Can information from centralized databases be used to characterize water stressed regions ?

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1. INTRODUCTION

Problem statement

Water stress is frequently encountered in many varieties, relating to surface water or groundwater, to quantity or quality. As a result, projects have been carried out to mitigate water stress problems in many regions across the world. The degree of success of these projects in providing sustainable solutions to the water stress is probably as diverse as the projects themselves. To maximize the success and minimize the risks of failure in present and future projects, the reuse of valuable experiences from past projects would be desirable. Moreover, transfer of knowledge on the management of water stress problems is an essential step in the identification of effective mitigation strategies to combat water stress in unmonitored regions (Franks *et al.*, 2005). When a monitored and an unmonitored region encounter similar kinds of water stress, for example due to comparable geographic and socio-economic conditions, a successful mitigation option applied in the monitored region may also be effective in the unmonitored region. The major question is now: how to optimize this transfer and reuse of knowledge?

Indicator approach

Knowledge transfer is favored if a generic approach is adopted and used by all the organizations involved. Characterization of water stress using common indicators generates common understanding, and conversely, a comparison of areas is almost impossible when different methods are used. In other words, any water stress ‘case’ (a water stress problem related to a specific area) is ideally characterized by a format that is uniform on the one hand, but on the other hand enables the policy maker to choose the optimal mitigation option. An indicator approach is likely suitable for this. Indicators capture the essentials of any given situation, if they are conceptually well chosen. They are widely used in practice to report, summarize, simplify and/or clarify the state of water resources and water management measures (e.g. in UN WWAP, European Environmental Agency). However, most of these indicators show aggregated figures at country-level, while most decisions on water management are made on decentralized levels. Additionally, country level figures are often yearly figures, whereas water stress is in many regions a seasonal phenomenon, for example summer droughts or flash floods. Finally, aggregated figures can hardly be coupled to the appropriate information about the underlying processes, which are highly variable on the regional or even local scale. This information is needed to pinpoint water stress problems and identify suitable mitigation options.

In conclusion, a need exists to bring together indicator information that obeys the following conditions: (1) it is available at the scale where water management decisions are taken, (2) it captures all the essential characteristics of the water situation, including implemented mitigation options, and (3) it originates from as many different regions and countries as possible. Currently, a lot of such information is dispersed over different organizations, working in many disciplines (social sciences, hydrology, economics, etc.).

Objective

A logical first step towards knowledge transfer would be to assess the usefulness of information that is stored in on-line, centralized and well accessible databases, because these databases generally contain many types of relatively detailed information for large areas. Hence, the objective of this study is to assess the feasibility of the use of centralized, widely accessible indicator data to characterize water stressed regions. The study was carried out in the framework of the EU-funded Aquastress project (www.aquastress.net). The focus in this paper is on indicators for anthropogenic conditions; application of the approach to indicators for natural conditions will be addressed briefly, but discussed more in detail in a separate paper.

2. CONCEPTS

Condition 1 : Appropriate information scale

A water stress ‘case’ is thought of as a water stress problem related to a specific area. The *drainage sub-basin* was selected as the spatial scale to represent such a 'case', or representative elementary volume (REV). This choice is motivated in the first place by the fact that in the implementation of the EU Water Framework Directive, that explicitly asks for river basin management planning, drainage sub-basins are used as spatial entities. A comparison at this level is considered most valuable, because drainage sub-basins generally boast a unique combination of climate, hydrogeology, water economics, land use, etc. Their water resources are assessed, developed and managed in a near independent manner from the rest of the basin. Nevertheless, some spatial variability within the subbasin may remain important. The sub-basin delineation according to Vogt et al. (2003) was used as REV. All data used were converted into the ETRS89 Lambert Azimuthal Equal Area Coordinate Reference System (ETRS-LAEA CRS) and linked to the basin database (CCM database, Vogt et al., 2003).

Condition 2: Representative characterization of the water stress situation

Water stress is essentially about an unbalance between water resources and water demands. Hence, these two factors need to be representatively covered in any characterization of water stress. Mitigation options make up a third important factor to be covered. Therefore, the ideal set of indicators consists of three subsets: (1) a subset describing the natural conditions related to water resources, (2) a subset describing anthropogenic conditions related to water stress, and (3) a subset describing which mitigation options were implemented, and to what degree they were successful in relieving water stress.

The *natural conditions* refer to conditions that would exist if there were no human-caused changes in the water system. This topic will be addressed in a separate paper.

The *anthropogenic conditions* relating to water stress and its causes may be environmental, social, economic, etc., and thus very diverse. To fully represent this aspect of water stress, the information needs to be carefully structured. For this purpose, the concept of the Integrated Sectoral Water Stress Index (ISWSI) was utilized (Sullivan et al., 2006). One of its key components is a matrix of indicators, showing the level of water stress across the anthropogenic sectors, and the components of stress associated with each sector. The major anthropogenic sectors to be considered within water management decisions are: the domestic sector, agriculture, industry, and tourism. In addition, the environment is included, to ensure that attention is paid to enabling ecological integrity. The challenge is to define a set of indicators that is capable of capturing the essence of water stress in many different regions. This requires a trade-off between case-specific and generic indicators, and ideally a combination of them. A set of conceptually valid, generic or 'core' indicators was developed by Manez et al. (2008), and this set was used as a starting point in this study. The resulting indicator matrix is summarized in Table 1. The indicator values need to be normalized to values between zero and one, in order to compare the scores of the sectors and / or components with respect to water stress. This normalization can be done by scaling the indicator value for the case under consideration to the lowest and highest values found in the database. For example, if the value for the case is exactly the average of the minimum and maximum values, then the resulting score would be 50% ({max – case-value}/ {max – min}). However, this approach would generate too positive normalized scores if *all* cases in the database score unfavorably. Therefore the normalization was also based on general standards and values, whenever possible. Examples of 'general standards and values' include legally enforced water quality standards, or a general notion that no more than a given percentage of households should suffer from water supply interruptions.

Table 1: Generic core indicator set for anthropogenic water stress (Manez et al., 2008)

	DOMESTIC	AGRICULTURE	INDUSTRY	TOURISM	ENVIRONMENT
Quantity Issues	Drinking water use	Irrigation dependability	Water use intensity	Water use intensity	Deviance from natural flow
Quality Issues	Quality standards	Salinity	Water treatment	Quality standards	Waste water polluted load
Institutional and adaptive capacity	Water regulation	Water saving technologies	Recycling	Water saving technologies	Protected areas
Infrastructure	Supply interruptions	Supply dependability	Supply interruptions	Water treatment	River fragmentation
Social and economic equity	Economy of water suppliers	Farm size dispersion	Labour-related water intensity	Labour-related water intensity	Nature protection
WEIGHTING indicator	% water use of total revenue per m3 of water used	% water use of total revenue per m3 of water used	% water use of total revenue per m3 of water used	% water use of total revenue per m3 of water used	ecological water requirement as % of total

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The normalization procedure also comprises an inversion of indicator values which are negatively related to water stress (the lower the value the higher the stress). By definition, a high indicator value must stand for a high level of stress.

After normalization, a weighting procedure must be carried out to account for situations where, e.g., a sector scores unfavorably with respect to the water stress indicators, but otherwise needs only little water to generate economic revenues. For this purpose, weighting indicators are added to the matrix, and they are also shown in Table 1.

The matrix can be evaluated in two ways. In the first place, the overall level of water stress can be calculated by summing, and then weighting, the normalized indicator scores in the matrix. This can be mathematically written as (Sullivan et al., 2006):

$$\mathrm{ISWSI} = \frac{w_d I_d + w_a I_a + w_i I_i + w_t I_t + w_e I_e}{w_d + w_a + w_i + w_t + w_e}$$

where I_k is the sum of the indicator scores for all the components within sector k, i.e. domestic (d), agriculture (a), industry (i) tourism services (t) and the environment (e). w_k represents the weight assigned to sector k, according to the weighting indicator. A high ISWSI indicates a high level of water stress. Secondly, the contributions of the sectors or components of stress to the problem can be graphically represented. As shown later in this paper, this provides the characterization of water stress necessary to identify mitigation options.

Mitigation options information is subdivided into (1) information about which options were implemented, and (2) how successful they were in providing relief to water stress.

The first information type can be little more than an alphanumerical variable, describing one or more implemented mitigation options. For the evaluation of mitigation options, ISWSI is preferably calculated for the situations before and after implementation.

Condition 3 : Availability for many regions

An important feature of indicator data on anthropogenic conditions is that they are mostly available at the scale of administrative units, corresponding to the Nomenclature of Territorial Units for Statistics (*http://ec.europa.eu/comm/EUROSTAT/ramon/nuts*). The NUTS-classification is valid for EU-countries and comprises three levels, going down to the most detailed NUTS3-level of provinces or districts. In many countries this level is coarser than the drainage sub-basin scale, as illustrated in Figure 1. This discrepancy can be overcome by GIS-elaborations, but inevitably some degree of fake precision is introduced here.

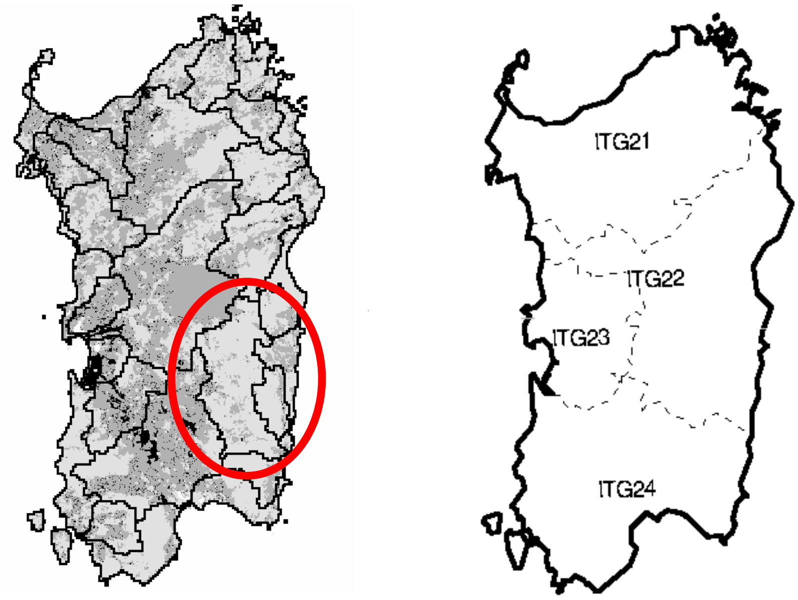

Figure 1. Drainage sub-basins (Vogt et al., 2003) versus administrative units on NUTS-3 level (EUROSTAT-NUTS, not dated): example of Sardinia (Italy). The circle indicates the Flumendosa catchment.

Because the indicator method is intended for applications to large regions, its feasibility depends on the easy accessibility of information. Therefore, our investigations focused on data that are on-line available. There are many digital, international databases and references to them on the internet, but most of them contain country-wise statistics only. This is generally too crude for our purposes, and therefore these databases were not utilized.

3. RESULTS

Anthropogenic conditions

Keeping in mind the concepts outlined earlier, our goal was to retrieve indicator data for the ISWSI-matrix, with the core indicator set shown in Table 1 as a starting point. Our initial data queries were into the EUROSTAT-database (De Michelis & Chantraine, 2003; ec.europa.eu/eurostat), because it contains pan-European data. Despite the fact that EUROSTAT offers a wealth of environmental information, sometimes on levels as detailed as NUTS3 for the whole of Europe, none of the IWSWI-matrix fields could be filled. The logical alternative was to rely more on databases centralized on national levels. These databases are mainly available with the national statistical offices, but useful information can also be found in on-line reports of national organizations covering specific domains, e.g., ministries. The switch of focus from pan-European to national databases invoked the need to choose between countries, because our resources were too limited to address all countries within Europe. For this purpose Italy was selected, in the first place because the Italian on-line information infrastructure is well organized. Secondly, one of the test sites within AquaStress, the Flumendosa sub-basin on the island of Sardinia, is located in Italy (Figure 1). Therefore, the presentation of the results will focus on this 'case'.

As outlined earlier, the spatial scale of the administrative information is generally NUTS-2 or NUTS-3 level. For the area considered, this corresponds to the region of Sardegna and the province of Cagliari, respectively. Relevant information at these levels could be found for 13 out of 25 core indicator fields mentioned in Table 1 (excluding the weighting indicators). Four additional, alternative indicators could be defined on the basis of the data retrieved. 11 indicators were derived at NUTS-2 scale, 4 indicators at NUTS-3 scale, and they were mainly retrieved from the databases of the Italian National Statistical Office (ISTAT). The two remaining indicators are 'number of dams per unit length of water course' and 'frequency of occurrence of Q90 low flows'. They were derived on a sub-basin scale, using information from the LIMNO-database website (www.ise.cnr.it/limno/; Tartari et al., 2002), and from runoff calculations with the global WATERGAP model (Döll et al., 2003).

Table 2 shows the results. Additional information for some of the remaining eight empty matrix fields can probably be derived from underlying, centralized information . An example is the indicator 'farm size dispersion'. This indicator is a measure of the accessibility to irrigation facilities of farms of varying sizes. The databases contain regional totals of irrigated areas, and the number of farms with and without irrigation, while the establishment of this indicator requires more detailed information about the variability within these populations. However, the available data are aggregated from nationwide agricultural census figures which will probably enable the establishment of the indicator.

Some of the alternative indicators are rather indirect, for example the percentage companies with ISO 14001. The reasoning behind it is that environmental awareness is positively correlated to awareness of water as a valuable resource. Some indicators may fit into more than one matrix fields. For example, domestic supply interruptions may be a consequence of an excess amount of water assigned to other sectors, and therefore may indicate inequity, but they may also indicate infrastructure management deficiencies.

Table 2: Case-specific indicator set for anthropogenic water stress. Case Sardegna / Cagliari, Italy. Based on generic set by Manez et al. (2008), see Table 1. Alternative indicators are marked with *.

	DOMESTIC	AGRICULTURE	INDUSTRY	TOURISM	ENVIRONMENT
Quantity Issues	Per capita consumption (l/d)	Ratio of irrigated to total agricultural area	Alternative sources of salt / brackish water as % of total water volume abstracted*	Percent change in population in tourist peak season (August)	Frequency of occurrence of Q90 low flows
Quality Issues	No. of reported incidents of diarrhoea per 1000 inhabitants*	---	---	---	1. Percentage Waste Water treated 2. Fertilizer distributed per unit area
Institutional and adaptive capacity	Per capita investment in water treatment (EUR)	Percentage of irrigated area equipped with micro/drip-irrigation	Percentage companies with ISO-14001*	---	Percentage protected area
Infrastructure	Losses in Infrastructure	Ratio of irrigated to potentially irrigated area*	---	Percentage overnight stays in accomodations with 4 or 5 stars (sauna, swimming pool, jacuzzi, solarium more likely)*	Number of dams per unit length of water course
Social and economic equity	Percentage families reporting irregularities in water supply	---	---	---	Percentage of humid areas (Ramsar) under high anthropogenic stress*
WEIGHTING indicator	---	---	---	---	---

As for the normalization procedure outlined earlier, a selection of areas with comparable climatic conditions is preferred; a comparison of Cagliari to a North-Italian, alpine province that may experience different water problems, e.g., flooding instead of drought, may not be desirable. Indicator information on natural conditions can be used to delineate the reference areas for normalization. However, at the time of writing, both databases for natural and anthropogenic indicator information were in the course of being coupled. For this reason, a provisional approach was chosen by selecting only the region of South Italy for the normalization.

Subsequently, the normalized indicator scores are averaged to a sectoral score, and these scores must be weighted. However, as can be seen in Table 2, no suitable information could be found for the weighting indicator. The on-line information revealed registered volumes of abstracted, distributed and invoiced *drinking* water only. As will be shown later, agriculture often uses *rough* water that is directly derived from reservoirs or other sources. This implies that the application of the drinking water data would cause the indicator approach to generate erroneous results .

Mitigation options

Despite the vast amount of past and current projects to mitigate water stress, information on mitigation options and their degree of success is currently not available from centralized databases. This is a major limitation to knowledge sharing within the water management community.

4. DISCUSSION

As shown in the previous section, the water stress situation in the region under consideration could not be evaluated using centralized data only, and this is mainly because of the absence of weighting information. Suppose that this information can be retrieved from other sources, then the applicability of the indicator approach would further depend on two factors: (1) the possibility to extend it to pan-European scale. (2) the performance of the indicator approach in correctly representing the local water stress.

Extension to pan-European scale

As stated before, comparisons of cases in similar climatic settings across different countries (e.g., the Mediterranean) may be more useful than comparisons of cases within an individual country. In order to investigate the feasibility to extend the approach from Italian to pan-European scale, the on-line availability of anthropogenic water stress indicator information was assessed for two other countries, The Netherlands and Cyprus. It is emphasized that only the availability of indicators was examined *that were already retrieved for Italy* . The assessment does not provide a general comparison of the availability of indicator data in the three countries.

Once more, EUROSTAT and national databases were queried for this purpose. It turned out that on-line information is available in both countries for 9 indicators, in any one of the two countries for 6 indicators, and in none of the two countries for 2 indicators. In some cases, alternative indicator information could be found, but this was not used further, since the ‘Italian’ indicator set was used as a reference for the queries.

A comparison between countries can be complicated because of different datings: the information dates from 2007 to well back into the 1990s. Furthermore, the information is in some cases generated using different methodologies. This is notably the case for indicators that are based on composite and / or processed information, e.g., the percentage humid areas under high anthropogenic stress.

It is concluded that application on a pan-European scale is not yet feasible, despite a fair availability of water stress indicator data in the individual countries. This is because (1) the countries have limited indicator data in common, and (2) comparison of the common indicators is not always straightforward.

Table 3. Availability of anthropogenic water stress indicator information retrieved for Italy, in centralized databases in The Netherlands and Cyprus. 0 = in none of the two countries, 1= in one other country, 2 = in both other countries.

	DOMESTIC	AGRICULTURE	INDUSTRY	TOURISM	ENVIRONMENT
Quantity Issues	2	1	2	2	2
Quality Issues	2	-	-	-	1
Institutional and adaptive capacity	2	1	1	-	2
Infrastructure	0	1	-	2	1
Social and economic equity	0	-	-	-	2
WEIGHTING indicator	-	-	-	-	-

Performance in representing water stress

For the Flumendosa case, a comprehensive summary was made of the water situation by Preziosi et al. (2008). This independent information was used to test the performance of the indicator approach.

Site description

The Flumendosa basin is located in the south-eastern part of Sardinia (see Figure 1). The southern part lies in the province of Cagliari, while the northern part lies in the province of Nuoro. It includes six interconnected reservoirs, and supplies water resources to different and conflicting uses mainly outside the basin, notably to the Campidano agricultural plain and to the Cagliari urban area and industrial agglomeration. Within the basin, the flow rate downstream of the dams, especially during dry periods, is very low, and adapting reservoir releases according to environmental flow requirements seems difficult to manage. As a further consequence, the natural recharge of the Muravera aquifer along the south east coast has strongly decreased, and groundwater overexploitation has led to its salinization. Available surface water resources during droughts can be evaluated about 210 Mm3/y; agriculture is responsible for 53% of the water consumption, and only 55% of the agricultural water demand can be satisfied. Domestic sector demands make up approximately 45% of demand (Preziosi et al., 2008). The Flumendosa system is an area of particular interest for European policies, because it is representative of problems typical to the Mediterranean climate.

Performance

The Flumendosa 'ground truth' as described in Preziosi et al.(2008) shows that between 1997 and 2002, 210 million m3 per year was reportedly abstracted from the reservoirs, of which 100 million m3 per year for use by agriculture (Apostolaki & Assimacopoulos, 2005). This is much more than the amount of drinking water used by agriculture in the region, which is only 312,000 m3 (1999) according to the centralized data. This illustrates the importance of carefully checking the relevance of information retrieved from centralized databases with local data.

The availability of local data on sectoral water use in the different sectors enabled the normalized indicator water stress scores to be weighted, where this was not possible using centralized data only. The resulting weighted anthropogenic water stress scores for each sector are graphically represented in a five point diagram, according to the method described by Sullivan et al. (2006), see Fig. 2. According to this diagram, the water stress is mainly a problem in the domestic, agricultural and environmental sectors, and less in the touristic and industrial sectors.

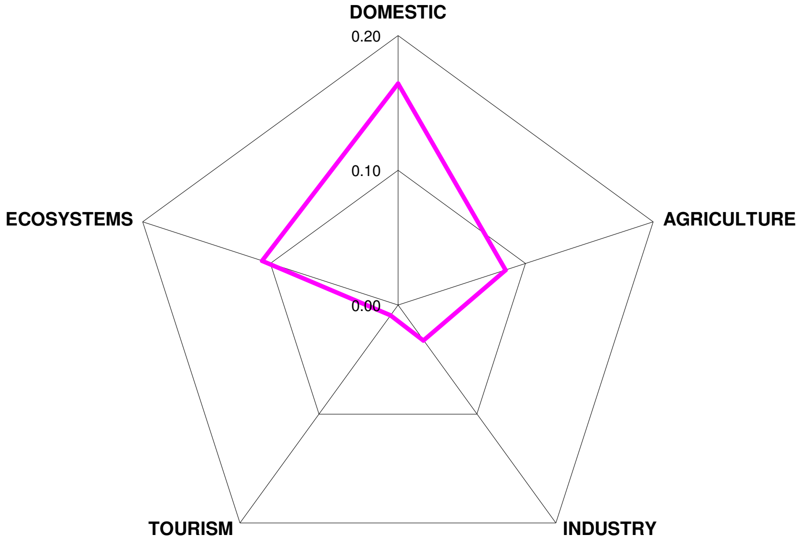

Figure 2. Five point diagram (Sullivan et al., 2006) showing the relative contributions of the anthropogenic sectors to water stress, as derived from centralized databases, but including local data as well.

As outlined earlier, seasonality may play an important role in determining the character of water stress. The ground truth data were used to assess this aspect. In case of strong seasonality and short memory of the water system, water use during winter would not influence water availability during summer, and as a consequence, only water use in summer should be analyzed instead of annual figures. Because agriculture and tourism mainly use water during summer, this would greatly influence the weighting procedure as outlined earlier. However, the six interconnected reservoirs of the Flumendosa allow for a large storage capacity of the system which is fed mainly by surface water related to rainfall. Measurements of discharge from the reservoirs show strong fluctuations with a wavelength of several years (see Figure 3). This indicates that the reservoir system has a long memory and is not dominantly influenced by seasonality. This means that annual data on water use should be sufficient for analysis.

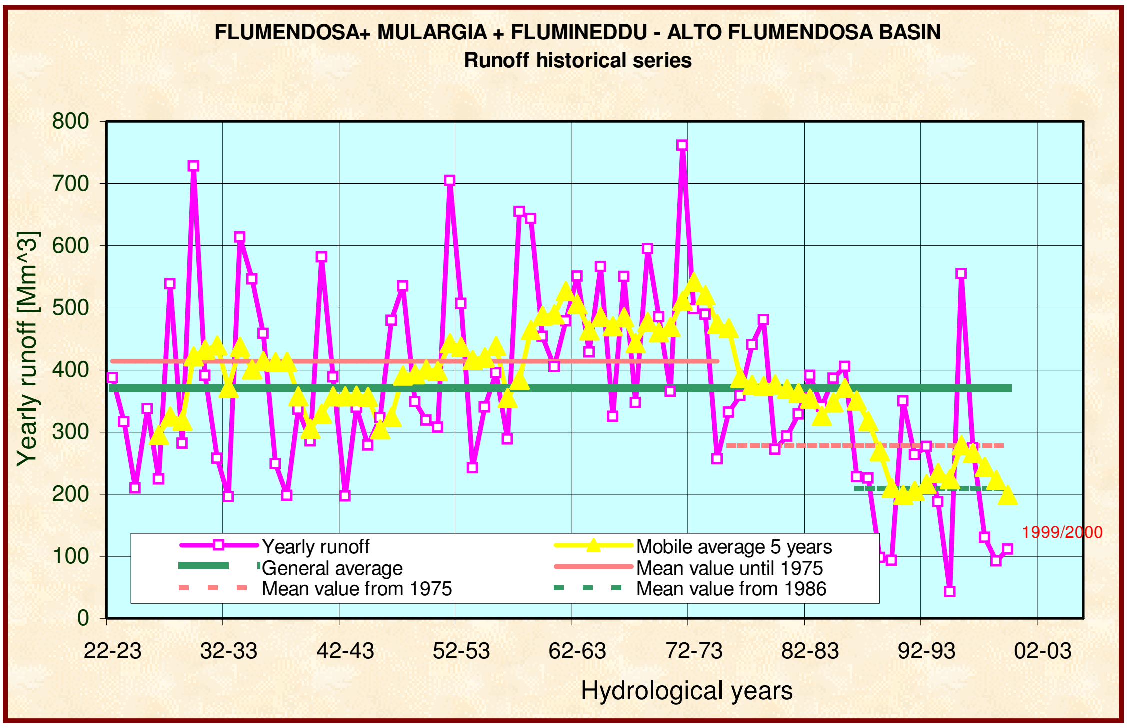

Figure 3. Runoff historical series for three of the artificial reservoirs in the Flumendosa-Mulargia sub-basin. Source: Botti et al.(unknown date).

Administrative regions versus catchments

As explained before, the Flumendosa catchment boundaries do not correspond to the provincial boundaries. Despite this, the catchment is hydraulically connected to the province of Cagliari due to the water transfer from Flumendosa to Campidano plain.
In this case, the mismatch between administrative and natural catchment boundaries may not cause large discrepancies. The close connection between the water stress problems in the sub-basin and in the province of Cagliari means that solving the problem for the sub-basin by reducing water transfer could negatively affect the water stress in the province, and vice versa by increasing water transfer. It may be argued that this situation requires integrated mitigation options at an administrative, rather than a sub-basin level. In other words, the mismatch between administrative and natural catchment boundaries may not cause large discrepancies in this case, but neither does it provide general proof for the validity of exchanging information between the two spatial scales.

The presence of the water transfer system probably influences the choice of mitigation options to considerable extent. However, it is not reflected in the generic core set of water stress indicators. As a consequence, false similarities with other water-stressed cases may be identified, and hence sub-optimal mitigation options. It is recommended to add an indicator for water transfer between catchments to the approach. More in general, it appears that the core set of water stress indicators is best extended on the basis of comparisons to ground truth data for a number of cases. This may eventually provide full conceptual coverage of water stress problems for a great variety of cases. Not until then is it justified to define a 'wish list' of indicator information to be registered centrally and systematically.

5. CONCLUSIONS AND RECOMMENDATIONS

The collection and processing of indicator information from centralized databases is a first step towards sharing knowledge about water stress mitigation across Europe. It can even be a considerable step, if the on-line information structure is well organized on a national level, as is the case in Italy. The example in this paper illustrates that more steps would be needed to reach the ultimate goal:

(1) It is essential to cooperate with, and ask advice from local experts in order to be sure that the centralized data used are actually representative of the analysed phenomenon at the scale of the representation;

(2) The generic core set of anthropogenic water stress indicators is best gradually adapted, or extended, using experiences with validating the indicator approach to local ground truth.

(3) A definitive 'wish list' of indicator information to be registered centrally and systematically can not be formulated until step (2) is taken.

(4) The anthropogenic water stress indicator data is better organized along sub-basin boundaries than along administrative boundaries. The drafting of river basin area management plans for the European Water Framework Directive offers possibilities in this direction. In addition, the available anthropogenic water stress indicator sets of the individual countries have little in common, and some harmonization would be useful.

(5) Systematic registration of information on the implementation, and subsequent success or failure of mitigation options in current, future and past projects, is a strong need.

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