Towards a framework for the economic assessment of drought risk. An ecosystems approach

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Towards a framework for the economic assessment of drought risk. An ecosystems approach

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Abstract. Drought risk is a combination of the probability of extended dry periods and the consequences for people, communities and their environment. The management of drought risk seeks to reduce the impacts of droughts, either by reducing their probability of occurrence (mitigation) or their consequences (adaptation). The paper shows how an ecosystems framework can be used to assess the diverse effects of droughts. This recognises the relationships between stocks of natural capital, such as land and water, and the services that they provide to support human endeavour, prosperity and wellbeing. Droughts disrupt these relationships, reducing the flow of services to society. Droughts have negative effects on a range of ecosystems services, namely: "provisioning" services (such as food production and water supply), "regulating" services (such as local climate and hydrological processes), "cultural" services (such as heritage, landscapes, and amenity) and "supporting" services (such as natural habitats and soil formation). Indeed, droughts also degrade the stock of natural resources such that their capacity to generate future flows of benefits is damaged. The paper shows how an ecosystems framework can help to classify the type and magnitude of impacts attributable to droughts, provide a basis for economic valuation, assess the social, geographical and temporal distribution of impacts, and identify major sources of uncertainty and vulnerability. The framework can also be used to inform cost-effective policies on drought management, recognising that a precautionary approach is required where data and methods are not able to provide robust economic assessments.

Keywords. Drought – Risk – Economics – Ecosystems.

Vers un cadre pour l'évaluation économique du risque de sécheresse. Une approche écosystémique

Résumé. *Le risque de sécheresse est la combinaison de la probabilité de périodes sèches prolongées et des conséquences sur les individus, les communautés et leur environnement. La gestion des risques de sécheresse vise à réduire leurs effets, soit en réduisant leur probabilité d'occurrence (mitigation) ou bien leurs conséquences (adaptation). Ce travail montre comment un cadre écosystémique peut être utilisé pour évaluer les effets divers des sécheresses. Ceci en tenant compte des relations entre le niveau de ressources en capital naturel comme le sol et l'eau, et les services qu'ils fournissent pour soutenir l'activité humaine, la prospérité et le bien-être. Les sécheresses perturbent ces relations. Les sécheresses ont des effets négatifs sur de nombreux services des écosystèmes, particulièrement sur les approvisionnements essentiels (tels que la production alimentaire et l'approvisionnement en eau), des services de "régulation" (tels que le climat local et les phénomènes hydrologiques), des services "culturels" (comme le patrimoine, les paysages, et les loisirs) et les services de "soutien à la vie" (tels que les habitats naturels et la formation des sols). En effet, les sécheresses contribuent à la dégradation des ressources naturelles détruisant ainsi leurs capacités de produire de futurs bénéfices. Cette publication montre comment une approche écosystémique peut aider à classifier les impacts attribuables à la sécheresse selon leurs types et leurs amplitudes, fournir une base pour une évaluation économique, sociale, géographique et temporelle, et même identifier les principales sources d'incertitude et de vulnérabilité. Cette approche peut également servir à mettre en place des politiques économiquement efficaces pour la gestion des sécheresses, tout en reconnaissant que l'approche de précaution est nécessaire là où les données et les méthodes ne sont pas capables de fournir des évaluations économiques rigoureuses.*

Mots-clés. *Sécheresse – Risque – Économie – Écosystèmes.*

I – Context

There is growing concern about the ability meet the future needs and expectations of a growing world population within the limits of available natural resources and without causing irreversible environmental damage. This prospect is made more challenging due human-induced climate change (IPCC, 2007; World Bank, 2009).

If left to continue unabated, climate change will impose major constraints on human prosperity and well-being. The Stern Review (Stern, 2007) explored the social and economic consequences of rising global and regional temperatures and changes in patterns of rainfall and evapotranspiration. It showed how climate change is likely to affect the relationship between people and the environment, with potential consequences for food production, water availability and ecosystems (Fig. 1). In Europe, climate change is likely to result in wetter and warmer winters, hotter and drier summers and greater frequency of extreme weather events associated with floods, droughts and heat waves (Alcamo *et al.*, 2007). Current best predictions suggest that, unless further mitigation measures are taken, a 2 degree Celsius increase in mean temperatures is likely over the next 50 years (IPCC, 2007). Although available evidence does not detect clear trends in droughts in the 20th century nor attribute any changes in droughts to climate change, modelled projections of climate change in dry and mid latitudes (including the Mediterranean) predict an increase in the future frequency and severity of droughts (see review by van Lanen *et al.*, 2007).

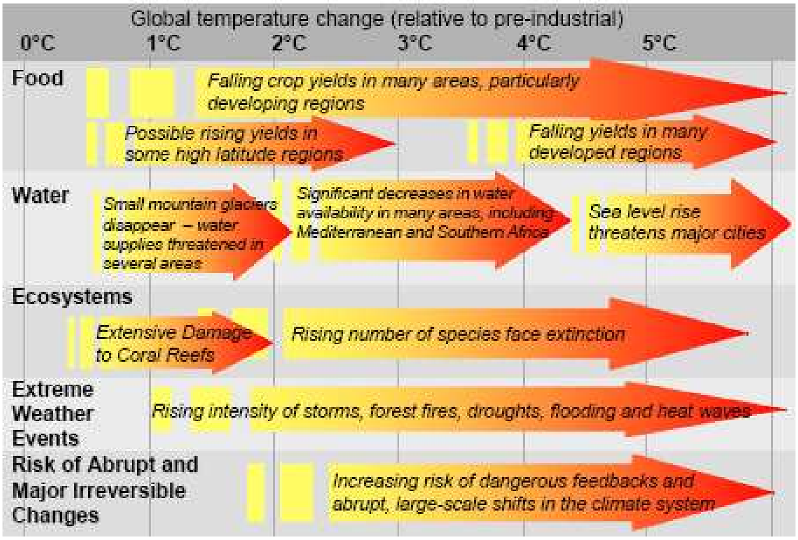


Fig. 1. Project impacts of climate change (*source: Stern, 2007*).

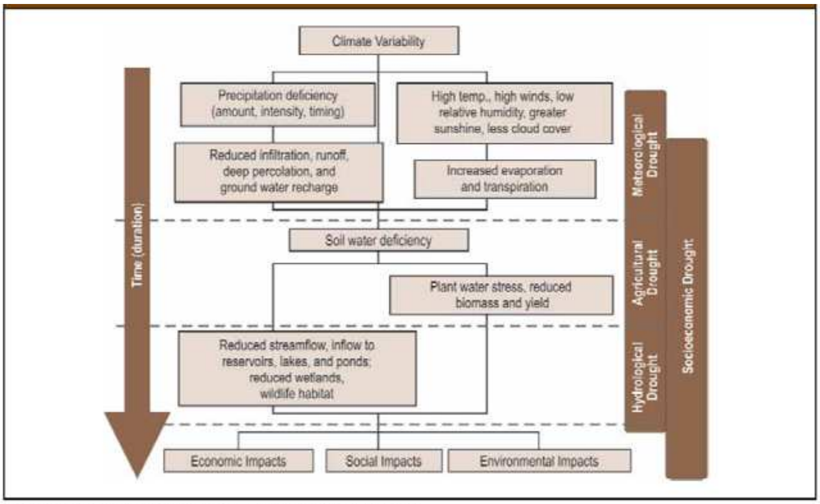
In this context, water scarcity and droughts have emerged as major environmental challenges. (UN/ISDR, 2007). In Europe, the area and number of people affected by droughts doubled in the 30 year period to 2006 (EC, 2007a). The total cost of droughts in Europe during this period is estimated at over Euro 100 billion (see below). The 2003 event alone affected over 100 million people, at a cost of about Euro 9 billion. In the period 2000 to 2006, 15% of the total area of the European Union and 17% of its total population were affected by droughts, mainly in the region (EC, 2007b) and this exposure to water stress is growing. The average annual cost associated with droughts is reported to have quadrupled over the last 30 years.

Droughts are an extreme form of water scarcity; the social, economic and environmental consequences of which depend on the intensity of the drought and vulnerability of the population and geographical areas affected (UN/ISDR, 2007). Droughts affect the use of land and water resources in economic sectors such as agriculture, forestry, industry, transport, energy, tourism and the resultant prosperity and well being of people and communities in urban and rural areas. Furthermore, droughts can affect the many non-market benefits provided by natural resources and ecological processes such as clean water, landscapes and wildlife with potentially major consequences for human welfare, now and into the future (EC, 2007a,b). They are particularly problematic in areas that under normal circumstances experience water scarcity and stress and where demand for water exceeds sustainable supply (NDMC, 2010). Given the prospect of increased incidence of droughts, drought risk management strategies have become a priority in many areas (UN/ISDR, 2007).

This paper explores the nature of drought risks and argues for a broad-based ecosystems approach to estimate the full economic costs of droughts and appraise options for managing drought risks.

II – Defining droughts

It is common to distinguish three, interrelated types of drought (UN/ISDR, 2007; NDMC, 2010) (Fig. 2). Meteorological droughts are associated with climatic variability, especially lower than normal rainfall in a given period, often associated with higher temperatures and evapotranspiration. This can result in persistent soil water deficiency with consequences for agriculture and terrestrial ecosystems, often referred to as agricultural deoughts, hydrological droughts involve reductions in the quantity and quality of surface and groundwater waters affecting the availability of water resources for a wide range of uses, including agriculture, domestic and industrial, power generation, navigation and aquatic ecosystems.



Source: National Drought Mitigation Center, University of Nebraska-Lincoln, USA

Fig. 2. Climate variability, soil water deficit and reduced surface waters are the main criteria for drought classification (from UN/ISDR, 2007).

Our focus here is with hydrological droughts that are characterised by long periods of abnormally low rainfall or stream flow that tend to occur most frequently in areas with relatively low water availability and reliability. Hydrological droughts affect the natural and man-made hydrological system as a whole, and impose the greatest impacts on human and ecological welfare. This hydrological perspective is therefore an appropriate focus for drought risk assessment.

III – Drought risk management

Drought risk is the combination of the probability of occurrence and the consequences for people, communities and their environment (UN/ISDR, 2007; UN Water 2007; WWF, 2006). Probabilities here relate to events of a given magnitude defined in terms of temporal and spatial extent and measured using a range of relevant indicators (Steinmann *et al.*, 2005). Consequences relate to the costs of damage and disruption imposed by droughts on the assets, livelihoods and welfare of people affected. Thus, damage depends on the magnitude of the event, the type and value of assets and livelihoods involved, and the extent to which they are vulnerable to drought (Wilhite *et al.*, 2005). Assets, as discussed below, include not only man-made assets but also those associated with natural and ecological resources. In this context, the management of drought risk seeks to reduce the impacts of droughts, either by reducing their probability of occurrence (mitigation, for example through regulation of the hydrological system) or their consequences (adaptation), or both.

From the economist's perspective, the management of drought risk concerns the valuation of expected damage costs. A large part of the cost of a drought comprise the loss of value derived from water in its various uses as a result of extended curtailment of water supply, both in terms of quantity and quality. The greater is the economic value of water at the margin of use, the greater is the likely cost of a drought. Thus economic costs tend to be greatest when high value uses of water, such as public water supply, industrial uses and horticultural production, are compromised by prolonged water shortage.

Again from an economist's perspective, drought risk management involves the appraisal of the relative costs and benefits of different approaches to drought mitigation and adaptation. Thus, the costs of these interventions are compared with the benefits of avoiding the costs of droughts. The purpose is to identify the most economically efficient actions that produce the greatest net welfare gain. This usually means giving priority to protecting essential and high value water uses. However, water use and values has been a relatively under-researched topic, although the introduction of the EU Water Framework Directive has gone some way to filling information gaps (Morris, 2007).

Assessment is also complicated by the spatial and temporal aspects of drought risk management. The causes of droughts and hence their frequency are associated with climatic processes, exacerbated by human induced climate change (IPCC, 2001; EU, 2007a,b; UN Water, 2007). These tend to operate at the global and macro scale, such as those associated with carbon emissions from fossil fuels or large scale changes in "soilscapes". The consequences of droughts, however, tend to operate more at the regional and micro scale, and are exacerbated by human activities that are particularly drought prone, such as arable farming. Thus those whose actions may contribute to droughts may not be the same as those that bear the costs, in time or space.

Furthermore, the causes and consequences of droughts are diverse, complex and interrelated such that mitigation and adaptation measures are often interdependent. Measures such as impoundment of water and irrigation to help cope with droughts in one place can exacerbate hydrological droughts elsewhere. Furthermore, overemphasis on adaptation rather than mitigation can create a dependency on increasingly costly and unsustainable measures. These can ultimately increase vulnerability, such as increased abstraction for irrigated farming to mitigate agricultural droughts resulting in hydrological droughts with consequences for other water users. Additionally, whereas "risk" management implies a degree of certainty based on prior experience, the reality of drought science is one of uncertainty. Here probabilities and consequences are not fully known such that precaution and "safe minimum standards" to guard against potential severe drought impacts are likely to be guiding principles.

IV – An ecosystems framework

The diverse effects of droughts on the prosperity and well being of people can be explored using an ecosystems framework of the kind developed in the recent Millennium Ecosystem Assessment (MA, 2005; UK-UNEP, 2009). This recognises the relationships between "stocks" of natural capital, such as land and water, and the "flows" of services that they provide to support human endeavour, prosperity and wellbeing.

As illustrated in Fig. 3, droughts can negatively affect the range of land and water based ecosystems services, namely: "provisioning" services (such as food production and water supply), "regulating" services (such as local climate and hydrological processes), "cultural" services (such as heritage, landscapes, and amenity) and "supporting" services (such as natural habitats and soil formation). Indeed, droughts not only disrupt these service flows but can also degrade the stock of natural resources such that their capacity to generate future flows of benefits is damaged. Figure 3 applies the ME framework to show the wide ranging potential impacts of droughts on ecosystem services and hence on human welfare and ecological health.

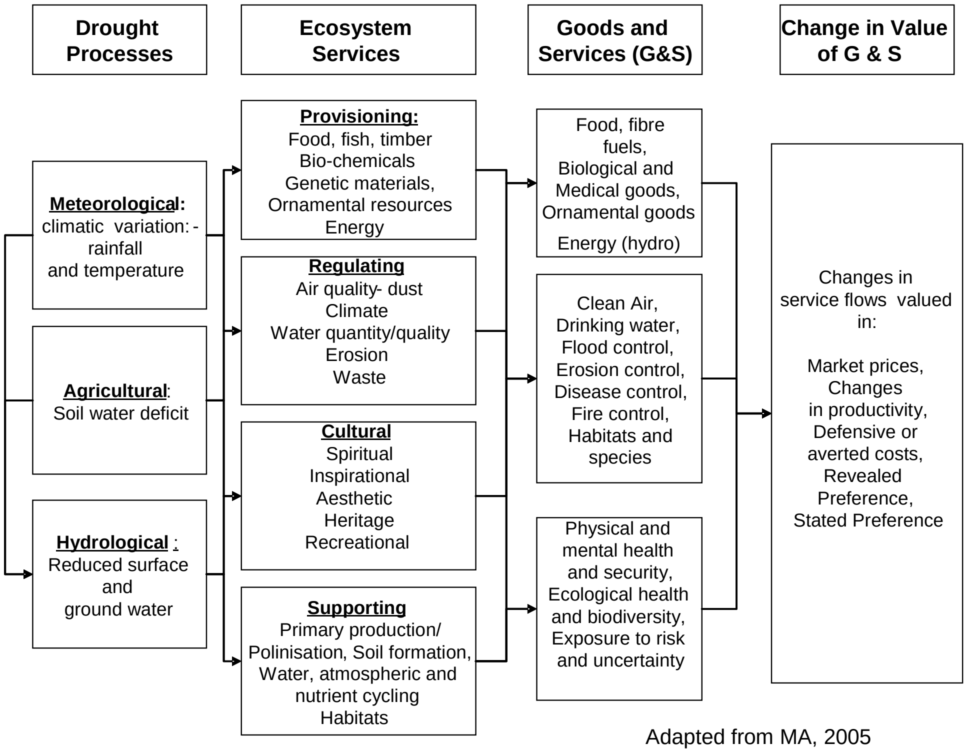


Fig. 3. The relationship between drought processes, and the type and value of ecosystem services (adapted from MA, 2005).

From an economic perspective, the ecosystems framework can help to systematically assess, for a drought prone area, the likely impact of droughts on the stocks of natural capital and the flows of services that are of value to people. More specifically, it can help to determine the type, magnitude and potential severity of changes in ecosystems services attributable to droughts. It can also provide a basis for valuation of these changes. This can involve the application of a range of methods to derive monetary estimates of drought damage costs based on evidence of actual damage costs (such as loss of crop yields at market prices) or alternatively derived from observed or implicit prices based on revealed or expressed preferences, such as willingness to pay to avoid disruption to water supplies.

Ultimately, the impacts of droughts are felt by people as individuals or members of households, organisations or communities. The framework can help to determine the distribution of impacts amongst different social groups and over different geographical areas and time periods. By way of example, Table 1 identifies the range of stakeholders affected by drought induced changes in ecosystem services. Some stakeholders have particular interest in and influence over particular ecosystems services and drought impacts, such as food and farmers, and habitats and conservationists. With respect to managing drought risks, some stakeholders are able to influence drought mitigation (such as environmental regulators) while others are mainly concerned with adaptation (such as farmers).

Table 1 also provides examples of ways to estimate the economic impacts of droughts using a variety of methods. Drought impact costs are probably best measured using estimates of damage to property, income lost and increased expenditure using adjusted or surrogate market prices. It is clear from Table 1 that droughts impact on a wide range of non-market public goods for which valuation is challenging. Monetary measurement of many non-provisioning ecosystem services, especially those associated with cultural and supporting services, remains problematic, both in terms of defining relevant "units of service" and "unit prices".

Economic assessment tends to focus on changes "at the margin" of the kind used in cost benefit analysis rather than on the major catastrophic changes that could arise from long duration droughts. Fundamental supporting services, such as providing soils and habitats, are particularly vulnerable to non-marginal, threshold changes that can result in systematic and permanent failure. For this reason, there is need to define safe minimum standards and precautionary regulatory measures to avoid permanent loss of ecosystem functions due to droughts. Where economists are unsure about the data and methods needed to derive reliable estimates of potentially significant drought risks, it is probably better to regulate for drought protection standards. Here, economics, rather than defining the standard of drought risk management, is used to determine the most cost effective way of achieving these predefined standards. Doing so, however, implicitly attributes a value to drought risk avoidance.

V – Case examples

The ecosystem framework can help to assess the impacts of historical, ongoing or potential droughts, combining it with checklists and inventories of drought impacts (Steinmann *et al.*, 2005).

The 1988 droughts in the United States and Canada illustrate the diversity of impacts and the potential relevance of an ecosystems approach (Changnon and Easterling, 1989; Riebsame *et al.*, 1991). The event was characterised by severe hydrological droughts that reduced river and groundwater levels, contaminated water due to continued industrial and agricultural discharges, imposing constraints on other water users, including public and industrial supply. Proposals to recharge rivers and aquifers were rendered infeasible because of general shortages and possible environmental impacts in source areas. Hydropower production was reduced, with losses estimated well in excess of US$ 30 billion. Navigation was disrupted on major rivers and saltwater intrusion contaminated soil water in coastal areas. In addition to the major impacts on agricultural production and incomes due complete crop loss or reduced yields over large areas. 5.1 million ha of federal forest was burned, involving fire fighting costs of U$ 300 million, and a loss of 40% of adjacent plantings. Drought related pest attack destroyed large quantities of timber. The total cost to US forests was US$ 5 billion. Large but unmeasured losses of fish, wildfowl and wildlife occurred, and commercial fisheries were affected by high water temperatures and pollution. Several thousand human deaths were attributed to high temperatures, and local governments provided respite cooling centres.

Table 1. Ecosystem services potentially affected by droughts and example of interested stakeholders and changes in values

Services and goods	Example stakeholders	Examples of estimation of changes in stakeholder values
Provisioning Food, Fibre Fuels, Biological and Medical goods, Ornamental Goods Energy (hydro)	Farmers, Fishermen, Foresters, Households, Industry and Trade, Power and Water companies Other impacted service providers	Changes in market prices due to drought, adjusted for tax and subsidies. Changes in productivity (changes in outputs and inputs) measured in adjusted market prices. Loss of income and earnings. Cost of replacement, substitute goods e.g. food, timber, animal feeds, or alternative supplies e.g. power and water.
Regulating Clean Air, Drinking water, Flood control, Salinity control,Erosion control, Disease control, Fire control, Waste treatment, Habitats and species	Communities, Local Government, National Government, International Agencies, Environment Protection Agencies, Water companies, Navigation operators, Conservation organisations	"Dose response" – cost of air quality loss and health impacts, salinity and yield loss. Cost of damage associated with loss of service or replacement cost, fire damage/prevention, soil loss/conservation, salt water intrusion/groundwater recharge. Willingness to pay (WTP) to avoid, or Willingness to accept (WTA) compensation for, service disruption or loss, e.g. water and power supplies. Mitigation expenditure or averted costs – e.g. wetland habitat protection. Replacement cost e.g. alternative transport. Loss of habitats and species valued at willingness to pay. Increased post-drought flood damage risks.
Cultural Recreation, Physical and mental health and security, Ecological health and biodiversity	National and Local Government, Communities, NGOs, Heritage Agencies, Tourism and recreational service providers	Loss of cultural assets and services valued at willingness to pay (WTP). Loss of tourism and recreation based on WTP and travel cost. Public health measured at cost of illness or WTP to avoid exposure to risk.
Supporting Primary production/ Pollination, Soil formation, Water, atmospheric and nutrient cycling, Geological and ground conditions (subsidence, movement), Habitats	Indirectly all of the above, and agencies with particular responsibility for natural resource and environmental protection acting in the public interest	Estimates based on units of service delivery to provisioning, regulating and cultural services, e.g. the pollination services of insects, costs of subsidence damage to buildings, the substitute value of nutrient cycling that reduces pollution risk and eutrophication impacts in rivers and lakes with consequences for other services.

A recent assessment of the impact of drought in the EU (EC, 2007b) put the cost of drought in the Member States over the last 30 years (1976-06) at about €100 billion and concluded that the annual cost of drought doubled in the period 1976-90 and 1991-06, reaching a total of approximately 6.2 €/a in the years up to 2006 (See Table in Appendix 1). On the whole, these data include costs in sectors which are more easily measured. The major impacts have been in agriculture (e.g. Spain: €2500 million in 2005), although other sectors, for example, public water supply, industry and energy sectors have also incurred significant drought related costs.

Environmental costs of European droughts have been significant, but generally under reported because of the limits of available data. By way of example, the drought in Spain in 2005 reduced hydroelectricity capacity by 36% which was then supplied by fossil fuels at a cost of €114 million. This led an additional emission of 5.7 million tons of CO_2 into the atmosphere. In Portugal in 2004-2006 two major reservoirs were totally depleted whilst in France in 2005, 400 km of permanent rivers dried up. Remaining water bodies suffered from eutrophication, leading to reductions in biodiversity. Forest fires cost Portugal €8.8 million in 2004-06, and Spain €36 million in 1994-95. Social costs have included restricting use of water for millions of inhabitants in Europe, and loss of employment. For example, in the Jucar basin in Spain, drought reduced the income of the population by about €70 million between 1992 and 1996. In severe drought years, the European Commission (2007b) has estimated that the area affected by drought has been up to 37% of the EU territory and 20% of its inhabitants.

Thus, although these European estimates indicate significant economic costs, they do not include losses in the broad range of ecosystem services alluded to earlier. The assessment concluded that "attention will have to be paid in a near future to the enhancement of data collection at EU and national levels, in order to improve the economic, social and environmental impact assessment" (EC, 2007a).

The types of impacts identified for the USA and European events could be more systematically and comprehensively accommodated in an ecosystems framework. Furthermore, this approach would draw attention to the interrelations between diverse ecosystem services as they are affected by both by drought impacts and response measures. Additionally, the method can explicitly link impacts to particular stakeholders and help to determine relevant data and methods for estimating costs.

VI – Conclusions

From an economist's perspective, drought risks combine the probability and consequences of drought events, and drought risk management involves the cost-benefit appraisal of options to mitigate and adapt to droughts. The ecosystems framework can provide a systematic and potentially comprehensive framework for drought risk assessment. It can help to identify the range and value of flows of services that are lost or disrupted by droughts, and the way that these impacts are distributed amongst different stakeholders.

The ecosystems approach to drought risk management draws attention to the importance of knowing how individuals, organisations and society use and derive value from water. Some of these values lend themselves to monetary valuation and some of them do not. While encouraging a value based approach, the ecosystems approach also forces recognition of safe minimum standards and critical thresholds in drought risk management, as these concern the vulnerability of humans or other living species. For these reasons, criteria other than economic efficiency should also be used, although economics can inform the most cost effective ways of achieving intended outcomes and tolerable levels of drought risk.

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Appendix 1. Costs of drought impacts in the European Union, 1975-2006 (source: EC, 2007a)

Example of costs incurred by Member States due to past droughts (million €)

Period	Member state	Economic impacts					Social impacts	Environmental impacts	Others	Overal impacts
		Public water supply	Industry	Energy	Agriculture	Navigation				
1975-1976	Portugal			147	53					
1976	Belgium[†]		350	5	21					
1961-1990	Hungary	50	300	200	4000	50	0.04	7	310	
1981-1983	Portugal	14		238	62				1	
1989-2002	France				1540			145/year	330/year	
1990-1995	Spain	22		210	1800				1541	
1992-1993	Portugal			426	241				12	
1995	UK[††]	352	265	24	324	141	0.5			
2002-2003	Finland	10	1	50	17	0.1	25	2.5	13	
2003	Belgium[†]		1		1	0.05				
2003	France			300	590					
2003	Germany				1000					
2004-2005	Portugal	9	32	261	519			9	14+23[†††]	
2005	France			270	250					
2005	Spain			713	2500			114		
2006	Netherlands			10	600	72				
2006	Lithuania				201					

[†]These figures are the results of simulations. For 1976, damages have been estimated taking into account actual water uses (2002).
[††]Costs are related to the 1995 hot dry summer and drought together. The impact of the 1995 drought itself was around € 140 million.
[†††]During the 2004-2006 drought, Portugal had to spend 23 million € in urban water supply. In 66 municipalities (100,500 inhabitants), urban water supply was supplemented by 22,850 water tank operations.