

DIAGNOSING CAUSES OF WATER SCARCITY IN COMPLEX WATER RESOURCES SYSTEMS AND IDENTIFYING RISK MANAGEMENT ACTIONS

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ABSTRACT

Diagnosing the causes of water scarcity in complex water resources systems is a precondition to adopt effective drought risk management actions. From the water management perspective, water scarcity is an unacceptable risk of facing water shortages to serve water demands in the near future. Water scarcity may be temporary and related to drought conditions or other accidental situation, or may be permanent and due to deeper causes such as excessive demand growth, lack of infrastructure for water storage or transport or constraints in water management (water rights, floods). One of the objectives of river basin planning is effective management of the risk of water scarcity. Planning and management decisions depend on the reliability and vulnerability of water resources systems to confront water scarcity. Lack of reliability can be easily identified with water resources system models, but diagnosing its causes in a given system is a more complex task. In this paper we present four indices which have been developed to evaluate water scarcity: the Water scarcity index, the Demand reliability index, the Sustainability index, and the Management potential index. We propose a methodology for interpretation of index values that can lead to conclusions about the reliability and vulnerability of systems to water scarcity, as well as to diagnose their possible causes and to propose solutions. In cases where several systems are analysed, indices are also useful to make a comparative study between them and to prioritise actions. The described methodology was applied to the Ebro river basin, identifying existing or expected problems and possible solutions. System diagnostics, based exclusively on the analysis of index values, were compared with the known reality as perceived by system managers, validating the conclusions in all cases.

1 INTRODUCTION

One of the main objectives of water resources planning is proactive drought risk management, which may be developed along two non-excluding courses of action. On the one hand, measures to avoid drought-induced water scarcity should be identified, prioritised and implemented. Timely availability of these means (supply enhancement and water conservation measures) increases the reliability of water resources systems to droughts and avoids demand deficits. On the other hand, mitigation actions should be planned to be taken while the drought is developing. Mitigation actions may reduce the

system's vulnerability to droughts by reducing the magnitude of damages through management strategies (distribution of available water among users, emergency supply works, etc.) and administrative measures (limitation of water consumption, water markets, emergency relief funds, etc.).

Several indices are found in the literature related to droughts and water scarcity. Most of them have been developed for drought identification purposes, focused on meteorological drought as the triggering phenomenon. The main objectives of these indices are to establish the onset of drought and to evaluate its severity in terms of intensity, duration, and spatial extent (Guttman 1998, McKee et al. 1993, Quiring and Papakryiakou 2003). But prolonged absence of precipitation and soil moisture deficits does not necessarily mean scarcity in a water resources system, because water can also be supplied from natural or artificial reservoirs where it has been conveniently stored: snowpack, aquifers, and regulation dams can sustain water demands during periods of meteorological drought. Other indices, such as the Reclamation Drought Index and the Surface Water Supply Index (Shafer and Dezman 1982, Garen 1993) combine climate and water supply factors, including snowpack and reservoir levels, but they are focused on water availability and do not account for water demands.

Since water scarcity is related to a shortage of water to satisfy demands, drought indices found in the literature are not fully representative of water scarcity situations. The shortage results from an imbalance between water supply and demand, which is usually originated by a meteorological phenomenon, but it is conditioned by other time-varying factors, such as demand development, supply infrastructure, and management strategies (Wilchfort and Lund 1997). Scarcity indices (Ohlsson 2000) and shortage indices (Hsu 1995), that account for infrastructure, demands, and operating rules, have been proposed. These indices are relevant for decision makers to predict problems, but they are limited in scope and do not provide enough information to diagnose the causes of water scarcity or to identify possible solutions.

This paper reports the results of a research project undertaken to improve the effectiveness of water resources systems analysis as a tool for drought contingency planning. The paper provides three main contributions. First, it presents a framework for theoretical analysis. The framework comprises a set of four indices that must be used in conjunction to quantify the severity of potential water scarcity problems in a system, to diagnose its causes, and to anticipate possible solutions. Second, empirical results are reported for a detailed case study: the Ebro river basin (85,000 km²) in northeast Spain. Third, the conclusions drawn from the case study are summarised to illustrate the improvement that can be achieved in drought planning efforts.

2 PROPOSED INDICES FOR WATER SCARCITY MANAGEMENT

Water scarcity is analysed by identifying demands which are not fully satisfied by the available water resources. The distribution of resources among multiple demands is a challenging task requiring careful planning. In a large system, mathematical simulation and optimisation models are used to obtain quantitative results accounting for all system complexities in an uncertain context. These models provide guidance for identifying unsatisfied demands, evaluating the effect of capacity building or water conservation measures, and scheduling available actions (Cai et al. 2002). All models provide a measure of demand reliability, quantified as the probability that a given

demand may suffer water shortages during the planning horizon. This (or an equivalent) reliability index is normally used for decision making, identifying the demands that do not comply with a pre-specified minimum standard.

Water resources system models provide additional information which usually does not reach decision makers because of its highly complex and technical nature. The system modeller could easily determine if the lack of reliability in any given demand should be corrected with new water supply sources, infrastructure for water regulation or transport, or demand management, but conveying this information to decision makers is usually a daunting task (Grigg 1996). As new hydraulic works become increasingly controversial due to rising marginal costs and reinforced environmental awareness, this analysis task becomes more important, and it is helpful to develop scarcity indices to summarize and transfer the results to the decision maker. Indices will also allow for comparisons of different systems and, therefore, are useful tools to objectively classify systems and establish priorities.

From the above decision oriented approach, three conditions need to be met by water scarcity indices: to convey relevant information for the planning process about scarcity causes and solutions, to be easily formulated and intuitively understood, and to have numerical form to allow for comparisons. The four indices proposed in next section meet these requirements.

2.1 The demand-reliability curve

In this work, reliability is understood as the probability that the system will be able to adequately supply the demand, expressed as a percentage. Demand units can be grouped in several categories or classes, according to the nature of water use and their relevance for basin policy. Categories could be, for instance, in-stream environmental use, urban water supply, irrigation, hydropower, industry, recreation, etc. For each category, k , an acceptable reliability level, r_k , is fixed, depending on the nature of the demand and the requirements of water usage. For instance, in the irrigation class the acceptable reliability threshold could be set to 85%, while in the urban supply class it could be set to 100%.

Model results in each demand category are analyzed through the Demand-Reliability (DR) curve, which is shown in Figure 1. The DR curve represents the cumulative value of demands which are supplied with a given reliability or more, so that the curve is always decreasing. From this curve, the following representative values are extracted:

- Demand, D^k : average water demand in class k , in Mm^3/yr .
- Supply, S^k : average amount of water supplied to demands in class k , regardless of reliability, in Mm^3/yr .
- Acceptable supply, $S_{r_k}^k$: average amount of water supplied to demands in class k with reliability greater than the acceptable value, in Mm^3/yr .
- Unacceptable supply, $U_{r_k}^k$: average amount of water supplied to demands in class k with reliability smaller than the acceptable value, in Mm^3/yr .

Management actions should, in part, be oriented to improve reliability and reduce $U_{r_k}^k$. A target for reliability improvement, Δr_k , is defined in every class, as the reliability increment that could be achieved through management actions. According to this definition, the following magnitudes could also be identified in the DR curve:

- Target supply, $S_{r_k - \Delta r_k}^k$: average amount of water supplied to demands in class k that are close to acceptable reliability, in Mm^3/yr .
- Improved supply, $\delta S_{r_k}^k = S_{r_k - \Delta r_k}^k - S_{r_k}^k$: average amount of water supplied to demands in class k that could satisfy the reliability requirements through management actions, in Mm^3/yr .

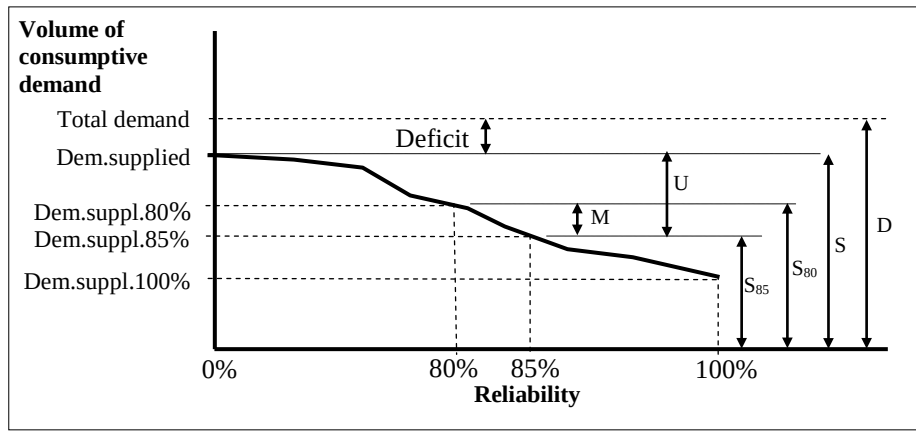


Figure 1. Distribution of consumptive demands according to their reliability

2.2 Water scarcity index: I_S

This index evaluates the system's capacity to supply its demands. For each class, k , the index is computed as the ratio between water supplied and water demanded:

$$I_S^k = \frac{S^k}{D^k} \quad (1)$$

The scarcity index for the system is computed as the weighted mean of the indices of each class. Two weights are used in the computation: the relative weight and the relevance weight. The relative weight, α_k , is computed as the fraction of the class demand in all system demands:

$$\alpha_k = \frac{D^k}{\sum_{i=1}^K D^i} = \frac{D^k}{D_T} \quad (2)$$

where K is the number of classes in the system and D_T is the total demand in the system, in Mm^3/yr .

The relevance weight, β_k , is assigned subjectively, depending on the objectives of basin policy. Demand classes which are considered more important in basin management should have the higher β_k values. Relevance weights should be assigned with the constraint that the sum of the products of relative and relevance weights for all classes in the system should be one:

$$\sum_{i=1}^{i=K} \alpha_i \beta_i = 1 \quad (3)$$

The value of the water scarcity index for the entire system is computed as a weighted average of class values:

$$I_S = \sum_{i=1}^{i=K} \alpha_i \beta_i I_S^i \quad (4)$$

If all relevance weights are equal to 1, the expression to compute I_S reduces to:

$$I_S = \sum_{i=1}^{i=K} \frac{D^i}{D_T} \frac{S^i}{D^i} = \frac{\sum_{i=1}^{i=K} S^i}{D_T} = \frac{S_T}{D_T} \quad (5)$$

where S_T is the average water supplied to demands in the system, in Mm^3/yr .

2.3 Demand reliability index: I_R

This index quantifies the reliability of the system to satisfy demands. It is computed as the ratio between demand supplied with acceptable reliability and total demand:

$$I_R^k = \frac{S_{r_k}^k}{D^k} \quad (6)$$

The index value for the system is computed as:

$$I_R = \sum_{i=1}^{i=K} \alpha_i \beta_i I_R^i \quad (7)$$

For systems where all relevance weights are equal, the demand reliability index results:

$$I_R = \frac{\sum_{i=1}^{i=K} S_{r_i}^i}{D_T} \quad (8)$$

2.4 Sustainability index: I_U

This index evaluates the natural resources available for development in the system. It can only be computed for the entire system, as the ratio between water not allocated to demands and natural yield:

$$I_U = \frac{Y - \sum_{i=1}^{i=K} S^i}{Y} = 1 - \frac{S_T}{Y} \quad (9)$$

where Y is average yield of water resources in the system under natural conditions, in Mm^3/yr .

2.5 Management potential index: I_M

This index quantifies the proportion of the demand with unacceptable reliability that is close to the acceptable level. For each class, the index is computed as a ratio. The numerator is the quantity $\delta S_{r_k}^k$ (see Figure 1), which is the difference between demand

supplied close to the acceptable reliability level (for instance 80%) and demand supplied with acceptable reliability level (for instance 85%). The denominator is the quantity $U_{r_k}^k$, which is the demand supplied with unacceptable reliability level (for instance, lower than 85%):

$$I_M^k = \frac{\delta S_{r_k}^k}{U_{r_k}^k} = \frac{S_{r_k - \Delta r_k}^k - S_{r_k}^k}{S^k - S_{r_k}^k} \quad (10)$$

The threshold for acceptable or unacceptable values should be adapted for each particular case under study, as it was previously suggested for the demand reliability index I_R .

The index value for the system is computed as:

$$I_M = \sum_{i=1}^{i=K} \alpha_i \beta_i I_M^i \quad (11)$$

3 QUALITATIVE ANALYSIS OF INDEX VALUES

The indices defined above are numerical values that can be used for the objective diagnosis of management problems in water resources systems. In order to simplify the decision-making process, numerical index values are classified in qualitative categories in the domain (favourable, neutral, unfavourable). In this section, criteria proposed for this classification are presented.

3.1 Water scarcity index: I_S

Numerical values of the water scarcity index are equal to or lower than 1. If the value of this index is high, the system has little deficit, because it is able to supply most part of the demand that is being requested from it. Systems with high I_S indices are less vulnerable to droughts than systems with low indices, because vulnerability is related to the magnitude of damages which are produced due to unsatisfied demand. When the index value is low, the system is only able to supply a small part of the demand that is being requested from it, which means that the system is vulnerable to scarcity. The reasons for this water scarcity (demand excess, lack of regulation works, inadequate management, conflict with non-consumptive demands, etc.) can be analysed with the help of the remaining indices. The results of sensitivity analyses performed suggest, as a general rule, that values of the water scarcity index, I_S , below 0.7 should be qualified as unfavourable, while they should not be qualified as favourable until they are over 0.85.

3.2 Demand reliability index: I_R

A high value of this index means great probability that the demands be satisfied any given year. These are reliable or robust systems, which can supply their demands even during drought years. A low value of this index means that the system is not reliable to satisfy its demands and is prone to water scarcity, even in droughts of moderate intensity. For the demand reliability index, I_R , values below 0.6 should be qualified as unfavourable, while they should not be qualified as favourable until they are over 0.75. However, other subjective values could be defined for a well-known system based on the analyst's experience, or could be supplied externally by the decision-maker. Finally,

it can be easily verified that values of this index are always lower than those of the water scarcity index, I_S .

3.3 Sustainability index: I_U

Values of this index could in theory be lower than 0, due to irrigation returns and water recycling, although this situation is extremely unlikely. Low values of this index mean high usage of natural resources. These systems may be prone to water scarcity because of demand excess. High values of this index mean little resource usage, which usually corresponds to systems with little economic development (low population density, irrigation, and industry). These systems have proportionately greater water surplus, which will be available for additional uses in the same or in neighbouring basins. Water scarcity in these systems can usually be overcome with regulation works.

Qualitative values of the sustainability index I_U can be classified as high (favourable) or low (unfavourable). The threshold value between high and low values is basin-specific, and should be lower for small systems and for systems with irregular streamflow regime. As a guideline for practical use, this threshold value should not be greater than 0.5 (for the Spanish basins described in the case study, with sizes below 10,000 km², threshold values between 0.75 and 0.6 were used, depending on streamflow irregularity).

3.4 Management potential index: I_M

Values of this index is irrelevant for systems with high values of the demand reliability index I_R . For the rest of the cases, a high value of the index means that a great proportion of the demand, which does not have acceptable reliability, is close to being adequately satisfied. Water scarcity in these systems can be overcome with additional infrastructure, usually of local scope. On the contrary, low values of this index suggest that the demand with unacceptable reliability is far from being satisfied. These systems require actions of greater importance to cope with water scarcity.

Qualitative values of the management potential index, I_M , may be classified as high (favourable) or low (unfavourable). The threshold value between high and low should be defined in every case, taking lower values for systems with less demand. It can be suggested, based on the sensitivity analyses performed, that values above 0.1 should be considered high.

3.5 Objective classification

In addition to the subjective limits to classify index values, which are specific for the Spanish case study, a simple procedure is proposed to compare several systems in a large basin to identify the more problematic cases and to establish action priorities. The procedure consists of defining for every index three intervals of values: low, average and high, which can be qualified as favourable, neutral or unfavourable, depending on the index interpretation. Systems in the basin are assigned relative weights γ_s . Weights can be proportional to natural yield, basin area, system demand, or any other objective quantity that characterises the system's size.

The average interval is defined by specifying its central value, I , and its width, Δ_I . The central value is the index value corresponding to a system which is an aggregate of all the systems being analysed:

$$\bar{I} = \sum_{j=1}^{j=S} \gamma_j I^j \quad (12)$$

where S is the number of systems considered in the analysis. The width of the average interval is proportional to the weighted standard deviation of the index values of the systems with respect to the central value.

$$\Delta_I = \sqrt{\frac{\sum_{j=1}^{j=S} (\gamma_j I^j - \bar{I})^2}{S-1}} \quad (13)$$

According to the procedure presented above, the following intervals for index values are defined: unfavourable $[0, I - \Delta_I/2]$, neutral: $[I - \Delta_I/2, I + \Delta_I/2]$, favourable: $(I + \Delta_I/2, 1]$.

4 SCARCITY ANALYSIS IN WATER RESOURCES SYSTEMS BASED ON THE INDICES

The criteria given in this section are summarised in Table 1. The aim of this table is to establish a general methodology for the use of these indices to study the effects of droughts in water resources systems. The table presents a general characterisation of water resources systems depending on the indices' qualitative values, which includes the assessment of the intensity of potential water scarcity, a diagnosis of the problems, and a proposal for their solution. Necessarily, problems and solutions have been greatly simplified. In general, systems with an unfavourable water scarcity index I_S require actions to increase the available resources, either from its own basin or from external basins, or to reduce demands. Systems with an unfavourable demand reliability index I_R require generally structural actions to consolidate water supply to demands, such as local regulation or transportation works, or non-structural actions to mitigate drought impacts. When these problems coincide with low values of the sustainability index I_U , actions should focus on the demand side, trying to improve water conservation by reducing losses, increasing water efficiency, encouraging water recycling, and making different demands compatible. Finally, the management potential index I_M may give an idea of the size of the actions to be carried out, which should be greater for low values of this index. As a complement to Table 1, Figure 2 shows the intensity of water scarcity problems in water resources systems depending on the combination of the indices I_S and I_R .

5 CASE STUDY

To validate practical usefulness, the above methodology was applied to a real case study: the Ebro river basin. This basin was selected because of the availability of the basic data required for the study.

5.1 The Ebro river basin

The Ebro basin, located on the northeast of the Iberian peninsula, is the largest basin in Spain, with an area of 85,000 km² and a mean annual yield of 18,200 Mm³/yr. It currently supplies water to 2,700,000 people, around 800,000 ha of irrigated land, and industrial demands totalling over 400 Mm³/yr. There are more than 300 hydropower plants. A further 2 nuclear and 5 conventional power plants use Ebro water for

refrigeration. These demands are expected to increase in the future (irrigated area will reach 1,300,000 ha in 20 year's time).

Table 1. Systems characterisation as a function of index values.

			$I_S \hat{u}$		$I_S =$		$I_S \downarrow$	
			Problem	Solution	Problem	Solution	Problem	Solution
$I_R \hat{u}$	$I_U +$				1	B1	1	B2 – C1
	$I_U -$				1	A – B1	1 – 3	A – B2 – C2
$I_R =$	$I_U +$	$I_M +$	2	D	1 – 2	B1	1 – 2	B2 – C1
		$I_M -$	2	D	1 – 2	B2	1 – 2	B3 – C1
	$I_U -$	$I_M +$	2	A – D	1 – 2	A – B1	1 – 2 – 3	A – B2 – C2
		$I_M -$	2	A – D	1 – 2	A – B2	1 – 2 – 3	A – B3 – C2
$I_R \downarrow$	$I_U +$	$I_M +$	2	B1 – D	1 – 2	B2 – C1	1 – 2	B3 – C1
		$I_M -$	2	B1 – D	1 – 2	B3 – C1	1 – 2	B3 – C1
	$I_U -$	$I_M +$	2 – 3	A – B1 – D	1 – 2 – 3	A – B2 – C2	1 – 2 – 3	A – B3 – C2
		$I_M -$	2 – 3	A – B1 – D	1 – 2 – 3	A – B3 – C2	1 – 2 – 3	A – B3 – C2

Index values: $\hat{u}$ favourable = neutral $\downarrow$ unfavourable + high - low

Problem:

1. Vulnerable: water scarcity may produce important damages
2. Unreliable: low intensity droughts may lead to water scarcity
3. Excess of demand with respect to natural resources

Solution

A. Demand management

B. Regulation works: 1 local within-year, 2 global within-year, 3 global over-year

C. Water transfers: 1 internal, 2 external or complement. resources (groundwater, desalination, etc.)

D. Non structural actions to mitigate impacts

Problem intensity

None	Medium	Serious	Very serious
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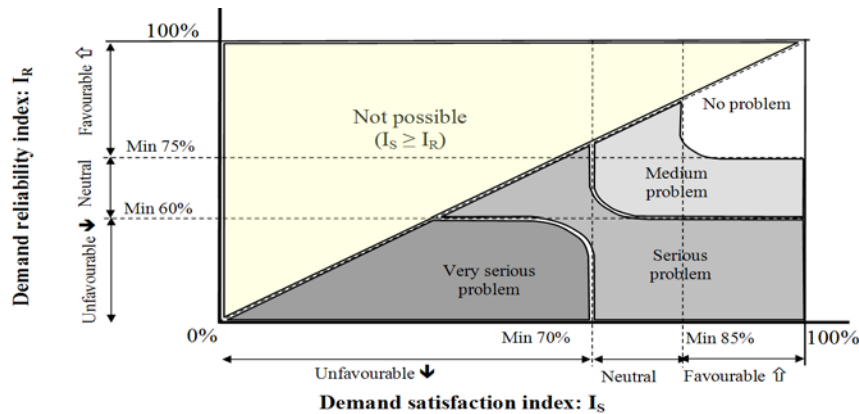


Figure 2. Intensity of water scarcity problems according to index values

Management of water resources for the entire Ebro basin has been analysed with the help of 28 simulation models. These models are operational tools that were created to evaluate current and future scenarios in the basin, and were used for the Ebro River Basin Water Plan (C.H.E. 1997). Once the models were calibrated for the current scenario, two future scenarios were analysed: one corresponding to mid range (10 years)

and other corresponding to long range (20 years). Every model simulates an independent system, generally corresponding to a single tributary to the Ebro river. However, 5 models are composed of several systems that are connected by existing or planned infrastructures or where management is conducted globally.

Time series of natural flows used in the models correspond to a historic period of 46 years, and were computed with a rainfall-runoff model using a homogeneous procedure for all systems. Although longer time series of natural flows were available for certain systems, it was decided to use the same historic period for the sake of uniformity to allow for result comparisons. Current and planned infrastructures (reservoirs, channels, hydropower plants, etc.) and current and forecasted demands (urban supply, irrigation, industrial, etc.) were considered. Non consumptive demands like environmental flows, hydropower, fish farms, power plant refrigeration, recreational, etc., were also included in the models, because they are a restriction to system operation, although they were not included in the index computations.

5.2 Index computations

The Ebro basin has many water resources systems, and some of them are interconnected. Index computations were limited to those systems whose behaviour is independent from the rest; that is, that their demands are supplied mainly with their own resources and their infrastructures are used only by demands within the system. Then, indices were not computed for systems that receive or supply water to other systems, as is the case in systems interconnected with water transfer channels. Very large systems were also disregarded, since average values could obscure relevant local features, and only systems with less than 10,000 km² were analysed (to compute index values for larger systems, those should be subdivided). Of the 28 systems in the Ebro river basin, 17 systems satisfy the previous requirements and were selected for index computations.

Indices for these systems were computed using the equations provided above. Required data were obtained from the results of the corresponding simulation models. Demands in each class of every system were grouped according to their reliability to obtain for each system a graph similar to that of Figure 1. Index values are obtained corresponding to the current situation, as well as for the mid term and long term future scenarios.

5.3 Diagnostic of Ebro water resources systems

The analysis of water scarcity begins with the definition of intervals for the qualitative classification of the water scarcity index I_S and the demand reliability index I_R . Values provided by the basin authority (Confederación Hidrográfica del Ebro) were used for this task: since the dominant component of demand in the systems is irrigation, values of $I_S > 0.9$ and $I_R > 0.8$ were considered favourable, while values of $I_S < 0.75$ and $I_R < 0.6$ were considered unfavourable. In addition to these limit values, a comparative analysis among all systems was performed by considering a fictitious system comprising the aggregation of all systems. The central value or the neutral interval is the index of this fictitious system, and the width of the neutral interval is the weighted standard deviation of system's indices with respect to the central value. The weights used were the average natural yield of every system. With the central value and the width, extreme values for the neutral interval can be computed, and favourable and unfavourable limits for the indices can be defined. Results are shown in Table 2.

Table 2. Intervals of index values

Criterion	I _S (%)			I _R (%)			I _U (%)		I _M (%)	
	fav.	neutral	unfav.	fav.	neutral	unfav.	high	low	high	low
CHE	100 - 90	90 - 75	75 - 0	100 - 80	80 - 60	60 - 0				
Comparative	100 - 89	89 - 77	77 - 0	100 - 57	57 - 21	21 - 0	≥40	<40	≥5	<5
Final	100 - 90	90 - 77	77 - 0	100 - 80	80 - 60	60 - 0				

Once the limit values had been defined, the indices of every system were classified in qualitative categories. Problems were diagnosed for every system and solutions were identified by applying the general criteria presented in Table 1.

This analysis, focused on decision support, is necessarily a simplification of reality. Data for index computations were taken from simulation model results. In the case study, results presented in Table 3 were validated through interviews with basin authority managers, in particular those responsible for water resources planning. In general, a good agreement was obtained with the conclusions of the technical studies carried out for the Ebro River Basin Water Plan. In fact, the lines of action contemplated in the Plan practically coincide with the guidelines provided here. This agreement validates the proposed methodology and proves the usefulness of the indices presented here as aggregate descriptors of the situation of a water resources system, encouraging its application to other basins.

Table 3. System diagnostics

System	Current scenario		Mid term scenario		Long term scenario	
	Problem	Solution	Problem	Solution	Problem	Solution
1 Nela						
2 Jerea						
3 Omecillo	2	D	2	D		
4 Ega	1 - 2	B3 - C1				
5 Rudrón						
6 Oca						
7 Oroncillo	1	B1	1	B1	1	B1
8 Tirón	2	D				
9 Najerilla						
10 Iregua	2 - 3	A - B1 - D				
11 Leza	1 - 2	B3 - C1	1 - 2	B3 - C1		
12 Cidacos	1 - 2	B3 - C1				
13 Arba	1 - 2	B3 - C1	1 - 2	B3 - C1		
14 Alhama	1 - 2 - 3	A - B3 - C2	1 - 2 - 3	A - B3 - C2	1 - 2	A - B1
15 Queiles	1 - 2 - 3	A - B3 - C2	1 - 2 - 3	A - B3 - C2	1 - 2 - 3	A - B3 - C2
16 Huecha	1 - 2 - 3	A - B3 - C2	1 - 2 - 3	A - B3 - C2	1 - 2 - 3	A - B3 - C2
17 Jalón	2 - 3	A - B1 - D				
<u>Problem</u> 1. Vulnerable: water scarcity may produce important damages. 2. Unreliable: low intensity droughts may lead to water scarcity. 3. Excess of demand with respect to natural resources <u>Solution</u> A. Demand management B. Regulation works: 1 local within-year, 2 global within-year, 3 global over-year C. Water transfers: 1 internal, 2 external or complement. resources (groundwater, desalination, etc.) D. Non structural actions to mitigate impacts <u>Problem intensity</u>						
	None	Medium	Serious	Very serious		

6 CONCLUSIONS

Four indices were presented to be used in conjunction, in order to characterise the behaviour of water resources systems with respect to water scarcity. In systems affected by water scarcity problems, the indices can also propose guidelines for solutions. The indices were conceived as an assistance tool to decision making in water resources planning. Indices are computed using simple mathematical relations, so that their meaning is intuitive for their target users. Required data for index computations can be easily obtained from the results of water resources simulation models. Therefore, indices can also be used to summarise and transfer the results obtained from the models.

Criteria were given to interpret index values, emphasising system analysis in order to establish lines of action in a context of proactive drought management. The analysis and interpretation of index values can lead to conclusions about the reliability and vulnerability of systems to water scarcity, as well as help diagnose their possible causes and to propose solutions. In cases where several systems are analysed, indices are also useful to make a comparative study between systems and to prioritise actions.

The described methodology was applied to the Ebro river basin, computing index values for 17 water resources systems and identifying existing or expected problems and possible solutions in each one. System diagnostics, based exclusively on the analysis of index values, were compared with the known reality as perceived by system managers, validating the conclusions in all cases.

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