Integrated Water Management Using Feasible Goals Method and Interactive Decision Maps: The Case of Odivelas Irrigation

Rui Fragoso\textsuperscript{1}, Vladimir Bushenkov\textsuperscript{2}, Carlos Marques\textsuperscript{3}

\textsuperscript{1} University of Évora, Department of Management, ICAM/CEFAGE
\textsuperscript{2} University of Évora, Department of Mathematics, CIMA
\textsuperscript{3} University of Évora, Department of Management, CEFAGE
INTEGRATED WATER MANAGEMENT USING FEASIBLE GOALS METHOD AND INTERACTIVE DECISION MAPS: THE CASE OF ODIVELAS IRRIGATION

Rui Fragoso*
University of Évora, Department of Management, ICAM/CEFAGE, Apartado 94, 7000 Évora, Portugal, rfragoso@uevora.pt

Vladimir Bushenkov
University of Évora, Department of Mathematics, CIMA, Apartado 94, 7000 Évora, Portugal, bushen@uevora.pt

Carlos Marques
University of Évora, Department of Management, CEFAGE, Apartado 94, 7000 Évora, Portugal, cmarques@uevora.pt

*Corresponding author Fax: + 351 266 740 807 Phone: +351 266 740 892

Abstract

In Mediterranean areas water scarcity is a real problem and stakeholders have conflicting visions and interests. This paper aims to determine feasible and efficient combinations of stakeholder goals using an integrated water management approach. A framework based on the Feasible Goals Method/Interactive Decision Maps (FGM/IDM) technique to approximate all Pareto optimal solutions of a linear multi-criteria model was developed. The model was applied to the Odivelas irrigated area in southern Portugal and a participative decision making was obtained considering multiple stakeholders goals that are in conflict.

Keywords: Operations Research; Water Management; Multiple Criteria Decision Making; Interactive Decision Maps; Feasible Goal Method.

JEL Classification: Q2, Q25, C6, C61
1. Introduction

According to UN (1987) sustainable development seeks to meet the present needs without compromising resource availability for future generations. During almost all of twenty century there was an enormous expansion of water supply driven by population growth, changing standards of living and expansion of irrigated areas. As a result of expansionist politics based on public investments in large infra-structures the demand for freshwater dramatically increased, and free flowing rivers, material riparian systems, and many aquatic species have become increasingly rare and valued, and a new water management paradigm emerged in the end of the last century (Gleick, 2000). The Water Framework Directive (WFD) approved by European Union in 2000 is the best example of the new water management paradigm in the World (DIRECTIVE 2000/60/EC; and Petersen et al., 2009).

Recent trends to include in water policy economic tools lead to think that agriculture can increase water efficiency and save large amounts of water from irrigation to other sectors such as for environmental uses. This is particularly important in the Mediterranean areas, where the problem of water scarcity is real and stakeholders have different visions and interests. Farmers search for the optimisation of their investments and want to get stable returns. Society and politicians wish for social benefits from water uses, namely diminishing unemployment in rural areas and maximising the utilization of public irrigation infrastructures. Water agency goals are related with equity on the water access, efficient resource allocation and with recovering water costs, which at least should include operating and capital costs.

Under these conditions, water can be considered as a public good and a common resource in which the use by one user will subtract benefits for another user enjoyment of the resource, and the exclusion of individuals has high transactions costs (Hardin, 1968). In order
to make a response to these issues, the principles of integrated water management can be used as a comprehensive planning approach setting economic, social and environmental goals.


Multi-criteria decision making methods (MCDM), where the Feasible Goals Method/Interactive Decision Maps (FGM/IDM) technique is included, are well placed to deal with integrate water management and in conflicting stakeholders goals. These techniques allow for planning in a multi-objective context considering simultaneously political, economic, environmental and social dimensions, and reducing conflicts in an optimization framework. The FGM/IDM technique provides a fast and easy way to display multiple stakeholders goals, that are in conflict showing them in a graphic form and to understand the efficient trade-offs between conflicting objectives (Lotov, 2004; Lotov et al, 2005; and Efremov, 2009).
Faced with that, the objective of this paper is to find feasible and efficient combinations of stakeholder goals using an integrated water management framework. One linear multi-criterion model is proposed to the Odivelas Irrigation in the Alentejo region, southern Portugal, and the FGM/IDM technique is used to construct (or approximate) all Pareto optimal solutions in multi-dimensional criteria space.

The paper includes six more sections. Section 2 describes how costs and benefits can be introduced into an integrated water management framework. Section 3 provides a brief review of research contributions on planning using multi-criteria decision making techniques. Section 4 makes a sketch of the FGM/IDM technique. In section 5 a multi-objective linear programming model applied to the Odivelas irrigation is presented. Section 6 describes the solution of the multi-objective linear model by means FGM/IDM to making a feasible compromise decision. Finally, section 7 respects to conclusion.

2. Economic analysis and integrated water management

Benefit cost analysis is the most commonly approach used in water economics and it should be adopted when the objective is the economic efficiency. Allocation of water among competing uses subject to environmental constraints is an important economic and political issue for countries in southern Europe (Gomez-Limon, et al., 2002). Agricultural benefits from irrigation are commonly measured by crop enterprise budgets. Data required include crop prices, costs of production, crop yields and crop water use. Urban benefits are often given by water bill paid plus any non priced consumer surplus from urban water use.

The policy objective of economic efficiency increases the feeling that water policies do not only benefit business and consumers, but also improves public health, safety and environment. For water reallocation, maximum economic efficiency is achieved when the marginal benefit of one additional unit is equal in all water uses.
Examples of water economic analysis include problems of crop irrigation (Al-Karaki, 1998), surface water treatment regulations (Regli et al., 1999), drip irrigation (Tiwari et al., 1998), groundwater quality improvements (Yadav and Wall, 1998), health risks from drinking water (Odom et al., 1999), agricultural water pollution control (Qiu, 2003), improvements of sewer systems (Schultz et al., 2004), groundwater recharge (Bolzan et al., 1999), rainwater harvesting (Ngigi et al., 2005), river health (Bennett, 2002), and re-allocations (Messner et al., 2006).

The hydro-economic model framework allows integrating water management at a scale of river basin and can contribute for a comprehensive economic analysis. Ward (2009) illustrates a simple structure of a hydro-economic model which includes various modules such as river basin structure, institutional constraints, hydrologic constraints, water use and economic efficiency and benefits. The river basin structure defines the supply and demand of water considering watershed inflows, agricultural and urban water uses and the stream-flows at river, measured in water volume units. The institutional constraints set the allocation of water according to previous formal or informal agreements such as water sharing arrangements, water rights, international delivery obligations, water pollution regulations and minimum guarantees to supply water to satisfy human rights.

3. Multi-criteria decision making methods

The usual process of MCDM defines objectives, specifies alternatives, transforms the criterion scales into commensurable units, assigns weights to the criteria that reflect their relative importance, selects and applies a mathematical algorithm for ranking alternatives and chooses an alternative (Howard, 1991; Keeney, 1992; Hajkowicz and Prato, 1998; and Massan, 1988).

MCDM can be classified into continuous and discrete methods (Hajkowicz, 2000b; and Janssen, 1992). Linear programming, goal programming and aspiration-based models are classified as continuous methods. Discrete MCDM methods include decision support techniques that have a finite number of alternatives (Hajkowicz et al., 2000a). Discrete methods can be devised into weighting methods and ranking methods (Nijkamp et al., 1990) and into qualitative, quantitative and mixed methods.

Analytic Hierarchy Process (AHP), multi-attribute value theory (MAVT) and multi-attribute utility theory (MAUT) are the most common approaches that use mathematical functions to help decision-makers to construct their preferences. MAVT belong to the riskless (certainty) models category, and MAUT as well as ELECTRE (Elimination and Choice Translating Reality) belong to the quantitative risk models category. Decision under risk and uncertainty are based on expected utility theory (Pollack, 1967; Keeney, 1968; Dyer, 1992; and Hardaker et al., 1997).

AHP aggregates individual criteria into an integrated criterion (Saaty, 1977; and Bouma et al., 2000). In this method the preferences are compared in a pairwise manner with regard to the proceeding element in the hierarchy. Pairwise comparison data can be done using either regression analysis or eigenvalue.

MAVT allows deal with multiple value functions $V_i$ of given attributes $Y_i$ which are weighted by scaling constants $\lambda_i$ and are aggregated into an additive value function.
\[ V(Y_1, ..., Y_n) = \sum_{i=1}^{n} \lambda_i V_i(Y_i), \] where \( V_i(\text{worst } Y_i) = 0, \) \( V_i(\text{best } Y_i) = 1, \) \( 0 < \lambda_i < 1, \) and \( \sum_{i=1}^{n} \lambda_i = 1. \) MAVT has modified the MCDM methods, allowing include into them the value of non-marketed environmental resources (Gregory et al., 1993).

MAUT is based on utility theory (Keeney, 1971) and according to the theorem of utility independence, if each utility \( U(Y_i) \) is independent of the utility \( U(Y_{i'}) \) then the utility function can be additive, being

\[ U(Y_1, ..., Y_n) = \sum_{i=1}^{n} k_i U_i(Y_i), \]

where \( k_i \) are the scaling constant in which \( 0 < k_i < 1 \) and \( \sum_{i=1}^{n} k_i = 1. \) The theoretical background of utility functions can be seen in Keeney and Raiffa (1976).

Goal programming (GP) has been also extensively used to multi-use management problems of natural resources including water (Amanda and Herath, 2009).

The value-based approaches have implicit the assumption that one should have some form of compensation between attributes and ordering of alternatives. The outranking methods allow for relaxing these assumptions by means of binary relations of indifference, strict preference, large preference and incomparability. ELECTRE is one of the most used outranking methods in which the decision-makers preferences are given by pairwise concordance and discordance tables (Raju and Pillai, 1999).

New techniques and developments of existing MCDM have emerged in the last decades. The combination of FGM and IDM is one of them, which is used to approximate the Pareto frontier and to identify efficient feasible goals.

4. The Feasible Goal Method and Interactive Decision Maps

According to Simon (1960) a decision making process has two main steps: 1) designing a small number of decision alternatives; and 2) final choice of a single decision alternative from a small list. The FGM/IDM technique is well suited to deal with these two steps in the multiple criteria decision making process and its developments and applications
can be seen in Bushenkov and Lotov (1982), Lotov et al. (2001 and 2004), Lotov et al. (2005) and Efremov et al. (2009).

When there are more than two criteria, visualization of Pareto frontier can be carried out using the IDM. The preferred point of decision maker in the Pareto frontier is the feasible goal. Its identification through Pareto frontier visualization as well as the associated decisions is known as FGM.

Let be $X$ the feasible decision set and $f: X \rightarrow \mathbb{R}^m$ a mapping from $X$ to the criterion space $\mathbb{R}^m$, the performance of each feasible decision $x \in X$ is described by criterion vector $y = f(x)$ with $y_i$ criteria and $Y = f(X)$ is the feasible criterion set, assuming that $X$ is compact and $f: X \rightarrow \mathbb{R}^m$ is continuous. When all criteria must be maximized, $y$ dominates $y'$ in a Pareto sense, if, and only if $y \geq y'$ and $y \neq y'$. The Pareto frontier of $y$ is given by:

$$P(Y) = \{y \in Y: \{y' \in Y: y' \geq y, y' \neq y\} = \emptyset\}$$

Being the $\mathbb{R}^m$ the non-positive orthant in $\mathbb{R}^m$, the set $H(Y) = Y + \mathbb{R}^m$ is the Edgeworth-Pareto Hull (EPH) of $Y$, which according to Stadler (1986) is the maximal set that satisfy $P(H(Y)) = P(Y)$. The dominated frontier of a variety of feasible objectives disappears in the EPH making it a simpler structure than the original feasible sets in criterion space.

The value function of stakeholders $V_i(y)$ with $i=1,...,n$ is not known and can be constructed through a process in which stakeholders indentify their feasible goals, this is, their preferred feasible criterion points $y_i \in Y$. For the $n$th stakeholder the preferences are associated with the decisions $x_i \in X$ that is the solution for the following optimization problem:

$$\text{Max} V_i(f(x)) \quad \text{s.t.} \quad x \in X \quad \text{and} \quad y_i = f(x_i)$$

If $V_i(y)$ is increasing, $V_i(y) > V_i(y')$ if $y > y'$ and $y \neq y'$. Then the solutions of the optimization problem will be non-dominated and $y_i \in P(Y)$. As in most cases the value function $V_i(y)$ is not known, the stakeholder has to find the preferred non-dominated point
\( y_1 \in P(Y) \) by himself. This can be done with the help of IDM technique to inform stakeholder about the Pareto frontier.

Gass and Saaty (1955) firstly showed Pareto frontier of bi-criteria linear problems. The IDM technique develops this idea and allows displaying the Pareto frontier for more than two criteria, by means of interactive display of the bi-criterion slices of the \( H(Y) \).

A bi-criterion slice is defined considering the criteria \( (y_1,y_2) \) in the ‘axis’ and the remaining criteria \( z \), which are fixed at \( z^* \). Then a bi-criterion slice of \( H(Y) \) parallel to the plan \( (y_1,y_2) \) and related to \( z^* \) can be represented as:

\[
G(H(Y), z^*) = \{(y_1,y_2): (y_1,y_2,z^*) \in H(Y)\}
\]

The slice of \( H(Y) \) includes all feasible combinations of criteria \( (y_1,y_2) \) when the remaining criteria is not worse than \( z^* \). These bi-criterion slices are used in IDM technique to show decision maps.

A decision map is defined specifying in addition to the first bi-criteria a third criterion or colour associated at it. Hence, a decision map is composed by various superimposed slices, for which the criterion values or associated colours vary, while the remaining criteria are fixed.

Under IDM technique the users can choose a trade-off curve by fixing the third criterion. Trade-off curves can be changed, improving the value of the third criterion until that both axes reach unjustifiable values, or vice versa, improving values of the two axis criteria until the value of third criterion attain inappropriate values. When the user chooses the right trade-off curve, he should try to find a compromise between the values of both criteria on the axis. More than three criteria can be specified using scroll-bars that help to indicate their values.
Decision maps help to find a preferable feasible goal, which once identified, is regarded as the reference point (Wierzbicki, 1981). An efficient decision is reached by solving the following optimization problem:

$$\max_i (y_i^* - y_i) + \sum_{i=1}^n \epsilon_i (y_i^* - y_i) \rightarrow \min \quad \text{with } y_i = f(x_i) \text{ and } x \in X$$

where $\epsilon_1, \ldots, \epsilon_n$ are small positive constants and $y_i^*$ is a fixed point in IDM.

5. The linear multi-criteria model of Odivelas irrigation area

A linear hydro-economic model including river basin and institutional constraints, and economic efficiency and benefits, under a structure of multiple stakeholder goals, that represents the main characteristics of the Odivelas irrigation, was developed.

Odivelas irrigation is a public irrigation from the sixties of the 20th century in the Alentejo region, southern Portugal. The climate has a Mediterranean pattern, being water scarce in the summer, and sequences of dry years are frequent. The main water sources are the lakes of Alvito and Odivelas with a storage capacity of 129 hm$^3$ and 70 hm$^3$, respectively. The lake of Odivelas is the main reservoir and the lake of Alvito is an upstream reservoir for regularization that is used when water lacks. The water flows by gravity in the Sado river, from Alvito lake to Odivelas lake and is delivered to irrigation through a distribution network with a length over 300 Km.

This river basin structure and hydrologic constraints were formulated considering the following relations of monthly water inflows and outflows in the lakes of Alvito and Odivelas:

$$a_{m-1} - a_m - t_m \geq 0 \quad (1)$$

$$a_m - t_m \geq 0 \quad (2)$$

$$o_{m-1} + i_m + t_m - o_m - q_m - w_m \geq 0 \quad (3)$$
where, $a_m$ and $o_m$ are the water available in the end of month $m$ in the two lakes, respectively; $t_m$ are the monthly water transfers from the Alvito lake to the Odivelas lake, $i_m$ and $q_m$ are the water inflows and outflows in the Odivelas lake from and to the Sado river basin, and $w_m$ is the water delivered to irrigation. Relations (1) and (2) ensure that the water transferred from the Alvito lake to Odivelas lake is always less than or equal to the water that remains in the Alvito lake. Relation (3) regards the monthly water balance in the Odivelas lake, guaranteeing that water available resources are greater than or at least equal to the total water requirements. Water supply is given by the water available in beginning of the month in the Odivelas lake $o_{m-1}$, plus water inflows from the Sado river $i_m$ and from the Alvito lake $t_m$. Total water requirements include water delivered to irrigation crops $w_m$, water outflows to the Sado river basin $q_m$ and the water available in end of the month $o_m$.

Regarding to the institutional constraints, the model considers the available irrigable area in each irrigation block (4) and upper bounds to the crop areas (5) representing agronomic and market constraints:

$$ \sum_k x_j^k \leq s_j \quad (4) $$

$$ x_j^k \leq d_j^k \quad (5) $$

where, $x_j^k$ is the decision variable on crop acreage $k$ in the $j$ irrigation block; $s_j$ is the parameter of irrigable area per block; and $d_j^k$ is the upper bound of demand for land per crop and irrigation block.

The irrigable area, this is, the potential irrigation area in the Odivelas system is 12,354 ha. This area is not all similar and is divided into three irrigation blocks which differ in irrigable area, in the way water is delivered and in water fees. The block 1 has an irrigable area of 5,545 ha (45%) and water is delivered by gravity. The block 2 has an irrigable area of 1,300 ha (11%) that recently received infrastructure improvements and now has water is
delivered under pressure. Block 3 is a modern irrigation system with 5,500 ha where water is also delivered under pressure. It was carried out just in 21\textsuperscript{th} century to be integrated in the hydraulic network of the Alqueva project, which is one of the biggest irrigation systems in Europe.

Water fees include fix rates of irrigable area and proportional rates of water consumption for each one of the three irrigation blocks. In block 1, water is delivered by gravity and the fix and variable rates are 24.94 Euros per ha and 0.018 Euros per m\textsuperscript{3}, respectively. In blocks 2 and 3, where water is delivered under pressure, the variable rate is 0.0466 Euros per m\textsuperscript{3}, and the fix rate is 41.9 and 46.5 Euros per ha, respectively.

The model includes the main irrigated crops in the region as acreage decision, namely rice, maize, tomato, sunflower, grasslands, wheat and other irrigated crops. Irrigated and dry crops compete both by the available irrigable area.

Private farmers aims and social and environmental aims were considered as goals of different stakeholders. Private farmers’ aims are represented by the criterion of farm profit maximization in the short term \((F_1)\) and by the criterion of business risk minimization \((F_2)\). The social goals are associated with reducing the unemployment in rural areas by maximizing the farm labor hiring \((F_3)\), increasing the utilization of public irrigation systems by maximizing the irrigated area \((F_4)\) and recovering of public costs with irrigation structures by maximizing the farmers’ payments of water fees \((F_6)\). As environmental goals was considered the criterion of the minimization of irrigation water consumption \((F_5)\), assuming that as less is the water consumption, more water can be delivered for environmental goods in the river basin. The mathematical formulation of these criteria is given by:

\[
F_1 = \sum_j \sum_k c_j^k x_j^k
\]  
(6)

\[
F_2 = \frac{1}{R} \sum_j \sum_k \sum_r |c_j^k - c_{jr}^k|x_j^k
\]  
(7)
\[ F_3 = \sum_j \sum_k l_j^k x_j^k \]  
(8)

\[ F_4 = \sum_j \sum_{kr} x_j^{kr} \text{ with } kr \in K \]  
(9)

\[ F_5 = \sum_j s_j a + \sum_m w_m p \]  
(10)

\[ F_6 = \sum_m \sum_k \sum_j w^k_{jm} x_j^{kr} \]  
(11)

where, \( c_j^k \) is the mean annual cash-flow of each crop \( k \) and irrigation block \( j \) per ha; \( c_{jr}^k \) is the crop profit per state of nature \( r \); \( x_j^k \) is the crop acreage; \( l_j^k \) is a parameter of labor requirements; \( a \) is the fix irrigation rate; \( p \) is the water rate; and \( w^k_{jm} \) are the monthly \( m \) water requirements per crop \( k \) and irrigation block \( j \).

6. Making a decision with Feasible Goal Method/Iterative Decision Maps

For making a decision with FGM/IDM we need to consider four steps. The first step is the construction or approximation of the Pareto frontier on the base of the EPH. The second step regards the interactive display of decision maps. This step is very important to prepare the third step, which is the choice of the preferable feasible goal. After selecting preferable goal, the last step is the computation and analysis of relevant decisions which are associated to that feasible point.

Let us start by studying the relationship between the farm profit \((F_1)\) and business risk \((F_2)\). The criterion \(F_1\) is given by the annual farm profit in the short term and the criterion \(F_2\) is measured through the mean deviation of the annual farm profit for five states of nature. These states accommodate the annual farm cash-flow during the period from 2004 to 2008. Usually farm profit and business risk are in conflict once more profit often brings more risk, and less profit can be associated to a low level of risk.
Figure 1 shows the decision map for these two criteria. The horizontal axis reports the $F_1$ values and the vertical axis lists the $F_2$ values. The EPH which contains all combinations of feasible two criteria vectors is represented by the shaded area. The frontier of this shaded area is the Pareto frontier and the combinations outside this area are not feasible.

**Figure 1. Decision map for criteria $F_1$ and $F_2$**

Values of $F_1$ and $F_2$ can vary from 0 Euros to 5 and 6.5 million Euros, respectively. A value of zero on the profit criterion is also associated to a business risk null. Likewise the maximum profit (5 million Euros) corresponds to the maximum level of risk. In this point the trade-off between the two criteria is 1.3 Euros/Euro, which means that by each one additional Euro of profit the deviation from the average profit increases 1.3 Euros.

The slope of the Pareto frontier displayed in the decision map shows that the relation between the two criteria changes near the point for which the profit is about 3 million Euros. Above this value, the trade-off between $F_1$ and $F_2$ is higher than 1 Euros/Euro.

For the criterion $F_2$ a value less than 3 million Euros is not very interesting because the marginal value of business risk is much lower than the marginal value of farm profit. Then,
not only is the farm profit too low as any marginal reduction on business risk leads to a great decrease on farm profit.

In the extensive trade-off two critical points are chosen as efficient compromises, the strategy A and the strategy B. The first one is associated to $F_1$ equal to 3.05 million Euros and $F_2$ equal to 3.1 million Euros. For the second strategy values for these two criteria are 4.4 and 5.1 thousand Euros, respectively. Strategy A is less profitable and less risky than strategy B and the trade-off between the two criteria is 1.02 Euros/Euro. Strategy A is in the initial part of the Pareto frontier where the marginal value of the profit is greater than the marginal value of the business risk. At this point the profit is 62% of its maximum value. Strategy B corresponds to 88% of the maximum profit and reflects a trade-off between profit and risk of 1.2 Euros, which is close to maximum trade-off (1.3 Euros/Euro).

Since strategies A and B are identified and the values for criteria $F_1$ and $F_2$ are fixed, we will analyze and make a decision with FGM/IDM to find the corresponding preferable feasible goals separately for each one of these points.

Figure 2 shows the multi-dimensional decision map that was built for the criteria $F_1$ to $F_6$ under the strategy A. In this decision map the criteria $F_3$ and $F_4$ are represented on the horizontal and on the vertical axis, respectively. Since the values of criteria $F_1$ and $F_2$ are fixed, the third criterion to be considered in the making decision process was $F_5$ corresponding to water consumption. In order to explore the trade-off between these three criteria ($F_3, F_4$ and $F_5$) we improve the value of $F_5$ until $F_3$ and $F_4$ reach unacceptable values.

The criterion $F_6$, regarding farmer’s water costs with irrigation public fees, is the last to be added on the decision map of the Figure 2 and changes on its values can be assessed by moving the scroll-bars sliders. The different colour slices and the slopes of curves show how the values and trade-offs between the three criteria $F_3, F_4$ and $F_5$ are displayed, while the
fourth criteria \(F_6\) changes. Since, the fourth criterion is represented by a scroll-bar its best value can be found easily.

**Figure 2: Multi-dimensional decision map for criteria \(F_1\) to \(F_6\) under the strategy A**

Water consumption under strategy A can change from 18 million \(m^3\) to 30 million \(m^3\). The smallest value is the best from the environmental point view, since the optimization sense of the criterion \(F_5\) is the minimization. However, this level of water consumption is associated to a poor performance of the criteria \(F_3\), \(F_4\) and \(F_6\). If the highest value of water consumption is considered the environmental goals are suffer. The social goals related with the criteria of irrigated area \(F_4\) and recovering water costs can be maximized \(F_6\). Irrigation structures often are underutilized, resulting in high opportunity costs for public investments and growth of irrigated areas can allow reducing these costs.

One can see that decreases on the marginal value of \(F_5\) depend on both values \(F_4\) and \(F_5\). When \(F_5\) decrease the strips are narrow and hence the trade-off concerning \(F_4\) is small. However, if decreases on \(F_5\) are associated to wide strips the reductions on \(F_4\) are great.
Traditionally agriculture has an important role in employment in rural areas, which justifies, from a social point of view, that hiring labor \((F_3)\) should increase and be maximized. As it was done for \(F_4\), one can explore and interpret the relation between \(F_3\) and \(F_5\).

Let us chose for \(F_5\), as the best compromise between the three criteria, a water consumption level of 20 million m\(^3\). This value represents a median level for the water consumption goal, which that is 11% higher than the minimum value of the criterion \(F_5\) and 67% or two third of its maximum.

The value of criterion \(F_6\) can range from 0.8 to 1.4 million Euros. Its minimum value is associated to the minimum value of \(F_5\), as well as, the maximum value of the recovering water costs is achieved when the water consumption reaches its maximum. For a consumption water level of 20 million m\(^3\) the trade-off between \(F_5\) and \(F_6\) ranges from 0.04 Euros/m\(^3\) at the minimum level of \(F_6\) (0.8 million Euros) to 0.06 Euros/m\(^3\) considering water fees of 1.1 million Euros.

In view of these issues, one adopts for the criterion \(F_6\) a water cost for farmers of 1.1 million Euros, which corresponding to 36% of the farm profit and represents an average charge of 200 Euros per ha.

Figure 3 represents the detail of Figure 2 relative to the scroll-bar slider in which \(F_6\) is equal to 1.1 million m\(^3\), and where one can identify the compromises between \(F_3\) and \(F_4\) having in account the fixed values for the remaining criteria. In this figure for the hired labor \((F_3)\) is chosen a level of 451 thousand hours of work which represents environ 200 annual units of work at full time and for irrigation area \((F_4)\) is considered the value of 5,300 ha. This figure also shows the values chosen for the criteria that compose the preferable feasible goal under the strategy A.

Strategy B which was identified as an alternative in the Figure 1 is more profitable and risky than the strategy A.
Figure 3. Decision map for criteria $F_1$ to $F_6$ and preferable feasible goal under strategy A

Source: Model results

Figures 4 and 5 display the decision maps for criteria $F_1$ to $F_6$ that are used to make a decision under the strategy B.

Figure 4. Multi-dimensional decision map for criteria $F_1$ to $F_6$ under strategy B

Source: Model results
Under the strategy B, the criterion $F_5$ can change from 28 to 34 million m$^3$. If we consider that on the distribution network water losses are 30%, the minimum and the maximum values of water consumption represent around 30% to 38% and 57% to 70% of the storage capacity of the lakes of Olivelas and Alvito, respectively. Considering the desirable values of the remaining two criteria ($F_3$ and $F_4$), we chose for $F_5$ a water consumption of 29 million m$^3$. This is more than 4% the minimum value of that criterion and represents less 15% than its maximum value.

Under strategy B, the criterion $F_6$ can change from 1.325 to 1.5 million Euros and we chose a level of 1.35 million Euros. This value is 2% higher than the minimum and is less 10% than its maximum. It is also the feasible point that offers the best trade-off between criteria $F_5$ and $F_6$.

Under the strategy A private goals regards a farm profit of 3.05 million Euros and a business risk of 3.1 million Euros. The compromise in terms of social goals leads to 451 thousand hours of hiring labour, 5,300 ha of irrigated area and 1.1 million Euros of recovering water costs. These levels of private and social goals are dependent on the environmental goals which are expressed by a water consumption level of 20 million m$^3$. 
Table 1: Main irrigation crops area (ha) under the initial and A and B simulated strategies

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<th>Strategy initial</th>
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<th>Strategy A</th>
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<th>Strategy B</th>
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<td>Rice</td>
<td>308</td>
<td>308</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Maize</td>
<td>1136</td>
<td>510</td>
<td>120</td>
<td>506</td>
<td>1207</td>
<td>456</td>
</tr>
<tr>
<td>Tomato</td>
<td>247</td>
<td>111</td>
<td>26</td>
<td>110</td>
<td>159</td>
<td>27</td>
</tr>
<tr>
<td>Melon</td>
<td>167</td>
<td>75</td>
<td>18</td>
<td>74</td>
<td>201</td>
<td>90</td>
</tr>
<tr>
<td>Sunflower</td>
<td>225</td>
<td>101</td>
<td>24</td>
<td>100</td>
<td>270</td>
<td>121</td>
</tr>
<tr>
<td>Grasslands</td>
<td>716</td>
<td>322</td>
<td>75</td>
<td>319</td>
<td>798</td>
<td>386</td>
</tr>
<tr>
<td>Wheat</td>
<td>145</td>
<td>65</td>
<td>15</td>
<td>65</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Other irrig. crops</td>
<td>71</td>
<td>32</td>
<td>7</td>
<td>32</td>
<td>84</td>
<td>38</td>
</tr>
<tr>
<td>Dry crops</td>
<td>3601</td>
<td>1607</td>
<td>381</td>
<td>1613</td>
<td>4005</td>
<td>1613</td>
</tr>
</tbody>
</table>

Source: Model results
The strategy B is more profitable and more risky than strategy A and its social impacts are more pronounced. However, it is environmentally less sustainable. In relation to the strategy A, the improvements on private and social goals are reflected in increases on the farm profit, hiring labour, irrigated area and recovering water costs of 44%, 30%, 49% and 23%, respectively. The worse environmental behaviour expressed by strategy B is reflected in an increase on water consumption of 45%.

Table 1 presents the main crop acreages for each irrigation block and for the whole of the Odivelas irrigation, under the two strategies considered. Results of the two simulations seem to be coherent with the initial reality in the Odivelas irrigation. As in the initial strategy, the maize, grassland and sunflower are always among the main irrigated crops. Rice does not appear in the model results, because this crop is too much demanding on water and in the simulations water consumption is a minimizing criterion.

In strategy A, the five main crops are carried out in 2,635 ha of irrigated land. These crops are maize (1207 ha), grasslands (798 ha), sunflower (270 ha), melon (201 ha) and tomato (159 ha). This crop pattern is maintained under strategy B, but the acreages of maize and tomato rise 13% and 50%, and the acreage of grasslands declines 72%. Maize and tomato are profitable crops with high requirements of labour and water and its harvest production and market price values are subject to a large variability. Unlike, grassland is less profitable, the profit is stable, and the requirements of water and labour are low. These reasons associated to the changes on acreage crops justify the improvements on farm profit and on all social goals, as well as, the environmental damages that are observed when we change from the strategy A to the strategy B.
7. Conclusion

In this paper a decision making process is constructed with FGM/IDM technique to find an efficient and equitable combination of stakeholder goals from a linear multi-criteria model applied to the Odivelas irrigation in southern Portugal. In order to respond efficiently to the issues related with the features of water as a public good and a common good, principles of integrated water management and economic, social and environmental goals of the different stakeholders were considered in this framework.

Two preferable feasible points were found corresponding to strategy A and strategy B. Under strategy B farm profit and the social goals related with employment, irrigated area and the recovering water costs, achieve more satisfactory levels than in the strategy A. However, strategy A is environmentally better and less risky than the strategy B because it leads to a lower water consumption level and to a more stable farm profit. These differences are mainly due to changes in crop areas associated to strategy B with increases of acreage of maize and tomato and decrease of grassland relatively to strategy A.

As Ananda and Herath (2009) refers that MCDM approaches, where FGM/IDM technique is included, should bring a greater degree of reality to the planning policy process. In our case results are coherent and realistic with the initial strategy in the Odivelas irrigation area.

FGM/IDM technique showed to be an interesting approach to study water economic management problems and is well suited to be applied to the Mediterranean irrigated areas. One of the main advantages is that, it allows for stakeholders and their subjective preferences on the making decision. However, in the process of displaying the decision maps the construction of the Pareto frontier never depends on the user subjective preferences, being these expressed only to identify a preferable goal. This technique can be easily implemented including on computer networks through the internet (Lotov et al., 2005).
References


