Guidance for the application of vulnerability assessment and multi-criteria decision analysis in integrated wetland management

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CONTENTS

1 Introduction

This report is a deliverable of the WETwin 7FP EU project. WETwin is an international research project funded by the FP7 programme of the European Commission. The project consortium consists of research, educational and governmental institutions from Africa, South-America and Europe. The overall objective was to enhance the role of *wetlands* in basin-scale integrated water resources management, with the aim of improving the community service functions while conserving good ecological status.

Despite of their national / international protection status (e.g. under the Ramsar Convention), many wetlands *lack proper planning and management*. This often leads to the deterioration of their status. The reason behind this is not necessarily the lack of funding. In many cases the problems are rooted in the institutional environment: unclear or overlapping spheres of authorities, lack of effective power to enforce laws and regulations, inadequate involvement of stakeholders - to mention a few. Furthermore, wetlands are often viewed as standalone systems rather than as elements of the river basin. As a result wetlands are poorly integrated into river basin management.

Wetlands provide multiple ecosystem services on local, and also on basin scales. These services range from food and raw material provision, through flood and water quality regulation, to habitat, recreation and tourism. In some cases there are trade-offs among these services meaning that enhancing one service tends to cause deteriorations at the others. This may lead to conflicts among the stakeholders benefiting from the different services. Integrated wetland management is thus often framed as a *decision problem with conflicting multiple objectives*, where the challenge is to identify the best compromise management solution.

Wetlands are exposed to the impacts of *external changes* especially to that of population growth and climate change. Population growth in developing countries will likely increase the demand towards provisioning and regulating services of wetlands, at the expense of habitat and cultural services. Wetlands are highly *vulnerable* to climate change (Ramsar, 2002). Decrease in precipitation and increase in temperature could seriously decrease the water resources of the wetland thus endangering all of its functions and services. Wetlands in regions like the Sahel are especially exposed to this threat (IPCC, 2007). Thus, external changes will likely cause the degradation of the wetlands in the future unless appropriate *adaptive* management measures are taken to counteract the negative effects.

This report aims to be a *guideline* supporting the integrated and adaptive management of wetlands. This guideline is embedded into a *Conceptual Framework*, which is introduced in Chapter 2. Further, the guideline consists of two main parts: Vulnerability Assessment (VA) in Chapter 3, and Multi-Criteria decision Analysis (MCA) in Chapter 4. The descriptions of these methodologies are illustrated by examples from the WETwin case studies. Also, references have been incorporated into the texts with regard to relevant publications and to other WETwin project reports. In this way, the guideline covers all relevant outcomes and results of WETwin, and it also works as a meta-document for the most important deliverables of the project. Chapter 5 at the end of the report draws conclusions and gives recommendations for the joint use of VA and MCA. The *targeted users* of this guideline are professionals, who are in charge of elaborating wetland management plans.

Glossary of terms is given in Annex I.

2 Conceptual Framework

A *Conceptual Framework* has been developed within the WETwin project for the integration of wetlands into river basin management (Figure 2-1). The Framework is based on three existing methodologies:

1) the Critical Path approach, as put forward by the Ramsar Convention on wetlands (Ramsar Convention Secretariat, 2007);
2) the European Water Framework Directive (WFD) and related guidance documents (CIS, 2003a);
3) the UNESCO spiral process for Integrated Water Resources Management (IWRM) (UNESCO, 2009).

These methodologies have been developed with the aim to cope with the requirements of *adaptive water management*.

The framework consists of the integration of the adaptive planning cycles at the wetland and the river basin levels. In this framework, integration means interaction and exchange of information such as problems, targets, management plans, bottlenecks and measured data, among agencies in charge of implementing the two management processes. An actual merge or transfer of responsibilities from e.g. environmental agencies to water management agencies is not envisaged, since wetlands remain to have their own dynamics, need to be managed at a different scale and have different challenges than river basins. The WETwin Conceptual Framework and guidelines, however, aim to improve the performance of management agencies and enhance the coordination between concerned institutions.

Both planning cycles consist of classical elements of a regular project management cycle, which are reflected both in the WFD and in the Critical Path (see also Figure 2-1):

- Initial multi-disciplinary *characterization* incl. biophysical, socio-economic, and institutional status/capacities; stakeholder preferences (about wetland management and use). Identification of *problems* and priorities.
- *Generation* and *evaluation* of *alternative management solutions* ('program of measures'). This ideally results in a '*best compromise solution*' identified together with decision-makers and stakeholders.
- In a next step a *management plan* is built upon the basis of the best compromise solution. This management plan should also take key aspects of the other plan (either wetland or river basin) into account.
- A final step of the planning cycle is *monitoring* and evaluation of the process of *implementation* which may result in a *review* of the existing plans. Monitoring and process evaluation must be planned well in advance at the start of the management cycle.

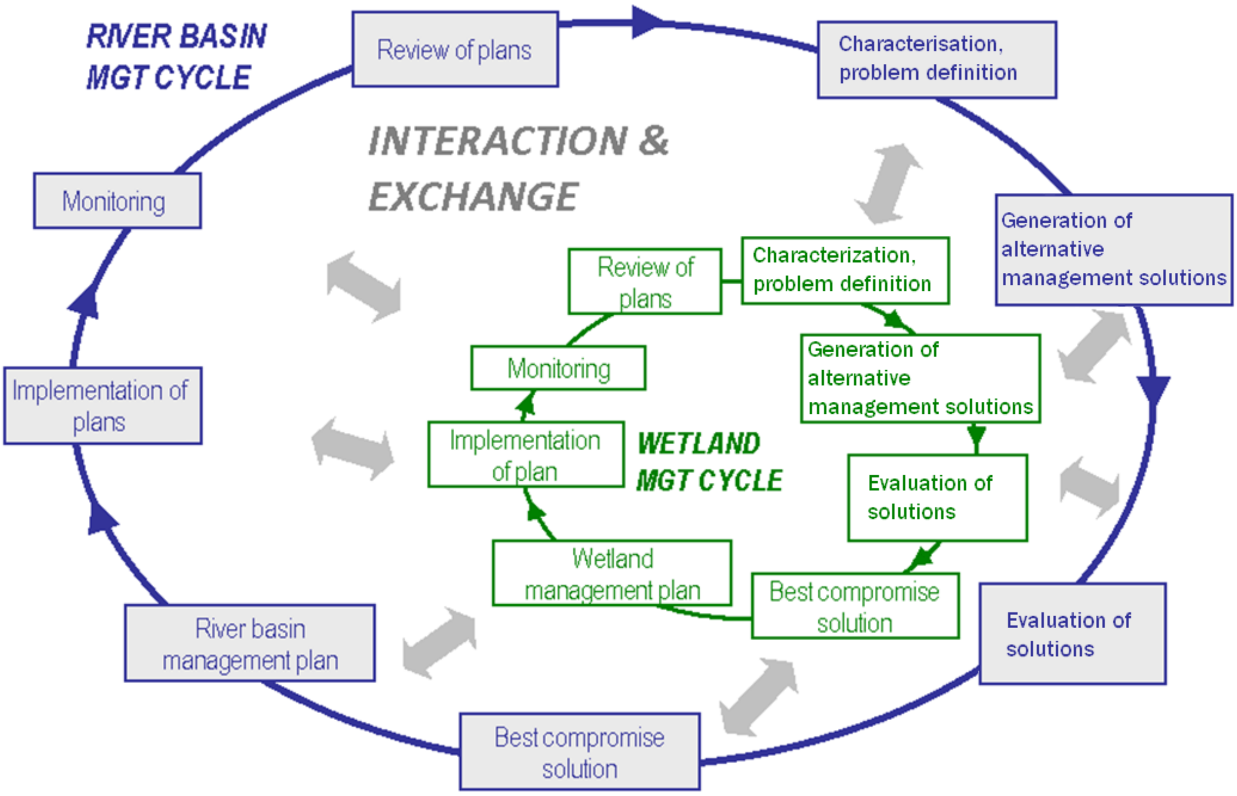


Figure 2-1: The Concept of the WETwin project for the cyclic and integrated wetland and river basin management

Adaptive management actually means that wetland and river basin management is an open-ended process that evolves in a spiral manner over time as one moves towards more coordinated water resources management. In order to illustrate the evolving and dynamic nature of the IWRM process, the cycle can be visualized as well as a spiral, based on the UNESCO spiral process for IWRM (see Figure 2-2). The spiral can be entered from any sector at any given level, making it a helpful aid for integrating wetland and river basin management. The advantages of the spiral are:

- It builds capacity over time
- It permits seeking better solutions that adapt to global and local changes such as climate change, population growth, economic growth and increasing water uses upstream
- It facilitates reaching agreements and increasing ownership at each ‘turn of the spiral’
- It is a step by step process, and provides a framework for looking ahead and planning for the next two or three ‘turns of the spiral’

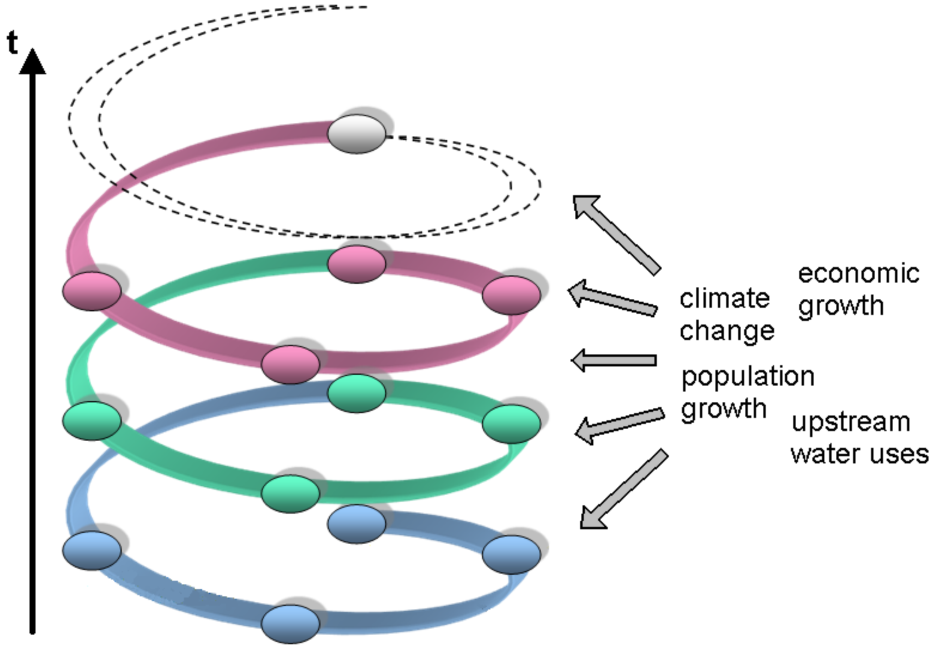


Figure 2-2: The spiral of integrated wetland and river basin management (after UNESCO, 2009)

The focus of this guidance document is restricted to the wetland management cycle from the 'Characterisation' to the identification of the 'Best compromise solution' inclusive of its interactions with the river basin management cycle (see Figure 2-3).

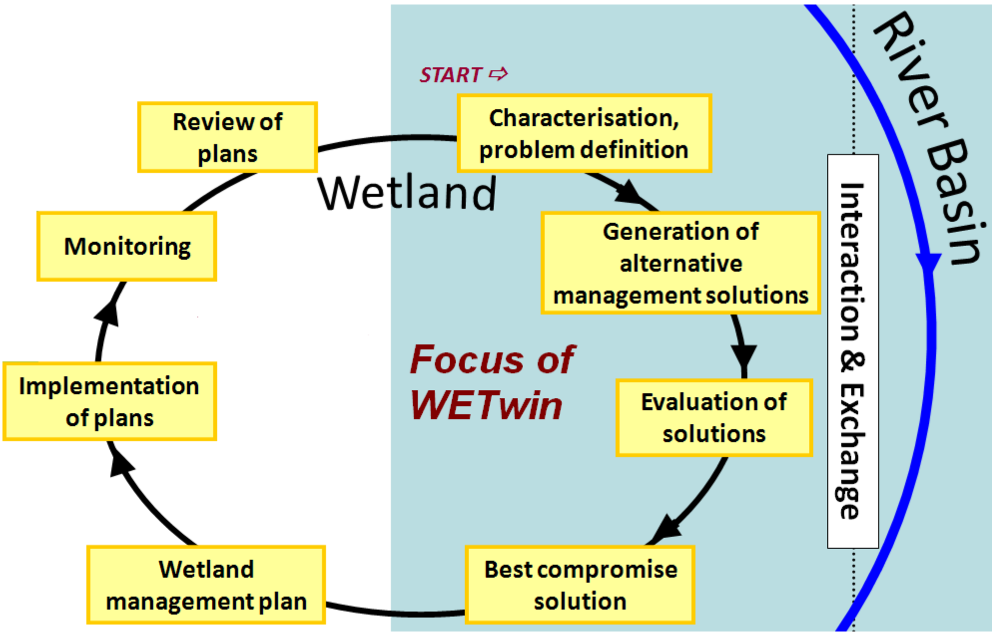


Figure 2-3: The focus of the WETwin guideline within the Management Cycle

This sub-system of the Conceptual Framework is supported by Vulnerability Assessment and Multi Criteria Decision Analysis. These methodologies are introduced subsequently in Chapter 3 and Chapter 4.

3 Vulnerability Assessment

Vulnerability and resilience have become important elements in discussions of global and regional change, but are conceptualised differently in different studies. WETwin is primarily concerned with the role of management in reducing vulnerability (or increasing resilience) of wetland systems to change; and with the degree to which management interventions remain viable in the face of change. For this reason, a framework for assessment of vulnerability was adopted and further developed that focuses on adaptive capacity relative to impacts of external change, such as climate change, population growth and upstream land and water management developments.

Vulnerability Assessment (VA) is thus a useful tool to:

- identify existing and/or future general and specific problems in the area of investigation
- raise awareness of existing and/or future problems
- explore uncertainties related to possible future changes using scenario analysis
- find management solutions that are robust under changing conditions

Thus, VA supports the implementation of the wetland management cycle from problem definition to the generation and evaluation of management solutions (see Figure 2-3).

3.1 Methodology

In WETwin, vulnerability is interpreted as being a function of the system's exposure to stress, its sensitivity, and its adaptive capacity as defined in IPCC (2001).

$$V = \mathrm{f}(E, S, AC) \qquad \text{Eq. 1}$$

where V is vulnerability, E the exposure, S the sensitivity, and AC the adaptive capacity. On the one hand the terminology and the concepts are well known, on the other hand these concepts are rather fuzzy, neither easy to grasp nor easy to quantify. Therefore, a simplification was applied to bring more clarity and transparency into the vulnerability concept used in the WETwin project.

An attempt was made to express the vulnerability components in quantitative terms. The quantitative values are meant to better understand and visualise the change of the vulnerability components under different scenario conditions.

In this regard, the impact of external stress (external impact or EI) is a function of a system's exposure to stressors, such as climate change, and its sensitivity to that stress, mainly considering the bio-physical environment.

$$EI = \mathrm{f}(E, S) \qquad \text{Eq. 2}$$

Scenarios are inevitable elements in the investigation of future vulnerability. The difference between the current system state (baseline) and a business as usual (BAU) scenario system state is used to determine or quantify external impacts using quantifiable indicators. The BAU scenarios are scenarios where the system is exposed to perturbations (e.g., climate change, upstream or external land and water management etc.) assuming no change in management in the system under consideration. Such scenarios reveal the consequences for human-ecological systems if no changes in future (re)action or no adaptation to changing boundary conditions take place.

$$EI = State_{(BAU)} - State_{(current)} \qquad \text{Eq. 3}$$

Adaptive capacity or AC is the extent to which these impacts can be withstood or mitigated and is usually related to management options and solutions, representing the socio-economic environment (Figure 3-1). By comparing the system states of the scenarios including management $State_{(mgt)}$ and not including management $State_{(BAU)}$, *AC* is quantifiable with following equation:

$$AC = State_{(mgt)} - State_{(BAU)} \qquad \text{Eq. 4}$$

The change in vulnerability (residual vulnerability or ΔV) of the system as it moves from its initial state to a new state (Figure 3-2) can be described by the sum of (usually negative) external impacts and (usually positive) adaptive capacity, that is:

$$\Delta V = EI + AC \qquad \text{Eq. 5}$$

$$\Delta V = State_{(mgt)} - State_{(current)} \qquad \text{Eq. 6}$$

Where the adaptive capacity of the system exceeds the external impacts ($AC>EI$, $\Delta V>0$), the system moves towards a resilient state; where external impacts exceed adaptive capacity ($EI>AC$, $\Delta V<0$), the system moves towards a more vulnerable state. This implies that the vulnerability of a system is very closely related to its state, or the state of its attributes considered, respectively. Hence, the system state provides a rough estimate of the system's vulnerability.

An assessment of the overall vulnerability of a system is a multi-step approach. Meaning that investigations of different attributes of a system have to be conducted separately, where complex attributes must be split into sub-attributes. If the attribute of concern is as complex as "livelihood of people" for instance, one must define and analyse the different sub-attributes of the "overall" attribute first. Livelihood might comprise the sub-attributes *health*, *food security*, and *income*.

Hence, a comprehensive vulnerability assessment comprises separate assessments of different attributes of a system (*attributes of concern*) in combination with a trade-off analysis. Ultimately, a narrative description, explaining why which component is changing and how, is an integral part of vulnerability assessments.

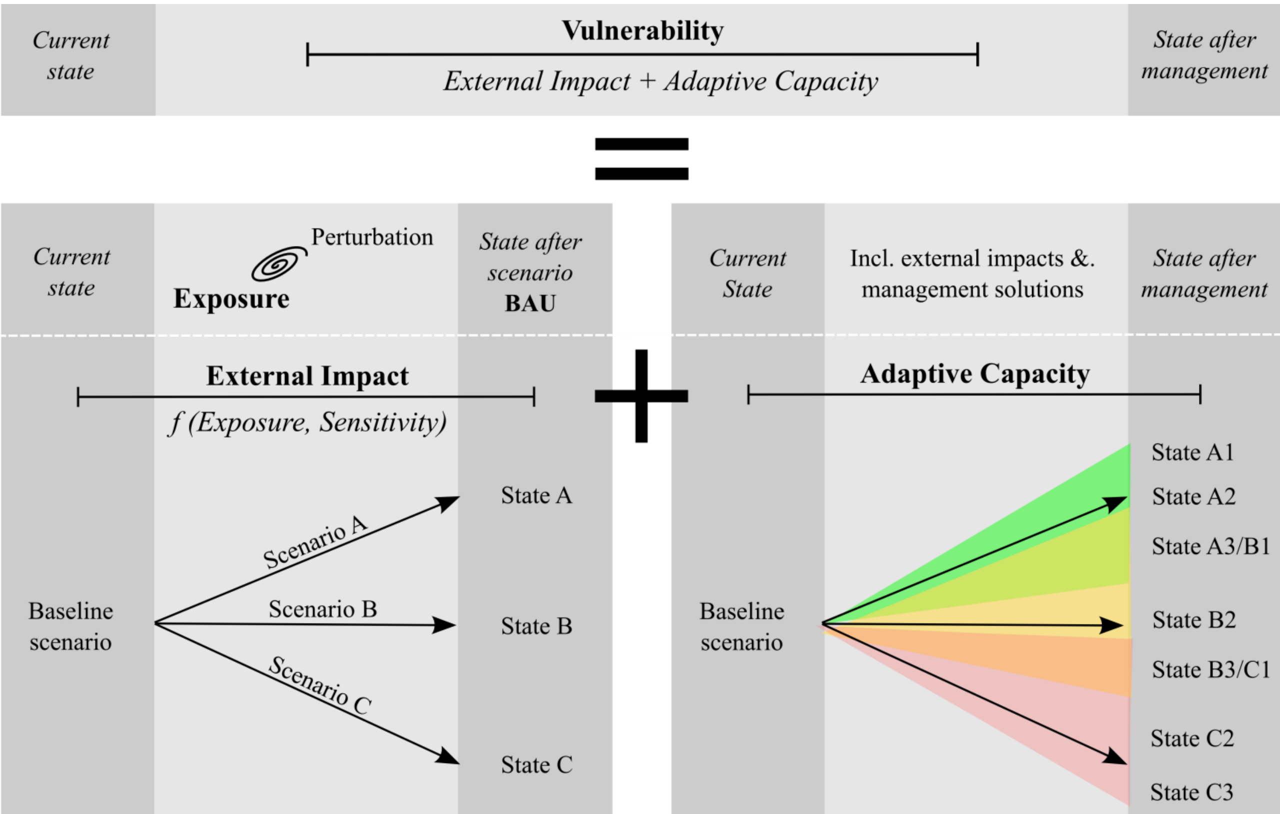


***Figure 3-1:* Vulnerability assessment framework**

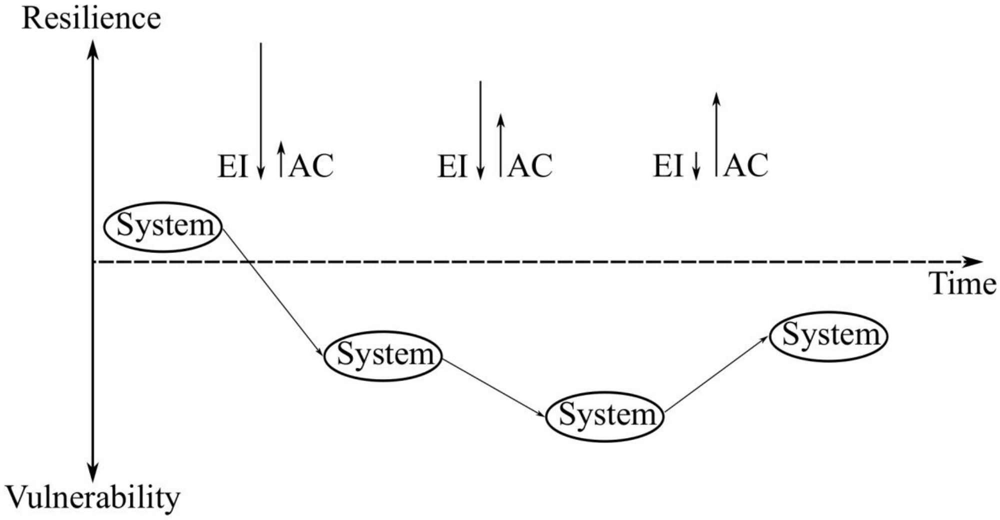


Figure 3-2: System states from vulnerable to resilient

In order to “measure” whether the state of the system is changing under changing boundary conditions, the current state must be determined. Therefore, it is useful to define thresholds of desired and undesired states.

Equation 7 is used to calculate a normalised value of the system state with *x* as the median of the indicator value, *lb* the lower bound (threshold for undesired state), *ub* the upper bound (threshold for desired state), *lbn* the normalised lower bound = 0, and *ubn* the normalised upper bound = 1. Note that the values of system states can be >1 and <0, if the thresholds of the desired and undesired states are not equal. In some cases the thresholds of the desired and the undesired state might be equal and do not represent a range, but a single value.

$$\text{System}_{state} = (x - lb)\frac{ubn - lbn}{ub - lb} + lbn \qquad \text{Eq. 7}$$

For instance, if supply is below the demand, the system can be considered to be in an undesired state and if supply is greater than the demand it is in its desired state. In this case, a value of the state can be assessed by counting how often the system is in the desired and in the undesired state. The value of *ub* is the total number of cases considered, the value of *lb* is 0, and *x* is the number of cases where the system was in its desired state. In the following, the classification shown in Table 3-1 is used to describe the system states in a qualitative way.

Table 3-1: System state classification

Range	System state
0.8 - 1.0	Very good
0.6 - 0.8	Good
0.4 - 0.6	Moderate
0.2 - 0.4	Poor
0.0 - 0.2	Very poor

3.2 Vulnerability Framework

The steps to perform a vulnerability analysis according to the WETwin framework are the following:

1. Precise **definition** of one or more **research questions** (storylines). It is important to define which system attributes (who or what) is vulnerable to what pressure and in what time period.
2. **Identification of quantifiable indicators** and their criteria or thresholds.
3. **Simulation of a baseline scenario** to represent the current state using integrated models.
4. **Scenario building**
   a. Definition of perturbations/stress the system is exposed to (e.g., climate change, population growth etc.).
   b. Definition of management options (adaptive capacity) assumed to mitigate negative impacts.
5. **Scenario simulation** using integrated models.
6. **Quantitative**/qualitative **assessment of the system's vulnerability**

The critical point for the quantification of the three vulnerability components is the definition of quantifiable indicators and their criteria. Quantitative models are used to represent the baseline scenario in order to determine the current state of the system. In the next step the system is exposed to perturbations (external impacts) such as climate change with no change in management "business as usual" (BAU). Three scenarios are applied in the example in Figure 3-1. The external impact is expressed by the difference between the system state(s) after perturbation and the baseline scenario. Management solutions are applied to the three BAU scenarios in order to assess adaptive capacity by comparing the system states including management solutions with the BAU scenarios.

This approach is useful to assess and quantify the impacts of changing drivers and the effectiveness of management solutions by comparison of different vulnerable situations.

3.2.1 Definition of one or More Research Questions (Storylines)

In order to meaningfully address vulnerability, the framework of Füssel (2007) is used. It is important to define which system attributes (who or what) is vulnerable to what drivers and pressures and in what time period. According to this framework, it is important to formulate precise research question(s) that address at least the following dimensions:

1. The *system* of analysis
2. The attribute of *concern* (the valued attribute(s) of the vulnerable system which is exposed to a hazard).
3. The *hazard*, a potentially damaging influence on the system
4. The *temporal reference*, the point in time or time period of interest

An example for such a definition of a vulnerable situation is:

How vulnerable is the food production (2) in the Inner Niger Delta (1) to climate change (3), upstream water management (3) and population growth (3) in the period 2031-2050 (4)?

This question, also called a storyline, is tackled as an example application in the section below.

3.2.2 Identification of Indicators and Their Criteria

In order quantify (to a certain extend) vulnerability components, indicators are required that:

- meaningfully represent the state of the system or the system components under investigation;
- are sensitive to changing boundary conditions;
- can be monitored and quantified by models.

Examples for such criteria are for instance: River runoff, agricultural production, population density, income from a certain source, etc.

Moreover, it is necessary to define indicator criteria and their thresholds. In the context of fresh water supply by a river, the indicator could be river runoff [m^3/s] that can be monitored by flow gauges and modelled by hydrological models. It is sensitive to changing rainfall patterns and/or upstream water management. A criterion for the supply of freshwater would be for instance the minimal flow during the dry season. The definition of flow thresholds are required in order to classify the criterion minimal flows into classes like "good > $75m^3/s$", "moderate <$75m^3/s$ >$50m^3/s$", and "poor < $50m^3/s$".

3.2.3 Simulation of a Baseline Scenario to Represent the Current State

Scenario analysis has the potential to reveal the consequences of human actions or inaction under changing boundary conditions such as climate change. They are suitable tools to anticipate change and to develop strategies to adapt to changing conditions and to assess the impacts of reactive or proactive behaviour. The extent, to which scenarios are useful for planning purposes is determined by their underlying assumptions, the time period considered, and the way how adaptive measures are implemented. While it is rather easy to assess the impacts of climate change on water availability over the next 50 years (neglecting the oftentimes opposing assertions of climate models), it is rather difficult to anticipate the way how societies will adapt to changing conditions during the scenario period (technical solutions, migration etc.). To account for and to implement the dynamic nature of adaptation in scenarios is challenging.

The simulation of a baseline scenario using quantitative model(s) is the basis for a quantitative vulnerability assessment. The model(s) must be able to adequately represent the system states of past and current conditions using the defined indicators. This is necessary in order to:

- observe (simulate) the future system states;
- to have a sound basis for the comparison of current and future system states;
- to determine external impacts; and
- to determine change in vulnerability.

3.2.4 Scenario Building

The scenario building consists of mainly two steps: 1. the definition of perturbations/stress the system is exposed to, and 2. the definition of management options that determine the adaptive capacity to mitigate negative impacts.

a. The definition of perturbations/stress refers to the hazard identified in the storylines. Such perturbations can be for instance, climate change, changes in upstream land and water management, a changing political regime etc. On the one hand this step involves the definition of the elements or drivers that determine changing boundary conditions and on the other hand the translation of scenarios into time series of input data used by the simulation models.

b. Anticipating the consequences of changing boundary conditions (in qualitative terms), the identification of management strategies that could mitigate negative impacts, is the second step in scenario building. Using again the example of fresh water supply by river runoff, a possible management option in case of not sufficient minimal flows could be to make alternative fresh water sources accessible, i.e. from ground water by digging wells or allocation of water from another area by construction of pipelines. Note, that it should be possible to quantify the effects of such measures. However, there must be made a distinction between measures that would theoretically improve the conditions under changing boundary conditions but also followed by an assessment of feasibility (taking into account the institutional and socio-economic capacities).

3.2.5 Scenario Simulation

The final step before a quantitative vulnerability assessment can be performed is the simulation of the scenarios by the model(s) used for the simulation of the baseline scenario. Here, we distinguish between the simulation of:

- The business as usual scenario (BAU), application of projected scenario time series without changes in management (current management).
- The scenarios including projected scenario time series with adapted management (including adaptive measures, management options and solutions).

3.2.6 Quantitative Vulnerability Assessment

The objective of a quantitative vulnerability assessment is basically an attempt to quantify the vulnerability components (*EI, AC, ΔV*) according to equations 3-6. Model results of the scenarios are used to assess changes of system states using the quantifiable indicators, defined in a previous step. In order to assess the current system state, it is necessary to define the desired and undesired system states, where the desired state is oftentimes considered as the resilient state and the undesired state as a vulnerable state. Examples are provided in the chapter "Vulnerability Assessment of the Inner Niger Delta Case Study" below.

3.3 Vulnerability Assessment of the Inner Niger Delta Case Study

3.3.1 The Case Study

The study area is the Inner Niger Delta (IND) in Mali and its upstream catchment in West Africa (Figure 3-3). The IND is situated in a semi-arid region in the Sahelian zone. The entire Upper Niger Basin, including the IND, covers an area of about 350,000 km^2 and stretches from south to north over the Soudano-Guinea, Soudan, and Sahel zones. The catchment is subject to enormous seasonal and inter-annual variation in rainfall and river flow (Zwarts et al., 2005; Zwarts et al., 2006) and rainfall is very unequally distributed in the Upper Niger Basin, where the headwater regions receive up to 2,000 mm of rainfall during the rainy season (July to October) and the northern regions only 200-500 mm. Therefore, the delta's main source of water is provided by discharges of the Rivers Niger and Bani.

The Inner Delta is a seasonally inundated floodplain, a network of tributaries, channels, swamps, and lakes providing vital habitats supporting livelihoods in fishing, farming, and stock farming (Zwarts et al., 2006) for currently 1.5 million people. In the literature, the area of the Inner Delta varies from 36,000 km^2 (Kuper et al., 2003) to 80,000 km^2 (Schuol et al., 2008). According to

(Mahé, 2009), the northern part of the IND covers an area of 15,000 km^2 and the southern part 58,000 km^2. Similar discrepancies are reported for maximum flooded surface areas. Here, the values range between 10,000 and 20,000 km^2 (Kuper et al., 2003), 10,000 and 45,000 km^2 (Schuol et al., 2008), and 15,000 km^2 as stated by (Dadson et al., 2010). (Mahé, 2011) investigated NOAA satellite images to estimate maximum flooded surfaces in the 1990s. They report a range between 6,150 km^2 and 22,360 km^2 for this period. Reasons for these discrepancies are different time periods considered by the different studies and the distinction of a northern and a southern part of the IND, not recognized by all authors.

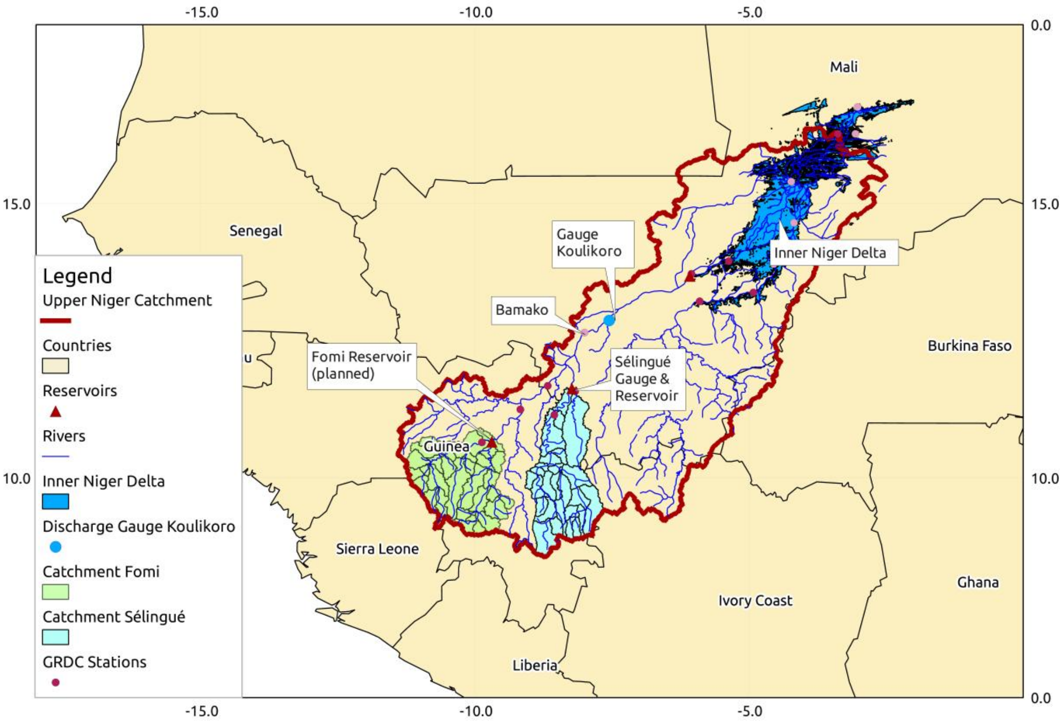


Figure 3-3: Map of the Upper Niger Basin including the Inner Niger Delta

3.3.2 Definition of a Research Question (Storyline)

In order to meaningfully address vulnerability, it is important to formulate a precise research question. The example used in this study is:

How vulnerable is the food production in the Inner Niger Delta to climate change, upstream water management and population growth in the period 2011-2050?

3.3.3 Identification of Indicators and Their Criteria

Due to the strong functional relationship between wetland inflow, inundation patterns, and food production, a suitable indicator is the *potentially usable area for floating rice production*. This area depends on inundation depth and duration and is determined by the following criteria:

- inundated by at least 90 days
- with a water level between 1-2 metres.

3.3.4 Simulation of a Baseline Scenario to Represent the Current State

The eco-hydrological model SWIM (Soil and Water Integrated Model, Krysanova et al., 2005), equipped with a reservoir (Koch et al., 2011) and an inundation module developed for this purpose, was used to simulate runoff and wetland inundation in the Upper Niger Basin including the Inner Delta. The time period representing the baseline scenario is the period 1970-2001.

3.3.5 Scenario Building

a. A set of three climate-driven scenarios using the statistical regional climate model STAR (Orlowsky et al., 2008), assuming temperature increase by the year 2050 of 0.0°C, 1.0°C, and 2.0°C, were combined with two population growth scenarios (0.7% and 2.6% annual growth rate) and three water management scenarios 1. without reservoirs; 2. with Sélingué (current situation); 3. with Sélingué and planned Fomi in the Niger headwaters in Guinea.

b. Irrigated rice has with 5-6 t/ha a much higher productivity than floating rice with 1-2 t/ha. According to Mali's recent development program of the IND (PDD-DIN, 2011), the area for irrigated rice shall be extended to 65,000 ha. This additional rice production measure in the IND determines adaptive capacity (*AC*) but will certainly lead to conflicts between different interest groups and jeopardise the Ramsar site status. However, ignoring this conflict, a dynamic increase of the irrigation area from 2011 with 1,620 ha to 2050 with 65,000 ha is presumed.

3.3.6 Scenario Simulation

The impacts of climate change on runoff, wetland inundation, and rice production were simulated by using 100 climate realisations (representing a range of dry to wet conditions) of each scenario. Additional information about modelling and scenario details is provided in Liersch et al., (2012).

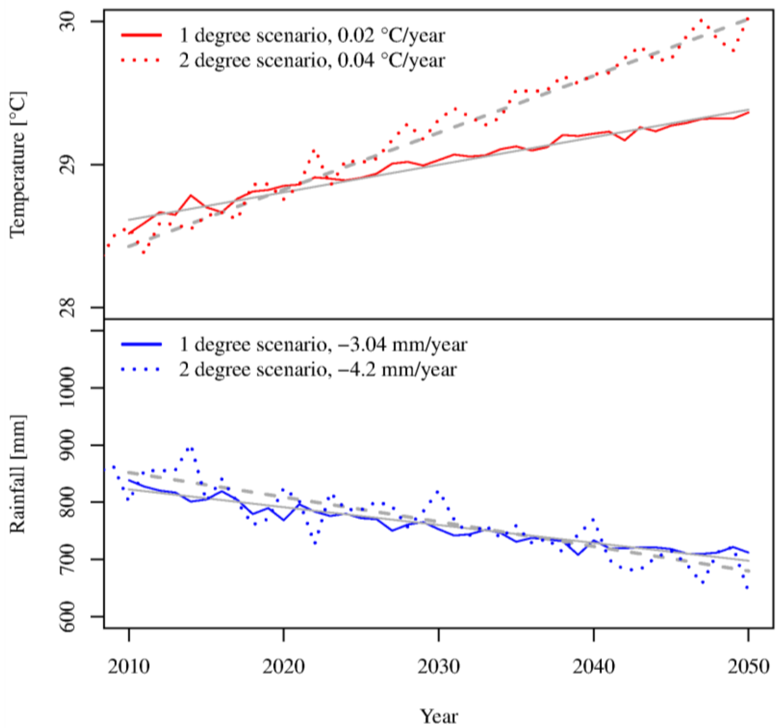


Figure 3-4: STAR temperature and rainfall projections for the Upper Niger Basin, averaged over the region

Figure 3-4 shows the temperature and rainfall trends of the 1°C and 2°C scenarios as projected by the model STAR. The impact of climate change scenarios on river runoff shows Figure 3-5. Figure 3-6 illustrates the impact of reservoir management on river runoff.

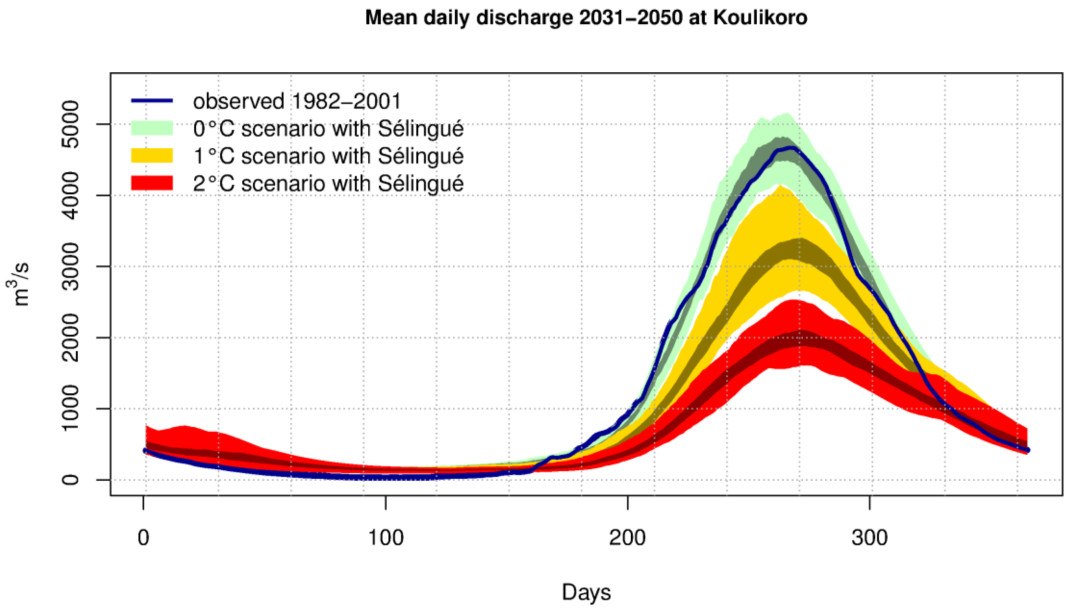


Figure 3-5: Climate change impacts on runoff at gauge Koulikoro

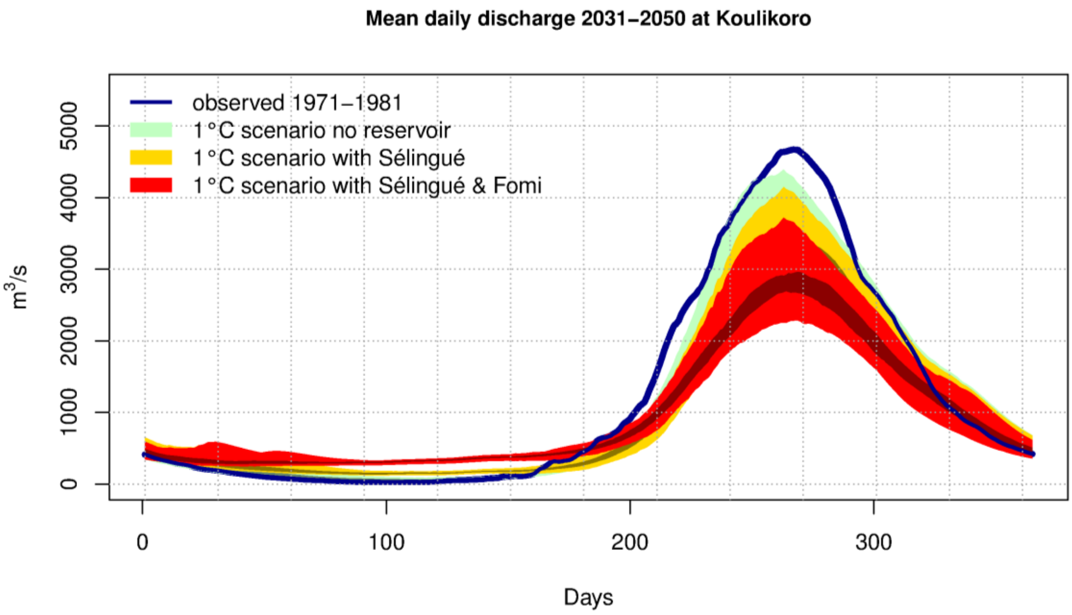


Figure 3-6: Reservoir management impacts on runoff at gauge Koulikoro (1°C scenario)

3.3.6.1 Business as Usual (BAU)

Food demand for all BAU scenarios was calculated assuming annual cereal requirements of 214 kg/capita (RDM, 2010), represented by rice equivalents, the main staple food in the IND. The potential production was calculated as the product of the simulated usable area and a productivity of 2 t/ha for floating rice.

3.3.6.2 *Scenarios Including Adaptive Capacity*

In the scenarios including adaptive capacity, additional 65,000 ha of potential bourgou pasture habitats (defined as areas flooded by 3-5 metres with a duration of >5 months) will be converted into irrigated rice fields with a productivity of approximately 5 t/ha. A dynamic increase of the irrigated rice area from the year 2011 with 1,620 ha to the year 2050 with 65,000 ha is presumed.

3.3.7 Quantitative Vulnerability Assessment

The target is to satisfy the rice demands of the growing population with rice produced within the IND. Therefore, the desired state is a state where sufficient rice is produced, the undesired state where the supply is lower than the demand. It is a dynamic function depending on the number of people per time step considered. Accordingly, the values of the thresholds of desired and undesired state are changing over the simulation period. The state can be assessed by counting how often the system was in the desired and in the undesired state.

During the baseline scenario in the period 1971-2000, simulated rice demands exceeded the supply from simulated floating rice areas in 12 out of 30 years. Accordingly, a value of 0.6 is calculated for the current state using the normalising function (Equation 7), illustrated in Figure 3-7 a) and b). A system in its desired state would have a value of 1.0. According to Table 3-1, the current system state is exactly on the threshold between moderate and good. The same approach was applied to quantify and evaluate the vulnerability components (external impacts, adaptive capacity, and system states) for the rice supply and demand scenarios.

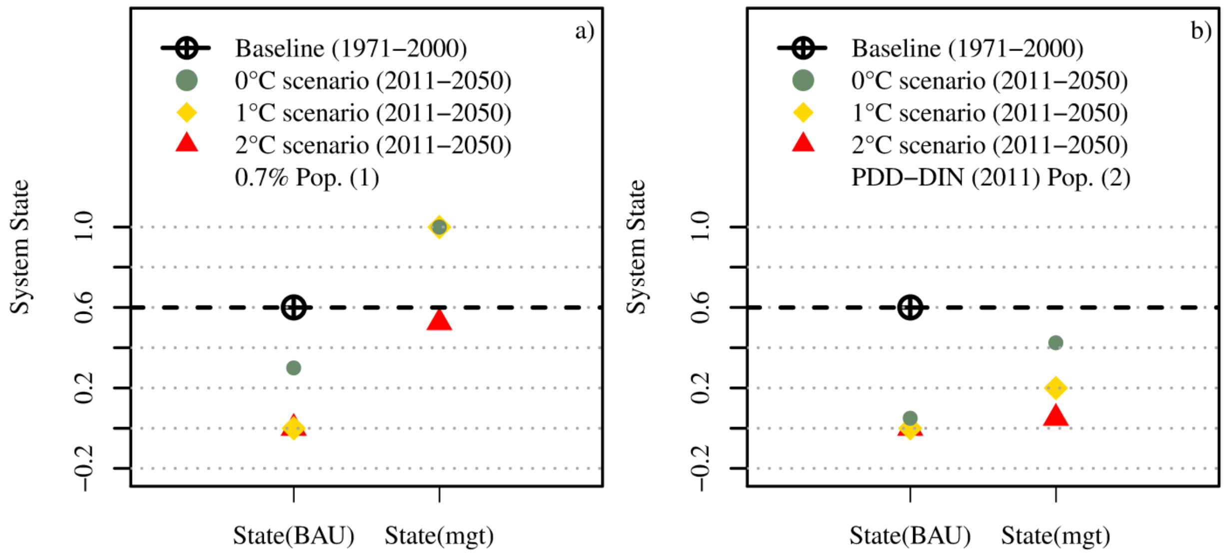


Figure 3-7: Rice production, external impacts and adaptive capacity. a) population growth scenario Pop 1. b) population growth scenario Pop 2. Both figures include the combined impacts of Sélingué and Fomi reservoirs.

A comprehensive overview, comparing 12 scenarios, is shown in Table 3-2. Abbreviations used to address the scenarios are: 0°C, 1°C, and 2°C for the climate scenarios; *Pop 1* for the moderate population growth scenario assuming a growth rate of 0.7%, *Pop 2* for the population scenario projected by (PDD-DIN, 2011) with a much higher growth rate (2.6% in average); *Seli* for the management scenario including the Sélingué dam, and *Seli&Fomi* for the management scenario including both dams, Sélingué and Fomi.

Figure 3-8 illustrates the impacts of population growth, climate change, and reservoir management on rice demands and supply without considering adaptive measures. In Figure 3-7 a) and b), these scenarios refer to the $State_{(BAU)}$ columns. Figure 3-9 is based on the same assumptions but demonstrates the impacts of the adaptive measure (increase of irrigated rice area by 65,000 ha by 2050) and refers to $State_{(mgt)}$ columns in Figure 3-7 a) and b). Thus, Figure 3-7 a) visualises the system states including (mgt) and not including (BAU) adaptive measures for three climate scenarios under the combined impact of Sélingué and Fomi dams assuming the moderate population growth scenario (*Pop 1*) with a growth rate of 0.7%. Figure 3-7 b) addresses the same conditions but assuming the extreme population growth scenario (*Pop 2*).

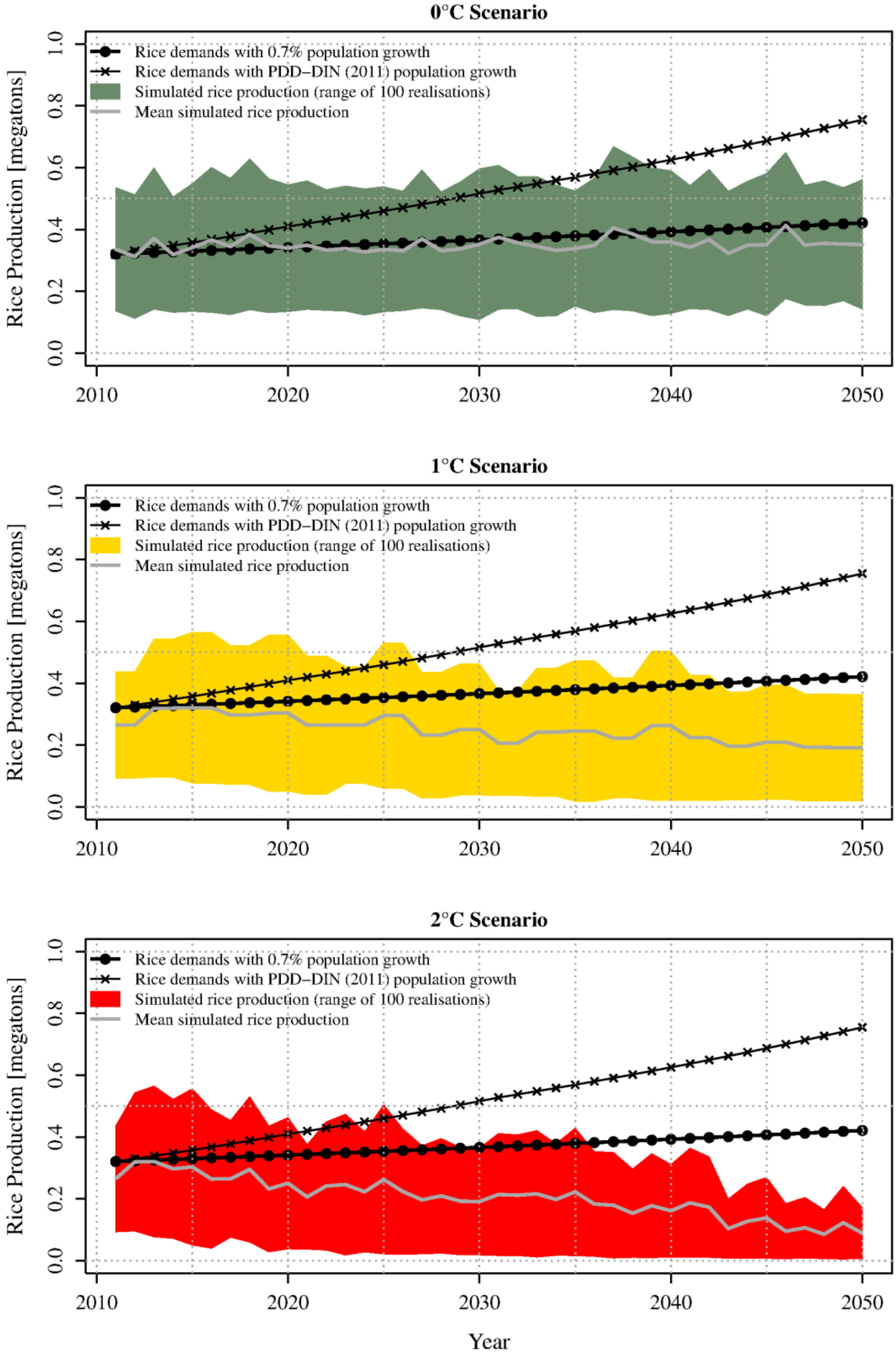


Figure 3-8: Rice demands and potential floating rice production

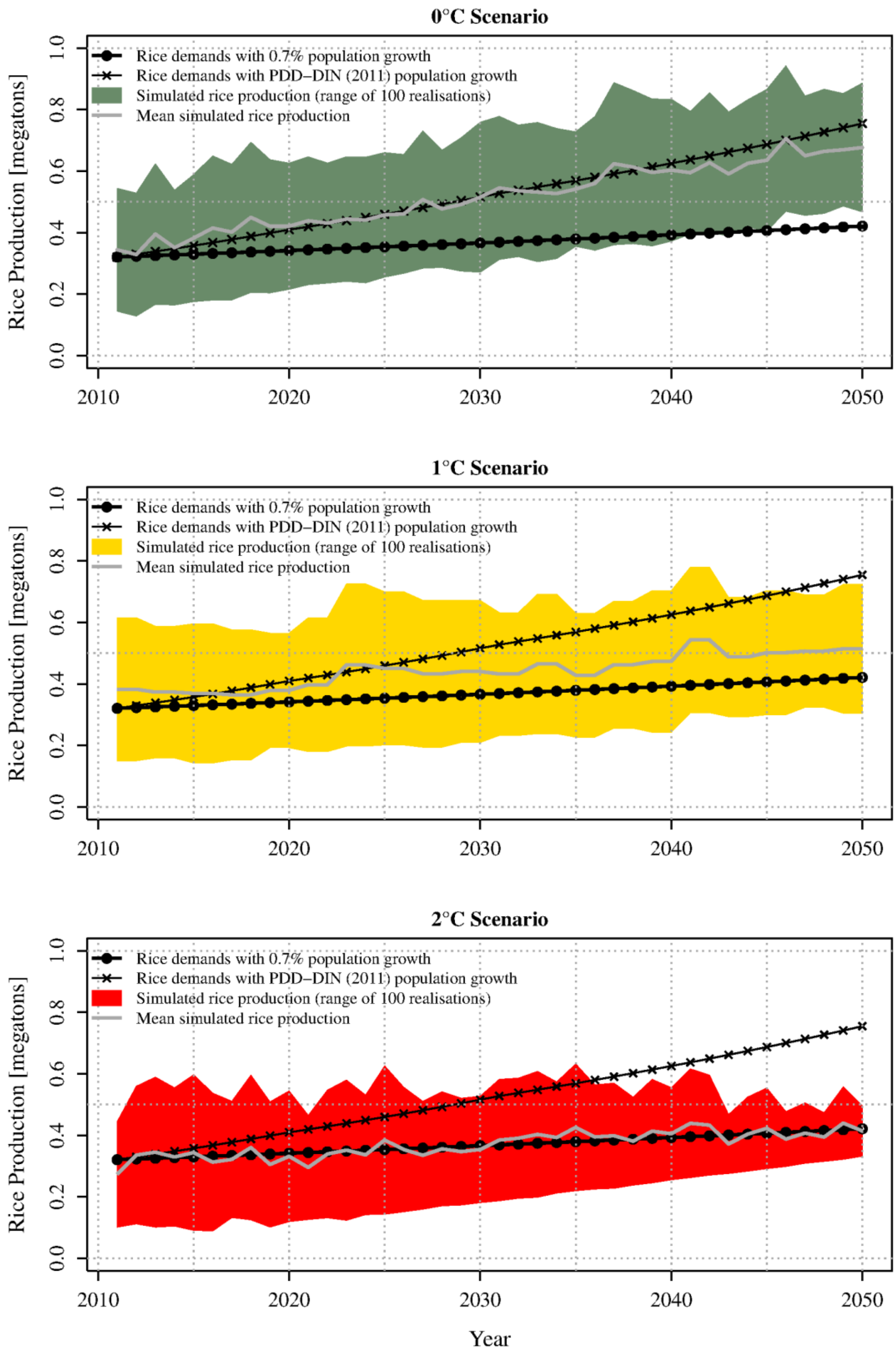


Figure 3-9: Rice demands and potential floating rice production with an additional increase of irrigated rice fields (65,000 ha by the year 2050)

The desired state is defined as potential rice production > average production of 100 realisations. The 1°C scenario is used as an example to interpret the values in Table 3-2. The combined external impacts (1°C, *Pop1*, *Seli*) of the 1°C scenario, the moderate population growth, and the Sélingué dam moves the system from the current state value of 0.6 to 0.3. In other words, from a state in between moderate and good (current) into a poor state ($State_{(BAU)}$). The estimated external impact is -0.3 (low). When the adaptive measure is included, the system state improves significantly from the poor into the desired state (very good), or expressed in numbers from 0.3 ($State_{(BAU)}$) to 1.0 ($State_{(mgt)}$). The estimated value for adaptive capacity is 0.7, or to be more precise it is a value larger or equal to 0.7, because it is limited by the upper value of the desired system state of 1.0, which is reached in this case. Consequently, the difference between the current and the scenario state, including external impacts as well as adaptive capacity, is 0.4, which is also defined as ΔV. The positive value implies an improvement of the situation and thus, a decrease in vulnerability. Hence, moderate population growth, climate change as well as upstream water management are projected to have negative impacts on food supply based on floating rice in the Inner Niger Delta in the period 2011-2050. In 12 out of 40 years, the rice demand is higher than the simulated supply. Compared to the current (baseline) situation, this is a deterioration and highlights the need for adaptation. The implemented simulated measure was the extension of the area for irrigated rice by 65,000 ha until 2050, to the disadvantage of bourgou pastures and flood forest habitats. This measure outbalances the negative external impacts in the corresponding scenario and thus guaranteed the supply of rice for the moderately increasing population in the IND.

When the impacts of the Fomi dam are included (1°C, *Pop 1*, *Seli&Fomi*), the system state drops from 0.6 to 0.0 (undesired state). In all years during the simulation period, the rice demand is higher than the simulated supply. The value of the external impact is therefore -0.6 (moderate to high), hence stronger negative than without the Fomi dam. The simulated adaptive measure is, as in the previous scenario, able to mitigate the negative external impacts. The system state increases from 0.0 (undesired state) to 1.0 (desired state), meaning that in all years of the simulation period, the simulated rice supply was higher than the demand. The calculated value of *AC* is 1.0, although it is the same measure as in the previous example. The change in vulnerability is also 0.4 because the system is moved from the moderate/good state into the desired or very good state.

The other two 1°C scenarios demonstrate the strong impact of the increasing food demands under the assumption of a rapid population development as projected by PDD-DIN (2011). The external impact forces the system states in both cases into an undesired state. Only in 3 out of 40 years (1°C, *Pop 2*, *Seli*) and in no year in the (1°C, *Pop2*, *Seli&Fomi*) scenario, the simulated rice supply satisfied the requirements. Noticeable is the difference of the effectiveness of the adaptive measure. In the scenario including only the Sélingué dam, the system state $State_{(mgt)}$ is with 0.125 a bit closer to the absolute undesired state than the scenario including both dams (0.2). Similar behaviour can be observed in the 0°C and 2°C scenarios. An explanation for this is that, although the Fomi dam has a negative impact on peak discharges during the rainy season leading to a decrease of the total flooded surface area, it facilitates at the same time the conditions that are suitable for floating rice. Thus, the production of floating rice is potentially higher in scenarios including the Fomi dam and sometimes, it can be the ounce that tips the scales when working with discrete thresholds.

Figure 3-9 and Table 3-2 demonstrate that an extension of the irrigated rice area of 65,000 ha by 2050 (to the disadvantage of bourgou pasture area and flooded forests), would theoretically “solve” the rice production deficit in all climate change scenarios for the 0.7% population increase scenario. Even in the extreme scenario with a temperature increase of 2°C, the simulated supply is maintained until the end of the simulation period, provided that the environment remains suitable for rice production i.e., sufficient resources (water, energy, finances) and human, organisational, and institutional capacity is sufficient to sustainably keep the rice production going.

However, it should be stressed again that the authors do not suggest to implement this measure without considering and investigating the impacts on other agricultural sectors, the environment, and social conflicts. Furthermore, it must be investigated if this conversion measure can be implemented at all and whether potential bourgou pasture habitats are available for conversion to irrigated rice areas under various scenario conditions. *These all demand to move to Multi-Criteria Decision Analysis where the objective is to identify the best compromise management strategy by taking into consideration* ***all*** *conflicting interests and objectives.*

Table 3-2: Estimated values of vulnerability components (rice production)

Scenario	EI	$State_{(BAU)}$	AC	$State_{(mgt)}$	ΔV
Current state = 0.6					
0°C, Pop 1, Seli	-0.350	0.250	0.750	1.000	0.400
0°C, Pop 1, Seli&Fomi	-0.300	0.300	0.700	1.000	0.400
0°C, Pop 2, Seli	-0.575	0.025	0.350	0.375	-0.225
0°C, Pop 2, Seli&Fomi	-0.550	0.050	0.420	0.425	-0.130
1°C, Pop 1, Seli	-0.300	0.300	0.700	1.000	0.400
1°C, Pop 1, Seli&Fomi	-0.600	0.000	1.000	1.000	0.400
1°C, Pop 2, Seli	-0.525	0.075	0.050	0.125	-0.475
1°C, Pop 2, Seli&Fomi	-0.600	0.000	0.200	0.200	-0.400
2°C, Pop 1, Seli	-0.575	0.025	0.575	0.600	0.000
2°C, Pop 1, Seli&Fomi	-0.600	0.000	0.525	0.525	-0.075
2°C, Pop 2, Seli	-0.600	0.000	0.025	0.025	-0.575
2°C, Pop 2, Seli&Fomi	-0.600	0.000	0.050	0.050	-0.550

4 Multi-Criteria Decision Analysis

The *objective* of this chapter is to provide guidance for identifying the best compromise solution(s) for the multi-objective problem of management and restoration of wetlands. For this purpose a **Decision Support Framework** (DS Framework) has been set up. This DS Framework actually supports the implementation of those steps of the Conceptual Framework, which are in the focus of the WETwin project (Figure 2-3). The descriptions of different stages of the DS Framework are illustrated by examples that are given in light-blue boxes. These examples are related to the GaMampa wetland, which was one of the case studies of the WETwin project.

The DS Framework and its methodology are based on the Trade-off Analysis approach. Trade-off analysis consists in evaluating effects of alternative development strategies (solutions) for a given wetland in order to make informed decisions about possibilities (and impossibilities) for sustainable, multi-functional use of wetland services (Secretariat of the Convention on Biological Diversity, 2007). Proper inclusion of all values of the wetland in trade-off analysis and decision-support systems is essential for achieving “wise use” of wetlands, i.e., best compromise management solutions that are ecologically sustainable, socially acceptable, and economically sound (de Groot et al. 2006).

The proposed methodology provides framework for a *toolbox* (Funk et al., 2012). This toolbox contains various modelling tools, qualitative assessment techniques, indicator sets and specialised decision support tools that have been selected/developed for supporting the different steps of the Decision Support Framework. The toolbox has a flexible structure, which allows the integration of alternative models and tools, thus making it possible to adapt the toolbox at different sites. One of the most important tools in the toolbox is the Multi-Criteria decision Analysis (MCA) tool, which helps ranking alternative management solutions on the basis of the preferences of stakeholders. The recommended MCA tool is the *mDSS* software developed by the MULINO EU project (Giupponi, 2007). The hereby described Decision Support Framework has been made compatible with the specific needs of the mDSS, though the concept and basic structure of the proposed methodology allows the integration of other MCA tools as well.

The trade-off analysis based Decision Support Framework of WETwin has been developed from the methodology proposed by Gamboa (2006) and Paneque Salgado et al. (2009). The components and structure of the DS Framework is presented on Figure 4-1.

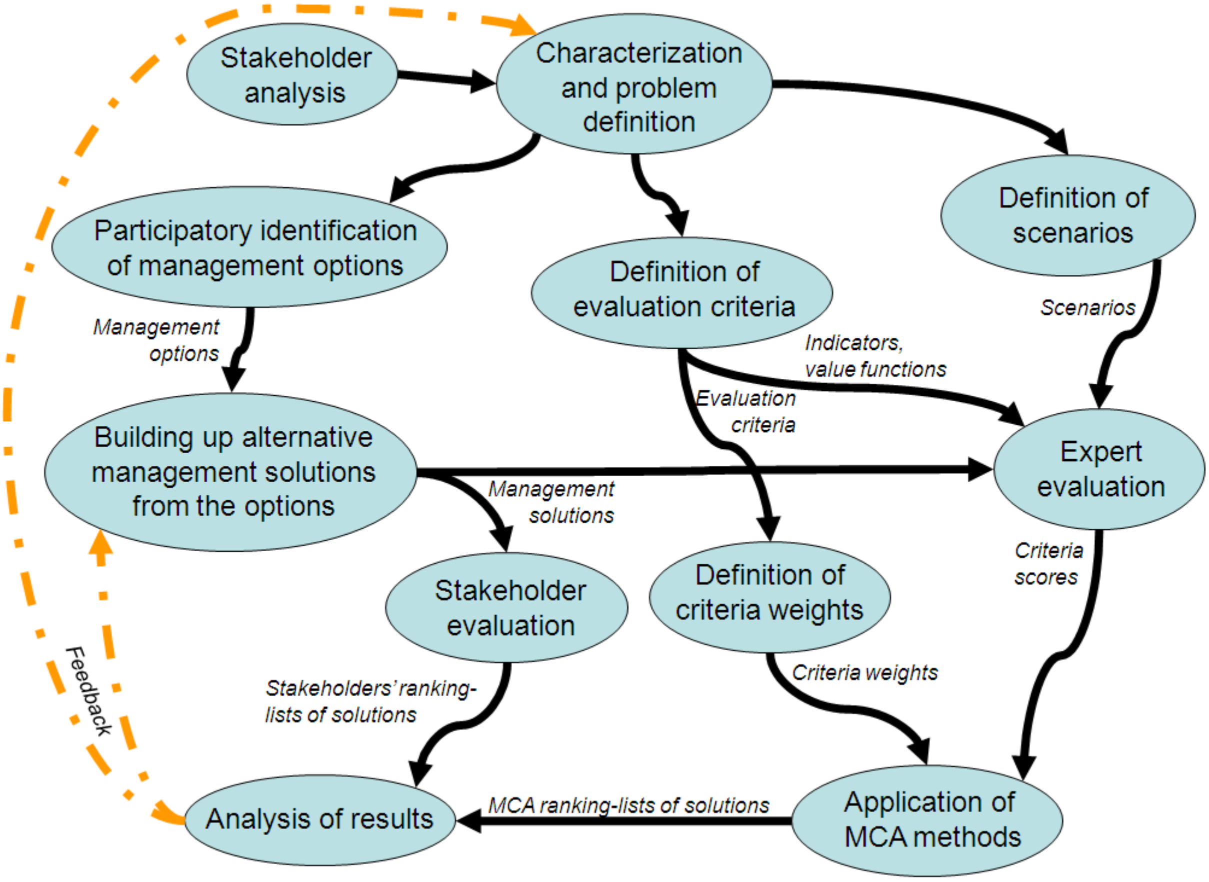


Figure 4-1: Decision Support Framework for supporting integrated wetland management

The following sections introduce the components of the framework in more details.

4.1 Stakeholder analysis

Stakeholder involvement plays a fundamental role in the decision support process. Knowledge, opinions and preferences of stakeholders are requested at several stages. Stakeholder involvement has to be organized on the basis of the results and conclusions of *stakeholder analysis*. Such an analysis should seek answers to the following type of questions:

- Who are the stakeholders interested in the use and development of the wetland?
- What sectors do these stakeholders represent?
- Which ecosystem services are the different stakeholders interested in?
- What conflicts do exist between the different stakeholder groups?
- What are the objectives of the stakeholders with regard to the management and development of the wetland?

Stakeholder analyses with regard to the WETwin case studies and a generic strategy for stakeholder engagement are presented in van Ingen (2010).

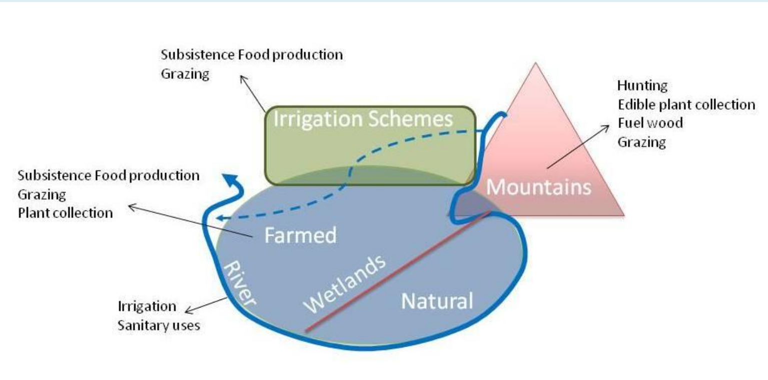
4.2 Characterisation and problem definition

This guideline is based on the *Ecosystem Services* approach for the characterisation of the natural and socio-economic status of wetlands. Identification of Ecosystem Services of the study sites has been carried out following the methodology given in the Millennium Ecosystem Assessment (Finlayson et al., 2005) and The Economics of Ecosystems & Biodiversity (TEEB, 2010) projects. Characterisation of wetland management structure and practice and institutional capacities at the WETwin case is given in Ostrovskaya et al. (2011).

Characterisation is followed by the identification of major environmental, livelihood and institutional problems at the wetlands. Cause-effect mechanisms behind the problems are advised to be explored with the help of the Driving-forces, State, Impact and Responses (DSIR) methodology (OECD, 1994; UNCSD, 1996; Becker, 2005; Soncini-Sessa 2005). The DSIR methodology also helps in screening measures (responses) with which the problem can be solved. Information and data for characterisation and problem definition have to be collected from multiple sources: stakeholders, literature and field measurements. Characterisation of natural and socio-economic status, and the DSIR analyses with regard to the WETwin sites are given in Zsuffa et al. (2010) and Zsuffa & Cools (2011).

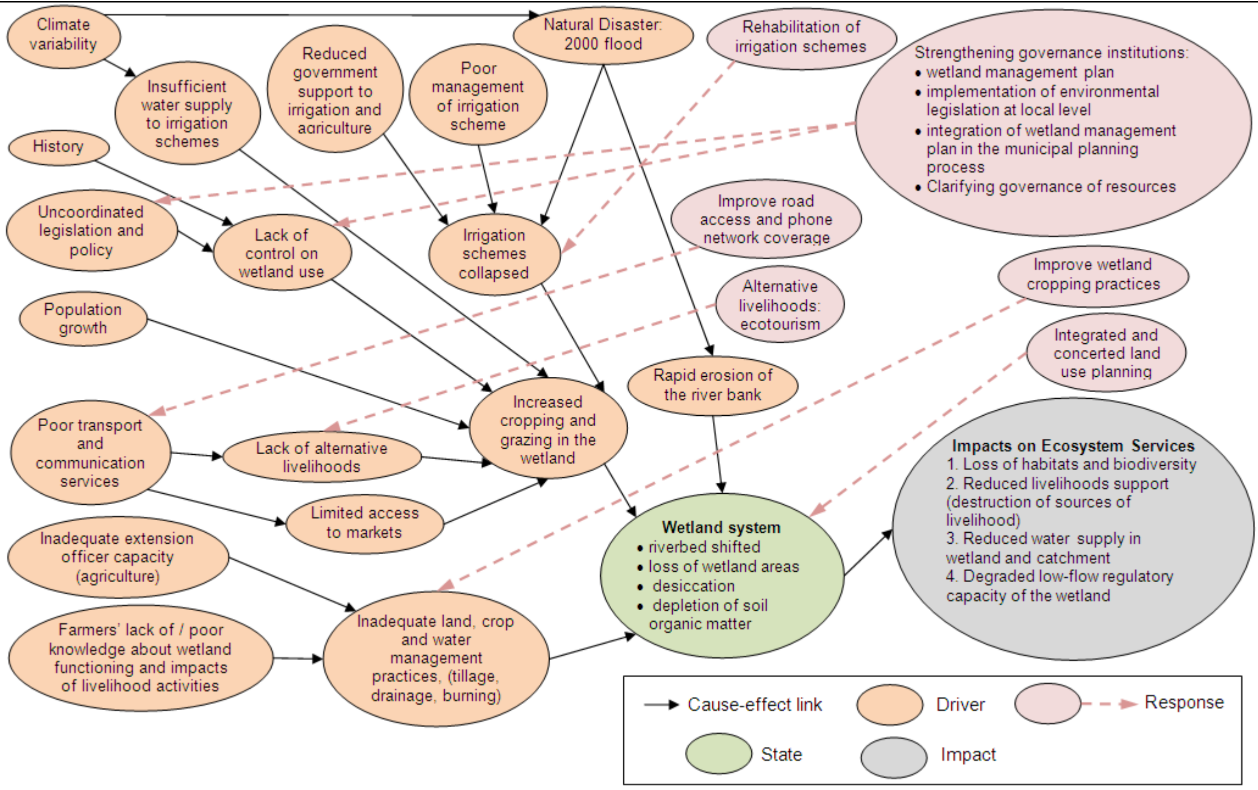
Example 1: Characterisation, problem definition and stakeholder analysis at the GaMampa wetland

The GaMampa wetland is located along the Mohlapitsi river, a perennial tributary to the Olifants river, in the Limpopo province of South Africa. Initially covered by reeds and sedge marshes used by the local community for grazing and collection of crafting and building materials, the wetland has been progressively encroached by maize cropping over the past 15 years, raising concerns about the ecosystem integrity and sustainability of its uses. The remaining natural wetland areas is fragmented in 3 major reed marshes formations, with patches of diverse wet grasslands and meadows along the river bed. Driving forces behind agriculture encroachment include the degradation of small-scale irrigation schemes infrastructures, changes in river bed after a major flood in 2000, and decreasing institutional control over wetland resources. The major trade-off, with regard to the management of the site, lies between food production and ecosystem integrity.

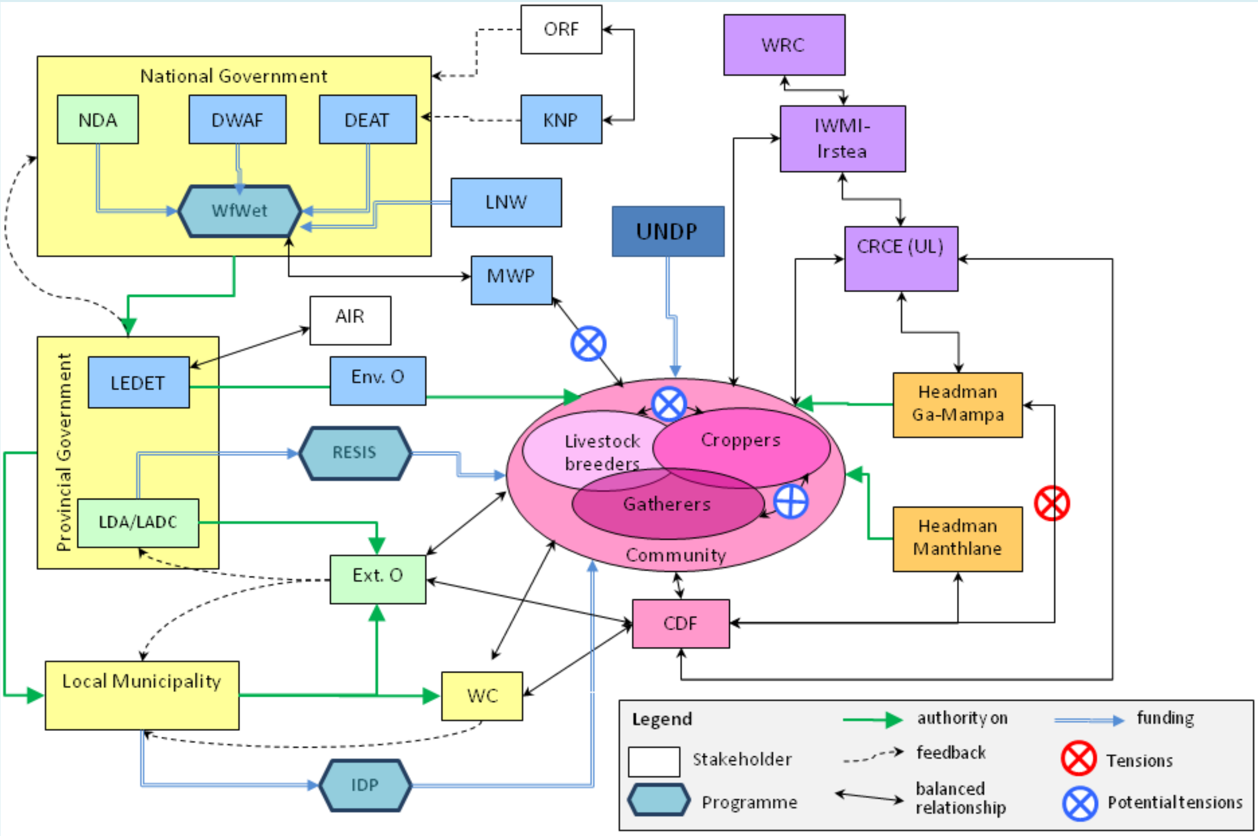


Ga-Mampa valley resources system

The Ga-Mampa wetland



Driver-State-Impact-Response (DSIR) analysis at the GaMampa wetland



Stakeholder analysis at the GaMampa wetland

It is important to extend problem analysis to the future as well by assessing the impacts of external perturbations (e.g. climate change, population growth) on the wetland and on its ecosystem services (see Chapter 3).

4.3 Participatory identification of management options

Management options (or 'Responses' according to the DSIR terminology) are different technical, land use, institutional and legal strategies for improving the ecosystem services of wetlands. Management options are thus brief, sector-specific ideas for the management of the wetland. Initial identification of options is carried out during the DSIR analysis. Options are often initiated by the stakeholders themselves.

Detailed information about potential management options identified for the WETwin case studies is provided in Johnston & Mahieu (2012).

4.4 Building-up alternative management solutions from the options

Management options form the building blocks for the *management solutions*, which are more elaborated concrete plans for the development of the system. Alternative management solutions, developed for the study sites, will be subjected to evaluations and multi-criteria analysis in the later stages of the DS Framework.

The process can be divided into three steps:

1. Select the options that will build up the solution
2. Concretize the solution by defining the parameters of the selected options
3. Check the compatibility of the selected options (It may happen that the implementation of a certain option makes the implementation of an other one impossible.)

A finite number (5-10) of alternative management solutions are proposed to be built-up. It is recommended that the set of alternatives are distributed along the trade-offs identified between the ecosystem services of the wetland[1]. This means that two types of solutions are aimed to be built up:

- Solutions representing the extremes of the trade-offs. In other words: solution favouring certain ecosystem services (and as such certain stakeholders); e.g. agriculture, fisheries, biodiversity etc.
- Solutions representing compromises between the conflicting ecosystem services

At first it is recommended to build up management solutions from non-institutional options such as land use changes, water regime control, pollution load reduction, water intake, and/or other 'technical' strategies. These solutions will be evaluated using either models or expert judgement (as described in the following steps of the framework). One of the objectives of evaluations will be to reveal whether the implementation and operation of the solution is institutionally and legally feasible or not, and if not then what institutional and legal options have to be added to the solution in order to make it feasible. This does not mean that institutional management options are less important to consider but that they are not integrated at the same stage of the process.

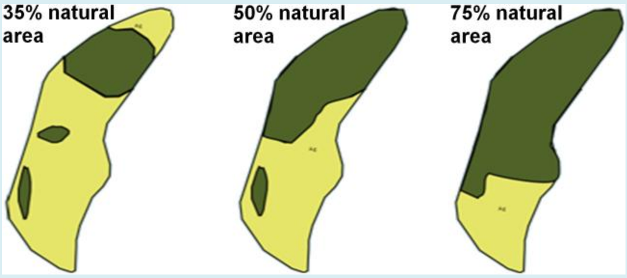
[1] These trade-offs were identified for each WETwin site in Zsuffa et al., (2010) and Zsuffa & Cools (2011)

Example 2: Building up alternative management solutions for the GaMampa wetland

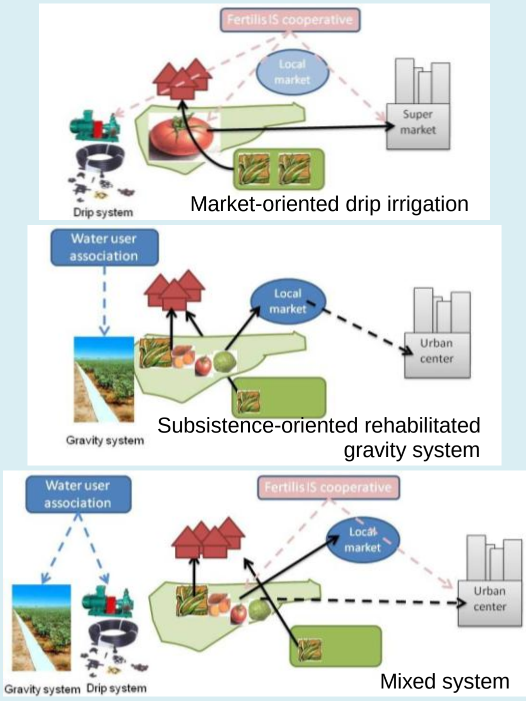
Management options

Management options were formulated from meetings with external and local wetland stakeholders based on DSIR analysis. They deal with the Ga-Mampa valley resources system as a whole, not only wetland issues, and are organized in groups reflecting four development objectives:

- Agricultural development: Rehabilitation of irrigation schemes and wetland cropping practices
- Conservation of natural resources: integrated and concerted land use planning, including integration of livestock, and land conservation infrastructures
- Alternative livelihoods opportunities: Eco-tourism development; investments in agro-processing; improved road access and phone network coverage
- Governance of natural resources: local resources management institutions; integration of wetland management plan in the municipal planning process; and implementation of environmental legislation at local level.



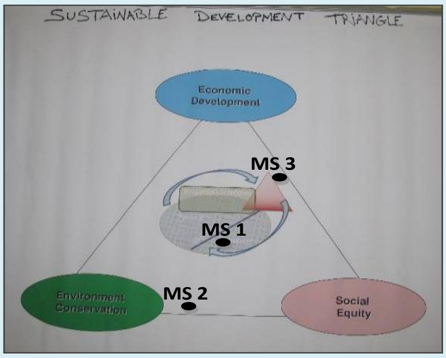
Alternative options for wetland use



Alternative options for rehabilitation of the irrigation scheme

Management solutions

Management solutions were elaborated by combining management options addressing different management issues. On the basis of stakeholder preferences and the practicality of implementation, the research team identified four solutions, chosen to emphasize each of the three pillars of sustainable development (economic development, environment conservation and social equity) plus a balanced integrated solution. At a workshop in March 2011, stakeholders discussed proposed solutions and elaborated their own solutions, in order to fulfil a defined objective. The three new solutions are mapped in the sustainable development triangle in the opposite figure.



Map of MS with regard to sustainable development pillars

Options	MS1	MS2	MS3	CON.	ECO.	SOC.	INT.
Rehabilitation of irrigation schemes	Drip + gravity (repaired)	Drip + gravity (improved)	Drip IS com.	Drip + gravity (repaired)	Drip IS commercial	Gravity subsistence	Drip + gravity (repaired)
Wetland use	Not specified	50% natural	50% natural	75% natural	35% natural	50% natural	50% natural
Livestock	current	Grazing control	Feedlot	current	Grazing control	current	Grazing control
Wetland cropping practices	current	improved	improved	improved	current	current	improved
Eco-tourism	Yes	Yes		Yes	Yes	Yes	Yes
Land conservation		Gabions					
Local institutions	Specialized committees	Specialized committees	Integrated committee	Integrated committee	Specialized committees	Integrated committee	Integrated committee
Wetland management plan	Local plan	Coordinate d gov. plan	Coordinate d gov. plan	Coordinate d gov. plan	Coordinated gov. plan	Local plan	Local plan
Environmental legislation	Identified office Appropriate means	Identified office Appropriate means	Identified office Appropriat e means	Identified office Appropriat e means	No office in charge	No office in charge	Identified office Appropriate means

Information about management solutions identified for the other WETwin case studies is provided in Johnston & Mahieu (2012).

4.5 Definition of evaluation criteria

Evaluation criteria refer to value system(s) used by stakeholders for evaluating a management solution. Criteria should be selected in order to reflect stakeholders' values (or interests) (De Marchi et al. 2000). The applied criteria are aimed to cover the four dimensions of sustainability as defined by the HELP initiative of the Unesco: Hydrology, Environment/Ecology, Livelihood and Policy (UNESCO, 2005). A preliminary list of criteria can be prepared by researchers but must be validated by stakeholders.

In this DS Framework criteria are linked to ***indicators***[2]. Indicators refer to variables that describe in a synthetic form the economic, social, physical, ecological etc. functioning of the system under different boundary conditions. These boundary conditions can represent the current conditions, a business as usual (BAU) scenario (future impacts of external perturbations (see section 4.6) but assuming no change in management) and a management solution combined with external perturbations. Models and other assessment tools play a key role in quantifying indicators.

More information about indicators and about their assessment is given in section 4.7.1.

[2] On the construction of sustainability indicators and indices see for example Boulanger 2008 (http://sapiens.revues.org/index166.html). The RUBICODE project developed an inventory of indication approaches and indicators developed and applied in different ecosystems including wetlands (Feld et al., 2007; 2010).

The link between criterion and indicator is the *value function*, which scales the raw indicator value between 0 and 1. The so-derived value is the *criteria score*. 0 means that the investigated management solution is unacceptable or very bad from the point of view represented by the indicator/criterion; 1 means that the solution is optimal from this point of view. Thus, the role of value functions is to capture the *target state*. These functions give the indicators a normative direction in relation to the planned management solutions. Translating indicator values into criteria scores is also called *normalization*.

Normalization enables to compare and combine raw evaluation results (indicator values), which are otherwise non-commensurable. Value functions enable to commensurate even quantitative and qualitative indicators as it is indicated by Figure 4-2.

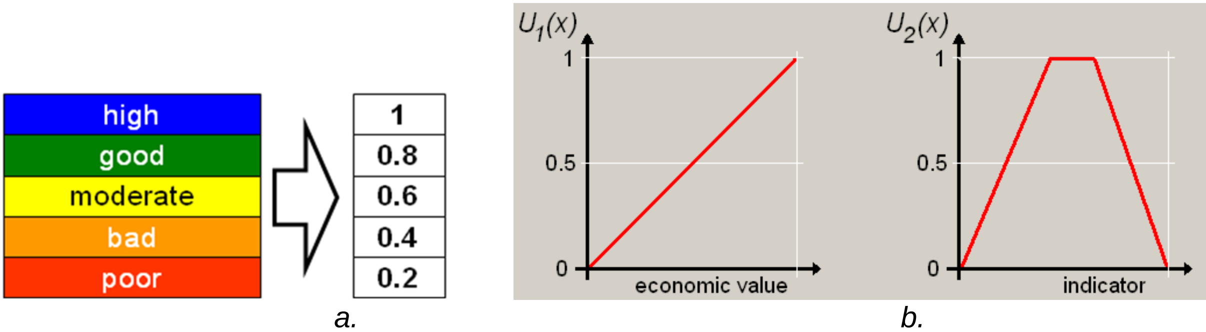


Figure 4-2: Examples for value functions: a.) for qualitative indicators; b.) for quantitative indicators

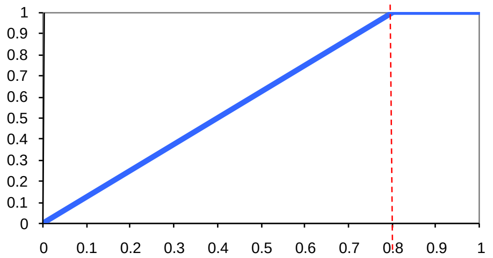
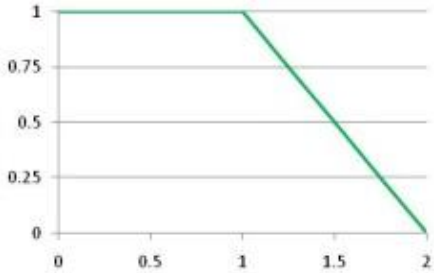
Example 3: Definition of indicators and value functions for the GaMampa wetland

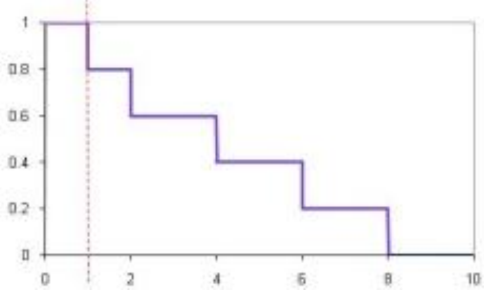
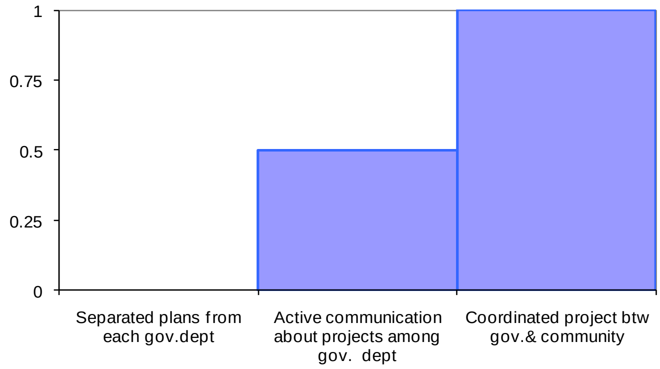
A first list of indicators was prepared by the research team based on problem and stakeholder analyses and management option description. Indicators were then grouped into categories to address multiple aspects of management such as environment, livelihoods, social equity, institutional feasibility and costs. For each category, management principles corresponding to values that should guide wetland management or values held by stakeholders, were defined by the team and discussed individually with stakeholders. The final list of principles was validated during the 4th stakeholder workshop in March 2011. Measurable or assessable indicators were then developed in relation with each principle. Based on stakeholders' interviews and expert inputs, thresholds were defined to establish value functions. The final list of indicators and value functions were finally discussed and validated by stakeholders during the 5th workshop in October 2011.

Category	Principle	Indicator
Environmental sustainability	Maintain soil quality in wetland (organic matter/moisture)	WET-Health hydrological score
		WET-Health geomorphological score
		Average depth of groundwater table in dry season
	Preserve wetland vegetation	Percentage of natural vegetation
		WET-Health vegetation score
	Maintain downstream river flow	River outflow as a percentage of natural flow in dry season
Economic development	Community can feed itself from local resources (staple crop/vegetables)	Percentage of maize needs covered by local production (wetland + irrigation)
		% of cash basic needs covered by cash income from natural resources
		Opportunities for local off-farm job
Social equity	Irrigation water is sufficient to satisfy	Percentage of irrigation scheme area irrigated in

	crop needs	dry season
	Access to cropping land is fair (area, location)	% of wetland farmers having a plot in IS
		% of households with access to IS or wetland plot
		Type of access to land
	Access to wetland for natural resources is possible for all (grazing, plant and raw material collection)	% of households engaged in reeds and sedges collection
		Grazing opportunities in the wetland
Cost effectiveness	Government covers investment costs Users pay for O&M costs	Investment costs (including labour) as percentage of municipal capital budget
		Costs for operation, maintenance and renewal of infrastructure as percentage of average household income
		Share of capital costs supported by local users
		Share of O&M costs supported by local users
Institutional clarity	Local community is involved in the decision making process to trigger ownership	Local committees and user participation
	Rules & responsibilities for natural resources management are clear and enforced	Rule clarity
	Effective and ongoing training is provided for any change in management, by the relevant institution	Dependence on awareness raising / training programme
	External Stakeholders collaborate together and with the community	Coordination of government programs

Examples of value functions developed for GaMampa:

Indicators:	Evaluation method	Type of value function
Percentage of maize needs covered by local production (wetland + irrigation)	WETSYS (Morardet, 2012) & farming system model	Maximise, minimum and maximum threshold 
Average depth of groundwater level during the dry season [m]	WETSYS model	Minimise, Minimum and maximum thresholds 

Geomorphological health score (Ecosystem)	WETHealth tool	Several levels, Minimise 
Coordination of government programs	Expert judgement	3 levels 

Detailed information about indicators and value functions identified for the WETwin case studies is given in Funk et al (2012).

4.6 Definition of scenarios

As Chapter 3 has already indicated, the state of the wetland can also be changed by perturbations, which fall beyond the range of management. These drivers are typically climate change, population growth, economic development, etc. Using different climatic, population growth and economic models, quantitative projections of temperature, precipitation, population size, land use, GDP and energy consumption can be generated on the basis of these drivers. These *scenarios* form additional boundary conditions for the evaluation of the management solutions (see Figure 4-1). Uncertainty in projections is tackled by constructing alternative scenarios for the same driver.

Examples for alternative climate change, population growth and water management scenarios are presented in Chapter 3 with regard to the Inner Niger Delta wetland.

4.7 Evaluation of management solutions

Management solutions are proposed to be evaluated in two parallel ways in the DS Framework: a) expert evaluation carried out by independent scientists; b) evaluation carried out by the interested stakeholders themselves.

4.7.1 Expert evaluation

Expert evaluation means the assessment of identified management solutions using models, expert assessment tools and, when necessary, expert knowledge. This step does not require stakeholder participation but intensive simulation work to explore the impacts of alternative management solutions under various scenarios (see Figure 4-3). Depending on case studies, different types of models and tools can be used in terms of accuracy, complexity, etc.

The direct outputs of expert evaluation are calculated/assessed values of indicators in case of the different alternative solutions. Indicator values are arranged into the *Analysis Matrix*, where the rows stand for the indicators while the columns stand for the alternatives. It is likely that data and models necessary to simulate the impact of some management solutions on certain indicators will not be available. In this case expert knowledge as well as specialised technical literature review can be used alternatively. It is important not to abandon certain indicator or solution because of lack or uncertainty of information to avoid rejection by stakeholders of final results.

Criteria scores of the alternatives are calculated from the raw indicator values with the help of value functions (see also section 0). The matrix of criteria scores is called *Evaluation Matrix*.

Example 4. Expert evaluation of alternative management solutions for GaMampa wetland

The Analysis Matrix was elaborated by the research team on the basis of information collected through hydrological monitoring, field observation, household surveys, expert interviews and stakeholders' input (focus group discussions, workshops). It corresponds to a qualitative expert judgments.

Indicator qualitative values were first determined for each management option independently on the basis of the options assessment undertaken by Murgue (2010). In particular, we identified whether the impact of the management option on indicators was direct, indirect, or the indicator was irrelevant for the option. When ascribing indicator values to management solutions, we first considered which options, among those forming the solution, have the main direct impact on the considered indicator, and their respective indicator values. We then analyzed how the combination with other options can possibly modify these indicator values, as shown in the following example:

Impact of MS3 on average depth of groundwater in dry season:

Management Options with an impact on indicator	Impact of MO on indicator	Global impact of MS on indicator	Comment
Drip system	**-** (Limited leakages from irrigation scheme)	**-**	Higher water retention capacity in the wetland does not compensate the reduction of leakages from the irrigation scheme
50% of natural vegetation	**+** (Higher water retention capacity)		
Improved cropping practices	**+**		

This process necessarily results in some uncertainties on indicator scores and therefore results of assessment should be considered with caution.

Analysis Matrix for GaMampa wetland

	BaU	MS1	MS2	MS3	CON	ECO	SOC	INT
Average depth of groundwater table in dry season	-	0	+	-	++	--	+	++
Percentage of natural vegetation	-	-	+	+	++	-	+	+
River outflow as a percentage of natural flow in dry season	+	+	++	0	++	-	+	++
WEThealth Hydrological health score	-	0	+	-	++	--	+	++
WEThealth Geomorphological health score	-	-	0	0	++	-	+	++
WEThealth Vegetation health score	-	-	+	+	++	-	+	+
Percentage of maize needs covered by local production	++	++	++	-	-	+	++	+
Percentage of cash basic needs covered by cash income from natural resources	--	0	++	++	0	++	+	+
Opportunities for local off-farm job	-	0	0	+	-	+	0	0
% of irrigation scheme area irrigable in dry season	--	+	++	++	+	++	++	++
% of wetland farmers with a plot in irrigation scheme	--	+	++	+	+	+	++	+
% of households with farm land	0	+	0	0	--	+	0	0
type of access to land	--	++	+	+	++	-	++	++
% of households engaged in reeds and sedges collection	+	+	++	++	++	+	++	+
Grazing opportunities in wetland	0	0	+	++	0	-	0	+
Investment costs (% of municipal capital budget)	++	++	--	0	++	0	0	++
Costs for O&M +renewal (% of average household income)	++	0	--	0	-	0	0	-
Share of capital costs supported by local users	++	--	-	++	-	++	+	-
Share of O&M costs supported by local users	++	++	++	++	++	++	++	++
Local committees and user participation	--	0	+	++	++	+	++	++
Rule clarity	--	+	++	++	++	+	0	++
Awareness raising / training programme	--	+	0	0	0	0	0	0
Coordination of government programs	--	0	0	0	+	0	++	++

Since all indicators were evaluated in the same qualitative way, one generic value function was used to translate indicator values into criteria scores:

Indicator 'value':	--	-	0	+	++
Criteria score:	0	0.25	0.5	0.75	1

This finally led to the Evaluation Matrix:

	BAU	MS1	MS2	MS3	CON	ECO	SOC	INT
Average depth of groundwater table in dry season	0.25	0.5	0.75	0.25	1	0	0.75	1
Percentage of natural vegetation	0.25	0.25	0.75	0.75	1	0.25	0.75	0.75
River outflow as a percentage of natural flow in dry season	0.75	0.75	1	0.5	1	0.25	0.75	1
WEThealth Hydrological health score	0.25	0.5	0.75	0.25	1	0	0.75	1
WEThealth Geomorphological health score	0.25	0.25	0.5	0.5	1	0.25	0.75	1
WEThealth Vegetation health score	0.25	0.25	0.75	0.75	1	0.25	0.75	0.75
Percentage of maize needs covered by local production	1	1	1	0.25	0.25	0.75	1	0.75
Percentage of cash basic needs covered by cash income from natural resources	0	0.5	1	1	0.5	1	0.75	0.75
Opportunities for local off-farm job	0.25	0.5	0.5	0.75	0.25	0.75	0.5	0.5
% of irrigation scheme area irrigable in dry season	0	0.75	1	1	0.75	1	1	1
% of wetland farmers with a plot in irrigation scheme	0	0.75	1	0.75	0.75	0.75	1	0.75
% of households with farm land	0.5	0.75	0.5	0.5	0	0.75	0.5	0.5
type of access to land	0	1	0.75	0.75	1	0.25	1	1
% of households engaged in reeds and sedges collection	0.75	0.75	1	1	1	0.75	1	1
Grazing opportunities in wetland	1	0.5	0.75	1	0.5	0.25	0.5	0.75
Investment costs (% of municipal capital budget)	1	0.98	0.16	0.51	0.92	0.53	0.43	0.96
Costs for O&M +renewal (% of average household income)	1	0.33	0	0.44	0.28	0.46	0.45	0.29
Share of capital costs supported by local users	1	0	0.2	1	0.33	1	0.73	0.27
Share of O&M costs supported by local users	1	1	1	1	1	1	1	1
Local committees and user participation	0	0.5	0.75	1	1	0.75	1	1
Rule clarity	0	0.75	1	1	1	0.75	0.5	1
Awareness raising / training programme	0	0.75	0.5	0.5	0.5	0.5	0.5	0.5
Coordination of government programs	0	0.5	0.5	0.5	0.75	0.5	1	1

The qualitative evaluation of indicators is currently being updated by results from undergoing modelling efforts (WETSYS integrated model (Morardet, 2012) and farming system model). Criteria scores will be updated on the basis of the value functions shown in the box of Example 3.

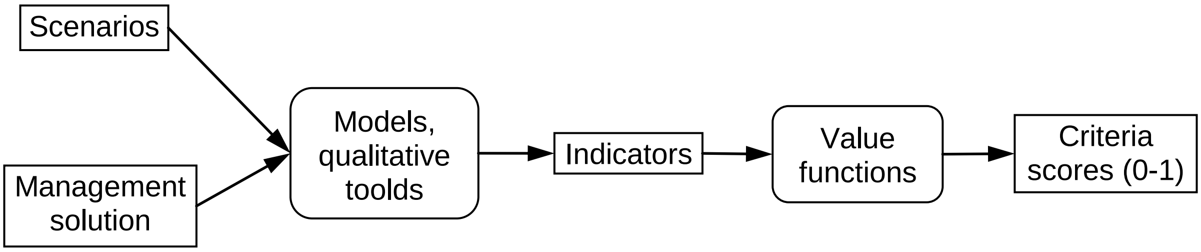
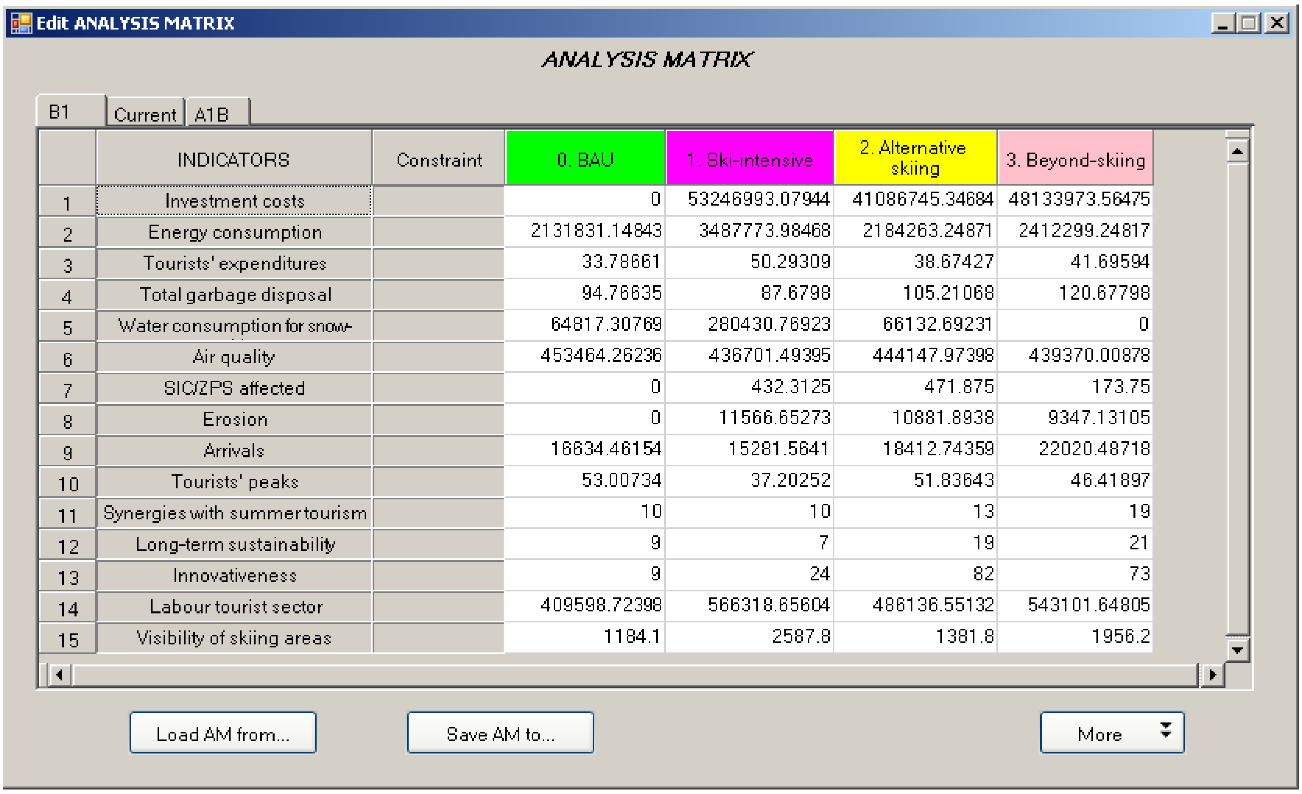


Figure 4-3: The generic framework of expert evaluation of a management solution

As Figure 4-3 also indicates, scenarios form boundary conditions for the expert evaluations. Incorporating scenarios enables to investigate the sensitivity of management solutions to various future conditions. Consideration of scenarios results in as many analysis matrices as the number of alternative scenarios considered. Figure 4-4 for example shows a set of analysis matrices, where four alternative solutions are evaluated under three alternative scenarios ('B1', 'Current', 'A1B').



	INDICATORS	Constraint	0. BAU	1. Ski-intensive	2. Alternative skiing	3. Beyond-skiing
1	Investment costs		0	53246993.07944	41086745.34684	48133973.56475
2	Energy consumption		2131831.14843	3487773.98468	2184263.24871	2412299.24817
3	Tourists' expenditures		33.78661	50.29309	38.67427	41.69594
4	Total garbage disposal		94.76635	87.6798	105.21068	120.67798
5	Water consumption for snow-		64817.30769	280430.76923	66132.69231	0
6	Air quality		453464.26236	436701.49395	444147.97398	439370.00878
7	SIC/ZPS affected		0	432.3125	471.875	173.75
8	Erosion		0	11566.65273	10881.8938	9347.13105
9	Arrivals		16634.46154	15281.5641	18412.74359	22020.48718
10	Tourists' peaks		53.00734	37.20252	51.83643	46.41897
11	Synergies with summer tourism		10	10	13	19
12	Long-term sustainability		9	7	19	21
13	Innovativeness		9	24	82	73
14	Labour tourist sector		409598.72398	566318.65604	486136.55132	543101.64805
15	Visibility of skiing areas		1184.1	2587.8	1381.8	1956.2

Figure 4-4: Set of analysis matrices as represented in the mDSS tool (example by Giupponi, 2007)

4.7.2 Stakeholder evaluation

In parallel with expert evaluation, it would be useful to get the a priori evaluation of management solutions by stakeholders: How do they score each alternative? What are their preferred solutions? In the approach proposed by Paneque Salgado et al. (2009), among others, the *Equity Matrix* is the result of a qualitative assessment of the management solutions by stakeholders.

Example 5. Stakeholder evaluation of alternative management solutions for Ga-Mampa wetland

Stakeholders were asked to individually rank the proposed management solutions during the 4th stakeholder workshop in March 2011 (from 1 for the most preferred solution to 7 for the least preferred one; the current situation was not considered). The ranking exercise took place after the discussion of the management principles and the design of management solutions from management options by stakeholders, but before detailed information on solutions' impact was provided to them.

Equity Matrix for Ga-Mampa wetland:

Stakeholder	Organisation	Level	MS1	MS2	MS3	CON	ECO	SOC	INT
SH1	Traditional Leader	Local	2	3	1	5	4	6	7
SH2	Development forum	Local	3	2	1	4	5	6	7
SH3	Ward Committee	Local	2	1	3	6	5	4	7
SH22	LDA (extension officer)	Local	1	2	3	3	4	3	2
SH23	LDA (extension officer)	Municipal	3	4	1	5	2	6	3
SH24	LDA (extension officer)	Municipal	4	3	1	2	1	2	3
SH5	LDA	Municipal	3	4	1	7	2	5	6
SH7	LDA	Municipal	3	1	2	2	5	1	4
SH6	LDA	Municipal	3	1	5	7	2	6	4
SH12	LEDET	Provincial	7	1	2	4	3	5	6
SH11	LEDET	Provincial	6	5	3	2	4	7	1
SH15	AIR	Provincial	7	3	6	1	4	2	5
SH17	Vela VKE	Consultant	3	1	2	5	6	6	3
SH18	Vela VKE	Consultant	3	4	2	5	2	3	6

LDA: Limpopo Department of Agriculture

LEDET: Limpopo Department of Economic Development, Environment and Tourism

AIR: African Ivory Route (eco-tourism semi-public company)

The purpose of this exercise is to get a better understanding of stakeholders' expectations and to ensure a better acceptation of the whole process of multi-criteria valuation. From the Equity Matrix it is also possible to derive possible coalitions of stakeholders around some management alternatives.

4.8 Definition of criteria weights

Linking weights to evaluation criteria is a way of eliciting stakeholders' preferences.

The simplest way of determining weights is to ask the stakeholders to distribute the number of 10 (or 100) among the criteria. Pebbles or chips can be used for supporting this weighing procedure in a context of low literacy. The so-derived criteria weights are then scaled between 0 and 1 (see Example 7). This method is quite effective in case of low number of criteria. Also it guarantees that the weights sum up to 1, which is a requirement of mDSS. In addition mDSS allows the user to determine such standardized weights with the help of adjustable graphical bars.

mDSS provides further methods that help stakeholders to assess their criteria weights, such as *ranking* and *pair-wise comparison*: For further information about these methods the reader is referred to Fondazione Eni Enrico Mattei, 2006.

Example 6. Elicitation of stakeholders' preferences with regard to Ga-Mampa wetland management

During the 4th stakeholder workshop in March 2011, stakeholders were asked to weigh the management principles according to their preferences. This was performed individually, using weighing sheets, and in three groups with heterogeneous composition, by distributing 100 marbles among the principles represented on show cards. When a management principle was represented by several criteria, its weight was then divided equally among the corresponding criteria. This resulted in the set of weights presented in the table below.

Stakeholder-specific sets of criteria weights related to the GaMampa wetland:

Stakeholders	SH1: GM traditional leader	SH2: GM CDF	SH3: Ward committee	SH4: GM farmer	SH5: LDA municipal	SH6: LDA municipal	SH7: LDA municipal	SH8: LDA provincial, Land Care	SH9: LDA provincial	SH10: LDA provincial	SH11: LEDET provincial	SH12: LEDET provincial	SH13: DWA provincial	SH14: SANBI provincial	[illegible]
Average depth of groundwater table in dry season	0.04	0.06	0.03	0.07	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.05	0.02	0.02	0.
Percentage of natural vegetation	0.07	0.04	0.10	0.05	0.06	0.05	0.05	0.05	0.03	0.05	0.05	0.05	0.03	0.02	0.
River outflow as a percentage of natural flow in dry	0.13	0.17	0.10	0.10	0.12	0.05	0.05	0.10	0.06	0.10	0.05	0.15	0.20	0.03	0.
WET-Health hydrological score	0.04	0.06	0.03	0.07	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.05	0.02	0.02	0.
WET-Health geomorphological score	0.04	0.06	0.03	0.07	0.04	0.03	0.03	0.03	0.02	0.03	0.03	0.05	0.02	0.02	0.
WET-Health vegetation score	0.07	0.04	0.10	0.05	0.06	0.05	0.05	0.05	0.03	0.05	0.05	0.05	0.03	0.02	0.
Percentage of maize needs covered by local	0.05	0.09	0.05	0.10	0.08	0.10	0.05	0.08	0.06	0.05	0.05	0.10	0.02	0.03	0.
percentage of cash basic needs covered by cash	0.03	0.00	0.03	0.05	0.04	0.03	0.07	0.04	0.03	0.03	0.03	0.03	0.01	0.02	0.
Opportunities for local off-farm job	0.03	0.00	0.03	0.05	0.04	0.03	0.07	0.04	0.03	0.03	0.03	0.03	0.01	0.02	0.
Percentage of irrigation scheme area irrigable in dry	0.10	0.09	0.10	0.05	0.05	0.10	0.07	0.10	0.09	0.10	0.05	0.05	0.10	0.10	0.
% of wetland farmers having a plot in IS	0.03	0.01	0.03	0.01	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.00	0.06	0.
% of households with access to IS or wetland plot	0.03	0.01	0.03	0.01	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.00	0.06	0.
type of access to land	0.03	0.01	0.03	0.01	0.02	0.03	0.02	0.03	0.03	0.02	0.02	0.01	0.00	0.06	0.
Percentage of households engaged in reeds and	0.05	0.04	0.03	0.01	0.02	0.03	0.04	0.05	0.03	0.03	0.03	0.08	0.05	0.09	0.
Grazing opportunities in the wetland	0.05	0.04	0.03	0.01	0.02	0.03	0.04	0.05	0.03	0.03	0.03	0.08	0.05	0.09	0.
Investment costs (% of municipal capital budget)	0.03	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.05	0.03	0.01	0.01	0.01	0.
Costs for O&M +renewal (% of average household	0.03	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.05	0.03	0.01	0.01	0.01	0.
Share of capital costs supported by local users	0.03	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.05	0.03	0.01	0.01	0.01	0.
Share of O&M costs supported by local users	0.03	0.02	0.01	0.03	0.01	0.01	0.01	0.01	0.01	0.05	0.03	0.01	0.01	0.01	0.
Local committees and user participation	0.03	0.04	0.05	0.05	0.10	0.10	0.07	0.05	0.17	0.05	0.20	0.02	0.10	0.07	0.
Rule clarity	0.03	0.09	0.05	0.05	0.10	0.05	0.04	0.05	0.04	0.05	0.10	0.02	0.10	0.10	0.
Awareness raising / training programme	0.03	0.00	0.05	0.05	0.05	0.10	0.07	0.05	0.17	0.05	0.05	0.03	0.10	0.07	0.
Coordination of government programs	0.03	0.04	0.05	0.05	0.05	0.05	0.17	0.05	0.06	0.05	0.05	0.10	0.10	0.07	0.

It is important to repeatedly emphasise that different stakeholders may have different preference structure, so they may identify different sets of criteria weights (see Example 6).

4.9 Application of MCA methods

This step consists of the multi-criteria analysis per se: it includes entering the information gathered in the previous steps into multi-criteria analysis tools and processing it. Answers are sought for the following questions:

- How are the various solutions ranked according to the criteria and according to the preferences of the stakeholders?
- Do the preferred solutions vary across stakeholders? Is it possible to identify potential coalitions of stakeholders around some solutions (pro or con)?

The mDSS software provides several techniques for ranking the alternative solutions on the basis of their criteria scores and also on the basis of weights associated with the criteria. There is for example the very simple SAW method (Simple Additive Weighting), which calculates the weighted sum of criteria scores to measure the performance of a solution:

$$\Phi_i = \sum_{j=1}^{n} w_j \cdot u_{ij}$$

where : w_j : weight assigned to criterion j ; u_{ij} : score of solution i at criterion j ; n ; number of criteria.

The solution with the highest weighted sum is ranked first according to the given weight set[3].

mDSS also provides more sophisticated ranking techniques such as Ordered Weighted Average, Ideal Point methods and ELECTRE (Giupponi, 2007).

As it has already been pointed out different stakeholders may have different preference structures, which means that each stakeholder may have its own MCA ranking(s)[4] of alternative solutions. mDSS provides group decision making methods, such as the Borda technique (Giupponi, 2007), for compromising these individual rankings. This will ultimately result in a *compromise ranking* of solutions.

4.10 Analysis of results

According to the previous sections, each stakeholder (or stakeholder group) can be associated with two types of ranking lists of alternative solutions:

1. Ranking list created by the stakeholder itself during the Stakeholder evaluation step (section 4.7.2)
2. Ranking list(s) generated by the MCA method on the basis of expert evaluations and on the basis of the criteria weights identified by the stakeholder (section 4.9).

Comparison of these ranking lists makes possible to check the outcomes of the decision support process. Similarities between the ranking lists strengthen the trust in evaluations made by both the experts and the stakeholders. On the other hand, significant differences between the two types of rankings indicate likely deficiencies and/or errors, which can have two reasons:

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[3] The method is applicable also when no weights are determined for the criteria. In that case each criterion has a uniform (e.g. 1) weight.

[4] In case of multiple scenarios one stakeholder has as many MCA-based ranking lists as the number of alternative scenarios considered.

1. *Errors and/or deficiencies in stakeholder evaluations*, due to erroneous perceptions of certain stakeholders about the functioning of the system. Detailed investigations are needed, and if they prove the hypothesis of erroneous stakeholder perception, then the concerned stakeholders need to be encouraged to improve their knowledge and to change position.
2. *Errors and/or deficiencies in expert evaluations*: Discrepancies between the two types of rankings are not necessarily the results of erroneous stakeholder perceptions, especially if discrepancies appear at several stakeholders. They could as well be the consequences of errors in expert evaluation such as, erroneous model simulations; or the absence of an important evaluation criterion, which has otherwise been taken into consideration implicitly by the stakeholders. In this case the process should better loop back to the beginning of the Decision Support Framework and redo the steps of the process in order to locate and eliminate the problem (see also Figure 4-1).

The ultimate aim of the decision support process is to identify, if possible, the best compromise management solution, which will form the basis of the wetland management plan (see Figure 2-3). The expert group operating the MCA tool may propose the solution that has been ranked first on the compromise ranking list. The decision makers and stakeholders may accept or reject it. Alternatively a lower ranked solution can also be accepted as the best compromise one. In case if all solutions get rejected, the process loops back to previous stages where new/improved management solutions can emerge from the results of the trade-off analysis and be subjected to analysis again (see Figure 4-1). The discussion can also result in identification of new problems, which require a repetition of the whole process.

Example 7. Outcomes of multi-criteria analysis in Ga-Mampa

On the basis of the evaluation matrix and criteria weights previously presented, and using simple additive weighing (SAW) decision rule, it is possible to rank the various management solutions. The table above displays the ranking obtained for various sets of weights.

Comparison of ranking of management solutions based on different sets of criteria weights

Stakeholder	*Solutions order (best → worst)*							
Average of individual weights	integ 85	soc 79	MS 2 77	cons 75	MS 3 69	MS 1 62	Econ 56	BAU 35
Group 1	integ 86	soc 80	MS 2 79	cons 79	MS 3 70	MS 1 61	Econ 56	BAU 32
Group 2	integ 84	soc 79	cons 77	MS 2 74	MS 3 67	MS 1 62	Econ 54	BAU 28
Group 3	integ 82	soc 80	MS 2 77	cons 70	MS 1 66	MS 3 65	Econ 59	BAU 40
SH3 (Ward council)	integ 84	cons 80	MS 2 78	soc 78	MS 3 69	MS 1 59	Econ 51	BAU 32
SH6 (LDA municipal)	integ 83	soc 80	MS 2 76	cons 73	MS 3 68	MS 1 64	Econ 57	BAU 30
SH11 (LEDET)	integ 86	cons 81	soc 79	MS 3 75	MS 2 74	MS 1 58	Econ 58	BAU 30
SH16 (AIR)	MS 2 82	soc 81	integ 77	MS 1 68	Econ 67	MS 3 66	cons 56	BAU 38

Results appear to be little sensitive to weights or decision rule, and there are not much difference of ranking between stakeholders. The integrated solution is preferred by all stakeholders but one. The largest variations occur in the 2nd, 3rd and 4th positions, with three solutions very close to each other (SOC, MS2 and CON). The end of the ranking is quite homogeneous across stakeholders. TOPSIS decision rule tends to reduce the range of scores across solutions and leads to even more homogeneous ranking. This homogeneity can be explained by the high number of criteria: when asked to ascribe weights stakeholders did not dare to give zero weight to any criteria and thus criteria weights tend to be close to each other, for all stakeholders.

During the 5th stakeholder workshop held in October 2011, after discussing the solution criteria scores, three groups of stakeholders (mixing local farmers and external stakeholders) were asked first to choose individually their three preferred solutions and then to reach an agreement on a common compromise solution. For two groups, the three preferred solutions included INT, CON and SOC solutions (respectively the 1st 4th and 2nd ranked solutions with mDSS). One group finally chose INT solution on the ground that it allows satisfying different kinds of interests. The other group made its final choice on the basis of acceptability and feasibility: CON solution was discarded because it implies giving back a part of the cultivated wetland to natural vegetation and SOC solution was finally selected over INT because it was deemed easier to implement. The third group only included in its set the three extreme solutions (ECO, CON, SOC). The focus of their discussion was more on the objectives of wetland management embodied in the title of these extreme solutions, than on the solution performances. Interestingly, in all groups, very few participants chose one of the management solutions elaborated during the previous workshop. Most of them focused on the three contrasted solutions and the integrated one. One possible reason is that their titles make them easy to understand.

Limited time and the absence of important stakeholders (department of agriculture) did not allow identifying a unique compromise solution. Further work is necessary with stakeholders to make sure that i) they all understand the consequences of individual options and the combined effects of proposed solutions on their domain of interest; ii) they are aware of the implementation hurdles associated with each of the solutions; and iii) if necessary, they elaborate new combinations of options more adapted to their objectives of development.

Individual ranking of solutions based on weights and criteria scores and direct ranking give very different results. The most striking difference is that although the integrated solution is always the preferred one when ranking is based on criteria scores, it is almost never chosen among the best solutions when performing direct ranking. Local stakeholders tended to choose solutions that were elaborated during the 4th workshop, maybe because they had been involved in their composition, so they understood better their potential impact. Representatives of the department of agriculture at municipal level favor MS3 solution followed by ECO solution (which includes the department initial project for irrigation rehabilitation), and those at provincial level prefer the MS2 solution. Representatives of environment department (LEDET) and tourism entity (AIR) at provincial level have divergent views.

Various reasons can explain the differences between these two rankings:

- When asked to directly rank the solutions, stakeholders did not fully understand the potential impacts of the management solutions, because they had not received yet the detailed information about all the options and solutions, although some of the impacts of options have been discussed individually.
- When making their choice, stakeholders only focus on a limited number of criteria, due to cognitive complexity, although when asked to assign weights to criteria they very rarely consider giving zero weights to any criteria.
- The expert based assessment of the solutions is inaccurate. This is also possible because the evaluation matrix was built based on expert judgment and some scores are uncertain.

Discussions during the last stakeholder workshop (October 2011) did not allow to really discriminate between these three reasons. In particular, time and budget were lacking for sharing detailed information about options and solutions with stakeholders prior to the last workshop.

Thus, it can be concluded that the first round of the MCA analysis at GaMampa did not lead to management solution that can be recommended for implementation, due to likely errors made at several stages. Now the procedure should loop back in the Decision Support Framework (Figure 4-1) and redo the steps of evaluations by taking into consideration the above described conclusions. First of all the qualitative expert judgements should be replaced by sophisticated well-calibrated models. Also improved strategy for communicating with stakeholders should be applied. These are the task of the next decision iteration cycle, which hopefully will lead to the best compromise management solution for the GaMampa wetland.

5 Conclusions

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Annex I : Glossary of terms

Term	Definition	Source
Adaptation	Initiatives and measures to reduce the vulnerability of natural and human systems against actual or expected climate change effects. Various types of adaptation exist, e.g. anticipatory and reactive, private and public, and autonomous and planned. Examples are raising river or coastal dikes, building reservoirs, re-naturalization of wetlands, insurance systems, etc.	Hattermann, 2008
Adaptive management	The mode of operation in which an intervention (action) is followed by monitoring (learning), with the information then being used in designing and implementing the next intervention (acting again) to steer the system toward a given objective or to modify the objective itself	Alcamo & Bennett, 2003
Best compromise solution	The solution of a multi-criterion problem that is judged to be the 'best' one by the *decision makers* and *stakeholders*.	Tecle & Duckstein, 1994
Criterion	A measure against which *management solutions* are assessed to evaluate the degree to which they achieve objectives. A tool for evaluating and comparing the potential solutions according to a well-defined point of view. *Criteria* values are derived by scaling *indicators* between 'worst' and 'best' (0-1) with the help of value functions.	Fondazione Eni Enrico Mattei, 2006
Decision	The choice of one from among a number of alternatives; a statement indicating a commitment to a specific course of action.	Giupponi et al., 2007
Decision maker	An executive person or group responsible for land-use policy, action and allocation of resources.	Giupponi. et al., 2007
Decision space	The full set of alternative *management solution*s (including status quo).	
Driving forces (drivers)	Driving forces are represented by natural and social processes which are the underlying causes and origins of *pressures* on the environment. E.g. agriculture/land use change, industry, waste management.(DSIR approach)	Fondazione Eni Enrico Mattei, 2006
Ecosystem	A dynamic complex of plant, animal, and micro-organism communities and the non-living environment interacting as a functional unit	Ecosystem Services: A Guide for Decision Makers (WRI)
Ecosystem	The benefits people obtain from *ecosystems*. The "services	Millennium

services	of nature"	Ecosystem Assessment, 2003.
Impact	Impacts on population, economy, *ecosystems* describe the ultimate effects of changes of *state*, in terms of damage caused. E.g. eutrophication, biodiversity loss. (DPSIR approach)	Fondazione Eni Enrico Mattei, 2006
Indicator	A parameter or value derived from parameters, which provides information about a phenomenon. In particular, an environmental indicator is a parameter, which provides information about the situation or trends in the state of the environment, in human activities that affect or are affected by the environment, or about relationships among such variables.	Fondazione Eni Enrico Mattei, 2006
Integrated Water Resources Management (IWRM)	Includes the planning and management of water resources and land. This takes account of social, economic and environmental factors and integrates surface water, groundwater and the ecosystems through which they flow.	Fondazione Eni Enrico Mattei, 2006
	A process, which promotes the co-ordinated development and management of water, land and related resources, in order to maximize the resultant economic and social welfare in an equitable manner without compromising the sustainability of vital *ecosystems*.	Hattermann, 2008
Management solution	A coherent set of measures (options) for the development and management of the whole system. It aims at the attainment of objectives and accounts for the different *stakeholders*' interests.	Hattermann, 2008
Model	A simplified representation of reality used to simulate process, understand a situation, predict an outcome, or analyse a problem.	Giupponi et al., 2007
Objective (criteria) space	A space determined by the value sets of *criteria*. Each dimension of the space stands for a particular *criteria* function.	
Policy maker	A person with power to influence or determine policies and practices at an international, national, regional, or local level.	Giupponi et al., 2007
Pressure	Pressures are outcomes of the *driving forces*, which influence the current environmental *state*. They are the variables which directly cause (or may cause) environmental problems. E.g. polluting emissions, noise. (DPSIR approach)	Fondazione Eni Enrico Mattei, 2006
Public participation	An approach allowing the public to influence the outcome of plans and working processes, used as a container concept	van Ingen, 2010; CIS, 2002

	covering all forms of participation in decision making.	
Response	Responses demonstrate the efforts of society (e.g. politicians, decision-makers) to solve the problems. E.g. policy measures. (DPSIR approach)	Fondazione Eni Enrico Mattei, 2006
Scenario	Hypothetical future event. It establishes the social, environmental and socio-economic settings that can create changes in *driving forces*, when human activities are involved, and in *state*, when dealing with the environment. It is an exploration of a possible future for which an underlying set of assumptions has been made.	Fondazione Eni Enrico Mattei, 2006
	A plausible and often simplified description of how the future may develop based on a coherent and internally consistent set of assumptions about *driving forces* and key relationships. Scenarios may be derived from projections, but are often based on additional information from other sources, sometimes combined with a narrative storyline. See also SRES scenarios; Climate scenario; Emission scenario.	Hattermann, 2008
Stakeholder	A person, organisation or group with interest in an issue or particular natural resources	De Groot et.al., 2006.
	A social actor (individual or collective), who is an actual or a potential user of water resources for different purposes such as agriculture, industry, domestic consumption, recreational, or communication. Stakeholders are affected by the decisions.	Fondazione Eni Enrico Mattei, 2006
	Those who have intersets in a particular decision, either as individuals or as representatives of a group. Including people who can influence a decision, as well as those affected by it.	Giupponi et al., 2007
	Any individuals, groups of people, institutions (government or non-government) or firms that may have a relationship with the project/programme or other intervention at stake. They may – directly or indirectly, positively or negatively – affect or be affected by the process and/or the outcomes. Usually, different sub-groups have to be considered because within a certain group interests may be different.	van Ingen, 2010; EU, 2001
State	State describes physical, chemical or biological phenomena in the given reference area. It reflects the condition of the environment. E.g. air, water, soil quality. (DPSIR)	Fondazione Eni Enrico Mattei, 2006
Trade off	Trade-offs occur when the provision of one *ecosystem service* is reduced as a consequence of increased use of another *ecosystem service*	Morardet et al., 2009
Uncertainty	An expression of the degree to which a value (e.g., the future	Hattermann,

	state of a hydrological system) is unknown. Uncertainty can result from lack of information or from disagreement about what is known or even knowable. It may have many types of sources, from quantifiable errors in the data to ambiguously defined concepts or terminology, or uncertain projections of human behaviour. Uncertainty can therefore be represented by quantitative measures, for example, a range of values calculated by various models, or by qualitative statements, for example, reflecting the judgement of a team of experts,	2008
Vulnerability	The degree to which a system is susceptible to, and unable to cope with, adverse effects of external *pressures*, including impacts of land use, water management and climate variability and extremes. Vulnerability is a function of the character, magnitude, and rate of *pressures* to which a system is exposed, its sensitivity, and its *adaptive capacity*.	Hattermann, 2008
Wetland	Diverse, hydrologically complex *ecosystem*, which tend to develop within a hydrological gradient going from terrestrial to mainly aquatic habitats	CIS, 2003b