

**IWRM Strategies at Local Sub-Basin level,
Sensitivity Analysis and Performance Assessment**

Special Deliverable
Consolidating Deliverables

D803 – D804 – D805

Editors

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April 2013



Federal Ministry
of Education
and Research

Key words:

IWRM, Multi-Criteria-Analysis, IWRM-Strategies, Optimization, Sensitivity Analysis

Funded by the German Federal Ministry of Education and Research (BMBF):

FKZ 02WM0801

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0. Executive Summary

1. Introduction

This document summarizes the work carried out in the frame of three deliverables of work-package WP08:

- **Deliverable 803:** Report on IWRM strategies for each sub-basin and the representation in SMART Knowledge Management;
- **Deliverable 804:** Sensitivity analysis of local IWRM strategies;
- **Deliverable 805:** Reports on performance, impact assessment and ranking of local IWRM strategies.

The reason for lumping these three deliverables stems from their deep inter-dependence and the conclusion of the editors that one integrated document has the potential to better contribute to the overall understanding of the methodologies and tools employed in the preparation of this document.

This document has two distinct parts: 1) a methodological part comprising mainly the description of the suggested logical steps to be taken in the preparation and evaluation of IWRM strategies; 2) demonstration of the implementation of the suggested methodology and associated tools (developed in the frame of WP06) to one sub-basin of the LJV in the West (Wadi Nueima) and one sub-basin in the east (Wadi Schuweib).

2. Objectives

The guiding research and development objectives of the deliverables are:

- Suggesting a methodology for the formulation of alternative IWRM strategies;
- Providing and demonstrating the tools for their evaluation and ranking;
- Assessing their robustness/resilience to instability factors;
- Demonstrate the application of the suggested IWRM-Approach.

This suggested systematic approach comprises all the basic ingredients of IWRM, including:

- Identifying, determining and quantifying the water sources;
- Identifying the evaluating the water needs (present and design time horizons);
- identifying suitable technologies for the needed treated of the water prior to its utilization;
- formulating water plans or IWRM strategies based on a new method for water resources system analysis;
- Identification of alternative candidate IWRM strategies by means of multi-criteria optimization;
- ranking the alternatives and selecting the preferred one by means of Multi-criteria decision making approaches, taking into account criteria of different natures (economic, environmental and social).

This work is heavily dictated by an engineering approach and as such it first deals the “W” (Water) component IWRM as it can regarded as a necessary condition for the whole IWRM

process. Altogether, this work will produce IWRM strategies that are transparent in the sense that once can clearly understand how they have been built, which are the relevant constraints imposed and what are the criteria for their evaluation.

3. Methodology (IWRM-Approach)

The building blocks of the suggested IWRM approach are illustrated in the chart of the following. The approach has been developed in the context of the SMART project in order to guide through the elaboration of an integrated water resources management plan. We shall provide below an explanation of the rationale beyond them.

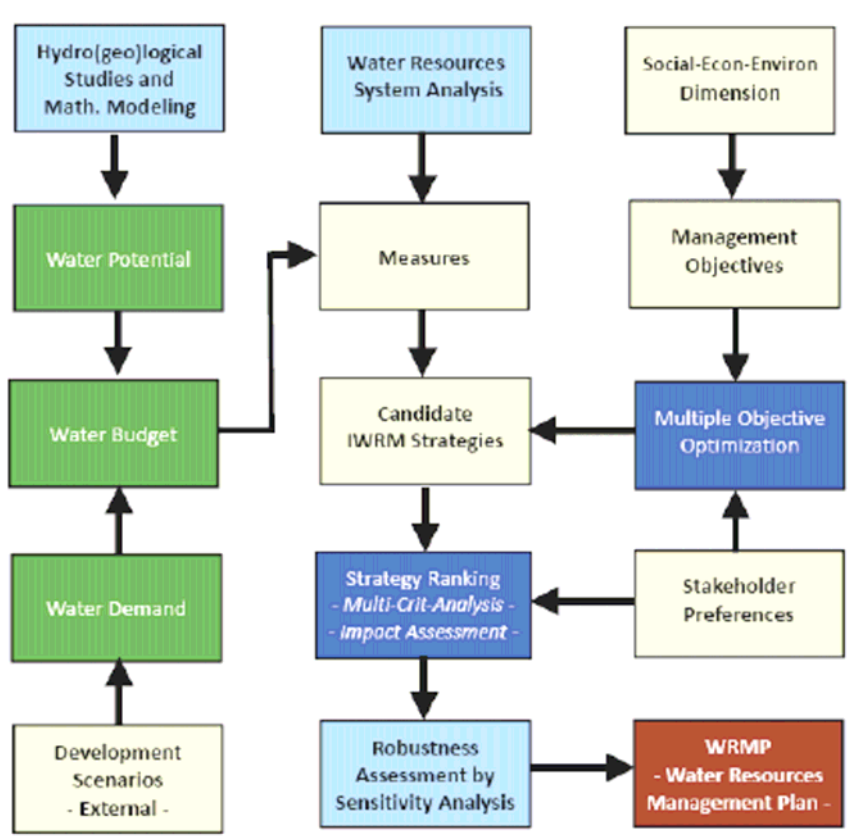


Figure 1: SMART IWRM approach towards the development of an integrated water resources management plan

Hydrogeological studies, modelling Water resources inventorying.

This is a fundamental step in the IWRM strategy preparation. It deals with the evaluation and inventorying of the available water resources. In the case of the LJV, we regard every single source of water, be it fresh water, saline – brackish water, treated or raw effluent, as a valuable sources of water. These evaluations can be conducted by means of various tools such as macro-hydrologic (cell models) to sophisticated groundwater models. Here the local models as well as the regional ones are the key elements.

Water Potential	The meaning of the water potential here means the amount of water that can be produced/abstracted with a certain degree of reliability/sustainability/stability. It does not provide a value of the water that needs to be abstracted nor does it provide an estimate of the associated production costs.
Development scenarios	This basically an input to the IWRM activities considered in this documents. Its aim is provide information on the expected development within the catchment such as what is the expected population growth? What is the expected development of the agriculture (what type of crops and constraints of the water needed – both in quantity and quality)?
Water Demand	The development scenarios above will allow determining the contours of the water demand of a specific basin, in terms of both qualities and quantities.
Water Budget	The water budget is the combination of the water potential and the water demand. This is probably the most important component of the IWRM workflow.
Water resources system analysis	This block deals with the in-depth analysis of the water resources system that characteristic of the basin under scrutiny. Its aims is to identify those components of the water potential which require further activation by means of hydro-infrastructure.
IWRM Measures	Required measures to activate the water potential, including hydro-infrastructure implementation for water production, water trade, water treatment and storage, taking different agricultural development options into account
IWRM Strategy	Combination of structural and non-structural measures towards the integrated management of water resources. The suggested approach towards IWRM implementation in the LJV, focuses on technological and hydro-infrastructural interventions and gives special attention to the sustainable agricultural development and the extension of irrigated lands.
Socio, Economic and Environmental considerations	Discuss and formulate a set constraints and objectives aimed at preserving the “interests” of the social, economic and environmental aspects of the IWRM problem relevant to the basin under consideration. Practically this means setting the order of preferences of the IWRM in form of objectives that often are contradictory (in competition with each other). This means that in this context improving one objective automatically induces a deterioration of one or more of the other objectives.

Water management and development objectives	The objectives are related to social, economic and environmental interests, which are partially conflicting with each other due to its nature, independent of any water scarcity situation.
Stakeholder preferences	The stakeholder preferences is the second component of the decision making. It is mainly driven by political and more subjective considerations. Together with the expert preferences, they will form the basis for the formulation of the objective functions and constraints to be analysed under MCO.
MCO Problem and its solution	Form a MCO problem, a set objective functions, general and bound constraints that embed the characteristics of the water budget, demand, and measures for the water resources development. This will lead to the Pareto set, or the set of non-dominated IWRM strategies.
Strategy ranking, Multi-criteria analysis, impact assessment	This building block comprises comprehensive work of screening the set of non-dominated solution (the Pareto set) and rank them according to more subjective criteria. We suggest to conduct this phase by means of a MCDS approach (either AHP or ELECTRE). The decision maker with the support of the technical expert will then make subjective choices, however, on a set of alternatives that have been formed using rigid and rigorous mathematical tools.
Robustness, resilience and stability assessment by means of sensitivity analysis.	Once the IWRM strategy (ies) is (are) selected, there is a need to assess their performance against three key criteria: 1) Robustness and resilience deal with the evaluation of the ability of an IWRM strategy to cope with defaulting assumptions (such as sudden reduction of a specific water source, a pollution event etc.). Resilience deals with evaluating the period of time needed for a specific strategy to cope with such incidents. Stability aims at ensuring that minor changes in the basic parameters of the IWRM strategy will not induce an overall change of its components (decision variables). Additionally we need to address also the performance against uncertainty factors such as the fluctuating rainfall and subsequent replenishment, unexpected response of specific water sources (such as aquifers) etc. All these can be carried out, either formally or qualitatively by means of sensitivity analysis. This analysis can be carried out at the level of the MCO problem or at the level of the ranking procedure.
WATER Resources Management and Utilization PLAN (WaRMUP)	This is the final building block of the IWRM strategy construction the WATER resources Management PLAN. This is basically the preferred strategy both from a technical and stakeholder point of view and from robustness and stability point of views. This is the strategy that should be recommended for implementation.

4. Components of Local IWRM-Strategies

According to UNESCO (2006) an IWRM-Strategy consists in the combination of structural and non-structural measures towards the integrated management of water resources. The suggested approach towards IWRM implementation in the LJV, focuses on technological and hydro-infrastructural interventions and gives special attention to the sustainable agricultural development and the extension of irrigated lands.

5. IWRM Tools

The tools developed in WP06 are destined to provide the computational support for the formulation and evaluation of IWRM strategies and the formulation of WaRMUPs. These are:

- a. **Hdyrobudgets**: this application integrates the agreed components of the water resources system and their potential yield. It provides the support needed for the water budget, together with the information of the water demand (which is not included in this application). The user is not allowed to modify the basic data in this application, as the suggested approach here is that this information has to be prepared by a team of independent experts with as little as possible external/subjective influence. Therefore, once it is agreed, HB provides the values needed for the formulation of the water yield and water budget.
- b. **Multi-criteria decision making (MCDM) tools**: here we have implemented the AHP (“AnalYTical Hierarchy Process”) and ELECTRE (“ELimination Et Choix Iraduisant la REalité”). These methods allow to screen and rank a number of alternatives according to a set of criteria. We have suggested these two approaches as they represent different philosophies of the decision making procedure (AHP is very simple highly intuitive and thus potentially unstable and ELECTRE is far more complex, much less intuitive and obviously more stable). MCDM tools can be used as stand-alone applications or can be integrated as part of the IWRM strategy construction.
- c. **Multi-criteria optimization (MCO)**: This application allows the creation of the set of non-dominated strategies (the Pareto set) through the formulation and solution of a MCO problem. The application allows the formulation of problems (of small to medium sizes) using a friendly user interface and expression syntax, instead of requiring formal programming, which requires substantially more resources and skills.
- d. **Scenario Generator (SG)**: This application allows the selection of the preferred IWRM strategy by integrated HB, MCO and MCDM tools. Once the water budget and water demands are set, objectives and constraints are formulated, MCO produces the Pareto set of the IWRM problem in form of a potentially large number of IWRM alternatives that need to be ranked. We then suggest to conduct the ranking using either one of the MCDM tools.

6. Sensitivity Analysis

Sensitivity analysis is a procedure that is applied in many disciplines, particularly in water resources management. Sensitivity analysis is mainly aimed at quantified the impact of what is unknown and or known with a substantial degree of uncertainty. Sensitivity analysis can be used to determine robustness, resilience and stability, resulting from uncertainties in one or more components of the IWRM strategies. In this section we shall briefly review the main causes of uncertainty in the frame of the IWRM in the LJV, the main formal approaches to the formulation and resolution of the sensitivity analysis and finally our suggestion for a sensitivity analysis in the frame of the SMART/II project.

6.1 Categories of Uncertainty

6.1.1 Physical Uncertainty

There are many factors, which can be associated with physical uncertainty. A non-exhaustive list would include:

1. **Climatic uncertainty:** the area is characterized by a tremendous variability in the rainfall regime, with minima and maxima that are substantially different from the average values, which makes the process of optimal utilization of surface water resources highly complex. Also high variability in the rainfall regime will result in substantial changes in aquifer replenishment rates and in the discharge of short-term springs. Additionally the extensively discussed, yet not fully quantified for the time horizons of IWRM planning of up 20 years, impact of climate change on the precipitation regime should be taken into consideration.
2. **Geological and hydrogeological uncertainty:** The main aquifers in the LJV are deep ones, and are poorly known as most of the wells are located in a few clusters. Additionally, the aquifers are characterized by sharp changes in the groundwater head elevation over relatively short distances, and this requires the inclusion of geological features (such barrier faults and or flexures) in order to produce sustainable groundwater flow regimes that are compatible to the water inputs and outlets.
3. **Boundary conditions uncertainty:** while the outcrop areas are relatively well defined, it is rather difficult to identify the replenishment coefficients (the part of the rainfall that actually reaches the aquifer). This is dues to the fractured and heterogeneous nature of the geological setting. In the east, the extent of the aquifer layers goes far beyond the borders of the study area and therefore, it is clear that uncertainties will result with regard to the water balance at the eastern edges of the LJV.
4. **Initial conditions uncertainty:** It is well known that in the aquifers of the LJV, there exist a delicate coexistence between freshwater bodies and saltwater bodies. While years of research have provide some idea about the location of the saline water

bodies, there is still massive uncertainty with regard to their boundaries and the characteristic salt concentrations. Any plan to further develop groundwater resources in the area has to address the impact of additional water abstraction on the migration of these saline water bodies and their possible impact on existing freshwater wells.

5. **Parameter uncertainty:** a major component of the water resources in the LJV is the deep aquifers, both in the west and in the east. These aquifers are still poorly characterized and the values of their key parameters (hydraulic conductivity, anisotropy, storativity and specific yield) suffer from large uncertainties, due to the suspected heterogeneity of the water bearing layers. As a result of this uncertainty, the location of well fields is highly problematic. The drilling of a new well involves substantial investment and if drilled in a location with poor hydraulic properties and or uncertainty with regard to the depth of the target layers, it can result at best additional investment or worse to a loss of investment.
6. **Land uncertainty:** the well-known drop of the Dead Sea level (of ~1 m/year) is associated with the sink-holes problem. Sink hole can occur suddenly anywhere in the vicinity of the Dead and beyond the danger to human being it can also result in the destruction of infrastructures (supply system, roads etc.).

6.1.2 Political uncertainty

It would be a euphemism to state that the area is characterized by political instability and thus uncertainty. In what follows we shall address the factors of political uncertainty that could have an impact on the IWRM for LJV. A non-exhaustive list of these factor would include:

1. **Degree of cooperation between the three parties in the water sector:** there is some degree of cooperation between Israeli and Palestinians on one side and between Israeli and Jordanians on the other. However, this cooperation is much less than what is needed for the implementation of integrated basin-scale IWRM strategies. Therefore the uncertainty here stems for the extent of the cooperation that is to be expected in the time horizon of the IWRM strategies and the degree of integration of the water systems that could be agreed upon if any.
2. **Demographic uncertainties:** the population of the LJV is expected to contemplate major shifts in the coming decade, as a result of expected peace agreements and or as the results of the speedy increase in population both in Jordan and in Palestine. Demographic changes are the basis for water demands for sectors (domestic, agricultural, industrial) and for the production of residual water, which could be reused.
3. **Standard of life changes:** it is well-known that water consumption increases with the standard of life, particularly in an area that is characterized by high temperatures. Additionally, the improvement of living standards will definitely require allocation of additional water for agriculture (higher demand) and for recreation. Therefore, this factor affects the estimation of the future water demands.

The interactions between the surveyed uncertainties and their impact on the IWRM components are schematically illustrated in [figure X](#).

6.2 Tools for sensitivity analysis

It is beyond the scope of this work to conduct an extensive review of sensitivity analysis tools. There is a huge wealth of publications and books such as Saltelli et al, 2009 or dedicated publications (for watershed management, for modeling and or for MCO/MCDS). In this section we shall review sensitivity analysis for the main components of our suggested methodology. It does not represent in no case a thorough and or formal review of sensitivity analysis techniques.

6.2.1 Sensitivity analysis in modeling

The main role of sensitivity analysis in modeling is to estimate the impact of uncertainty of one more characteristics of the model (setting, parameters, boundary conditions, initial conditions) on the model output. There are many approaches of various mathematical complexity that address this problem, including:

- **Monte-Carlo method:** This is probably the most widely used approach for this type of problem is the. It simply consists in varying the parameter values according to specific statistical distributions (whether parametric or not) and to conduct a simulation for each resulting set of parameters. This method requires executing a large number of simulations (often hundreds or even thousands). Statistics (such as average values and moments) can then be calculated from the output of each simulation. The process is simple to implement and intuitive, however it can become prohibitive if the time required for one simulation is large (as this is the case of large regional models).
- **Statistical Emulators:** In this approach we assume a specific model for the uncertainty such as Gaussian and its parameters are determined by means of simulations (often a small fraction of the number required by the Monte Carlo approach). Statistics are then derived directed from the emulator.
- **Small perturbation methods:** this approach is more sophisticated assumes that uncertainty of parameters are the result of small perturbations with known probabilistic structure (normal or log-normal). This results in the derivation of formulae of different complexities of “effective parameters” that incorporate the uncertainties impacts. Gelhar suggested to solve this problem by means of spectral methods, others such as (Dagan, Neumann, Kitanidis, Rubin, etc.) suggested mathematical approaches leading all, to closed form equations of the effective parameters (either implicit or explicit).
- **Stochastic differential equations:** this approach is highly sophisticated from a mathematical point of view and its starting point is to assume that the state variables (groundwater head, concentration etc.) are representation by probability distributions rather by values. The resulting differential equations (representing the physics of the

problem) are thus resolved for the probability distribution from which statistics can be derived. This approach is at its early stages of development and is being investigated among others by Dentz, Sanchez Vila, Carrera, Tartakowski and others.

Altogether, there is a very rich literature with regarding to estimation of uncertainty or spatial variability in modeling. However, our suggestion is to adopt the statistical emulators as a basic tool for sensitivity analysis as these are relatively easy to implement and require an affordable number of model simulations.

6.2.2 Sensitivity analysis in basin management

Assuming that a model, M representative of the behavior of basin, depends on a vector of parameters, $\mathbf{e} (e_1, e_2, e_3, \dots, e_n)$, the sensitivity, $S(M, e_i)$ of the model output with regard to parameter e_i is given by (Yoon, 1996 among others):

$$S(M, e_i) = \frac{e_i}{M} \frac{\partial M}{\partial e_i} \quad (1)$$

Numerically the sensitivity can be evaluated as follows:

$$S(M, e_i) = \frac{\frac{M(e_1, e_2, \dots, e_{i-1}, e_i + \Delta e_i, e_{i+1}, \dots, e_n) - M(e_1, e_2, \dots, e_{i-1}, e_i, e_{i+1}, \dots, e_n)}{\Delta e_i}}{\frac{e_i}{M}} \quad (2)$$

In simple terms, this consists in checking the dependence of the model output on variations of a specific parameter, exactly this is done in Monte-Carlo Analysis. However the aim of Monte-Carlo analysis is to evaluate statistical measures of the impact of uncertainty, here we evaluate the sensitivity of the output to one single parameter. The key element in this procedure is to determine a sampling strategy, i.e. determining the candidate parameters for sensitivity analysis. In the case of an IWRM strategy, we would formally vary a number of global parameters, for instance, sensitivity to a sudden reduction of the spring discharge, sensitivity to a pollution event (migration of a salt water body towards a well field, etc.).

6.2.3 Sensitivity analysis in MCDM

AHP: In this case we have a set of criteria and a set of alternatives and the sensitivity mainly focuses on three issues:

1. To what extent our judgment in comparing two alternatives with a regard to a specific criterion can change as a result of a modification (perturbation) of that criterion.

2. To what extent we would change the weights of each criterion when modifying (applying a perturbation) to specific criterion.
3. What could be the impact of a different judgment for a specific number of pairwise comparisons with the same set of criteria and alternatives?

The main reason for sensitivity analysis for AHP in the context of IWRM is to check the consistency and stability of our subjective judgment. This is of crucial important as one the main deficiencies of the AHP method is exactly the potential inconsistencies that can be added by the user/decision maker.

6.2.4 Sensitivity analysis in MCO

According to Zhang (2003), at a given Pareto optimum X^* , Pareto optimum sensitivity analysis consists in calculating the derivatives of the objective functions with respect to a certain one when a perturbation is applied to it. Therefore Zhang, suggests an algorithm for the optimum Pareto sensitivity analysis. This algorithm requires substantial knowledge in optimization theory in order for its reading to be useful and will be therefore skipped in this document.

A much simpler way to achieve the same objective using the numerical evaluation of the partial derivatives of one objective function with regard to another, just by using a finite difference scheme over the Pareto set created with MCO, i.e.:

$$\frac{\partial f_i}{\partial f_j} \approx \frac{f_i(f_1, \dots, f_j + \delta f_j, \dots, f_n)}{\delta f_j} \quad (3)$$

By using the Pareto set only we make sure that every derivative is calculated only on the relevant set of non-dominated solutions. One direct application of sensitivity analysis of the Pareto surface is for the selection of the IWRM strategies for ranking by mean of MCDM (via either AHP or ELECTRE). One way to do so is to select only those Pareto solutions with mild tradeoff, i.e.:

$$L \leq \frac{\partial f_i}{\partial f_j} \leq U \quad (4)$$

Where L and U denote the lower and upper bounds on the derivative, respectively. By applying this condition we would limit our search of candidate strategies that satisfy some form of consensus.

7. Case Study Lower Wadi Nueimah

For more detailed hydro(geo)logical investigations in the context of the SMART project, the catchment cluster, consisting of the three Wadis Auja (260 km²), Nueimah (128 km²) and Qilt (189 km²), have been selected. The application of the suggested IWRM approach will be demonstrated at the Lower Wadi Nueimah catchment.

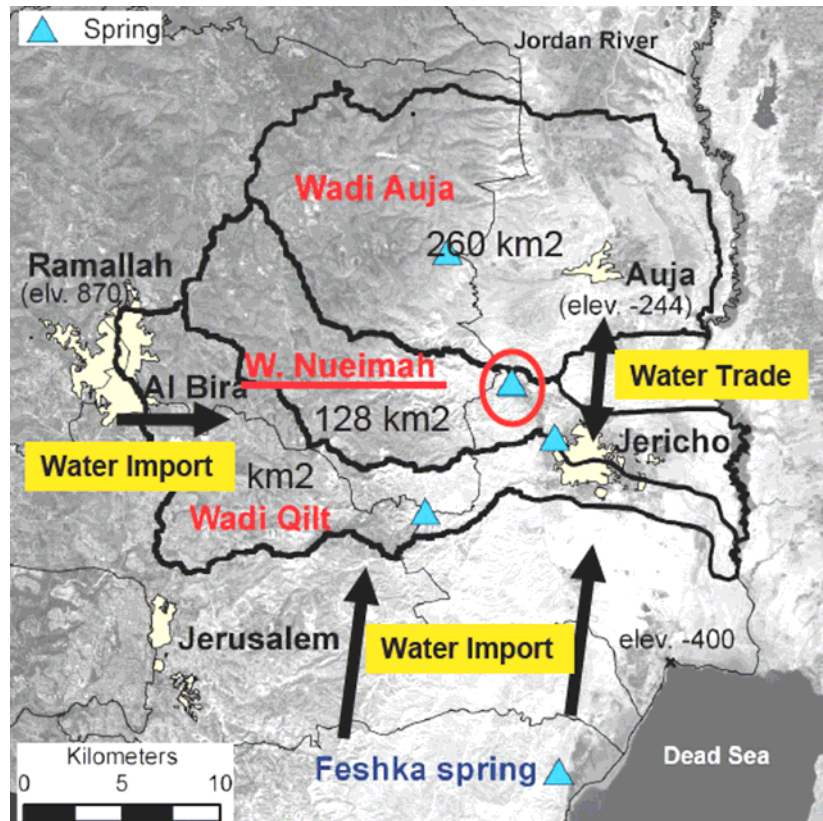


Figure 2: Catchment Cluster Wadis Auja, Nueimah and Qilt at the West-Bank

7.1 Water Budget Assessment

Table 1 presents the results of a water budget assessment for a planning horizon between 2010 and 2050 for both, Wadi Auja and Nueimah, comparing the water potential with present and future expected water demands. According to the water qualities, the available water resources have been divided between freshwater (blue), brackish water (red) and waste water resources (grey). The freshwater resources in that Wadis consist in discharge of the local spring groups, surface runoff, mainly in form of flash floods and groundwater of the deep carbonate aquifer, east of the geological fault in the valley and in the Mountain areas. The shallow alluvial aquifer as well as the deep carbonate system between the geological fault and the Jordan river mainly consist of moderately saline brackish water salinities above 2000 mg/l.

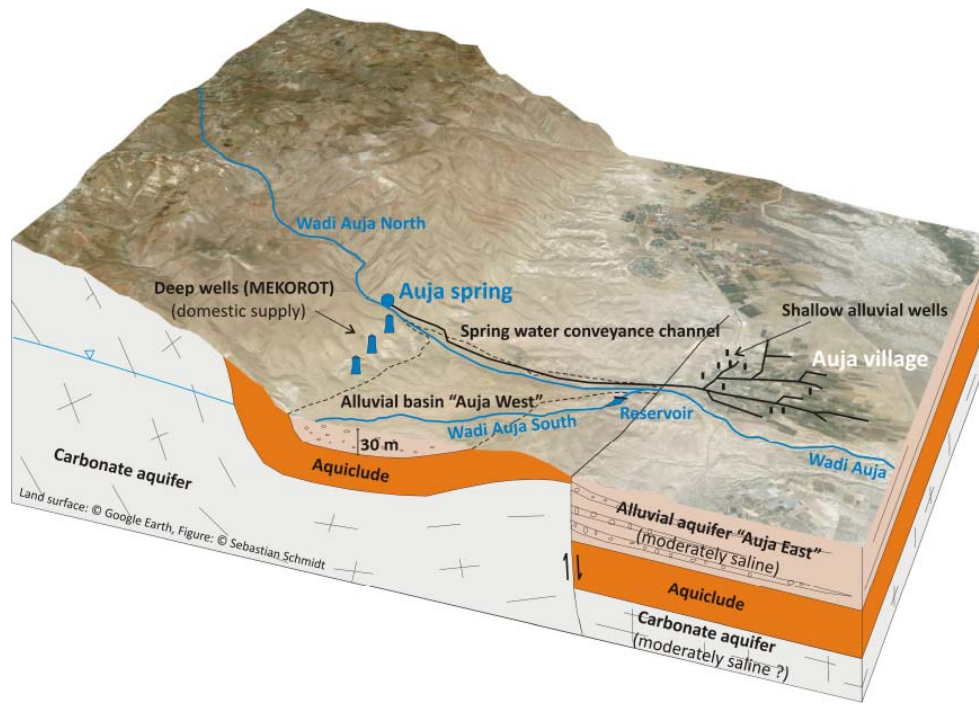


Figure 3: Geological profile and aquifer systems in the case study area

Both Wadis present typical rural conditions with very small waste water production. Decentralized waste water treatment is not existing. The local spring groups present a very important water potential of about 8.2 MCM/a in Wadi Nueimah.

Table 1: Present and future water budget for Wadis Auja and Nueimah

The water potential of the deep carbonate aquifer systems is already partially exploited by Israeli Authorities (3.1 MCM/a). The sustainable yield of the shallow alluvial groundwater system is estimated in 2 MCM/a. This system plays an important role as potential reservoir for the underground storage of surface water surpluses and their controlled recovery by means of Managed Aquifer Recharge.

The water budget table shows that there is a considerable potential for the extension of irrigated agriculture at Wadi Nueimah which may be covered by local water resources only. Since the Jericho City is not part of this Wadi, domestic water consumption will remain small over the next decades. The studies on socio-economic development and demand assessment have been conducted by the Palestinian Hydrology Group (PHG, 2011).

7.2 Water Resources System Analysis

For water resources system analysis a methodological approach has been developed which provides information supports the identification of required infra-structure and technologies in order to activate the available potential of the water resources of different qualities.

Figure 4 presents the results of the WRS-Analysis for the Nueimah Catchment. The available water resources, their water potential (no losses) in MCM/a, existing and further required hydro-infra-structure (dotted lines) for water potential activation as well as relevant water sector demands between 2010-2050 are given.

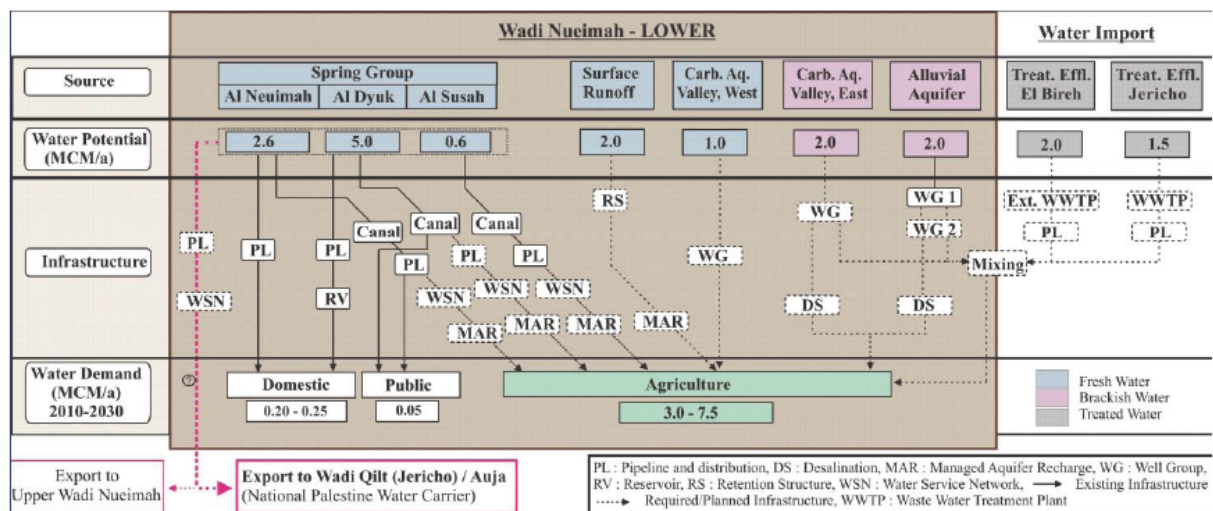


Figure 4: Water Resources System Analysis for Lower Wadi Nueimah

The local spring group is the dominating source of water in the Wadi, which is able to cover the small present and future domestic and public demand. The water is supplied by pipelines with minimum losses. The main water user at Wadi Nueimah is irrigated agriculture, Both, present and future water demand, may be covered by spring discharge which may be directly supplied to irrigation by new pipelines to ensure high water supply efficiency or stored in the alluvial aquifer by practicing Managed Aquifer recharge (MAR). In order to cope with the fluctuation of spring discharge and high variability of the hydrological regime including the presence of drought years, over-the-year storage of surface water surplus will be required.

Optionally, surface water surplus, especially during wet years may be exported to Jericho or Wadi Auja.

Freshwater in form of surface runoff, mainly concentrated as flash floods, is actually lost to the Jordan river due to missing flood retention structure. Some small parts may contribute to the natural recharge of the carbonate and alluvial groundwater systems in the valley. Surface dams or retention ponds are required to activate this water potential.

Due to high variability of surface runoff, the corresponding water potential is difficult to quantify (Moe et al, 1998). Based on runoff-precipitation studies (Abadi, 2006), it has been estimated that a mean runoff of 2 MCM/a may be stored retention structures. Additional freshwater from the deep carbonate system in the valley may be produced by a deep well at the geological fault.

Brackish groundwater from shallow wells in the alluvial aquifer (2 MCM/a) and deep wells in the carbonate aquifer (2 MCM/a) may be desalinated and used in local agriculture for high value crops. This would require the installation of new well groups in both aquifer systems. Optionally, brackish water may be mixed with treated effluent or directly applied for irrigation of salt resistant crops, such as palm trees. Due to insignificant effluent production, additional effluents could be imported from El Bira WWTP (Figure 1) by gravity pipeline or Jericho WWTP to reduce salt concentrations by mixing. Wadi Nueimah effluents have not been considered in the WRS Analysis. Extraction of surface water from the Jordan river is not considered due to political restrictions.

7.3 Potential IWRM Measures

Based on water resources system analysis and water budget assessments a number of potential IWRM measures have been identified which aim on the activation of the water potential of the water resources of different qualities based on additional water production, water trade with regards to import or export, water treatment and management, e.g. with regards to desalination and Managed Aquifer Recharge and different agricultural development options, referring to the extension of agricultural lands, introduction of salt resistant crops and new irrigation technologies, such as greenhouses. The measures are focusing on technological and hydro-infrastructural interventions. Collateral measures of IWRM implementations, such as institutional development and capacity building are not considered. An adequate demand management is obligatory for the entire Lower Jordan Valley and has not been specifically listed. Furthermore, irrigated agriculture as main water user, is already applying drip irrigation technologies with high water use efficiency. Table 2 presents the list of potential IWRM measures.

Table 2: List of potential IWRM measures

No.	Description of IWRM Measures	
M1	Implementation and renewal of water service network (pipelines)	Water Production
M2	Retention of flash floods	
M3	Deep wells in the carbonate aquifer – Fresh Water	
M4	Deep wells in the carbonate aquifer – Brackish	
M5	Shallow wells in the alluvium aquifer - Brackish	
M6	Import of treated effluents from El Bireh WWTP	Water Trade
M7	Import of treated effluent from Jericho WWTP	
M8	Water import from Feshka spring	
M9	Fresh water import from Palestinian National Water Carrier	
M10	Export of surplus water	Desalination & Management
M11	Groundwater desalination	
M12	Mixing of brackish water and fresh water resources	
M13	Mixing of brackish water and treated effluent	
M14	Managed Aquifer Recharge (MAR) – spring discharge & surface runoff	Agric. Develop.
M15	Extension of regular agriculture	
M16	Greenhouse technology implementation	
M17	Palm tree production	

7.4 Water Resources Management and Development Objectives

The following list represents most relevant water resources management objectives which have been selected together with local stakeholders. The objectives are related to social, economic and environmental interests, which are partially conflicting with each other due to its nature, independent of any water scarcity situation.

- ❖ Maximize water sector development (Agriculture)
- ❖ Maximum use of irrigable lands
- ➔ Maximize economic profits (cost-benefits)
- ❖ Maximize peak demand coverage
- ❖ Maximize water supply reliability
- ❖ Maximize social welfare and family income
- ➔ Maximize social acceptance
- ➔ Minimize environmental impact

In order to identify sustainable compromise solutions for the integrated management of water resources towards the achievement of conflicting interests, the application of Multi-Objective-Optimization procedures is required. By means of these procedures a set of optimized, so-called Pareto-optimal solutions is being identified. These set of potential IWRM-Strategies may be all considered as optimal solutions with regards to the set of conflicting water resources management and development objectives.

7.5 Potential IWRM Strategies

7.5.1 Multi-Objectives-Optimization

For Multi-Objective Optimization, the MOO-Decision Support Tool, developed by EWRE (2012) has been applied. The tool, available in a web-based environment, considers the (Enhanced) Normalized normal constrained and Normal Boundary Intersection method to solve the following type of minimization problem:

$$\begin{aligned} &\text{Min } \mu(x) \\ &\text{subject to} \\ &g(x) \leq 0 \\ &h(x) = 0 \\ &x_L \leq x \leq x_U \end{aligned}$$

a. Objective Functions

From the list of the most relevant water resources management objectives, presented under section 7.4, the following objectives have been selected in a participatory process with some of the main stakeholders to represent the overall social, environmental and economic water resources management and development goals:

- ➔ ECONOMIC: Maximize Profits (Benefits-cost)
- ➔ SOCIAL: Maximize Regular Agriculture & Minimize use of low quality water and high-tech solutions
- ➔ ENVIRON: Maximize Treatment and Reuse of Effluents

It may be mentioned that any maximization problem can be resolved as minimization problem just by multiplying the corresponding objective function by (-1) in order to attend to the above described format of the optimization problem.

[Appendix 1](#) contains the definition of the numerical objective functions based on the relevant decision variables, according to the above description.

b. Decision Variables and Constraints

According to figure 5, a total of 32 decision variables X_1 to X_{32} have been defined, referring to the water allocation to different water sectors, taking different options for agricultural development as main water user into consideration. Since this is a typical water resources planning task, the decision variables refer to the annual water allocation in MCM/a and water sector demands, not considering the actual water distribution to different water users on the ground. The decision variables are explained and listed under [appendix 2](#).

The 35 constraints to the optimization problem as function of the decision variables are given under [appendix 3](#) and refer to the following aspects:

- ❖ Water potential of all available sources of water
- ❖ Available area for extension of irrigated lands
- ❖ Water allocation to sectors and for different irrigation schemes
- ❖ Fresh and brackish water mixing
- ❖ Brackish water mixing with treated effluents
- ❖ Brackish water desalination

The set of problem constraints refer specifically to the local conditions of the Lower Wadi Nueimah and would have to be extended, if the approach would be applied to neighbouring basins or the entire catchment cluster. The so-called box constraints refer to the availability of natural resources at the case study area. The today irrigated area at Lower Wadi Nueimah is about 3000 dunam (300 ha), while the irrigable land amounts to the double, constraining the extension of irrigated lands and corresponding water allocation.

c. Water Allocation Structure

Figure 5 shows a graphical presentation of the water allocation problem which is the basis for the mathematical description of the problem constraints as stated under [appendix 3](#). In reference to the water resources system (WRS-) analysis, the colours blue, red and grey refer to the source water quality, differentiating between fresh and brackish water resources as well as treated effluents, which may be imported from El Bireh and/or Jericho waste water treatment plants.

The water management measures are referring to water quality improvements by brackish water desalination and brackish water mixing, either with treated effluent or fresh water. The water quality and related costs to achieve a certain quality standard is relevant for decisions with regards to agricultural sector development, since regular agriculture and greenhouse irrigation would require high water quality, while salt resistant, high value crops, such as palm trees, should not be irrigated with fresh water.

The underground storage of surface water surpluses, consisting of spring discharge and surface runoff, by means of Managed Aquifer Recharge is obligatory in the case study area in order to adapt water availability fluctuation within a year to the demand structure and ensure a high reliability in water supply. Since the
is not explicitly considered, but

d. Parameters and Thresholds

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- Cost of water production options and water transport in NIS/m³
- Cost of management options and (waste) water treatment in NIS/m³
- Benefits of water allocation in NIS/m³ and NIS/dunam
- Water demand for regular agriculture, palm trees & greenhouses in mm/dunam
- Salinity thresholds of mixed water
- Salinity threshold & parameters for overpumping of carbonate aquifer
- Threshold for area available for greenhouse technology implementation

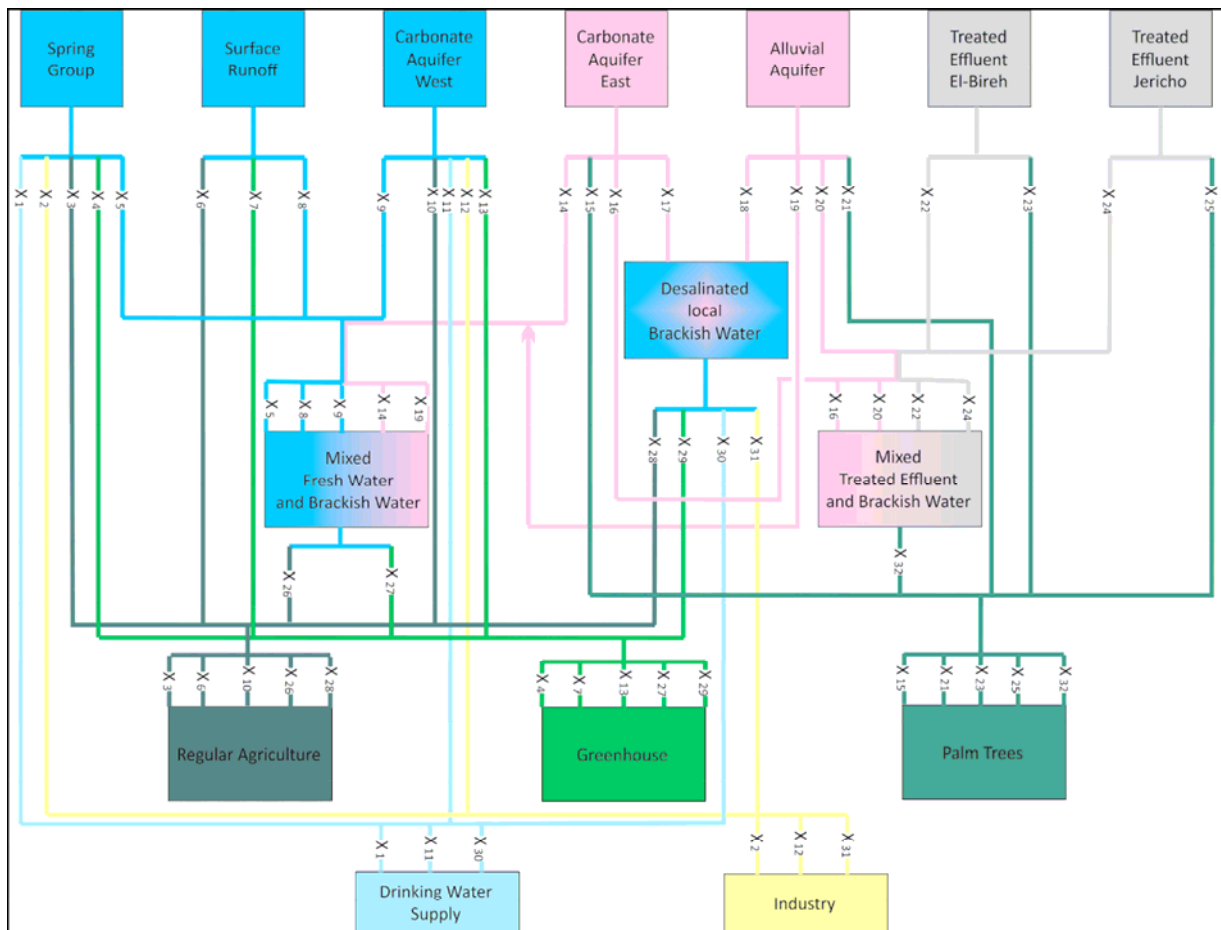


Figure 5: Water allocation structure referring to decision variables X1 to X32 (MCM/a)

e. Surface of Pareto-optimal Solutions

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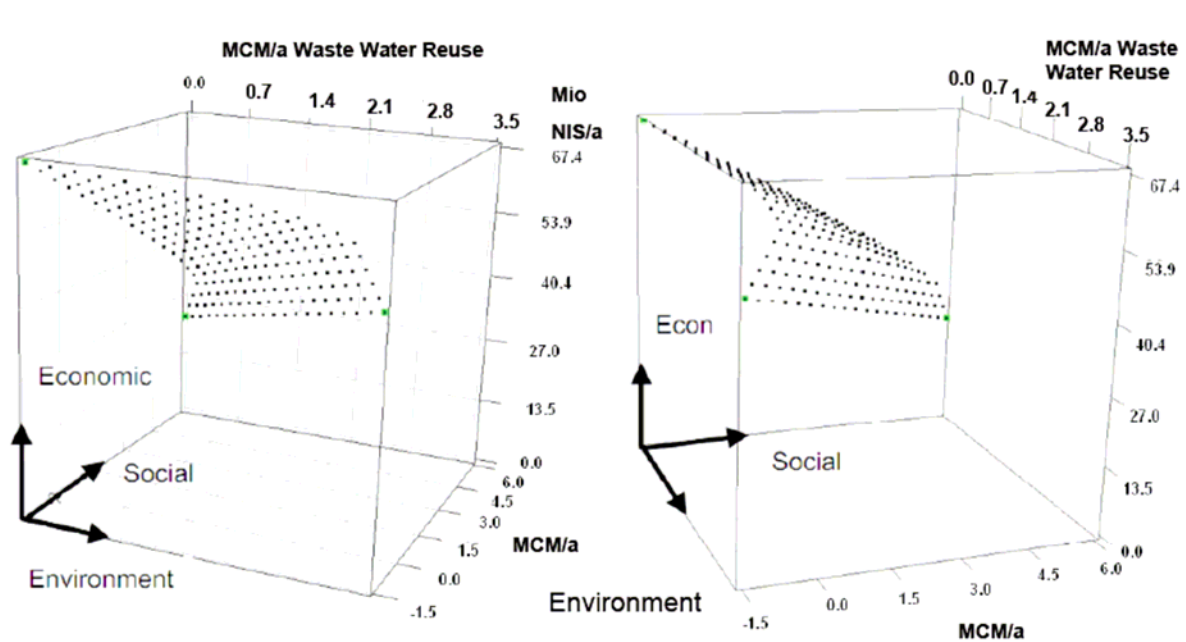


Figure 6: Pareto-Surface

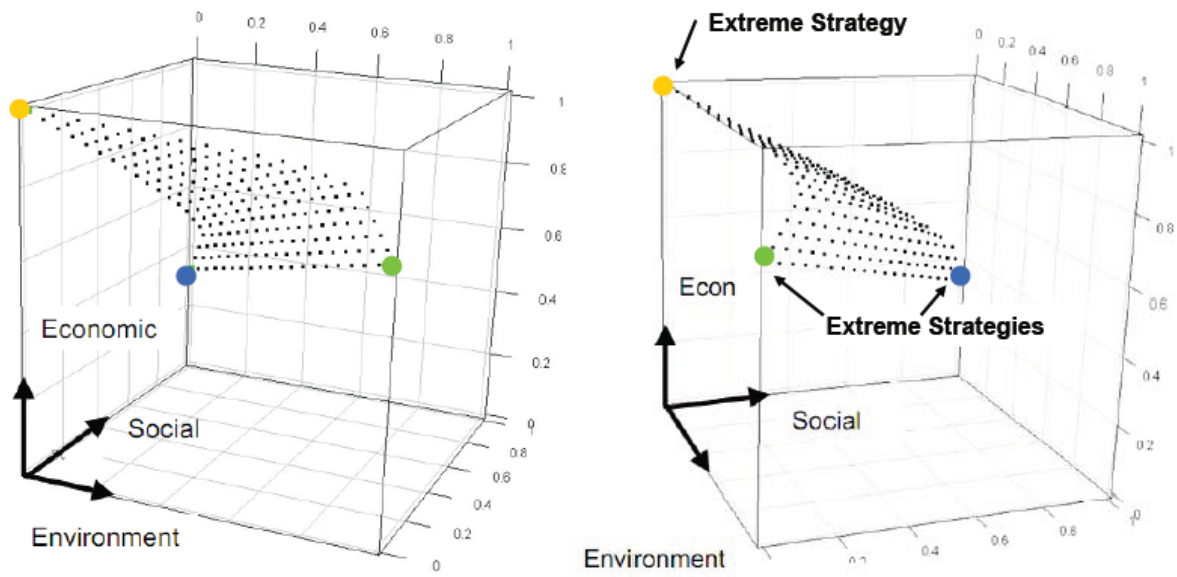


Figure 7: Pareto-Surface with normalized axes

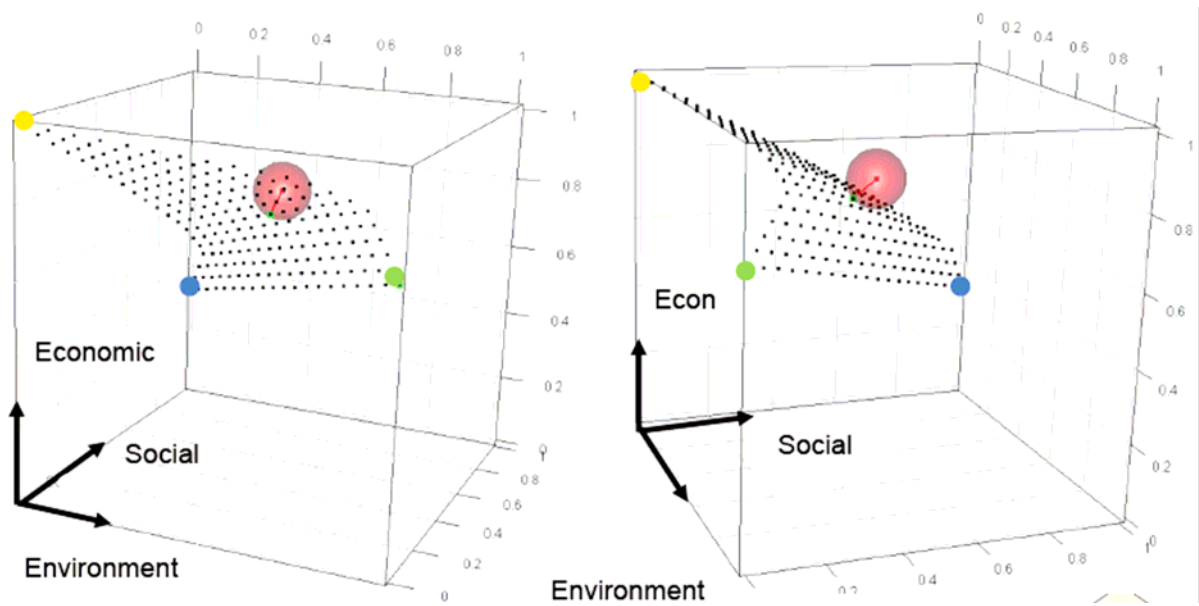


Figure 8: Pareto-Surface with compromise solution (goal point)

7.6 Agricultural Development Options and IWRM Candidate Strategies

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Table 3: Agricultural development options, water trade and water requirements

	Water Allocation in Agriculture			Water Trade		Water Requirements		Irrigated Area at Lower Wadi Nueimah
	Palm Trees Irrigation (MCM/a)	Greenhouse Technology (MCM/a)	Regular Agriculture (MCM/a)	Import (MCM/a)	Freshwater Export (MCM/a)	Local (MCM/a)	Total (MCM/a)	
Area	(dunam)	(dunam)	(dunam)					(dunam)
ADO 1 (env_extr)	1.0 B + 3.5 E 3000	-	3.0 F 3000	2E1+1.5E2	7.45 F5	4.0	7.5	6000
ADO 2 (soc_extr)	-	-	6.0 F 6000	-	4.45 F5	6.0	6.0	6000
ADO 3 (eco_extr)	3.75 B 2500	0.75 F 500	3.0 F 3000	-	6.70 F5	7.5	7.5	6000
ADO 4 (Compr.1)	2.22 B 1476	0.31 F 204	4.32 F 4319	-	5.82 F5	6.85	6.85	6000

Type of Local Water Resources	Local Water Potential	Water Import	Agricultural Water Demand	Irrigated Area (2012)
F: Fresh water resources B: Brackish water resources E: Treated Effluent ----- F1: Dyuk spring Group (surface w.) F2: Surface water runoff F3: Deep wells valley (west of flexure) B1: Deep wells valley (east of flexure) B2: Shallow alluvial aquifer	(Extractable) F1: 8.2 MCM/a F2: 2.0 MCM/a F3: 1.0 MCM/a B1: 2.0 MCM/a B2: 2.0 MCM/a ----- Losses are not considered in the WP estimation	E1: El Bireh WWTP E1: 2.0 MCM/a E2: Jericho WWTP E2: 1.5 MCM/a Water Export F5: Jericho/Auja (also via Palestinian Nat. water carrier)	Palm tree irrigation: 1500 mm/dunam Greenhouse technol: 1500 mm/dunam Regular agriculture: 1000 mm/dunam Local Water Potential WA: 8.2F1+2F2+1F3+2B1+2B2= 15.2 MCM/a Local Freshwater Potential: 11.2 MCM/a Local Water Demand (WD) in 2020 WD IRR(2020)= 6 to 7.5 MCM/a WD IND & DOMESTIC (2020)= 0.75 MCM/a → further available freshwater resources may be exported to neighbouring basins	3000 dunam Irrigation Potential 6.000 dunam

Several compromise solutions to be selected based on commonly agreed trade-offs between objective functions...

7.7 IWRM Strategy Ranking

7.8 Sensitivity Analysis and Robustness Assessment

7.9 Conclusions and Recommendations

8 Case Study No.2: Wadi Shueib

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9 Main Results

10 Conclusions and Recommendations

REFERENCES