	132.5
North East (4 dams)	23.1	19.2	23.3	7.0
Total (volume)	1342.0	704.6	378.3	605.7
Total (%)	100.0	56.7	30.4	45.1

† 1992-1993 could be supposed with satisfactory water resources availability since water storages since the precedent year had not been affected by drought.

Table 13. Water volumes stored in the dams during 1992-1993, 1993-1994 and 1994-1995 in Tunisia. Source: DGBGTH, 1996

Dams	1992-1993		1993-1994		1994-1995	
	Volume (Mm^3)	Filling rate (%)	Volume (Mm^3)	Filling rate (%)	Volume (Mm^3)	Filling rate (%)
North West	864.8	81.7	698.7	66.0	403.3	38.1
Centre	307.3	84.0	287.2	78.5	194.8	53.3
North East	36.7	71.5	29.9	58.2	26.0	50.6
Total	1208.8	81.9	1015.8	68.8	624.1	42.2

Reservoir management during 1992-1995: Decision Tools

The decision tools used for water management were based on the measurement instrumentation spread in all the water supply locations, information and data transfer to the Central Direction (in Tunis) for decision taking, the filed database, specialized software and simulation models related to the water management optimization.

The water management policy established has been highly proficient since the following results were obtained:

(i) The drinking water supply (for domestic, tourist and industrial use as well) has been ensured without any restriction during the successive years 1992-1993, 1993-1994 and 1994-1995.

(ii) The agricultural water demand was satisfied during 1992-1993 and 1993-1994. A restriction plan was prepared for 1994-1995. This plan was applied in March 1995 and adapted in July 1995 regarding the water resources situation which was improved by the exceptional rainfall of June 1995 (in Mellègue). For all the irrigated areas, the restriction has been about 50% (with normal year as reference). This restriction ranged from 19.5 to 27.5% referring to a dry conditions year (1993-1994). Therefore during this year (1993-1994), in spite of the dry conditions all agricultural demand was satisfied (Table 14). Farmers adopted some "self modifications" in their farming systems to adapt them to drought situation.

Table 14. Agricultural water supply restriction during 1994-1995 in Tunisia before and after the "Restriction Plan" adaptation. Source: DGBGTH, 1996

Regions	Water demand during 93-94 (Mm^3)	Water supply ensured during 94-95		Restriction rate % (93-94 water demand as reference)	
		Before	After	Before	After
North West	272	170.1	199.2	37.7	27.5
Centre	35.7	25.9	25.9	27.5	27.5
North East	44.3	27.0	35.7	39.1	19.5
Total	352.0	223.0	260.8	36.9	26.2

Lessons learned during the 1992-1995 drought (Hydraulic management exercise)

From all the previous drought management events, actions related to agricultural production (crop systems and livestock care) were well monitored. It is from the practical decisions taken during 1992-1995 drought events that tools decisions linked to water reservoir management were tested. Some conclusions that are related to the improvement of the water system could be drawn:

(i) Improving the water storage dam capacity. Existing dams have to be heightened or new dams should be built in order to maximize the valorization of the wet years rainfall.

(ii) To follow and reinforce the maintenance improvement of hydraulic infrastructures to reach their maximum performances.

(iii) To interconnect the regional hydraulic systems (surface and ground water) – integrated and combined management of the resources.

(iv) To adopt an adequate irrigation system.

(v) To give responsibilities to the water users by the implementation of associations of collective interest.

(vi) Strengthen the knowledge in water resources management control subject to the climatic changes.

(vii) Set up a database of measurements and observations which can constitute a reference for the future.

(viii) Dams conceived for inter annual regulation played their role completely in the satisfaction of demand during normal periods.

(ix) Reservoirs conceived for inter annual regulation are, in case of drought, subject to sensitive deficits. These deficits should be filled by supplements of water from the north waters network as is the case of Bezirk, Nasri and Chiba dams, or from direct pumping in the "oued" (river) as is the case for Lakhmess.

Plans and actions for coping with the 1999-2002 drought (Guideline approach application and lessons learned)

Drought has been upon Tunisia during 3 consecutive years (1999-2002). This drought was characterized by different types: regional, global, seasonal and annual. In this section a brief description of the drought events is presented. The lessons learned are identified. The updating mitigation system necessity is underlined.

Rainfall during 1999-2002

From the precipitation data, observed in the different regions in Tunisia and presented in Table 15 the following conclusions could be drawn:

(i) Rainfall during summer has no importance in the cropping systems or in the water resources mobilization process. Such precipitations are generally small quantities and occur with hot weather, consequently they are totally evaporated. The global drought index related to the cumulated rainfall during the effective seasons – autumn, winter and spring is more significant than the yearly values.

(ii) During 1999-2000 the autumn was safe, but the winter and spring were severely dry in the Centre and South. In the effective season’s level, the water deficiency ranged on about 80%. The droughts during this year have been seasonal (winter and spring), and moderate in the North and severe in the South and the Centre. This situation has created awareness on the decision makers as well as on the water users. Hence, a preparedness programme, for eventual subsequent dry years, was in the mind of all.

(iii) During 2000-2001, the drought has been generalized in the country, expect the North side.

(iv) Unfortunately, 2001-2002 was dry in the whole country, so it could be considered as the third year of drought. This situation is generally rare but it occurred in Tunisia. The drought was severe and generalized during the autumn and the winter and moderate during the spring in the North, Centre, and SW of the country. A severe drought occurred in the SE regions.

Table 15. Rainfall [Pm: historical mean (mm); P: measured (mm)] and drought index (DI = P/Pm * 100) during 1999-2002 (autumn, winter and spring) in Tunisia

Regions	Autumn-winter-spring			Year		
	Pm	P	DI (%)	Pm	P	DI (%)
1999-2000						
NW	587	436	74	619	504	81
NE	467	418	90	489	437	89
CW	283	235	83	320	252	79
CE	305	296	97	317	335	106
SW	116	82	71	124	116	94
SE	172	125	73	175	125	71
2000-2001						
NW	587	599	102	619	625	101
NE	467	436	93	489	455	93
CW	283	178	63	320	189	59
CE	305	156	51	317	158	50
SW	116	55	47	124	56	45
SE	172	53	31	175	54	31
2001-2002						
NW	587	371	63	619	468	76
NE	467	262	56	489	308	63
CW	283	176	62	320	229	72
CE	305	185	61	317	201	63
SW	116	82	71	124	87	70
SE	172	86	50	175	87	50

Drought mitigation operations during 1999-2002

All operations described above were realized. It is important to mention that the hydraulic system was highly efficient, since during the third dry year no significant restriction in the water supply was applied. The restriction was around 10% for drinking water and about 30% on agricultural uses. All media and extension services contributed in increasing public awareness on the drought event and sensitization for the saving water.

(i) During 1999-2000, principal measures were localized in the sensitive regions. A preparedness programme, for eventual subsequent dry years, was in the mind of all.

(ii) During 2000-2001, the principal measures were related to the livestock nutrition providing subsided prices and also free barley quantities were attributed to 170,000 small farmers. Circumstance decisions were taken by exempting the importation from taxes and customs charges. Livestock vaccination was operated. On the other hand, the farmers were advised in the soil tillage (dry farming operations) and in the trees pruning. Priorities were attributed to water transportation by tank track in order to irrigate fruit trees, especially the young ones and to protect the trees, particularly the olive tree, against insects and diseases. A water management programme for satisfying the demand was realized: water transportation, new artesian wells creation and maintenance of the shallow wells. In the national level, markets were supplied by sufficient quantities of principal products. The cost was estimated by 19,550 millions of Tunisian Dinars, scheduled in two stages and supported by a presidential special attention.

(iii) During the third dry year 2001-2002, that was general for the whole country, all measures listed above were intensified and evaluated with a cost of 33,172 millions of Tunisian Dinars that were also scheduled in two stages.

Proactive and reactive measures

All drought mitigation actions undertaken before 1999 in Tunisia are basically characterized by being "adaptation measures" that are linked to emergency interventions, rarely integrated and overloading the State budget. The intervention measures consist particularly of: (i) free vaccination of animals; (ii) distribution of free livestock nutrition products for small farmers who are the most financially affected by drought; (iii) subsidizing forage product prices; and (iv) attribution of yearly credit for farmers in order to cope with drought. Such interventions were not planned before 1999. But today drought is considered as a climatic reality and is taken into account in the national development plans (e.g. the tenth plan 2002-2006) as well as in the State annual budgeting.

Although the four mentioned measures conducted during drought are really reactive, regarding their importance in securing the farmers, they tend to be proactive measures since they approach an insurance system.

Strengths and weakness of drought management system

The drought plan or the drought management system has not been analysed deeply until now in Tunisia. Actually, a wide-spreading study is in process (since 2003). The study entitled "The Climatic Changes and their Impacts on the Agricultural Sector and the Ecosystems" is actually in its first phase, and diagnostic and evaluation of the drought mitigation plan in Tunisia would be realized in the near future.

Strengths

(i) A high Presidential interest and support is devoted to the drought mitigation system in Tunisia.

(ii) The approach based on three drought management phases (before, during and after drought process), is a very important strategy and relevant to the basic elements of drought management theory.

(iii) Productive capital sharing and preservation.

(iv) Sustainability of farmers incomes.

(v) Integrated and optimized water resources management in Tunisia, especially during drought depending on its intensity and duration.

(vi) Water saving is a national policy not only related to drought.

Weaknesses

(i) The financial incidences are supported by the State budget because of the absence of insurance systems linked to droughts, and the private sector contribution is limited.

(ii) Updating the drought mitigation plan until 2003 was based on simple note taking and observation findings, without any wide-spread evaluation study. The latter would be realized by in process studies "The Climatic Changes and their Impacts on the Agricultural Sector and the Ecosystems".

(iii) The deficiency in the relations between the different information data stakeholders, which should be resolved by the establishment of the Unified Water Resources National Information System "Système d’Information National des Ressources en Eau (SINEAU)" in the near future.

Conclusions

Rainfall in Tunisia is characterized by a spatiotemporal variability and it has a high importance in the irrigated and rainfed agricultural production systems and also in the water supply for the other sectors. For this reason, Tunisia focused its policy on the water mobilization with inter annual volume regulation approach. From Tunisian water system complexity results a complex water management process, where diversified organizations and institutions are involved in water resources data and information system, in water management and consequently in drought mitigation process.

The integrated water resources management system in Tunisia considers the drought as a climatic reality that is taken into account in the development plan programmes. The planning for drought moving from crisis to risk management dates only from the end of the eighties. Before, droughts were erroneously considered for several years as temporary and rare climatic events, and consequently the drought management was "a forced reaction" to respond to immediate needs. When drought is upon the country, irrigated areas as well as the rainfed lands are affected, and the other water demands are also subjected to some restriction. For coping efficiently with the drought periods, Tunisia established a drought management system which has been used for the drought events occurred during 1987-1989 and 1993-1995. In 1999, Tunisia elaborated its first drought mitigation guideline. The latter, has been applied during the drought during 1999-2002.

Finally the following points could be underlined:

(i) The performance of the Tunisian hydraulic system is demonstrated during the water shortage.

(ii) A consolidation of the interaction between the different organizations and institutions that are involved in the water and drought data collection and between those related to the drought mitigation process is required.

(iii) The Unified Water Resources National Information System "Système d'Information National des Resources en eau (SINEAU)", which will be established in Tunisia in the near future, will be useful for several situations of water resources management, particularly during drought.

(iv) The drought management system could be qualified as moderately sufficient, and has to be improved; the lessons learned should be established in order to update the system (the guideline and its approach).

(v) The partners of MEDROPLAN project experience in the water and drought mitigation, when identified, could enhance the Tunisian system. The outputs and deliverables of MEDROPLAN will have certainly a high importance in the updating process of the drought mitigation system in Tunisia.

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Practical Guidelines for drought management in Tunisia

Generally, drought is upon Tunisia 2 to 3 times every 10 years. It is considered as a reality and not as a rare and random event. In order to reduce the resulting effects of the drought in Tunisia, a related management system was developed and adopted for the drought events occurred during 1987-1989 and 1993-1995. In 1999, Tunisia published its first guideline of drought management "Guide pratique de la gestion de la sécheresse en Tunisie" (Louati *et al.*, 1999). The guideline was elaborated by referring to the drought management system and by analysing the data and information recorded during the drought periods of 1987-1989 and 1993-1995. The American and Australian drought mitigation systems were overviewed and explored in order to adapt some approaches to the Tunisian natural conditions. This guideline, consisting of methodological approaches, identifies the principal drought indices, describes the drought preparedness and management process, and maps the intervening parties.

Drought Indices

Precipitation Deficit

The principal drought indices adopted in Tunisia are related to the quantification, for a given period of time, of the percentage of precipitation deviation from the mean historically established values. According to the experience in Tunisia, when precipitation quantities are ranged between 70 to 50% of the historical mean value, drought is declared and when they are less than 50%, a severe drought is declared. Yearly, the first kind of drought is predominant, but the second one is rare in the North and frequently occurred in the Centre and the South of the country.

The delay of the first autumn precipitation (September-October) is a pertinent index relevant to the meteorological conditions during the remaining year. The rainfall data analysis showed that during the last century there was a highly correlated relation between autumn rainfall quantities and the yearly precipitation amount. Around 70% of the autumnal drought cases are generally followed by an annual drought event. This percentage is 78 and 90% respectively for the North and both the Centre and the South. Precipitation during autumn is very important since it is representing 40% of the mean annual quantity.

On the other hand, if the drought persists during the beginning of the winter, especially from 13 January to 2 February (called in the agricultural local language the black night), the drought is confirmed. The March precipitations are impatiently awaited. Such precipitations are very important; they are a great weight off of farmers' minds since they save their crops, especially the cereal and the young trees. The importance of that precipitation appears in the popular proverb: "rain of March is pure gold.

The Azores anticyclone

There are other drought indices related to the Azores anticyclone coming from the West of the country. This results in a rise in temperature that could reach 30 to 35°C and an outstanding SW wind that hampers the NW atmospheric disturbance, characterized by rainfall events. During the drought events occurred on 1987-1988 and 1994-1995 the Azores anticyclone was observed.

The drought committees

Because of the importance of the committees' work, they are nominated by Ministerial Special Decisions. In order to ensure an efficient drought management, three types of committees are established:

The Drought National Commission (DNC)

This DNC regroups representatives of MARH, Interior, Economic Development, Finances, Commerce, Transport, and Public Health. It has principally: (i) to keep track of the drought circumstance; (ii) to elaborate the measures and provisions against the drought situation (intensity, duration, etc.), according to regional and national indices analysis; and (iii) to coordinate the execution of drought mitigation operation programmes. This commission is supported by the Specialized Sectors Commissions (DSC) at the national level and by the Regional Commissions (DRC) in each province (Governorate).

The Drought Regional Commissions (DRC)

Tunisia has 24 Governorates. For each one there is a DRC. The members belong to the Regional Departments of all Ministries involved in drought mitigation. The UTAP (United Farmers Organisation) is associated. The main task of DRCs is to present the situation of the different sectors and inform the national authorities about the necessary measures for drought management if observed in their regions. They work in strong collaboration with DNC and DSC.

The Drought Specialized Commissions (DSC)

The DSC(s) are responsible for the preparation of the drought indicators observed in each field. They propose an operation planning and scenarios for mitigation of the different eventual drought events. The DSC(s) are as following:

(i) Water Resources Management Committee. This Committee regroups representatives of all departments involved in the water management in MARH. The INM (relevant of Ministry of Transport) and the Ministries of Interior and Public Health are also associated in this committee. Referring to the data collected by the DRC, this committee has to analyse the water resources situations, to establish the drought indicators related to water resources and to elaborate diverse water management scenarios that should be adopted. The DSC submits a measures programme to the approbation and decision making by DNC.

(ii) Livestock Safeguard Committee. Organizations and institutions not involved in water management, but that are associated in drought mitigation, are represented in the Livestock Safeguard Committee. The latter is formed by representatives of organizations and institutions that are involved in the animal husbandry within MARH. The UTAP is associated in the activities of this committee, and the Ministries of Commerce, Transport, Interior, Finances and Economic Development. In collaboration with the DRC, the committee identifies the forage stocks and reserves, analyses the fodder crop fields and fits the livestock health situation. Depending on the drought intensity, this committee has to elaborate an intervention programme and to establish the eventual importations needs in order make up the eventual forage deficit.

(iii) Cereal Sector Management Committee. This committee is organized by the cereal sector intervening parties. Its members are representatives from different departments of the MARH that are working in the cereal field. The UTAP is associated and also the Ministries of Finances and Economic Development. This committee has to quantify the cereal production stocks and seeds reserves, to propose a programme in order to promote the irrigated cereal production, to enhance the production collecting, with a principal preoccupation of satisfying the seeds demand for the next year. In the case of insufficiency in cereal an importation programme is elaborated.

(iv) Arboriculture Sector Committee. The members of this committee work in the arboriculture departments of MARH and are concerned with the situation of all trees and aim the arboriculture heritage (patrimony) safeguard. The UTAP is associated.

Phases of drought management system

The drought management system in Tunisia is based on three phases: (i) Before drought (preparedness and early warning); (ii) Drought management (mitigation when drought is upon); and (iii) Subsequent drought (when drought is over). This could be resumed by "Before, during and after". The drought management system in Tunisia process in 3 major successive steps:

(i) Drought Announcement: Referring to rain fall, hydrologic and agricultural indicators as observed in the different regions affected by drought and transmitted by the agricultural, economic, and hydrologic districts (services) relevant to MARH, a drought announcement is established by mean a circumstance memorandum.

(ii) This announcement, qualified as warning note, is transmitted to MARH Minister, who proposes scheduled operations plan to the National Commission (committee), which is composed by a decision makers and beneficiaries.

(iii) The National Commission is loaded by the supervision of the execution of all the operation actions, with strength collaboration of the regional and specialized committees. The National Commission supervises also all operations when the drought is over.

Drought Preparedness

During this phase different organizations and institutions involved in the data collection systems, and also the universities, the research institutions, the extension organization (AVFA), the water management NGOs and the UTAP are associated. During this phase the following actions are realized:

(i) The climatic and hydrologic data are analysed in order to predict the hydro climatic situation.

(ii) A water management programme is established. This programme adopts the use of aquifers water resources during the scarcity periods.

(iii) Equipment of water points for domestic use when the drought has set in.

(iv) Contributing within the National Programme of Water Saving by a growing public awareness on the drought event.

(v) Ensuring sufficient quantities in forage and cereal seeds.

(vi) Fitting the reserves on forage and cereal in order to preparing a programme of an eventual importation.

(vii) Identifying the drought sensitive farmers.

(viii) Forecasting a financial supply for undertaking the farmers' drought disasters.

(ix) Preparing research topics related to drought mitigation.

Drought management

The drought management phase is characterized by the execution of the planning programmes of drought mitigation. Depending on the type, intensity and duration of the drought event, different scenarios are adopted:

Scenario 1 – Dry autumn

At the national level, around 70% of dry autumn cases are generally followed by an annual drought event. Nevertheless, this percentage is 78 and 90% respectively for the North and for both the Centre and the South. Precipitation during autumn is very important since it is representing 40% of the historical mean annual amount. Under such conditions the drought affects the cereal fields especially in the Centre and South and the forage crops in the north as well as the rangelands. Some mitigation and preventive operations are conducted:

(i) Identification of affected and sensitive zones.

(ii) Enhancing of the irrigated cereal programme, especially in the Centre and the South.

(iii) Evaluation of animal nutrition stocks and prevision of the eventual importation.

(iv) Supply the drought damaged regions by barley and other forage products.

(v) Establishing dams management plan according to the climatic conditions evolution.

Scenario 2 – Dry winter

Winter rainfalls are very important, particularly in the North where they contribute with about 41% of annual precipitation. They influence the cereal production, and have an impact on water collected in the dams and also on natural aquifer recharge. The mitigation programme is focused on:

(i) Identification of drought affected regions, in order to establish an intervention programme.

(ii) Evaluation of dams, water reserves and fitting a management plan regarding the available water.

(iii) Encouragement of the cereal complementary irrigation, especially in the seed production areas.

(iv) Prevision of priority products importation.

(v) Supplying the farmers with the livestock nutrition with a strong control of the distribution network.

Scenario 3 – Dry spring

The spring precipitation has an influence essentially on cereal yields, arboriculture fields, olive trees particularly, rangelands and surface water resources. Several operations are undertaken against any undesirable effects:

(i) Enhancing of the cereal complementary irrigation, in order to ensure the identified minimum production.

(ii) Evaluation of the rangelands, in order to fill the gap related to the livestock nutrition deficiency.

(iii) Predicting the cereal production and establishing an importation programme in order to remedy the eventual shortage.

(iv) Stored water evaluation and demand identification. A water resources management process is consequently adopted.

Scenario 4 – Dry year

The year is considered dry when the precipitation deficit is beyond 50% of the mean historically established value. The probability of having a dry year is 7 to 23% in the North and between 25 to 30% in the Centre and the South. Such a situation results in a substantial shortage in the available water resources, a fall in production and range shortage, and some problems related to the domestic water supply appear in the drought sensitive regions. Livestock sickness could be observed, because of change and unbalanced nutrition regime. In order to attenuate those problems a mitigation programme is executed:

(i) For Livestock safeguard, the identification of the animal nutrition stocks is established and an importation plan is applied in order to make up for the deficiency.

(ii) Prevision of vaccination campaigning on the livestock against the sickness related to drought.

(iii) To satisfy the domestic water demand, in urban as well as in rural areas, a programme of aquifer use is adopted, the use of the surface water resources are avoided or minimized. Particular attention is given to water transportation to the rural drought sensitive regions.

(iv) Establishing dams' water management plans regarding the evolution of the climatic conditions. The possibility of a second dry year is taken especially into account.

(v) Intensification of the preparedness operations related to the following year (short loans, soil tillage, seeds distribution, etc.).

Scenario 5 – Second dry year

A successive second dry year occurs with a probability of 3% in the North and 10% in the Centre and the South. Although classified as generally infrequent, this situation involves problems and constraints on water management and agricultural production. It requires an intensive importation planning in order to adapt to the shortages. This situation has unfavourable effects on the natural ecosystems. The major problem is to attempt to balance competing interest in a charged atmosphere by establishing awareness among the farmers, especially the small ones. For all these reasons, the Tunisian Government anticipates those inevitable problems by adopting several mitigation operations to dealing with drought:

(i) Since during this period the water resources are at their minimum level, a careful water management programme is established in order to balance the different demands and the limited available water resources.

(ii) The aquifers exploitation is intensified in order to alleviate the demand on the surface water resources.

(iii) Intensifying the measures taken during the first year essentially for the drinking water, which has a priority in the Tunisian legislation (Water Code).

(iv) Promoting the irrigation of the cereal crops, and those having small water requirements.

(v) Encouraging of the reclaimed water use for the specified forage crops.

(vi) Contributing within the National Programme of Water Saving through growing public awareness on the drought event and sensitization to the water saving in all usages.

(vii) Importation of products for the livestock nutrition and distribution to the farmers with subsidized prices.

(viii) Intensification of the livestock husbandry programme.

(ix) Organization of the products distribution networks.

Subsequent drought

When drought is over, the principal measures taken are:

(i) Intensification of the extension programme related to the soil tillage and farming practices in order to maximize the valorization of the precipitation coming during the eventually subsequent wet year.

(ii) Establishing a scheme of delaying the credit payment, and facilitate the obtaining of post drought loans.

(iii) Programming the distribution of cereal and forage seeds.

(iv) Evaluation of the available water resources (dams and aquifers).

(v) Reconstitution of the aquifers water reserves by the artificial recharging.

(vi) Evaluation of the mitigation programme efficiency and estimation of their cost.

(vii) Updating the drought mitigation programmes with reference to the identified deficiency. Such evaluation is conducted on the different aspects: economic, commercial, social, hydraulic and agronomic. All organizations and institutions involved in the drought management are associated in the evaluation process.

(viii) Associate the research institutes and universities in the development of research programmes related to drought mitigation, referring to the lessons learned by the past drought periods.

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Annex 1. Data and information systems

The current water information system

Water resources in Tunisia, as described above, are classified as surface, groundwater and non conventional resources. Tunisia devoted a high attention to the Data Information System on Water Resources (quantity and quality), in order to satisfy equitably the different water demand. The natural resources sustainability and the socio-economic approach are maintained as a policy basis. There are several stakeholders water information data institutions, that have diversities of objectives uses, but they are complementary (Table 1). Since the Tunisian water system is complex, the water data system includes eight major components:

(i) Precipitation (rainfall).

(ii) Surface Water (hydrometric data, reservoirs data –dams, hill dams, lakes–, water transfer by network connection, etc.).

(iii) Aquifers (management and artificial discharge).

(iv) Non conventional water (desalinized and reclaimed used water).

(v) Water quality monitoring network.

(vi) Water demand, cost and pricing.

(vii) Soil sweetening and drainage.

(viii) Demography (population).

Table 1. Summary of the principal institutions and organizations involved in water and drought data collect and processing

Institution	Data	Type of Data	Frecuency	Transmission mode
DGBGTH	Dams Data	Location, Capacity, Year of creation, Silting & Life Duration	Monthly &Yearly	Report
	Basin Hydrologic and Dams data Management	Water quality and quantity in dams, Daily water harvested, Rainfall, Rainfall management, Dam control, Management of hydrometric and hydrologic measurements, Volume used	Daily	48 radio VHF, 39 mobile transceivers, 60 walkie-talkies, Phone modem, Fax, Telemetry system for rainfall and hydrometric data every 30 minutes
	Dams Simulation and Statistical Analysis	Transfer, Losses, Exploitation	Monthly & Yearly	Report
	Dams Management	Annual volume, Annual hydrologic situation, Water losses in dams, Water dams balance, Water demand	Yearly	Report
	Water exploitation	Dams balance, Hydrologic studies, Statistics studies, Water demand	Monthly	Report
	Flood Early Warning	Instantaneous hydrologic situation	Instantaneously	Phone modem, Fax, Radio
DGRE & BIRH	Rainfall	Observation and Measurement Weather Station	Daily Monthly Yearly	Phone modem, Fax, Radio, Satellite, Report

Table 1. Summary of the principal institutions and organizations involved in water and drought data collect and processing (continuation)

Institution	Data	Type of Data	Frecuency	Transmission mode
	Hydrometric	Basin data, Oued (River), discharge, Stations, Maps, Water quality	Instantaneously, Daily, Monthly and Yearly	Magnetic support
	Flooding	Discharge of flood, Initial and final date and hour, Runoff	Instantaneously	Magnetic support
	Aquifers Supervision	Shallow and deep aquifers quantitative and qualitative situations and exploitation	Continually supervision and yearly data compilation	Report
	Shallow aquifers	Artificial recharging	Yearly	Report
	Aquifers Water Supervision	Quality and Quality (BIRH)	Yearly	Report
DGACTA-IRD	Rainfall	Observation and measurement around hill lakes	Instantaneously	Telemetry, ARGOS System
	Water Reservoir Hydrologic Balance	Volume, Evaporation, Runoff, Overflow, Emptying	Yearly	Report
	Strong Rainfall Characteristics	Intensity, Volume, Qmax	Instantaneously	Telemetry, ARGOS System
	Overflowing Risk	Spillway Maximum Discharge, Instantaneous Maximum Discharge, Dyke Overflowing	Instantaneously	Telemetry, ARGOS System
	Water Quality	pH & Salinity	Half-yearly	Report
	Water Reservoir Silting & Life Duration	Creation date, Initial and final volumes, Estimation of life duration	Yearly	Report
	Hill Lakes Exploitation	Water quantities, Irrigated areas	Yearly	Report
DGGREE	GIC Associations	Number, Water resources, Water quality, volume and cost	Yearly	Report
	Public Irrigated Areas	Surface, Intensification rate, Water resources, Water quality, volume and cost	Yearly	Report
	Rural Domestic Water Prevision	Statistics data: Supply & Demand evolution	Yearly	Database using GIS, Report
INM	Rainfall	Quantity and Intensity	Daily, Weekly, Decadal, Monthly, Yearly	Bulletins, Report, Web site
	Weather Observations and Prediction	All Weather observations	Continually	Bulletins, Report, Web site
	Weather Observations	Meteorological, Astronomy and Geophysical data	Continually	Bulletins, Report, Web site (for various national economic sectors)
	Seismic recording	Recording and Location	Instantaneously	Fax, Magnetic Support, Report, Web Site
	Climate Data	All Weather Historical Observations Data Base	Continually updated	Storage and filling (Technical Documents, Magnetic Support)

Rainfall

The DGRE has an important precipitation stations network (1,157 stations). Moreover, DGRE has 67 pluviograph stations distributed in the different regions. The data analysis is realized by the PLUVIOM Software.

The INM, Institut National de la Météorologie (National Institute of Meteorology), is the main precipitation data network in Tunisia. The first rainfall station measurement dated from 1873, and actually the INM network allows the management of 234 stations, were 26 are synoptic (principal stations), 31 agro meteorological, 59 climatic and 208 merely pluviometric. The database facilitates use by means of periodically structured applications namely:

(i) Acquisition of recent data and feeding the database tables.

(ii) Control of data quality.

(iii) Interactive management allowing visualization and updating.

(iv) Data computing by means a computer programs.

(v) Storage and filing of all climatic data.

(vi) Information provision, regular editing and dispatching of climate tables and statistics and preparation and worldwide distribution of "CLIMAT" messages.

(vii) Use of methods that combine climate data and socio-economic and physical data to meet the requirements of planners and decision makers.

In other hand, weather forecasting consists on collecting, analyzing and interpreting the different observations products, direct measurements or from remote sensing sources, as well as the products of the models of numerical weather prediction. It proceeds 24 hours a day, 7 days per week, and weather forecasts are provided in the form of bulletins, directives, or files in various communication supports. Different economic sectors are interested in forecast bulletins and other INM output (aeronautical and marine services, agriculture, environment, industry, energy, and tourism) and also other fields like health, sports, recreation, and media. INM has its WEB site *(www.meteo.tn)* where weather general information is supplied; specific data could be obtained by subscribing.

The DGACTA/DGRE has a network of meteorological stations located at the 30 hydrologic stations, 4 installed by DGBGTH nearby the hill dams and supervised by DGRE and the remaining 26 are equipped with telemetry systems realized in collaboration with IRD.

The DGBGTH includes a station network localized on the dams' sites. Every day, at 7h 30 am the precipitation quantities are recorded with other data related to dam situation.

The CRDA has a network in each district (Governorate), where the DGRE has a precipitation measurement post, that is managed by A/RE (the regional department of DGRE).

Surface water

Three institutions form a hydrologic measurement network: DGRE, DGBGTH and DGACTA.

Data are collected by the Hydrometric Network and by the Flood Early Warning Network. The Hydrometric Network includes a hydrometric station in each basin. There are 52 principal stations. The oldest is in Medjerda Basin were data are available for 80 years, and the newest are located in the Centre and the South, which have been in place since 14 years ago. DGRE analyses the data by mean HYDROM Software.

The Flood Early Warning Network started in 1970. The DGRE network focuses on the short term prevision of flood by the principal oueds (rivers). The objectives are the hydraulic system protection and the population preservation. Information is communicated by phone modem, and/or by mean 26 radio systems. The DGRE system is enhanced by the DGBGTH Flood Early Warning Network witch is based on 48 radio VHF communication system, vehicle mobile 39 transceivers, and 60 walkie-talkies.

Groundwater: Management and artificial recharging

Shallow and deep aquifers data are insured by DGRE and CRDA (A/RE). Quantitative and qualitative data's are recorded and published in special technical issues (Annuaires). Hydro geologic information on the deep aquifers are well mastered and simulated by mean numerical models. Shallow aquifers data are target on the quantitative and qualitative information, were artificial recharging is monitored.

Non conventional water

Until 2002, there were 60 stations of water used purifying that could reclaiming about 150 M m^3/year, and they were managed by ONAS. The reclaimed water use is restricted for the municipal activities and for the irrigation of golf courses and some forage crops (listed by legislation texts). Data on the production and uses of reclaimed water are supplied by ONAS, CRDA, DGGREE and Touristy services.

Desalinized water is produced especially for regions (Gabès, Zarzis, and Djerba and Kerkennah islands) which suffler fresh water shortage. SONEDE is the institution that is in charge of by this operation as well as of supplying information on the production quantities and the demand evolution.

Water quality attending network

Water quality is followed up by DGRE-BIRH for the aquifers and surface water quality is supervised by two groups of operators. Firstly DGRE-BIRH, DGBGTH, DGACTA, INRGREF, SECANDENORD, SONEDE, CRDA, and ONAS could be listed. The second group, formed by the regional departments of Health Ministry and the ANPE institution, is responsible on the health effect of water quality with respect of the OMS norms. Several laboratories assure water analysis that are relevant to DGRE-BIRH, DGBGTH, SONEDE, DGACTA, CRDA, ONAS, CITET, INRGREF, Sciences Faculty, Pasteur Institute, and numerous private laboratories.

Water quality information and data related to aquifers resources and the surface water resources are disseminated by BIRH (institution linked to DGRE).

Water demand, cost and pricing

Domestic (as well as industrial and touristy) water demand is established by SONEDE, GIC (NGO), and CRDA Department of DGGREE. For the irrigation needs, the quantities required are identified by CRDAs and GIC organizations.

Soil sweetening and drainage

The soil drainage supervising network is insured by DGACTA, DGGREE and INRGREF by mean a target studies and permanent measurement. The Geographic Information System is associated in the database of the soil description and analysis. Soil sweetening and drainage data are regularly published by mean annual reports, specific studies and technical bulletins.

Population data

Demographic information is provided by INS (Institut National des Statistiques: Statistics National Institute) through periodical national census (every 10 years), which includes several informations on the population pyramid age, and the different economic activities (active people and their domain, school-attending, etc.).

Strengths and weakness of the current water information system

The actual water information system is characterized by a highly diversified but complementary water resources information and data stakeholders. Nevertheless this diversities constraint the water data and information exchange, and consequently hamper the efficient valorization of the important recorded information. To avoid this weakness, Tunisian Government decided to establish an Unified Water Resources National Information System called "Système d'Information National des Resources en Eau (SINEAU)". The first phase of the identification study have been completed on October 2003. SINEAU system will add more efficiency in the water data collection, analysis, and its real time diffusion.

The SINEAU has as main objective to establish a coherent and efficient information water system, that is set by an advanced data management and updating system and uses unified and normalized data analysis software. This system will allow an efficient support for data use and will serve as tool for the decision making on water resources management in diversified situations of availability. The major strengths of SINEAU system are the standardization of data language and the integration of all water information in a unique database, so consequently information transfer or use will be endowed with a height efficiency. Such system will be characterized by easy and rapid communication process between all organizations and institutions involved in the water management, particularly in the drought mitigation.

Chapter 23. Methods of risk management (Technology and water quality)

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Introduction

The availability of, and the demand for water form one of the most complex relationships the mankind is facing. The primary reason for this is the ultimate importance of water for the life on the planet. Under "availability of water" one should primarily underline the limiting amount of water in our hydrological cycle, the uneven distribution of its quantities in space and time, and the crucial role of water in preserving and maintaining the planet's environment and the life on it. By "demand for water" one should consider drinking and agricultural water consumption as the essential preconditions for human life sustenance, as well as the areas of water use which could be considered as contributing factors to the improvement of the quality of life (i.e. non-consumptive household, industrial, navigation, energy production, recreation water demands, etc.).

Another driving factor in the effort to reconcile water availability and demand is water quality. On the one hand, the quality of available water resources determines, to a varying degree, their suitability for different purposes. The quality of water released back to the environment after its use, on the other, influences the extent of environmental pollution and, in turn, prospects for the maintenance of the sustainable use of the water resources in the future. Furthermore, both the use of the available water resources and the release of the used effluents back to the environment have an impact on the environmental balance in the affected areas.

The aforementioned quantitative and qualitative aspects of the balance of this precious resource have been recognized as crucial in the strive to maintain the necessary environmental quality, ensuring at the same time that everyone gets a just share of water of good quality. Unfortunately, the state of the quantitative and qualitative balance of water resources have been degrading due to the decades of irresponsible human actions mainly based on the notion that water, although indispensable, is still a renewable resource which is never going to be depleted.

Objective criteria

The case study system consists of 15 large reservoirs in the Northern part of Tunisia. The reservoirs are mutually interconnected in either serial or parallel fashion, both through natural river reaches as well as man-made water transfers.

The system encompasses 36 individual demand centres grouped into three principal water user types: urban (five demands), irrigation (thirty demands) and environmental (one demand). The demands have been described by two parameters: demand volume and the maximum acceptable supply salinity.

System topology studied indicates that the analyses are to address a rather difficult operations research problem. On the one hand, the system itself can contain multiple reservoirs and demand centres, which can be linked together in an intricate network. On the other hand, the consideration of salinity of reservoir inflows and releases, and thereby allocations to individual demands, adds additional complexity to the operation problem. It is obvious therefore that the optimization problem must apply criteria which will be able to address both the quantity and salinity of reservoir allocations to individual demands. Furthermore, reservoir operating storage targets (rule curves) are considered as an additional objective criterion.

The primary goal of the analyses is to identify the preferable water resource allocation strategies within a complex water supply reservoir system and, at the same time, to derive the respective optimum operating policies of system reservoirs. To achieve this goal, three objective criteria have been defined and adopted for the analyses:

(i) To minimize the supply quantity deficit.

(ii) To minimize the violation (surpassing) of supply salinity thresholds set for individual demands.

(iii) To minimize the deviation of the operating final storage of reservoirs from the predefined final storage targets.

Supply quantity objective

The adoption of this objective criterion is unavoidable since the system serves primarily a water supply purpose. The choice of minimization of supply quantity deficit as opposed to maximizing the allocation for consumptive uses from the reservoirs is due to the fact that the demand volumes are known in advance. In addition, the problem has not been defined as yield estimation but rather an improvement of resource allocation and operating policies of supply reservoirs within a complex reservoir system. In this regard, the supply quantity objective choice of deficit minimization is a preferred one.

Supply salinity objective

Due to the fact that salinity of system allocations plays an important role in many water supply systems we attempt to address this issue in the formulation of the operations research problem to be analyzed. In this respect, each demand centre has been assigned a salinity threshold feature describing the maximum salinity of supply the demand centre deems acceptable. To reflect system’s ability to comply with the imposed salinity thresholds, an objective criterion which minimizes the excess salinity of supply allocations has been introduced. In addition to the use of this objective criterion in optimization, a number of related system performance indicators have been defined to assess reliability aspects of system operation upon simulation.

Reservoir storage target objective

In addition to the demand aspect, the derivation of reservoir operating policies also addresses the target storage volumes of the individual reservoirs. The rationale to incorporate a storage target objective criterion is due to the fact that the system being analyzed is assumed to be a pure water supply system. Namely, considering only the demand satisfaction side of system operation it is not possible, for instance, to address the issue of reservoir filling and spill. On the other hand, reservoir operating rule curves are widely in use as guidelines for operating decisions and more complex operating policies are seldom favoured by reservoir operators. In this respect, it is the goal of the work to introduce a possibility to utilize rule curve targets as an additional objective criterion while deriving the optimum operating policies of individual reservoirs. This option also gives a possibility to carry out a comparison between operating policies with and without consideration of operating rule curve (i.e. storage target) objectives. Similarly to the other two objective criteria used in optimization, a number of storage target related system performance indicators have been defined to assess reliability aspects of system operation upon simulation.

Structure of the optimization problem

The main goal of this work is to assess the applicability of a combination of several operations research approaches to a strategic operational problem of complex reservoir supply systems. System topology requires that the adopted approach for the analyses be able to tackle rather complex system configurations. With regard to such a system topology, the focus of the work is limited to the optimization of the long-term operating strategy of a multiple reservoir water supply system. In principle, an operating strategy of such a complex system may be understood as a composition of two main parts:

(i) Reservoir-demand allocation patterns.

(ii) Reservoir operating policies reflecting the aforementioned allocation patterns.

Such a decomposition of the operating strategy is justified by the fact that the original problem is rather complex, thus requiring either huge, if not prohibitive, computational resources to arrive at the optimum solution, or enormous simplifications of the problem to render it manageable at an acceptable cost.

Reservoir-demand allocation patterns are introduced to resolve the problem of demand sharing among groups of reservoirs. In other words, these patterns represent the portions of individual demands each reservoir is targeting. This simply means that each demand is split into its sub-component demands, each of which is supplied by a single reservoir only. The task of optimization is therefore to identify those demand sharing patterns which would lead to the best allocation of water resources within a system.

Once reservoir-demand allocation patterns have been derived, the optimization of individual reservoir operating policies can be carried out. This process is therefore based on the assumption that the derived allocation patterns have to be complied with in policy optimization. As a consequence, the obtained operating policies will preserve the imposed reservoir-demand allocation patterns.

Uncertainty is inherent in the operation of any water resource system and since the nature of the problem in hand is to derive a long-term operating strategy of a reservoir system, the stochasticity of reservoir inflows is considered. This is however not to say that stochasticity of other factors influencing the operation of the system is diminished. It is only decided that the uncertainty of the inflow processes is sufficient for the case being analyzed. With regard to the temporal discretization, the analyses are limited to monthly time steps assuming the stationarity of the stochastic properties of monthly river flows (i.e. the probability distribution of a stochastic process is not changing over time). Monthly water demands, on the other hand, are assumed to be deterministic and considered to be recurring in annual cycles. Since the chosen monthly time base is long enough the required time for the released water to travel between any two serially linked reservoirs and any reservoir and the respective demand centres can safely be neglected.

Optimization problem characteristics

The main goal of the analyses is to derive the best long-term operating strategy of a complex reservoir system. Since the size of such a problem can be prohibitively large (i.e. number of reservoirs and demand centres, the complexity of reservoir-reservoir and reservoir-demand interconnections, consideration of flow stochasticity, and multiple objectives) it is inevitable to opt for some kind of adjustment of, and modification to the problem itself to render it manageable by an appropriate operations research method. Therefore, the adopted methodology to solve the operational problem for such a system, and with respect to the given objectives, falls into the group of decomposition techniques. In essence, decomposition approaches break down a complex optimization problem into a series of simpler tasks. They subsequently employ an iterative derivation procedure to arrive at the respective solution. One common characteristic of almost all the approaches of this kind is, however, that the global optimality of the obtained solution cannot be guaranteed. It is, therefore, necessary to emphasize that the starting point of this work was not to pursue a methodology which would guarantee the derivation of the global optimum operating strategy at any cost, but rather to try and identify a relatively simple and transparent, however yet efficient and effective approach for the analysis of the operation of complex reservoir systems. With this notion in view, the decomposition applied in this study is done at two levels:

(i) Problem decomposition.

(ii) Reservoir system (topology) decomposition.

Problem decomposition

An operating strategy of a complex reservoir system may be understood as a coupling of:

(i) Reservoir-demand allocation patterns.

(ii) Reservoir operating policies reflecting the aforementioned allocation patterns.

Such a decomposition of the problem reduces the complexity of the optimization task and allows that it can be solved with less computational effort. What needs to be ensured when deciding on the approaches to solve these two resulting sub-problems is that the two keep the maximum similarity with regard to the links between them which are broken by decomposition.

Reservoir system decomposition

Each of the two sub-problems can still require formidable computational effort to solve it, especially in cases where the systems being studied are highly complex. Therefore, a general concept of reservoir system decomposition is applied in both sub-problems. The main features of the applied system decomposition approach are:

(i) It is an iterative procedure, with main iterative cycles repeated until a desired convergence is achieved.

(ii) A multiple-reservoir system is decomposed into single-reservoir sub-systems.

(iii) Appropriate optimization/simulation techniques are applied to single-reservoir sub-systems.

(iv) Single reservoirs are entering an iterative cycle of analyses in a predefined sequence.

(v) The interaction between the reservoirs is modelled by an auxiliary model, which is selected on the basis of the type of problem being solved (i.e. reservoir-demand allocation patterns or reservoir operating policies).

General optimization approach structure

Based on the aforementioned description of the problem and its decomposition, the general structure of adopted approach to derive long-term operating strategy of a complex reservoir system can be formulated as follows:

(i) Decompose the problem into resource allocation and policy optimization.

(ii) Decompose the reservoir system into individual reservoir sub-systems.

(iii) Solve the resource allocation sub-problem applying the appropriate optimization method combined with the reservoir system decomposition principles.

(iv) Solve the policy optimization sub-problem applying the appropriate optimization method combined with the reservoir system decomposition principles.

(v) Simulate the operation of the system according to the derived resource allocation patterns and operating policies.

(vi) Evaluate the performance of the system.

Without entering into the details on decomposition (it is introduced earlier in this chapter) and performance evaluation components of the list above, the methods used to solve the two optimization sub-problems and simulation are briefly introduced in the following.

Namely, the resource allocation sub-problem is solved by a genetic algorithm (GA) based search model. The principal idea of a GA search is to sweep the objective function space looking for solutions which bring improvement to the objective function. Genetic algorithms belong to the family of evolutionary methods, which are based on the principles of natural evolution. They work on a family of potential solutions and apply effective recombination rules to known solution candidates to guide their search towards the best solution to the problem. In this specific case, the GA model assumes that a solution is a collection of reservoir-demand allocation targets for the entire system and uses reservoir system simulation to estimate the objective function value for each potential solution to the allocation problem.

The adopted methodology for the optimization of the long-term operating policies for individual reservoirs combines a physical decomposition of the system into individual reservoir subsystems, stochastic dynamic programming (SDP) optimization of a single reservoir operation, simulation and release allocation among each reservoir's water users. Since the SDP model derives the operating policy for a single reservoir (as opposed to the GA model which derives the allocation pattern for the entire system) its application has to be combined with system decomposition, simulation and release allocation. In addition, the developed SDP model utilizes the reservoir-demand allocation patterns derived by the preceding run of the GA.

Finally, simulation of the system operation according to the derived policies is essential due to three reasons:

(i) It is necessary for the evaluation of potential solutions in the genetic algorithm.

(ii) It is an integral component of the stochastic dynamic optimization model.

(iii) System performance evaluation cannot be done without simulation.

Transformation of a multiobjective decision making problem

The consideration of three distinct objective criteria implies that the problem of derivation of system operating strategies belongs to multiobjective decision making analyses. It is however no the intention of this study to address the issue from a strict multiobjective decision making point of view, but rather to transform the problem into a single-objective optimization.

In this respect, the obvious choice is to opt for a composite objective function which would include all three objectives. However, and since the optimization problem has been split into two smaller sub-problems, the ultimate decision on the composite objective has been made so as to combine two objective criteria in deriving reservoir-demand allocation patterns, and different pair of criteria for the optimization of reservoir operating policies:

(i) Reservoir-demand allocation patterns: supply quantity and supply salinity objectives.

(ii) Reservoir operating policies reflecting the aforementioned allocation patterns: supply quantity and storage target objectives.

Another reason for such a selection of composite objectives for the two sub-problems lies in the choice of methods used to solve them. Namely, a genetic algorithm search is used to derive reservoir-demand allocation patterns. A GA search is based on objective function estimation using simulation of system operation and, therefore, it is no problem to develop a simulation model for a single reservoir which is able to simulate both the volumetric and salt balance of water in a reservoir during a time step. Hence, supply salinity objective can be applied to the first problem without difficulty. On the other hand, stochastic dynamic programming is applied to derive reservoir operating policies and considers reservoir inflows as a stochastic process. Thus, SDP describes reservoir inflows as a Markov process through estimation of monthly inflow transitional probabilities. Consideration of salinity would therefore also require that inflow salinity time series is also described as a Markov process, which would impose that joint probability distributions of flow volumes and salinities are estimated. This would however, render a discrete SDP formulation rather complicated. Furthermore, salinity data available for the research show very little variability over the years of record, thus justifying the assumption that the consideration of supply salinity objective only in reservoir-demand allocation sub-problem. That is, the derived allocation patterns would then sufficiently reflect the objective to minimize the violation of supply salinity threshold and would thereafter implicitly incorporate the salinity consideration into the SDP-based operating policies derived within the second sub-problem.

Additional reason for such a division of objective use is in the fact that the genetic algorithm search for the best reservoir-demand allocation patterns is also used to derive the storage targets of individual reservoirs.

Finally, the combination of supply quantity and storage target objectives in SDP optimization of reservoir operating policies completes the combination of the three objectives. In addition, the derived SDP operating policies would reconcile, in a single policy, the aim to maintain the optimum level of supply quantity and salinity, and the desired storage target curve.

System performance evaluation

The optimization approaches applied here employ different combinations of pairs of objective criteria to arrive at the solutions to the respective multiple-reservoir operating problems. That is, the individual objective functions used in the applied approaches all take some form aggregated penalty incurred by the respective monthly decisions on release.

However, the estimate of the objective function value contains no information about the frequency of the system's failing to provide the required service, the duration and severity of potential failures, nor the ability of the system to return to satisfactory operating state once a failure has occurred. These important facets of system performance are widely known as reliability or performance indicators (PI). Performance indicators provide valuable additional information about the respective performance of the entire system. The choice of PIs is primarily problem dependent and can be made from a variety of reliability, risk and other performance related indicators. Consequently, in order to reflect better the most relevant aspects of a particular operating problem, the definition of the adopted performance indicators often varies from one application to another. It is therefore important to point out that no universal definition exists for almost any one of the most frequently used performance indicators.

Therefore, to reflect on those aspects of the operation of the entire system, the alternative optimization approaches developed in this case study are compared not only on the basis of their respective optimization-based objective function achievements but are also weighed with regard to a number of additional simulation-based performance indicators. Namely, once an operating strategy of the system is derived, the system's operation is simulated and the resulting performance is appraised against a number of criteria.

The advantage of the simulation-based performance assessment is particularly pronounced in the operational analysis of multiple reservoir systems where the complexity prohibits the explicit consideration of performance criteria in the optimization process. By adopting this simulation-based reliability appraisal approach, analysts can opt for simpler optimization methods enabling at the same time the application of complex simulation models to obtain detailed information about various operating aspects of the system's performance. Therefore, the evaluation of different operating strategies derived for the case study system is based on this approach.

Since there are three objective criteria adopted, the selection of performance indicators must also reflect the criteria themselves. Therefore, three distinctive sets of performance indicators are defined to provide additional information on the analyzed system performance:

(i) Performance indicators for the supply quantity objective.

(ii) Performance indicators for the supply salinity objective.

(iii) Performance indicators for the storage target objective.

Reliability criteria assessment in evaluation of reservoir performance

Various optimization techniques have been extensively used to derive operating strategies of reservoir systems. Most frequently, the devised optimization models have relied on maximization or minimization of the selected objective criterion to arrive to the best achievable operating policy of the system in question. Similarly, within a multiobjective framework, the proposed approaches have usually utilized repeated optimization analyses concentrated on alternative single criteria while considering the remaining objectives as constraints. In this way, the analysts have been able to construct the trade-off relationships among the estimated achievements of the objectives imposed upon the analyzed system.

Within stochastic optimization concepts the most frequently used objective criteria include either the maximization of the expected system output or benefit function, or the minimization of the expectation of some form of loss function. Utilization of this type of criteria provides the estimate of the expected performance of the system on the long run. However, they cannot shed any light on the frequency of the system's failing to provide the required service, the duration and severity of potential failures, nor the ability of the system to return to satisfactory operating state once a failure has occurred. These important facets of a system's performance are widely known as reliability indicators. Consequently, substantial effort has been put into the explicit consideration of reliability into the optimization of the operation of reservoir systems. It could be said that the most significant in the field started with the work on chance-constrained programming by ReVelle *et al*. (1969), which was further extended by, to name just a few, ReVelle and Kirby (1970), Eastman and ReVelle (1973), ReVelle and Gundelach (1975), Gundelach and ReVelle (1975), Louks and Dorfman (1975), Houck (1979), Houck and Datta (1981), and many others, including the works on reliability programming by Simonovic and Mariño (1980, 1981, 1982).

Recognizing that the simulated estimates of the mean and the variance of the selected performance measure (e.g. output, operating cost) could not provide accurate information about the frequency and magnitude of operational failures, Hashimoto *et al*. (1982) used three additional performance indicators to compare a number of different operating policies of a single irrigation water supply reservoir. They introduced *reliability* to describe how often the system failed to meet the target; *resiliency* to assess how quickly the system managed to return to a satisfactory state once a failure had occurred; *vulnerability* to estimate how significant the likely consequences of a failure might be. Based on simulation of the reservoir's operation over a long synthetic inflow time series, a set of operating strategies was evaluated by deriving trade-offs among the expected loss, reliability, resiliency and vulnerability. For instance, one conclusion that could be drawn from the analyses was that, for the given case study, high system reliability was always accompanied by high vulnerability (i.e. the fewer failures the reservoir had, the higher deficits were encountered in the failure periods). The authors also pointed out that each problem bears its own unique features and, therefore, the selection of appropriate performance indicators should always reflect upon those unique characteristics of the problem.

Similar conclusions were also drawn by Moy *et al*. (1986) in their study of the operation of a single water supply reservoir. They used mixed-integer linear programming to derive trade-off curves among the virtually same three performance indicators presented by Hashimoto *et al*. (1982). Namely, they defined *reliability* as the probability of failing to meet the desired target; *resilience* as the maximum number of consecutive failures prior to the reservoirs return to the full supply state of operation; and *vulnerability* as the maximum supply deficit observed during simulation. The major finding described the relationship between vulnerability and the other two PIs. In general, the results showed that a reservoir would likely exhibit higher vulnerability (i.e. larger magnitude of failures) if it were more reliable (i.e. had fewer operating failures), or if it were more resilient (i.e. had short sequences of repeated failures).

The expensive study of Bogardi and Verhoef (1995) presented a more detailed analysis of the sensitivity of the operation of same three-reservoir Mahaweli river development scheme in Sri Lanka. Using a range of different objective criteria, they optimized the operation of the system by means of SDP and subsequently appraised the derived operating strategies by simulation. In addition to the simulated objective criterion estimates, the comparisons were carried out on the bases of an array of both energy and irrigation related PIs. The set of PIs included (n.b. for each PI, separate estimates were derived for energy and irrigation):

(i) *The number of failure months* was defined as the total number of time steps with the recorded failure to meet the desired target (i.e. failure mode).

(ii) *The number of failures* indicated the number of time intervals consisting of one or more consecutive failure months.

(iii) *The annual occurrence-based reliability* depicted the fraction of years without failure months detected.

(iv) *The time based reliability* was defined as the fraction of the total time period when the system's operation was not exhibiting a failure.

(v) *The quantity based-reliability* was define as the ratio between the total system output and the total target output over the entire simulation period.

(vi) *The period of incident* depicted the mean duration of periods between two failure months.

(vii) *The reparability* described the average duration the system stayed in a failure mode.

(viii) *The mean vulnerability* was defined as the average magnitude of failure.

(ix) *The maximum vulnerability* equaled the largest magnitude of failure.

Nandalal and Bogardi (1996) used an array of quantity related PIs to evaluate the performance of a single water supply reservoir whose operating strategies were derived by optimization considering both the quantity and quality of reservoir releases. Specifically, they adopted seven PIs to investigate the impact of different salinity reduction measures of reservoir releases on the quantitative aspects of the reservoir's performance:

(i) *The quantity-based reliability* depicted the total amount of delivered water relative to the total target release.

(ii) *The time-based reliability* was defined as the probability that the reservoir would be able to meet the full demand.

(iii) *The average interarrival time* described the average duration the system was continuously failing to provide the desired service.

(iv) *The average interevent time* depicted the average duration the system was managing to maintain full supply (i.e. the average time between two failure events).

(v) *The mean monthly deficit* measured the average magnitude of failures.

(vi) *The resilience* was defined as the longest duration of consecutive failure events.

(vii) *The maximum vulnerability* measured the magnitude of the most severe failure event.

A number of PIs is selected to compare different operating strategies of the case study system in this dissertation. The defined PIs do not depict the operating details of individual reservoirs. They rather describe the performance of the entire multiple-reservoir system with respect to the quantitative fulfillment of the water demand imposed upon the system (n.b. similar approach has also been adopted in Milutin and Bogardi 1995, 1996a and 1996b). The set of PIs used in this case study includes a number of criteria defined to evaluate various facets of reliability, resilience and vulnerability of the system's operation. A detailed definition of the adopted PIs is given in section 7.

Objective criteria

This section provides the detailed description of the three objective criteria used. Each of the three objective functions (i.e. supply quantity achievement, salinity threshold non-breach and reservoir storage target achievement) is presented in its full mathematical formulation. In addition, an introduction and an argumentation about the combined use of the objective functions in different optimization steps are given here as well.

Supply quantity objective

The supply quantity objective aims at minimizing the deviation of supply from the respective demand targets. The objective function is defined as an aggregate of the squared supply deviations from the respective demand targets over all individual demands and over the entire time span of the analyses:

$$Z_1 = \sum_{t=1}^{T} \sum_{i=1}^{N} (R_{ti} - D_{ti})^2 \tag{1}$$

where:

Z_1: supply quantity objective criterion achievement

T: number of time steps in the objective criterion assessment

N: number of demands

R_{ti}:: allocation of supply to demand *i* in time step *t*

D_{ti}: demand *i* in time step *t*

To force the optimization procedure to seek the solution which is reducing the risk from extreme supply shortages, this objective is penalizing the supply deviation from its respective target as the square of the resulting deviation. If the objective function were linear, the optimization procedure would not make any distinction between, for example, a single large deficit and a number of smaller deficits amounting to the same total volume, which can clearly be deducted from an example presented in Table 1

Table1. An example of linear versus squared supply quantity objective function

Number of incidents	Individual deviations from the target (volume unit)	Aggregate linear deviation penalty (volume unit)	Aggregate squared deviation penalty [(volume unit)^2]
1	10	10	100
5	2, 2, 2, 2, 2	10	20
10	1, 1, 1, 1, 1, 1, 1, 1, 1, 1	10	10

By adopting such an objective function form, it is ensured that the optimization procedure will disregard, to the maximum extent possible, solutions which result in excessive supply shortages or surpluses. This approach therefore strives to reduce the vulnerability of the system performance.

Supply salinity objective

In essence, the initial assumptions used to define this objective function have been very similar to the ones used in the definition of the other two objectives. That is, given a certain salinity threshold beyond which the salinity of supply to a demand centre should not occur, this objective function should represent a penalty if such a case does happen. There are two principal differences between the supply salinity threshold objective and the other two objective functions:

(i) Supply salinity objective penalizes only the surplus of salt concentration beyond the specified threshold value, whereas the other two penalize the deviation from their respective target.

(ii) The units and the magnitude of surplus of salinity differ significantly from those in the other two objectives.

The first difference is no obstacle for the definition of the objective function. However, the second one does require careful consideration when defining the objective function. This is due to the fact that the intrinsic multiobjective decision making problem is to be transformed into a single (composite) objective optimization, thus requiring that different objective function components be additive (i.e. supply quantity achievement and salinity threshold non-breach objectives).

Since the objective functions should be used jointly in optimization, the second obstacle is overcome by redefining the supply salinity surplus formulation into a volumetric equivalent (volume of water) describing the relationship between the supplied volume and salinity, and the imposed supply salinity threshold. Namely, let the following be the variables and relations describing the aforementioned quantities:

(i) Salt concentration of the allocated supply to a demand centre (C_{ti}):

$$C_{ti} = \sum_{j=1}^{M} r_{tij} c_{tj} \Big/ \sum_{j=1}^{M} r_{tij} \tag{2}$$

(ii) The total amount of water allocated (R_{ti}) to meet the demanded volume D_{ti}

$$R_{ti} = \sum_{j=1}^{M} r_{tij} \tag{3}$$

where the newly introduced symbols so far are:

r_{tij}: volume released from reservoir *j* for demand *i* in time step *t*

c_{tj}: salinity of release from reservoir *j* in time step *t*

If the salinity of the supply C_{ti} is beyond the maximum threshold salinity $C_{i\max}$ for that particular demand, one can assume that the supplied volume will have to be additionally treated or partially replaced by some fresh water amount (volume A_{ti} of salinity c_{ext}) which would then reduce the salinity of the originally supplied water to the threshold level, or lower. This amount of additional fresh water can be estimated from the salt balance inequality:

$$R_{ti} \cdot C_{i\max} \geq \left(R_{ti} - A_{ti}\right) \cdot C_{ti} + A_{ti} \cdot c_{ext} \tag{4}$$

or, expressed as the equality for estimating the minimum value of the volume A_{ti}:

$$A_{ti} = \begin{cases} R_{ti} \dfrac{C_{i\max} - C_{ti}}{c_{ext} - C_{ti}} & , \quad C_{ti} > C_{i\max} \\ 0 & , \quad otherwise \end{cases} \tag{5}$$

It need not be mentioned that the assumed salinity c_{ext} of this "external" source of fresh water must be lower than the supply salinity threshold $C_{i\max}$ of the demand in question.

Given the estimates of the required external source supply A_{ti} to dilute the allocated volumes in each time step when the supply salinity threshold breach occurs, the objective function value can be estimated as:

$$Z_2 = \sum_{t=1}^{T} \sum_{i=1}^{N} A_{ti}^2 \tag{6}$$

The objective is penalizing the volumetric equivalent of the supply salinity surplus beyond its respective threshold as the square of the equivalent volume of fresh water needed to dilute the allocated salinity to the respective threshold value. Again, the choice of a squared rather than linear form of the penalty is forcing the optimization procedure to opt for more failures of lesser magnitude rather than just a few of high ones (the principle of the example presented in Table1 is illustrative for this objective function as well.)

Reservoir storage target objective

The reservoir storage target objective function is very similar in its form to the supply quantity objective described before. Namely, it penalizes the deviation of the final storage volume of a reservoir observed in optimization/simulation from the respective target storage volume. The function itself is defined as an aggregate of the squared final storage volume deviations from their respective targets over all individual reservoirs and over the entire time span of the analyses:

$$Z_3 = \sum_{t=1}^{T} \sum_{j=1}^{M} \left(SF_{tj} - ST_{tj} \right)^2 \qquad (7)$$

where the newly introduced symbols so far are:

Z_3: reservoir storage target objective criterion achievement

M: number of reservoirs

SF_{tj}: observed final storage volume of reservoir *j* in time step *t*

ST_{tj}: target final storage volume of reservoir *j* in time step *t*

Similarly to the discussion on the other two objective functions presented in the above sections, the storage target objective function is also defined as an aggregate of squared deviations to force the optimization procedure to avoid solutions with fewer high deviations as opposed to those with numerous lower deviations from the target (the example, which is not presented here, would resemble the one given in Table1).

Composite objective within resource allocation optimization

A genetic algorithm search for the best resource allocation pattern is based on the objective which minimizes the value of a so-called fitness function. In essence, a genetic algorithm fitness function is the equivalent of an objective function in an optimization procedure. The adopted fitness function is defined as an aggregate of two distinct components:

(i) Quantity related squared deviation of supply from the target demand, multiplied by the respective weight factor.

(ii) Salinity related squared penalty of a volumetric equivalent of the violation of the maximum acceptable supply salinity, multiplied by the respective weight factor.

Given the definition of the two individual objective functions Z_1 and Z_2, it is necessary to adjust their estimation for the purpose of their combined use in the aforementioned fitness evaluation. It should also be noted here that in the definition of the genetic algorithm’s fitness evaluation model the allocated consumptive release cannot exceed the respective demand. Therefore supply shortage is the only possible quantitative supply failure, and surplus can never occur.

The penalty associated with a failure of meeting the quantity and/or quality requirement is derived under the assumption that either of the two is to be compensated for from an imaginary external source with water of a constant (low and known) salt concentration. The joint penalty for utilization of such a source is proportional to the square of the amount of water withdrawn regardless of the purpose of such a withdrawal (i.e. to compensate for quantity shortage or to improve the quality of delivered water or both). The penalty is thus estimated in four steps described below.

Step 1

Based on the observed quantitative supply deficit associated with a demand during a certain time step, the imaginary external source provides full compensation for the incurred shortage. The external compensation for the supply deficit affects the salt concentration of the water delivered to the demand centre. The estimation of the resulting salinity of the assumed "full supply" is computed from the following equations:

Salinity of the original supply from the associated reservoirs:

$$C_{ti} = \sum_{j=1}^{M} r_{tij} c_{tj} \bigg/ \sum_{j=1}^{M} r_{tij} \qquad (8)$$

Total volume supplied by the associated reservoirs:

$$R_{ti} = \sum_{j=1}^{M} r_{tij} \quad (9)$$

Salinity of "full supply" (including the volume provided by the external source):

$$C'_{ti} = \frac{R_{ti} \cdot C_{ti} + (D_{ti} - R_{ti}) \cdot c_{ext}}{D_{ti}} \quad (10)$$

Salinity of "full supply" (in a slightly different form):

$$C'_{ti} = \frac{R_{ti}}{D_{ti}} \cdot C_{ti} + \left(1 - \frac{R_{ti}}{D_{ti}}\right) \cdot c_{ext} \quad (11)$$

Step 2

Having estimated the salinity of the "full supply" after the initial compensation from the external source for the quantitative shortage, it is necessary to assess whether the newly obtained supply salinity is below the supply salinity threshold associated with this demand:

The "full supply" salinity is below the threshold value,

$$C'_{ti} \leq C_{i\max} \quad (12)$$

and there is no need for additional fresh water supply, i.e. $A_{ti} = 0$.

The "full supply" salinity is still higher than the threshold value,

$$C'_{ti} > C_{i\max} \quad (13)$$

and the additional fresh water volume (A_{ti}) is estimated from the salt balance equation for this demand (it needs no mention that $C_{ext} < C_{i\max}$)

$$D_{ti} \cdot C_{i\max} = (D_{ti} - A_{ti}) \cdot C'_{ti} + A_{ti} \cdot c_{ext} \quad (14)$$

which leads to

$$A_{ti} = D_{ti} \cdot \frac{C'_{ti} - C_{i\max}}{C'_{ti} - c_{ext}} \quad (15)$$

Step 3

The total penalty f_{ti} (both quantity and salinity related) associated with the supply to this demand centre during one time step then becomes (w_q and w_s are penalty weights associated with the quantity and quality penalty components respectively):

$$f_{ti} = w_q \cdot (R_{ti} - D_{ti})^2 + w_s \cdot A_{ti}^2 \quad (16)$$

where

$$w_q \geq 0 \quad (17)$$

$$w_s \geq 0 \quad (18)$$

$$w_q + w_s = 1.0 \quad (19)$$

Step 4

Summing up these individual penalties over all demand centres and over the entire period under consideration gives the total penalty associated with the system for the chosen release distribution pattern:

$$f = w_q \sum_{t=1}^{T} \sum_{i=1}^{N} \left(R_{ti} - D_{ti} \right)^2 + w_s \sum_{t=1}^{T} \sum_{i=1}^{N} A_{ti}^2 \qquad (20)$$

The volume $(R_{ti} - D_{ti})$ in the above equation is the penalty base associated with the quantitative supply shortage whereas the amount of water A_{ti} represents the penalty base for the inadequate salinity of the delivered water.

Since genetic algorithms are essentially maximization search procedures, the presented penalty function must be transformed into an equivalent whose maximum will refer to the optimum solution of the allocation problem. In this case, the choice of transformation is rather simple. Namely, the actual fitness (objective) function f^* used is computed as the difference between the maximum possible penalty f_{max} estimated on the basis of equation (20) and the actual penalty f for a particular alternative solution [equation (20)]):

$$f^* = f_{max} - f \qquad (21)$$

where f_{max} is estimated assuming the following:

(i) Weight factors w_q and w_s are set to 1.0 and 0.0, respectively.

(ii) Demands supplied by a single reservoir only encounter 100% deficit (no supply).

(iii) Demands supplied by multiple reservoirs receive full demand supply from each of the reservoirs (maximum surplus). It should be noted here that such a case is actually not possible within the settings of the genetic algorithm model. Nevertheless, it does ensure that the maximum possible fitness be certainly beyond any penalty value that can be encountered in the search.

Composite objective within operating policy optimization

The operating policy optimization is carried out using stochastic dynamic programming (SDP). The SDP model applies reservoir system decomposition and optimizes the operating policies of individual reservoirs in an iterative fashion. Therefore, the objective function does not reflect the objective achievement of the entire system like the allocation optimization model of the previous section, but only a contribution of a single reservoir operation to the overall objective function value. The adopted objective function is the sum of two components:

(i) The annual aggregate of the squared monthly deviation of release from the respective demand, multiplied by a given weight factor.

(ii) The annual aggregate of the squared deviation of monthly final storage volume from the respective target storage volume, multiplied by a given weight factor.

Since this model applies stochastic dynamic programming, the objective function value represents the expectation of the objective achievement covering the span of one annual cycle.

Unlike the combination of supply deficit and supply salinity objectives (Section 5.4), this compound objective function does not require transformation of either of its components since both represent volumetric quantities of the same type:

$$G = w_d \cdot \sum_{t=1}^{T} \left(R_{tj} - D_{tj} \right)^2 + w_v \cdot \sum_{t=1}^{T} \left(SF_{tj} - ST_{tj} \right)^2 \qquad (22)$$

where the newly introduced symbols so far are:

w_d: weight factor for supply deviation component ($w_d \geq 0$)

w_v: weight factor for storage target deviation component ($w_v \geq 0$)

R_{tj}: total consumptive release of reservoir *j* in time step *t*

D_{tj}: total demand imposed upon reservoir *j* in time step *t*

Suffice it to say at this stage that both weight factors are predefined positive real numbers and must meet the condition:

$$w_d + w_v = 1.0 \tag{23}$$

Performance indicators

This section gives a full description of the risk and reliability indicators, hereafter referred to as performance indicators (PI), used in the present work. Performance Indicators (PIs) provide specific information about the performance of a system with regard to, for instance, the likelihood of the occurrence of insufficient supply, the probable severity of such a failure and the estimate of the likely duration of periods of full and insufficient supply, respectively. Since there are three objective criteria, the description distinguishes which indicators are appropriate for use in which of the objective cases. Furthermore, and due to the complexity of the system being analyzed, the estimation of performance indicators can be applied either to the system as a whole, to individual reservoirs or groups thereof, or to individual/groups of demand centres. The ultimate choice among the aforementioned alternatives is made during the analyses and is addressed accordingly.

Definitions

Since there are three distinct objective criteria considered it is deemed appropriate to introduce a few important terms at this stage to ensure that consistent terminology is used throughout the text:

(i) *Level of service.* The term "level of service" describes the extent to which a "service provider" (i.e. reservoir, reservoir system) fulfils its obligations towards meeting the agreed requirements of its "client(s)" (i.e. demand centres) during a single time step.

(ii) *Failure vs success.* Contrary to a "success" event, a "failure" event indicates that a "service provider" has not managed to provide the full service to meet the requirement of its "client(s)" during a certain time step (e.g. supply shortage occurred, maximum acceptable salinity of supply surpassed, storage target not achieved).

(iii) *Quantity-based performance indicators.* This set of PIs evaluate the performance of the selected system (i.e. single reservoir, system of reservoirs, single or group of demands) from the level of service point of view (i.e. supply quantity, supply salinity, storage target). Thus, the performance is assessed reflecting the magnitude of failure events and not their temporal distribution.

(iv) *Time-based performance indicators.* Contrary to quantity-based PIs, time-based indicators describe the temporal facets of failure and success event occurrence related to the level of service of the selected system (i.e. single reservoir, system of reservoirs, single or group of demands).

Quantity-based performance indicators

(i) *Quantity-based reliability* (PI_1), is a simulation-based estimate of the mean level of service delivery over the entire period under consideration:

$$PI_1 = \frac{\sum_{i=1}^{N_t} \max(0, T_i - S_i)}{\sum_{i=1}^{N_t} T_i} \quad \text{(failure: shortage)} \tag{24}$$

(ii) *Average magnitude of failure* (PI_3) is the simulation-based estimate of the mean magnitude of failure:

$$PI_3 = \frac{\sum_{i=1}^{N_t} \max(0, T_i - S_i)}{N_t} \qquad \text{(failure: shortage) (25)}$$

$$PI_3 = \frac{\sum_{i=1}^{N_t} \max(0, S_i - T_i)}{N_t} \qquad \text{(failure: surplus) (26)}$$

$$PI_3 = \frac{\sum_{i=1}^{N_t} (T_i - S_i)}{N_t} \qquad \text{(failure: desviation) (27)}$$

(iii) *(Undershooting) vulnerability* (PI_5) indicates the magnitude of the most severe failure, i.e. shortage failure type, observed over the entire simulation period:

$$PI_5 = \max_i [\max(0, T_i - S_i)] \qquad \text{(failure: shortage) (28)}$$

(iv) *(Overshooting) vulnerability* (PI_6) indicates the magnitude of the most severe failure, i.e. surplus failure type, observed over the entire simulation period:

$$PI_6 = \max_i [\max(0, S_i - T_i)] \qquad \text{(failure: surplus) (29)}$$

Time-based performance indicators

(v) *Time-based reliability* (PI_7) is the simulation-based estimate of the long-term probability that the system service will be able to meet the target (consequently, the likelihood that the system will fail to provide the targeted service is 1 - PI_7):

$$PI_7 = 1 - \frac{1}{N_t} \sum_{i=1}^{N_t} u_i \qquad (30)$$

(vi) *Average (success) recovery time* (PI_8) is defined as the average number of successive time steps the system continuously fails to meet the target, thus stating the expected time required by the system to switch to an operating mode characterized by full service delivery once it has encountered an operating service failure during one time step (this PI can thus be described as the *average duration of failure*):

$$PI_8 = \frac{\sum_{i=1}^{N_t} u_i}{\sum_{i=1}^{N_t} v_i} \qquad (31)$$

(vii) *Average (failure) recurrence time* (PI_9) is defined as the average number of successive time steps the system sustains full service delivery before switching to a failure operating mode. In other words, it gives the estimate on how long the system may be expected to provide full service once it has recovered from an operating failure (this PI can thus be described as the *average duration of success, or full service*):

$$PI_9 = \frac{N_t - \sum_{i=1}^{N_t} u_i}{\sum_{i=1}^{N_t} w_i} \qquad (32)$$

(viii) *Resilience (or failure persistence)* (PI_{10}) is the longest interval *Di* (in number of time steps) of consecutive operating failure events:

$$PI_{10} = \max_i \left(\Delta i \mid v_i = 1 \wedge w_{i+\Delta i} = 1, \Delta i \geq 0 \wedge u_j = 1 \; \forall j \in \{i+1,...,i+\Delta i - 1\} \right) \tag{33}$$

(ix) *Resistance (or success persistence)* (PI_{11}) is the longest interval *Di* (in number of time steps) of consecutive full operating service:

$$PI_{11} = \max_i \left(\Delta i \mid w_i = 1 \wedge v_{i+\Delta i} = 1, \Delta i \geq 0 \wedge u_j = 0 \; \forall j \in \{i+1,...,i+\Delta i - 1\} \right) \tag{34}$$

The notation used in equations above is described in the following:

I: the index depicting a time step (i.e. month);

N_t: the length, in time steps (i.e. months), of the simulation time period;

N_y: the length, in years, of the simulation time period;

T_i: the target that the system service is expected to reach in time step *i*;

S_i: the service that the system is expected to provide in time step *i*;

$\sum_{i=1}^{12} T_{ij}$: the annual target that the system service is expected to reach in year *j*;

$\sum_{i=1}^{12} S_{ij}$: the annual service that the system is expected to provide in year *j*;

u_i: the *success/failure* (*u_i=0/u_i=1*) descriptor which indicates whether the system has managed to provide the expected service during time step *i*:

$$u_i = \begin{cases} 1, & T_i > S_i \\ 0, & T_i \leq S_i \end{cases}, \quad \forall i \qquad \text{(failure: shortage) (35)}$$

$$u_i = \begin{cases} 0, & T_i \geq S_i \\ 1, & T_i < S_i \end{cases}, \quad \forall i \qquad \text{(failure: surplus) (36)}$$

$$u_i = \begin{cases} 0, & T_i = S_i \\ 1, & T_i \neq S_i \end{cases}, \quad \forall i \qquad \text{(failure: desviation) (37)}$$

v_i: the descriptor indicating a *success-to-failure* operating transition:

$$v_i = \begin{cases} 1, & u_{i-1} = 0 \wedge u_i = 1 \\ 0, & otherwise \end{cases}, \quad \forall i > 1, \quad v_1 = u_1 \tag{38}$$

w_i: the descriptor indicating a *failure-to-success* operating transition:

$$w_i = \begin{cases} 1, & u_{i-1} = 1 \wedge u_i = 0 \\ 0, & otherwise \end{cases}, \quad \forall i > 1, \quad w_1 = 1 - u_1 \tag{39}$$

It should be noted here that the definitions and functional relationships of all the PIs have been presented assuming that the system's operation is characterized by both success and failure events thus excluding a possibility of a division by zero in the estimation of any of the PIs. Similarly, it is assumed that the target service imposed upon the system over the whole simulation span, as well as the length of the simulation period, are not zero.

To conclude, Table 2 summarizes the applicability of individual PIs to the assessment of system performance with regard to each of the three objective criteria.

Table 2. Summary on performance indicator applicability

Performance indicator	Objective: Supply quantity	Supply quality	Storage target
Quantity-based			
1. Reliability	✓		
2. Shortage index	✓		
3. Average magnitude of failure	✓	✓	✓
4. Average absolute magnitude of failure			✓
5. (Undershooting) vulnerability	✓		✓
6. (Overshooting) vulnerability		✓	✓
Time-based			
7. Reliability	✓	✓	✓
8. Average (failure) recurrence time	✓	✓	✓
9. Average (success) recovery time	✓	✓	✓
10. Resilience (or failure persistence)	✓	✓	✓
11. Resistance (or success persistence)	✓	✓	✓

Methods and Models

The adopted operations research methodology for the analysis of a multiple-reservoir system operation is based on the operating problem decomposition. In other words, a complex optimization problem is split into a series of simpler problems, which are subsequently solved individually with due consideration of extraneous variables created by problem decomposition. The adopted approach combines the decomposition of the original problem into two components, i.e. derivation of reservoir-demand allocation patterns and optimization of individual reservoir operating policies, with a physical decomposition of the system into individual reservoir subsystems (N.B. the approach flowchart is given in Fig. 1). The solution to the first sub-problem is obtained by a genetic algorithm (GA) search whereas the second sub-problem is solved by a stochastic dynamic programming (SDP) optimization. Both approaches, however, make use of system decomposition into single reservoir subsystems, simulation and hierarchical release allocation among each reservoir's water users.

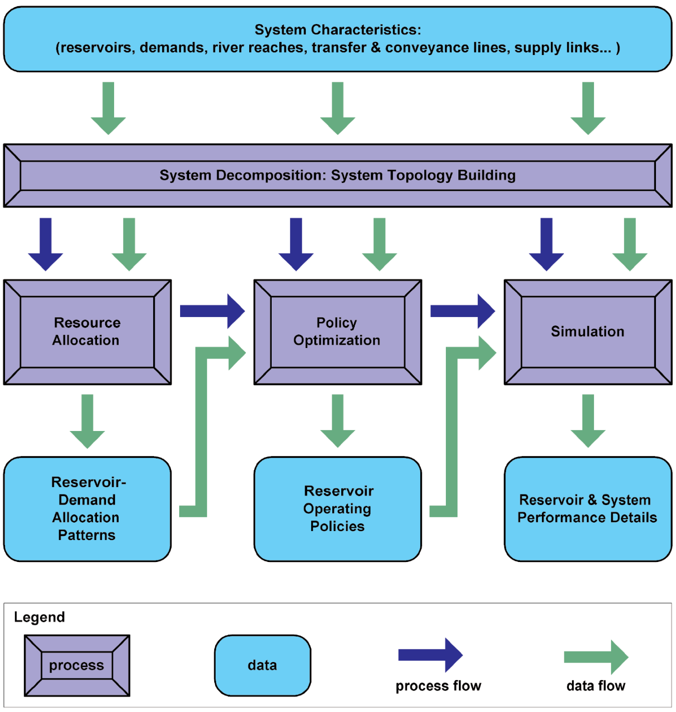

Fig.1. The adopted approach for system operation optimization.