DSS application to the development of water management strategies in Ribeiras do Algarve River Basin

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Abstract:

Within the Project – "Developing Strategies for Regulating and Managing Water Resources and Demand in Water Deficient Regions (WSM)" funded by the EU in 5th Research Framework Program, the Ribeiras do Algarve River Basin was chosen as a case study to develop a DSS for planning purposes. Located in the southern stretch of the Portuguese territory, crucial conflicts do exist between tourist and agricultural water uses within the river basin. Additionally, there are important deficiencies in urban secondary water supply. Also inadequate irrigation methods and poor quality of water existing in some areas urge the implementation of management measures. Different ways to improve the water management situation were analysed: (i) structural options, (ii) demand management options and (iii) socio - economic measures. These options were analysed using a range of combinations of extreme demand and availability scenarios and ranked based on indicators reflecting the perception of the local stakeholders towards economic development and social and environmental sustainability. On a second phase, the formulation of strategies using the available options was addressed and two different strategies, resulting from a tentative timeframe of water management options combination, were applied aiming to achieve goals defined with regional stakeholders, namely: (i) on a first stage, the optimization of the domestic and irrigation water demand coverage and aquifer's groundwater exploitation use ratio; (ii) on a second stage, the determination of the water pricing increase necessary to achieve economical sustainability, aiming at cost recovery goals in accordance with the Water Framework Directive compliance.

Key words: WSM-DSS tool – water resources – sustainable management – Ribeiras do Algarve River Basin – strategies

1. Introduction: The WaterStrategyMan Project

The WaterStrategyMan project, financed by the EU, was undertaken from 2002 to 2005 by nine Project partners from eight different countries: Greece, Germany, Italy, France, Israel, Cyprus, Spain and Portugal. The project was strongly related to the ideas of Integrated Water Resources Management. In that context, the two basic categories of IWRM, the natural system and the human system, as well as their interdependencies and also the different internal relationships within each category were considered. The natural system is of critical importance for resource availability and quality, and the human system fundamentally determines the resource use, waste production and pollution of the resource.

The two main goals of the WaterStrategyMan Project (WSM) were:

- to review existing approaches in terms of Integrated Water Resources Management (IWRM), e.g. demand management under consideration of sustainability indicators and comparison of different developmental strategies;

- to develop alternative options of water management, based on long-term scenarios for water deficient regions, taking into account economic, technical, social, institutional and environmental aspects and having in mind the European Union (EU) requirements.

The project consisted of four phases. In the first phase (diagnostic phase) a set of representative regions in Southern Europe were identified to define paradigms for water deficient regions which would form the theoretical framework for developing, analysing and evaluating water management options. Six water deficient regions in the Mediterranean region were analysed, among them the Algarve region. In phase two (analysis phase), a consistent methodology for analysing and evaluating different water allocation scenarios and water management options was developed to encompass the entire range of the selected paradigms. The strategy formulation phase was aimed at comparing and identifying appropriate plans, actions and policies that apply to these paradigms during the third phase. The main objective of phase four, the synthesis and dissemination phase, is the synthesis of the results from the previous project phases. Based on the six identified paradigms, widely acceptable guidelines and protocols were formulated. As a result, a decision support system (WSM-DSS) was developed and built along the project duration, in order to enable the evaluation of the current situation and of the eventual impacts of new water management options within any region and/or river basin. This system can be used to help decision makers to assess water management options fitting the specificities of each region and to implement water schemes that will enable cost recovery on water use. To ensure its practical applicability regional and national stakeholders were involved in this project, with whom different options to generate alternatives and to specify the criteria to evaluate them were discussed. This process which was continuously repeated was essential to understand the major water problems in the river basin and the major expectations and concerns of water managers interested to solve them.

The backbone of the WSM-DSS (WaterStrategyMan Decision Support System) is an GIS-based information system. It includes many capabilities of GIS e.g. to handle vector and raster information, treating geo-referenced and time-referenced data. With a Graphical User Interface the users have access on the following functionalities:

- to analyse the contemporary water management taking into account water supply and demand and to evaluate the state of the water system;

- to forecast the water system behaviour, according to existing or expected regional hydrological and demand scenarios and the future performance of the system under different water management options;

- to define and apply alternative strategies, relying on water and demand management measures, in order to assess their sustainability;

- to evaluate the impact of the different water management options analysing the results of different future scenarios which are based on a multidisciplinary approach under consideration of local, national and international constraints.

The information system contains GIS data and time series. It includes (i) water sources as aquifers and storage reservoirs; (ii) water quality nodes as water treatment plants and wastewater treatment plants; (iii) domestic, agricultural and industrial water users; (iv) time series at monitoring points for water quality and quantity and, (v) water-related elements of infrastructures as pipelines, canals and reservoirs. Within the WSM-DSS it is possible to simulate the water management conditions over a simulation period up to 50 years. In a first phase, a reference case based on the current system definition is analysed. Shortages are identified under different demand and hydrological scenarios. After that, different structural and non-structural alternatives can be integrated and evaluated individually. These options are divided in three major categories (1): (i) supply enhancement (e.g., new reservoirs, water re-use); (ii) demand management (e.g., reduction of network losses, conservation measures); and (iii) institutional policies (e.g., water pricing, environmental policies). These options can be combined into sets of actions which form the preferential sequence of responses to existing and emerging conditions, aiming at the fulfilment of the general goal of sustainable IWRM.

In order to evaluate these different strategies the WSM-DSS tool presents different performance indicators, which can be differentiated into three groups (2): (i) utilization of environmental resources (e.g., groundwater exploitation index, usage of local water resources and dependencies on imported water); (ii) efficiency to cover demand (specified for the different sectors); and, (iii) economic criteria (e.g., rate of cost recovery, total environmental cost). The temporal variability of each indicator is taken into account by consideration of different time scales. Among these parameters, comprehensive characteristics as reliability, resilience and vulnerability are applied.

With regard to economic sustainability cost recovery is considered explicitly. After evaluating the performance of each strategy, the user can propose a cost recovery scheme in order to reach pre-defined targets in terms of cost recovery levels for direct, environmental and resource costs. By re-evaluation of the water management strategies based on this cost-recovery scheme and under consideration of demand elasticity the user is able to explore effective water management strategies and compare their efficiencies in terms of reduced water stress, environmental constrains and economic sustainability. Figure 1 summarizes the methodology explained above.

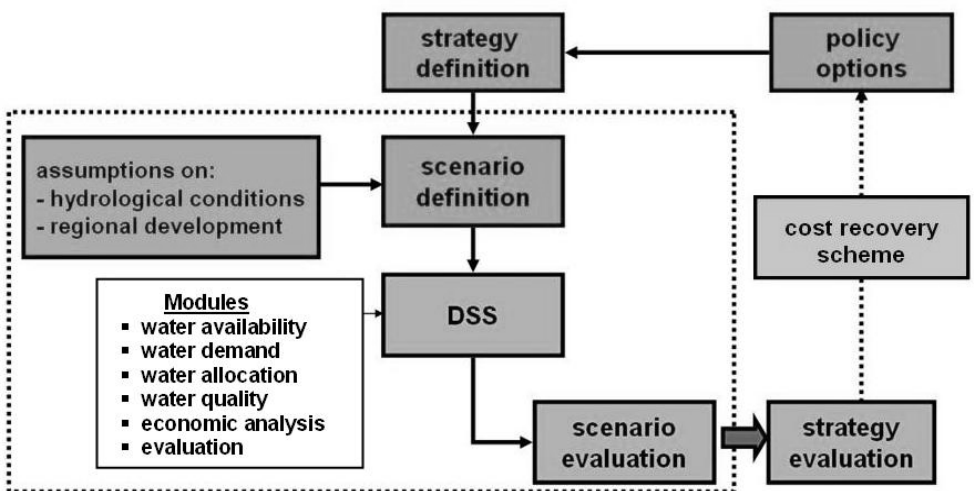

Figure 1. Methodology

2. The case study region from Portugal: the Ribeiras do Algarve river basin

The Ribeiras do Algarve River Basin is located in the southern stretch of the Portuguese territory, occupying about 3837 km^2. It includes 18 Municipalities, as shown in Figure 2. In this basin water management was faced with deep changes during the last decades, as aquifers were overexploited. This led to their degradation such as salinisation and water quality deterioration, transforming most of it into a non-reliable water source. The Querença-Silves aquifer appears to be the only one owing water quantity and quality to be used for sustainable abstraction in the future (Figure 2). The regional development was caused by a significant increase in tourism in the Algarve region. To assure reliable water supply for resident and tourist population and for agriculture, a shift was made in water supply traditional ways. By the end of the 90's, a new primary water supply system for urban supply was established.

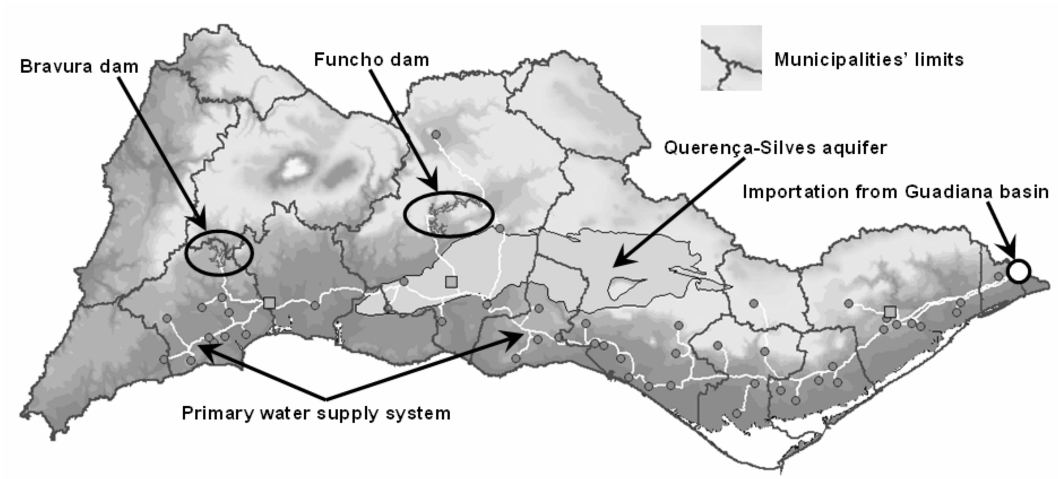

Figure 2 Ribeiras do Algarve River Basin: Municipalities, primary water supply system and main supply sources

The primary water supply system (Figure 2), which is mostly based on surface water sources, supplies 29 of the 51 secondary water distribution network systems in the River Basin, to which corresponds more than 85% of the total urban water consumption in 2002. The remaining 22 secondary systems are supplied by groundwater under the Municipalities responsibility. Industrial consumption represents only less than 1,5% of total urban consumption. Agriculture is still the main water consumer in the basin (65%), using mainly groundwater (86%). In fact, groundwater is the main source for private irrigation sites (where irrigation efficiency is on average 80%) whereas public irrigation sites (with irrigation efficiency around 60%, on average) are mostly supplied by surface water. As part of the new developmental strategy of increasing tourism activity, golf courses implementation also increased. By the end of 2003, about 25 golf courses already existed in the Algarve River Basin, representing approximately 41% of the total existing in Portugal.

The referred water resources regional situation adds to deficient infrastructures, poor groundwater quality, high values of secondary water supply network losses (16% to 61%) and inadequate irrigation methods, urging the implementation of alternative water management measures.

3. The development of the DSS for the Ribeiras do Algarve river basin

The application of the DSS follows the following methodology: (i) establishment of the decision context, (ii) identification of objectives and criteria, (iii) identification of options to solve the problems, (iv) estimation of the impacts of the different options and (v) evaluation within a multi-criteria environment.

3.1. Formulation of scenarios translating a required decision context

First of all, the decision context has to be described with a specification of the water management problems. This decision context is translated into tentative scenarios, very helpful to specify the variety of expected developments. Here two types of scenarios are needed: scenarios for the water demand and scenarios for water availability.

Within the framework of the WSM DSS, demand scenarios can be defined by the user through the introduction of a global steady increase of demand (fixed rate), or different growth rates for each municipality. In each case, different growth rates can be considered for permanent and tourist population. In the present work, a steady rate of demand differentiated by Municipality has been considered, corresponding to the current trend and entitled as “business as usual” (BAU). With regard to agriculture, only an irrigation growth scenario was considered here, which was based on the correspondent data for irrigation demand provided by the River Basin Plan (RBP) (3) and admitting a moderate development of agriculture. According to the RBP, different growth rates were considered for each public irrigation site until 2020. For private irrigation sites, a 1.3% growth rate was used for the same period. It should be emphasized that only already existing golf courses were considered, as new licensing of golf courses are at risk due to sustainability issues and environmental goals.

To translate the variability of hydrological conditions two hydrological scenarios of 35 years, comprising sequences of very dry, dry, normal, wet and very wet years, were considered:

- the normal scenario (Normal), based on historical data from 1970 to 2000;
- a high frequency of dry years scenario (HD), which corresponded to a 10% decrease of the normal scenario’s precipitation values, aiming to translate the decrease in water availability that may be expected (with more impacts visible during the drier months) according to studies on climate change (4).

In order to present some of the WSM-DSS capabilities, two combinations of a demand scenario with a hydrological scenario were established:

- the BAU+Normal scenario, expressing the current trends of the regional water system, according to the River Basin Plan; and
- the BAU+HD scenario, reflecting a more severe situation in terms of water availability and demand.

3.2. Simulations to specify existing and future water problems without additional measures

In a first simulation, the behaviour of the system over a period of 35 years, starting in year 2000 (containing a sequence of hydrological years of different types, from very dry to very wet) was simulated under the assumption that no additional water management actions were taken. Using the water availability scenarios described before, these “reference cases” allow identifying the water shortages spatial and temporally and the need for additional actions either to increase water availability or to reduce water demand within the river basin. The results obtained from those simulations characterise the state of the river basin not only in terms of water availability but also with regard to the resulting economic and environmental aspects under the referred scenarios.

3.3. Evaluation of planned water management measures

Different water management options were explored in order to decrease the observed water deficit in the whole basin. The envisaged options were based on the goals defined in the River Basin Plan and on the interests and needs manifested by the stakeholders:

- **Structural measures for supply enhancement**:

(i) Dam construction in the Barlavento (the west side) region of the river basin;

(ii) Network enhancements, to increase the number of Municipalities supplied by the primary water supply system;

(iii) Desalination, to solve local water deficit and/or water quality problems in domestic use and golf courses;

(iv) New abstraction boreholes;

(v) Reduction of network losses, in all the Municipal secondary water supply systems, to reduce water deficit in domestic use.

- **Demand management options, including**:

(i) Water re-use for golf courses, to mitigate water deficit and/or water quality problems in some aquifers;

(ii) Improved irrigation methods at all private irrigation sites and at selected public irrigation sites to increase irrigation efficiency;

(iii) Conservation measures in the domestic sector, to reduce water demand.

- **Socio-economic measures:** analysis of the impacts of new water pricing schemes for settlements and irrigation sites.

The evaluation and comparison of the effects of these measures were based on the following indicators, which are aggregated in Table 1 under the "effectiveness" column:

- domestic demand coverage (percentage of supply over demand), with satisfactory values over 95%, all over the year;
- irrigation demand coverage, aimed greater than 80% all over the year, due to the major importance of agriculture water use; and
- groundwater exploitation index (percentage of abstractions over recharge), always under 80% in order to avoid aquifer overexploitation and salinisation.

A global performance indicator was estimated by weighted averaging. The domestic coverage indicator was assigned with a weight of 0,4 and the other two indicators with 0,3. In addition, the WSM-DSS performs a cost evaluation, considering direct costs and environmental costs, expressed in terms of Present Value (PV) over the total time period of the analysis. Direct costs were estimated through the evaluation of two different components: (i) depreciation of capital costs associated to past and new investments, for both domestic irrigation and industrial uses; and (ii) operation and maintenance costs of new and existing infrastructures, for domestic, irrigation and industrial purposes. Regarding environmental costs, the WATECO Guidance document principles (5) were adopted in the WSM DSS.

Table 1 exemplifies the evaluation regarding demand coverage and economic efficiency for the most severe scenario of water shortage, the BAU+HD ("Business As Usual"+High Frequency of Dry years) scenario, which can be used to compare all single water management options. As it can be seen, the two options that perform better are the "dam construction" and the "new abstraction boreholes". Effectiveness values slightly higher than the ones of the reference case are due to "desalination" and "domestic pricing" options, showing that they are more efficient in solving the water shortages identified in the reference case than the remaining options.

Table 1. Performance matrix (BAU+HD scenario)

Option	Effectiveness (Relative Performance Index for Demand Coverage)	Economic Efficiency	
		Environmental Cost PV, million €	Direct Cost PV, million €
Reference case (BAU+HD)	0,300	686,9	1664,9
Dam construction	0,475	719,2	1875,1
Network enhancement	0,300	683,4	1661,3
Desalination	0,307	686,8	1837,8
New abstraction boreholes	0,493	736,9	1801,1
Reduction of network losses	0,300	685,7	1675,0
Irrigation method improvements	0,300	670,2	2129,9
Water re-use	0,300	681,2	1665,4
Conservation Measures	0,300	687,2	1669,8
Domestic pricing	0,305	659,6	1553,8
Irrigation pricing	0,300	651,3	1607,9

Concerning economic efficiency, besides "domestic pricing" and "irrigation pricing" options, the lower values, and consequently the most favourable, are obtained for the "irrigation method improvements" option for PV direct costs and for the "network enhancement" for PV environmental costs. These lower values can be explained by the decrease in demand, created by these options and therefore the decrease in associated costs as operation and maintenance costs and also environmental costs. Globally, none of these options is better in terms of both effectiveness and economic efficiency. In fact, as one can see in Table 1, the higher values of effectiveness are associated to higher values of PV direct costs and PV environmental costs.It has to be emphasized that a similar analysis was undertaken for BAU+Nomal and LD+HW scenarios (referred in 3.2) and the correspondent results are presented in (6). This evaluation and comparison of single measure types with the WSM-DSS was an important step to formulate consistent strategies.

4. Application of the DSS - Formulation and Evaluation of Strategies

4.1. Evaluation of strategies based on effectiveness and economic efficiencies

According to the results obtained for the different water management options, two alternative strategies were defined based on two different paradigms. These two alternative strategies were:

- strategy 1, following a dominant paradigm, which is mostly the exploitation of surface water combined with the introduction of structural measures;
- strategy 2, where a new paradigm is used, which is not a radical shift from structural to non-structural options but which considers (after consultations with stakeholders) alternative options for water supply (e.g. water re-use); introduction of localized management measures; and a sustainable use of surface and groundwater in order to preserve water resources.

Table 2 and Table 3 describe summarily the options of strategies 1 and 2 respectively, and present the corresponding implementation schedule. In strategy 2, the dam construction option of strategy 1 is replaced by an increase in groundwater abstractions and by other alternative options as e.g. desalination.

Table 2. Strategy 1 schedule

Water management option	**Year of implementation**	**Description**
New boreholes	2005	Abstraction in Querença-Silves aquifer (0,6 hm^3/month, until 2010)
System enhancement	2006	System enhancement in Loulé Municipality
	2012	System expansion in Aljezur and Monchique Municipalities
Irrigation methods improvement	2006/2012/2020	Differentiated for public and private irrigation sites
Dam construction	2010	Construction of (Odelouca) dam
Losses reduction	2010/2015/2020	5% of losses reduction (total maximum: 15%)

Table 3. Strategy 2 schedule

Water management option	**Year of implementation**	**Description**
New boreholes	2005	Abstraction in Querença-Silves aquifer (1 hm^3/month)
Water re-use	2005	In four golf courses
System enhancement	2006	System enhancement in Loulé Municipality
	2008	System expansion in Monchique Municipality
Irrigation methods improvement	2006/2012/2020	Differentiated for public and private irrigation sites
Desalination (seawater)	2006	1) Desalination unit in Aljezur Municipality for domestic use
	2007	2) Desalination unit in Loulé Municipality for golf courses
	2015	3) Desalination unit in Portimão Municipality for domestic use
Conservation measures	2006	In 1/3 of the hotels through the substitution of taps and flushing cisterns
Losses reduction	2010/2015/2020	5% of losses reduction (total maximum: 15%)

In order to evaluate both strategies, the two scenarios defined in 3.1. (BAU+Normal and BAU+HD) were considered. Table 4 summarizes the main evaluation results obtained for the two strategies considered in comparison with the reference case. In terms of effectiveness, strategy 2 performs slightly better than strategy 1 under both scenarios, mostly translating the “conservation measures” option use. In terms of environmental costs, strategy 2 achieves better results even than the reference case. This aspect is related with the introduction of water management options as “desalination”, “water re-use” and “losses reduction” that cause a decrease in surface and groundwater abstractions.

Table 4. Strategy evaluation table

Option	Effectiveness (relative performance index for demand coverage)	Economic efficiency	
		Environmental cost PV, million €	Direct cost PV, million €
BAU+Normal			
reference case	0,300	692	1690
strategy 1	0,572	700	2361
strategy 2	0.638	667	2252
BAU+HD			
reference case	0.300	687	1665
strategy 1	0.566	699	2360
Strategy 2	0.638	667	2245

Finally, the investments needed in both strategies understandably originate an increase in terms of direct costs. The higher operation and maintenance costs, associated to the increase in the water volume supplied, also contribute to that fact.

4.2. Re-evaluation of strategies under cost recovery goals

Here cost recovery was considered by an increase of water prices for domestic users. These cost recovery targets intend to achieve economical sustainability, following the principles defined in the WFD. For the Portuguese case study of Ribeiras do Algarve River Basin, the targets were: (i) 100% recovery of direct costs from 2020 onwards and (ii) a minimum cost recovery of 70% of environmental costs by 2025. Despite being among the capabilities of the WSM-DSS tool, irrigation pricing was not considered in this study. In fact, the introduction of this measure within a strategy would have major institutional implications, as agriculture largely depends on subsidies.

Following the WSM-DSS methodology, for both strategies an iterative process was conducted aiming to determine the water price increase necessary to attain the cost recovery targets set above. The option chosen was to implement a temporal differentiated increase in water prices for domestic users, every two years from 2005 to 2015. At present, according to the data presented in the Water National Plan (7), the average weighted price for domestic supply in the Ribeiras do Algarve River Basin is around 0,68 €/ m^3. The average final water prices obtained for domestic use in the year 2035, the end of the simulation period, was on average 1,21 €/m^3 for strategy 1 and 1,12 €/m^3 for strategy 2. Under both strategies, these increases allow obtaining 100% of recovery of direct costs by 2020 and approximately 70% of recovery of environmental costs in 2035, fulfilling the targets set for the cost recovery strategy. Table 5 presents the results of the re-evaluation of the two strategies according to these new prices. The values between brackets correspond to the results presented in Table 4 (before cost recovery strategy was applied).

Table 5. Strategy evaluation table under cost recovery strategy

Option	Effectiveness (relative performance index for demand coverage)	Environmental cost PV, million €	Direct cost PV, million €
BAU+Normal			
strategy 1	0,703 (0,572)	647 (700)	2137 (2361)
strategy 2	0.704 (0.638)	628 (667)	2079 (2252)
BAU+HD			
strategy 1	0.701 (0.566)	647 (699)	2136 (2360)
Strategy 2	0.701 (0.638)	627 (667)	2076 (2245)

The changes in water tariffs caused a decrease in domestic demand due to the elasticity of water demand considered (-0.5, in accordance with the primary water supply utility). This reduction in demand caused a further decrease in both direct and environmental costs. The decrease in direct costs under both scenarios was 9.5% for strategy 1 and around 7.5% for strategy 2. Concerning environmental costs, the results obtained reflect the decrease in water abstractions made.

5. Summary and Conclusions

Within the WSM Project, partners from different countries with different experiences and different perspectives regarding water resources management could cooperate. Through the analysis and exploitation of the six case studies, it became possible to define guidelines and protocols in order to improve water management and help decision makers by providing a decision support system tool, which is able to reflect the specificities of each region and to present simple but exhaustive results.

The Portuguese case study, the Ribeiras do Algarve River Basin, was selected with regard to the conflicting water users, agriculture and tourism, and the overexploitation already verified in some aquifers. The analysis of the different water management options was the first necessary step in order to identify local or regional water shortages within the river basin and to propose efficient alternatives to cope with these problems. On the following stage, two alternative strategies were defined, based on two different paradigms. Analysing the two strategies in terms of effectiveness and economic efficiency, one has concluded that strategy 2, mostly relying on small-scale measures and the exploitation of both surface and groundwater, could reach similar or even better results than strategy 1, based on structural measures only, if cost recovery goals were imposed.

Finally, it should be emphasized that, for each scenario, the results depend on the defined targets and the weights given by the decision-maker to the different indicators used. A different selection of indicators and weights assignment could obviously lead to different results. That way, the water management options and strategies presented in this paper shall be taken into account as examples, based on specific stakeholders' concerns.

Acknowledgment

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