# Evaluating management solutions for WETwin case studies

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# PART A – Methods and approach

## 1 Introduction

Decisions about wetland management are made in a complex and dynamic context involving a range of stakeholders with different and sometime competing objectives. The aim of the WETwin project is to provide a rigorous framework for evaluating the effects of alternative development strategies to identify best compromise management solutions that are ecologically sustainable, socially acceptable, and economically sound, taking into account values of different stakeholders.

This report describes application of the WETwin decision framework to identify and assess management solutions for each case study. Chapter 1 outlines the theoretical framework used in the analysis and discusses general conclusions and lessons learnt; the remaining chapters describes application of the DSF to each case study site.

### 1.1 WETwin conceptual framework

WETwin starts from four basic premises of wetland management:

- **Wise use** (Ramsar Convention Secretariat, 2007) encapsulates the understanding that wetlands provide a wide range of ecosystem services and are an important component of livelihood systems. As such, the aim is to manage for a range of functions, not only for conservation values, but to do this in ways that protect and enhance ecological status.
- **Adaptive management** recognises management as an on-going cyclical process, not an end point; the critical components of such an approach for wetland have been described by Dickens *et al*. (2004) in the “Critical Path” approach, adopted by Ramsar as a standard for wetland management (Ramsar Convention Secretariat 2007).
- **Integrated water resource management** acknowledges that wetlands function within a hydrological context, where the management of the catchment impacts on the health of the wetland; and the wetland contributes to the overall functioning of the catchment (CIS, 2003; UNESCO, 2009). The Conceptual Framework for wetland management developed in the WETwin project nests adaptive management of the wetland within the adaptive management cycle of the river basin, with on-going feedback between the two (Zsuffa et al., this volume).
- **Participatory planning and management** recognises that local communities and stakeholders are ultimately both the actors and the beneficiaries of management, and must be involved at all stages (UN, 1994).

The focus of WETwin was the preparatory and planning stages of the Critical Path adaptive management cycle. This sub-system has been developed into a Decision Support Framework (DSF) (Figure 1), drawing on concepts from Gamboa (2006) and Paneque Salgado et al. (2009), which was applied and tested on the case studies under WP8. This report will focus on the process of evaluation of proposed solutions, and multi-criteria analysis (MCA) to determine best compromise solutions. It builds on existing reports covering other aspects of the decision framework, as follows:

- Characterisation and problem definition: D3.1, D3.2 (Zsuffa et al 2010)
- Stakeholder analysis, consultation and preference elicitation: D2.1 (Van Ingen 2010), D4.2 (Ostrovskaya et al. 2010)
- Evaluation criteria: WP7 (Funk et al., 2011)
- Identifying management options and solutions: D7.2 (Johnston et al., 2012)
- Definition of local and global scenarios: D5.1 (Liersch et al., 2011)

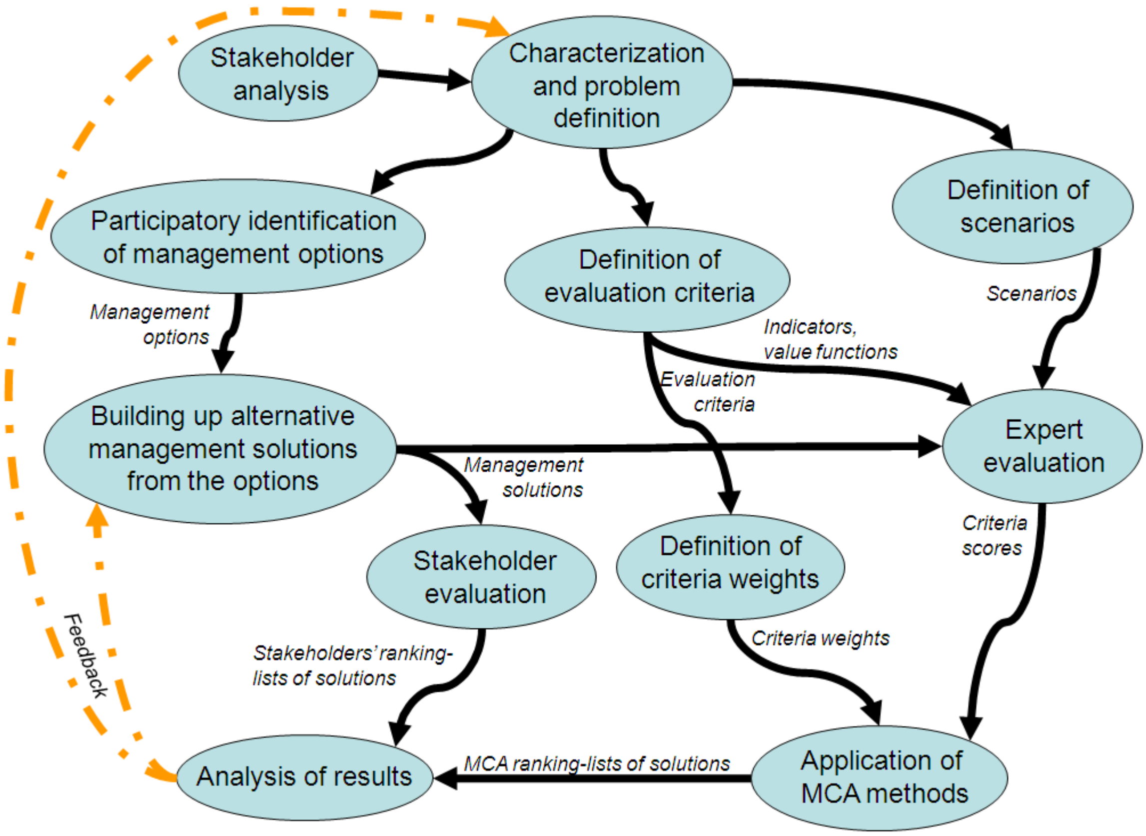



Figure 1.1 DSF framework

## 1.2 Evaluation framework

Evaluation of different potential management paths for the case study wetlands is a complex, inherently multi-dimensional problem, needing to take account of multiple functions and values of the wetland, multiple stakeholders with varying perspectives, feedback between the wetland and the catchment, and vulnerability to external pressures.

In assessing management interventions in WETwin, five key questions were considered:

1. Does it work? (impact assessment)
2. Is it technically feasible and cost effective? (feasibility assessment)
3. Will it work in the future if external conditions change? (vulnerability assessment)
4. Who wins and who loses? Are there trade-offs or synergies between different sectors or stakeholders? (trade-off analysis)
5. Does it have local support? (stakeholder acceptance)

The WETwin decision support framework explicitly acknowledges that decision processes are often subjective, driven by the needs and interests of particular groups. Thus management solutions are evaluated in two parallel pathways in WETwin: expert evaluation carried out by independent scientists, which aims to be as objective as possible (see Figure 1.2); and evaluation by interested stakeholders, which is explicitly subjective.

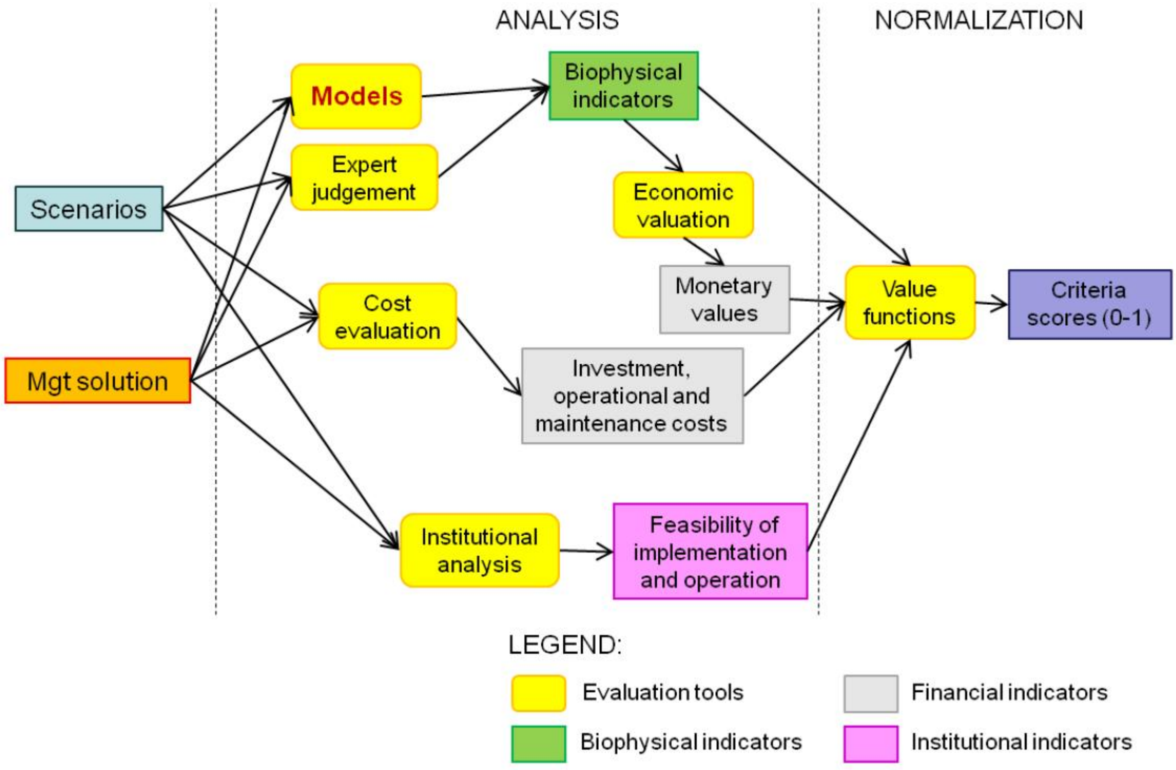



Figure 1.2 Components of the generic framework for expert evaluation, from Zsuffa et al (2010).

# 2 Constructing the decision space

Defining "best" management involves a complex interplay between values and aspirations of different stakeholders and the constraints imposed by the physical and economic realities of the system. This complexity can conceptualized as a decision space (see Figure 2-1a), where

- the dimensions of the decision space are defined by key system values (represented by criteria);
- the state of the system is defined in terms of these values / criteria; state can be changed either by management or by external drivers / pressures
- feasible limits of decision space are determined by external physical, social and economic conditions (described by scenarios)
- acceptable outcome domains for different stakeholders are defined on the basis of stakeholder values and preferences (expressed as ranges for criteria).

The aim of management is to shift or maintain the state of the wetland system so that it delivers specific values, in line with stakeholder requirements. Management must work within the constraints of the physical, social and economic realities of the external context. In WETwin, these are described in terms of scenarios, which can be seen as setting the overall shape and location of the feasible decision space. Different scenarios will thus define different decision spaces: for example, a shift in climate may restrict ecological values; or economic growth may open up new development possibilities. Different scenarios may mean that currently acceptable practices move into infeasible space under new external conditions; or that new management possibilities open up. Although these forces are beyond the control of managers, management must take account of these shifts. The distinction between external pressures and internal (manageable) components is not always clear-cut, but depends on the scale at which management occurs. For example, operation of a dam upstream of a wetland is within the management sphere of a catchment manager; but is an imposed external condition for a wetland community.

Figure 2-1 illustrates these concepts. In a hypothetical wetlands, the feasible set of states for the wetland under current conditions is limited by biophysical and socio-economic conditions to the illustrated zone of values for criteria 1 (ecological values) and criteria 2 (economic values). Stakeholder 1 (SH1) has a strict requirement that ecological state remain above an identified threshold, but has no interest in use values. Stakeholder 2 is prepared to trade ecological values for economic use. The current state of the wetland (S0) satisfies neither. Three management solutions are proposed: ecological restoration with no new economic uses (MS1); large increase in wetland use with some decrease in ecological values (MS3); and a compromise solution with some increase in both economic uses and ecological health (MS2). Under current conditions, MS3 is acceptable only to SH2 but both MS1 and MS2 are acceptable solutions. However, under climate change the ecological values of this wetland are significantly reduced (Scenario A, Figure 2.1b); redefining the decision space so that MS1 is no longer a feasible option. (Changed conditions under the new scenario mean that the outcomes from the other proposed solutions also change). MS2 is thus the preferred solution, robust under a range of conditions and acceptable to all stakeholders.

## 2.1 Characterisation and problem definition

The initial stage of each case study involved a review of current understanding of the wetland and its context, to define the components of the decision space. The initial assessment covered biophysical, socio-economic and the institutional and governance context (see Zsuffa et al 2010, D3.2). Information on the wetland and basin was collated using the structure of the Ramsar Information Sheets (Ramsar 2010). Information was collected by case study teams based on literature review, reports of previous projects and consultation with stakeholders. An assessment was also undertaken of the management structures and institutions and the related legal framework for both wetlands and river basins for each case study site (Ostrovskaya et al., 2011).

An important component of WETwin was to establish methods that can be applied in data-poor contexts, by combining best available local information and knowledge with understanding of wetland processes garnered from international experience. Structured frameworks were developed to guide and document qualitative assessments by both technical “experts” and local stakeholders. Methods were explored to summarise and present information in simple, standard formats that could be used to compare results across the different case studies.

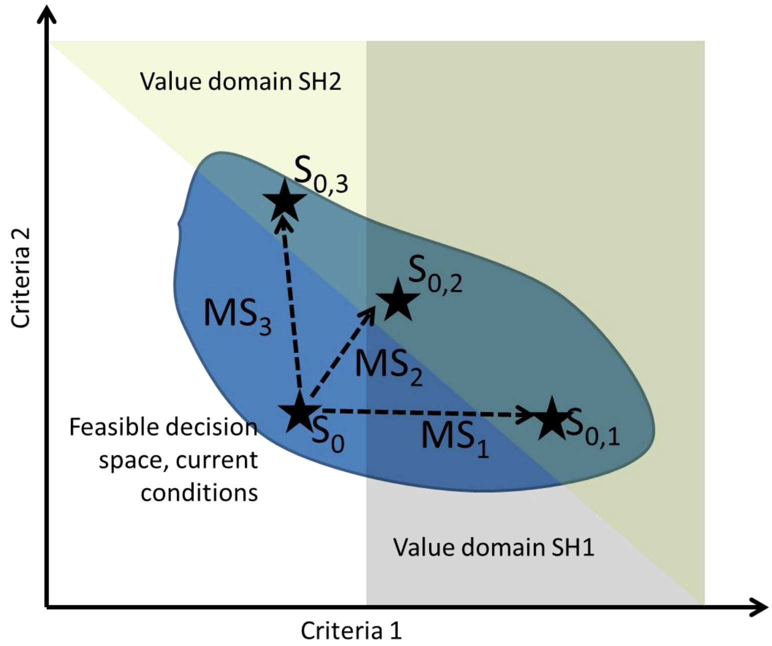
### 2.1.1 Rapid assessment tools

**DSIR analysis**: problems and issues to be dealt with in each wetland case study were characterised through analysis of Drivers – State – Impacts – Responses (DSIR, modified from the DPSIR approach developed by the European Environmental Agency (EEA, 2005). The DSIR chains are described in detail in Zsuffa (2010) (WP3, D3.2). As part of this analysis, potential trade-offs between different ecosystem services were also identified.

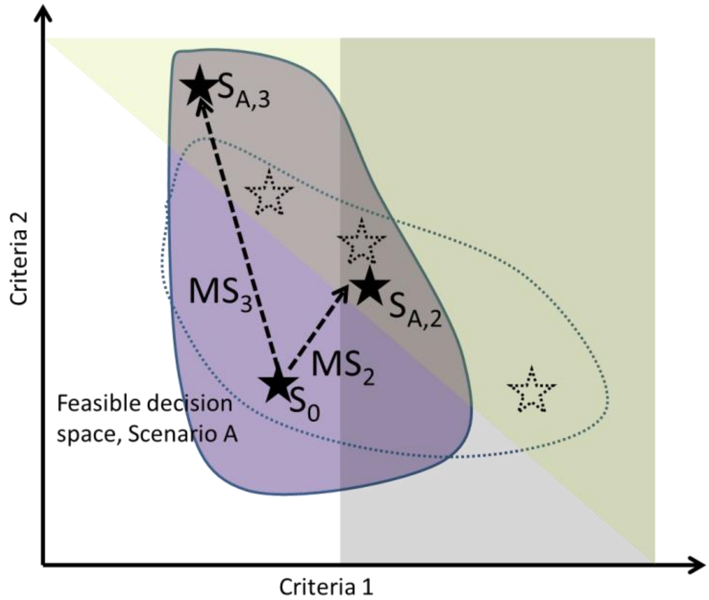
**WET-Health and WET-Ecoservices**: in South Africa, rapid assessment tools have been developed using semi-quantitative methods to assess wetland health (WET-Health – Macfarlane et al., 2008)) and ecosystem services provision (WET-EcoServices - Kotze et al*.,* 2009). These tools allow different levels of assessment, based on the degree of available information, from simple desktop analysis to rigorous field-based assessments. They are structured using checklists with detailed descriptions of the features to be scored and the rationale for assigning scores. These tools were adapted for use in WETwin case studies to provide a structured approach to assessing ecological status.

**TEEB Report Cards: b**ased on concepts outlined in TEEB (2010) and Ranganathan et al. (2008), a summary “report card” of wetland status and sensitivity to future changes was produced for each wetland.

**Figure 2-1: Illustration of the WETwin decision space.**




a). The deep blue area represents the feasible decision space under current conditions (as defined by criteria 1 and 2). Domains of acceptable values for stakeholders are represented by the shaded areas. Current state of the system at $S_0$ is not acceptable to either stakeholder 1 (SH1) or SH2. Proposed management solutions MS1 and MS2 are acceptable to both stakeholders; MS3 is not acceptable to SH1.




b). The purple area represents the feasible decision space under Scenario A – feasible region for Criteria 1 has been significantly reduced. Solution MS1 is no longer within the feasible space; MS2 is thus a more robust solution, acceptable to all stakeholders under a range of conditions.

**Institutional context – Twin2Go**: for the assessment of institutional capacity, a similar questionnaire method using standard criteria and scoring rubrics has been developed under the European-funded FP7 project Twin2Go (Pahl-Wostl et al., 2009, Lebel et al., 2011) and applied to the WETwin river basins. The scoring represents relative (rather than absolute) strengths and weaknesses of each criterion, based on the perceptions of stakeholders within the basin. Results are presented as simple "spider" diagrams, allowing comparison between basins.

## 2.2 Stakeholder engagement

Stakeholder involvement plays a fundamental role in the WETwin decision process. The WETwin DSF explicitly acknowledges that decision processes are subjective, driven by the needs and interests of particular groups. Local knowledge is a valuable resource, particularly in contexts where data is otherwise lacking. Knowledge, opinions and preferences of stakeholders are incorporated into the evaluation at several stages. Management solutions are evaluated in two parallel pathways: expert evaluation carried out by independent scientists which aims to be as objective as possible; and evaluation by interested stakeholders, which is explicitly subjective.

An analysis of relevant stakeholders was conducted for each case study, and a strategy for stakeholder engagement was formulated (van Ingen, 2010). Stakeholders were involved through consultation in workshops, small groups and individual discussions. Innovative methods for consultation were explored - for example, the use of role-playing games to structure discussions in Ga-Mampa (Morardet and Milhau, 2010) and the Inner Niger Delta. Input from stakeholders was used in four main ways:

- to identify and refine management solutions for further assessment;
- to reveal stakeholder preferences and perceptions;
- to elucidate the preferences underlying decisions (used to establish criteria categories and weightings in MCA);
- to assist in the qualitative scoring of indicators; and to identify preferred management solutions directly, for comparison with results from expert evaluation.

In most cases, local experts are also interested stakeholders (e.g. wetland managers), so to avoid bias in the expert judgment, scoring was done by multiple experts. In order to better understand the given scores, the reasons behind are also collected, and where scores differ, the motivations behind the scores are compared to find a compromise.

## 2.3 Scenarios

An important component of the initial analysis was to define the management domain for each case study site: which actions are within the scope of management and which are external pressures that must be dealt with, but cannot be influenced directly (for example, population growth, climate change). The distinction between external pressures and internal (manageable) components is not always clear-cut, but depends on the scale at which management occurs. For example, operation of a dam upstream of a wetland is within the management sphere of a catchment management agency; but is an imposed external condition for a wetland community. In WETwin, external drivers and pressures are described in terms of scenarios.

The aim of scenario analysis in WETwin is twofold: firstly, to illustrate the potential range of future conditions under which wetland management may operate, and the way external factors influence what will or won't work; and secondly to find management responses that are robust under a range of external conditions. Different scenarios define different decision spaces: economic growth may open up new development possibilities; or a shift in climate may change ecological values. Although these forces may be beyond local control, managers must take account of the shifts entailed. Conditions under different scenarios are compared to baseline conditions (formulated to represent current conditions). "Business as usual" (BAU) scenarios (with external changes, but no change in management) are used to distinguish the effects of external (scenario) change from management impacts.

At the global scale, Liersch and Hattermann (2010) identified population growth, climate change and different trajectories of economic development as the main drivers of changes affecting wetland management; and delineated three representative global scenarios which define boundary conditions for regional and local change. Within these bounds, local, site-specific scenarios were developed for each case study, to represent a range of different long-term outcomes (to 2050). Formulation and analysis of scenarios is discussed in detail in D5.2 (Liersch and Hatterman 2010).

## 2.4 Management options and solutions

The Millenium Ecosystem Assessment (MA, 2003) defined management responses as actions, policies, strategies and interventions undertaken by different actors, from governments to communities. Responses can operate from local to international scales, depending on the driver or issue being addressed. As well as technological and infrastructural measures, management interventions can range from legal and economic measures (such as land use regulations and payment for environmental services) to social and cognitive responses aiming to change behavior (such as public education and awareness campaigns) (Chambers and Toth, 2005).

In each case study, management responses to address specific wetland issues were identified in consultation with stakeholders, drawing on international experience. In most cases, a mix of technological and local regulatory responses (mainly land use zoning and restriction of agrochemicals) was proposed. Working at the community level, economic and legal mechanisms were not favored, or were perceived as beyond the capacity or responsibility of local groups.

Because of the multiple values of wetlands, management usually addresses more than one component or ecosystem value. Interventions addressing specific components or issues are combined in packages of complementary or compatible interventions as management solutions that will provide desired outcomes for the wetland system as a whole. Options can be combined as complementary (addressing different elements of system); enabling (interventions designed to support or enhance another intervention – for example, land tenure changes to support land use change); or mitigating (interventions designed to offset or compensate for adverse impacts of another intervention). Many of the interventions identified are “no regrets” options, where impacts are positive or neutral across all criteria: for example, improvements in wastewater treatment and agricultural practices.

Formulation of management solutions from a long list of potential options requires a pragmatic approach to selecting feasible combinations and narrowing down to a practical number for evaluation, based on stakeholder preferences and practical considerations for implementation**.** The diversity of the WETwin case studies required somewhat different approaches in each case study. Management options and solutions for each case study are described in detail in Johnston and Mahieu (2012), D7.2.

## 2.5 Criteria and indicators

Management solutions were evaluated and compared against criteria chosen to represent the main values of the system. Criteria were selected to reflect the values and interests of all stakeholders, in three key domains:

- Ecosystem services (including livelihood support, agricultural production, water supply, sanitation)
- Ecosystem health and integrity (including hydrology, geomorphology, vegetation, biodiversity)
- Factors influencing feasibility of implementation, including technical difficulty, cost, policy, organizational and institutional factors.

Criteria represent broad values, and are described and quantified using specific indicators. Indicators are variables that reflect change, and which can be measured or estimated. Where possible, quantitative indicators were identified for each criterion, but measurable indicators could not be identified for all important criteria. Setting the criterion aside would skew the analysis by ignoring important values, simply because they could not be quantified. To avoid this, qualitative indicators scored by combining available information and expert judgement were used where other options were not available.

The number and type of indicators used in each case study varied, reflecting the different issues and priorities, and the availability of data. Criteria and indicators for each case study are described in detail in Funk et al. (2011), D7.1.

## 2.6 Evaluation matrices, scoring and value functions

Evaluation matrices to compare management solutions are constructed by scoring each solution in terms of its impact on each indicator / criteria. Scoring can be qualitative or quantitative. To compare disparate criteria, indicator scores are normalised to a common unit and range.

A range of quantitative biophysical and socio-economic modelling approaches was used to assess impacts, where sufficient data were available to construct and calibrate them. Hydrological models of different complexity were used to describe flows and in some cases water. In Ga-Mampa, a dynamic simulation model (WETSYS) combining biophysical and socio-economic components was developed using the STELLA® platform (Costanza et al., 1998) to simulate the impacts of wetland management strategies and external pressures on wetland ecosystem functioning, ecosystem services and ultimately on community well-being in Ga-Mampa area (Morardet et al., 2010). Modelling tools used in the case studies are described in detail in Funk et al (2011) (D7.2)

Qualitative scoring is used in WETwin in three different contexts. The first is where the indicator / criterion of interest is inherently qualitative – for example, indicators relating to institutional capacity. The second is in cases where insufficient data were available to measure or score an indicator quantitatively. The third case is where the criteria is a complex variable integrating several components, for example the Wet-Health scores. In many cases, qualitative assessment and scoring is a subjective process based on expert judgement but it is also possible to establish more structured, repeatable and transparent approaches using scoring rubrics which describe in detail the logic behind allocating particular scores: for example, the WET-Health and WET-EcoServices tools described above.

In order to compare disparate criteria in MCA, indicator scores must be translated to a common unit and range. Normalization enables comparison and combination of raw evaluation results (indicator values), which are otherwise non-commensurable. The role of the value function is to capture the target state, and so to give a normative direction in relation to the planned management solutions (Boulanger 2008). Value functions were used to normalise scores to a range from 0 (representing the worst outcome) to 1 (best outcome). Value functions can be defined for quantitative and qualitative indicators; the shape of the function can be varied to describe different relationships between the indicator and the criteria score, including thresholds. It is important to note that value functions inherently imply subjectivity (since the concept of worst and best varies between stakeholders), and so it is possible for different stakeholders to define different value functions for the same criterion. Two approaches to value functions were used: defined by scientists on the basis of scientific knowledge; or defined according to stakeholders' preferences towards the target state. Value functions used for each case study are described in detail in Funk et al 2011 (D7.2).

The use of scoring, rather than raw indicator values, has a number of advantages. It allows comparison between different types of variables and enables inclusion of a much wider range of criteria. In addition, scores normalised to give a ranking from "bad" (0) to "good" (1) are easily understood, and facilitate reporting of results to non-technical audiences. However, the inherent weaknesses of scoring approaches must be taken into account. There are inconsistencies in comparing well defined modeled parameters (where a shift in value of 0.1 is meaningful) with data scored on a three class scale of "poor – moderate – good" (where a shift in value of 0.1 is not significant). The WETwin methodology does not explicitly track uncertainty associated with different parameters, so that the overall uncertainty associated with rankings cannot be described. This is a shortcoming in the methodology which should be addressed.

# 3 Evaluation of management solutions

The WETwin evaluation process has three linked components: a comparative multi-criteria analysis (MCA) of the outcomes of different interventions in terms of both impacts and feasibility; an analysis of the trade-offs between wetland functions and between stakeholders; and assessment of the vulnerability of the system to external pressures to determine whether proposed management options are robust in the context of imposed change. In each case, the underlying information for analysis was compiled in the form of evaluation matrices setting out comparative scores for key criteria for the system under different scenarios and management regimes (Figure 3.1). The evaluation matrices provide a consistent basis for all assessments.

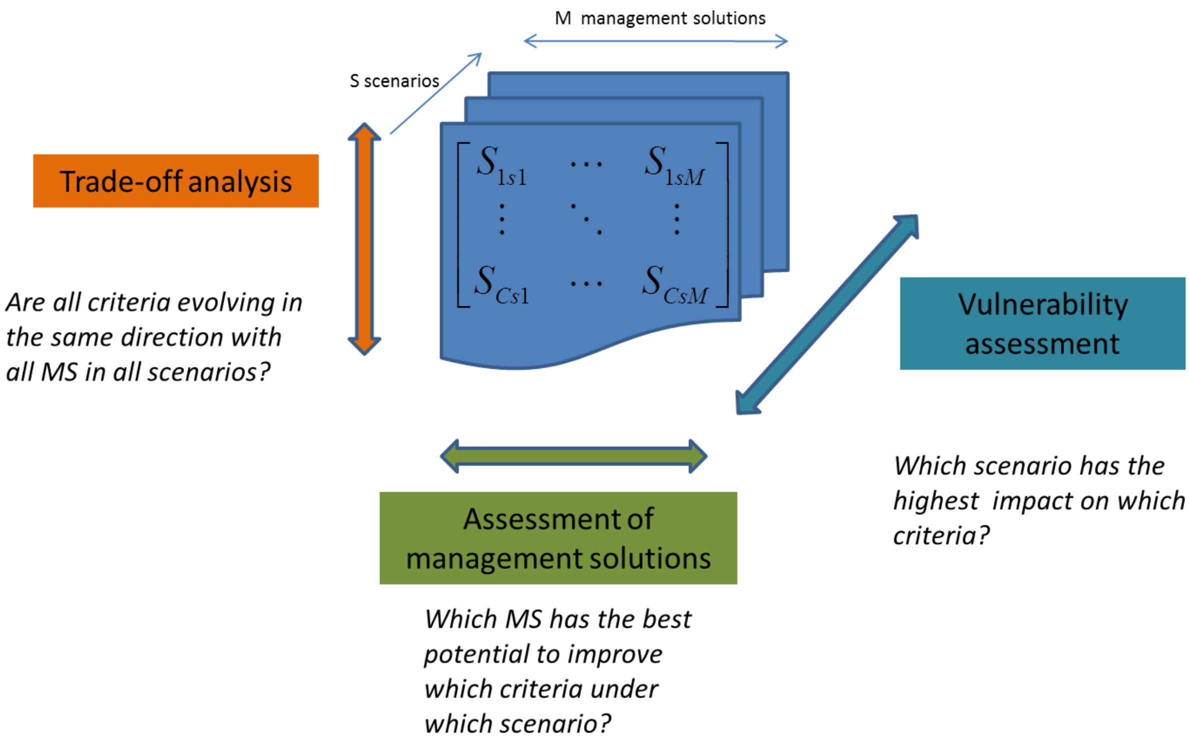



**Figure 3.1:** Linked analysis of impacts/ feasibility, trade-offs and vulnerability, based on evaluation matrices

## 3.1 Multi-criteria analysis

Multi-criteria analysis (MCA) techniques are widely used in complex decision-making, and are reviewed in WETwin SD3/SD4 (Interwies and Cools 2010). MCA helps to structure the management problem and offers a transparent, accountable and auditable procedure for decision making, and is thus an important tool for natural resource management, and specifically water resources management, which typically has multiple objectives (Hajkowicz and Collins, 2006; Figueira et al., 2005). MCA requires

- a set of <u>decision alternatives</u> to be evaluated by the decision makers
- set of <u>criteria for evaluation</u> (which may be measured in different units) and
- a set of <u>performance measures</u> (scores) allocated to each alternative against each criterion
- methods to combine scores to rank alternatives.

MCA can be used in either individual or group decision making and can handle issues with multiple objectives and conflicting criteria. It can deal with a variety of quantitative and qualitative data (measured in different units) and even expert judgments, and can be used in a participatory environment involving both experts and stakeholders (Nayak and Panda, 2001; Greiner et al. 2005; Mendoza and Martins, 2006).

In the context of assessing the economic effectiveness of wetland management decisions, Interwiess et al (2010) compared the use of MCA with other methods of assessment including Cost-effectiveness Analysis (CEA) and Cost-benefit analysis (CBA). CEA is usually applied when all costs are easy to assess and there are not many trade-offs between options; CBA can be used in more complex situations but both cost and benefit data must be available. Since wetland management deals with environmental and social impacts, and monetizing these impacts is difficult, MCA can be a facilitating approach (Interwies and Cools, 2010).

There are various techniques used in MCA to rank alternatives, classified by Hajkowicz and Collins (2006) as: multi-criteria value functions; outranking approaches; distance to ideal point methods; pairwise comparisons and others. According to a number of studies comparing application of different MCA techniques in water resource management, there is no clear advantage for any single ranking technique (Hajkowicz and Collins, 2006). In contrast, the selection of different criteria and decision options can result in very different outcomes (Howard, 1991).

### 3.1.1 mDSS

In the WETwin project, the MULINO Decision Support System (mDSS) is used to facilitate the MCA approach and guide the process for data collection and analysis. mDSS was developed under the EU Framework, to assist decision makers in managing environmental issues in catchment scale water resource management (Guipponi et al 2004; Guipponi 2007, mDSS 2010). mDSS is able to integrate hydrological, ecological or socio-economic models with multi-criteria analysis methods and is designed to help decision makers:

- better understand the decision problem by structuring relevant information
- explain the problem at hand to involved actors (disciplinary experts, policy/decision makers, other stakeholders)
- explore possible decision options
- explore the impact of alternative scenarios on decisions
- facilitate public participation,
- resolve conflicts related to alternative courses of action
- extend collaboration with and between different stakeholder groups.

Within mDSS, scores can be aggregated and ranked using different decision rules, as follows:

- *Simple Additive Weighting (SAW)* which is a simple sum of the criteria values for each option, weighted by the vector of weights. The results are expressed by means of scores: the option with the highest score should be preferred.
- *Ordered Weighted Averaging (OWA)* focuses on the risk attitude of decision makers
- *Technique for Order Preference by Similarity to Ideal Solution (TOPSIS*) in which the option closest to the positive ideal solution and furthest from the negative ideal solution is considered as being best. Both ideal solutions are described by the extreme indicator values. Since these solutions are not real and describe only ideal states (which cannot be achieved), the distance of the real options from both of them is combined to make the final choice.
- *ELECTRE* is an outranking approach, based on pairwise comparison of the alternatives, which assigns weights in an iterative manner to fill the thresholds parameters (preference threshold, indifference threshold and veto threshold) and is computationally demanding.

Within WETwin, only SAW and TOPSIS approaches were used. In most cases, results were not highly sensitive to ranking method, but were much more strongly affected by changes in weightings.

## 3.2 Trade-off analysis

Explicit trade-offs occur when an improvement in one ecosystem value or service is achieved at the expense of a decrease in another: for example, increase in agricultural area at the expense of natural wetland area. Implicit trade-offs may occur between stakeholders where the objectives or values of stakeholders groups differ, where one group benefits at the expense of another or has to forgo benefits to protect the interests of another. Common approaches to addressing trade-offs include economic valuation, multi-criteria analysis (eg Brown et al., 2001), and a range of modelling approaches, linking biophysical and socio-economic systems either heuristically or dynamically (eg Moradet et al., 2010).

In the WETwin analytical framework, trade-offs are explored at two stages: qualitatively, as part of the initial DSIR and stakeholder analysis; and quantitatively as part of MCA.

For all case studies, initial DSIR analysis identified high-level trade-offs in terms of land or water use at catchment scale: for example, conversion of wetlands for agriculture or urban use (eg Lobau, Ga-Mampa); or diversion of wetland flows for irrigation or hydropower (eg Inner Niger Delta, Abras de Mantequilla). Identification of trade-offs at an early stage in the process, and the structured approach to identifying and assessing management solutions collaboratively with stakeholders, resulted in two different responses. First, the stakeholder groups involved in some case studies considered the decisions determining major trade-offs to be outside their management sphere, and treated them as externally imposed scenarios. Efforts were then focused on identifying management options to adapt wetland use and conditions to these externally imposed conditions. Secondly, potential trade-offs were explicitly built into the choice of solutions at the design stage. For example, in Ga-Mampa, packages of interventions were specifically designed to address potentially competing management objectives for the wetland as “conservation oriented”, “economic oriented”, “socially oriented” and “integrated”. Ranking was dominated by stakeholder preferences for a specific orientation rather than relative scoring, since each solution scored well in its particular domain. In Abras de Mantequilla, a management continuum was designed with progressive addition of options favouring environmental outcomes at the expense of agricultural production; the choice for stakeholders was thus about the degree, not the direction, of change. In working communally to identify acceptable management solutions, a large number of proposed management interventions were “no regrets” options deliberately designed to benefit all stakeholders (such as interventions to improve water quality and land management practices).

Within a MCA framework, direct trade-offs are identified through pairwise comparison of criteria scores, using concepts of Pareto optimality to find non-dominated options (that is, options where the score for one criterion cannot be increased except by decrease in another) – see Figure 3.2 from

Sanon (2010), who applied this method to explore trade-offs for the Lobau wetland. The extent of the trade-off can be quantified by calculating the distance to the ideal solution. Within mDSS, the TOPSIS model uses distance to the ideal and non-ideal solutions as one way to rank solutions. In case studies where assessments were mainly qualitative (with only a few value levels), pairwise comparison of criteria was often not sufficiently sensitive to determine non-dominance, but the approach was useful for visualising potential trade-offs.

Implicit trade-offs between stakeholders are explored using analysis of preferences (expressed as criteria weightings) and the way these influenced rankings; and through use discussion and negotiation to find mutually acceptable solutions.

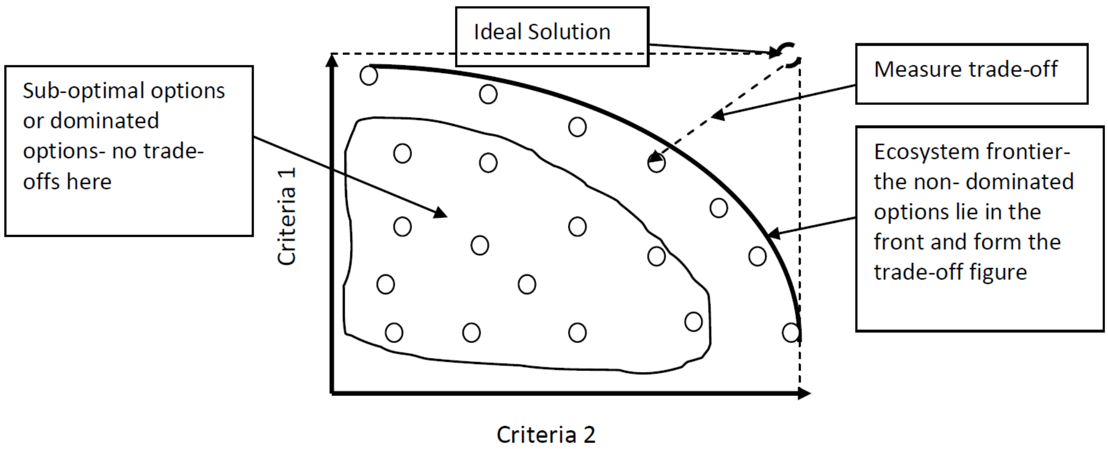



**Figure 3.2** Pairwise comparison of criteria to identify trade-offs (from Sanon 2010).

### 3.3 Vulnerability, resilience and adaptive capacity

Vulnerability and resilience have become important elements in discussions of global change, but are conceptualised differently in different studies: see, for example, reviews by Gbetibouo and Ringler (2009), Fussel and Klein (2006) and Turner et al. (2003). Within WETwin, we are 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 that focuses on adaptive capacity relative to impacts of external change. In this framework, resilience is considered to be a characteristic of the state of the whole system (including the institutional, bio-physical, infrastructural and behavioural aspects); while robustness relates to specific management options or solutions. Composite indicators to assess vulnerability are widely used, and have proved valuable for identifying trends and to capture the complexity of vulnerability in reasonably simple terms (Gbetibouo and Ringler 2009).

The WETwin framework for vulnerability assessment is discussed in detail in Liersch et al (2012) (D5.1), and is summarized in Figure 3.3. Vulnerability is usually described in terms of three components: exposure, sensitivity and adaptive capacity. The impact of external stress (external impact or EI) is a function of exposure to stressors and the sensitivity of the system to that stress. Adaptive capacity (AC) is the extent to which these impacts can be withstood or mitigated. The change in vulnerability (residual vulnerability or ΔV) of the system as it moves from its initial state to a new state can be described by the sum of (usually negative) external impacts and (usually positive) adaptive capacity, that is:

$$\Delta V = EI + AC$$

If the state of a system can be described using criteria or indicators representing key values (above), and scores can be allocated for these criteria under different conditions, then the vulnerability of the system to change can be described, at least in relative terms. External impacts (EI), or the changes in the system due to things other than management, can be derived from the evaluation matrices as the change in system condition for business as usual under a Scenario A (that is, with no change in management) compared to baseline conditions
ie

$$EI = BAU – Baseline$$

Similarly, adaptive capacity (AC), defined as the extent to which system condition can be changed by management, is derived from the evaluation matrices for each management solution ($MS_x$) as

$$AC = MS_x - BAU$$

Where the adaptive capacity of the system exceeds the external impacts (AC>EI, ΔV>0), the system is resilient; where external impacts exceed adaptive capacity (EI>AC, ΔV<0), the system is vulnerable.

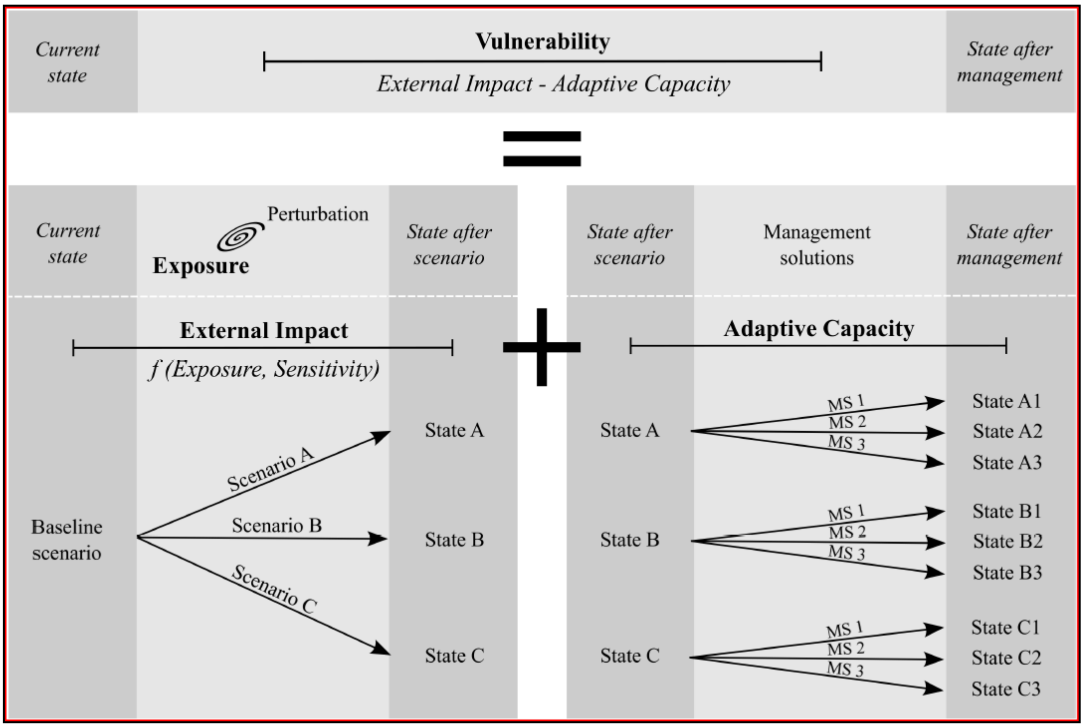



**Figure 3.3**: WETwin framework for vulnerability assessment of future states (from Liersch et al 2012)

# 4 Finding “best compromise” solutions

## 4.1 Discussion

The WETwin methodology was initially devised to handle a large number of both management solutions and evaluation criteria, to allow consideration of a wide range of management possibilities and to ensure that a wide range of values were taken into consideration in evaluating outcomes. However, experience in all case studies emphasized the need to simplify, and to focus on the most important options and criteria. This is driven partly by the need to present results to stakeholders in reasonably simple terms; and partly by the paucity and quality of available data for evaluation.

Through the process of working with stakeholders the number of management responses to be evaluated was narrowed down to a few (5-10), albeit as packages of multiple options grouped into management solutions. Only in the Lobau case study was a large number (31) of solutions assessed; and this was possible primarily because there was sufficient sensitivity in scoring different options, as a result of strong biophysical models (validated with extensive monitoring and field data), that could simulate changes in conditions under different management regimes. In the other case studies, the lack of sensitivity in scoring meant that distinctions could only be made a relatively high level. The results from case studies emphasized that highly quantitative approaches to scoring and ranking are only justified when supported by quality data.

Similarly, for discussing and presenting the final rankings all case studies condensed indicators into a limited set of criteria classes (between 5 and 8). Although weighting and combining large indicator sets is mathematically straightforward, it can be problematic in terms of presenting and explaining results. Grouping indicators into criteria classes (e.g., ecological health; contribution to livelihoods) reduced the complexity, but may in some cases have obscured contradictory results within classes. However, a large number of criteria may also work to obscure the important issues. In theory, weighting criteria to reflect stakeholder priorities will draw out those that are significant. In practice, it was observed that when asked to weight a long list of criteria (for example, by distributing 100 pebbles amongst 23 criteria in 5 classes) stakeholders do not assign zero weight to any criterion; so that the number of indicators in a criteria class skews the importance of the class.

The evaluation matrix provides an important way to summarise and present information on management outcomes. The use of scoring has a number of advantages. It allows comparison between different types of variables and enables inclusion of a much wider range of criteria. In addition, scores normalised to give a ranking from “bad” (0) to “good” (1) are easily understood, and facilitate reporting of results to non-technical audiences. However, the inherent weaknesses of scoring approaches must be taken into account. There are inconsistencies in comparing well defined modeled parameters (where a shift in value of 0.1 is meaningful) with data scored on a three class scale of “poor – moderate – good” (where a shift in value of 0.1 is not significant). The WETwin methodology does not explicitly track uncertainty associated with different parameters, so that the overall uncertainty associated with rankings cannot be described. This is a shortcoming in the methodology which should be addressed.

The ranking of solutions using MCA was very sensitive to weightings, and ranking became more an exploration of the preferences of different stakeholders than a definitive way to “choose” solutions, concurring with the findings of Hajkowicz (2006) that the strength of MCA is as tool to support discussion, rather than a primary decision making tool.

The MCA was conceptually structured to allow analysis of trade-offs between different criteria. However, major trade-offs identified in the initial DSIR assessments often either were, or were perceived to be, outside the management domain of the wetland managers. Trade-offs between different stakeholders within the wetlands were explicitly addressed as part of the management solutions. Stakeholders side-stepped conflict and tradeoffs by seeking compromise within the proposed management solutions: that is, by seeking solutions that packaged measures responding to the concerns of all groups. The strong preference for “no regrets” measures reflects that fact that for all stakeholders, a healthy wetland delivers more benefits.

Vulnerability analysis required ability to score management responses under both current and future conditions. In most of the case studies, the information available to score future management regimes was not sufficiently sensitive to reflect differences between scenarios. Only in the Inner Niger Delta, where there is potentially a very large change in the water regime due to upstream development, were scenarios considered in any detail. In other case studies, visioning of future scenarios was important in helping stakeholders to identify potential issues and trends, but quantitative analysis of vulnerability was not possible.

## 4.2 Conclusions

The challenge faced in the WETwin project was to find a robust methodology to assist wetland communities in a range of contexts to identify and assess management options. The starting point for the project was the understanding that the multiple uses and users of wetland are likely to engender different perspectives about what constitutes "best" management; that competing objectives mean that a wide range of assessment criteria are needed to adequately capture those perspectives; and that trade-offs and compromise are integral to wetland management. Building from current international best practice, a structured approach was devised which combined Multi Criteria Analysis, trade-off analysis and vulnerability analysis and involved stakeholders at all stages. The methodological framework was applied in case studies in Africa, South America and Europe.

The approach used in WETwin has three important strengths. First, it involves stakeholders at all stages of the decision process, and explicitly acknowledges and incorporates different perspectives so that local concerns are reflected in both the choice of options for evaluation and the final rankings. Secondly, it combines qualitative and quantitative data, so that assessments can be based on all important criteria, whether quantifiable or not. This allows inclusion of information relating to system components that are poorly known (but potentially important), not just components which can be measured with high confidence. Thirdly, it provides a relatively simple, structured approach to the complex problem of evaluating diverse wetland management interventions and a conceptually coherent framework to integrate impact and feasibility assessment, vulnerability analysis and trade-off analysis, based on evaluation matrices.

While the overall conceptual framework developed for WETwin was found to be robust and transferable to different contexts, the realities of implementation varied significantly between case studies. Not all components were applicable in all case studies; and the practical aspects of implementation depended on context, and particularly on the stakeholders involved. Working with stakeholder groups was a challenging and essential component of the project, and their different interests and concerns shaped the way the framework was applied. Ultimately, the strength of the approach was not in the rankings resulting from the analysis, but in the participatory process of exploration, debate and negotiation used to derive them.

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# PART B – Case studies

# 5 Ga Mampa (South Africa)

## 5.1 Decision space

### 5.1.1 Management solutions

Management solutions were elaborated by combining management options addressing different management issues (see WETwin D7.2). 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 Figure 5.1 below. Management options retained in each solution are described in Table 5.1.

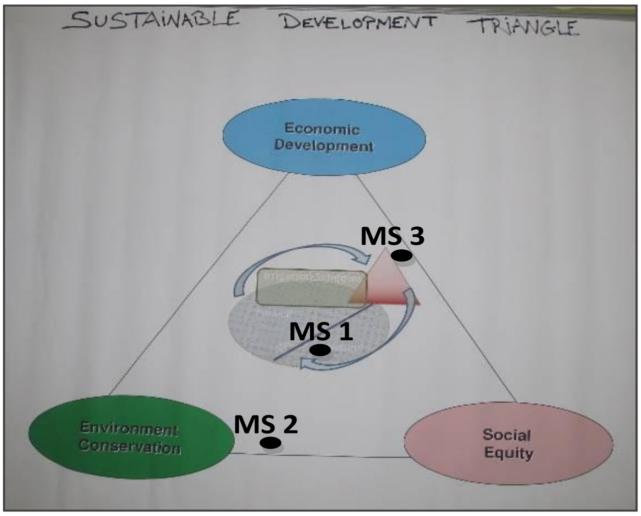


**Figure 5.1:** Conceptual map of MS in the sustainable development triangle

### 5.1.2 Criteria for evaluation

23 indicators grouped in 5 criteria categories are considered for the evaluation: among them 13 are quantitative indicators and 10 are qualitative, presented in the following table with their respective type of value function and indication of minimal and maximal thresholds. Rationale for all criteria value functions is given in WETwin D7.1. Regarding environmental sustainability, 6 indicators have been defined: three correspond to the WET-Health indicators developed under a WRC research project (Macfarlane *et al.* 2008); each of them is a combined impact score ranging from 0 to 10 with 10 corresponding to the highest negative impact. Each score encompasses several types of impacts from diverse forms of pressure. Three quantitative indicators have also been proposed to measure the impacts of management options on wetland health. They are used as output variables in the WETSYS model. These two sets of indicators are to be used alternatively; only 20 indicators are thus simultaneously used.

These indicators and their value functions were submitted to stakeholders' assessment during a workshop in October 2011. In general, indicators and their value functions were validated by stakeholders. The most contested indicators are related to social equity, especially to land access. Participants of the workshop (mainly local stakeholders) did not agree with the proposed value function for *percentage of wetland farmers with access to irrigation scheme.* They explained that, for

**Table 5.1:** Management options composing proposed management solutions for Ga-Mampa wetland management

| | MS1 | MS2 | MS3 | ENV. | ECO. | SOC. | INT. |
|---|---|---|---|---|---|---|---|
| Rehabilitation of irrigation schemes | Drip + gravity (repaired) | Drip + gravity (improved) | Drip IS commercial | 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 | Coordinated gov. Plan | Coordinated gov. plan | Coordinated gov. plan | Coordinated gov. plan | Local plan | Local plan |
| Environmental legislation | Identified office Appropriate means | Identified office Appropriate means | Identified office Appropriate means | Identified office Appropriate means | No office in charge | No office in charge | Identified office Appropriate means |
| Others (*) | Education programs Alternative livelihoods for farmers moving out of the wetland | | Business plan | | | | |

(*) these options are not taken into account in the assessment process because they could not be documented due to time constraints

**Table 5.2:** Indicators for assessing management solutions in Ga-Mampa case study

| *Criteria* | *Indicators* | *Qualit.* | *Quanti* | *Type of value function* |
|---|---|---|---|---|
| Environmental sustainability | Average depth of groundwater table in dry season | | X | Minimize; maximal below 1 m, minimal above 2 m |
| | % of natural vegetation | | X | Maximize, maximal above 75% |
| | River outflow as a % of natural flow in dry season | | X | Maximize, minimal below 20%, maximal above 75% |
| | WETHealth Hydrology | X | | Minimize |
| | WETHealth Geomorphic | X | | Minimize |
| | WETHealth Vegetation | X | | Minimize |
| Economic development | % of maize needs covered by local production (wetland + irrigation) | | X | Maximize, minimal at 0, maximal above 80% |
| | % of cash basic needs covered by cash income from natural resources | | X | maximize, minimal below 50% |
| | Opportunities for local off-farm job | X | | 3 levels: low, medium, high |
| Social equity | % of irrigation scheme area irrigable in dry season | | X | Maximize, minimal below 20% |
| | % of wetland farmers having a plot in IS | | X | Minimize, minimal above 33% |
| | % of households with access to IS or wetland plot | | X | Maximize, maximal above 66% |
| | type of access to land | X | | 2 levels: unregulated, regulated |
| | % of households engaged in reeds and sedges collection | | X | Maximize, maximal above 25% |
| | Grazing opportunities in the wetland | X | | Maximize, 3 levels: limited to river bank, free access to crop residue, crop residues and pastures |
| Cost effectiveness | Investment costs (% of municipal capital budget) | | X | Minimize, minimal below 15% , maximal above 50% |
| | Costs for O&M +renewal (% of average household income) | | X | Minimize, minimal above 10% |
| | Share of capital costs supported by local users | | X | Minimize, minimal above 15% |
| | Share of O&M costs supported by local users | | X | Maximize, maximal above 20% |
| Institutional clarity | Local committees and user participation | X | | 3 levels: none, specialized, integrated & coordinating |
| | Rule clarity | X | | 3 levels: no rules, clear rules, coordinated and enforced |
| | Awareness raising / training program | X | | 3 levels: none, once off, continuous |
| | Coordination of government programs | X | | 4 levels: none; separated plans from each government dept; active communication among government dept;, community & government coordinated project |

cultural reason, it is very unlikely that a farmer will let his/her plot to another one on a long term basis, even if he/she does not use it. However, as participants failed to propose an alternative indicator for the corresponding management principle ("*access to cropping land is fair*"), which was considered as important during the March 2011 stakeholder workshop, we decided to maintain this indicator in the list. Some other indicators such as *opportunities for local off-farm jobs* or *grazing opportunities*, also contested but with a lesser importance, can be removed from the list of indicators, which would be reduced to 18 indicators.

### 5.1.3 Storylines and scenarios for the GaMampa Case Study

DPSIR analysis (Zsuffa et al. 2010) indicates that the main issues of concern at GaMampa are loss of livelihood support (food production and other benefits) from the wetland and overall degradation in wetland health, due to increased pressure from a number of sources. The function, health and use of the wetland by the community are closely interlinked with other resources in the valley, particularly small irrigation systems bordering the wetlands and drawing from the same water sources. Drivers of change are mainly socio-economic conditions in the community in the valley, including overall population, poverty and availability of alternative livelihoods and food sources, and levels of education, awareness and local governance. Climate change may also affect water availability for the wetland and agricultural productivity.

Three storylines have been formulated to explore research questions on the influence of external drivers (climate, population and economic conditions) on livelihood options of the community, and the way these impact on the management, ecosystem services and health of the wetland. Each storyline has multiple scenarios associated.

- Storyline 1: Vulnerability of food production (crop yields, particularly maize) in GaMampa valley (irrigation scheme and wetland) to climate changes over the next 30 years. Three climate outlooks are examined, reflecting likely temperature increase and rainfall variability, based on the regional climate model STAR (Orlowsky et al 2008), assuming temperature increases of 0.5 (1A), 1.0 (1B), and 1.5 (1C) degrees C respectively compared to the period 1961-2000
- Storyline 2: Vulnerability of community livelihoods in GaMampa valley to population change over the next 30 years. An increase in population will put more pressure on the wetland and narrow its uses even more if the opportunities for local off farm jobs do not increase too. A decrease or stabilization in population would allow a more formal regulation of uses and encourage a diversity of livelihoods. Three outlooks reflecting likely changes in population were considered: constant population, in-migration and out-migration.
    - 2A: BAU constant population
    - 2B: population decrease (corresponds to G-Ec in D5.1 global scenarios) – improved economic conditions lead to out-migration, higher external income and food sources, lower pressures on wetland.
    - 2C: population increase (corresponds to R-Ec in D5.1) – low rates of growth and high unemployment result in move back to rural areas, high dependence on local resources, low external income
- Storyline 3: Vulnerability of wetland health (water supply, natural resources) in GaMampa valley to climate change and population growth over the next 30 years. Only the worst case outlook was considered (population increase, low economic growth, decrease in water availability), corresponding to 1B + 2C above.

Based on the storylines above 3 scenarios have been described in detail for further analysis of vulnerability of the system:

- Scenario 1: limited change - steady population, climate 1A

- Scenario 2: optimistic:  population decrease (corresponds to G-Ec) – improved economic conditions lead to out-migration, higher external income and food sources, lower pressures on wetland; better institutional support for NRM.  Climate from 1A
- Scenario 3: worst case -  population increase (corresponds to R-Ec) – low rates of growth and high unemployment result in move back to rural areas, high dependence on local resources, low external income, low levels of government support for NRM.   Climate from 1B.

Details of the scenarios are set out in Honarmand (2011).

The WETSYS model is being used to assess impacts of the scenarios on food production, livelihoods and wetland health.  This work is on-going in Irstea (formerly Cemagref); as of January 2012, results were not yet available.

## 5.2 Results of expert analysis

### 5.2.1 Scoring of solutions

The evaluation matrix (Table 5.3) 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) (partially reflected in Murgue 2010). It corresponds to a qualitative expert judgment and is meant to be updated with results from undergoing modeling efforts (WETSYS integrated model and farming system model).

Indicator nominal 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 examples.

First example: impact of MS1 on percentage of maize needs covered by local production

| Management options with an impact on indicator | Impact of MO on indicator | Global impact of MS on indicator | Comment |
|---|---|---|---|
| Restored canal + drip system | + | ++ | Maize production in irrigation scheme can be increased with higher water availability and wetland cropped area remains high |
| 35% of natural vegetation | = | | |

Second 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 criteria scores and therefore results of assessment should be considered with caution.

**Table 5.3:** Evaluation matrix of proposed management solutions for the Ga-Mampa wetland based on qualitative expert judgment

| | | Business as usual | MS1 | MS2 | MS3 | Conservation oriented | Economic oriented | Social oriented | Integrated solution |
|---|---|---|---|---|---|---|---|---|---|
| Environmental sustainability | 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 |
| | WET -Health Hydrology | 0.25 | 0.5 | 0.75 | 0.25 | 1 | 0 | 0.75 | 1 |
| | WET- Health Geomorphic | 0.25 | 0.25 | 0.5 | 0.5 | 1 | 0.25 | 0.75 | 1 |
| | WET-Health Vegetation | 0.25 | 0.25 | 0.75 | 0.75 | 1 | 0.25 | 0.75 | 0.75 |
| Economic development | Percentage of maize needs covered by local production (wetland + irrigation) | 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 |
| Social equity | Percentage of irrigation scheme area irrigable in dry season | 0 | 0.75 | 1 | 1 | 0.75 | 1 | 1 | 1 |
| | % of wetland farmers having a plot in IS | 0 | 0.75 | 1 | 0.75 | 0.75 | 0.75 | 1 | 0.75 |
| | % of households with access to IS or wetland plot | 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 |
| | Percentage of households engaged in reeds and sedges collection | 0.75 | 0.75 | 1 | 1 | 1 | 0.75 | 1 | 1 |
| | Grazing opportunities in the wetland | 1 | 0.5 | 0.75 | 1 | 0.5 | 0.25 | 0.5 | 0.75 |
| Cost effectiveness | 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 |
| Institutional clarity | 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 |

Scores ascribed to management solutions by the research team were presented to stakeholders during a workshop in October 2011. Due to time constraints only some of them were subjected to discussion in the following way: participants, split up into three groups, were asked to score one of the management solutions elaborated during the March 2011 workshop (MS1, MS2, MS3) against a limited set of criteria. Scores for the other solutions as well as for the current situation were provided as a reference. Moreover, management options fact sheets, gathering the available information on management options and their potential impacts on the Ga-Mampa valley were provided to each group.

In general, half of the scores proposed by stakeholders presented significant differences with values attributed by the research team (see the 5th Ga-Mampa stakeholder workshop report). This exercise proved to be difficult for the stakeholders, because they had to handle a lot of information at the same time: i) composition of MSs in terms of options; ii) information about potential impacts of options on the indicators; and iii) criteria value functions. The result of the exercise could have been improved by i) presenting MSs in a more readable way using graphical representations of options and solutions; ii) going through the MO fact sheets with every group of stakeholders prior to the workshop and summarizing main impacts in a table, so that they can assimilate easily the information and iii) using raw values of indicators, or even a qualitative comparison with the current situation instead of standardized values between 0 and 1. Due to the limitations of the valuation exercise, the scores initially proposed by the research team are kept without change in the rest of the multi-criteria analysis process.

### 5.2.2 Analysing trade-offs - impact of stakeholder preferences, alignment of stakeholder groups

Problem analysis performed in consultation with stakeholders identified the major trade-offs in the Ga-Mampa valley (Table 5.4). The analysis of solution scores against valuation criteria is used to confirm (or refute) and refine this diagnosis.

**Table 5.4:** Trade-offs between wetland's ecosystem services

| **Trade-offs between wetland's function and eco-services** identified through solutions and indicators evaluation (no stakeholders' weights) | | |
|---|---|---|
| Food or crop production | ←→ | Biodiversity<br>Traditional use of the wetland |
| Food production (on-site SH) | ←→ | Hydrological regulation, water supply downstream (off-site stakeholders) |
| Livestock grazing | ←→ | Cultivation |

*Trade-off analysis (without considering criteria weights)*

Solutions and options are not defined in an incremental way as in the Ecuadorian case study, but are combinations of options addressing technical, economic, governance and institutional aspects. Thus the interpretation of trade-offs is a bit different.

As in the Abras de Mantequilla case study, we first looked at major trade-offs between criteria categories, by calculating average scores of management solutions per category as shown in Table 5.5. Figure 5.2 and Figure 5.3 summarize the trade-offs between environmental sustainability on one hand and either economic development or social equity on the other hand. We then look in more details to some pair-wise comparison of individual scores.

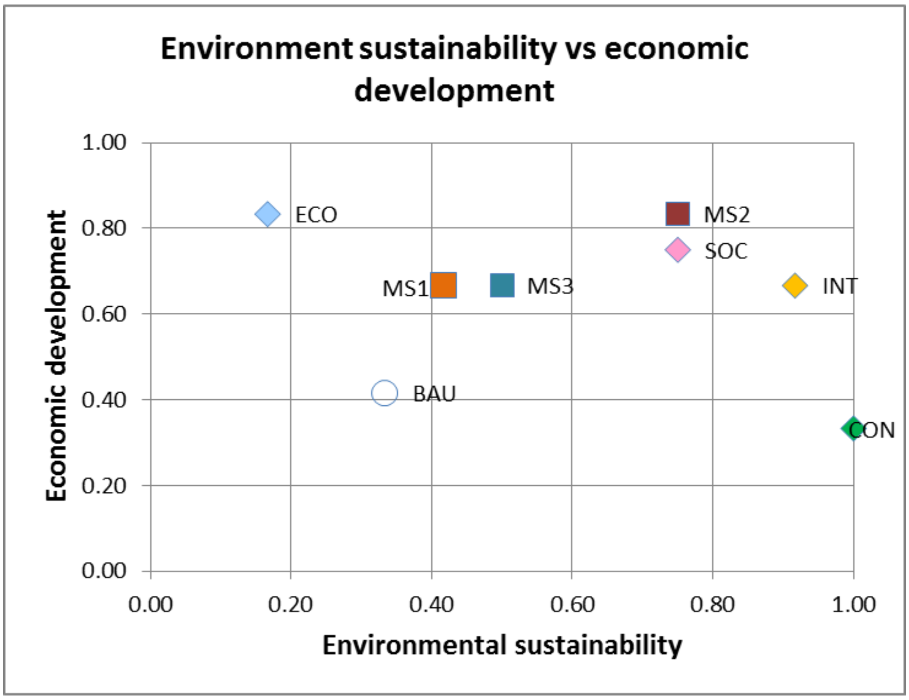


**Figure 5.2:** Analysis of trade-offs between environmental sustainability and economic development

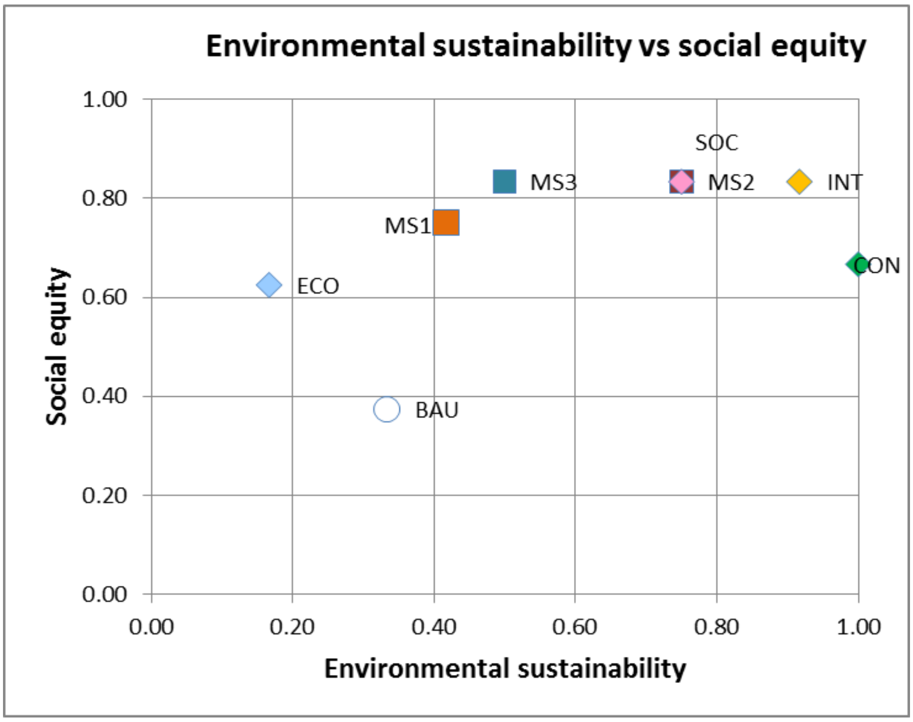


**Figure 5.3:** Analysis of trade-offs between environmental sustainability and social equity

**Table 5.5:** Average scores of management solutions per category of criteria (equal weights)

| | BaU | MS1 | MS2 | MS3 | CON | ECO | SOC | INT |
|---|---|---|---|---|---|---|---|---|
| Environmental sustainability | 0.25 | 0.33 | 0.67 | 0.50 | 1.00 | 0.17 | 0.75 | 0.92 |
| Economic development | 0.42 | 0.67 | 0.83 | 0.67 | 0.33 | 0.83 | 0.75 | 0.67 |
| Social equity | 0.38 | 0.75 | 0.83 | 0.83 | 0.67 | 0.63 | 0.83 | 0.83 |
| Cost effectiveness | 1.00 | 0.44 | 0.12 | 0.65 | 0.51 | 0.66 | 0.54 | 0.51 |
| Institutional clarity | 0.00 | 0.63 | 0.69 | 0.75 | 0.81 | 0.63 | 0.75 | 0.88 |
| Overall score | 0.39 | 0.58 | 0.69 | 0.68 | 0.72 | 0.53 | 0.74 | 0.80 |

As expected the conservation oriented solution offers the best performance in terms of environmental sustainability but is rather poor regarding impacts on economic development. At the opposite, the economic oriented solution has high positive impacts on economic development but poor effects in terms of environment sustainability. MS2, social oriented and integrated solutions represent the best compromises between these two dimensions of sustainable development. There is a limited variability of social equity scores as, except for the Business as Usual solution, all solutions score between 0.63 and 0.83. Four solutions (MS2, MS3, social oriented and integrated) present the highest scores.

All environmental indicators give a similar ranking of solutions, all representing an improvement compared to the current situation. On the contrary, solutions present very different profiles with regards to the three economic indicators: there is a clear trade-off between food production and cash generation opposing BaU on one hand and MS3 on the other hand. MS2, and in a lesser extent ECO, SOC and INT solutions, perform best on both criteria.

The trade-off between crop (maize) production and grazing is illustrated on Figure 2.4: it opposes MS1, SOC and Eco which favor maize production over grazing, on one hand, to MS3 on the other hand. BaU, MS2 and INT offer a good compromise.

Figure 5.5 compares solutions in terms of access to land and land concentration (percentage of farmers cumulating land in irrigation scheme and wetland): compared to the current situation all solutions present an improvement in land concentration (MS2 and SOC performing the best on this criterion). However the likeliness of such achievements can be questioned, given the discussion of this indicator by local farmers (see discussion on valuation criteria). The conservation oriented solution offers the least availability of land for crop production. ECO and MS1 represent an improvement both in terms of land access and of limiting land concentration. Finally all solutions, except BaU and ECO, require a more controlled access to land.

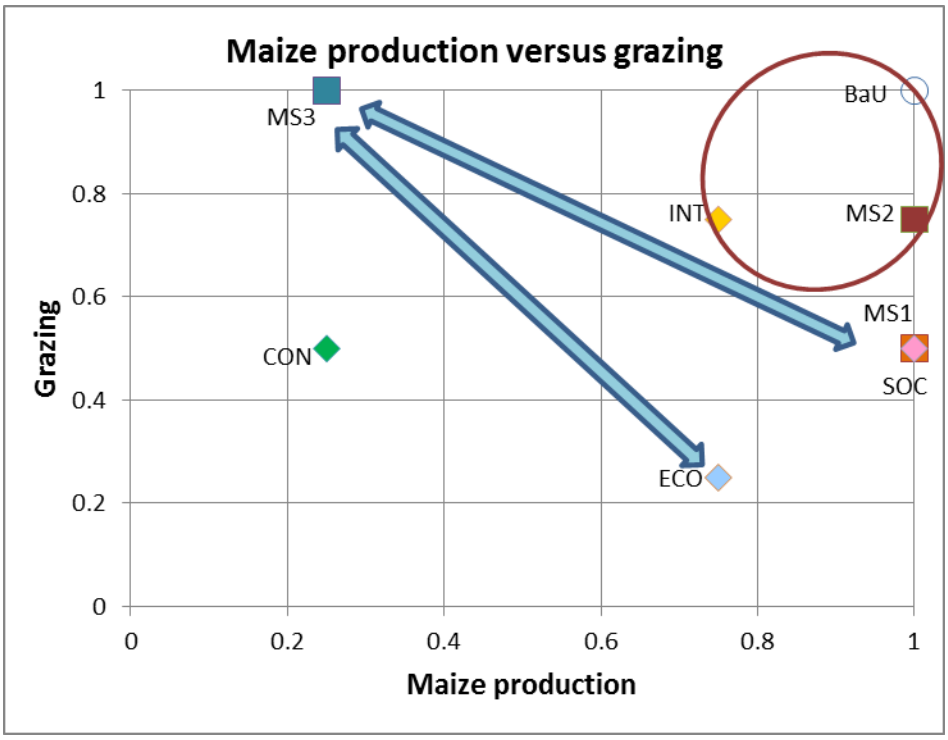


**Figure 2.4:** Analysis of trade-off between maize production and grazing

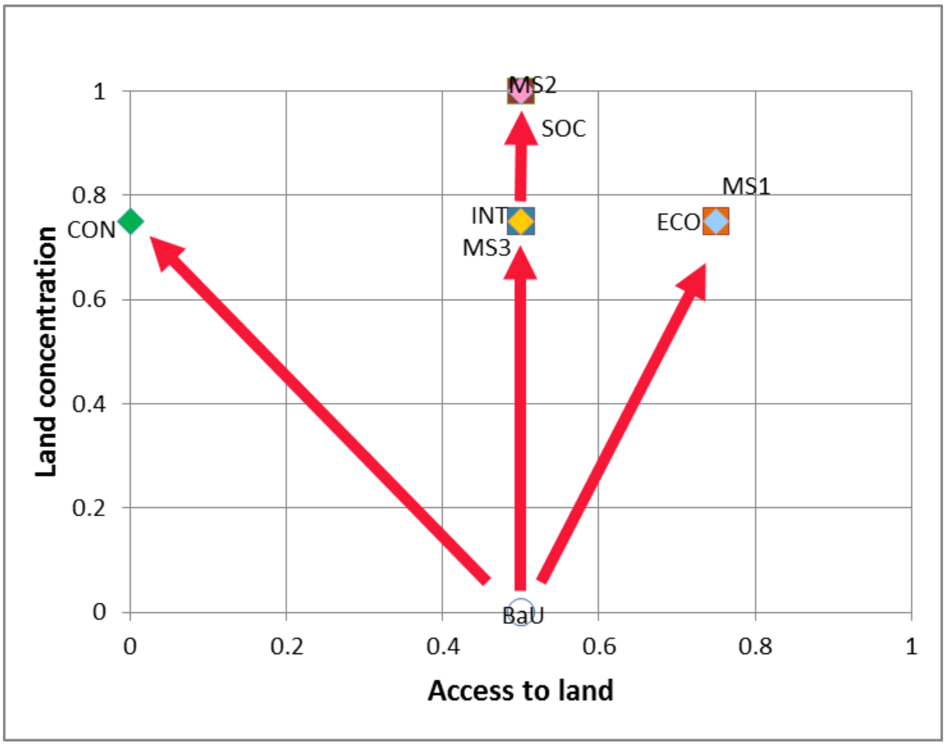


**Figure 5.5:** Trade-off between land access and land concentration

MS2 solution is by far the most expensive both in terms of capital costs and operation and maintenance, because it combines an upgraded gravity system with a drip irrigation system. MS1, INT and CON are the less expensive, with MS3, ECO and SOC in intermediate position. The O&M costs indicator is not discriminating, except for MS2 (the most expensive) and BaU (costless). The same holds for the share of O&M cost supported by local users which remains in an ideal range for all solutions. Focusing then on capital cost related variables 2 groups of solutions can be identified (Figure 5.6):

- MS3, ECO and SOC with moderate investment costs and a low contribution from local users, which would increase community acceptance;
- CON, INT, and MS1 which display low investment cost but require somehow a higher contribution from local users (which can be seen as a deterrent but also as a condition for sustainability)

Regarding institutional indicators, it appears that the type of training programs and, to a lesser extent, rule clarity, are not very discriminating. From Figure 5.7, one can see that MS1, MS2, ECO and MS3 require increasing levels of local organization, whereas moving from MS3 to CON and then INT and SOC solutions implies higher government coordination. Thus, although institutional clarity should be pursued and is ensuring the success of chosen solutions in the long run, higher institutional requirements make INT and SOC solutions more risky or difficult to implement.

Figure 5.8 summarizes the feasibility scores of proposed solutions for Ga-Mampa wetland: among the solutions performing well on the three pillars of sustainable development (MS2, SOC and INT), MS2 appears to be the less feasible, especially because of its very high costs (and also because of its technical complexity, which was not taken formally into account in this assessment). INT and SOC are less costly but require in any case challenging institutional changes. With slightly lower performances in terms of environment and economic development, MS3 appears to be more feasible, at least cost-wise.

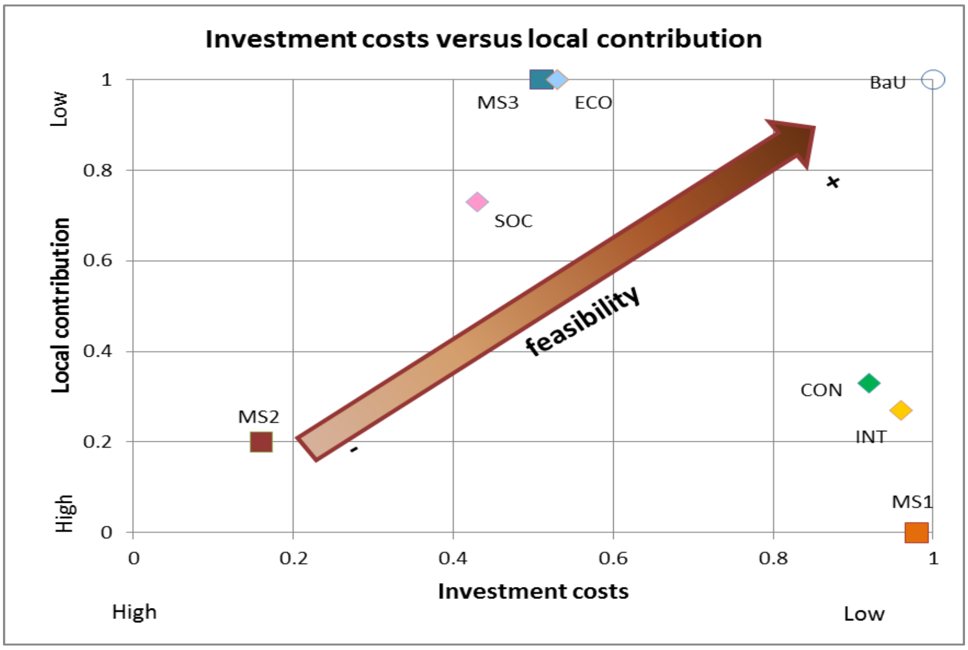


**Figure 5.6:** Total investment costs versus contribution by local users

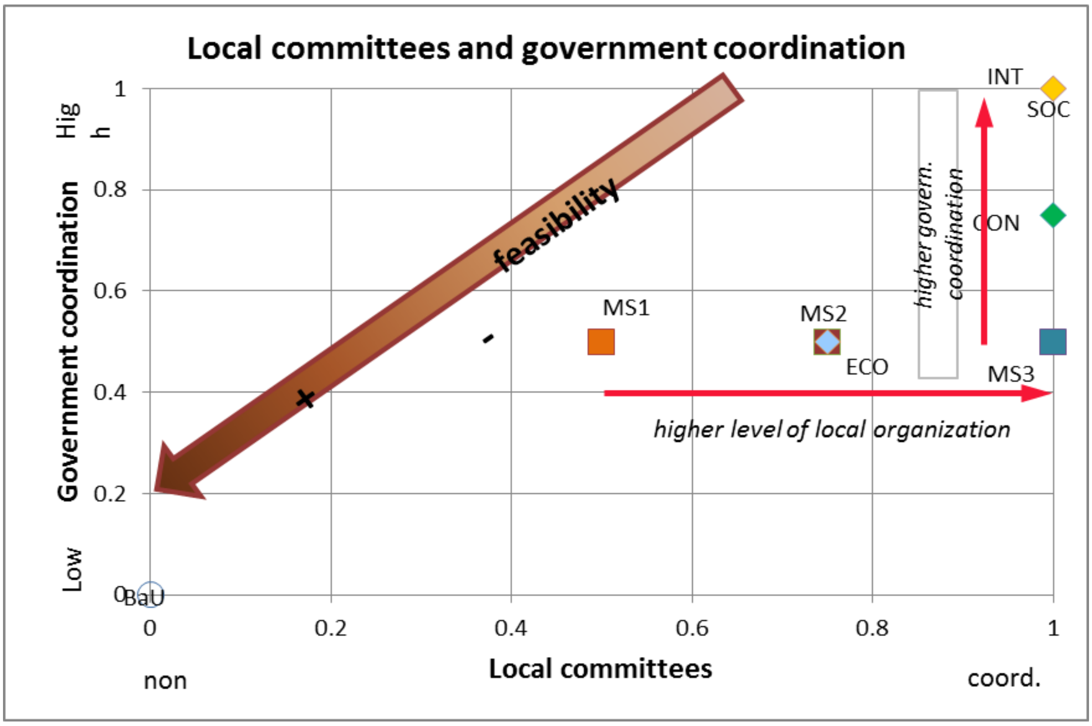


**Figure 5.7:** Institutional clarity: local committees and government coordination

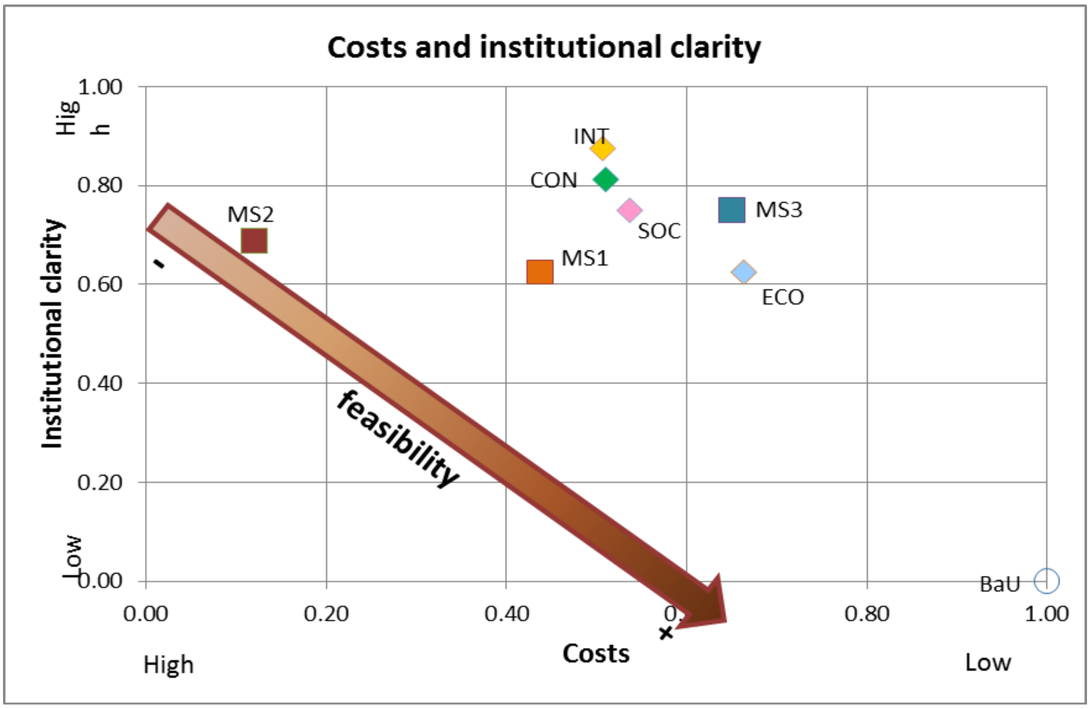


**Figure 5.8:** Feasibility of solutions: costs and institutional requirements

**Summary**

1. The previously identified trade-off between environmental impacts and economic consequences is confirmed, however there are possible compromise solutions (INT, SOC, MS2)
2. The trade-off between crop production and other, more traditional, uses of the wetland is also confirmed, but again, there are possible compromises (MS2, INT)
3. A new trade-off appears between solutions favoring cash generation and those promoting food production, with MS2, ECO, SOC, and INT offering a compromise.
4. All environmental indicators are positively related and there is no trade-off among them.
5. There is a trade-off between the level of investment costs and the contribution of local users
6. Among institutional indicators, the levels of local organization and of government coordination appear to be the most discriminating.
7. Institutional indicators are more difficult to handle than other categories as the institutional clarity required to ensure sustainability of management in the long run is more difficult to implement.
8. The best performing solutions in terms of impacts are also the most difficult to implement due to high costs and institutional complexity.

### 5.2.3 Ranking of solutions by mDSS considering stakeholders' priorities

During the 4th stakeholder workshop, stakeholders were asked to rank management principles[1] according to their preferences (see the Report_WS4_April_2011_Vfinal, C. Murgue, 2011). Regarding environment related indicators three sets can be considered: qualitative indicators derived from WET-Health tools; quantitative indicators assessed through modeling; and all 6 indicators. As weighing exercise was performed individually and by group, it is possible to use several sets of average weights:

- Average of group weights, qualitative environmental indicators
- Average of group weights, quantitative environmental indicators
- Average of group weights, all environmental indicators
- Average of individual weights, qualitative environmental indicators
- Average of individual weights, quantitative environmental indicators
- Average of individual weights, all environmental indicators

In addition, two decision rules can be applied:

- Simple Additive Weighing (SAW)
- Technique for Order Preference by Similarity to Ideal Solution (TOPSIS)

[1] Management principles are defined as objectives that management should achieve. These principles were formulated in consultation with stakeholders. They were later translated into measurable indicators by the research team. For some principles, several indicators were proposed, either as alternative or as complementary. For principles related to environment sustainability, two sets of indicators were proposed: one set is derived from the WET-Health assessment tools; the other is composed of quantitative indicators. For the principle "access to land is fair", three complementary indicators were proposed. In this case, the weight ascribed by stakeholders to this principle was distributed equally among the 3 indicators.

**Table 2.6:** Ranking of solutions with different sets of weights and decision rules

| *Decision Rule* | *Weights' set* | *Solutions order (best → worst)* | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| **SAW** | Group average, qualitative env. ind. | integ 84 | soc 80 | MS 2 76 | cons 75 | MS 3 68 | MS 1 62 | Econ 57 | BAU 34 |
| | Group average, quantitative env. ind. | integ 84 | soc 80 | MS 2 78 | cons 75 | MS 3 67 | MS 1 64 | Econ 55 | BAU 34 |
| | Group average, all env. ind. | integ 84 | soc 90 | MS 2 77 | cons 75 | MS 3 68 | MS 1 63 | Econ 56 | BAU 34 |
| | Individual average, all env. ind. | integ 85 | soc 79 | MS 2 77 | cons 75 | MS 3 69 | MS 1 62 | Econ 56 | BAU 35 |
| **TOPSIS** | Group average, qualitative env. ind. | integ 79 | soc 75 | MS 2 69 | cons 67 | MS 3 62 | MS 1 57 | Econ 53 | BAU 34 |
| | Group average, quantitative env. ind. | integ 79 | soc 75 | MS 2 71 | cons 68 | MS 3 61 | MS 1 58 | Econ 52 | BAU 34 |
| | Group average, all env. ind. | integ 79 | soc 75 | MS 2 70 | cons 67 | MS 3 62 | MS 1 57 | Econ 52 | BAU 34 |
| | Individual average, all env. ind. | integ 79 | soc 74 | MS 2 70 | cons 67 | MS 3 62 | MS 1 56 | Econ 52 | BAU 34 |

Table 2.6 shows that the results are not sensitive to the set of weights or decision rule. Individual stakeholder ranking based on weights confirmed this result (Table 5.7): the integrated solution is preferred by all stakeholders but one. The largest variations occur in the 2$^{nd}$, 3$^{rd}$ and 4$^{th}$ 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 (the difference between maximum and minimum weight varies from 0.08 to 0.23 across stakeholders). Preferences are the most homogeneous for environmental indicators, and the least for two economic indicators (percentage of cash basic needs covered by income from natural resources and opportunities for off farm jobs).

**Table 5.7:** Positions of solutions in individual ranking (SAW) (number of occurrences)

| Position | INT | SOC | MS2 | CON | MS3 | MS1 | ECO | BaU |
|---|---|---|---|---|---|---|---|---|
| 1$^{st}$ | 20 | | 1 | | | | | |
| 2$^{nd}$ | | 13 | 3 | 5 | | | | |
| 3$^{rd}$ | 1 | 4 | 12 | 4 | | | | |
| 4$^{th}$ | | 4 | 4 | 10 | 2 | 1 | | |
| 5$^{th}$ | | | 1 | 1 | 18 | | 1 | |
| 6$^{th}$ | | | | | 1 | 20 | | |
| 7$^{th}$ | | | | 1 | | | 20 | |
| 8$^{th}$ | | | | | | | | 21 |

During the 5th stakeholder workshop, three groups of stakeholders (mixing local farmers and external stakeholders) were asked first to choose their three preferred solutions and then to reach an agreement on a common compromise solution. For two groups (groups 2 and 3), the three preferred solutions included the integrated, the conservation oriented and the social oriented solutions (respectively the 1st 4th and 2nd ranked solutions with mDSS). Group 2 finally chose the integrated solution on the ground that it allows satisfying different kind of interests. Group 3 made its final choice on the basis of feasibility: although the conservation solution was chosen more often in group 3, it was discarded because it implies giving back a part of the cultivated wetland to natural vegetation. The social oriented solution was finally selected over the integrated one because it was deemed easier to implement. The third group (group 1) only included in its set the three extreme solutions (ECO, CON, SOC). In this group, the focus of the discussion was more on the objectives of wetland management embodied in the title of these extreme solutions, than on the solution performances. Individual choices among the Ga-Mampa community members of this group were very homogeneous and targeted towards economic development. It is possible that the presence of the traditional leader in the group had influenced the choice of other community members. Interestingly 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. This approach could be applied by CRCE for example in the framework of the UNDP funded project.

### 5.2.4 Sensitivity analysis

*Sensitivity to changes in weights*

Looking at individual weights, one can notice that the highest variability is observed for cash income and off farm job opportunities (variation coefficient 75%), and then for reeds and sedges collection and grazing opportunities (variation coefficient 66%). At the opposite, preferences of stakeholders for environmental related indicators are quite homogenous (variation coefficient 37 to 45%).

As already mentioned ranking of solutions does not seem to be very sensitive to weights as solution ranking is quite stable across stakeholders. Applying the method proposed by Triantaphylou (2010) and reported by Mysiak 2010, one can identify the most critical criterion for pair-wise change of rank order (Table 5.8). The most critical criterion is the one which requires the minimal amount of change in the current value of its weight in order to change solutions' rank order. One can see that changes in weights of investment costs, share of capital costs supported by locals and maize production would lead to most changes in the head of ranking while control of land access, irrigable land area and institutional criteria play a bigger role in the tail of the ranking.

**Table 5.8:** Most critical criteria for pair wise solution rank order

| | SOC | MS2 | CON | MS3 | MS1 | ECO | BaU |
|---|---|---|---|---|---|---|---|
| INT | investment cost | investment cost | land access maize production | groundwater depth Wet-Health hydro | Wet-Health geom | groundwater depth Wet-Health hydro | irrigable area **land access control** local committees rule clarity gov. coordination |
| SOC | | share of capital cost by locals | maize production | maize production | share of capital cost by locals | groundwater depth Wet-Health hydro **land access control** | irrigable area land concentration **land access control** local committees gov. coordination |
| MS2 | | | investment cost | share of capital cost by locals | investment cost | share of capital cost by locals | cash income irrigable area land concentration O&M costs rule clarity |
| CON | | | | investment cost | % nat. vegetation Wet-Health geom Wet-Health veg maize production land access | groundwater depth Wet-Health hydro | **land access control** local committee rule clarity |
| MS3 | | | | | share of capital cost by locals | grazing | cash income irrigable area local committees rule clarity |
| MS1 | | | | | | share of capital cost by locals | share of capital cost by locals **land access control** |
| ECO | | | | | | | cash income irrigable area |

*Sensitivity to changes in criteria scores.*

As already observed on the evaluation matrix some criteria, such as share of O&M costs supported by locals or percentage of households engaged in reeds and sedges are not or little discriminating across solutions. Other low discriminating criteria include: irrigable area, land concentration (% of wetland farmers with IS plot), training, and O&M costs. On the other hand, depth of groundwater, Wet-Health hydrological score, share of capital costs supported by locals and investment costs present the largest range of variations across solutions.

The criteria for which scoring was the most uncertain are: depth of groundwater, river outflow, cash income, land concentration, and percentage of households in reeds and sedges collection. It is expected that the use of models (integrated model and farming system model) will help reduce uncertainties on these scores.

## 5.3 Results of stakeholder consultations (equity matrix)

Direct ranking of solutions was performed during the 4th stakeholder workshop in March 2011 and results are reported in Table 5.9. When compared to the individual ranking of solutions based on weights and criteria scores it is obvious that both approaches 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 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 the economic oriented 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 rank solutions, stakeholders did not fully understand the potential impacts of the management solutions. This is possible because when the equity matrix was established, stakeholders had not received yet the detailed information about all the options and solutions, although some of the impacts of options have been discussed individually.
- 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.
- 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.

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. In consequence, there was no point in revising the equity matrix.

## 5.4 Summary and recommendations

For Gamampa, different management solutions were formulated, with input from the community, to emphasise specific outcomes (economic, social, environmental) and to explore integrated solutions where potential trade-offs were explicitly addressed and incorporated into the planning. Potential tradeoffs identified for the wetland are primarily between food production and other uses, dominantly traditional collection and hydrological regulation. There is also potential conflict between cultivation and livestock grazing

The evaluation matrix was scored 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) and corresponds to a qualitative expert judgment; it is meant to be updated with results from undergoing modeling efforts (WETSYS integrated model and farming system model). This process necessarily results in some uncertainties on criteria scores and therefore results of assessment should be considered with caution.

An integrated solution (incorporating drip and gravity irrigation schemes, grazing control, retention of 50% of the wetland under natural conditions and a locally administered wetland management plan) consistently scored highest in the MCA. Results are not sensitive to the set of weights or decision rule. Individual stakeholder ranking based on weights confirmed this result: the integrated solution is preferred by all stakeholders but one. The analysis indicated that the best performing solutions in terms of impacts are also the most difficult to implement due to high costs and institutional complexity, emphasizing the importance of supporting programs to improve local and institutional capacity when implementing natural resource management programs.

In comparing expert scoring with direct ranking by stakeholders, 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. Individual choices among the Ga-Mampa community members of this group were very homogeneous and targeted towards economic development. This may be attributagle, at least in part, to the fact that 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.

Further work with stakeholders is needed identify a unique compromise solution; and to explore the vulnerability of the system to external change. This could be carried out by University of Limpopo CRCE in the framework of an on-going UNDP funded project.

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**Table 5.9:** Direct ranking of solutions by stakeholders

| 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 |

# 6 Nabajjuzi

## 6.1 Decision space

### 6.1.1 Management options and solutions

The management options and solutions taken into consideration for Nabajjuzi  focus mainly on **water supply** and **distribution**, **water quality** and **water quantity**, and are described in detail in WETwin D7.2 (Johnston and Mahieu 2012).

Five axes of management were identified to address changes in water supply (abstraction and distribution), improvements in water quality (through waste water treatment and collection) and protection of the watershed (ecological state and high water quality).  In order to formulate solutions consistent with Integrated Water Management, each proposed solution included an option from each management axis, options from different axes are complementary (Solutions can also include 'Business as Usual' options for one or more axes). To narrow down the number of solutions, a preliminary screening was carried out to choose the preferred alternative in each axis, based on an assessment of vulnerability and adaptive capacity. To perform the trade-off analysis all possible combinations between the preferred management options will be assessed (see WETwin D7.2 for more details).

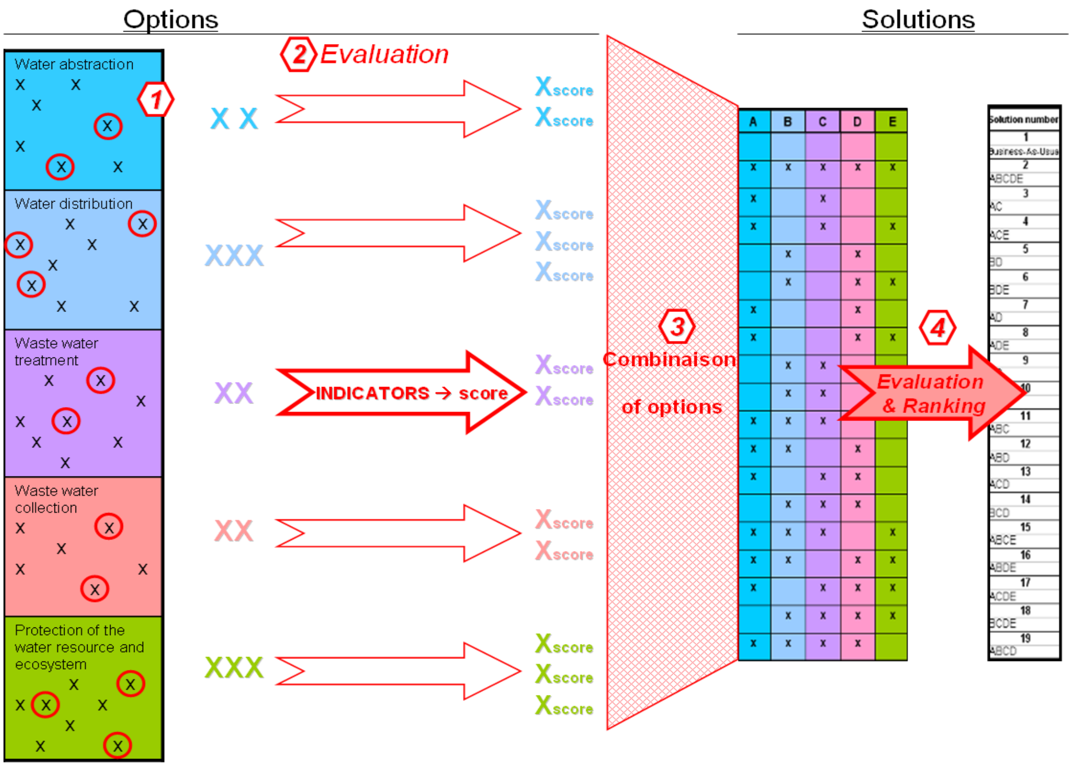



**Figure:** From Management Options to Management Solutions (Mahieu, 2010)

### 6.1.2 Indicators, value functions, criteria

To evaluate the impacts and requirements of the different management options and solutions, a set of 19 common indicators has been defined. All indicators can be scored from 0 to 4, with 0 representing the worst possible situation and 4 the best possible situation. Six categories of indicators were formulated:

| *Criteria* | *Indicators* | *Qualit.* | *Quant.* | ***Value function*** | | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | **0** | **1** | **2** | **3** | **4** |
| **Ecosystem Services** | Drinking water supply eco-service | X | | -- | - | 0 | + | ++ |
| | Water Quality regulation eco-service | X | | -- | - | 0 | + | ++ |
| **Ecosystem Health** | WETHealth hydrology | X | | F-E | D | C | B | A |
| | WETHealth Geomorphology | X | | F-E | D | C | B | A |
| | WETHealth Vegetation | X | | F-E | D | C | B | A |
| **Direct Costs** | Costs of implementation of management option | X | | Very High | High | Mod. | Low | No |
| | Costs of maintenance and operation | X | | >100% | +80%/100 | +50%/80% | +20%/50% | No/ <20% |
| **Benefits & Positive impact** | Access: occurrence of benefit | X | | <20% | 20% /40% | 40% /60% | 60% /80% | >80% |
| | Increase of benefits from economic activities | X | | No | +20%/50% | +50%/100 | +100/150% | >150% |
| | Time spared | X | | | No | 0-1 h/day | 1-3 h/day | >3 h/day |
| | Potential health improvement | X | | | Bad | None | Good | Very good |
| **Success Factors** | Level of awareness raising program | X | | Priority | Necessary | minimum | Not Neces. | No |
| | Energy requirements for M&O | X | | Very High | High | Mod. | Low | Very Low |
| | Risk of technical failure | X | | Very High | High | Mod. | Low | Very Low |
| | Risk of failure of societal dimension | X | | Very High | High | Mod. | Low | Very Low |
| **Socio-Economical-political Context** | Financial sustainability | X | | Not | Little | Mod. | Good | Very Good |
| | Availability of financial resources (dependency on the economical wealth) | X | | Very Neces. | Necessary | Actual State | Little | No |
| | Organization capacity | X | | <20% | 20% /40% | 40% /60% | 60% /80% | >80% |
| | Need institutional capacity | X | | Urgently | Necessary | Yes | Little | No |

### 6.1.3 Scenarios and storylines

Using the down scaling of Global scenarios in WP5, scenarios for the case study were formulated based on projections for population growth and climate change. Scenarios and storylines for Nabajjuzi case study are described in detail in WETwin D5.1 (Liersch and Hatterman 2011).

**Storyline 1**: Assessment of the vulnerability of water provisioning by the Nabajjuzzi wetland to the Masaka supply area to climate change/variability and population growth in the period 2010 to 2050.

Due to the growing population and urbanization trends in the Masaka district, there is an increasing demand of drinking water. Currently, the population is provided with drinking water removed from the Nabajjuzzi wetland by an intake point upstream of the town. Increasing demands as well as climate variability are likely to overstress the capacity of this intake point in future. Therefore it is planned to install a new intake point. It should be emphasized here that community waste water is discharged into the Nakaiba arm (Nabajjuzzi wetland). The envisaged additional intake point need to be installed approximately ten kilometres downstream of the town or waste water discharge point, respectively. Hence, not only water quantity issues will be tackled here, but also water quality issues including an assessment of the wetlands capacity to remove discharged nutrients. Seasonality of climate, streamflow (particular low flow periods), and vegetation is of outmost importance in this context.

**Storyline 2**: Assessment of the vulnerability of the Nabajjuzzi ecosystem and its riparian population downstream of the city of Masaka to increased water abstraction, climate change/variability and population growth in the period 2010 to 2050.

In this storyline the impact of various water abstraction and waste water discharge scenarios (as a consequence of storyline 1) on downstream Nabajjuzzi ecosystems and riparian populations are investigated. Downstream in this connection means downstream of the envisaged additional intake point.

## 6.2 Results of expert analysis

Results from the MCA are summarised here; detailed working is given in Excel spreadsheets at Appendix 1.

### 6.2.1 Ranking of solutions

**Calculation Method (= Weighted Averages)**

For each alternative management option, all the indicators received a score between 0 and 4. The lowest score (0) referring to the worst possible situation, the highest scoring (4) referring to the best possible situation.

All options are characterized by **six category scores**, calculated using the following formula:

$$\textbf{score (Category X)}_{[0\text{-}4]} = \textbf{average (indicators of the category X}_{[0;1;2;3;4]}\textbf{)}$$

Starting from the category scores, overall **option scores** are calculated using the following formula:

$$\textbf{Option's Score}_{[0\text{-}4]} = \textbf{Weighted Average of Category Scores}$$
$$= [(\text{Ecoservices}*Wa) + (\text{Ecosystem health}*Wb) + (\text{Benefits}*Wc) + (\text{Costs}*Wd) + (\text{Success factor}*We) + (\text{Context}*Wf)] / 100$$

Depending on what the evaluation should emphasise on, different weights can be attributed to the categories (*e.g.* if the costs are more relevant to evaluate, *Direct Costs will receive a higher weight*). In our analysis four weight sets were formulated, one based on expert judgement, and the three other focussing on certain criteria (Costs & Benefits; Success Factors & Context Dependence; Ecosystem Services & Ecosystem Health). In our analysis we prefer to work with the 'Expert Weighting'. The effect of other weight sets will be evaluated in a later stage.

| Category Weight sets | | *Expert Weighting* | *Focus on Costs & Benefits* | *Focus on Success & Context* | *Focus on Ecosystems* |
|---|---|---|---|---|---|
| ECOSYSTEM SERVICES | *Wa* | **15** | 10 | 10 | **30** |
| ECOSYSTEM HEALTH | *Wb* | **10** | 10 | 10 | **30** |
| DIRECT COSTS | *Wc* | **25** | **30** | 10 | 10 |
| BENEFITS AND POSITIVE IMPACTS | *Wd* | **25** | **30** | 10 | 10 |
| SUCCESS FACTORS | *We* | **12** | 10 | **30** | 10 |
| CONTEXT DEPENDENCE | *Wf* | **15** | 10 | **30** | 10 |
| TOTAL WEIGHT | | *100* | *100* | *100* | *100* |

### Reduction of the number of management options

All management solutions include one alternative option from each axis of management, or BAU (= no changes in management during 50 years). In order to reduce the number of possible combinations, the total number of management options need to be reduced. In our analysis it is decided only to take into account the best scoring option from each axis of management (= preferred option). The table shows the five preferred management options.

| SOLUTIONS combinations | | | | | | |
|---|---|---|---|---|---|---|
| | Options | | | | | |
| **Solutions number** | A | B | C | D | E |
| **1. Business-As-Usual** | | | | | |
| **2. ABCDE** | x | x | x | x | x |
| **3. AC** | x | | x | | |
| **4. ACE** | x | | x | | x |
| **5. BD** | | x | | x | |
| **6. BDE** | | x | | x | x |
| **7. AD** | x | | | x | |
| **8. ADE** | x | | | x | x |
| **9. BC** | | x | x | | |
| **10. BCE** | | x | x | | x |
| **11. ABC** | x | x | x | | |
| **12. ABD** | x | x | | x | |
| **13. ACD** | x | | x | x | |
| **14. BCD** | | x | x | x | |
| **15. ABCE** | x | x | x | | x |
| **16. ABDE** | x | x | | x | x |
| **17. ACDE** | x | | x | x | x |
| **18. BCDE** | | x | x | x | x |
| **19. ABCD** | x | x | x | x | |

| IWRM issues | Axes of Management | **<u>Alternative Management Options</u>;** **Management Solutions only take into account Best Option in each Axe of Management.** |
|---|---|---|
| Water Supply | Water Abstraction | ~~– Implement a new intake point~~ |
| | | **A** Increase the current intake dam capacity |
| | | ~~– Implement ground-water wells~~ |
| | Water Distribution | **B** Extension and intensification of the water network |
| Waste Water Management | Waste water Treatment | **C** Rehabilitation of the current WWTP and restore the manipulated natural wetland (tertiary treatment): it will cover 60% of the current sewage flow and the remaining 40 % will be redirected to the WSP |
| | | ~~– Expand the water stabilization pond (lagoon) and pump all the waste water to the stabilization ponds~~ |
| | Waste Water Collection and Disposal | **D** Improve the individual waste water management including sanitation at households/institutional level |
| | | ~~– Extend the sewerage network (shallow /deep sewerage mains)~~ |
| Water quality and ecosystem protection | Protection of the good ecological state and the high quality water resource | **E** Enhance sustainable agricultural practices and papyrus harvesting + Enforcement of the law. |

### 6.2.2 Analysing trade-offs – impact of stakeholder preferences, alignment of stakeholder groups

**Driving forces, Pressures, State and impacts on ecosystem services**

<u>Drivers</u>: Climate change and variability, water supply (quantity and quality), population growth, urbanization.

<u>Pressures</u>: Agricultural and human encroachment of wetland, industrialisation, increasing water demand, water pollution (from agriculture and industry).

<u>State:</u> Deteriorating water quality, water shortage, loss of wetland habitat.

<u>Impact on ecosystem services</u>: Water supply becomes difficult and costly, loss of habitats and biodiversity.

The main driving force considered in this report is the population growth, with rapid urbanisation. Climate change hasn't been considered, because of the models not being ready and also the potential difficulty to incorporate climate variables in this socio-economical valuation. So the main pressure considered on the wetland is the **demographic pressure**.

*Problem of water quality linked to natural iron:* Nabajuzzi wetland presents a high level of iron: the source of iron is likely to be natural but is not defined yet. This results in high costs for water treatment (need of high quantities of chemicals to treat water and remove iron), which are not likely to decrease.  One of the options for water abstraction was to find another point source for water, still in Nabajuzzi wetland, but presenting a lower level of iron. But, first results from NWSC's investigation show that the level of iron seems as high everywhere. The finding of a new intake point location is nevertheless still considered, since the investigation is not over.

The main trade-offs identified are then:

**Trade-Offs Between Criteria  (Based on DPSI analysis)**

| Trade-offs between wetland's function and eco-services | | |
|---|---|---|
| Resource Harvesting | ←→ | Hydrological and Ecological functioning |
| Agriculture | ←→ | Water Quality |
| Water Abstraction | ←→ | Ecosystem Health |

Resources harvesting, especially papyrus harvesting can be controversial: sustainable harvesting can have beneficial effects on water quality (removal of nutrient and toxic products), and on the other hand, over-harvesting has negative effects on the hydrology of the wetland (higher evapo-transpiration, loss of hydrology regulating services such as stream-flow control, erosion control, etc…). One of the though questions remaining is: how to differentiate sustainable from un-sustainable harvesting?

Agricultural practices are still traditional, but the rapid changes in commercial crops and the pressure of international commerce are bringing more and more farmers to the use of agrochemicals (mainly fertilizers). The amount uses are still low, but rapid expansion of uses is threatening the water quality.

Finally, water abstraction is increasing under population growth pressure, reducing the amount of water allocated to the ecosystem and thus, threatening its health and bio-physical functioning.

**Trade-Offs Between stakeholder groups**

| Stakeholder | Interests |
|---|---|
| **Resource Harvesters** | Wetland resources, wetland conservation |
| **Crop Farmers** | Land & Water resources |
| **Fisheries** | Fish, wetland conservation (Papyrus) |
| **Pastoralists** | Pastures |
| **Water Users** | Clean Water, Purification Capacity Wetland |
| **Central Government:** | Good policy, best-compromise between livelihood, conservation, development, etc. |
| • **Wetland Management Department** | Wetland Conservation |
| • **Forest Department, Environment Management Authority, etc.** | Conservation of Biodiversity |
| • **Agriculture Department, Department of employment, etc.** | Agriculture, income generation, food security |
| • **National Water and Sewerage Corporation, Directorate of Water Resources Management, etc.** | Clean drinking water, purification capacity of wetland. |
| **Nature Uganda** | Birds, Nature Conservation |
| **Opinion and Religious leaders** | Heritage, culture, sustainable use, welfare |
| **Donors, NGO's/CBO's** | Diversity of Objectives: Income generation, food security, conservation, sustainability, prestige |
| • **Nature Ngo's, etc.** | Conservation of Biodiversity and Wetland |
| • **Development Ngo's, etc.** | Food security, income generation |
| **Schools** | Dissemination of information, building skills |
| **Politicians** | Voters, improve livelihoods |

### 6.3 Impact of scenarios – vulnerability and robustness

| Vulnerability = f(External Impact, Adaptive Capacity) |
|---|
| $\Delta V = EI + AC$ |
| $EI = State_{(BAU)} - State_{(Current)}$ |
| $AC = State_{(mgt)} - State_{(BAU)}$ |

**Exposure**

The social-ecological system of Nabajjuzzi is extremely exposed to population growth and urbanization. Uganda's population is projected to increase from currently 32.4 million (2009) to approximately almost 100 million people in 2050, assuming an annual growth rate of approximately 2.7% (CIA, 2010).

The system is also exposed to climate variability and change, but it is not yet clear to what extent. This will be investigated in the connection with drinking water supply for the city of Masaka.

The social-ecological system of Nabajjuzzi is exposed to:

- Climate change and variability
- Population growth / urbanization

### Sensitivity

It is assumed that the Nabajjuzzi system is sensitive to changes in the water regime (quantity) and to changes in nutrient inputs by waste water discharge (water quality). To what extend the system is sensitive to the stressors and what the critical thresholds for sustainability are, is not yet know.

The social-ecological system of Nabajjuzzi is sensitive to:

- Water abstraction
- Waste water discharge

### Adaptive Capacity

Adaptive capacity is the capacity of a socio-ecological system to cope with external and internal impacts and to implement measures to mitigate negative effects in order to ensure sustainability. In this regard management options and their effectiveness determine adaptive capacity. The management options to ensure water supply and sustain ecological functions of the wetland are the following in this study:

- **Increasing** water **intake** from current intake point (now new intake point)
- Implementation of a **new intake** point
  - Downstream at Nakaiba arm (as envisaged)
  - Alternative location for new intake
- **Replacing** the old intake by the new intake point
- **Reducing** the input of **organic loads**
  - Papyrus management
  - Waste water treatment (at household or community level)
- Additional drinking water supply by **ground water** (construction of wells)

### External Impact (Defining BAU under different scenarios)

**Figure 29: Reference Scenario – Nabajuzi Swamp Stream flow at both Present and Doubled Water System Production Capacity January 2010 to December 2050**

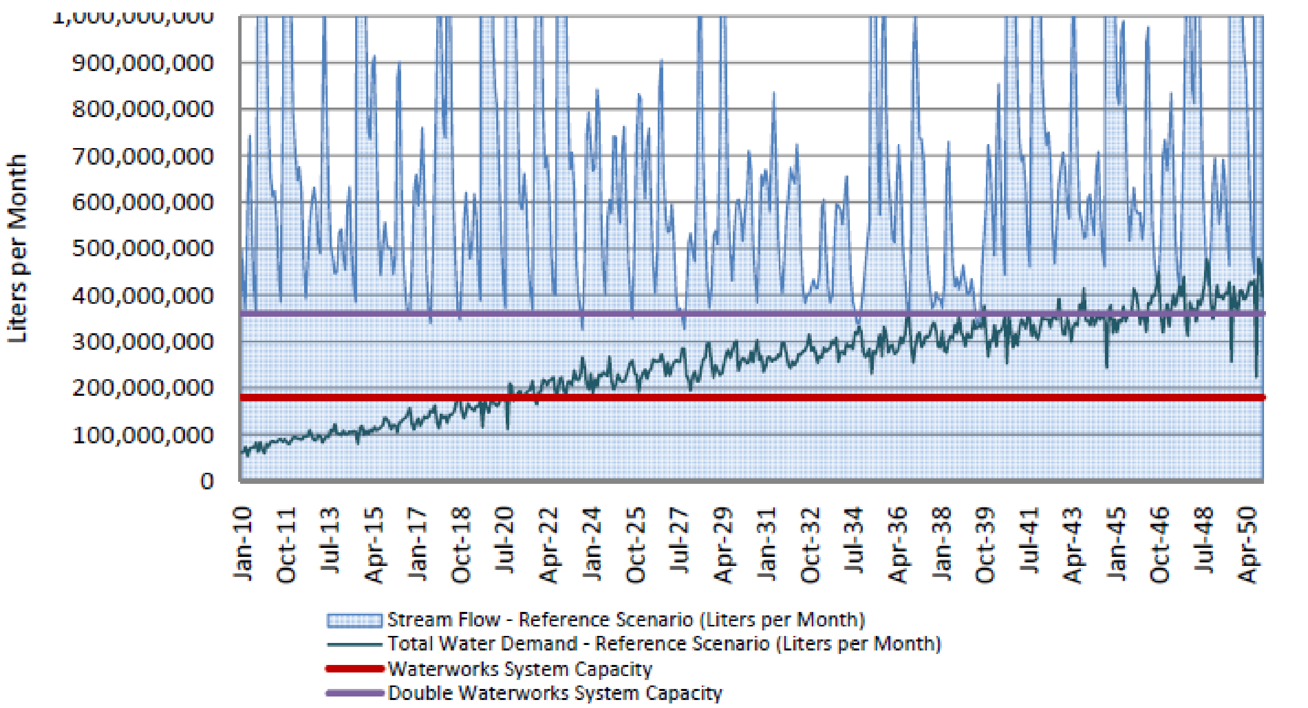


**Figure 30: Climate Change Scenario – Nabajuzi Swamp Stream Flow at both Present and Doubled Water System Production Capacity January 2010 to December 2050**

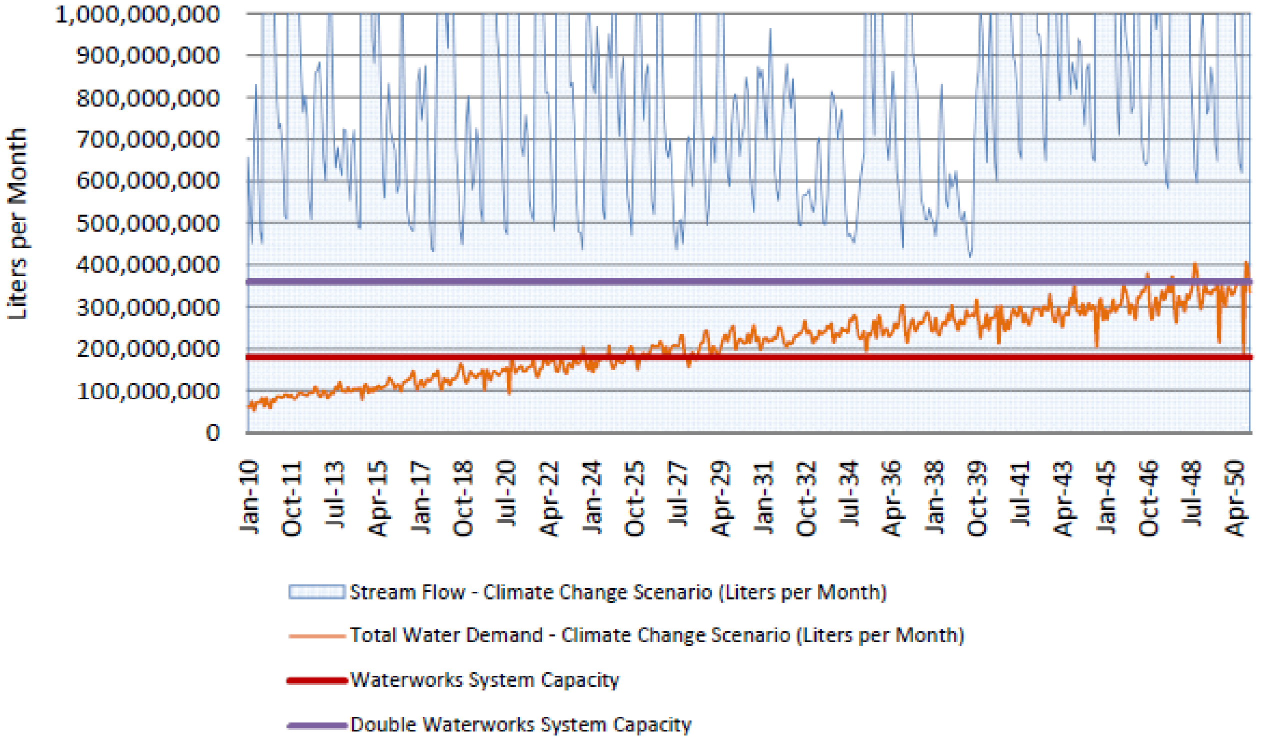
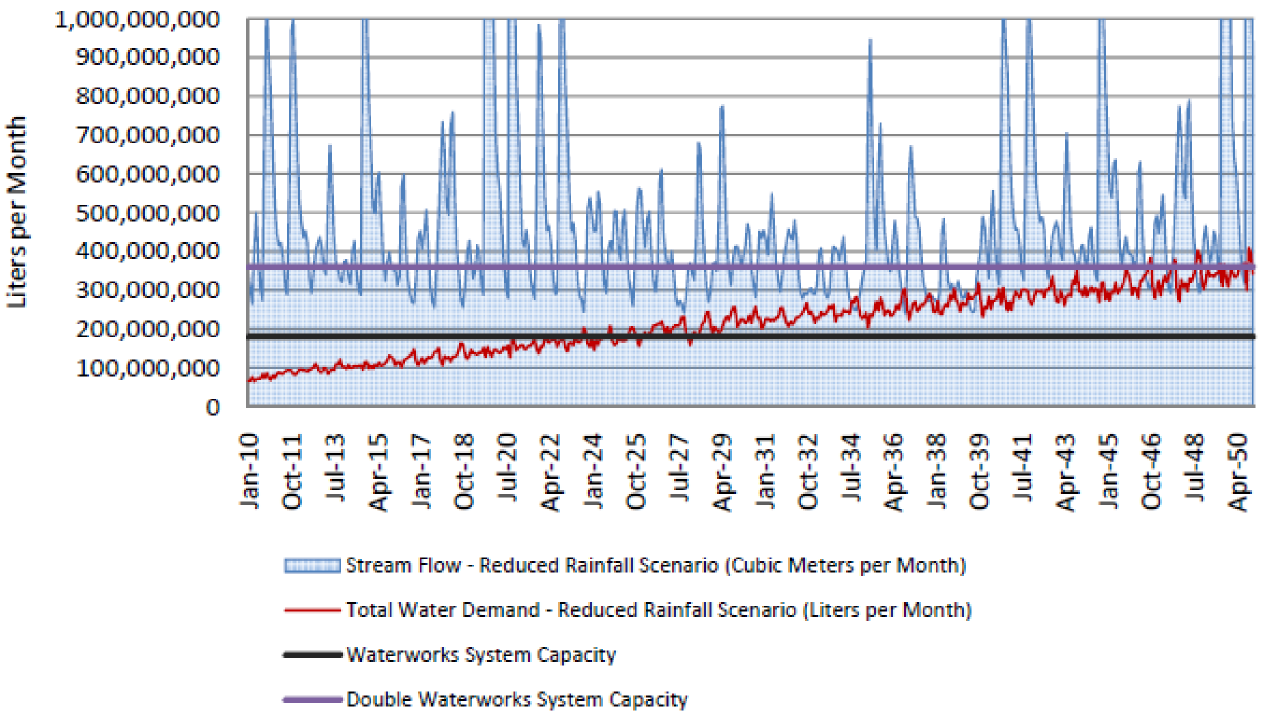



**Figure 31: Reduced Rainfall Scenario – Nabajuzi Swamp Stream Flow at both Present and Doubled Water System Production Capacity January 2010 to December 2050**




Source: Aslam et al. 2010: Assessing Climate Vulnerabilities and Infrastructure of Three Small Scale Water Utilities in the Lake Victoria Basin. UN Habitat.

### 6.3.1 Qualitative Assessment

The following matrix illustrates the qualitative impact assessment for the two storylines developed for the Nabajjuzzi case study in Uganda. Impacts during dry and wet seasons (periods) are distinguished. The impacts of management options under the three global scenarios are neglected in the qualitative assessment. It is thus an assessment of general impacts of management options on the storylines. The likelihood to favour certain management options might be different in the scenarios and will be tackled in the quantitative assessment (deliverable 5.2).

| | Mgt. option → | Increasing Current Intake capacity | | New Intake | | Ground water abstraction | | Improve wastewater treatment | | Protection of the upstream water shed | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Season<br>Impact on ↓ | wet | dry | Wet | dry | wet | dry | wet | dry | wet | dry |
| Storyline 1 | Water Supply | + | - | + | + | + | + | 0 | 0 | + | + |
| | Water Quality | 0 | 0 | 0 | 0 | + | + | ++ | ++ | ++ | ++ |
| Storyline 2 | Water Quantity | - | - | - | - | - | - | 0 | 0 | + | + |
| | Water Quality | - | - | - | - | - | - | + | + | + | + |

| Category | Impact |
|---|---|
| ++ | Very positive |
| + | Positive |
| 0 | No expected impact |
| - | Negative |
| -- | Very negative |

## 6.4 Results of stakeholder consultations (equity matrix)

Results from final stakeholder consultation are not yet available.

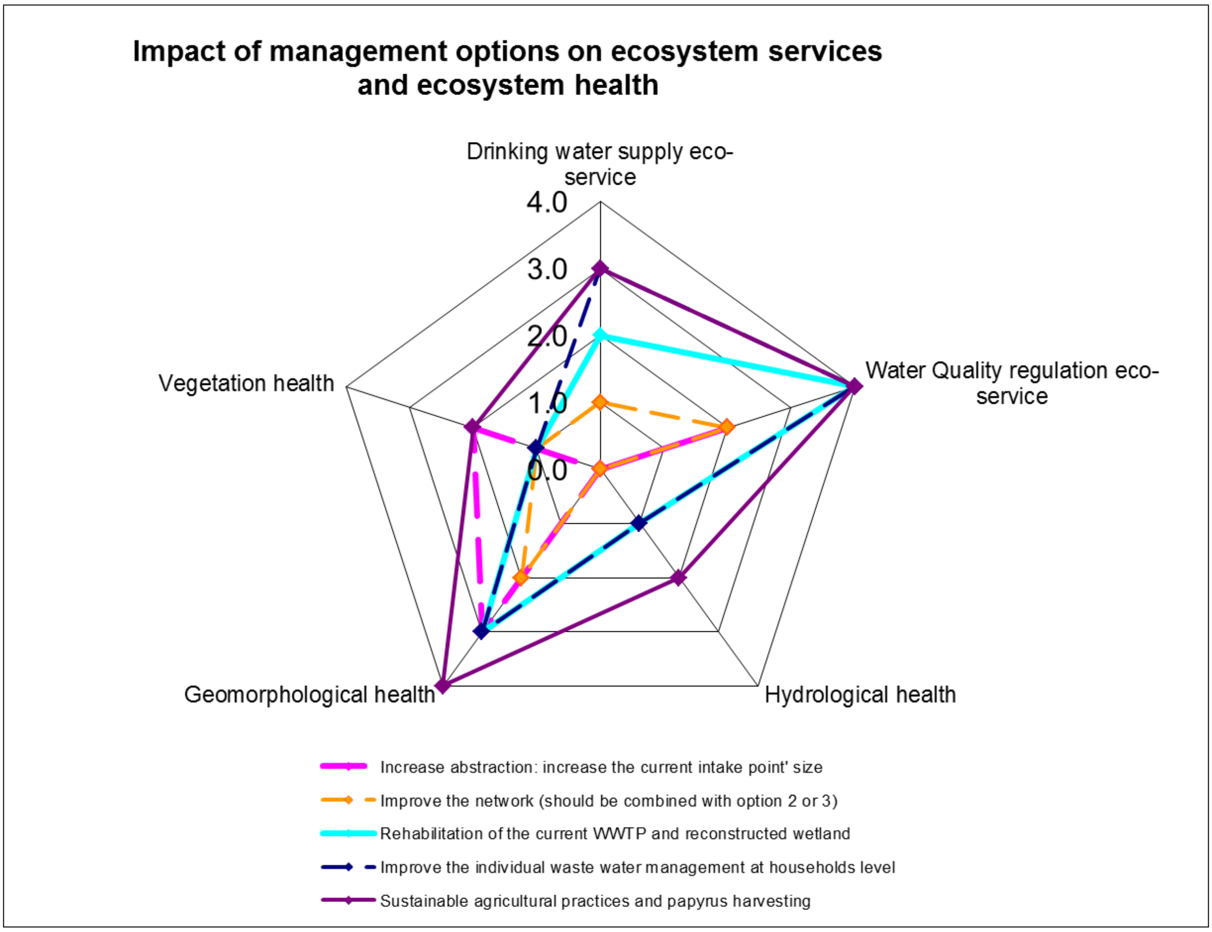
## 6.5 Summary and recommendations

At Nabajjuzi, five axes of management were identified to address changes in water supply (**abstraction** and **distribution**), improvements in water quality (through waste water **treatment** and **collection**) and **protection of the watershed** (ecological state and high water quality). Main potential trade-offs identified are between resource harvesting (water, papyrus) and ecological function; and between agriculture and water quality In order to formulate solutions consistent with Integrated Water Management, each proposed solution included an option from each management axis. To narrow down the number of solutions, only the best scoring option (on the basis of adaptive capacity and vulnerability) from each axis of management was included in the analysis.

The main driving force considered in this report is population growth, with rapid urbanisation. Wetland health and ecosystem services are very vulnerable to the population pressure, and under "business as usual" management, significant degradation is expected. Even with management intervention, in many cases the scores for ecosystem health and service provision are expected to decline. The aim of the analysis was to identify options with the most positive impacts on specific components, and on the system as a whole. Management options were evaluated using expert judgement, by scoring criteria relating to impacts on the system (ecosystem health and ecosystem services); and to feasibility / ease of implementation (direct costs, context dependence, technical considerations).

Ranking using MCA was very dependent on the weighting of criteria. Four different weights sets were explored, expressing different priorities. The solutions which consistently score highest (ACDE and BCDE) using the "expert" weightings are those combining rehabilitation of the current wastewater treatment and natural wetland with improved sanitation at household level and measures to protect ecological status of the site. In terms of water supply, both increasing abstraction from the current intake and extension of the water network provide satisfactory results.

The analysis used for Nabajjuzi provided an effective way to structure and analyse complex information relating to multiple options, but did not provide a single answer as to the "best" solution. Further work is needed with stakeholder communities to ascertain priorities and preferences. The complexity of the analysis limited its usefulness in working with stakeholders; however, it did help in establishing which management actions would best support different components of ecosystem health and services (see Figure below).



# 7 Namatala

## 7.1 Decision space

### 7.1.1 Management solutions

Five management solutions are proposed for Namatala with different focus: water quality; land management and conservation; and an integrated solution drawing together aspects of both. Within these solutions, alternatives are considered with different degrees of financial effort. Table X illustrates the management alternatives included in the different solutions, including components considered to be essential pre-requisites.

| Management Responses | Management Options | Alternatives | MS 0 (BAU) | MS 1 | | MS 2 | | MS 3 |
|---|---|---|---|---|---|---|---|---|
| | | | | 1a | 1b | 2a | 2b | |
| A: Land use change in upper wetland | A1: No change | A.1.1 No change (BAU) | X | | | | | |
| | A3: Buffer strips | A.3.1 Buffer strips along Namatala river in upper wetland | | | X | X | X | X |
| | | A.3.2 Replace agricultural land with papyrus in upper wetland | | | | | ??? | ??? |
| B: Land use change in lower wetland | B1: No change | B.1.1 No change | X | | | | | |
| | B2: Sustainable use | B.2.3 Awareness campaign among communities (churches, schools, etc.) on wetland values | | | | | X | X |
| | | B.2.2 Strict enforcement of wetland and land ownership policy (conservation) | | | | | X | X |
| C: Improving wastewater treatment facilities | C1: no change | C.1.1 No change | X | | | | | |
| | C2: Rehabilitation and improved mgmt of existing facilities | C.2.1 Rehabilitation and improved management | | X | X | | | X |
| | | C.2.3 Increased capacity and improved management. | | | X | | | X |
| | C3: Provision of faecal sludge treatment unit (s) | C.3.1 Increased on site treatment of household wastes and established mechanism for collection & disposal | | | X | | | X |
| | | C.3.2. Construction of faecal sludge treatment facility | | | | | | X |
| | C4: Buffer zone at discharge | C.3.1 Papyrus buffer zone with harvesting regime | | | X | X | X | X |
| **Prerequisites** | | | | | | | | |
| A: Land use change in upper wetland | A2: Sustainable agriculture | A.2.2 Training in sustainable agricultural practices | | X | X | X | X | X |
| | | A.2.1 Community-based management plan for ecological management in upper wetland | | X | X | X | X | X |
| B: Land use change in lower wetland | B2: Sustainable use | B.2.1 Training on sustainable fishing in lower wetland | | X | X | X | X | X |
| | | B.2.2 Training on sustainable papyrus harvesting in lower wetland | | X | X | X | X | X |
| | | B.3.2 Community–based wetland management plan for lower wetland | | X | X | X | X | X |

### 7.1.2. Indicators, Categories and Value Functions

In order to assess the performance of the different management solutions a set of 17 indicators, subdivided into 5 categories were identified. 12 indicators were assessed in a quantitative way and 5 in a qualitative way (by expert judgment). The table below summarizes the set of indicators and the value functions used to convert the raw scores from the evaluation matrix into normalized scores for the analysis matrix [0,1]. The first three indicator categories (livelihood, human health and ecology) are **impact categories**, meant to assess the performance of the different management solutions. The two other indicator categories (costs and risk of failure) are **feasibility categories**, meant to assess the feasibility of implementation of the management solutions.

**List of Criteria and Indicators for Namatala**

| *Criteria* | *Indicators* | | *Qtt* | *Qlv* |
|---|---|---|---|---|
| **Livelihood** | Total rice production in wetland (tonnes/year) | | | X |
| | Total fish production in wetland (tonnes/year) | | | X |
| | Total production of papyrus biomass (tonnes/year) | | | X |
| **Human Health** | Disease Risk (Water-born Diseases) | | X | |
| **Ecology** | Total area of Papyrus wetland in Lower Namatala wetland | | | X |
| | Total area of buffer strips in Upper Namatala Wetland | | | X |
| | Downstream Water Quality (Sapiri) | Suspended solids | X | |
| | | Nitrogen | X | |
| | | Phosphorus | X | |
| | Nutrient removal by rice [tons of rice/year] | | | X |
| | Nutrient removal by papyrus lower wetland [kg/year] | | | X |
| **Costs** | Investment in rehabilitation of water treatment facility | | | |
| | Cost of training of communities | | X | |
| | Cost of awareness campaign | | | |
| **Risk of Failure** | Risk of technical failure | | | X |
| | Risk of non-acceptance by community | | X | |
| | Lack of institutional capacity | | X | |

### 7.1.3. Scenarios

Using the down scaling of Global scenarios in WP5, scenarios for the case study were formulated based on projections for population growth and climate change. Scenarios and storylines for Namatala case study are described in detail in WETwin D5.1 (Liersch and Hatterman 2011).

The **Storyline** to be assessed in the Namatala Case Study is: the vulnerability of the wetland functions to increased wastewater loads, climate variability and rice production in the period 2010 to 2050.

Population growth is expected to cause various constraints for sustainable management of the wetland and the communities depending on it. Two major constraints are, firstly the demand for food and related agricultural production will increase enormously. This will probably result in continued agricultural encroachment in the wetland. Secondly, the (urban) waste water load will increase, creating pollution and contamination risk in the wetland. Both aspects risk to deteriorate the Namatala wetland partially or even entirely. Management solution 0 (= Business as Usual) takes into account these two aspects related to population growth.

With regard to future precipitation in the region of the Namatala wetland the two datasets reviewed show opposing trends (-2.32 mm/year, PIK) and (+0.12 mm/year, H08). Future rainfall patterns and trends are very uncertain. Thus, the projections show no trend at all but a possible range of future rainfall events. Because of this uncertainty climate change is not considered.

## 7.2 Ranking from MCA

To be able to rank the different management solutions, a normalised scoring method was developed, illustrated in the figure below. In a first step the impact and feasibility of the management solutions was assessed using the common set of quantitative and qualitative indicators. This first step results in the **evaluation matrix**. In a second step the various scores needed to be converted into normalised scores [0,1], using value functions. Normalised scores range from 0 (=worst situation) to 1 (=best situation). This second step results in a new matrix, the **analysis or decision matrix**. In a third step weighted category scores and overall solution scores are calculated. Both the method and weight set used for this calculation can be differentiated. The standard calculation method (or decision rule) is **SAW (Simple Additive Weighting)**, and the standard weight set is **'equal shares'**, attributing equal weights to each indicator and category.

Detailed results are presented in Excel spreadsheets at Appendix B.

### 7.2.1 Performance of Management Solutions

The figures below illustrate the performance (impact or feasibility) of the different management solutions on the five criteria livelihood, human health, ecology, costs and risk of failure. Closer to 1 means better performance and closer to 0 means worse performance for each of the five axis. The category scores presented in these figures are the raw/simple scores, obtained by using the standard decision rule (SAW) and standard weight set (Equal Shares = similar to no weights). Other decision rules and weight sets will be introduced in a later stage.

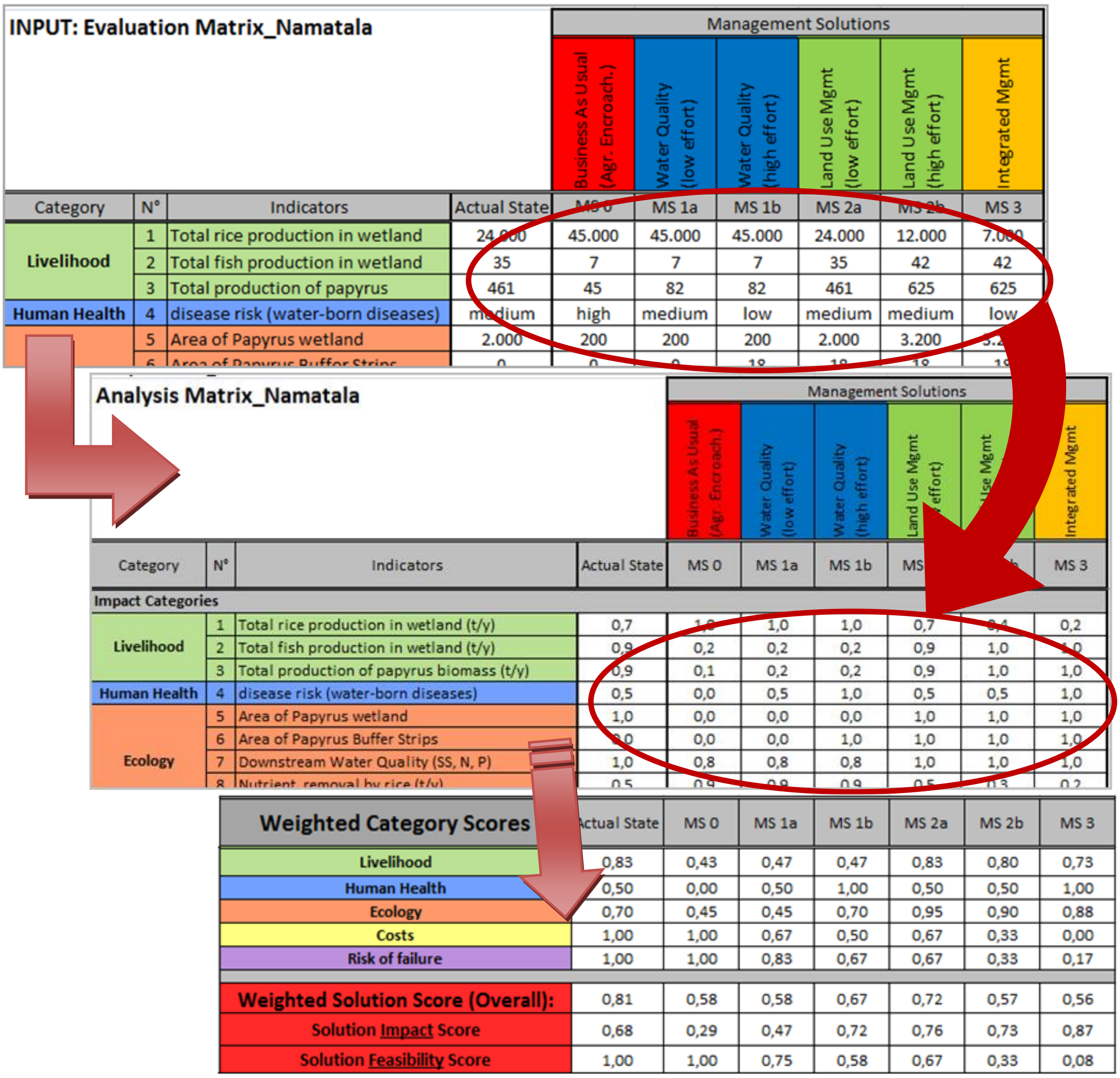
**Impact Categories (Livelihood, Human Health and Ecology)**

**MS0 (BAU)**: In a future without management all three categories are expected to decrease considerably in relation to actual state. Livelihood and Ecology are expected to decrease with almost half of the actual state score, and the human health situation will even decrease to the minimal score of 0.

**MS 1**: Compared with actual state and business as usual, the added value of the management solutions MS1a (red) and MS1b (green) can mainly be attributed to its positive impact on the human health situation (especially MS1b, that receives a maximum score). The implementation of MS1b will also prevent the decrease in ecology expected to happen in the BAU situation. On the other hand, MS1b won't prevent a decline in livelihood, and MS1a won't prevent a decline in both livelihood and ecology. The overall conclusion is that MS1a scores rather bad, while the impact of MS2b is worth considering.

**MS2**: Opposite to MS1, the management solutions MS2a (purple) and MS2b (blue) will prevent a decline in livelihood, and will even improve ecology significantly. On the other hand MS2 won't have an additional positive impact on human health, but it will prevent a decline as well. Overall, the impact of both MS1a and MS1b is similar to each other, and definitely worth considering for implementation.

**MS3:** Integrated management will combine the good performance on human health (equal to MS1b) and on ecology (equal to MS2). On the other hand it will prevent a decline in livelihood only partially. Overall, MS3 is expected to have a good impact on all three categories.
Overall, the best performing management solutions per category are: MS2a and MS2b on livelihood, MS1b and MS3 on human health, and MS2a and MS3 on ecology.



INPUT: Evaluation Matrix_Namatala

| Category | N° | Indicators | Actual State | MS 0 (Business As Usual (Agr. Encroach.)) | MS 1a (Water Quality (low effort)) | MS 1b (Water Quality (high effort)) | MS 2a (Land Use Mgmt (low effort)) | MS 2b (Land Use Mgmt (high effort)) | MS 3 (Integrated Mgmt) |
|---|---|---|---|---|---|---|---|---|---|
| Livelihood | 1 | Total rice production in wetland | 24.000 | 45.000 | 45.000 | 45.000 | 24.000 | 12.000 | 7.000 |
| | 2 | Total fish production in wetland | 35 | 7 | 7 | 7 | 35 | 42 | 42 |
| | 3 | Total production of papyrus | 461 | 45 | 82 | 82 | 461 | 625 | 625 |
| Human Health | 4 | disease risk (water-born diseases) | medium | high | medium | low | medium | medium | low |
| | 5 | Area of Papyrus wetland | 2.000 | 200 | 200 | 200 | 2.000 | 3.200 | [illegible] |

Analysis Matrix_Namatala

| Category | N° | Indicators | Actual State | MS 0 | MS 1a | MS 1b | MS 2a | MS 2b | MS 3 |
|---|---|---|---|---|---|---|---|---|---|
| Impact Categories | | | | | | | | | |
| Livelihood | 1 | Total rice production in wetland (t/y) | 0,7 | 1,0 | 1,0 | 1,0 | 0,7 | 0,4 | 0,2 |
| | 2 | Total fish production in wetland (t/y) | 0,9 | 0,2 | 0,2 | 0,2 | 0,9 | 1,0 | 1,0 |
| | 3 | Total production of papyrus biomass (t/y) | 0,9 | 0,1 | 0,2 | 0,2 | 0,9 | 1,0 | 1,0 |
| Human Health | 4 | disease risk (water-born diseases) | 0,5 | 0,0 | 0,5 | 1,0 | 0,5 | 0,5 | 1,0 |
| Ecology | 5 | Area of Papyrus wetland | 1,0 | 0,0 | 0,0 | 0,0 | 1,0 | 1,0 | 1,0 |
| | 6 | Area of Papyrus Buffer Strips | 0,0 | 0,0 | 0,0 | 1,0 | 1,0 | 1,0 | 1,0 |
| | 7 | Downstream Water Quality (SS, N, P) | 1,0 | 0,8 | 0,8 | 0,8 | 1,0 | 1,0 | 1,0 |
| | 8 | Nutrient removal by rice (t/y) | 0,5 | 0,9 | 0,9 | 0,9 | 0,5 | 0,3 | 0,2 |

| Weighted Category Scores | Actual State | MS 0 | MS 1a | MS 1b | MS 2a | MS 2b | MS 3 |
|---|---|---|---|---|---|---|---|
| Livelihood | 0,83 | 0,43 | 0,47 | 0,47 | 0,83 | 0,80 | 0,73 |
| Human Health | 0,50 | 0,00 | 0,50 | 1,00 | 0,50 | 0,50 | 1,00 |
| Ecology | 0,70 | 0,45 | 0,45 | 0,70 | 0,95 | 0,90 | 0,88 |
| Costs | 1,00 | 1,00 | 0,67 | 0,50 | 0,67 | 0,33 | 0,00 |
| Risk of failure | 1,00 | 1,00 | 0,83 | 0,67 | 0,67 | 0,33 | 0,17 |
| **Weighted Solution Score (Overall):** | 0,81 | 0,58 | 0,58 | 0,67 | 0,72 | 0,57 | 0,56 |
| Solution Impact Score | 0,68 | 0,29 | 0,47 | 0,72 | 0,76 | 0,73 | 0,87 |
| Solution Feasibility Score | 1,00 | 1,00 | 0,75 | 0,58 | 0,67 | 0,33 | 0,08 |

***Figure*: Scoring of Solutions – Method (Screenshots)**

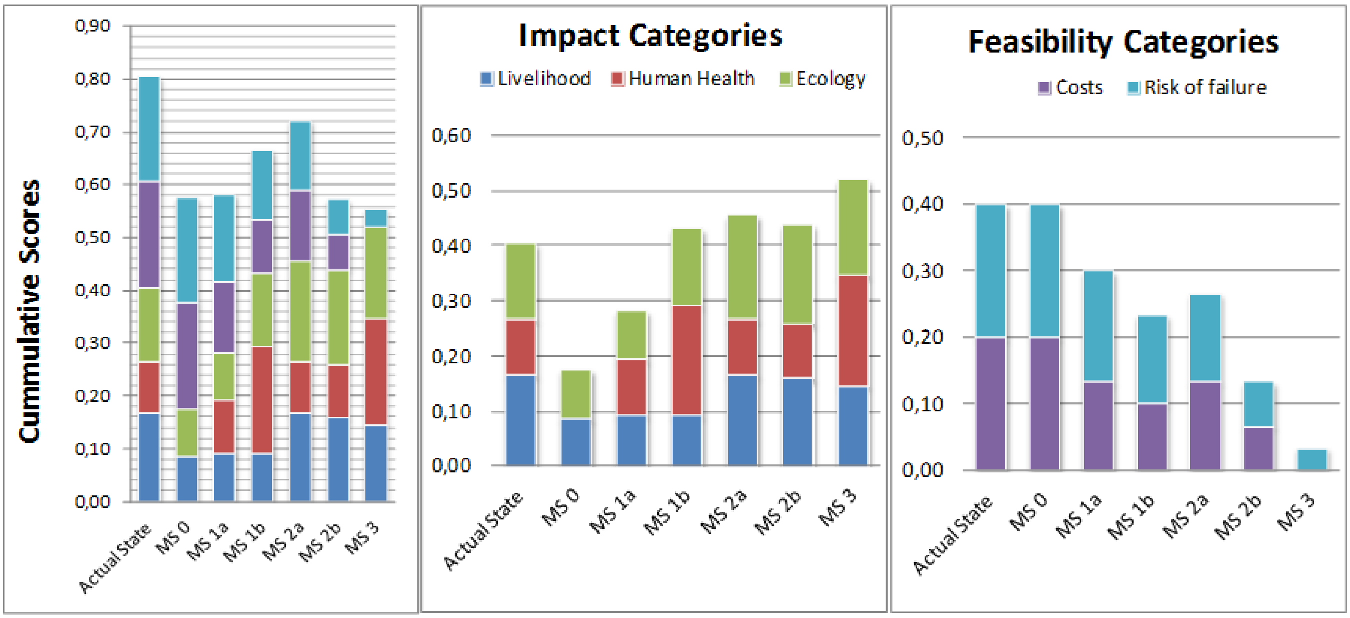
### Feasibility (Costs and Risk of Failure)

In particular **MS3** is expected to be unfeasible (both because of costs and risk of failure). This means that to be able to implement MS3 several enabling conditions will have to be met (in advance-, during-, or after the implementation). On the other hand the management solutions **MS1a**, **MS1b** and **MS2a** are expected to be feasible more easily. Implementation of **MS2b** was judged to be less feasible compared to MS2a, and additionally its impact doesn't exceed the performance of MS2a despite the fact that it's the '*more effort alternative*'. This last aspect already indicates that MS2a is probably more interesting to implement compared to MS2b.

### Ranking of Solutions

The bar charts below assemble the weighted category scores for each management solution as well as for actual state, the latter is an easy reference to compare with. The higher the bars, the better the performance and/or feasibility. Note that the chosen weight set for these figures is still the one with equal shares for each category and indicator.

From these figures it is clear that the management solutions with better performance on the impact categories will be less feasible to implement. Especially MS3, with the highest overall score and the biggest impact on human health and ecology, will be difficult to implement. Based on these figures, the most interesting solution seems to be MS2a, with a high overall impact score (highest score on livelihood and ecology) combined with a rather acceptable feasibility score. That's also the reason why MS2a has the highest score in the first bar chart combining the impact and feasibility scores.




***<u>Figure</u>:   Solutions Ranking  (Decision rule: SAW; weight set: Equal Shares)***

**<u>Decision Rules</u>:**
The aggregation of the indicator scores into category scores and category scores into solution scores can be done by different **decision rules**; for this analysis we preferred to compare the SAW and TOPSIS method:

- ***Simple Additive Weighting (SAW)*** which is a simple sum of the criterion values of every option, weighted by the vector of weights. The results are expressed by means of scores: the option with the highest score should be preferred.
- ***Technique of Order Preference by Similarity to Ideal Solution (TOPSIS)*** in which the option which is closer to the positive ideal solution and further from the negative ideal solution is considered as being best. Both ideal solutions are described by the extreme indicator values. Since these solutions are not real and describe only ideal states (which cannot be achieved), the distance of the real options from both of them is combined to make the final choice.

**<u>Weight Sets</u>:**
Weight sets can attribute more weight to indicators and categories that were judged to be more important than others, and vice versa. The two weight sets compared in this analysis are:

- '**Equal Shares**' which attributes equal weights to each category and indicator.
- '**Expert Weighting**' defined by local experts, focussing more on ecology and livelihood, and within these categories respectively on area of papyrus wetland and total rice production.

- Different sets of '**stakeholder weights**' representing subjective stakeholder preferences. (These weight sets will be assessed in the trade-off analysis later in this document)

| **Weight Sets** | | **Equal Shares** | **Expert Weighting** |
|---|---|---|---|
| **Livelihood** | | **20,0%** | **25,00%** |
| 1 | Total rice production in wetland (t/y) | 0,33 | 0,50 |
| 2 | Total fish production in wetland (t/y) | 0,33 | 0,20 |
| 3 | Total production of papyrus biomass (t/y) | 0,33 | 0,30 |
| **Human Health** | | **20,0%** | **10,00%** |
| 4 | disease risk (water-borne diseases) | 1,00 | 1,00 |
| **Ecology** | | **20,0%** | **25,0%** |
| 5 | Area of Papyrus wetland | 0,25 | 0,30 |
| 6 | Area of Papyrus Buffer Strips | 0,25 | 0,10 |
| 7 | Downstream Water Quality (SS, N, P) | 0,25 | 0,20 |
| 8 | Nutrient removal by rice (t/y) | 0,25 | 0,25 |
| 9 | Nutrient removal by papyrus (t/y) | 0,25 | 0,15 |
| **Costs** | | **20,0%** | **15,0%** |
| 10 | Investment WWTP | 0,33 | 0,33 |
| 11 | Cost of training of communities | 0,33 | 0,33 |
| 12 | Cost of awareness campaign | 0,33 | 0,33 |
| **Risk of failure** | | **20,0%** | **25,0%** |
| 13 | Risk of technical failure | 0,33 | 0,25 |
| 14 | Risk of non-acceptance by community | 0,33 | 0,35 |
| 15 | Lack of institutional capacity | 0,33 | 0,40 |
| | | 100,00% | 100,00% |

The next table shows a comparative analysis of the scores and ranking of the management solutions with different decision rules (SAW or TOPSIS) and different weight sets (Expert weighting or Equal Shares).

| ***Decision Rule*** | ***Weight set*** | ***Solutions order based on Impact Scores (best→worst)*** | | | | | |
|---|---|---|---|---|---|---|---|
| **SAW** | Expert Weighting | MS2a | MS3 | MS2b | MS1b | MS1a | MS0 |
| | | 74 | 68 | 71 | 63 | 50 | 40 |
| | Equal Shares | MS3 | M2a | MS2b | MS1b | MS1a | MS0 |
| | | 87 | 76 | 73 | 72 | 47 | 29 |
| **TOPSIS** | Expert Weighting | MS2a | MS3 | MS2b | MS1b | MS1a | MS0 |
| | | 80 | 73 | 65 | 53 | 23 | 00 |
| | Equal Shares | MS3 | MS2a | MS2b | MS1b | MS1a | MS0 |
| | | 91 | 74 | 69 | 68 | 28 | 00 |

**Decision Rules:** Both methods (SAW and TOPSIS) result in the same ranking of solutions. The exact values of the scores are not entirely the same (TOPSIS scores are more extreme), but the proportions between the management solutions are similar.
**Weight Set**: The most interesting outcome of this comparative analysis is definitely the difference in the top two in the solution ranking. With 'equal shares' MS3 has the highest score (Cf. See also previous figures). However, with the expert weighting, focussing more on ecology and livelihood, MS2a jumps over MS3, with a significant lead.

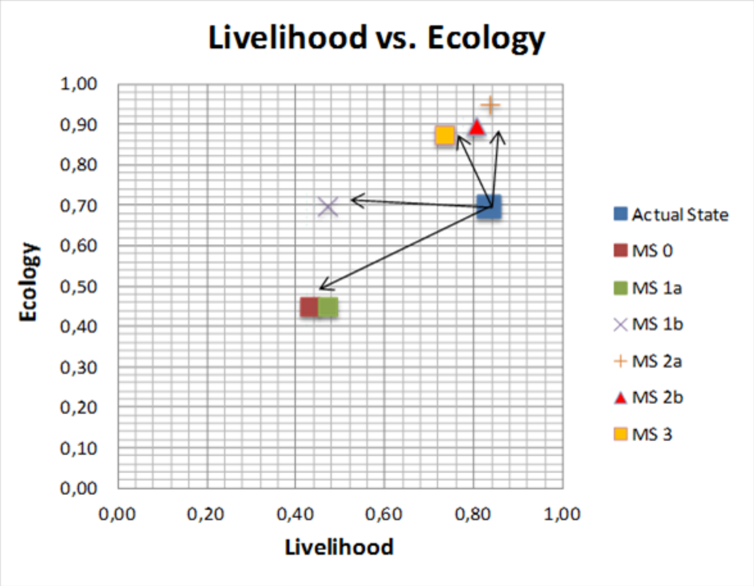
### Theoretical Best Solution (Overall Conclusion)

- Exclude MS0 and MS1a because of bad performance:
- Exclude MS2b because of worse performance compared to '*less effort alternative*' (MS2a). Additional effort doesn't seem to have a significant impact on performance.
- **Theoretical best solution(s): MS3 & MS2a** depending on preferred focus (weight set) and enabling conditions (feasibility).
    - **MS3**: Good score on all impact categories, also on human health. However feasibility can be a problem. Additional effort may be needed for implementation.
    - **MS2a**: Best score on livelihood and ecology (judged to be most important by local experts). Moreover implementation will be more feasible.

### 7.2.2 Trade-offs

In this trade-off analysis the categories livelihood, human health and ecology will be compared pair wise. The central question is which management solution is best in optimizing both categories. In a first step optimal solutions can be distinguished from sub-optimal solutions. Sub-optimal solutions are solutions that are dominated by other solutions (on both categories). Only optimal solutions can be taken into account in the Trade of Analysis. If there is a trade-off, meaning that there is more than one optimal solution, the shortest distance to the ideal solution (= both categories optimized) can be calculated to quantify the trade-off (illustration in figure below).

These figures illustrate that there is no trade-off between ecology and livelihood. **MS2a** optimizes both criteria, and the performance of MS2b and MS3 is similar as well. However, there are two trade-offs between; on the one hand human health (MS3 or MS1b), and on the other hand both ecology (MS2a) and livelihood (MS2a). The 'best compromise solution' resulting from these two trade-offs is both times **MS3**. Again, MS2a and MS3 seem to be the most promising solutions. This conclusion is similar to the conclusion on the theoretical best solution.

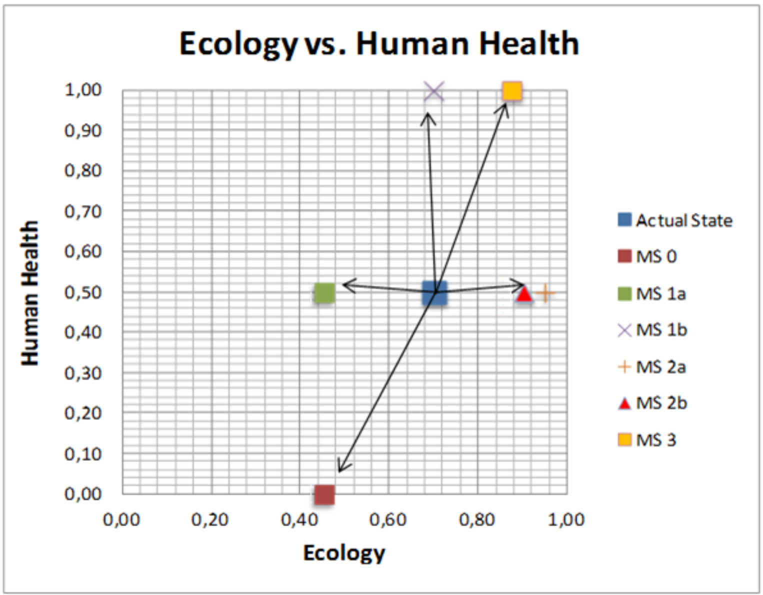



**Sub-optimal solutions**:
- MS0; MS1a; MS1b; MS3; MS2b

**Optimal solutions**:
- **MS2a**

**Trade-off**:
- No trade-off between livelihood and ecology

**Best alternative(s)**:
- MS2b; MS3

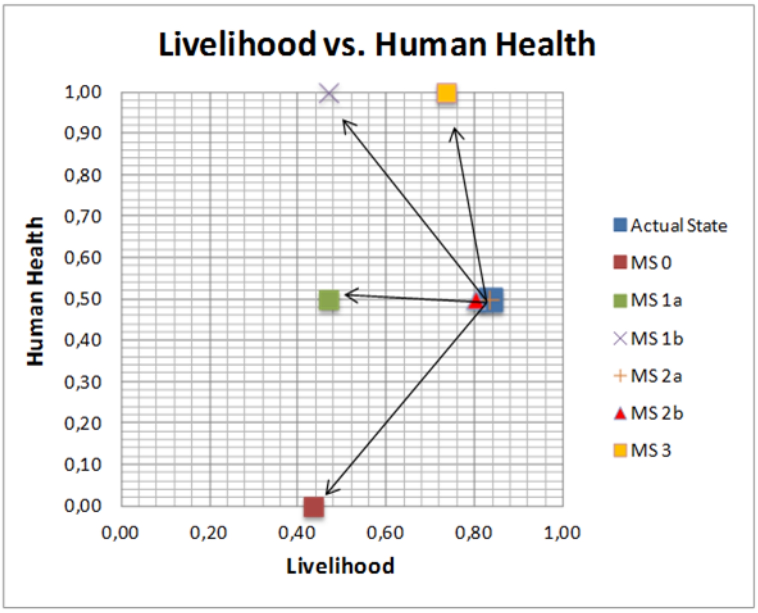



**Sub-optimal solutions**:
- MS0; MS1a; MS2b

**Optimal solutions**:
- MS2a; MS3; MS1b

**Trade-off**:
- Maximise human health (MS1b or MS3) <-> Maximise ecology (MS2a)

**Shortest distance to ideal solution**:
- **MS3** (MS1b; MS2a)




**Sub-optimal solutions**:
- MS0; MS1a; MS2b

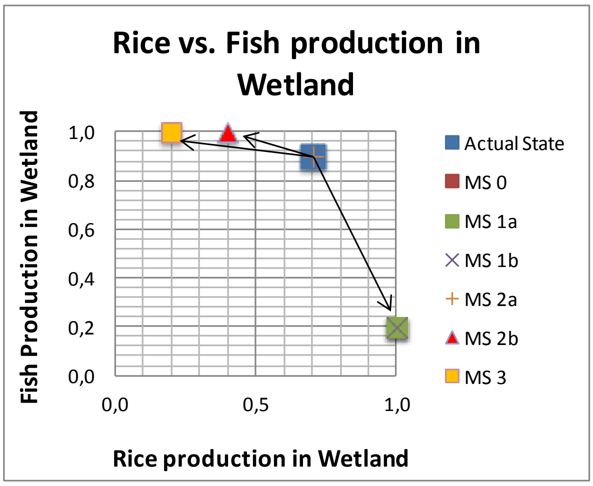
**Optimal solutions**:
- MS1b; MS3; MS2a

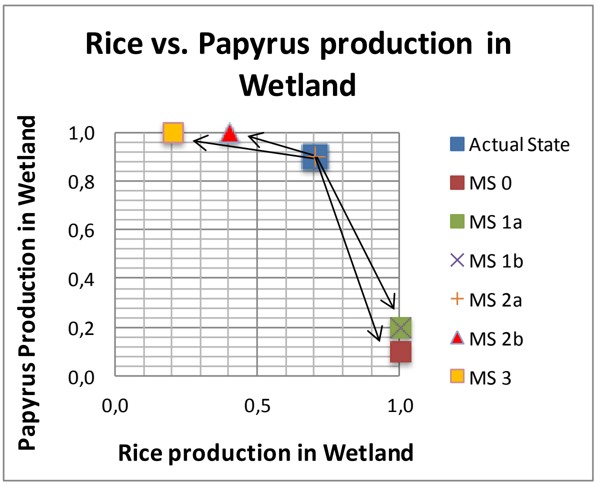
**Trade-off**:
- Maximize human health (MS1b or MS3) <-> Maximize livelihood (MS2a)

**Shortest distance to ideal solution**:
- **MS3** (MS 2a; MS1b)

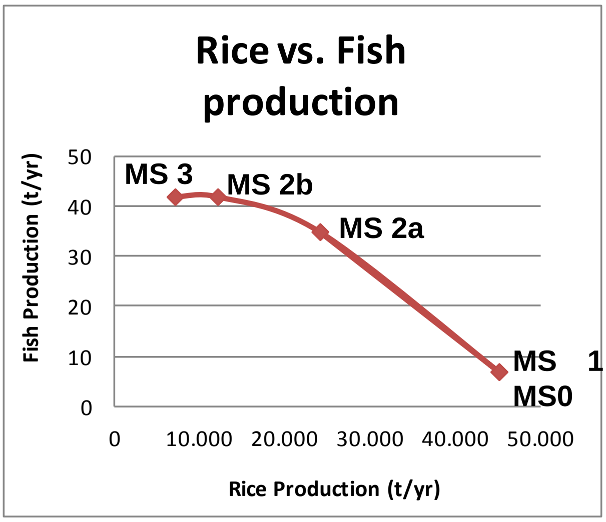
### Trade-Offs between indicators

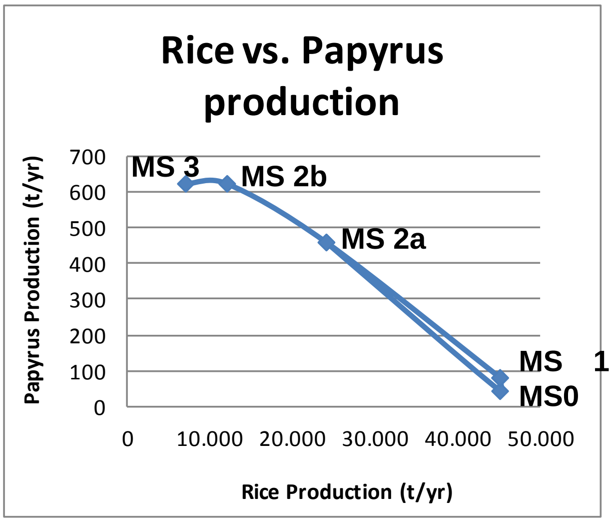
Also between the indicators within the category ‘livelihood’ major trade-offs appear. Indeed rice production goes at the expense of both fish and papyrus production, illustrated in the figures below.
This raises the question whether our categories are well-defined? The indicators on fish and papyrus production are not only linked to livelihood, but also to ecology. Indeed, larger and good working ecosystems will offer opportunities for fisheries and papyrus harvesting. The correlation between these two indicators and the category ecology is indeed obvious. Thus, the conclusion drawn earlier that there is no trade-off between ecology and livelihood is distorted. More or less, the trade-offs illustrated in the figures below can also be seen as a trade-off between ecology and livelihood.
Nevertheless, the conclusion is definitely similar. In these figures there are no sub-optimal solutions, MS0, MS1a and MS1b optimize rice production, while MS3 and MS2b optimizes fish and papyrus production. And indeed the best compromise solution resulting from these trade-offs is also MS2a, like we concluded above for the trade-off livelihood – ecology.




Because both axes (X & Y) of these two trade-offs or individual indicators we can abandon the normalised scores [0,1], and go back to the initial quantitative scores. Which gives us more information on the trade-off, namely on quantities of rice, fish and papyrus production (in tonnes/year), illustration in figures below.



### Trade-Offs Identified in DPSI analysis Namatala

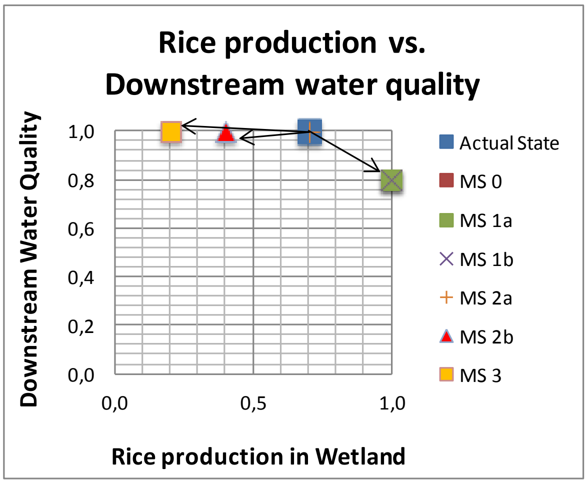
Following trade-offs were identified in a DPSI study on Namatala, effectuated earlier in the WETwin project.

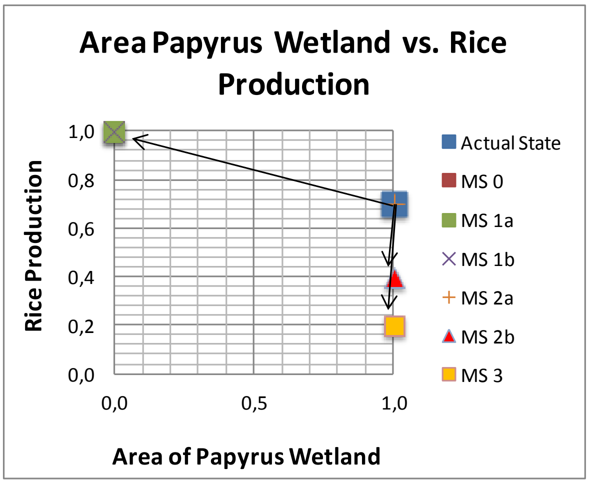
| Trade-offs between wetland's function and eco-services | | |
|---|---|---|
| Food Production | ←→ | Water Purification |
| Crop Production | ←→ | Biodiversity Conservation |

An important question to ask is whether we can translate these two trade-offs into trade-offs between our categories or indicators?

The first trade-off, between food production and water purification, can possibly be framed by the trade-off '*Livelihood-Ecology*'. However the trade-off between the individual indicators '*total rice production and downstream water quality*' is a lot more specific. The question is whether the later trade-off will result in the same conclusion (namely MS2a as best compromise solution)? The figure below illustrates that this is not the case. The best compromise solution between rice production and downstream water quality is MS1a or MS1b, not a big surprise because these solutions focus on water quality. Moreover, MS2a is the best alternative.

The second trade-off, between crop production and biodiversity conservation, can also be framed by the trade-off '*Livelihood-Ecology*', as well as by the trade-offs described earlier between rice production and fish and papyrus production (all three trade-offs resulted in MS2a as best compromise solution). Another possible combination is the trade-off 'rice production – Area of papyrus wetland'. The figure below illustrates that this trade-off results in the same best-compromise solution, namely MS2a.




### Implicit Trade-Offs (= Trade-Offs Between Stakeholder Groups)

- **Solutions Ranking using stakeholder weights**

In the first analysis on solution raking, earlier in this document, we already examined the influence of changing the standard weight set 'equal shares' to a weight set defined by local experts. To identify implicit trade-offs between stakeholder groups, different weight sets were defined based on stakeholder preferences. During a meeting with local stakeholders the participants were asked to attribute weights to the different categories of the analysis.

The results, illustrated in the table below, show that the ranking of solutions doesn't change if we differentiate between stakeholder weight sets. These rankings are equal to the ranking obtained earlier by the weight set 'equal shares'.
Based on these results the conclusion should be that MS3 is the best compromise solution, followed by MS2a. This conclusion is similar to earlier conclusions, and backs up our contention that managing for a healthy system optimises for multiple users.

| *Method* | ***Weight set*** | ***Solutions order based on Impact Scores (best→worst)*** | | | | | |
|---|---|---|---|---|---|---|---|
| **SAW** | Water Managers | MS3 | M2a | MS2b | MS1b | MS1a | MS0 |
| | | 80 | 77 | **74** | **74** | 47 | 30 |
| | Resource Users | MS3 | M2a | MS2b | MS1b | MS1a | MS0 |
| | | 85 | 80 | 77 | 69 | 47 | 34 |
| | Political Leaders | MS3 | MS2a | MS2b | MS1b | MS1a | MS0 |
| | | 87 | 78 | 75 | 72 | 47 | 31 |
| | Environmentalists | MS3 | MS2a | MS2b | MS1b | MS1a | MS0 |
| | | 86 | 79 | 76 | 70 | 47 | 33 |
| | Civil Society | MS3 | MS2a | MS2b | MS1b | MS1a | MS0 |
| | | 87 | 76 | 73 | 72 | 47 | 29 |
| | Community Services | MS3 | MS2a | MS2b | MS1b | MS1a | MS0 |
| | | 85 | 81 | 77 | 68 | 47 | 34 |

The Stakeholder Weight sets (based on the equity matrix from the stakeholder workshop) can be found in the table below. Note that only category scores were defined by the stakeholders, and not indicator weights.

**Stakeholder Weight Sets**

| | **Water Managers** | **Resource Users** | **Political Leaders** | **Environmentalists** | **Civil Society** | **Community Services** |
|---|---|---|---|---|---|---|
| **Livelihood** | 17,00% | 27,00% | 19,00% | 25,00% | 25,00% | 25,00% |
| **Human Health** | 21,00% | 18,00% | 20,00% | 19,00% | 25,00% | 15,00% |
| **Ecology** | 27,00% | 32,00% | 26,00% | 28,00% | 25,00% | 27,00% |
| **Costs** | 18,00% | 5,00% | 18,00% | 10,00% | 8,00% | 15,00% |
| **Risk of failure** | 17,00% | 18,00% | 17,00% | 18,00% | 17,00% | 18,00% |
| | 100,00% | 100,00% | 100,00% | 100,00% | 100,00% | 100,00% |

- **Stakeholders and their Interests:**

Another method to identify the best compromise solution is by discussing it directly with the different stakeholders. This can be done in another stakeholder workshop. In this respect it is definitely interesting to try to identify the stakeholders that will be inclined to profile themselves on certain management solutions and trade-offs. A stakeholder analysis, executed earlier in the WETwin project, defined all the stakeholders and their interests. Based on this study, stakeholders will be assigned to the major explicit trade-offs that were identified in the Trade off Analysis.

### Stakeholders and their interests in the Namatala Wetland

| Stakeholder | Interests |
|---|---|
| Crop Farmers (mainly rice farmers) | Land & Water Resources |
| Pastoralists | Pastures |
| Fisheries | Fish, Conservation of Wetland (papyrus) |
| Wetland Resource Harvesters (e.g. Papyrus harvesters), Hunters, Beekeepers, etc. | Nature Conservation -> Papyrus, palm, leaves, grass, herbs, wild animals, fish, trees, timber, fuel wood, etc. |
| Water Users | Clean Water, Purification Capacity Wetland |
| Sand and Clay Miners | Sand & Clay mining; Water and Land |
| Central Government: | Good policy, best-compromise between livelihood, conservation, development, etc. |
| • Wetland Management Department | Wetland Conservation |
| • Forest Department, Environment Management Authority, etc. | Conservation of Biodiversity |
| • Agriculture Department, Department of employment, etc. | Agriculture, income generation, food security |
| • National Water and Sewerage Corporation, Directorate of Water Resources Management, etc. | Clean drinking water, purification capacity of wetland. |
| Nature Uganda | Birds, Nature Conservation |
| Opinion and Religious leaders | Heritage, culture, sustainable use, welfare |
| Donors, NGO's/CBO's | Diversity of Objectives: Income generation, food security, conservation, sustainability, prestige |
| • Nature Ngo's, etc. | Conservation of Biodiversity and Wetland |
| • Development Ngo's, etc. | Food security, income generation |
| Schools | Dissemination of information, building skills |
| Politicians | Voters, improve livelihoods |

| Trade-Off Human Health-Ecology | | |
|---|---|---|
| Max. Human Health | MS1b, MS3 | Water Users, NWSC, WRM |
| Max. Ecology | MS2a | Environmentalists, WMD, Pastoralists and Fisheries, Wetland resource users |
| Best Compromise Solution? -> MS3 is most likely | | |

| Trade-Off Human Health-Livelihood | | |
|---|---|---|
| Max. Human Health | MS1b, MS3 | Water Users, NWSC, WRM |
| Max. Livelihood | MS2a | Government, Development NGO's |
| Best Compromise Solution? -> MS3 is most likely | | |

| Trade-Offs Livelihood-Ecology (Rice production -vs.- Fish & Papyrus production; or Area of Papyrus Wetland) | | |
|---|---|---|
| Max. Rice production | MS0 (MS1a, MS1b) | Crop farmers |
| Max. Fish & Papyrus production | MS3, MS2b | Environmentalists, WMD, Pastoralists and Fisheries, Wetland resource users, Water users, NWSC, WRM |
| Max. Area of Papyrus Wetland | MS3, MS2b, MS2a | |
| Best Compromise Solution? -> MS2a is most likely | | |

| Trade-Off Rice Production-Downstream Water Quality | | |
|---|---|---|
| Max. Rice production | MS 0 (MS1a, MS1b) | Crop farmers |
| Max. Water Quality | MS2a, MS2b, MS3 | Water users, NWSC, WRM |
| Best Compromise Solution? -> MS1a or MS1b are most likely | | |

## Best Compromise Solution (Overall Conclusion)

Qualified solutions: again MS2a & MS3
Trade-off analysis doesn't provide a decisive conclusion as well.

### 7.2.3 Sensitivity analysis

Analysis indicated that stakeholder weights do not have an impact on the ranking of the solutions. Differences in solution scores are only limited as well.

For the scoring of the indicators from 0 to 1, value functions were determined based on quantitative data, but were slightly modified when it seemed to be necessary to improve the sensitivity of the indicator (e.g. to use a bigger part of the continuum from 0 to 1).

## 7.3 Vulnerability analysis

- **External Impact (Defining BAU scenario)**

The social-ecological system of the Namatala wetland is extremely exposed to impacts of man-made modifications of the natural system, namely the removal of the natural papyrus cover to the benefit of agricultural land (agricultural encroachment). The highly modified and artificial wetland is thus more exposed to impacts of climate change and variability. Population growth has been addressed as additional stressor increasing the demand for food production, natural resources, drinking water, and increasing nutrient loads in form of waste water discharge and maybe fertilizer applications.
The social-ecological system of Namatala is exposed to:

- Agricultural encroachment and unsustainable practices
- Climate change and variability
- Population growth

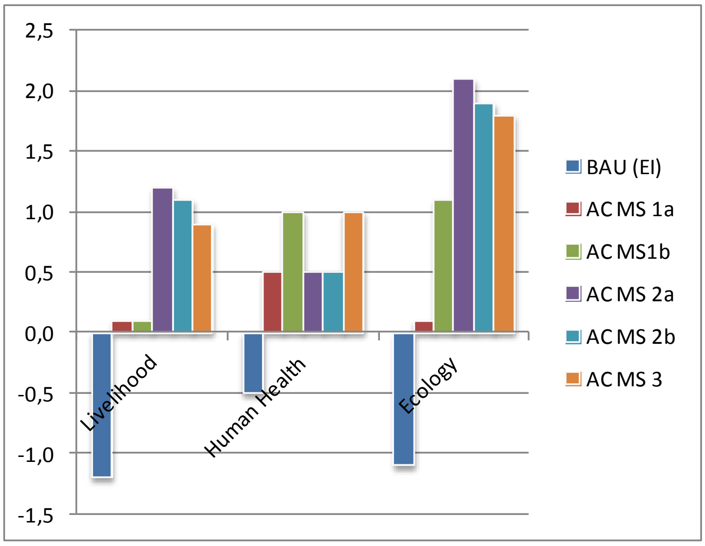
Important ecosystem functions, such as water purification capacity and water regulation of the highly modified Namatala wetland are very likely to be sensitive to current intensive management practices. The unsustainable wetland management has impacts on the water regime and water quality.
To include the concept of external impact into our analysis, a business as usual scenario (= MS0) was defined. This scenario supposes continuation of actual trends, namely: continued agricultural encroachment and increased waste water loads as a consequence of demographic growth, and continuation of unsustainable management (time span of 20 years) . MS0 (BAU) formulates the indicator trends in such a scenario. Because of the uncertainty associated with climate change, BAU doesn't include assumptions about climate change.

- **Adaptive Capacity**

Adaptive Capacity can be defined as the ability of different management solutions to mitigate and cope with external impacts and manage the social-ecological system of the Namatala wetland sustainably. Conditions that hinder the implementation of such measures, e.g. a lack of financial resources or a lack of reasonable alternatives for income, reduce adaptive capacity.

- **Vulnerability**

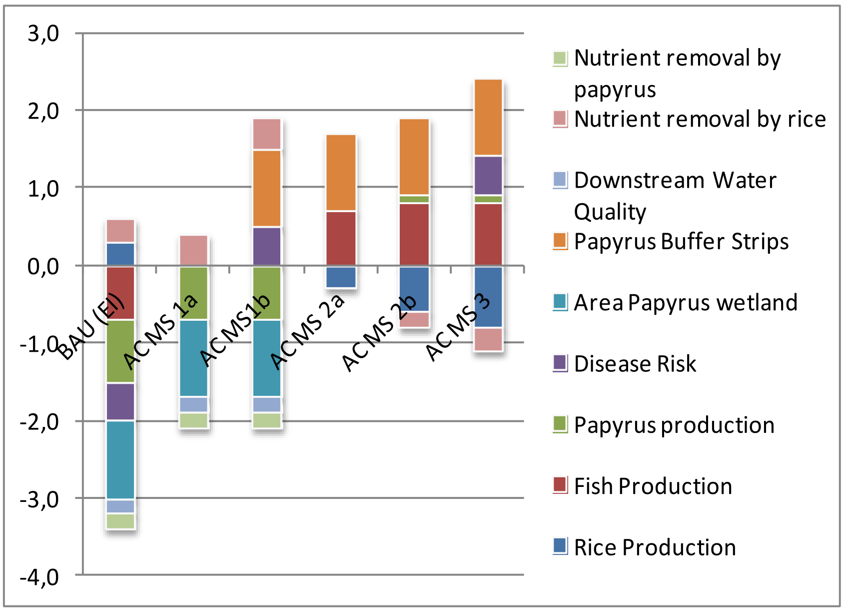
The figure below illustrates the expected external impact on each category (= dark blue), as well as the potential adaptive capacity of the different management solutions. The reference situation (no change) is the actual state. Based on this figure it can be concluded that the external impact on the categories livelihood and ecology is worse compared to the external impact on human health. On both of these categories MS2a is expected to have the best adaptive capacity. To improve human health, MS1b and MS3 are the best alternatives.




An overall ranking of the change in vulnerability (table below) indicates that MS2a is expected to have the best impact on vulnerability of the system. However, the difference with MS3 is almost negligible.

| ***Scenario*** | ***(ΔV) Overall Change in Vulnerability*** | | | | | |
|---|---|---|---|---|---|---|
| BAU (MS0) | MS2a | MS3 | MS2b | MS1b | MS1a | MS0 |
| | +3,8 | +3,7 | +3,5 | +2,2 | +0,7 | -2,8 |

Next figure illustrates for each management solution and BAU the indicator trends (both positive and negative) for each indicator of the three impact categories. This figure enables to interpret the change in vulnerability of the management solutions more in detail. Interesting is that MS3 and MS2b are expected to have considerably more positive impact on more indicators compared to the other solutions. However, because these solutions also have a bigger negative impact on rice production, the overall score of MS3 and MS2b is worse compared to MS2a.



## 7.4 Summary and recommendations

Five management solutions are proposed for Namatala with different focus: water quality; land management and conservation; and an integrated solution drawing together aspects of both. Within these solutions, alternatives are considered with different degrees of financial effort. Management solutions were scored using expert judgement on the basis of three impact criteria (livelihood, human health and ecology) and two feasibility criteria (costs and risk of failure).

The main driver of change in the system is population growth, which is expected to cause various constraints for sustainable management of the wetland and the communities depending on it. Under "business as usual" (without management) all three impact criteria are expected to decrease considerably in relation to current state. Livelihood and ecology are expected to decrease to almost half of the current state score, and the human health situation will even decrease to the minimal score

While the proposed solution integrating land use change in the upper and lower wetland with improved waste water treatment (MS3) has the most suitable outcomes in terms of impacts on human health, livelihoods and ecology, it is judged to be costly and with high risk of failure. The simpler solution focusing on management of papyrus harvesting and buffer strips (MS2a) provides similar outcomes with lower cost and risk. The favoured management solution (MS2a) optimises both livelihood and ecosystem impacts, although there are trade-offs with the human health criterion. Within the livelihood criteria, there is a conflict between rice cultivation and both fish and papyrus production.

Inclusion of criteria weighting to express stakeholder preferences for specific outcomes did not alter the ranking of solutions, which were the same for all stakeholder groups (MS3 followed by MS2a on the basis of impact criteria only).

# 8 Inner Niger Delta (IND), Mali

## 8.1 Decision space

### 8.1.1 Management Options

The Inner Niger Delta in Mali is one of the largest floodplains in Africa, intensively used by local populations for their subsistence. Arising in the mountainous regions in Guinea, the Niger River flows through Mali forming an immense delta between Ke-Macina and Tombouctou, just below the Sahara desert in West-Africa. All main issues in the Inner Niger Delta are related to the availability of water (both in the wet and dry season). This aspect is strongly dependent on hydrology and water allocation in the catchment, linked with climate variability and change, and influenced by manmade structures such as dams in upstream regions. Although these aspects on larger scale are very important, the proposed management options for this analysis only focus on local scale (interventions that can be implemented locally). By focussing on the local scale, aspects related to the flow regime can be considered as external factors, and thus are taken into account in the scenarios and vulnerability assessment.

Table 8.1 summarizes the 11 alternative management options that can be implemented on local scale. The local entity chosen to assess the performance and feasibility of these management options is Mopti, a city located in the middle of the Inner Niger Delta confronted with severe problems related to water quality (both sanitation and drinking water provisioning) and livelihood and ecosystem degradation. A full description of management options is given in WETwin D7.2 (Johnston and Mahieu 2011).

**Table 8.1:** management options at local scale

| IWRM issues | Axes of Management | Alternative Management Options |
|---|---|---|
| Water Quality | Sanitation | - **A1.1**: Improved Latrines |
| | | - **A1.2**: Sewerage |
| | | - **A1.3**: Solid Waste Management |
| | Drinking Water | - **A2.1**: Deep Wells |
| | | - **A2.2**: Public Water Distribution |
| Livelihood & Ecosystems | Ecosystems | - **A3.1**: Native Species Conservation and Restoration |
| | | - **A3.2**: Restoration of Breeding Habitats for Fish |
| | | - **A3.3**: Eliminate Breeding Habitats for Disease Vectors |
| | Income Generation | - **A4.1**: Support Micro Credit Initiatives |
| | | - **A4.2**: Processing Facilities for Rice, Fish and Vegetables |
| | | - **A4.3**: Development of Rice Cultivation |

**Table 8.2: List of Criteria and Indicators for IND, Mali**

| *Criteria* | *Indicators* | *Value function* | | | | |
|---|---|---|---|---|---|---|
| | | VL | L | M | H | VH |
| **Impact Categories** | | **Expert judgment based on: (reference)** | | | | |
| **Human Health** | Health State: Diarrhea | National Average (prevalence) | | | | |
| | Health State: Malaria | National Average (prevalence) | | | | |
| | Health State: Schistosomiasis | National Average (prevalence) | | | | |
| | Health State: Malnutrition | National Average (prevalence) | | | | |
| | Healthy Living Environment: Breeding Habitats for disease vector | Extent to which these habitats are a constraint for human health (mainly malaria and Schisto). | | | | |
| | Water Quality of Surface Water in Living Environment | Degree in which it is usable for human purposes | | | | |
| **Ecosystem Health** | Water Quality of Surface Water in Natural Environment | Degree in which it is usable for human purposes | | | | |
| | Bourgou Habitat | Ranging from largely degraded to large and healthy habitats | | | | |
| | Flooded Forests Habitat | Ranging from largely degraded to large and healthy habitats | | | | |
| | Habitat for Birds | Ranging from largely degraded to large and healthy habitats | | | | |
| | Habitat for Fish | Ranging from largely degraded to large and healthy habitats | | | | |
| | Cultural Significance | Link between ecosystems and cultural life. | | | | |
| **Socio-Econ. Development** | Income Generation | Average income level | | | | |
| | Provisioning Services from Ecosystems | Value of ecosystem services, in relation to overall income level. | | | | |
| | Access to clean drinking water from groundwater | Availability & affordability for local population | | | | |
| | Access to clean drinking water from surface water | Availability & affordability for local population | | | | |
| | Access to Sanitation | Availability & affordability for local population | | | | |
| | Access to wetland natural resources | Availability & affordability for local population | | | | |
| **Affordability/Costs** | Investment Costs | In relation to financial capacity of local government | | | | |
| | Maintenance Costs | In relation to financial capacity of local government | | | | |
| | Affordability of investment cost for local people | In relation to average income level of local population | | | | |
| | Affordability of Maintenance cost for local people | In relation to average income level of local population | | | | |

| | | |
|---|---|---|
| Planning | Local Committees and user participation | Level of importance to guarantee success |
| | Government Coordination | Level of importance to guarantee success |
| | Rule Clarity and Enforcement | Level of importance to guarantee success |
| | Awareness Raising | Level of importance to guarantee success |
| | Organizational Complexity | Level of importance to guarantee success |
| | Cultural Acceptance | Level of importance to guarantee success |

### 8.1.2 Indicators, Categories and Value Functions

In order to assess the performance of the different management options a set of 28 indicators, subdivided into 5 categories were identified. All indicators were assessed in a quantitative way (by expert judgment). Table 8.2 below summarizes the set of indicators and the value functions used to convert the scores from the evaluation matrix [ranging from Very Low (VL) to Very High (VH)], into normalized scores for the analysis matrix [0,1]. The first three indicator categories (Human health, Ecosystem health and Socio-Economic development) are **impact categories**, meant to assess the performance of the different management solutions. The two other indicator categories (Affordability/Costs and Planning) are **feasibility categories**, meant to assess the feasibility of implementation of the management options.

### 8.1.3 Scenarios

Management options need to be robust for changes in the future. The vulnerability of the Inner Niger Delta and the proposed management options will be examined in a vulnerability assessment in the second part of this document. Based on scenarios for population growth, climate change and flow regime changes, several Business As Usual (BAU) scenarios can be defined based on our normalized scores.

***Precipitation projections Inner Niger Delta under Climate Change scenarios***

Figure 8.1 below illustrates future temperature scenarios (+1°C and +2°C), as well as its expected impact on future precipitation patterns for the Inner Niger Delta, in the time period 2011-2050. These figures are based on continuation of actual trends, supposing one or two degrees temperature increase. Assuming these two climate change scenarios, a considerable precipitation decrease can be expected for the future (from -3.04 to -4.2 mm/year).

What is most important to know is the impact of these possible climate changes on the flow regime in the IND, and more in specific the daily discharge into the IND which is a major determinant of the total area of floodplains that can be expected. Figure 8.2 illustrates this impact for the period 2031-2050, calculated by Liersch et al. (2012).

These results indicate a worrying decrease in water discharge at Koulikoro, downstream of Bamako and upstream of the IND. Based on this figure we can conclude that climate change is expected to have a devastating impact on the flow regime of the IND. Another factor that influences the discharge into the IND is human interference, mainly the construction of upstream dams.

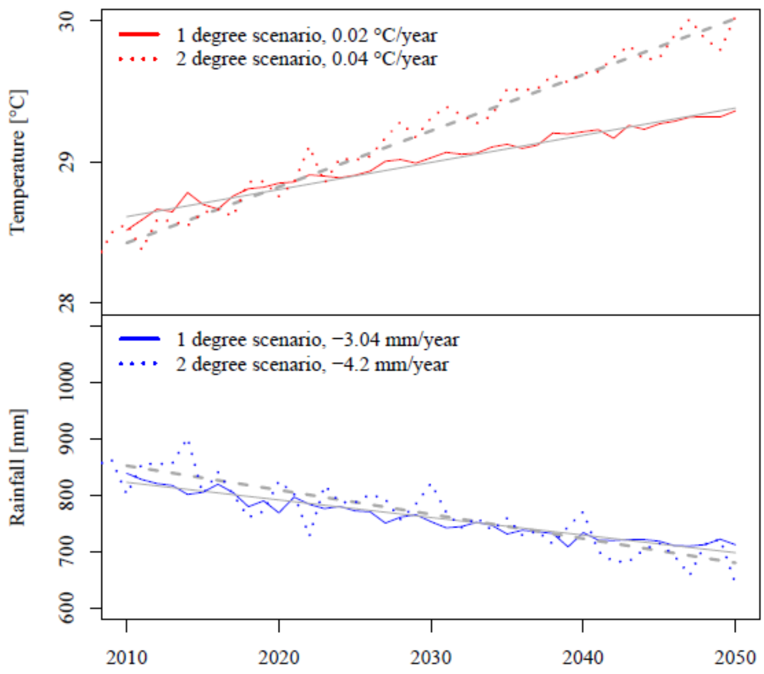



**Figure 8.1:** *STAR – projections for the Upper Niger Basin (Liersch et.al., 2011)*

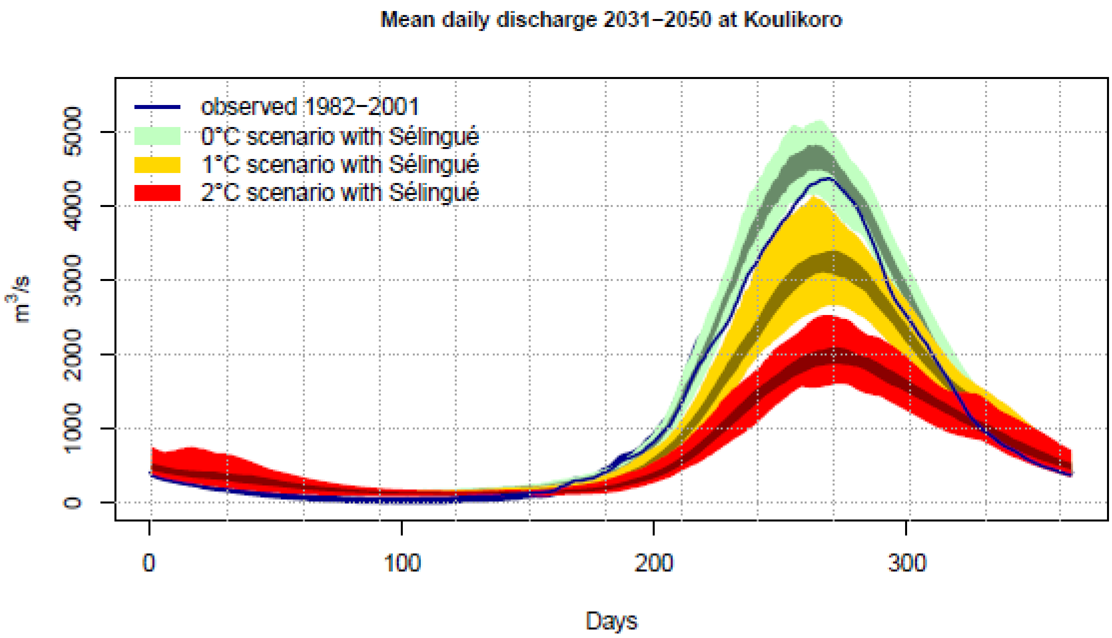



**Figure 8.2 :** *Climate Change impact on discharge at Koulikoro (Liersch et.al., 2011)*

***Actual and Expected Flow Regime Changes in the Inner Niger Delta due to dams***

Hydrology and water allocation in the Inner Niger Delta are governed by two dams, and a third is being considered at the moment:

- Selingue dam is used for water storage, flow control, irrigation and hydropower. It leads to a reduction of peak flow during wet season. In addition, energy production leads to increased outflow from the dam during dry season, which is a positive side-effect for the Inner Niger Delta.
- Markala dam, in contrast, is used for the irrigation of the upstream Office du Niger only. It also leads to reduced peak flow during wet season. On the other hand, during dry season Markala dam abstracts up to 50% of the water during dry season, which is a strong negative effect for the IND. In addition, rice farming in Office du Niger leads to an increased Malaria problem.
- A new dam, Fomi dam, is being considered. An earlier design was considered to have a large impact on the delta and is currently in revision.

Liersch et al. (2012) calculated respectively the actual and expected impact of the Sélingué and Fomi dam on the daily discharge upstream of the IND. Figure 8.3 below illustrates the results, indicating an additional decrease in water discharge at Koulikoro for the period 2031-2050.

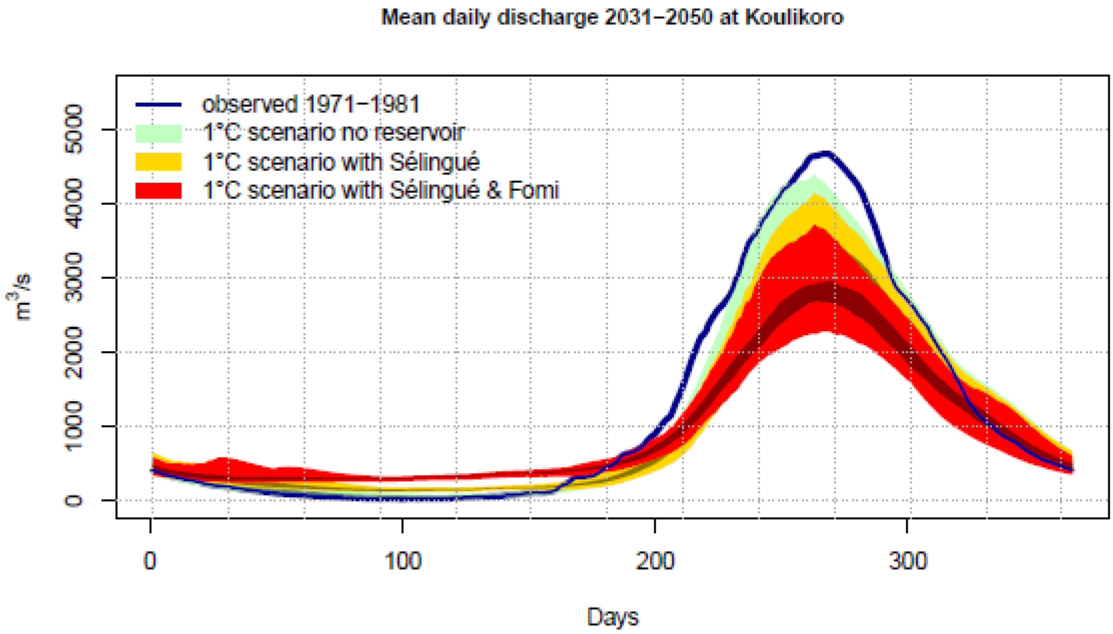



**Figure 8.3:** *Reservoir management impacts on discharge at Koulikoro (1°C scenario) (Liersch et. al., 2011)*

The consequences of these flow regime scenarios (both from climate change as well as from upstream dams) will have devastating consequences for the local communities living in the IND, as well as for biodiversity. Indeed, previous research indicated the importance of a sufficient flow in the IND for agriculture, fisheries, livestock, important habitats providing numerous ecosystem services, etc. An additional factor predicting constraints for the development of the IND-region is population growth.

*Population Growth in Mali*

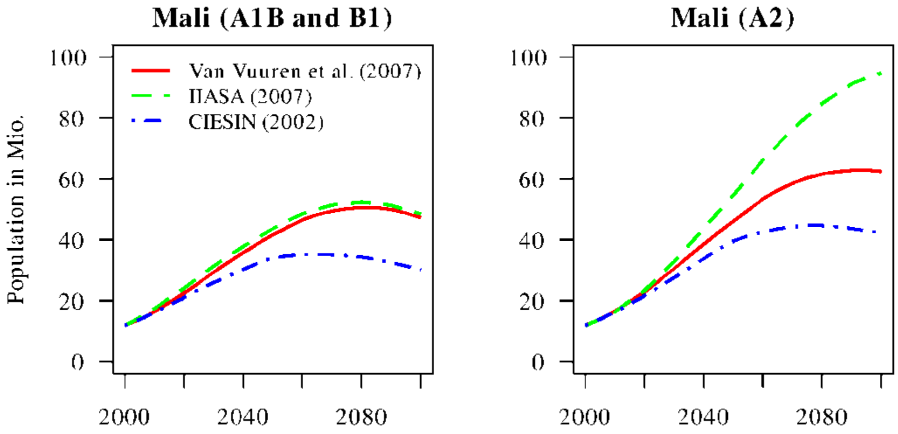
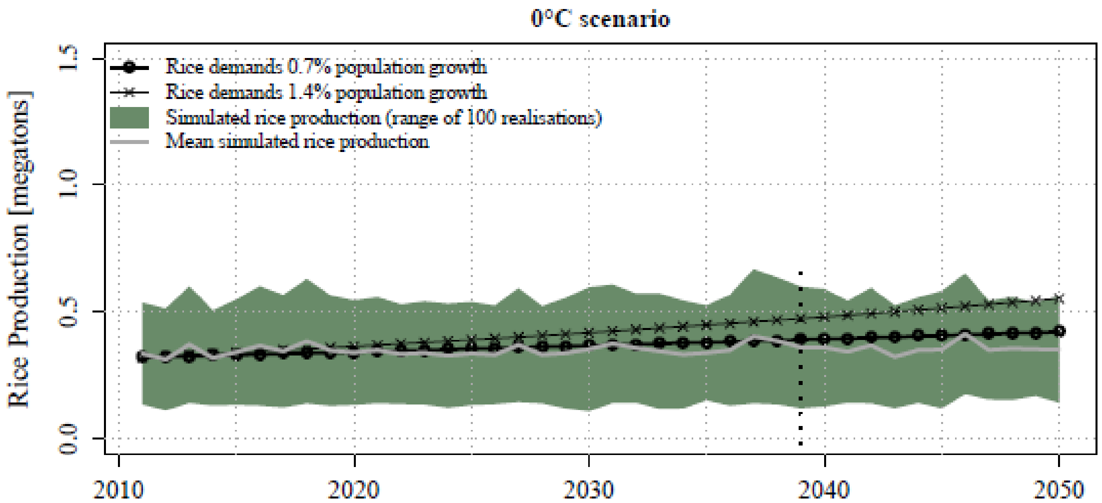



**Figure 8.4**: *Population projections for Mali from three different sources*

Population growth is expected to cause various constraints for the development of the IND-region and its local communities. Two major constraints are, firstly the demand for food and related agricultural production will increase enormously. Secondly, the (urban) waste water load will increase, creating pollution and contamination risk in the wetland.

Liersch et.al. (2012) calculated the future rice demands in relation with potential rice production under different climate change scenarios. Two population growth scenarios were investigated, namely an increase of 0.7% and an increase of 1.4%. The latter is the national average, but population growth in the IND is expected to be lower, because of the hard living circumstances in the IND and the absence of large urban areas that attract large groups of rural immigrants.



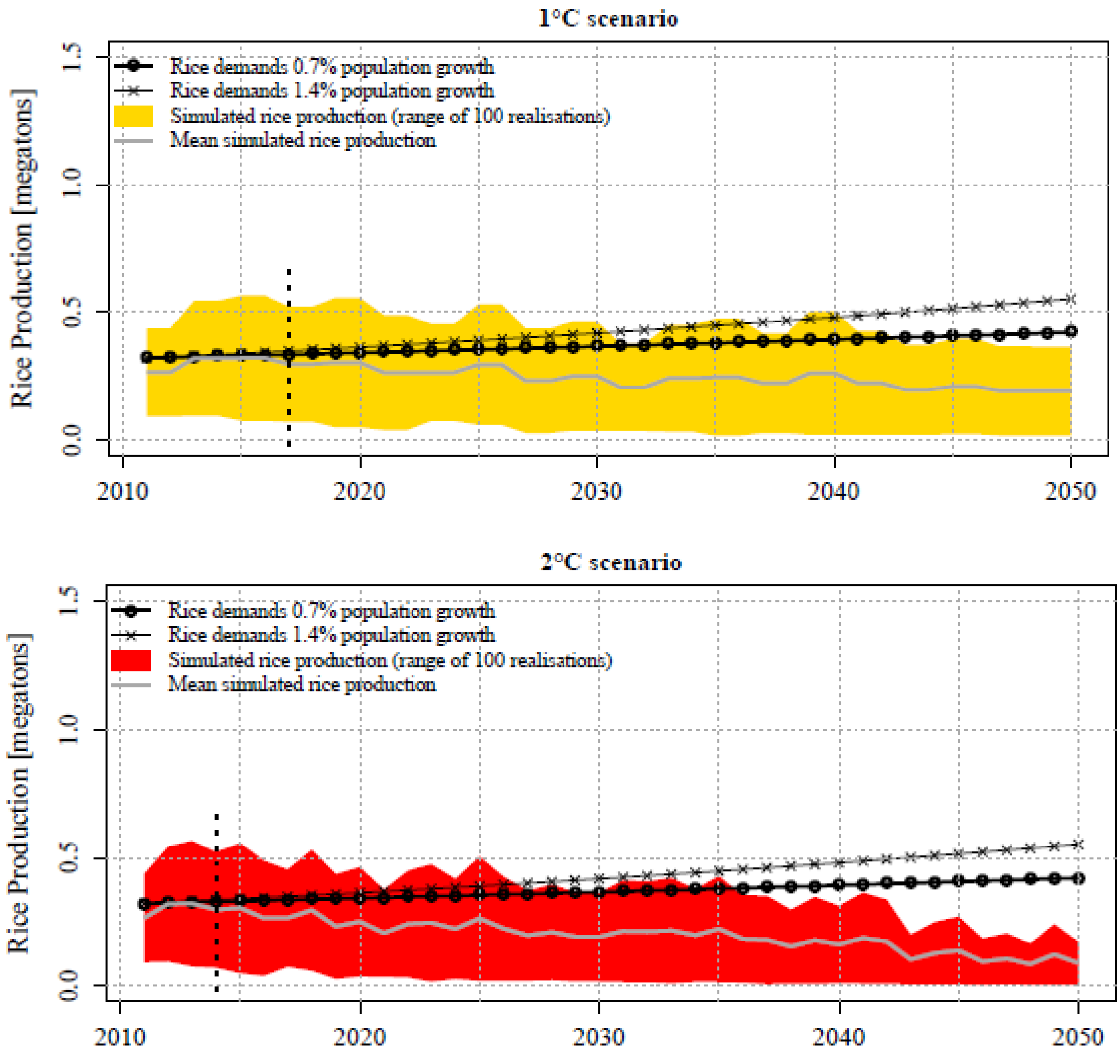



**Figure 8.5:** *Rice demands and potential production, climate change scenarios (including impacts of Sélingué Dam)*

## 8.2 Results of Expert Analysis

### 8.2.1 Scoring of management options

To be able to rank the different management options, a normalised scoring method was developed. In a first step the impact and feasibility of the management options was assessed using the common set of quantitative and qualitative indicators. This first step results in the **evaluation matrix** [scores from VL->VH]. In a second step the various scores needed to be converted into normalised scores [0,1], using value functions. Normalised scores range from 0 (=worst situation) to 1 (=best situation). This second step results in a new matrix, the **analysis or decision matrix**. In a third step weighted category scores and overall option scores are calculated. The method (or decision rule) used to calculate these scores is **SAW (Simple Additive Weighting)**, and the standard weight set is **'equal shares'**, attributing equal weights to each indicator and category. However, the weight set can be differentiated to be able to emphasize on certain categories.

Figure 8.6 (a-d) below illustrate the performance (impact or feasibility) of the different management options on the five criteria human health, ecosystem health, socio-economic development, affordability/costs and planning. Closer to 1 means better performance and closer to 0 means worse performance for each of the five axis. The category scores presented in these figures are the raw/simple scores, obtained by using the standard decision rule (SAW) and standard weight set (Equal Shares).

Three sanitation options were assessed. From Figure 8.6a below it can be concluded that the grey water sewer (green) is expected to have the best performance on the three impact categories (especially on human health). Solid waste management (orange) has scores similar to sewerage. The extension of improved latrines (dark red) seems to be the most feasible option, on both feasibility categories, but on the other hand its impact scores are only a bit better compared to actual state.

Both drinking water options have similar performance scores on all three impact categories (Figure 8.6b). Moreover the implementation of a public water distribution system (green) will be considerably less feasible compared to modern protected deep wells (red), especially because of high costs. Because of these two reasons the option to implement modern protected deep wells seems to be more interesting.

Figure 8.6c shows a more differentiated picture. The option to eliminate breeding habitats for disease vectors (green) scores best on the category human health (no surprise), but worst on the two other impact categories (no improvement compared to actual state). In contrast, native species conservation and restoration (red) scores best on ecosystem health and socio-economic development, but implies no improvement on human health (= same as actual state). The score for the option to restore fish habitats (blue) is similar, but in a lesser extent. But indeed, native species conservation and restoration entails fish habitats restoration and more. All three options seem to be feasible.

The three livelihood options (Figure 8.6d) perform rather moderately. Supporting micro credit initiatives (green) and investments in processing facilities for vegetables, rice and fish (blue) both score similar, namely limited improvement on human health and socio economic development. The third option, development of controlled rice cultivation (yellow), scores even worse on ecosystem health compared to actual state. But on the other hand controlled rice cultivation scores good on socio-economic development.

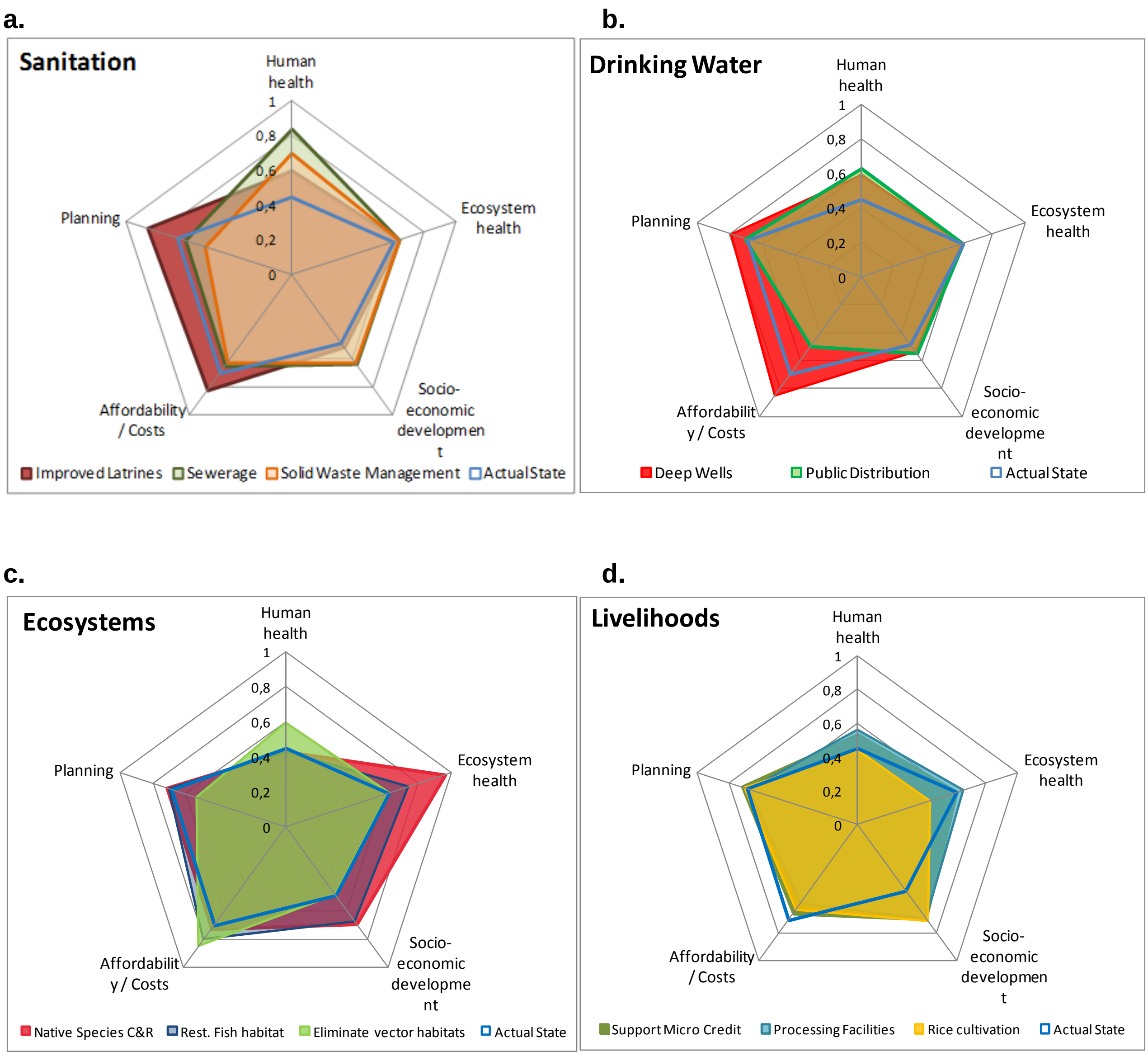


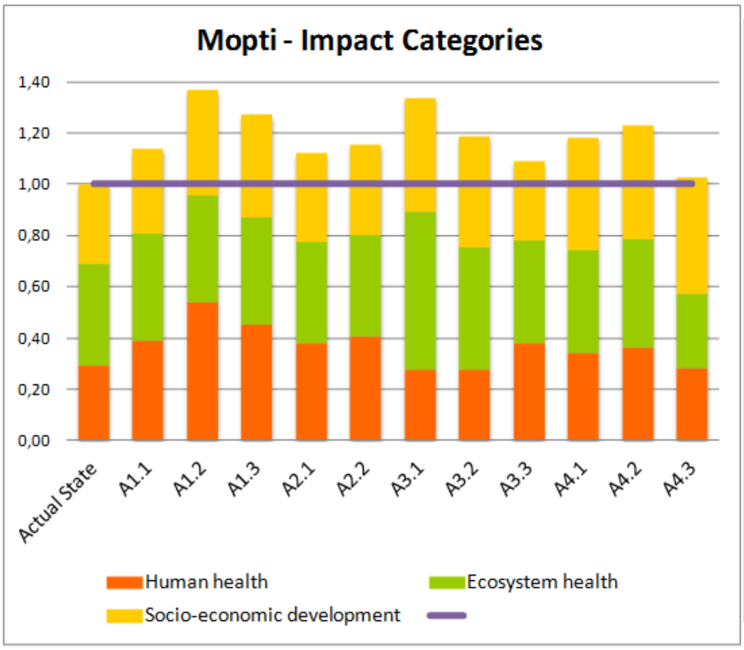

**Figure 8.6***:* *Performance of Management Options (Decision rule: SAW; weight set: Equal Shares)*

### 8.2.2 Ranking of management options

The bar charts below (Figure 8.7) assemble the weighted category scores (performance on impact categories) for each management option as well as for actual state (as reference for comparison): the higher the bars, the better the performance. (Note that the chosen weight set for these figures is equal shares for each category and indicator).

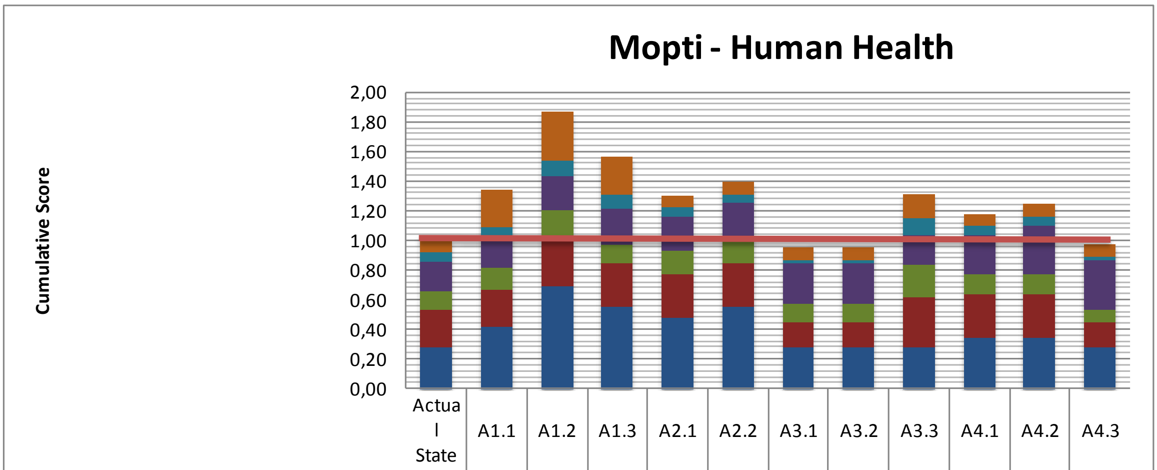
The option with the best overall score is option **A1.2 Sewerage,** a result of the good score on human health, combined with reasonably good scores on ecosystem health and socio-economic development. The second best option is **A3.1 Native Species Conservation and Restoration,** particularly because of its good score on ecosystem health and socio-economic development, although the score on human health is rather low. The third and fourth options are respectively **A1.3 Solid Waste Management** and **A4.2 Processing Facilities for vegetables, rice and fish**. The worst scoring option is definitely A4.3 Development of Controlled Rice Cultivation (= similar to actual state), because of its poor score on human health and ecosystem health, despite its good score on socio-economic development.

Note that since each category score is composed by different indicator scores, figures can be produced illustrating all indicator scores within each category – an example is given in Figure 8.8. Not all of these figures are included in this report.




**A1.1: Improved Latrines**
**A1.2: Sewerage**
**A1.3: Solid Waste Management**
**A2.1: Protected deep Wells**
**A2.2: Water Distribution**
**A3.1: Native Species R&C**
**A3.2: Breeding Habitats Fish**
**A3.3: Eliminate Vector Habitats**
**A4.1: Support Micro Credit**
**A4.2: Processing Facilities**
**A4.3: Controlled Rice Cultivation**

**Figure 8.7:** *Ranking of options based on impacts (Decision rule: SAW; weight set: Equal Shares)*




| | Actual State | A1.1 | A1.2 | A1.3 | A2.1 | A2.2 | A3.1 | A3.2 | A3.3 | A4.1 | A4.2 | A4.3 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| Water Quality of Surface Water in Living Environment | 0,08 | 0,25 | 0,33 | 0,25 | 0,08 | 0,08 | 0,08 | 0,08 | 0,16 | 0,08 | 0,08 | 0,08 |
| Healthy Living Environment: Breeding Habitats for Disease Vectors | 0,06 | 0,07 | 0,10 | 0,10 | 0,06 | 0,06 | 0,03 | 0,03 | 0,12 | 0,06 | 0,06 | 0,03 |
| Health state: Malnutrition | 0,20 | 0,20 | 0,23 | 0,23 | 0,23 | 0,23 | 0,27 | 0,27 | 0,20 | 0,27 | 0,33 | 0,33 |
| Health state: schistosomiasis | 0,13 | 0,16 | 0,18 | 0,13 | 0,16 | 0,18 | 0,13 | 0,13 | 0,22 | 0,13 | 0,13 | 0,09 |
| Health state: malaria | 0,25 | 0,25 | 0,34 | 0,29 | 0,29 | 0,29 | 0,17 | 0,17 | 0,34 | 0,29 | 0,29 | 0,17 |
| Health state: diarrhea | 0,27 | 0,41 | 0,69 | 0,55 | 0,48 | 0,55 | 0,27 | 0,27 | 0,27 | 0,34 | 0,34 | 0,27 |

**Figure 8.8:** *Option Indicator Scores, Category Human Health.*

Figure 8.9 compares scores based on impacts with those from the two feasibility categories (cost and planning). None of these options seems to be radically unfeasible, but these scores indicate enabling conditions that possibly need to be addressed prior to implementation. Options confronted with high costs are **A2.2 Water Distribution**, **A4.2 Processing Facilities for Vegetables, Rice and Fish** and **A1.3 Solid Waste Management**. Options confronted with difficulties regarding to planning are mainly **A1.3 Solid Waste Management** and **A3.3 Eliminate Vector Habitats**.

Figure 8.10 illustrates ranking that takes into account both impact and feasibility scores (using the formula: Impact scores * Feasibility index). Option A1.2 with the best score on the previous ranking loses ground because both planning and costs weighs rather heavily. The second best option A3.2 reconfirms its position, while also the third and fourth options in the previous ranking (A1.3 and A4.2) loses ground. Options **A1.1 Improved Latrines** and **A2.1 Protected Deep Wells** enter the top3.

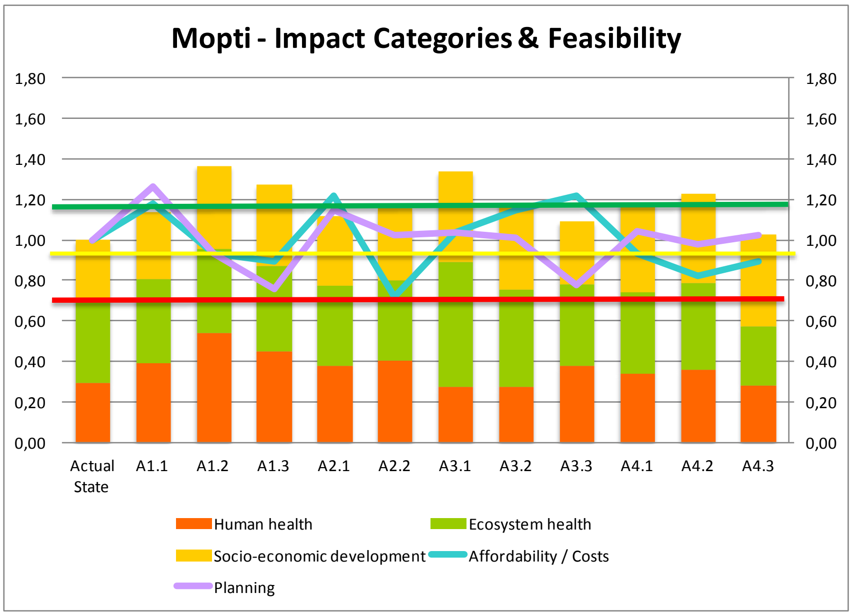



**Figure 8.9:** *Comparison of scores for impact and feasibility*

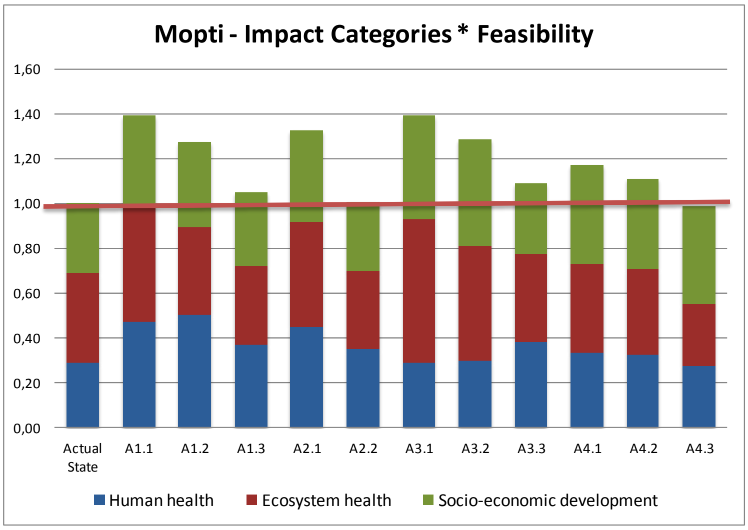



**Figure 8.10:** Ranking of options, adjusted to include feasibility scores

### 8.2.3 Weight Sets

Weight sets can attribute more weight to indicators and categories that were judged to be more important than others, and vice versa. The different weight sets compared in this analysis are:

- '**Equal Shares**' which attributes equal weights to each category and indicator.
- '**50% Human Health**' which focuses attention on human health.
- '**50% Ecosystem Health**' which focuses attention on ecosystem health.
- '**50% Socio-Economic Development**' which focuses attention on socio-economic development.

Table 8.3 shows a comparative analysis of the scores and ranking of the management options with different weight sets (only taking into account impact categories). The top 3 options are always the same, being in another order. Also positions 4, 5 and 6 are filled with the same options, with the exception of one case. The fact that the top 3 as well as top 6 options are not changing indicates that this ranking is not that sensitive to changes in weight sets, even when extreme weight combination are used. The fact that some options change places with different weight sets is expected considering the focus on the options. A more detailed analysis of stakeholder-assigned weights is hence not done, considering its limited impact.

**Table 8.3: Comparison of rankings using different weightings.**

| *Weight set* | *Options order based on Impact Scores (best→worst)* | | | | | |
|---|---|---|---|---|---|---|
| Equal Shares | A1.2 | A3.1 | A1.3 | A4.2 | A3.2 | A4.1 |
| | 1,37 | 1,34 | 1,27 | 1,23 | 1,19 | 1,18 |
| 50% Human Health | A1.2 | A1.3 | A3.1 | A4.2 | A2.2 | A4.1 |
| | 1,43 | 1,29 | 1,21 | 1,19 | 1,17 | 1,14 |
| 50% Ecosyst. Health | A3.1 | A1.2 | A1.3 | A3.2 | A4.2 | A4.1 |
| | 1,47 | 1,34 | 1,27 | 1,25 | 1,24 | 1,19 |
| 50% Soc-Econ Dev. | A3.1 | A1.2 | A1.3 | A4.2 | A4.1 | A3.2 |
| | 1,34 | 1,33 | 1,25 | 1,25 | 1,22 | 1,21 |

### 8.2.4 Theoretical Best Option

The **top 3** theoretical best options, based on technically best performance are **A1.2 Sewerage**, **A3.1 Native Species Conservation and Restoration** and **A1.3 Solid Waste Management**. When looking at the total impact of the management options, the above options are scoring the highest. Depending on which category is judged to be most important A1.2 (focus on Human Health) or A3.1 (focus on Ecosystem Health and Socio-Economic Development) is the theoretical best option.

Note that most options can be implemented together, at least if (financial) resources are available and enabling conditions regarding to planning are met. From this perspective the ranking of options is more like a priority list. All selected management options are deemed to be important and need to be implemented. The fact that improved latrines e.g. do not appear as a top measure does not imply that it is not important. Only that latrines have few impact on the other categories than health. Alternatively, the selected indicators might not be sensitive to the real impact of improved latrines.

## 8.3 Trade-Off Analysis

Some criteria are difficult to manage simultaneously. Often improvements in the one field have negative consequences in the other field (physically), or improvements of the situation of one group of people are at the expense of the situation of another group of people (human interests). These kind of trade-offs are inherent to decision making. On the other hand different options can also be independent of each other (no regret measures), or even lead to a win-win situation if implemented together. This part of the analysis tries to identify major trade-offs between the proposed management options, and tries to look for options producing better or similar results with less conflict. Two types of trade-offs can be investigated: **explicit trade-offs** (determined by physical law, improvements in the one field will automatically lead to deteriorations in the other field), and **implicit trade-offs** (based on values and stakeholders interests or preferences).

### 8.3.1 Explicit Trade-Offs (Trade-Offs between Categories)

Scores for the categories livelihood, human health and ecology are compared pair wise in Figure 8.11. The central question is which management option is best in optimizing both categories. In a first step optimal options can be distinguished from sub-optimal options. Sub-optimal options are options that are dominated by other options (on both categories). Only optimal options can be taken into account in the Trade of Analysis. If there is a trade-off, meaning that there is more than one optimal option, the shortest distance to the ideal option (= both categories optimized) can be calculated to quantify the trade-off (see Figure 3.x, Part A).

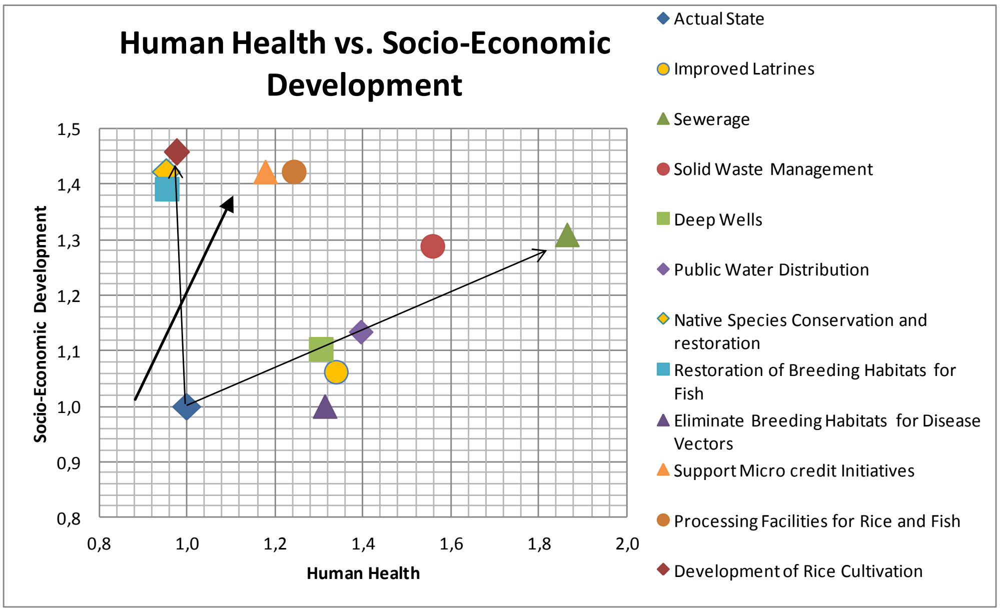
The first trade off (human health vs. socio-economic development) has three optimal options, namely **A4.3 development of controlled rice cultivation** (optimizing socio-economic development), **A1.2 Sewerage** (optimising human health) and **A4.2 Processing facilities for vegetables, rice and fish**. All other options are sub-optimal. The option closest to the ideal option, and thus best-compromise option in this trade off is **A1.2 Sewerage.**

The next trade-off (ecosystem health vs. socio-economic development) results in two optimal options, namely **A4.3 development of controlled rice cultivation** (optimizing socio-economic development) and **A3.1 native species conservation and restoration** (optimizing ecosystem health). The option with shortest distance to ideal option is clearly **A3.1 native species conservation and restoration** because it improves both categories, while controlled rice cultivation only improves socio-economic development and even decreases the ecosystem health situation.

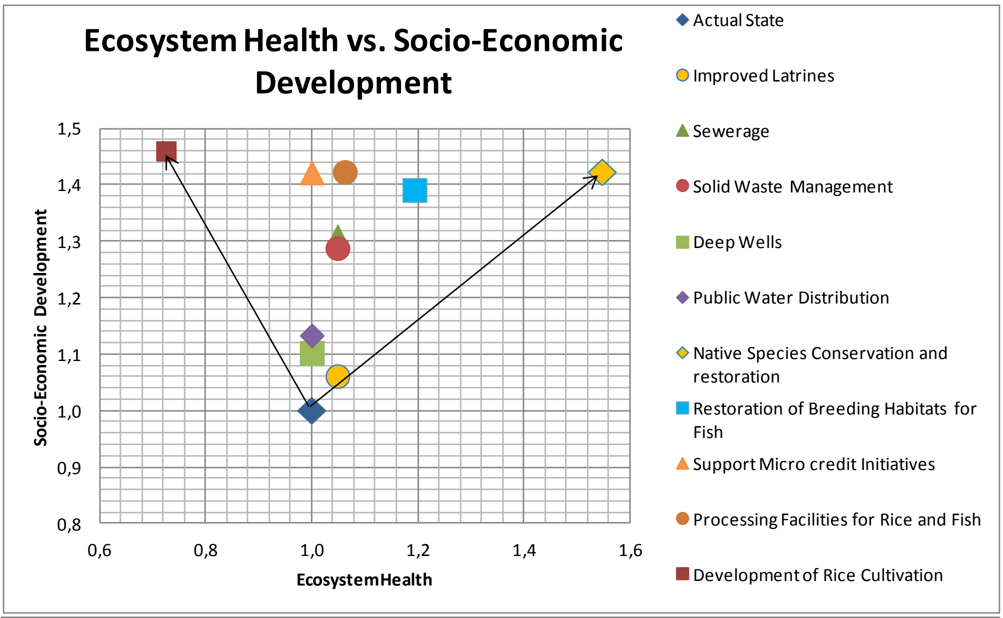
The third trade off (human health vs. ecosystem health) results in two optimal options, **A1.2 Sewerage** (optimizing human health) and **A3.1 native species conservation and restoration** (optimizing ecosystem health). In this trade-off figure option A4.3 development of controlled rice cultivation is definitely the least interesting option, decreasing both human health and ecosystem health. The option with shortest distance to ideal option is **A1.2 Sewerage**, however in this case the trade off is most outspoken with both options optimising one category while almost not affecting the other category.

Also in light of this trade-off analysis options **A1.2 Sewerage** and **A3.1 Native Species Conservation and Restoration** seem to be the most interesting options. Depending on which categories are judged to be most important, one of these two options will be the best-compromise option.

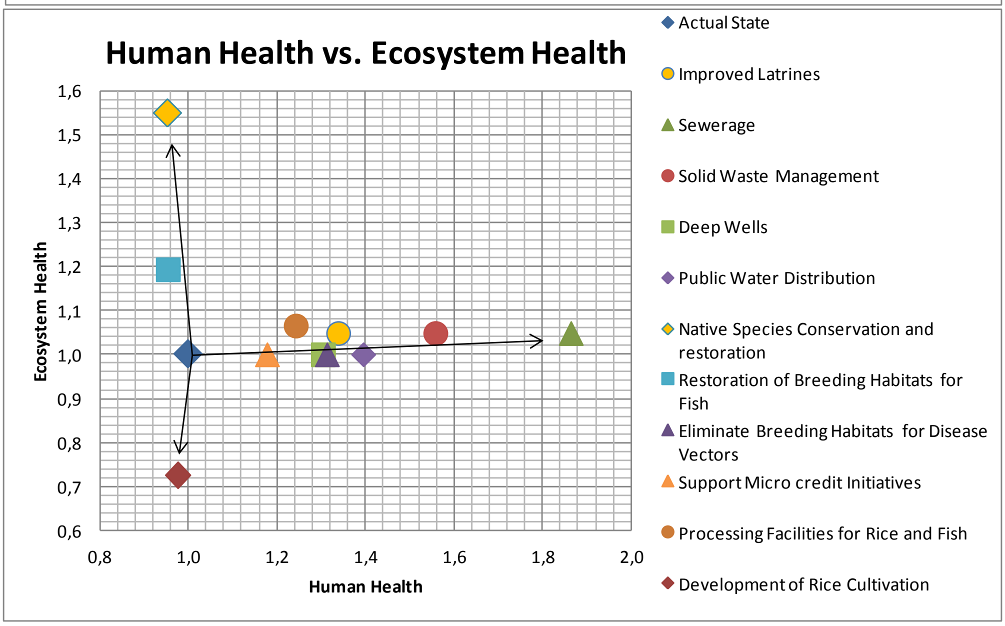
**Figure 8.11** Pairwise comparison of scores for management options in different categories (next page)



Human Health vs. Socio-Economic Development
Socio-Economic Development
Human Health
1,5
1,4
1,3
1,2
1,1
1,0
0,9
0,8
0,8
1,0
1,2
1,4
1,6
1,8
2,0
Actual State
Improved Latrines
Sewerage
Solid Waste Management
Deep Wells
Public Water Distribution
Native Species Conservation and restoration
Restoration of Breeding Habitats for Fish
Eliminate Breeding Habitats for Disease Vectors
Support Micro credit Initiatives
Processing Facilities for Rice and Fish
Development of Rice Cultivation

Ecosystem Health vs. Socio-Economic Development
Socio-Economic Development
EcosystemHealth
1,5
1,4
1,3
1,2
1,1
1,0
0,9
0,8
0,6
0,8
1,0
1,2
1,4
1,6
Actual State
Improved Latrines
Sewerage
Solid Waste Management
Deep Wells
Public Water Distribution
Native Species Conservation and restoration
Restoration of Breeding Habitats for Fish
Support Micro credit Initiatives
Processing Facilities for Rice and Fish
Development of Rice Cultivation

Human Health vs. Ecosystem Health
Ecosystem Health
Human Health
1,6
1,5
1,4
1,3
1,2
1,1
1,0
0,9
0,8
0,7
0,6
0,8
1,0
1,2
1,4
1,6
1,8
2,0
Actual State
Improved Latrines
Sewerage
Solid Waste Management
Deep Wells
Public Water Distribution
Native Species Conservation and restoration
Restoration of Breeding Habitats for Fish
Eliminate Breeding Habitats for Disease Vectors
Support Micro credit Initiatives
Processing Facilities for Rice and Fish
Development of Rice Cultivation

### 8.3.2 Implicit Trade-Offs (= Trade-Offs Between Stakeholder Groups)

Stakeholders were asked to allocate weights to different 'principles' (individually). Two workshops have been done in Mopti and one in Macina. Besides numerous experts have been interviewed and consulted regularly. Based on these principles, indicators have been developed in an iterative process in indicator development.

However, the box-plots below (Figure 8.12) illustrate the distribution of the attributed weights by the stakeholders for each principle. It can be noted that the principles judged most important by the stakeholders are the ones with a direct impact on their lives, mainly health and water quality & sanitation, and in third instance food provisioning. The principles hydrology, biodiversity and policy & institutions clearly receive less weight.

Based on what we concluded earlier, namely that: **A1.2 Sewerage** (focus on Human Health) or **A3.1 Native species conservation and restoration** (focus on Ecosystem Health and Socio-Economic Development) is the theoretical best option, depending on which category is judged to be most important, it can be stated that option **A1.2 Sewerage** will probably be judged as more important by the stakeholders because of its good performance on health and water quality & sanitation.

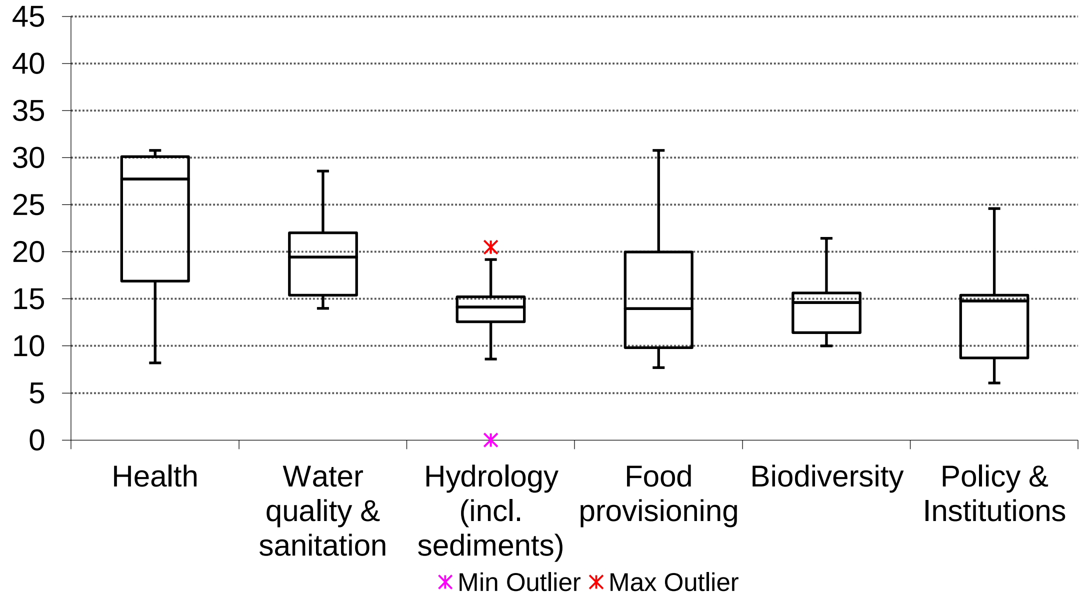



**Figure 8.12** Stakeholder weights by criteria category, as given in Mopti based on the pebble method (where stakeholders are asked to distribute 100 pebbles between the different categories).

When looking at the individual priorities rather than the average ones, water quality and sanitation score well, but less than ¼ of stakeholders considered prioritized them. Also relevant is that none of the stakeholders find the latter as less important. The average score for hydrology, policy and institutions and biodiversity is moderate and only 1-2 stakeholders prioritized these criteria. Policy and institutions are furthermore considered less important by a ¼ of stakeholders.

The scoring of indicators was similar to the criteria scores, but provided more detail as shown in Figure 8.13. Stakeholders were asked to score the importance of indicators as very important, important or less important. Stakeholders see the indicators with a direct impact on their life as most important (e.g. diseases, drinking water, food production). Malaria is considered as the priority disease by more than ¾ of the stakeholders even though the malaria parasite rate in Mopti is moderate. Diarrhoea is considered very important by half of the stakeholders whereas schistosomiasis is less important. The stated importance for malaria and diarrhoea however is contradiction with the low importance for management of the breeding habitats, i.e. stagnant water and water quality. Despite the lack of sanitation and obvious discomfort for people, sanitation is not considered as a priority. Especially health institutes saw access to sanitation, water quality and stagnant water as less important. On the contrary, Sanitation and water quality was very important for the local authorities, NGOs and the ministry for environment and sanitation. The apparent lack of interest for sanitation can be explained by the fact that the drivers and pathways behind disease transmission are not perceived as important as is demonstrated by the low importance of water quality of the wetland and stagnant water. Stagnant water was an acknowledged bottleneck for agriculture, but not in urban environment where the water is also highly polluted. The better access to safe groundwater is scored as very important although the availability of groundwater is made available in Mopti.

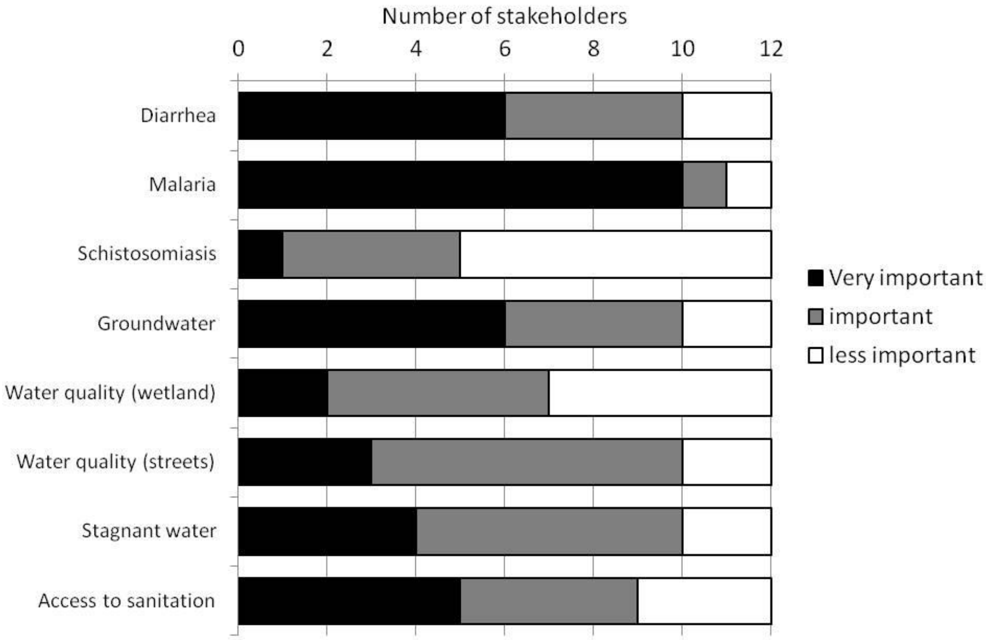



**Figure 8.13:** stakeholder weights by indicator

### 8.3.3 Best Compromise Option

The trade-off analysis performed as part of the MCA confirms our conclusion on theoretical best option. Namely that the options **A1.2 Sewerage** and **A3.1 Native Species Conservation and Restoration** seem to be the most interesting options respectively to improve sanitation and ecosystem and livelihood. The explicit trade-off analysis confirmed the above conclusion. The implicit trade-off based on stakeholder preferences indicated that **A1.2 Sewerage** is more important.

## 8.4 Impact of scenarios – vulnerability and robustness

| Vulnerability = f(External Impact, Adaptive Capacity) |
|---|
| **$\Delta V = EI + AC$**<br>**(-> Change in Vulnerability = External Impact + Adaptive Capacity)** |
| **$EI = State_{(BAU)} – State_{(Current)}$** |
| **$AC = State_{(mgt)} – State_{(BAU)}$** |

### 8.4.1 External Impact (Defining BAU scenario)

External conditions impacting on the water flows and social-ecological system of the Inner Niger Delta include:

- Climate change and variability
- Water demand in the upstream catchment
- Population growth
- Water- and vector borne diseases

Water demand and management (including infrastructure) in the upstream catchment are considered here as external conditions, since there is no direct way for local stakeholders to influence upstream development, and the prevailing water regime is, in effect, an imposed external condition.

In the IND-case study, five business as usual (BAU) scenario's were defined. These BAU scenario's indicate the expected evolution of actual state in the future.

- BAU Climate Change 0°C
- BAU Climate Change 1°C
- Upstream Flow Regulation, priority for energy production (FR energy)
- Upstream Flow Regulation, priority for irrigation in Office du Niger (FR Office du Niger)
- Upstream Flow Regulation, priority for minimum flow Inner Niger Delta (FR min flow IND)

For each BAU scenario, all indicators were given a score for expected change, based on a qualitative assessment, by expert judgment. Figure 9.X illustrates the expected external impact for each category, under five different BAU scenario's (using the formula: EI = state BAU – state current). All scenarios, with exception of BAU minimum flow for IND, will have a negative impact on evaluation categories. Ecosystem health and socio-economic development are expected to be affected seriously. The minimum flow scenarios is the only one that is expected to change the IND positively. For the other scenarios, the External Impact is negative and needs to be compensated by means of management options, if the IND is to be kept at the current or improved conditions.

The category that is most exposed to external impact, for all projected scenario's, seems to be ecosystem health. Especially the four indicators on habitat (Bourgou, flooded forests, fish and bird habitats) are affected seriously, because these indicators are highly sensitive to the project changes in flow. Considering that socio-economic development in the IND is depending on the provided ecosystem services, socio-economic development is likewise affected considerably (especially because of the impact on the indicators regarding provisioning services from ecosystems, natural resources and availability of clean drinking water). On the other hand, the category human health seems largely unaffected by external impacts. Only the indicators malnutrition (linked to food production) and malaria (linked to stagnant water) are impacted. Moreover, all scenario's indicate the same trend, namely the more water quantity decreases in wet season, the more negative the impact will be, and the other way around.

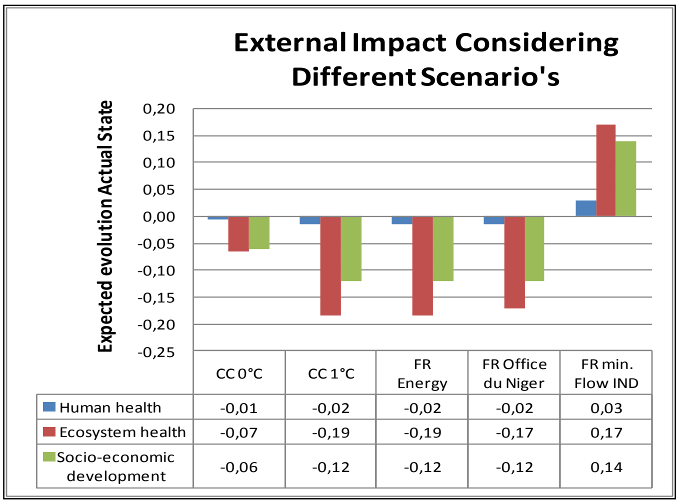



**Figure 8.14**: Calculated external impact of scenarios

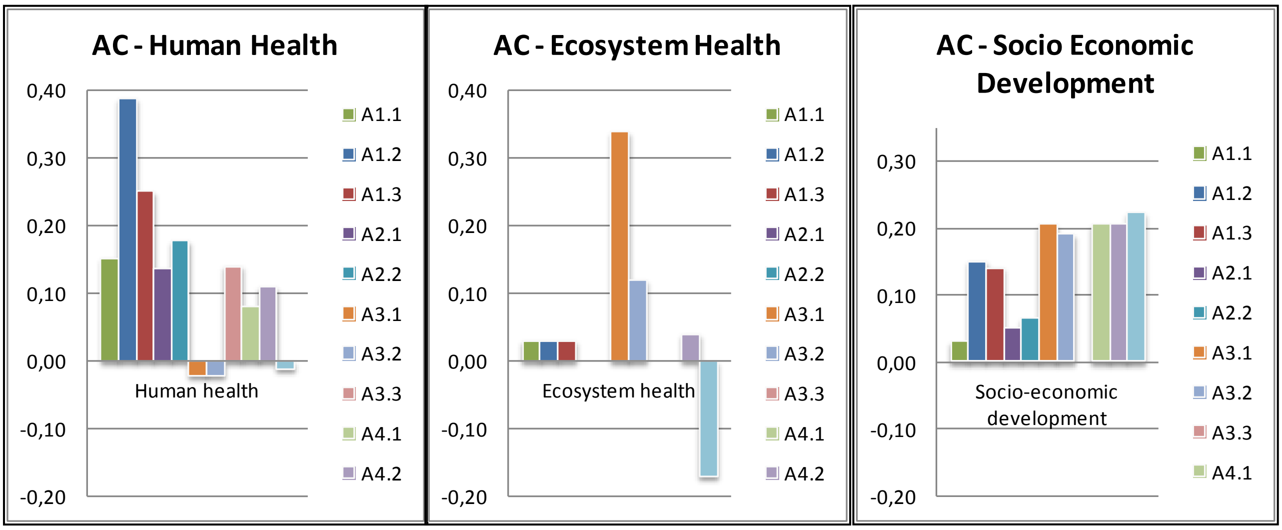



**Figure 8.15**: Calculated adaptive capacity

| *Scenario* | *(ΔV) Overall Change in Vulnerability* | | | | | |
|---|---|---|---|---|---|---|
| | *Top3 best* | | | *Top3 worst* | | |
| BAU CC 0°C | A1.2 | A3.1 | A1.3 | A2.1 | A3.3 | A4.3 |
| | 0,44 | 0,39 | 0,29 | 0,06 | 0,01 | -0,09 |
| BAU CC 1°C | A1.2 | A3.1 | A1.3 | A2.1 | A3.3 | A4.3 |
| | 0,25 | 0,20 | 0,10 | -0,13 | -0,18 | -0,28 |
| BAU FR Energy | A1.2 | A3.1 | A1.3 | A2.1 | A3.3 | A4.3 |
| | 0,25 | 0,20 | 0,10 | -0,13 | -0,18 | -0,28 |
| BAU FR Office du Niger | A1.2 | A3.1 | A1.3 | A2.1 | A3.3 | A4.3 |
| | 0,26 | 0,22 | 0,12 | -0,12 | -0,16 | -0,26 |
| BAU FR min. Flow IND | A1.2 | A3.1 | A1.3 | A2.1 | A3.3 | A4.3 |
| | 0,91 | 0,86 | 0,76 | 0,53 | 0,48 | 0,38 |

**Figure 8.16** Calculated vulnerability scores

### 8.4.2 Adaptive Capacity

Adaptive capacity is the capacity of a socio-ecological system to cope with external and internal impacts and to implement measures to mitigate negative effects in order to ensure sustainability. In this regard, the socio-ecological system of the Inner Niger Delta has to combat negative effects of climate change and variability and water management in the upstream basin. Potential measures to mitigate these negative effects can be considered as indicators of adaptive capacity.

Figure 8.15 illustrates the adaptive capacity of all the management options, on each category. This is the ability of the management options to affect these categories positively (or in some cases negatively). To calculate adaptive capacity, the following formula is used: AC = state management – state BAU.

It is no surprise that the first options (sanitation and drinking water) are best in affecting the human health situation, the ecosystem options best in positively affecting ecosystem health (all other options only have a small or even negative impact), and the livelihood options best in improving socio economic development. Most important is the combination of the adaptive capacity scores with the external impact scores. Categories that encounter a higher negative impact, will also have a higher need for adaptation. Adaptive capacity and external impact are combined in the concept of 'vulnerability'.

### 8.4.3 Vulnerability

The combination of external impact and adaptive capacity (both for each category, and depending on the scenario) gives us a score on vulnerability ($\Delta V$ = change in vulnerability). A positive score means that the option will decrease overall vulnerability, and in reverse, a negative score means that the option will increase overall vulnerability. An overall ranking of the change in vulnerability (table below) indicates that, although the values of EI and AC vary, the same top 3 appears compared to our previous ranking of options.

These results should indicate that our top 3 options are expected to be most robust for changes in the future. Yet, the results need to be interpreted with care taking into account the applied methodology and associated weaknesses. The weaknesses are following: Adaptive capacity is calculated by the following formula: AC = state management – state BAU. This means that adaptive capacity is directly linked to the impact scores that determined the initial ranking of options (= state management). Because of this reason it is no surprise that the same top 3 appears. Another weaknesses is linked to the inevitable need to simplify reality by trying to quantify it. External impact is identified for each indicator and category, but does not take into account potential mitigation linked with implementation of certain management options (EI is always the same, not differentiating between the different options). And also for adaptive capacity, it is not taken into account that the impact scores can possibly change depending on the scenario (state management is always the same, not differentiating between scenario's). A third shortage is that the five scenario's only comprise changes in the flow regime, and not population growth, change in wealth, or other factors.

### 8.4.4 Conclusion – Robustness of Options:

The extent of the expected impact of our previous top3 options will change depending on the scenario that is assumed. However, for each scenario the adaptive capacity of options **A1.2 Sewerage**, **A3.1 Native species conservation and restoration**, and **A1.3 solid waste management** stays always positive. Thus, these options are expected to be robust under different scenarios of climate change and upstream flow regulation. The results need to be interpreted with care.

## 8.5 Sensitivity analysis

In section 8.2.1 on '*Ranking of Options*', weight sets were differentiated (including extreme weight sets, focussing for 50% on one of the categories). This analysis showed that the overall ranking did not change considerably. This indicates that the results presented in this report are not sensitive to minor changes.

## 8.6 Results of stakeholder consultations

No ex-post stakeholder consultation was carried out. Results from an ex-ante stakeholder workshop were presented in part 8.2.2 on '*Trade-off analysis*'

## 8.7 Summary and recommendations

In the Inner Niger Delta, livelihoods and ecological health are related to the availability of water, which is influenced by both climate variability and dams in upstream regions. Although these aspects on larger scale are very important, the proposed management options for this analysis only focus on interventions that can be implemented locally. Aspects related to the flow regime are considered as externally imposed conditions. Projections of climate change in the region indicate rising temperature and decreasing rainfall, with a significant decrease in flows to the IND (peak flows could fall to 50% of current levels). Construction of upstream dams (Selingue, Markala) will further reduce wet season flows (although dry season flows may increase). The consequences of these flow regime scenarios (both from climate change and upstream dams) will have devastating consequences for the local communities living in the IND, as well as for biodiversity. Population growth, with concomitant increase in food requirements, will further exacerbate water shortages and upstream irrigation demand.

The study considered 11 management options that can be implemented on local scale. The local entity chosen to assess the performance and feasibility of these management options is Mopti, a city located in the middle of the Inner Niger Delta confronted with severe problems related to water quality (both sanitation and drinking water provisioning) and livelihood and ecosystem degradation. Outcomes were assessed on the basis of criteria relating to Human health, Ecosystem health and Socio-Economic development (impact categories), and Affordability/Costs and Planning (feasibility categories). Scores were assigned using expert judgement.

Based on highest overall scores, the top ranking options are **A1.2 Sewerage** and **A3.1 Native Species Conservation and Restoration**. Depending on expressed priorities for specific critiera, the theoretical best option is A1.2 (focus on Human Health) or A3.1 (focus on Ecosystem Health and Socio-Economic Development). The identified options are robust under scenarios of climate change and upstream flow regulation. Note that most options can be implemented together, at least if (financial) resources are available and enabling conditions regarding to planning are met. From this perspective the ranking of options is more like a priority list. All selected management options are deemed to be important and need to be implemented. The fact that improved latrines do not appear as a top measure does not imply that they are not important, only that latrines have few impacts on categories other than health.

# 9 Abras de Mantequilla

## 9.1 Decision space

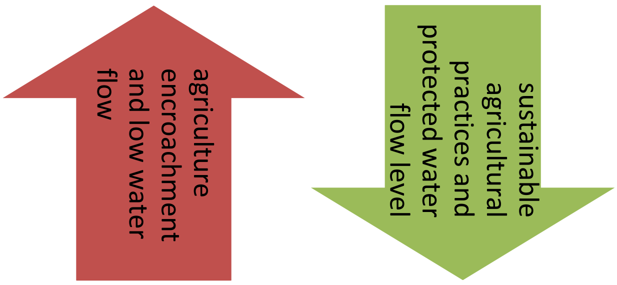
### 9.1.1 Management solutions

Proposed management solutions were formulated as progressively more comprehensive packages of options relating to sustainable land management, in combination with improved agricultural practices. Increased water retention through operation of hydraulic gates was included as a component of all management solutions.

- O1: Increase water retention in AdM through hydraulic gates.
- O2: Implementation of an agricultural practices improvement plan (prohibition of red and yellow label pesticide use, compost elaboration, crop waste management, etc.)
- O3: Land use change scheme at 10% rate per decade (short-term crops to perennial agroforestry)
- O4: Land use change scheme at 20% rate per decade (short-term crops to perennial agroforestry).
- O5: Natural vegetation expansion through ecological corridors at 5% LUC per decade.

More details about the options can be found in Villa-Cox et al (2011) (fact sheet in Spanish) and in WETwin D7.2 (Johnston and Mahieu 2012).

S0 – BAU
S1 – O1 + O2
S2 – O1 + O2 + O3
S3 – O1 + O2 + O4
S4 – O1 + O2 + O3 + O5
S5 – O1 + O2 + O4 + O5




### 9.1.2 Indicators and criteria

Nineteen indicators in seven criteria categories were used to evaluated management solutions for AdM. Two quantitative hydrological indicators (water quantity and quality) were assessed using the WEAP model. All other indicator were scored qualitatively using expert judgment by a panel of local stakeholders.

All socio-economic and institutional indicators (qualitative) were scored in a centered Lickert scale from 1 (worst) to 5 (best). The actual meaning of each scale value depends on the specific indicator. Indicators have been grouped in criteria categories to help in the trade-offs analysis and summarized the main description idea brought by the indicators' scoring.

Because it was hard to grasp the concept of value function by the stakeholders, for qualitative indicators various alternatives of values functions were presented to the AdM Commonwealth of Municipalities and one was selected by them. They considered 4 different types of value functions as extreme cases of assessment of MS impact over each of the assessed criteria. Each value function was qualitatively described to the Technical Secretariat of the AdM Commonwealth of Municipalities, who chose the *potential value function* as adequate to normalize the impact of MS on the elicitated criteria. All quantitative indicators have specific value functions for each case.

| CRITERIA | INDICATORS | Abbreviations |
|---|---|---|
| Agriculture costs | Crop maintenance cost per Ha<br>Crop sowing/investment cost per Ha | crop_acost<br>crop_scost |
| Production / extraction of natural resources | Crop productivity per Ha<br>Local populace income level<br>Food safety for local populace | crop_prod<br>income_lev<br>food_safe |
| Regulation of the water flow | Water quantity<br>Water navigability of the wetland | wrt_qty<br>wtr_naveg |
| Regulation of the water quality and carbon storage capacity | Water quality<br>Eutrophication indicator (measured by the presence of water hyacinths)<br>Sediment and nutrient contribution of land use | wtr_qlt<br>eutroph<br>sed_nutr |
| Biodiversity and ecology | Degradation of natural habitat<br>Biodiversity indicator | degrad<br>biodiver |
| Cultural significance | Economic association potential of local stakeholders<br>Level of environmental conscience and education of local populace<br>Touristic potential of AdM | econ_asoc<br>envir_educ<br>touris_pot |
| Institutional and stakeholders' capacity requirements | Budget adequacy to undertake MS<br>Local stakeholder capacity<br>Local management structure capacity (municipalities, NGOs, etc)<br>Regional/national management structure capacity to coordinate action and support initiatives | budget<br>stak_capac<br>lcmgt_cap<br>rgmgt_cap |

### 9.1.3 Scenarios

In the way the AdM case study has been conceptualized the scenarios and management solutions are wrapped together. Solution 0 (S0) is BAU under an assumed set of climate, population and infrastructure conditions. No other scenarios will be considered since the system is not sensitive for indicators (such as stakeholder & institutional capacity, tourist potential, etc. qualitative indicators mostly) if we try to dimension more than one scenario.

The BAU scenario includes the combined effect of the following external drivers:

- *Climate change trends:* +0.5 degree scenario (temperature & precipitation)
- *Population trends:* Rural population growth and basin scale agricultural productivity trends.
- *Infrastructure works*: Impacts in water quality and quantity of various national priority infrastructures works (Dauvin, and Baba projects).

Considering a time span of 40 years (2002-2043), the first two decades do not show significant variations in flow magnitudes whereas the third one sees an increment of 10 to 20% for flows in Chojampe River. Finally, the decade 2031-2040 registers a higher growing tendency, 24 to 40% more water than current conditions.

| indicator | 2002-2010 | 2011-2020 | 2021-2030 | 2031-2040 |
|---|---|---|---|---|
| baba_diver | 30 | 30 | 30 | 30 |
| dauv_diver | 0 | 0 | 0 | 0 |
| precip_tr | 4.5 | 5.3 | 7.3 | 6.0 |
| temp_tr | 26.1 | 26.1 | 26.3 | 26.2 |

Construction and operation of upstream infrastructure is planned in the coming years by the National Secretariat of Water (SENAGUA). Water transfer projects are planned for upstream (Daule Peripa to

La Esperanza, from the proposed Baba Dam) and downstream from the Chongon project (Daule River to Santa Elena peninsula) and Dauvin project (Daule to Vinces and Nuevo River). These future transfer projects will potentially sum to a 30% average reduction of inflows to the AdM system (see further details in the fact_sheet).

The Baba project, planned for completion in 2012, has various aims: irrigation, hydro-electrical energy generation, flood control and water transfer to the Presa Daule-Peripa. The dam, at the junction of the rivers Baba and Toachi, has total capacity of 93 $m^3$ and will supply Daule Peripa with a maximum flow of 243 m3/s through the river Chaune. With this project of retention and water transfers, 40% reduction in flow volume is expected downstream in the Vinces River. However Efficacitas (2006) concluded that a minimum ecological flow of 10 m3/s would secure not only the navigability but also the sustainability of fish and aquatic species. Such a criterion could be extended to the Abras de Mantequilla wetland.

Although the Baba project reduces flow volumes of water in the upstream course of river Vinces, it does not affect the downstream course, which include the river Nuevo and the wetlands in AdM, since outflows from the Lulu and San Pablo Rivers make up the deficiency occasioned by the dam. However, if rainfall decreases with climate change, shortages could occur in the lower reaches.

The DAUVIN diversion will provide irrigation to an extended zone between the rivers Daule, Vinces and Puebloviejo. It will also improve conditions for fish breeding in area currently prone to inundation in the rainy season and drought between May and December. It will transfer 93m3/s from Daule and to the San Vicente, El Diablo, Macul, Nuevo, Puebloviejo and Colorado, rivers. It has negligible impact on the AdM wetlands.

## 9.2 Rankings from MCA

### 9.2.1 Ranking by mDSS considering stakeholders' priorities

Proposed management solutions were ranked by combining scores for all criteria, weighted according to preferences for three different stakeholder groups: local wetland users considering only current priorities; local wetland users taking into consideration future concerns; and the AdM Commonwealth of Municipalities. A simple additive weighting approach was applied. Scores were normalized using either a simple linear function, or a potential value function, as described in section 6.1.2 above.

| *Choice option* | ***Value functions*** | *Weights' set* | *Solutions order (best →worst)* | | | | | |
|---|---|---|---|---|---|---|---|---|
| SAW | **Simple linear normalization** | users current | S4 | S3 | S5 | S2 | S1 | S0 |
| | | | 100 | 95 | 87 | 84 | 72 | 43 |
| | | users future | S5 | S4 | S3 | S2 | S1 | S0 |
| | | | 100 | 93 | 59 | 47 | 35 | 13 |
| | | AdM municipality | S5 | S4 | S3 | S2 | S1 | S0 |
| | | | 100 | 96 | 84 | 72 | 56 | 27 |
| | **Normalization using potential value function** | users current | S4 | S5 | S3 | S2 | S1 | S0 |
| | | | 100 | 99 | 97 | 94 | 92 | 87 |
| | | users future | S5 | S4 | S3 | S2 | S1 | S0 |
| | | | 100 | 95 | 81 | 78 | 76 | 71 |
| | | AdM municipality | S5 | S4 | S3 | S2 | S1 | S0 |
| | | | 100 | 96 | 92 | 87 | 83 | 78 |

It is apparent from the table that changing the value function set does not result in major changes in scores and ranking, but there is some variation with different weights:

- with the *current users* weights only the 2nd and 3rd solutions change position and score.
- with the *future users* and *AdM municipality* weights the rankings of solutions stay the same whatever the set of value functions chose is but the scores are different, using larger range of score and widening the gap between solutions' scores in the case of linear normalization.

The current priorities of local stakeholders' and AdM municipality do not match; but taking into account future concerns, the two converge to the so that priorities are in line with the policy directions of AdM municipalities.

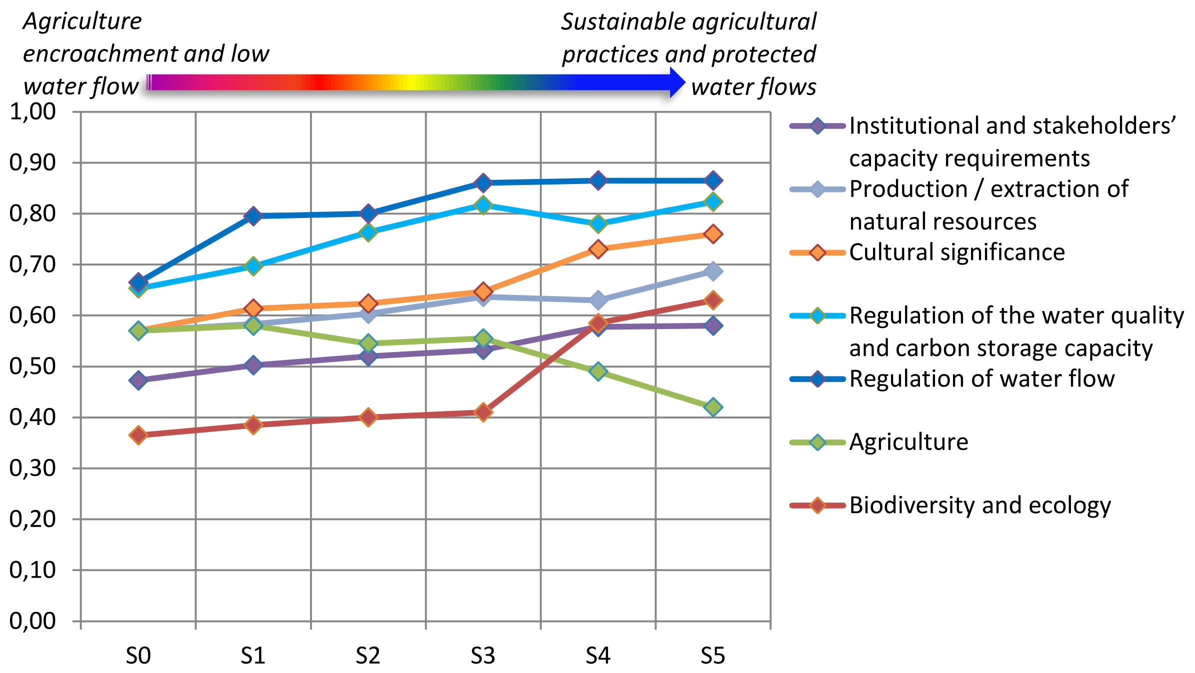
### 9.2.2 Trade-offs

Drivers of change identified for the wetland include population growth, urbanization, energy production (hydropower existing and planned upstream), river regulation (multipurpose dams and water transfer projects upstream) (see Zsuffa et al 2010). The pressures resulting from these drivers include change in water quality (agrochemicals in surface water), pollution due to poor solid waste management, agricultural encroachment in the wetlands, and decline of the fishery. These in turn impact on biodiversity, navigability, access to water and food production.

| Drivers and Pressure | | Impacts on Ecosystem services |
|---|---|---|
| **Agriculture and urban development** | → | Biodiversity<br>Navigability (dev. hyacinths and eutrophication)<br>Water quality (water born diseases) |
| **Basin scale river management projects and water allocation projects** | → | Biodiversity<br>Navigability (dev. hyacinths and eutrophication)<br>Water access (irrigation and drinking)<br>Food production (agriculture fisheries) |

The idea here is to see how the criteria or indicators evolve compare to each other with the alternative options. Especially we will look at how the indicators and criteria respond to an evolution of land use toward sustainable agricultural practices including also the protection AdM's socio-ecological water flow levels. From that we will derive trade-offs between ecosystem services.

We could directly look at the way the criteria scores respond to management options, without looking in details by indicators: it is a short and clear method to reach main trade-offs but it makes a short cut in the ToA and could hide some trade-offs between indicators of the same criteria. In our case there are 19 indicators for 7 categories (see B. 1.1.3) so the number of indicators is still manageable: therefore we will first look at the criteria to identify trade-offs and then we can refine the ToA analysis using indicators. The criteria scores are calculated as average of the indicator scores belonging to each criterion.



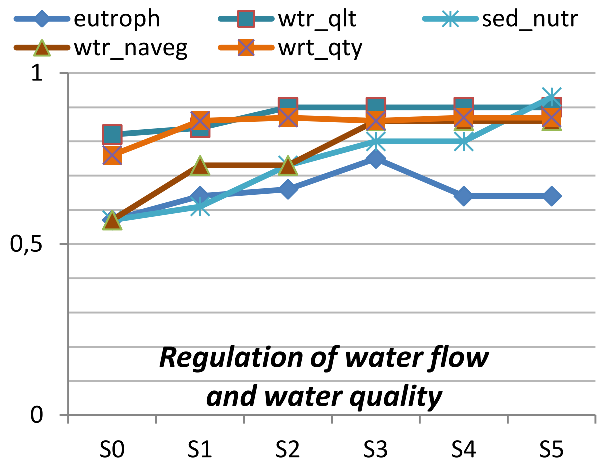

Two major steps come out of this previous graphic:

- First step is the transition from S1 to S2 or S3: that is, addition of options relating to LUC. S 2 and S3 present similar results compare to S1 (only that S3 presents a bit higher scores) and reveals a trade-off between decreasing agricultural score and an increasing trend for the rest of the indicators especially the indicators related to the regulation of water quality and water flow.
- Second step happens with the transition from S3 to S4 or S5: that is, addition of the ecological corridor. The first trade-off identified still remain and is accentuated while a second trade-off is apparent between a decreasing regulation of water quality function and a jump in biodiversity conservation function score.

From the level of each criteria and their ranking compare to each other, roughly we can see that:

- Score for biodiversity conservation has increased, while that for agriculture has lost as much
- Score for cultural significance has increased, especially compared to the production and extraction of natural resources criteria, which was at the same level in S0 case.

Let us now have a look in depth at the following graphics representing the indicators' scores per solution grouped per criteria. It will help us to confirm or refine previous statements about trade-offs.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wtr_qlt
sed_nutr
wtr_naveg
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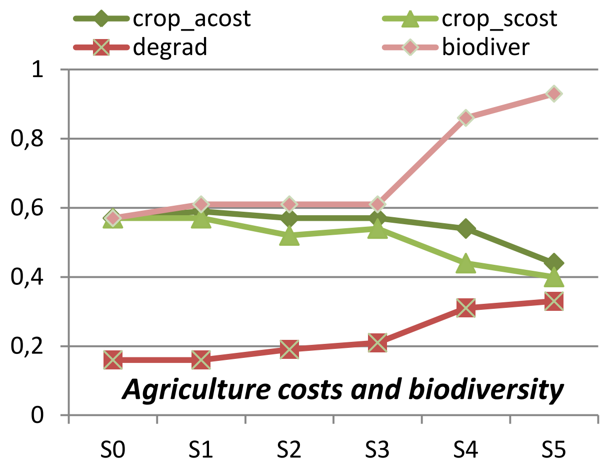
S5
Regulation of water flow
and water quality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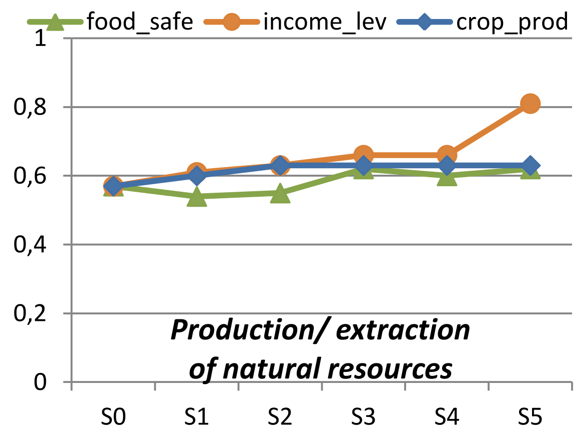
S4
S5
Agriculture costs and biodiversity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income_lev
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S1
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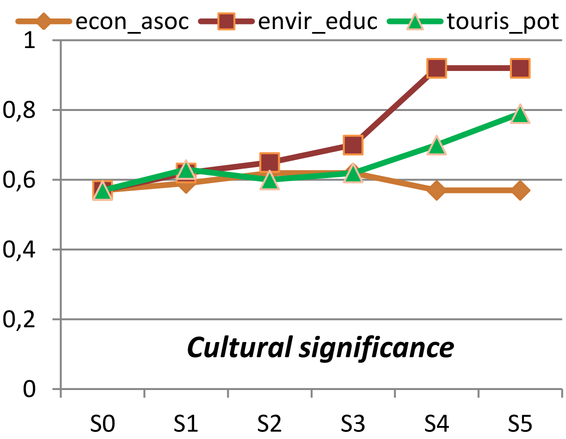
S5
Production/ extraction
of natural resources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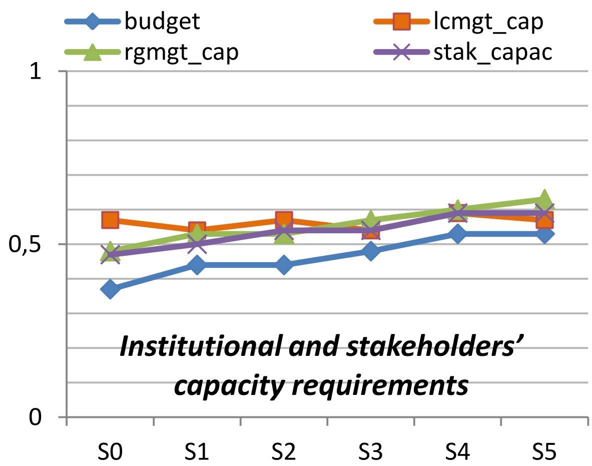
Cultural significance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stak_capac
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0,5
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S0
S1
S2
S3
S4
S5
Institutional and stakeholders'
capacity requirements

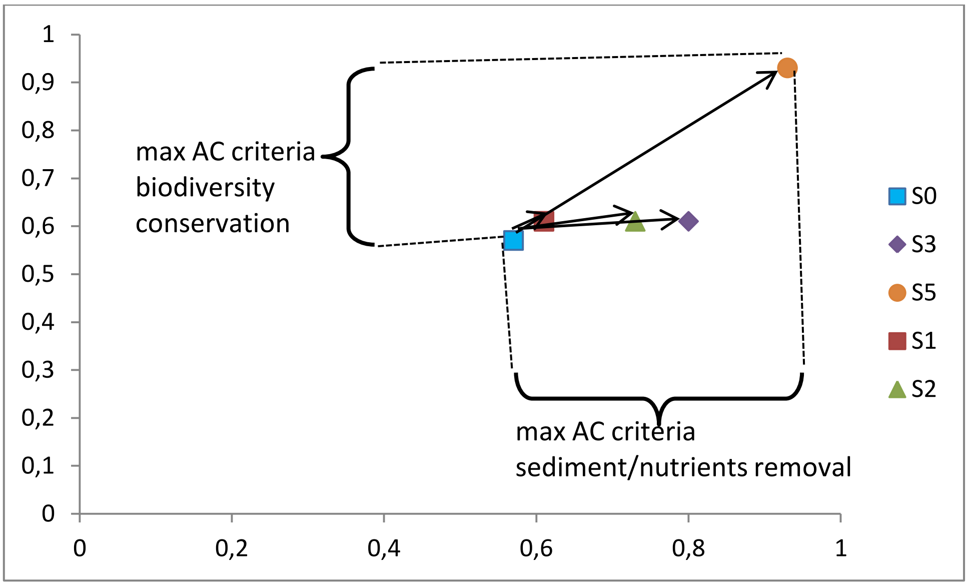
*Trade-off analysis between wetland's function and eco-services*

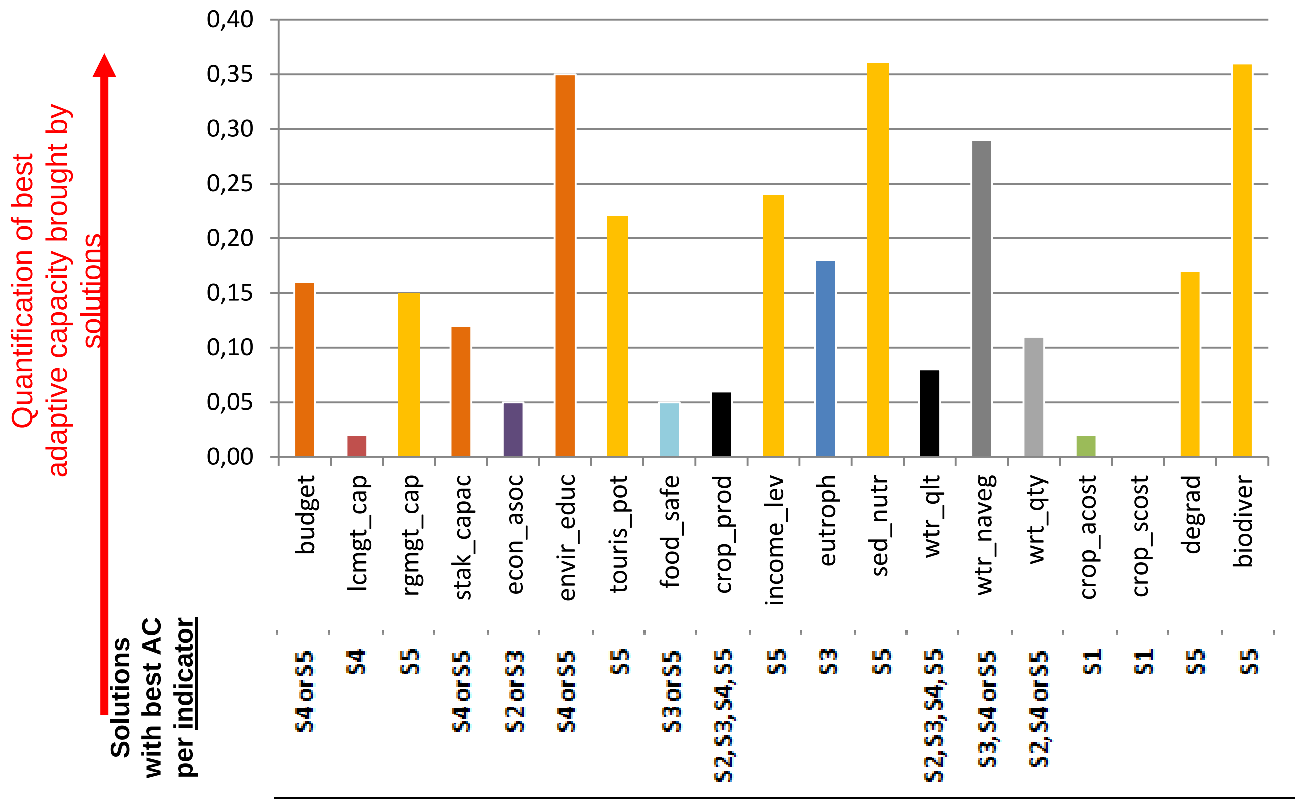
In implementing the management solutions, trade-offs between different criteria emerge only with the implementation of O5 (ecological corridors) in S4 and S5. The clearest trade-off is between agricultural costs and biodiversity conservation. While agricultural costs increase significantly, agricultural production does not vary. Thus the real trade-off is between the production costs and biodiversity and habitat conservation: actual production remains stable. The cultural significance, through the educational and tourist potential, depends on the biodiversity conservation, hence a second trade-off is seen between agricultural production costs and the cultural enhancement of the wetland. The improvement in sediment and nutrient scores are consistent with the notion of sustainable nutrient use and erosion control required by the options (especially O2 and O5), so a last trade-off between agricultural costs and sediment and nutrients control is to be enhanced.

The graphs above also indicate a relationship between *Institutional and stakeholders' capacity; and biodiversity conservation; cultural significance;and production and extraction of natural resources.* . Although the range of variation is small, the trend is an increase with additional options implementation. This indicates, not a trade-off, but a precondition for successful implementation - the institutional and individual capacity required are higher.

| **Trade-offs between wetland's function and eco-services**<br>identified through solutions and indicators evaluation (no stakeholders' weights) | | |
|---|---|---|
| Agriculture production's costs | ←→ | Biodiversity and habitats conservation<br>Cultural significance (touristic potential, environmental education)<br>Sediments and nutrients control |
| Institutional strengthening | ←→ | Cultural significance<br>Production and extraction of natural resources<br>Biodiversity conservation |

## 9.3 Vulnerability analysis




Quantification of best adaptive capacity brought by solutions
Solutions with best AC per indicator
0,40
0,35
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budget
lcmgt_cap
rgmgt_cap
stak_capac
econ_asoc
envir_educ
touris_pot
food_safe
crop_prod
income_lev
eutroph
sed_nutr
wtr_qlt
wtr_naveg
wrt_qty
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crop_scost
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biodiver
S4 or S5
S4
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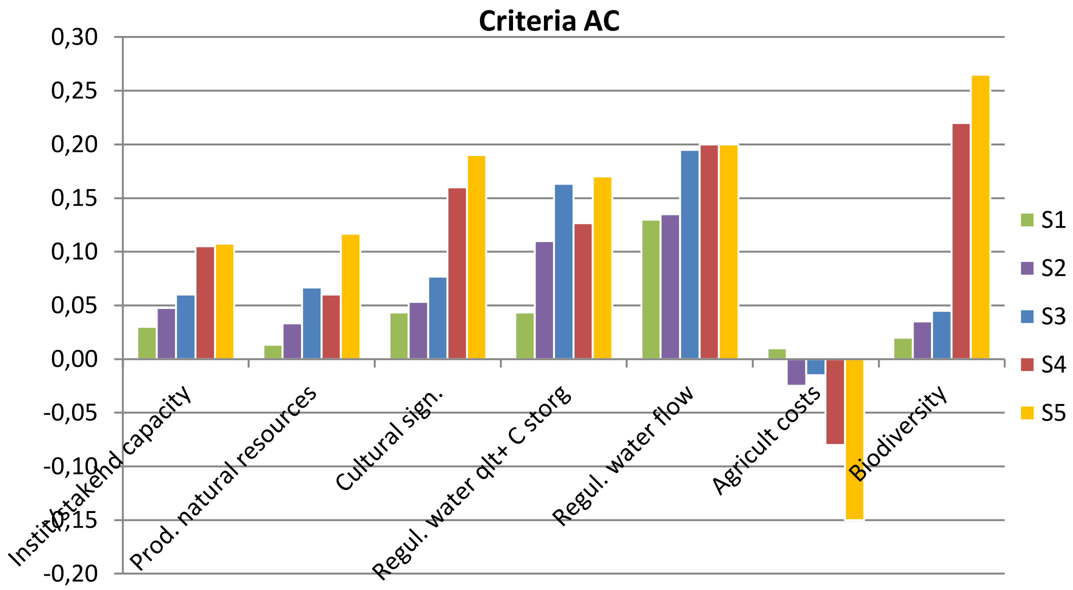
Criteria AC
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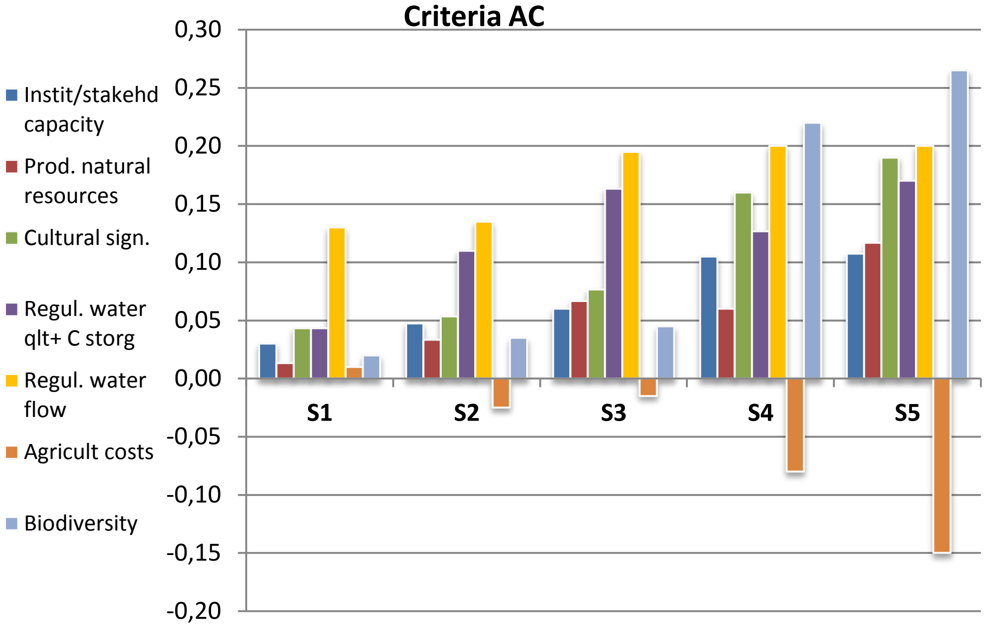
-0,20
Instit/stakehd capacity
Prod. natural resources
Cultural sign.
Regul. water qlt+ C storg
Regul. water flow
Agricult costs
Biodiversity
S1
S2
S3
S4
S5

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## 9.4 Sensitivity analysis

The sensitivity analysis concentrates on the sensitivity of the solutions' ranking to a change of weight in criteria. Sensitivity analysis was carried out for the case of simple normalized value functions' implementation. Since the solutions' ranking is different depending on the set of weights chosen, three sensitivity analyses can be considered:

| *Weights' set* | *Best solutions* | *Importance of indicators on the solutions ranking (presented in order of ranking influence for the 6 first indicators):* |
|---|---|---|
| **Users current** | S4 vs S3 | econ_asoc > lcmgt_cap > crop_scosts > biodiv > degrade > stake_cap |
| **Users future** | S5 vs S4 | crop_acost > lcmgt_cap > crop_scost > incom_lev > rgmgt_cap > sed_nutr |
| **Adm munic current** | S5 vs S4 | crop_acost > lcmgt_cap > crop_scost > incom_lev > rgmgt_cap > sed_nutr |

The AdM municipality's views on agricultural production's costs, management capacity, income level and to a lesser extent, the sediment and nutrient loads in water are determinative for the choice between S5 and S4. On the other side the stakeholders' views are sensitive to agricultural production's costs and local management capacity but also to biodiversity conservation and local stakeholders and economic associations' capacity. So the present trade-offs may be emphasized between **biodiversity conservation, agricultural production, allocation of management capacity and economic association potential**. In the future if the municipality maintains its planned policy views, the trade-offs may tone down.

These findings are coherent with the previous trade-offs identified without stakeholders' preferences consideration, which could be interpreted as the stakeholders are well aware of natural trade-offs between ecosystem services and wetlands' functions and therefore their contribution in the analysis is very reliable and essential.

## 9.5 Summary and recommendations

In Abras de Mantequilla, proposed management solutions were formulated as progressively more comprehensive packages of options relating to sustainable land management, in combination with improved agricultural practices. Increased water retention through operation of hydraulic gates was included as a component of all management solutions, as a response to upstream development. Nineteen indicators in seven criteria categories were used to evaluated management solutions for AdM. Two quantitative hydrological indicators (water quantity and quality) were assessed using the WEAP model. All other indicator were scored qualitatively using expert judgment by a panel of local stakeholders. In the way the AdM case study has been conceptualized the scenarios and management solutions are wrapped together. Solution 0 (S0) is BAU under an assumed set of climate, population and infrastructure conditions. No other scenarios were considered.

Proposed management solutions were ranked by combining scores for all criteria, weighted according to preferences for three different stakeholder groups: local wetland users considering only current priorities; local wetland users taking into consideration future concerns; and the AdM Commonwealth of Municipalities. The current priorities of local stakeholders' and AdM municipality do not match; but taking into account future concerns, the two converge to the so that priorities are in line with the policy directions of AdM municipalities. The more comprehensive solutions (S4 and S5, which combine improved agricultural practices with conversion of crops to agroforestry) were preferred in all cases. The current priorities of local stakeholders' and AdM municipality do not match; but taking into account future concerns, the two converge to the so that priorities are in line with the policy directions of AdM municipalities.

In implementing the management solutions, trade-offs between different criteria emerge only with the implementation of O5 (ecological corridors) in S4 and S5. The clearest trade-off is between agricultural costs and biodiversity conservation. While agricultural costs increase significantly, agricultural production does not vary. Thus the real trade-off is between the production costs and biodiversity and habitat conservation: actual production remains stable.

# 10 Lobau

Results for identification of best-compromise management solutions for the Lobau wetland are described in detail in Sanon (2010) and are not repeated here; the abstract of the thesis is reproduced below.

*Wetland ecosystems provide multiple functions and services of importance for human well being. Planning and decision making of wetland ecosystems inevitably involve conflicting objectives, trade-offs, uncertainties and conflicting value judgments. Compromises between the stakeholder objectives and values are the only possible sustainable outcome of such a conflict. Multi criteria decision analysis framework provides methods and steps to identify the conflict and trade-offs so that decision making can become more informed and transparent. This study implements trade-off and multi criteria decision analyses on alternative development options created for the restoration of the Lobau floodplain in Austria. The tool applied for these analyses is the mDSS4 software. The approach is a WETwin project approach to evaluate the mDSS4 as a tool to support and make trade- off analysis and to find a best compromised option. Stakeholder objectives were identified by reviewing the WETwin project documents. The 31 management options (6 hydraulic for 5 use- scenarios including the current status) and 75 indicators were identified in the Optima Lobau project. The purpose of the hydraulic options was to develop a hydraulic gradient ranging from complete isolation and full re-connection of the Lobau floodplain with the Danube River channel. The five use-scenarios included (1) dominant ecological development, (2) dominant drinking water production, (3) dominant recreation, (4) dominant agriculture, and (5) dominant fishery. Further development of cost and flood reduction criteria was done is this research. Nine decision maker types were identified in the Optima Lobau project based on their preferences on the management criteria. Trade-off analysis revealed the major trade-offs to be between the criteria that scored higher for the increased hydraulic connectivity options and the criteria that scored higher for the lower hydraulic connectivity options. The criteria that scored high for the increased hydraulic connectivity options include development of aquatic habitats, potential flood reduction and potential fishery. The criteria that scored low under increased hydraulic connectivity options include the ecological conditions of the terrestrial habitats, potential drinking water and the potential cost reduction. The major trade-offs were calculated as the shortest distance to the ideal solution between two criteria. No management options dominated according to all criteria. According to the multi criteria decision analysis, the hydraulic option that increases the water input from the upper part of the Lobau floodplain with restriction of socio-economic utilization to sustainable fishery seems to be the most acceptable option to most decision maker types. No decision makers could be approached in this study. Instead five scientist of the Optima Lobau evaluated the use of the approach in wetland planning and decision making and the results the study. The respondents considered the approach to be useful in the preparation phase, decision making phase and also in the involvement of stakeholders. The research also added new insight to the Optima Lobau project. Further research with similar approach should be conducted with more active involvement of the stakeholder at the other WETwin study sites to fully evaluate the mDSS4.*

Sanon, S. 2010 Trade-Off Analysis for Floodplain Restoration:- A Case Study of the Lobau Floodplain in Vienna, Austria. MSc Thesis, UNESCO-IHE Institute for Water Education, Delft.

# 11 Gemenc

## 11.1 Decision space

### 11.1.1 Management solutions

Management solutions for restoration of the Báta subsystem of Gemenc are based on the plan proposed by the ‘Danube-Drava National Park Component’ of the ‘Nutrient Reduction Project’, which is implemented within the framework of the Global Environment Facility (GEF) (Tornyai & Virág, 2009; VTK Innosystem & VITUKI, 2010). Henceforth this project is referred to as the ‘GEF project’. The plan of the GEF project was elaborated by combining the option of installing a retention weir at the lateral connecting channel of the Báta oxbow lake, with the option of dredging the bed of the lake (Figure 11.1).

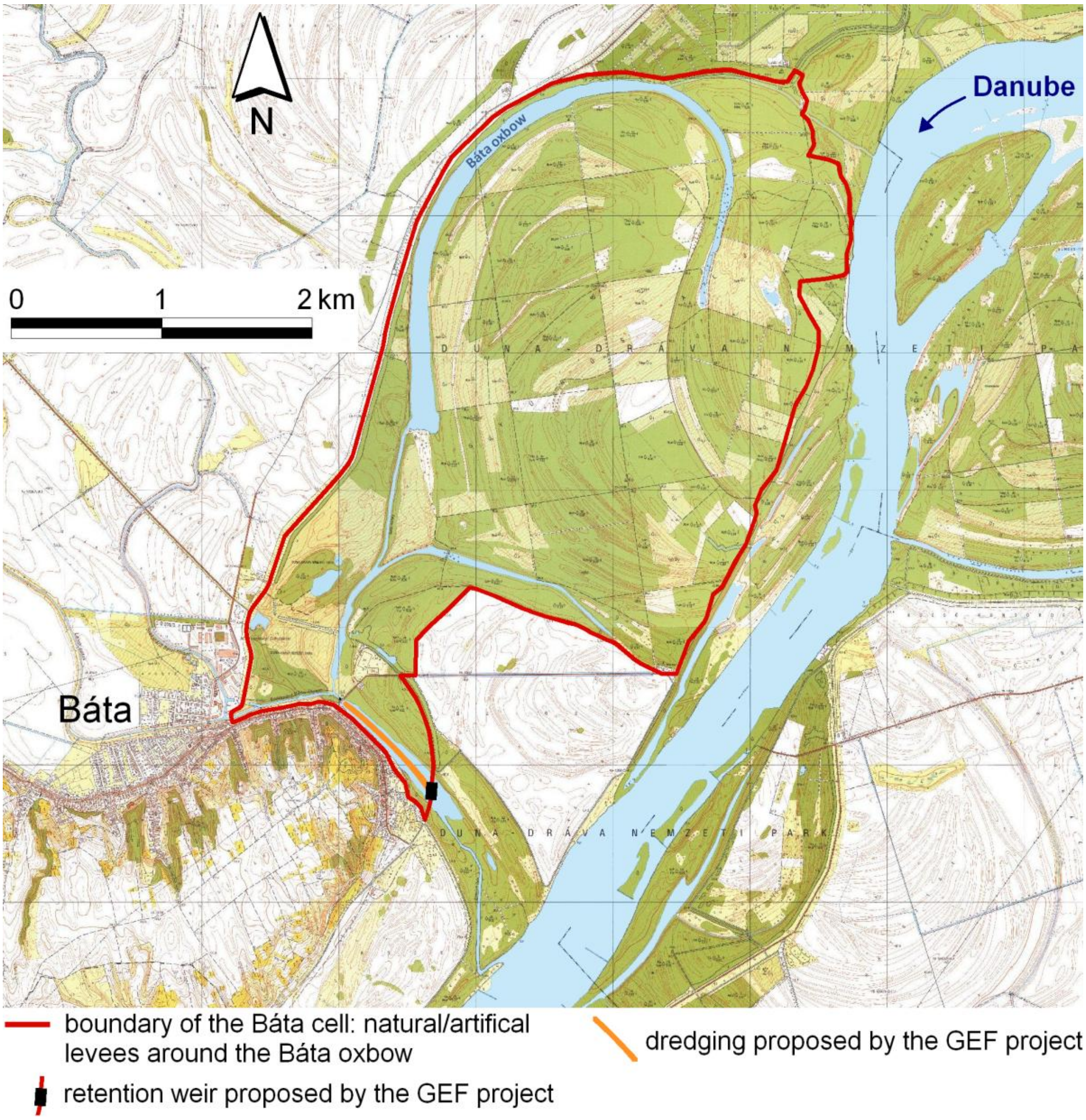


**Figure 11.1** Restoration plan of the GEF project for the Báta sub-system

*Two management solutions* were formulated on the basis of this plan according to the impoundment level that can be adjusted by the envisaged weir:

1. Impoundment level on 84.5 maB (meters above Baltic Sea level). This is proposed by the GEF project
2. Impoundment level on 85 maB.

For more details the reader is referred to Johnston & Mahieu (2012).

### 11.1.2 Indicators for evaluation

Zonation of vegetation in riverine floodplains under temperate climate is determined primarily by inundation conditions during the growing season. For the Gemenc floodplain the zonation of natural vegetation has proven to be strongly correlated with the mean annual inundation duration in the growing season (April-September), as indicated by Table 11.1.

**Table 11.1.** Ecological zonation in the Gemenc according to mean growing season inundations (Burián *et al., 1999; Zsuffa, 2001)*

| Name of zone (according to Burián et al. (1999)) | Range of mean inundation duration in the growing season (days) | Dominant plant species |
|---|---|---|
| no surface water influence | 0 - 7 | oak-ash-elm |
| periodic surface water influence | 7 - 30 | poplars |
| permanent surface water influence | 30 - 60 | willows |
| water logged | 60 - 90 | willow bushes |
| water cover | 90 - 183 | Pioneers |
| permanent water cover | 183 (total length of the growing season) | water plants |

Knowing the vertical distribution of mean inundation durations, one can derive the vertical zonation of vegetation on the floodplain by using Table 11.1. This vertical zonation can be translated into area zonation with the help of the digital terrain model of the floodplain. The so-computed *areas of vegetation zones* are indicators that will be applied for assessing the vulnerability of the Gemenc.

An other indicator applied for assessment is the *lateral surface water connectivity between the Báta oxbow and the Danube main channel*. This indicator is quantified by calculating the mean number of those days of the growing season, when the water level of the Danube exceeds the threshold of hydraulic connectivity between the oxbow and the main channel (see Figure 11.1).

### 11.1.3 Scenarios

Ecosystems of the Gemenc floodplain are subject to long-term harmful changes driven by river bed incision, floodplain aggradation (Figure 11.2) and climate change.

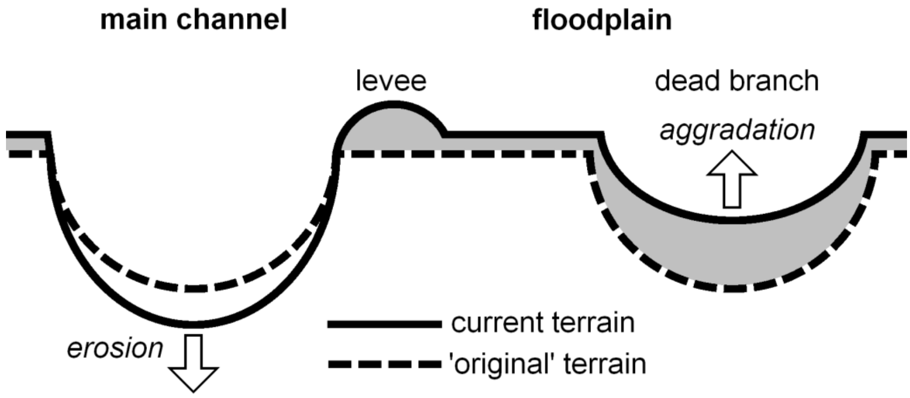


**Figure 11.2**. Illustration of the most important morphological processes on the Gemenc floodplain (Kalocsa & Tamás, 2004)

As Figure 11.3 indicates, these drivers influence the hydrological conditions of the floodplain by altering (directly or indirectly) floodplain topography, river water levels and local precipitation/evaporation conditions. Model-based investigation of vulnerability requires quantitative predictions of these boundary conditions well into the future. This section describes how such scenarios have been derived with regard to the Báta sub-system.

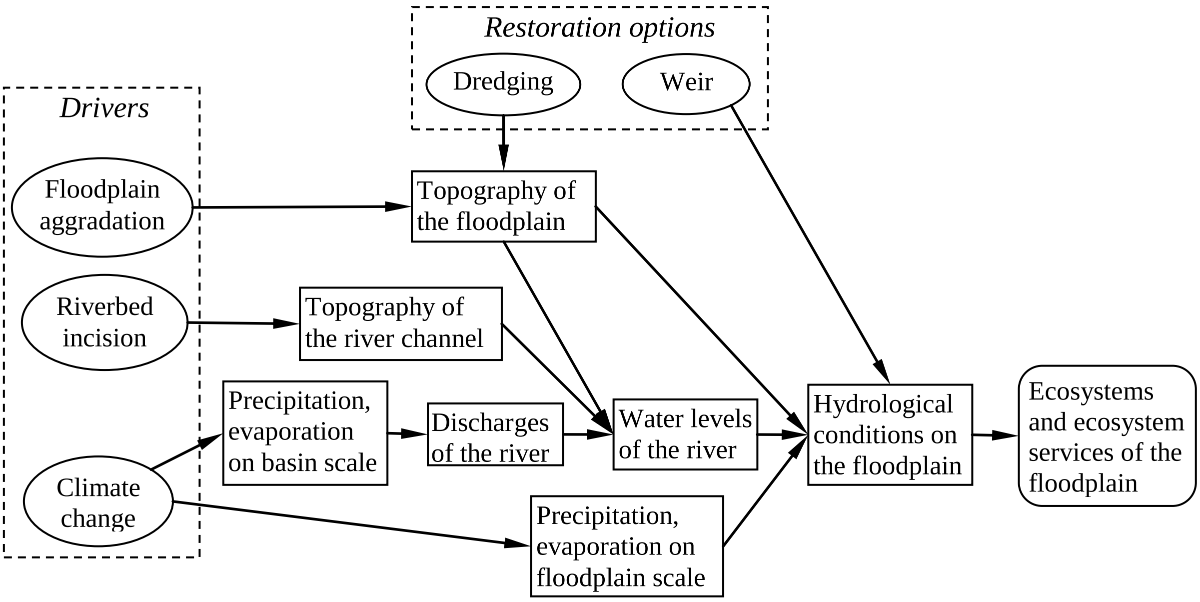


**Figure 11.3**. Influence chains through which drivers and restoration options influence the ecosystems and ecosystem services of the Gemenc floodplain

#### 11.1.3.1 Future topography of the Báta system

Due to the lack of information about sedimentation in Báta, prediction of aggradation of this oxbow was carried out on the basis of the assumption that the process and rate of sedimentation are similar to that of Lake Nyéki, where such information is available. This assumption is justified by the strong hydro-morphological similarities between the two lakes:

1. The lakes are situated quite close to each other
2. Both are paleopotamon water bodies as they are standing waters with no permanent and direct connection to the river, and they are only mildly influenced by river discharge (Amoros et al., 1987)
3. In both cases the downstream connection to the Danube main channel is closed by an artificial weir.

For the Báta system the last two statements will become fully valid in 2012, when the interventions of the GEF project will become operational.
The aggradation of Lake Nyéki was investigated by Winkler et al. (2009), on the basis of measured topographical data from 1993 and 2005 (Figure 11.4).

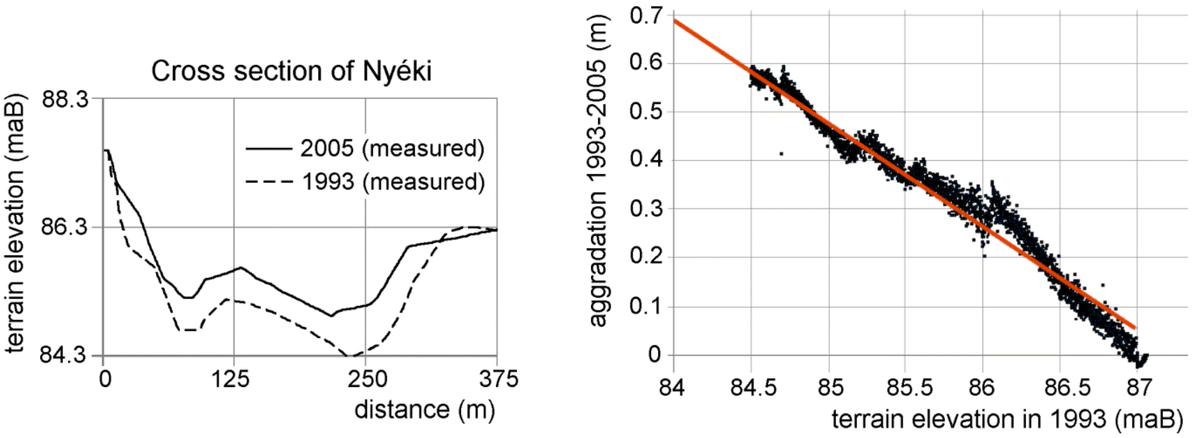


**Figure 11.4**. Aggradation of Lake Nyéki within the period 1993-2005 (Winkler et al., 2009)

The results show a good (linear) correlation, which indicates that lower grounds experience more sedimentation than higher ones. Above 87 maB the sedimentation is negligible.
Based on these observations, we use a linear aggradation model, which leads to an exponential expression for terrain level:

$$H(t) = (H_0 - H_m)\cdot e^{-a\cdot(t-t_0)} + H_m \qquad \text{if} \quad H_0 < H_m$$
$$H(t) = H_0 \qquad \text{if} \quad H_0 \geq H_m$$

where:

$H(t)$ : terrain level at time $t$ (maB)
$H_0$ : initial terrain level at time $t_0$ (maB)
$H_m$ : terrain level where the rate of aggradation is 0 (maB)
$a$ : aggradation constant (1/y) ($a\bullet(H_m-H)$ : aggradation rate at level $H$ (m/y))

This model has been used for generating the future topography of the Báta system (Figure 11.5). The aggradation constant '$a$' was set to 0.01 1/y. This means an aggradation rate of 4.25 cm/year on the bottom of the Báta oxbow, which is very similar to the observed aggradation rate on the bottom of Nyéki Lake.

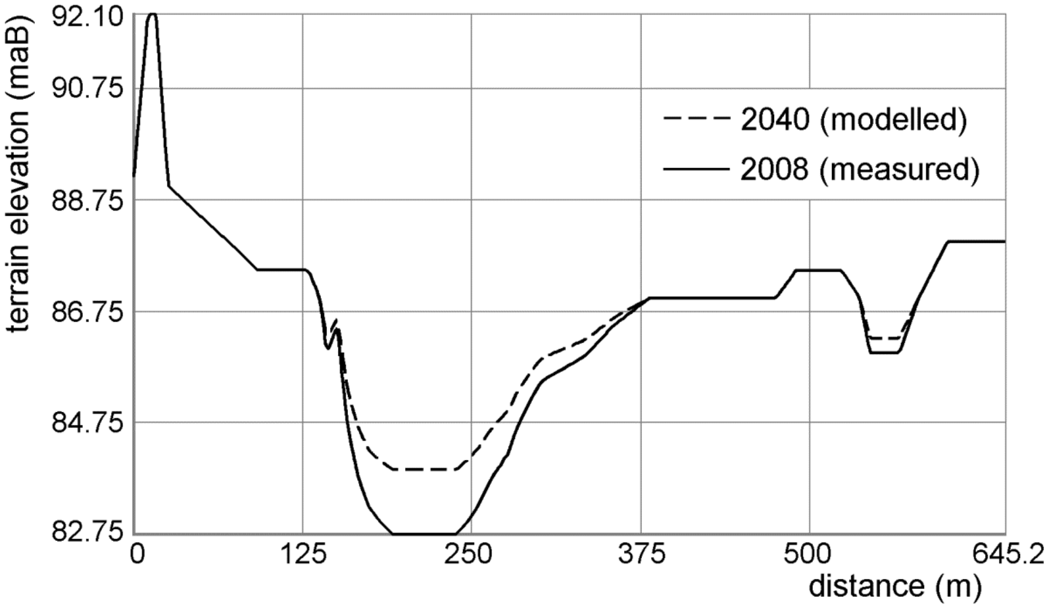


**Figure 11.5**. Predicted aggradation of the Báta oxbow lake

#### *11.1.3.2 Generation of precipitation and evaporation scenarios*

Generation of climate scenarios was carried out on the basis of the outcomes of the CLAVIER project (CLAVIER, 2009). Based on the IPPC SRES emission scenario A1B (IPPC, 2001), daily precipitation and temperature time series were generated for Central and Eastern Europe for the period 1951-2050 on a 25x25 km grid (CLAVIER, 2009). The applied tool was the REMO 5.7, a three-dimensional hydrostatic limited-area atmospheric model (Jacob & Podzun, 1997; Jacob et al., 2008). The results have been error-corrected and downscaled to a 10×10 km grid and 6 hr time resolution (CLAVIER, 2009). Evaporation time series on floodplain scale (Figure 11.6) were generated from the temperature data using the Thornthwaite formula (Thornthwaite, 1948). This formula is adequate for estimating the monthly potential evaporation over an open water surface, like that of an oxbow lake. As Figure 11.6 indicates, climate change will increase the precipitation deficit in the future thus aggravating further the problem of desiccation in the Gemenc floodplain.

#### *11.1.3.3 Generation of river water levels*

As Figure 11.3 indicates, generation of river water level scenarios is the most complex issue, as river levels depend not just on the discharges, but also on the topography of the river channel and the floodplain. Discharges of the Danube at Gemenc were generated with the help of the VITUKI-HHFS hydrological forecasting and simulation system (Gauzer, 2001). The basis of the system is a semi-distributed hydrological model, which consists of snow, rainfall-runoff and channel routing modules. Inputs to this model were basin-scale precipitation and temperature time series generated under the A1B emission scenario (see the previous section).

Discharge data are translated into water levels with the help of Q-H rating curves. To follow morphological changes in the channel bed and on the floodplain, the Q-H curve of a river needs to be updated periodically. For the gauging station of the Danube at Gemenc, altogether 17 Q-H curves were generated and used between 1943 and 2008. Plotting the points of these curves along the time axis (Figure 11.7) shows the impact of riverbed incision. As Figure 11.7 also indicates, the points of these curves fit on linear trend lines. The reasonably good fits allow us to assume that riverbed incision will follow these linear trends for a number of decades in the future as well. Accordingly, we used these trend lines to extrapolate Q-H relationships into the future. The generated Q-H curve series (Figure 11.8) were used to transform the projected discharge time series into water level time series (Figure 11.9).

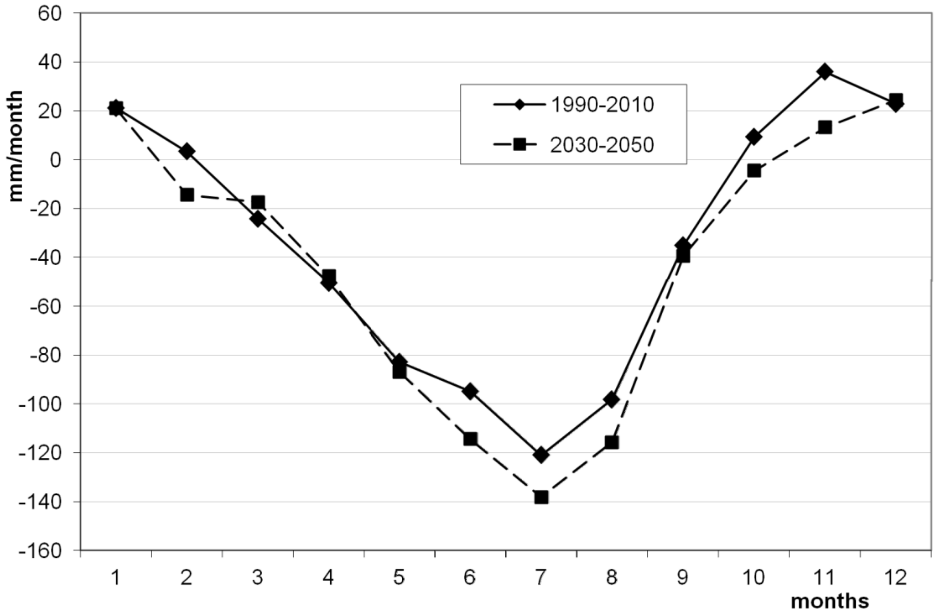


**Figure 11.6**. Mean values of monthly precipitation-surplus (precipitation-evaporation) data generated for the Gemenc region.

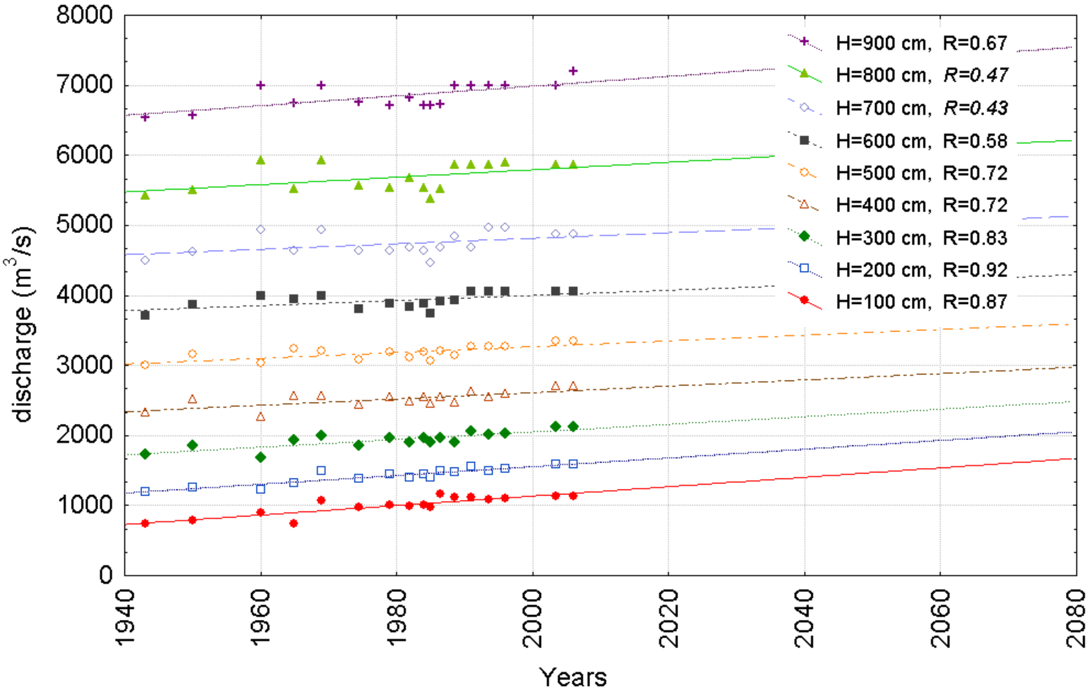


**Figure 11.7**. Trend analyses of discharge data taken from the observed Q-H curves of the Danube at the Gemenc gauging station.

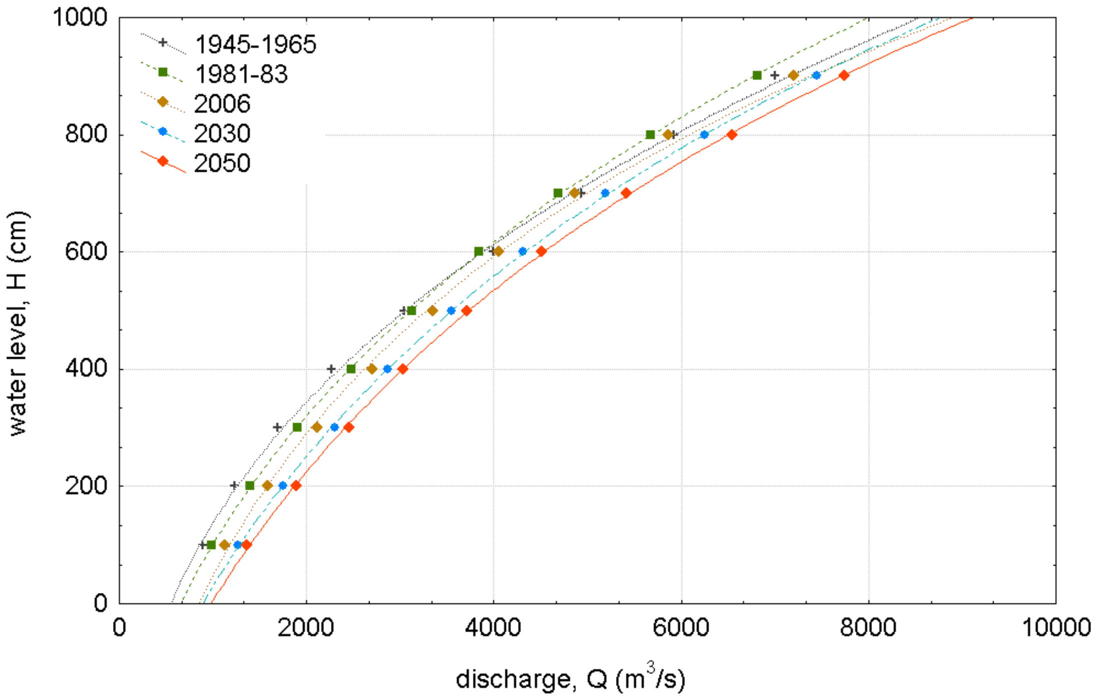


**Figure 11.8**. Observed and extrapolated Q-H curves of the Danube at Gemenc

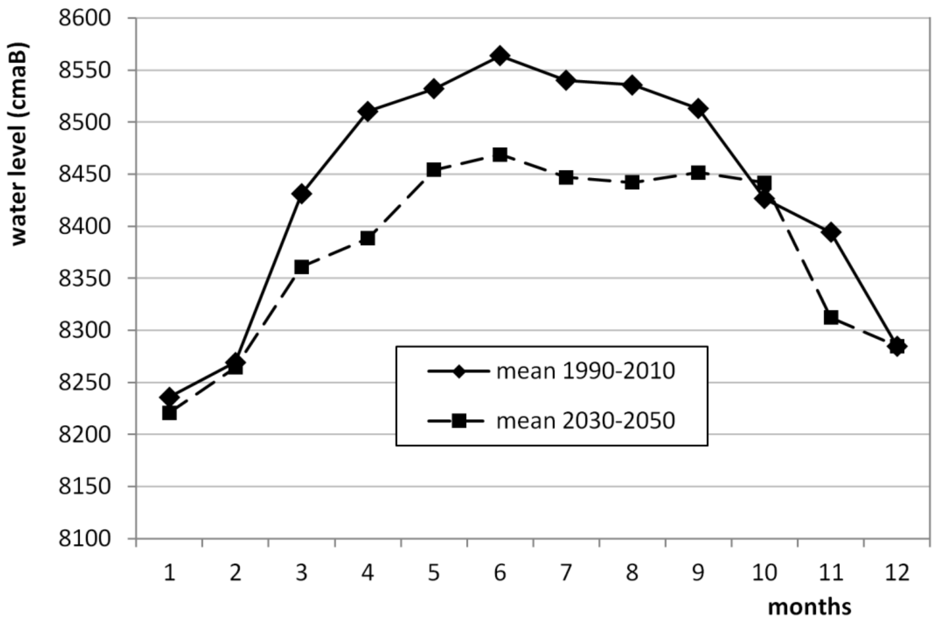


**Figure 11.9**. Monthly means of daily water level data of the Danube generated for the gauging station at Gemenc

As Figure 11.9 indicates, water levels during the growing season of the year (April-September) will be lower by 1 m on average in the future, due to riverbed incision and climate change. On the other hand, there will be no significant changes during the dormant season (October-March), because contrary to the growing season, the dormant season will be characterised by intensified rainfall events at the basin-scale (CLAVIER, 2009), which will compensate for the impact of riverbed incision.

## 11.2 Results of expert analysis

The generated hydrological, meteorological and morphological scenarios were used as boundary conditions for simulating hydrological conditions in the Báta system (see Figure 11.3). The applied model was a cell-based quasi-2D hydrodynamic model developed exclusively for simulating the water regime of floodplain systems (Zsuffa, 2001). Simulations were carried out for the periods of 1990-2010 and 2030-2050, for the status quo (situation before the GEF project) and for the restoration solution proposed by the GEF project. The 21-year daily water level time series generated in this way were subjected to statistical analyses. The purpose was to derive the distribution of mean growing season inundation durations along the elevation interval of water level fluctuation (Figure 11.10).

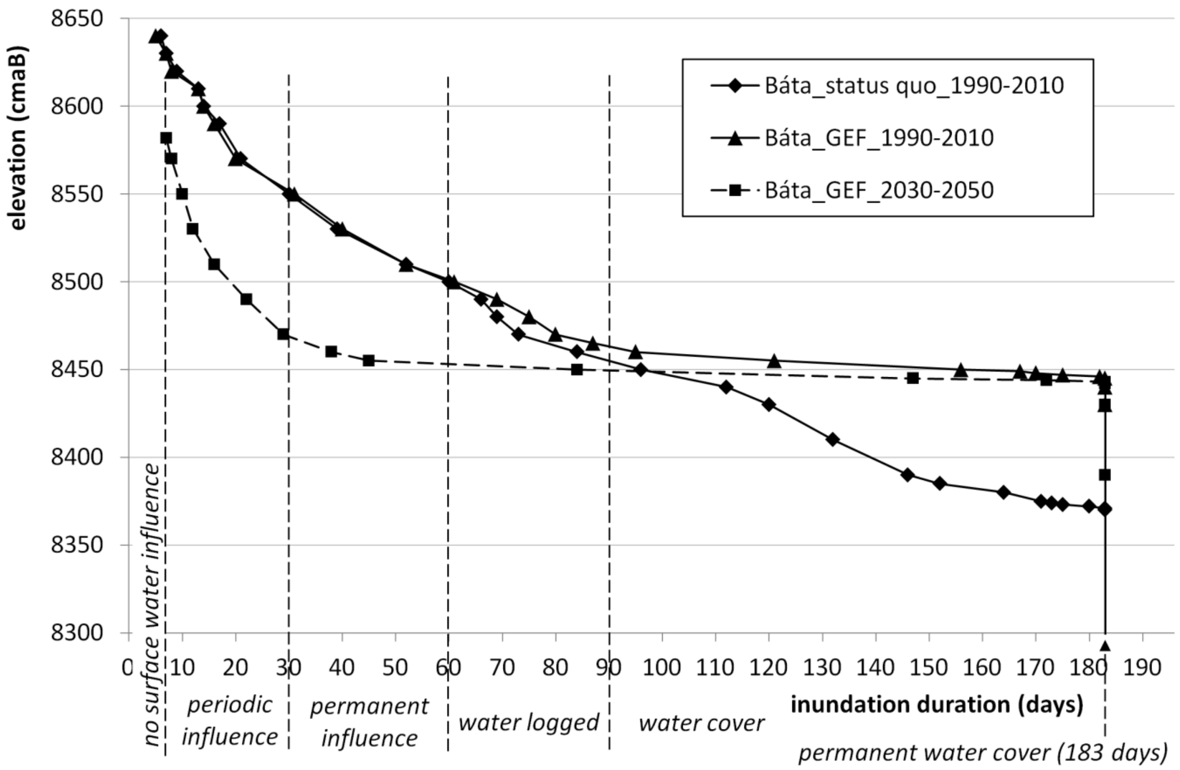


**Figure 11.10**. Mean growing season inundation durations in the Báta cell in case of the status quo and in case of the restoration solution proposed by the GEF project. The abscissa is the duration of inundation in days and the ordinate is the terrain elevations in centimeters above Baltic sea level. The division of the abscissa indicates the eco-zones defined by Table 11.1.

As Figure 11.10 indicates, the immediate impacts of the GEF project are significant only below the proposed impoundment level (84.5 maB), where the mean inundation durations become much longer than in case of the status quo. Above this level, the GEF project doesn't change the inundation conditions significantly. In the long run however, the changing hydro-meteorological boundary conditions will cause considerable changes in the hydrology of the Báta cell, even above the impoundment level: The elevations for 7, 30, 60 and 90 days inundations will be lowered by 40, 80, 50 and 10 cm respectively, as indicated by the curve of mean inundation durations calculated for the period 2030-2050.

Based on the elevation boundaries of the eco-zones (as derived from Figure 11.10), and also on the present and projected topography of the Báta cell, we quantified the evaluation indicators of vegetation zones at present and also in the future (Table 11.2). In this way, the impact of aggradation is also taken into consideration, above that of riverbed incision and climate change.

**Table 11.2.** Areal distributions of eco-zones in the Báta cell

| Name of zone: | Status quo 1990-2010 | GEF plan 1990-2010 | GEF plan 2030-2050 |
|---|---|---|---|
| no surface water influence | 81.7% | 81.7% | 93.5% |
| periodic surface water influence | 11.4% | 11.3% | 4.3% |
| permanent surface water influence | 2.2% | 2.2% | 0.5% |
| water logged | 1.0% | 0.9% | 0.1% |
| water cover | 1.9% | 0.3% | 0.1% |
| permanent water cover | 1.9% | 3.7% | 1.4% |

As Table 11.2 indicates, the implementation of the GEF plan will double the area of 'permanent water cover' in the short run, for the benefit of aquatic ecosystems. This will be realized at the expense of the 'water cover' zone. No significant changes will happen in the areas of the other zones. In the long run however, the spatial extends of all zones, except the 'no surface water influence' zone will decrease dramatically as compared to the status quo, in spite of the implementation of the GEF plan. The zones of 'water cover' and 'water logged' will practically disappear, while 'permanent water cover' and 'periodic surface water influence' will decrease by 26% and 62% respectively, due to river bed incision, floodplain aggradation and climate change.

We also investigated the impacts of scenarios and management strategies on the lateral surface water connectivity of the Báta oxbow. According to statistical analysis, the mean duration of connectivity during the growing season is 158 days at status quo. The implementation of the GEF project will immediately decrease this value to 96 days. Due to river bed incision first of all, and also due to climate change to some extent, lateral connectivity will be reduced further in the future: the mean duration of lateral connectivity will be only 32 days in the period 2030-2050.

As mentioned previously, the GEF project envisages an impoundment level for the Báta system at 84.5 maB, which will be set with the sluice built into the weir. From the point of view of vulnerability assessment, it is important to analyse the system's behaviour under the highest possible impoundment level that can be achieved with this infrastructure. This level is 85 maB (Tornyai & Virág, 2009). Accordingly, we carried out the impact assessment for this potential management solution as well (Table 11.3).

**Table 11.3**. Areal distributions of eco-zones in the Báta cell predicted for the period 2030-2050 for the case of the maximum impoundment (85 maB)

| | |
|---|---|
| no surface water influence | 93.9% |
| periodic surface water influence | 2.7% |
| permanent surface water influence | 0.0% |
| water logged | 0.1% |
| water cover | 0.7% |
| permanent water cover | 2.6% |

As Table 11.3 indicates, even the option with a maximum impoundment of the Báta system cannot counteract the ongoing hydro-ecological degradation. Although the area of 'permanent water cover' will be higher than in case of the status quo (because of the high level of impoundment), the semi-aquatic and wetland zones will almost disappear and the dry zone of 'no surface water influence' will increase in size significantly. In addition, this solution would result in a highly isolated system: the mean duration of lateral connectivity between the Báta oxbow and the main Danube channel during the growing season would be only 16 days in 2030-2050.

## 11.3 Vulnerability

As defined in Part A of this project report, vulnerability is a function of external impacts and adaptive capacity. In our investigation external impacts are that of riverbed incision, floodplain aggradation and climate change. Adaptive capacity is the ability of the management system to mitigate the negative external impacts. In this study, adaptive capacity is the water regime control capacity provided by the GEF project. Where the adaptive capacity of the system exceeds the external impacts, the system is resilient; where external impacts exceed adaptive capacity, the system is vulnerable (see Part A).

Model-based investigations showed that the Báta system of the Gemenc floodplain is *highly vulnerable* to the drivers of sedimentation, river bed incision and climate change. The current restoration project will restore the desired aquatic habitats only in the short run, even if water retention is pushed to its limit. In the long term, the conditions will quickly deteriorate, especially with regard to aquatic and semi-aquatic ecosystems. We can state with reasonable confidence that 60-70 years from now the Báta oxbow will no longer provide habitats for aquatic species, and terrestrial communities will cover the entire area. This will be fatal not just for the aquatic communities, but also for terrestrial organisms feeding on aquatic species. For example: living conditions for the black stork, the symbol animal of Gemenc, will deteriorate significantly. In addition, several important ecosystem services, such as nutrient retention, ecotourism, recreation and opportunity for traditional livelihoods will also be affected negatively. Only the commercial wood production may benefit from this desiccation process, as more and more areas will become available for planting trees.

The above conclusions are valid not just for the Báta system but also for the other water bodies of Gemenc.

## 11.4 Summary and recommendations

Thus, decision makers interested in the management of the Gemenc floodplain will have to look for auxiliary/alternative management options to ensure the sustainability of the envisaged ecological conditions. Turning back to fully natural conditions, by allowing the river to meander again, is not feasible, since navigation and flood control require the maintenance of a regulated river channel. A feasible auxiliary management option would be to connect the floodplain water bodies to the river channel *from upstream*, by means of new channels. This will raise further the water levels in the water bodies, without degrading the lateral connectivity. Nevertheless, maintaining the envisaged alluvial conditions in the long term will inevitably necessitate the dredging of the beds and banks of the oxbow lakes after every 30-40 years. The challenge here is how to raise the high costs of such interventions.

As riverbed incision, floodplain aggradation and climate change are basin-wide phenomena; most river floodplains in the Danube basin have gone through similar degradations and are vulnerable to further degradations (Funk et al., 2012; Zsuffa, 2005). Since floodplains play a key role in the maintenance and functioning of ecosystems and ecosystem services on basin scale, restoration and sustainable management of these sites should be a top priority in the management of the Danube River Basin.

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