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Multi-Criteria Analysis and Decision-Support for Water Management at the Catchment Scale: An Application to Diffuse Pollution Control in the Venice Lagoon

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Summary

Water pollution in the Venice Lagoon and its catchment is a main environmental issue. In Italy public funds are made available by specific national and regional regulations in order to support the realisation of initiatives for the abatement of pollutant loads that travel from the catchment into the lagoon.

Local agencies in charge of water management may apply for funds by presenting suitable projects in the field of hydraulic and environmental engineering particularly modifications to the surface water network aimed at reducing diffuse pollutant loads in the Venice Lagoon.

Because the need to support those agencies in choosing among options often arises, together with the need of presenting and supporting choices that are made, in front of the funding administration.

The decisional context of the present study was determined by a given amount of public funds made available by the regional administration, to be used in an optimal way by choosing what to do (within a list of possible interventions like flow regulation, plantation of riparian vegetation, etc.) and where (within the surface water network of the district).

A multi-stage multi-criteria evaluation approach was developed, which subdivided the decisional problem into two operational phases.

In a first step a priority sub-area was chosen within the district with a multi-criteria evaluation procedure which took into account several decisional criteria, formulated by the authority responsible for the decision. Those criteria were quantified by using thematic maps (GIS layers), as spatial indicators for prioritising the location of pollution control initiatives.

In a second step the choice among alternative projects within the chosen area was supported by a second round of multi-criteria analysis developed in collaboration with a decisional board.

The results of the application of the proposed method to the case study demonstrated the potentials of collaborative multi-criteria analysis in supporting the activity of operational agencies during the whole process of development of proposals, plans for interventions and projects, both internally to share information and build consensus within the various component of the board, and outside, in the relationship with external bodies (funding agencies, local stakeholders, etc.), to present and support the decisions proposed.

JEL: Q15, Q25, Q30

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Introduction

The introduction of the concept of sustainable development in the management of natural resources is leading to a consistent rethinking of the principles of water management. Among the driving forces of this new approach is the integration of the economic and social development in a long-term ecological perspective. This perspective, also adopted by recent EU legislation, such as the Water Framework Directive (2000/60/EC), requires new scientific know-how and suitable tools to support the administrations that manage water resources. In Italy, a pivotal role in this field is played by the Land Reclamation Boards, which are public administrative bodies made up of all the private individuals who live or have economic activities in a given territory requiring water management (i.e. in general all the alluvial plains), defined according to hydrological and administrative criteria. In the Venetian hinterland in recent years the political will to tackle and solve the environmental problems of the Venice Lagoon has made relatively large sums of public funds available for water management, and the Land Reclamation Boards are the main recipients. They therefore face new decision-making and planning problems and require suitable scientific support and methodological and operational tools for supporting water resource management. In this context, the planning of operations to minimise the impact of diffuse pollution on the waters of the Venice Lagoon has great relevance.
Various interventions can be financed using the funds made available by the Veneto Region, all however within the field of environmental and hydraulic engineering, such as the planting of wooded belts (buffer strips), supports on water courses, diversions, drainage, and constructed wetlands.
Environmental engineering projects, such as revitalising and re-naturalising water courses, are among the most interesting of the new proposals to reduce non-point source pollution (agricultural and other) of public surface waters. As well as showing a good capacity for reducing pollution loads, they can also have other functions such as upgrading the farming landscape and improving the recreational use of rural areas.
This multi-functionality, public and private, of these projects poses planning problems at a territorial scale, as the methods used may affect the improvement of one or more functions (pollution prevention and mitigation, recreational use, landscape quality,). Because these are complex operations, that include a combination of hydraulic engineering, natural resource management and, forestry, all of which must be planned for the specific area, the decision-making process is quite complicated.
Within this framework, Decision Support Systems (DSS) may be developed to allow scenario simulations and the evaluation of different strategies and interventions in water management, taking into account different aspects of the local socio-economic system together with the implementation of the current local and European policies.

There are various ways to steer the choices about what can be done in a given territory, that are bound by legislative or financial constraints. A possible solution is the division of the decisional problem into consecutive phases. In a first phase, limiting the analysis to localisation, the decisional problem can be tackled by identifying the sites, or areas that, with respect to a given general objective, maximise the efficiency at a given cost, or else minimise the cost of a given standard of efficiency. In subsequent phases specific aspects can be analysed, such as the identification of the types of intervention and the choice between alternative projects.

In general, taking into account the possible positive effects of environmental engineering projects on the water network, general criteria can be identified that can guide the planning of operations at the water catchment level. The localisation phase can therefore be orientated towards:

- areas of higher generation of diffuse pollution loads;
- sub-basins that contribute more to polluting the receiving water bodies;

• the sub-basins and areas along the watercourses where the water quality is worse in terms of the parameters upon which re-naturalising can have a positive affect;
• watercourses that have a lower self-purification potential;
• watercourses with higher landscape value.

Within this context, the decision-making process that leads to identifying the more suitable territorial situations emerges as a typical problem of multidisciplinary analysis that can be solved with a cartographic model of multi-criteria screening. The subsequent phases, while maintaining an approach based on the classical theory of multi-criteria analysis, must instead be more in line with the evaluation methods of alternative projects, according to the theory of environmental impact evaluation.

This paper presents an application of decision support for optimising public investments, aimed at controlling nutrient run-off through integrated environmental and hydraulic engineering interventions on the surface water network. In an initial phase a decision model supported by data managed by a geographical information system is utilised to identify the priority areas within a district whose waters are managed by the local Land Reclamation Board. Combinations of maps, representing the decisional criteria (e.g. the map of water risk), are combined in an information system based on homogeneous zones (macro-areas) that are the alternative options to be ranked, according to a priority criterion for the investments. In the area identified as highest priority, alternative projects designed on the specific territorial and hydrological characteristics of that area, are then compared according to a multi-attribute approach, based in part on the same decisional criteria that steered the choice between macro-areas and in part on new parameters that are significant for the new, more detailed decision-making context.

1. The multi-criteria approach to public choices in the environment

Many evaluation problems are posed by pollution control operations, even if they all lead back to the question common to all operations of a mainly public nature, i.e. if the operation is worthwhile from the point of view of the community and if the proposal is the best among those possible.
Evaluation of the public worth of the use of a given investment can be tackled with the classical tools of cost analysis (CA), cost-efficiency analysis (CEA), cost-benefit analysis (CBA), or else with the more recent methods of multi-criteria analysis (MCA).

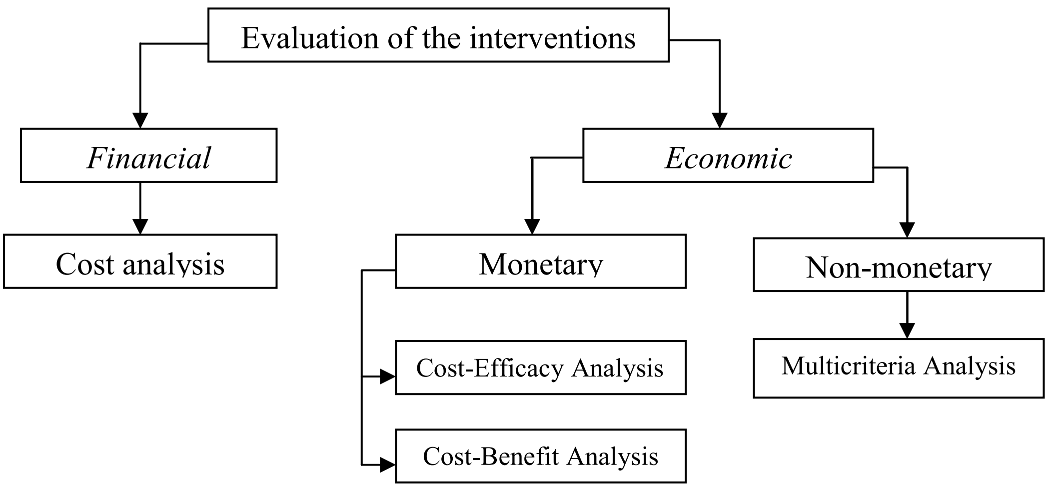

Figure 1 – Flowchart of possible valuation approaches

CA aims to evaluate the feasibility of the operation in a strictly financial way and is applicable to public contexts when the advisability of the choice of investment has been evaluated previously. For example, estimating if a project is worth financing on behalf of a banking institute. This analysis can also be enough to cover the evaluation of operations that aim to counter negative externalities[1] whose economic impact is certainly greater than the resources necessary to eliminate them.

CEA widens the evaluative horizons to the public dimension and makes a comparison between the costs of the operation and the obtainable benefit, measured in technical terms. It is a rapid analysis for evaluating one or more alternative investments. Its main limitation is the lack of a process to weight the costs against the benefits obtained when these differ between the projects. CEA is fairly widely used in public evaluation and is efficient where there is an important political requirement and the projects have the same aims.

CBA is, in some ways, the best developed of the techniques for economic monetary valuations of investments, it boasts a long tradition and continuing progress in theoretical and methodological improvement. As is well known, the advisability judgement formulated by CBA considers the monetary valuation and the time discounting of the costs and benefits, both private and public, produced by the project. It has the advantage of being easy to understand and allows a simple comparison between the various investment alternatives. Yet it has some fairly obvious limitations due to two main questions. The first is the need to evaluate the benefits and costs monetarily. Such an evaluation is fairly easy in the private context. Vice versa, for benefits of a public nature the question is much more complicated. Textbooks on the subject of CBA propose various procedures for attributing a monetary value to goods and services without a market, and therefore a price (Pennisi, 1985). The second limitation is the need to choose an appropriate discount rate (social) that, because of the public nature of part of the benefits and costs, cannot be obtained directly or exclusively from the market[2].

These limitations of the monetary approaches for evaluating projects with high environmental impact have stimulated the development of a new methodological approach to evaluation for the public domain. This approach recognises that the monetary valuation of externalities is extremely difficult and, although it is possible to reach a monetary judgement of value, it is very hard to establish its reliability. So much so that it is often used as a tool to verify decisions already taken.

The push that has led to the development of these new approaches has been the recognition that public choices are rarely made with respect to just one criterion, but are always multidimensional. Furthermore, the multidimensional nature of the choices doesn't just characterise the initial phases of the evaluation process (analysis phases) but permeates it throughout. Assuming this, the commonly used methods to reduce the problem to a single dimension, such as a monetary value in the case of CBA, always involve an over-simplification, if not a distortion of the evaluation elements. In the final analysis, the possibility of representing social wellbeing through the VAN measured in monetary terms must be considered an exception and not the rule.

All this shows that the choice of investment, that is a decisional problem, must always settle a dispute, i.e. it must manage to identify compromise solutions. The choice process can therefore be made up, alternatively, by selections that slowly reduce the number of options until the preferable one is identified. A possible representation of multi-criteria decision-making is given in figure 2.

The cartesian axes represent the aims (a_1 and $\mathbf{a_2}$) pursued with the hypothesised alternative investment (A, .., F). It is assumed that an increasing state of $\boldsymbol{a}$ is preferable to society. In this case the choice consists of identifying which alternative option is preferable. It is possible to use the principle of exclusion, eliminating those alternatives that would never be taken into consideration

[1] Technically, an externality is the effect of the production and consumption activities of one subject on the production and consumption activities of another subject without an equivalent monetary compensation.

[2] The question of the choice of discount rate in CBA is a bit controversial as it involves financial, social and ethical questions. There is open debate and to date the positions of the different experts differ widely (Brosio, 1993).

by a rational decision-maker and through a scoring procedure that ranks the options that cannot be excluded at the outset.

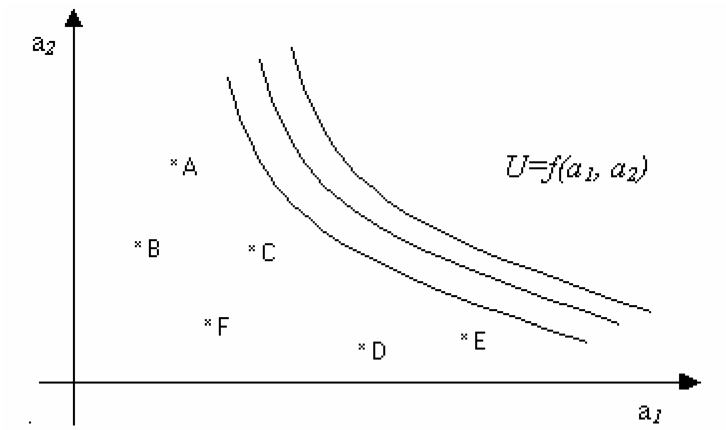

Figure 2 – Representation of a multi-criteria decision-making problem.

The figure shows that investments B, F and D can be excluded immediately as, for each of them another investment exists with a better performance compared to one criterion and not worse compared to the other.

In fact:

C vs B: $a_{1C} > a_{1B}$ *and* $a_{2C} = a_{2B}$
C vs F: $a_{1C} > a_{1F}$ *and* $a_{2C} > a_{2F}$
E vs D: $a_{1E} > a_{1D}$ *and* $a_{2E} > a_{2D}$

In other words C dominates (in the Paretian sense[3]) B and F, while E dominates D.

The figure also demonstrates that the principle of dominance used to reject investments B, F and D is not useful for continuing the analysis, i.e. to formulate a socially optimal ranking of the alternative options A, C and E. To continue the analysis it is necessary to formulate hypotheses on the structure of the preferences of the society that will accommodate the investment. Assuming that the social preferences are represented by the convex and monotonous function $U=f(a_1,a_2)$, it is possible to a rank the alternative options with respect to U.

This ranking is C, E, A as $U_C>U_E>U_A$ (see also the following figure).

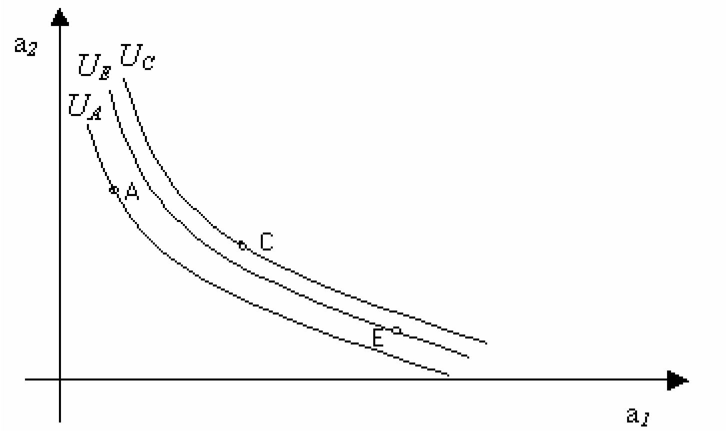

Figure 3 – The solution of the multi-criteria decision-making problem.

[3] The principle of Paretian dominance (Pareto-optimal) is extremely useful in the choices of a public nature and even more so in multi-criteria analysis as it allows the alternatives of choice to be isolated for which discordant orders exist with respect to the different criteria of choice and therefore explains the real conflicts (trade-offs) in the decision-making process.

The main question related to evaluating the investments with multi-criteria analysis is therefore the setting-up of suitable procedures that represent the social preferences when applied to a set of alternative investments not dominated in the Paretian sense. Multi-attribute analysis (MAA) aids the choice between the *n* finite alternative options (A_i) through their evaluation with respect to a finite number, k, of attributes (a_j), for which each option shows a given definable ranked performance index (a_{ij}).
Therefore, the problem of MAA can be represented as follows:

$$\text{Choose} \quad \{A_1, A_2, ..., A_n\} \qquad [1]$$
$$\text{as a function of} \quad \{a_1, a_2, ., a_k\}$$

2. Hierarchy analysis

In the previous section the motivations that have led to the multi-criteria analysis methods have been briefly illustrated and the main theoretical premises presented, now one of the most widely-used techniques will be presented: hierarchy analysis, which belongs to the MAA group. Hierarchy analysis allows a rational and realistic implementation of the general model.
The analytic hierarchy process (AHP) developed by Saaty (1980) is based on the assumption, common to most MAA methods, that the decision-maker is always able to state a preference. This, even where information is incomplete, always allows a weight to be associated to the attributes of evaluation that is proportional to their importance and allows a rank to be given to the alternative options with respect to each attribute considered. AHP is therefore a very useful procedure when there is little quantitative information on the impacts of the options to be evaluated.
The general AHP approach to the decision-making problem predicts some distinct phases through which it is possible to split a complex decision-making situation into a series of much smaller problems that are easy to solve. An initial phase defines the target of the choice; the criteria with respect to which the choice must be made (attributes); the alternative options among which the choice must be made. Into this outline the preferences of the decision-maker and the performance of the possible options are inserted. In the next phase rankings are produced that are coherent with the structure of the decision-maker's preferences and the trade-offs are explored between the possible choices in order to identify the most satisfactory alternative options.
The hierarchy analysis phases can be summarised as follows:
1) Identifying the aim of the investment;
2) Identifying the attributes for evaluating the investment;
3) Evaluating the role (importance) of each attribute with respect to the aim of the investment;
4) Identifying the possible intervention options;
5) Evaluating the alternative options with respect to each evaluation attribute;
6) Ranking the options with respect to the pursuit level of the aim of the investment;
7) Sensitivity analysis of the ranking obtained.

The evaluation route is therefore similar to the general multi-attribute approach through which, starting from an evaluation matrix containing the performances of the alternative options with respect to the evaluation criteria, the rankings are subsequently elaborated, hypothesising specific functions of utility or value (Vinke, 1992; Keeney and Raiffa, 1976). Hierarchy analysis differs in that it offers a general method for building up the evaluation matrix and the value functions even in the absence of precise quantitative information.
This method can be summarised in the following principles:
1) Breakdown
2) Paired comparison
3) Hierarchy structure

The idea of splitting the problem leads to the definition of a structure that allows the information to be ranked on reciprocal ratios of the variables that intervene in the choice. For example, in the case of a hierarchy on three levels related to the choice between three options according to three conflicting attributes, a breakdown can be identified like that shown in figure 4.

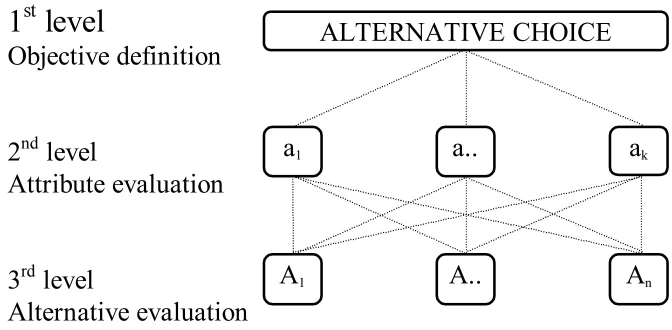

Figure 4 – Example of hierarchy on three levels

The splitting can identify any finite number of levels so it can be done to the desired level of detail.
The task of the splitting phase, as well as representing all the aspects influencing the decision, is that of structuring the subsequent evaluation by means of paired comparisons.
In fact, the analysis now concentrates on many easily faced partial problems. Each partial problem is solved through the compiling of a paired comparison matrix and the subsequent interpolation of the preferences expressed in a vector. For example, referring to the problem represented in figure 3, the evaluation is split into the compilation of positive and reciprocal K squared matrixes $(n \ x \ n)$, whose generic element i.j represents the decision-maker's preference for the ith option over the j^{th} according to the k^{th} criterion. K eigenvectors are then obtained from the K matrixes that, together, define the evaluation matrix ($k \ x \ n$).
A squared matrix ($k \ x \ k$) is then compiled to derive the weighting vector, i.e. the relative importance of the criteria with respect to the final target.
Defining the methods for compiling the squared matrixes of paired comparisons and those of the estimate of the interpolating vector representing the judgements made is therefore of fundamental importance for the analysis. With reference to psychological studies on the " indistinguishableness classes", Saaty (1980) proposed a scale of values that allows the qualitative judgements of comparison to be translated into quantitative terms. This scale of relative importance covers an interval of values between 1 (equal importance between the compared aspects) and 9 (extreme importance of one over the other). The reciprocal values of the precedents are also defined so that, if for example, a preference intensity of 3 is assigned to an aspect compared to another aspect, then the latter has a preference intensity that is the inverse of the first (1/3).
The complete scale of comparative judgements used to indicate preferences is reported in the following table.

Comparative judgement	Numerical equivalent
Absolutely the most important	9
Much more important	7
More important	5
Slightly more important	3
Equal importance	1
Slightly less important	1/3
Less important	1/5
Much less important	1/7
Absolutely of least importance	1/9

Table 1 – Saaty's hierarchical ranking

In other words, the comparisons are initially formulated by a verbal judgement to which a corresponding numerical value is subsequently associated. This judgement is given on the alternative option reported on the line compared to the option reported in the column.
After having formulated all the comparative judgements and compiled the matrices containing the corresponding numerical values one passes to the phase of hierarchic composition through which the ranking of the options is obtained with respect to each attribute and of the attributes with respect to the final aim of the choice. Saaty proposes as best solution for ranking the options that given by the values of the maximum eigenvector of the paired comparison matrix. The goodness of the obtainable hierarchical ranking is strictly dependent on the congruence with which the judgements are formulated in the paired comparison matrix. In fact, the main cause of the inconsistency of that matrix is due to the lack of transitivity in the preferences that translates into the fact that the judgements made may not have transitivity. To evaluate the consistency of the paired comparisons matrix[4] A it is possible to calculate an index, named "inconsistency", that shows the shift of the judgements made away from a situation of perfect coherence.
Saaty defines the inconsistency index as

$$\text{I.I.} = \frac{\lambda_1 - n}{n-1}$$

where λ_1 is the maximum associated eigenvector and $n = \sum_{i=1}^{n} \lambda_i$

An inconsistency index equal to 0.1 is generally considered acceptable.
The hierarchic analysis procedure has been the subject of much analysis and further work that has partly re-assessed or clarified the potential (Dodd et al., 1995; Bana e Costa and Vasninck, 2000). Nevertheless Saaty's procedure has shown itself to be a valid support for solving many decision-making problems characterised by mainly qualitative information.

3. Analysis and formalising of the decision-making process for the operations for safeguarding the Venice Lagoon

3.1. Identification of the decision-making context

The application context in this case was determined following two essential but different elements:
- The growing perception and preoccupation of the authorities and public opinion about the problem of the conservation and safeguarding of the Venice Lagoon environment and its drainage basin;
- The activation of extraordinary state funding for the safeguarding of the Lagoon (Deliberation of the Veneto Regional Council no. 1115 of 8/3/95).

It wouldn't be possible to carry out conservation and safeguarding projects if no extra resources were made available and these resources would not exist if there had not been technical and scientific studies demonstrating the existence of the problem and creating a consensus in public opinion and among the national and local authorities about the entity of the problems and possible approaches for solving them. The regional legislation cited identifies the types of projects that can be financed in different areas and, in particular for the catchments of the rivers Zero, Dese and Marzenego, that are dealt with here:
1. Remodelling of the riverbanks by planting vegetation (buffer strips);
2. Re-calibration of the watercourse and acquisition of flood bed expansion areas;
3. Hydraulic gate hangers equipped with a remote control system.

[4] A matrix $\mathbf{A}=(a_{ij})$ is defined perfectly consistent if $a_{ik}a_{kj}=a_{ij}$ $\forall$ i, j.

All these operations are intended to increase the capacity of water courses in terms of self-purification, in-stream storage and retention times to obtain a reduction in diffuse pollution.
Given the aims and types of projects, expected results and limited financial resources, the competent area authority (in this case the Dese Sile Land Reclamation Board) is therefore faced with a decision-making problem of project optimisation in terms of:

1. territorial distribution and localization and
2. combination and use of different types of project.

These two aspects have to be tackled within a territorial context and therefore with a geographical connotation.

3.2. Formalisation of the decision-making context

The decision-making context described above clearly identifies the ambits within which the problem of decisional support is set: an authority exists (Land Reclamation Board) that can access regional funds, submitting projects that must respond to determined requisites and has the problem of setting up a method that can firstly identify alternative solutions and then evaluate them to identify which to submit to the funding authority (Veneto Region) that must judge them within the context of the allocation of funds. The basic problem is that of creating a procedure of multi-criteria analysis within a geographical context, that will firstly support the proposing authority's analyses and choices and secondly, facilitate the documentation of the process in such a way as to aid the analysis of the funding authority. Technical aspects are highlighted that relate to planning the works, as are managerial aspects for the Board that must then carry out and maintain the project and political aspects related to the decisional structure of the Board, based on representative elected bodies (council and executive committee).
The elements that define the context within which the decision support will develop are:

1. The Region's desire to take action on the depollution of the Venice Lagoon through structural projects in minor reclamation networks.
2. This desire has led to funding of Lit. 45 billion for the Dese-Zero and Marzenego sub-basins for the three types of project mentioned above. It has been estimated that these investments will produce benefits in terms of reducing the nitrogen and phosphorus loads generated in the area by 210 and 55 tonnes per year, respectively.
3. Given the money available, the project cannot cover the entire drainage network of the Board, but must be planned to optimise the use of the financial resources through a decisional process that is based on identifying priorities in terms of selected sites.
4. The siting of the projects cannot be based on just one decisional criterion, but must adapt different needs (planning, management and political) and should also probably seek compromise solutions between the different aims.
5. Given this complexity, the decisional process must proceed in two phases, tackling, in a co-ordinated fashion, first the identification of areas suitable for possible projects and then the definition of their best combination. The planning of projects is thus integrated with other types of actions, such as the promotion of and orientating towards eco-compatible practices of the people living and working in the area.

3.3. The multi-criteria model in a geographical context

In theory the question of optimisation siting should analyse the territory as a continuum of infinite spots to be evaluated. With the modern technique of Geographical Information Systems this can be tackled in two ways:

1. by vector based data management, or
2. by raster based data management.

In the first case the territory is analysed according to the different variables that can influence the decision, dividing it into more or less complex homogeneous areas, identified by the co-ordinates of the vertices of the polygons that delimit them and by their relations with external objects (topology).

Each area thus identified constitutes a possible alternative option in the multi-criteria analysis process.
In the second case the territory is divided into a huge number of regular shaped cells (generally square) and each geographical element (cell or pixel) becomes a possible option, i.e. a small area that could be included in the possible project if the multi-criteria analysis identifies it as a priority site compared to the others.
The first approach analyses a smaller number of cases (options) and therefore allows fairly complex evaluation approaches to be adopted, the second usually involves the analysis of thousands of alternatives (cells) and therefore requires a simpler elaboration, e.g. land suitability evaluations. This approach offers the possibility of an objective and dynamic identification of the areas where action can be taken through for example the use of thresholds, such as in the case of the best 1000 hectares of land for a given transformation; in this case the area can therefore be defined as the 100 cells of 10 ha that obtain the best results during the evaluation.
In the Dese Sile case, the complex planning, that involves the definition of work on linear elements (e.g. riverbanks of the water network), areas (e.g. portions of land or water bodies) and points (e.g. drainage constructions), clearly suggests avoiding the raster approach and using the vector one. The first step of the evaluation procedure should therefore be the identification of homogeneous areas, within which the intervention priorities are located on the basis of a series of criteria (evaluation attributes) defined on the basis of the above-described decisional context. A second step would then be to identify possible planning options within the priority area or areas and to evaluate them.
The next section presents the results of the territorial analysis that led to the identification of seven macro-areas to be evaluated using interactive overlay mapping procedures set up by the authors in collaboration with technicians from the Land Reclamation Board.

4. Identification of the macro-areas

The territory of the Dese Sile Land Reclamation Board includes parts of the provinces of Padova, Treviso and Venice, and has a total surface area of 435 km^2. Located in the central part of the Veneto plain, the area includes the catchments of the rivers Sile, Dese, Zero and Marzenego together with an area that drains directly into the Venice Lagoon.

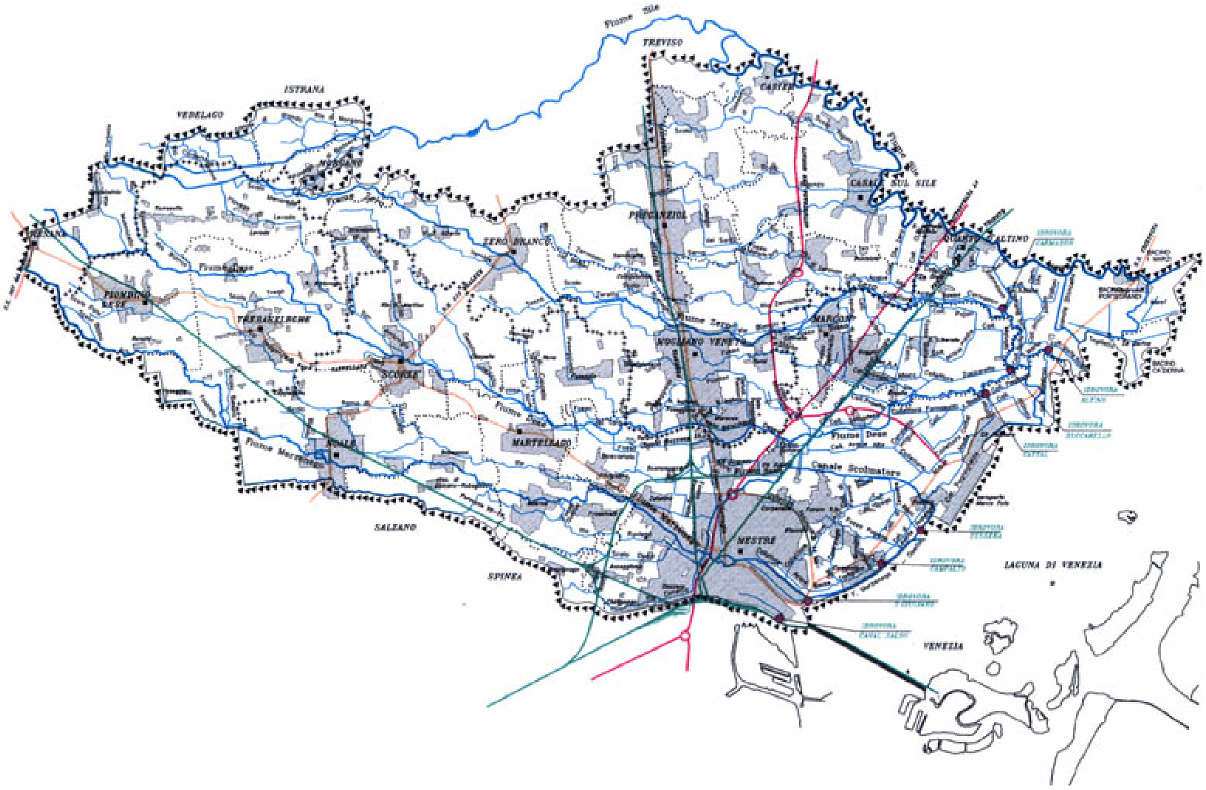

Figure 5 – The Dese Sile area

The territory is extremely diversified, ranging from conditions of high plains in the spring belt (north), to the area lying beneath sea level, along the so-called lagoon gutter. Land use is also very varied. Farming areas are interspersed with industrial and urban settlements which are either distributed sparsely or concentrated in large nuclei like Mestre.
The Board manages a 627 km network of natural and mechanical drainage channels , of which 345 km have raised banks. There are 8 drainage units that serve a surface area (partly mechanical drainage, partly alternated drainage) of more than 160 km^2.
The area has been the subject of many territorial studies that have led to the production of a Geographical Information System, which has been used to identify the territorial ambits for the multi-criteria analysis for identifying the work priorities. These macro-areas are as follows:

Area no. 1: Zucarello and Carmason catchments – lower river Zero
This is an area of about 6000 ha in which three different water regimes typical of reclamation still coexist: natural, alternated and mechanical drainage. This area has recently seen intense urbanisation (in the centres of Marcon and Quarto d'Altino), that has strongly interfered with the management of run-offs and the generation of polluting loads, thereby creating problems for water regulation.

Area no. 2: Hinterland of Mestre
The part of Mestre that falls within the Board's territory is an area of about 3000 ha, more than 2000 of which are urbanised. This area has a complex set of sub-basins in which the drainage and sewer systems that must cope with the particularly short flow times typical of urban areas are often interconnected. New elements in the area are the initiatives of environmental upgrading like the S. Giuliano Park and the Mestre Wood.

Area n. 3: Scolmatore canal catchment of the river Marzenego
In the seventies the Scolmatore canal of the river Marzenego was built to rectify the serious state of water instability in the north-western part of the Venice hinterland, creating a new water catchment in the cases of full carrying capacities, which are deviated away from the centre of Mestre. The area is comprised of the communes of Martellago, Salzano, Scorzè and part of Noale. The water network in this area is characterised by an efficient primary drainage network set against insufficient secondary drainage.

Area no. 4: The upper Marzenego, Dese and Zero rivers
This is the area furthest to the west and contains the springs that are the sources of the rivers that then flow eastwards for around 40 km to empty into the lagoon. It includes the towns and villages of Noale, Scorzè, Trabaseleghe and Zero Branco. The whole area is characterised by sparse inhabitation and productive settlements.

Area no. 5: The Castelfranco link
The Castelfranco link is outside the area, but is of particular interest as the rivers Marzenego, Dese and Zero flow from here into the Board's network. The catchment that could potentially supply the Board's water network is around 20,000 ha and extends beyond the town of Asolo, thereby conferring problems of water management co-ordination to different neighbouring authorities.

Area no.6: Cattal catchment and Scolmatore canal of the river Marzenego
This is the strip of territory between macro-areas 1 and 2, to each of which it is in some way linked, although with differences that mean they must be treated separately. This area is still an important farming area, even if the development of infrastructures like the new motorway link road, the airport expansion and the planned stadium are progressively mutating the old order. Hydraulically it is an area with long stretches of continuous mechanical drainage and partly alternated mechanical

drainage and a new drainage unit at Tessera that services the Scolmatore canal of the river Marzenego.

Area no. 7: Central stretch of the rivers Dese and Zero
While the river Marzenego, becomes a sort of overhanging embanked collector without the function of receiving local run-offs because the Scolmatore canal in the central and lower stretches, , the rivers Zero and Dese still have many tributaries almost all from the east. Under the territorial aspect, the state highway S.S. 13 Terraglio and the parallel Mestre-Treviso railway line, running from north to south, constitute a barycentric element of the area and create a barrier for the water courses that cross it.

6. Evaluation of the areas where the depolluting projects will be set up

Multi-attribute analysis and the evaluation methods typical to the study of environmental impact have been utilised to develop a decision support system organised in two phases:
1. identifying a scale of priorities for the homogeneous areas in which the territory is divided;
2. evaluating the alternative solutions (hydraulic and environmental engineering projects) within each area.

To do this, the authors assisted the Board personnel, guiding them through the analysis of the decision-making process, addressing the principle statements contained in the approved political documents on the one hand, and on the other the related geographical information, i.e. the geo-spatial data bases to which the general criteria were applied. This study led to identifying a series of evaluation criteria, and corresponding informational supports (map layers of the Dese Sile GIS) that can describe how the different parts of the territory respond to each criterion. From this information a scale of priorities for projects within the macro-areas can be determined. The criteria are described below.

6.1. Evaluation criteria

Programmatic priority. The term "programmatic priority" briefly identifies a location criterion based on the analysis of the documents and maps produced by the Dese Sile Board within their current master plan (PGBTTR) and in particular the "Map of Priorities", which identifies all the sections of the water network that are a priority for the aim of eliminating the danger of flooding. This criterion, although not being a priority with respect to regional funding, represents the main function of the Board and has obvious synergies with acts of depolluting, for example by means of increases in useful capacity. The GIS procedure adopted to quantify the criterion is based on the analysis of the linear development of the sections of the network with high priority within each macro-area.

Work already done. In this case, a map that depicts the work already done on the basis of the PGBTTR "Map of Priorities" was analysed with respect to the boundaries of the macro-areas. and the evaluation judgements were tackled that were proportionally high to the macro-areas in the final stretches of the major water courses, or just upriver from the work already done, as it is always necessary to take action from beneath.

Hydraulic risk. Unlike the first criterion, in this case the territory was not analysed by a linear approach (sections of the network), but an area one, to calculate the surface areas at risk of flooding. The importance of this criterion is that each flood causes a further polluting of the waters following leaching from the agricultural land and urban areas, as well as direct economic damage, that is particularly relevant in urban areas.

Irrigation. As the Board also manages water for irrigation purposes and given that the experimental data have shown that the quality of the waters leaching from the irrigated areas is better (especially in relation to nutrient contents) than that of the water used, the state of the network for irrigation and indiscriminate use (linear elements) and the types of farming in the territory (area elements) were evaluated together to identify the work priorities of the seven macro-areas.

Recreation. Analysis of the macro-areas according to their recreational use identified the territorial ambits most susceptible to potential synergies between this and the planned project. Environmental upgrading by means of riparian vegetation that is of value for increasing the recreational availability of the areas was taken into particular consideration.

Environmental quality. This is of interest to a territorial protection agency not only from the point of view of recreation, but also for the intrinsic value, ecosystem quality, and the conservation and upgrading of the ecosystems. Indicators of natural value were evaluated for the different macro-areas together with consideration for the upgrading priority through the possible types of project, as in the previous criterion.

Residence. As already mentioned, the area is densely populated. The planned projects can be of positive or negative value for the population, in improving environmental and landscape quality, or else causing inconvenience with some types of project. These effects were taken into account in this evaluation criterion adopted to determine the priorities of the macro-areas.

Synergies with other projects. The Board and other bodies have various other environmental upgrading and territorial protection activities underway, such as work on the network of low drainage waters at the Campalto link, reorganisation of farm production, a system for the remote control of the network. There is also funding for Mestre Wood, San Giuliano Park, the Marzenego Project, and the Cave Project. It is clear that whatever synergy can be created with these projects could offer financial savings equal to the effects of the results expected at the planning stage.

6.2. The evaluation procedure

The methodology presented in section 2 was implemented in the following steps:

1) construction of the evaluation matrix;
2) the drawing up of a suitable weighting vector;
3) ranking the areas.

The evaluation matrix that shows the project options' effects on the different areas in terms of the evaluation parameters was drawn up using hierarchy analysis. Table 2 shows the evaluation matrix of the macro-areas with regard to the evaluation criteria.

	AREA						
Criteria	A01	A02	A03	A04	A05	A06	A07
Priority	274	274	238	63	42	53	56
Jobs	267	267	267	67	33	67	33
Risk	328	119	216	82	82	67	105
Irrigation	196	27	159	171	223	182	41
Recreation	213	170	128	106	21	149	213
Eco	193	217	207	157	24	118	84
Residence	157	180	333	23	47	137	123
Synergies	219	299	122	146	85	55	73

Table 2 – The evaluation matrix of the areas

The weights were obtained using an analogous procedure, substituting the macro-areas by the evaluation criteria in the paired comparison.

Two criteria were used for ranking the areas:

1) the net concordance index
2) the net discordance index.

The concordance criterion aims to identify the option that, compared to the others, produces the best agreement. The discordance criterion instead identifies the alternative option that produces the least disagreement. The calculation of the concordance and discordance indexes (Nijkamp and van Delft, 1977) is based on the information contained in the evaluation matrix (***a***) and the weights vector (***w***). On this basis two squared matrices (n x n with empty diagonal) are drawn up: the concordance

matrix and discordance matrix. In the concordance matrix the generic element c_{kh} is given by the sum of the weights of the criteria for which the option k is better than option h.
In the discordance matrix the generic element d_{kh} is the index of the loss of well-being as a consequence of choosing h in favour of k, and is calculated as follows:

- the criteria are identified for which k is worse than h, and between these criteria, the criterion (j) is identified for which the product (P_p) between the weight (w_j) and the difference between the performances of the two options (a_j-a_{hj}) is maximum (abs value);
- among all the choice criteria, the one is identified for which the product (P_t) between the weight and the difference between the performances of the two options is maximum;
- the discordance index is calculated using the following equation: $d_{kh} = P_p \cdot P_t^{-1}$.

Starting from the concordance and discordance matrices it is possible to derive the net concordance (IC) and net discordance indexes (ID). These are calculated, for each option, by the difference between the sum of the row and the sum of the column of the concordance and discordance indexes[5].

i.e.:

$$IC_h = \sum_{i=1}^{n} c_h^r - \sum_{i=1}^{n} c_h^c$$

$$where:$$

$$C_h^r = concordance\ indexes\ on\ alternative\ h\ row$$

$$C_h^c = concordance\ indexes\ on\ alternative\ h\ column$$

$$ID_h = \sum_{i=1}^{n} d_h^r - \sum_{i=1}^{n} d_h^c$$

$$where:$$

$$D_h^r = discordance\ indexes\ on\ the\ alternative\ h\ row$$

$$D_h^c = discordance\ indexes\ on\ the\ alternative\ h\ column$$

These indexes represent the level of net concordance and discordance achieved by each alternative option compared with the others. The one that achieves the highest value of IC_h and/or the lowest ID_h will be the preferable one (Hwang and Yoon, 1981). The concordance/discordance analysis lends itself very well to representing problems of a "political" nature where prudent management is necessary for the approval or disapproval generated by the choices made.

6.3. Evaluation results

The next figure gives the weights expressed by the decision-maker (Board president). The graph shows that water safety and guidelines for territorial planning are priorities for the territory. The ranking obtained with respect to the previously identified set of weights is shown in figure 7.
The figure shows clearly that option A01, which identifies the macro-area "Zuccarello and Carmason Catchments – Lower Stretch of the River Zero" is preferable in terms of both concordance and discordance. In substance macro-area A01 is the one that produces the best level of adhesion and the fewest conflicts. To verify the ranking of the different areas on the technical plan, as well as on the political decision-making plan, other sets of weights have been constructed, responding better to the technical sensibility. The rankings obtained have substantially confirmed the ranking reported in figure 7. This result confirms the advisability of giving priority to macro-area A01, demonstrating on the one hand the high level of agreement and approval built up over

[5] For details of the algorithm for calculating the indexes of concordance and discordance see Marangon and Rosato (1995).

months of analysis and discussions with the various parts of the Board and on the other the high consistence of the evaluation vectors constructed in the technical analysis of the macro-areas with respect to the evaluation criteria. The problem of identifying the priority areas in which to take action having been solved, the problem of defining possible projects and evaluating them is posed.

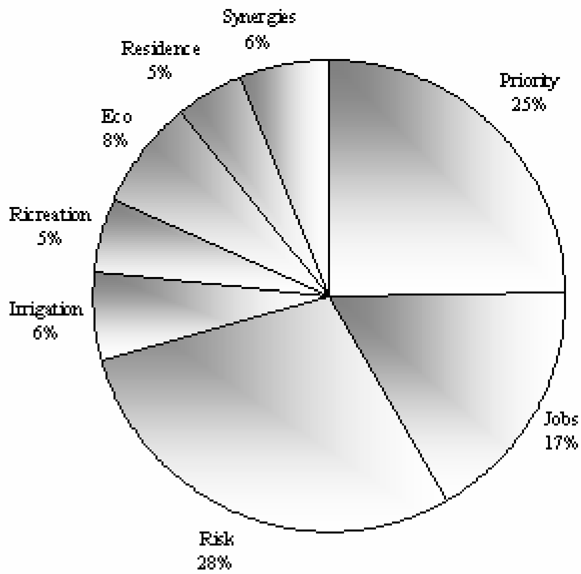

Figure 6 - The weights expressed by the decision-maker for the choice of area.

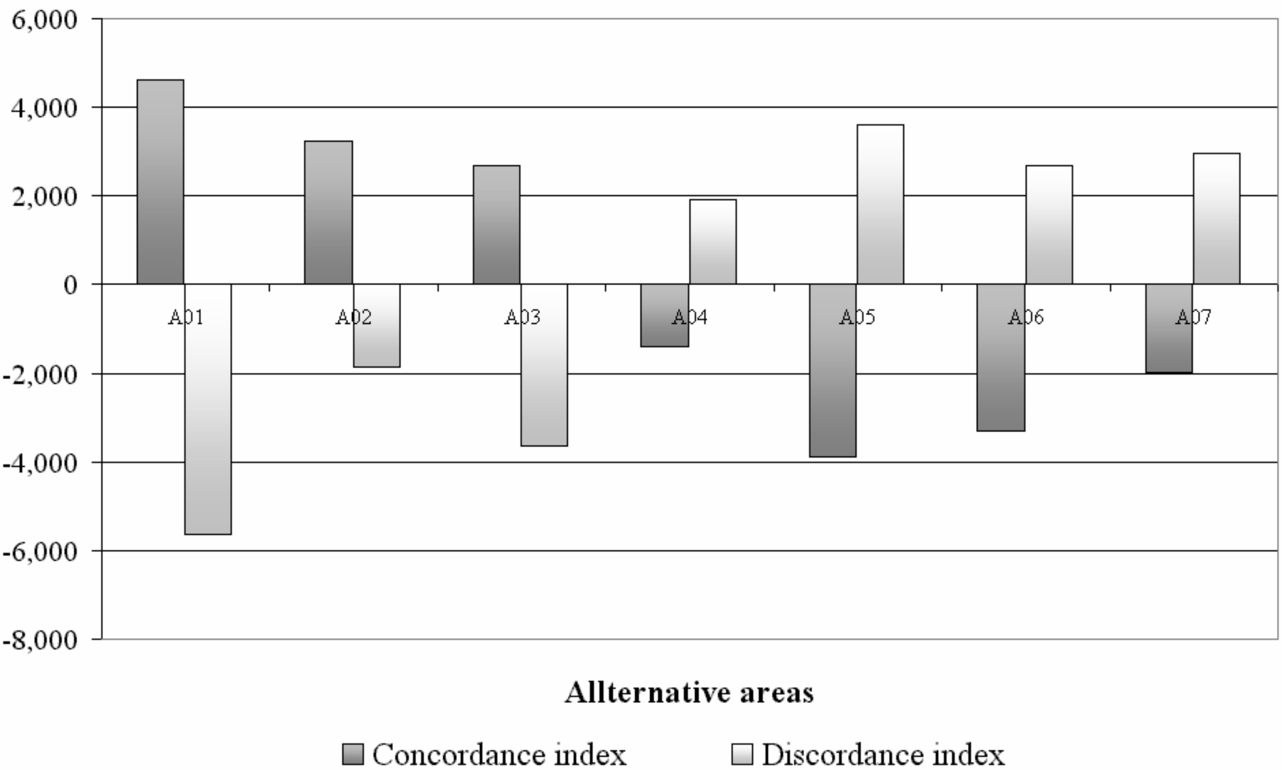

Figure 7 - The ranking of areas.

7. Project options in macro-area A01

Given the types of public works financed by the regional administration, the identification phase of the interventions in the chosen macro-area consisted of planning suitable areas, with buffer strips along rivers and land-reclamation, thus respecting the provision of the financing law on reducing

loads carried by the waters and obtaining positive feed-backs for optimising the water regime, by means of buffer zones, the creation of auxiliary useful capacity, the increase of the time the water remains there. The types of work that can be proposed are therefore aimed at promoting self-purification phenomena through widening the river beds, creating additional areas for laminating water, with suitable vegetation, barriers and water leaps and introducing new drainage systems. Given the functions of the Board, the multi-functionality of the project options is an element fundamental to their choice, making it important to discover all the possible positive consequences in terms of water regime and irrigation capacity, together with the environmental effects.
Given these requisites, the identification of the project alternatives progressed to successive approximations that led to the prior exclusion of some solutions, such as the complete diversion of the waters away from the Venice Lagoon or the setting up of large areas of estuarine vegetation for purifying the water, because of their obvious drawbacks. Attention was therefore focussed on a series of possible work combinations for the middle stretch of the river Zero that, on entering the area, carries, along with the spring water, the drainage water from a densely populated area with intensive farming and has a water regime that lends itself to the self-purification phenomena that have already been demonstrated in previous monitoring.

7.1. Innovative characteristics of the project

Agronomic research has paid a lot of attention recently to setting up farming practices that allow the negative environmental impacts of agriculture to be reduced. However this research has concentrated on reducing the release of polluting loads. Very little has been done to evaluate the possibility of intercepting the flow of pollutants that are released from the farmland as they reach the water bodies. The international literature indicates that buffer strips are an efficient method with high environmental value and positive effects on the landscape. The EC regulations 2078/92 and 2080/92 have encouraged the use of these buffer strips in Italy and particularly in Veneto, where there have been some interesting achievements. Therefore projects of this type carried out on the Board's water system can integrate well and have positive synergies in the surrounding farmland, especially in the areas along the watercourses.

7.2. The possible options

Following the preliminary considerations described above that have led to some types of projects being excluded, the planner still has various possible options for drawing up the working plan. Further refining eliminated the projects that are clearly inopportune in comparison to the others.
At the end of this process two types of project, both potentially useful, were identified:
- damming the watercourse and reshaping the banks;
- lagoon maintenance near the main watercourse.

At this point there is once again a decisional problem in terms of:
- optimising the combination of the two types of project; and
- selecting the best site.

Similarly to preceding phases in defining the project, the basic evaluation criteria were identified upon which to base the choice of the alternative options and the possible project scenarios. The considerations that led to the drawing up of the decision-making scenario are reported below.
Further analysis of macro-area A01 led to the identification of a series of questions and preliminary choices that could lead to the definition of alternative preliminary plans to be evaluated. This process took the form of questions and answers as follows:
- *Which water bodies and areas should be included within the macro-area?*
  The priority was found to be the Zero river watershed and the areas of natural drainage, through work on the riverbanks, for at least three reasons. First of all because the level of water risk linked to the conditions of the riverbanks is notably higher than the risk associated with the embankments of the minor network where drainage pumps drain the area mechanically. Moreover, the potential self-purification phenomena of the river are limited by the rise of tidal

waters. The water can only be blocked by means of a dam that can be built safely only if the riverbanks are raised. Lastly, flooding or breaking the riverbanks would anyway thwart any work on the drainage pump systems;

- *Assuming that it is appropriate to keep the water in the main bed of the river Zero, where and how should the dam be built?*

  This is not an easily solved problem, as there are no theoretically reasonable options, but rather a continuous series of possible solutions. Nevertheless, three possible options for the site can be identified easily enough:

  - **The mouth of the River Dese, below the point where it is joined by the River Zero**

    This would be very costly and would surely have significant effects as it would involve the course of both rivers and their catchment areas. It would require more or less the entire funding earmarked for the territory and from a management point of view it would be equally demanding. Among the foreseeable effects is the raising of the water level below both the Carmason and Zuccarello drainage units, so increased costs for the hydraulic raising of the drainage waters could therefore be expected. Other possible negative effects would be on the risk of flooding and on the navigability of the Dese. The efficacy of the project is doubtful due to the existence of another dam a few kilometres upriver, on the river Dese. This is therefore an important possibility with potential effects on wide areas and on the links upriver, with merits and defects typical to large-scale solutions.

  - **The mouth of the River Zero**

    This solution wouldn't face any particular problems for its realisation and is characterised as an intermediate option. Its cost is lower than the cost of the first solution, but higher than the following solution and it has the same possible hydraulic problems as cited above, but these are limited to the Carmason drainage unit. The forecast costs are also intermediate.

  - **The Carmason Drainage Unit**

    This is the upriver solution on a smaller scale, which therefore has the opposite merits and defects of the first one. It would be sited in a position on the river where the dam could be built in easier conditions than the previous options.

- *How should the nutrient loads currently released into the Lagoon be controlled by exploiting self-purification processes to the full?*

  Given that the response to the previous question has demonstrated the advisability of using a dam and re-shaping the riverbanks in one of the three ways explained above, the problem of finding the best way to combine them with establishing wetland areas to exploit the phenomenon of phyto-remediation is now posed. The increase in wetland areas is foreseen as a result of the dam itself and the expected introduction of riparian vegetation, but it is expected that without introducing new artificial wetlands it would not be possible to achieve the load reduction provided for in the regulations. The preliminary studies in the Board's territory have demonstrated, through a monitoring and modelling approach, that most of the nutrients are carried by normal run-off and it would therefore not be enough to take action only on peak events. The type of project would therefore have to be scaled appropriately but in such a way as to be secure in floods. Three possible planning options for lagoon maintenance are identified, as well as the "zero" hypothesis, i.e. to limit projects to the damming of the river and re-shaping the riverbanks.

  - **The mouth of the River Dese, down river from where it is joined by the River Zero**

    As with the dams, the possibility of siting an area of estuarine phyto-purification at the mouth of the Dese can be hypothesised. This option has the merits and defects of a dam in the same position. In this case, however, negative aspects have led to excluding this type of project: costs for the compulsory purchase of the land, concentration in confined areas, little added value etc. In this case the fact that the waters would be purified just before reaching the lagoon and water quality would be in no way improved within the Board's network is cause for doubt. Also in this case, however, a single project of big dimensions would tackle the management of the waters in a vast catchment area.

- **The mouth of the River Zero**
  As with the dams, the option at the mouth of the Zero is an intermediate solution for lagoon maintenance, a compromise between the merits and defects of the others.
- **The Cavalli Clay Pits**
  A possible upriver site is the existing wetland area of the ex Cavalli Clay Pits. This solution would have obvious positive aspects from an economic point of view, requiring only minor works with limited earth movements to connect the river Zero and the quarry. . Greater complexity is foreseen from an institutional point of view, since the agreement of the local councils and environmental associations that currently manage them would be necessary. Another potentially positive aspect is that this is a degraded area that requires upgrading to improve it's natural worth.

- *Which institutional forms should be adopted for buying and managing the areas involved?*
  In practice this is a case of evaluating the option between proceeding with the compulsory purchase of all the areas involved in the hydraulic and environmental projects, or else compulsory purchases for the hydraulic projects and voluntary agreements for the environmental actions. The regional regulation states only that compulsory purchasing cannot be done for re-afforestation alone. Compulsory purchase is clearly much more onerous and of greater socio-economic impact than agreements with land owners.
- *How should the the irrigation function of the project be improved?*
  Given the functions of the Board it is obvious that a possible irrigation value of the projects, i.e. a contribution towards maintaining or increasing the availability of irrigation volumes must be striven for. Added to this is the fact that the use of run-off waters for irrigation can also contribute to their purification, exploiting the filtering effect of the soil and the nutrient absorption by crops. This could lead to the need to carry out complementary project for water distribution, which would be worth examining in the evaluation phase of the alternative plans.

The combination of the hypotheses for siting the dams and lagoon maintenance has resulted in a list of 9 planning options:

1. Dam the River Dese close to the mouth and set up a lagoon maintenance system in the same area
2. Dam the River Dese close to the mouth and set up a lagoon maintenance system at the mouth of the Zero
3. Dam the River Dese close to the mouth and set up a lagoon maintenance system at the Cavalli Clay Pits
4. Dam the River Dese close to the mouth with no lagoon maintenance system
5. Dam the River Zero close to the mouth and set up a lagoon maintenance system in the same area
6. Dam the River Zero close to the mouth and set up a lagoon maintenance system at the Cavalli Clay Pits
7. Dam the River Dese close to the mouth with no lagoon maintenance system
8. Dam the River Zero at Carmason and set up a lagoon maintenance system at the Cavalli Clay Pits
9. Dam the River Zero at Carmason with no lagoon maintenance system

8. Evaluation of the alternative options

The alternative plans were evaluated by the Board specialists who used a careful technical analysis to define the general lines of the possible options and the main evaluation criteria. The project evaluation phase is strictly more technical than the phase concerning the macro-areas.

Examination of the materials produced during the elaboration of the set of alternative plans led to the identification of a series of nine evaluation parameters, in part similar to those adopted for the choice between macro-areas, and in part new and more specific to a more advanced phase of the development of the project.

In this case the evaluation criteria, which correspond to the informational supportfor the technical-plan type, are aimed at describing how the different siting options and combinations between dams and lagoon maintenance contribute towards determining a scale of preference with respect to the objectives stated in the regional regulations. The evaluation criteria identified are:

1. Reduction of the amounts of nutrients conveyed to the Lagoon
2. Reduction of flood risk
3. Investment cost
4. Management cost
5. Impact on the landscape
6. Impact on irrigation
7. Coherence with the Board's planning policies
8. Flexibility and capability when completed
9. Synergy with other existing or planned initiatives.

The plans were evaluated using the same procedure as was used in the area evaluation. Table 3 shows the vectors interpolating the paired comparison matrixes. The table can be considered as the evaluation matrix of the alternative plans with respect to the adopted evaluation criteria.

The evaluation matrix underwent a dominance analysis, i.e. it was verified if options exist that are dominated in the Paretian sense. In this case it would be clear that whatever vector of weights is assigned to the evaluation criteria, the dominated options would result as being worse than the dominant ones, which would always perform better. It is obvious that it is completely useless to put the dominated options through the subsequent evaluation phases.

Analysis of the evaluation matrix identified the cases of Paretian dominance:

Dese/Dese dominated by Zero/Zero
Zero/Cavalli
Carmason/Cavalli

Dese/Zero dominated by Zero/Zero
Zero/Cavalli
Carmason/Cavalli

Dese/Cavalli dominated by Zero/Cavalli
Carmason/Cavalli

Criteria	Work method								
	Dese/ Dese	Dese/ Zero	Dese/ Cavalli	Dese/no lagun	Zero/ Zero	Zero/ Cavalli	Zero/ no lagun	Carmason /Cavalli	Carmason /no lagun.
Releases reduction	143	143	143	56	143	143	56	143	16
Food risk reduction	139	135	131	36	148	156	43	154	43
Investment costs	10	17	37	50	44	90	104	150	164
Management cost	38	38	38	139	91	89	89	72	167
Landscape impact	17	17	52	63	52	81	115	150	164
Irrigation impact	110	110	110	110	110	110	110	110	110
Planning coherence	105	105	105	105	111	111	111	116	117
Flexibility	44	39	85	78	51	97	114	102	146
Synergies	110	130	142	60	130	142	60	142	60

Table 3 – Evaluation matrix

The evaluation continued, concentrating on "non-dominated" projects with the estimate of the weights vector. The vector was obtained using the usual procedure of paired comparison on the basis of a 9 x 9 matrix (parameter x parameter). In this case, being a substantially technical choice, the rankings were done using the judgements given by the Board technical staff.
The following figure represents the weights used for ranking the alternative projects.
Obviously, the reduction of nutrient releases is considered, along with the reduction of flood risk, the most important parameters for the ranking of alternative projects. In other words, pollution control projects that a land reclamation board can carry out cannot disregard flood risk.
It can therefore be stated that, on the basis of the weights vector, the optimal solution will be the project that minimises nutrient releases, contributing positively to the solving of problems of water regulation. No other parameter reaches a weight equal to 10% of the total and all range between 5 and 9%. The other highest values are for the management cost and irrigation value of the projects.

9. Evaluation results

The ranking method used to evaluate the projects was the weighted sum (IS). This ranking criterion represents the process of technical evaluation quite well, in that it assesses and summarises the various aspects of the projects. The ranking criterion was obtained from the usual evaluation matrix (**a**) and related weights vector (**w**). The following algorithm was used:

$$IS_h = \sum_{j=1}^{k} a_{hj} w_j$$

The ranking obtained with respect to the criterion of the weighted sum is given in figure 9 and clearly shows that the winning options are those that include lagoon maintenance at the Cavalli Clay Pits, with a dam close to the Carmason plant (first place) or at the mouth of the Zero (second place).

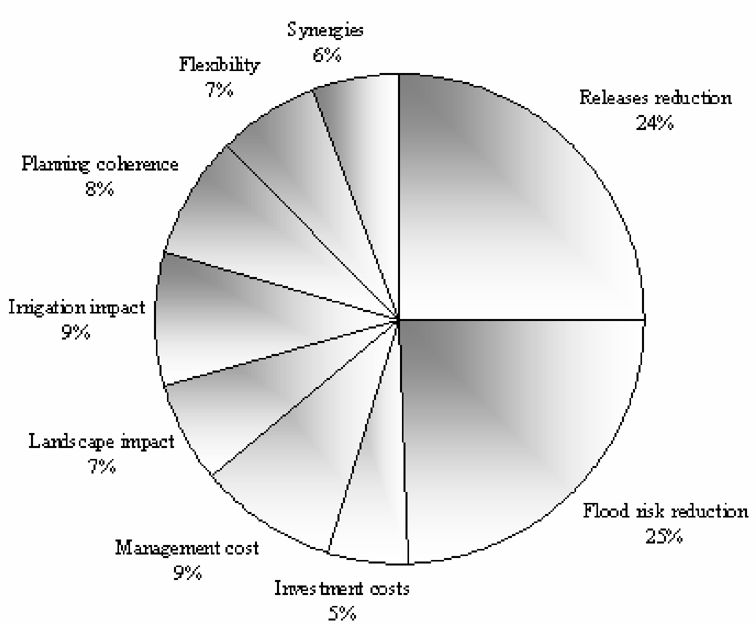

Figure 8 – The weighs given by the decision-maker for the choice of project

Lagoon maintenance, according to the decisional criteria used, is the most important intervention for depolluting. In fact, the options that do not include it are always placed last in the ranking. In other words, the high costs of projects consisting of damming alone, of undoubted impact on flood risk and irrigation, would not be justified by the water benefits that would be obtained.

A sensitivity analysis was applied to the ranking, varying the weights that showed that the the solution Carmason/Cavalli Clay Pits is very stable in first place. Only by increasing the flood risk by almost 14 times would the option Zero/Cavalli win.

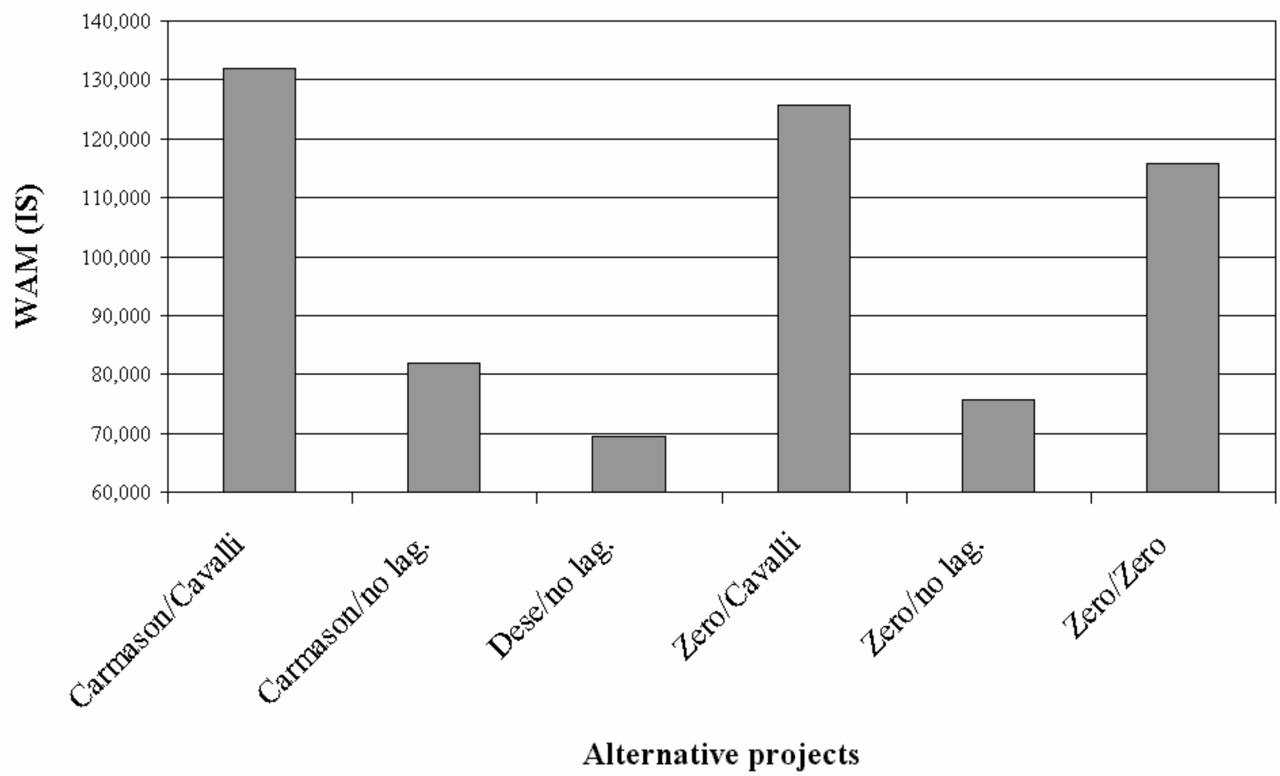

Figure 9 – Projects ranking

10. Conclusions

Water management at the catchment scale requires ever greater efforts from the appointed administrations to carry out their functions. They must try to adapt the traditional objectives of water regulation, reclamation and irrigation with new social needs, such as maintaining and upgrading the landscape and the natural value of the territory and, more generally, environmental protection, for which water resources are a basic element.

Continuous water management is required for water regulation and systems maintenance, and this involves the application of specific technical-scientific methods and thorough territorial knowledge. These projects can be small and localised on the water network or more consistent and complex operations that can effect environmental quality and the quality of life for the local population.

Every project implies a decision that generates a series of co-ordinated actions, set up according to precise aims and that can require months of preliminary processing, or, on the contrary, must be made from day to day.

Usually the administrators of water catchment areas possess experienced knowledge of managing the waters in the area, historically consolidated over many years, if not centuries, and supported by suitable technical-engineering know-how. Often information is managed by complex hydrological models, that formalise this know-how in mathematical terms on a catchment scale. There is therefore no real need for decision support for the day to day management of the network, if not in particularly complex and important cases, such as extreme events or flood risks.

Planning the use of water resources, on the contrary, has been the subject of major rethinking. New directions implement new concepts such as the prospect of sustainable development, and the improvement of multifunctional territorial use. All this requires an effort from administrators to re-orientate their programming to take these new principles into account.

It is increasingly rare that decisions can be taken by one person without taking into account the opinions of others involved in the effects of that decision. This signifies that different criteria and

objectives must be taken into consideration, evaluated, weighted and integrated by methods that are relatively new for the water management sector, such as the multi-criteria analysis methods used in this study.
Integrated water management at a catchment scale is complex, involving many disciplines (geographical, engineering, chemical, etc.) and therefore many experts with different backgrounds and requires long and detailed analysis procedures.
For this reason the tools for decision-support based on multi-criteria analysis have great potential, aiding the choice between alternative solutions. They use methods that are robust from a logical-mathematical point of view, can be documented, and are therefore clear and more easily understood by the different players involved in the decisional process (public decision-makers, people with a financial interest, ordinary citizens).
Future research efforts will be necessary to obtain more fully-developed methods for managing particular aspects of the sector, such as spatial/geographical ones, and to develop increasingly evolved interfaces that are effective for the end-users.

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