Multicriteria analysis for the use of CW in a multipurpose project in the Venice Lagoon watershed

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Abstract
The Consorzio di Bonifica Dese Sile is a drainage authority located near Venice, Italy , created to improve the hydraulic functionality of rivers , canals and ditches of its territory, reducing hydraulic risk whereas it exists. The Regional Government asked it to define actions and projects in order to reduce the load of nutrients carried through the minor river network to the lagoon. Particular emphasis was requested to consider natural treatment technologies. The project, took place in a densely inhabitated and intensively farmed area and therefore there was the need to minimize any environmental and social impact, while addressing the two potentially conflicting objectives: minimizing hydraulic risk and removing the maximum load. So the Consorzio Dese Sile, together with a working group selected through a public bid, decided to develop the Environmental Impact Assessment (EIA) procedure – envisaged by law – as a multicriteria analysis. Such an analysis was intended to consider different project alternatives and compare their pros and cons. The EIA has been used as a Decision Support tool to facilitate public participation, and to identify a more rational project design. The project selected (between 5 alternatives) is now undergoing the final executive phase, and will realize two multipurpose constructed wetlands (for a cumulative area of 65.000 square meters), one flooding area, the enlargement and rehabilitation of part of the main river channel, the creation – in a critical urban area – of a new "naturally shaped" by-pass channel, the elimination of a few localized flow constrictions.

Keywords
Diffuse pollution; constructed wetland; multicriteria analysis.

INTRODUCTION

To reduce eutrophication of Venice Lagoon, Italian Government and Regione Veneto started a policy aimed at reduction of nitrogen load generated in the lagoon watershed: nitrogen, in fact, has been identified as the limiting factor in the lagoon ecosystem. One significant part of the policy has been devoted to increase the self-purification capacity of the drainage network, composed by a few "natural" rivers and a diffused system of small artificial channels.

To implement such a policy, drainage authorities were invited to present projects able to improve self-purification capacity of the system: project should possibly be "multipurpose" (besides nitrogen load reduction, should be able to reduce hydraulic risk and to increase the natural value of the system) and with low environmental and social impact.

Consorzio Dese Sile – one of the Drainage Authority of Venice Lagoon watershed – worked out a multipurpose project, able to remove nitrogen from a sub-basin of 916 hectars, while reducing flooding problems occurring in the area. Together with the working group selected through a public bid, Consorzio Dese Sile decided to develop the Environmental Impact Assessment (EIA) procedure – envisaged by law for any project occurring on watercourses – as a multicriteria analysis (MCA). Such an analysis was intended to consider different project alternatives and compare their positive and negative impacts.

METHODS AND MATERIALS

The potential solution-option considered within the project were the following

1. OFF STREAM CW. Off stream constructed wetlands: CW where part of the flow of the watercourses could be diverted and treated; such systems could work all year round, even in summer when the flow is at its minimum
2. ON STREAM CW. On stream wetland: CW where the whole flow of the watercourse is treated with a retention time that depends on the flow conditions
3. FLOODING AREAS. Areas – normally dry – where excess flow occurring during high flow events, could be diverted;
4. MULTIPURPOSE CW. Multipurpose wetlands: a mixture of solution 1 and 2; CW built in a way that could remove nutrients all year round (less effective compared to 1) and save some storage volume to be used only in high flow events;
5. CAVA PISANI ACQUISITION. Acquisition and transformation of "Cava Pisani", an existing exhausted gravel quarry, aimed at maximize its nutrient removal capacity;
6. CAVA PISANI AGREEMENT. Agreement with the owners of Cava Pisani to restore hydraulic circulation to allow nutrient removal capacity (less effective compared to 5)
7. RIVER SECTION ENLARGEMENT. Enlargement of river bed: creation of new, enlarged river section, in order to reduce water velocity during low flow and allow higher flow when needed;
8. BY PASS. Realization of river diversion for high flow events;
9. BRIDGE REMOVAL. Elimination of river constrictions (small section bridges);
10. AWARENESS RAISING. Activity to raise farmer awareness to promote low scale action (diffuse buffer zones), to be realized by farmers on their properties
11. HYDRAULIC CONNECTION TO ZERO RIVER to allow a significant flow to wetlands during summer (and meanwhile provide water for irrigation)

The items listed above are not the project alternatives. Each project alternative is indeed a combination of one or more of such solution-options to be integrated. The project has been developed according to the following steps:

A. Estimation of nitrogen loads (by diffused and point sources of pollution and extra watershed contribution due to groundwater uprise);
B. Analisys of the hydrological and hydraulic behaviour of the system via simulation
C. Definition of alternatives (including the "0" alternative)
D. Prediction of the "impacts" of each alternative on each one of the selected evaluation criteria through specific logic or mathematical models
E. Meeting with Decision Makers and involved stakeholders for the elicitation of the weights to be used in the analisys
F. Comparison of the "performance" of the alternatives through multicriteria analysis and identification of the most performing alternative
G. Meeting with Decision Makers and involved stakeholders for discussing results

Load estimation

Load estimation has been done through two different approaches:

a) Estimation based on existing river flow and nitrogen concentration data
b) Estimation based on theoretic contribution of different sources: soil leachate (through land use maps) , urban, import from other watershed through groundwater

The difference between the two estimations (20,8 against 31, kg/y/hectare) has been attributed to two factors: an underestimation of the first method due to the lack of data during high flow; an overestimation of the second method due to self-purification processes (denitrification and volatilization) already occurring in the system and not taken into account. An average value of 25 kg/y/hectare has been considered coherentely with other studies on the area (Bendoricchio et al. 1999) and has been used for the prediction of nitrogen removal capacity.

Hydrologic-hydraulic analysis

The hydrologic and hydraulic behavior of the watershed has been simulated through the Hydroworks computer model (Wallingford Software Ltd.). The model has been calibrated through the observation of flooding occurred during high rain event on 7^{th}-8^{th} of May 2000.

Definition of Alternatives

Since the major aims of the project were i) nitrogen removal and ii) hydraulic risk reduction, the design group firstly identified two extreme project alternatives (A and B) aimed at maximizing, respectively and independently, such objectives. *Alternative A* is based mainly on solutions 1,2,5, for a total amount of 150,000 m^2 of newly built on-stream and off-stream wetlands; furthermore the acquisition and transformation of an existing wetland formed on the site of an exploited gravel quarry (Cava Pisani) could allow other 75000m^2 of area devoted to nutrient removal. *Alternative A* shows very "poor" performance in terms of hydraulic risk reduction and was perceived by the local population as not useful for their interests and potentially "disturbing" from many points of view (expropriation of farmland, mosquito increase linked to large wetlands, etc.)

Alternative B is aimed at maximize hydraulic risk reduction, and is based mainly on solutions 3,7,8,9, envisaging 150.000 m^2 of flooding areas, the creation of a hydraulic by-pass in an urban area, a river section enlargement and 25 bridge removals. *Alternative B* has practically no effect in terms of nitrogen removal, but it was very "well accepted" by local population (except for environmental groups that are a minority).

Other 3 alternatives have been designed during the process, which are just a "mixture" of solutions designed for A and B.

For each alternative, part of the budget has been saved for awareness raising campaign directed to landowners, to facilitate the use of Agro-environmental EU subsidies to implement buffer zones or small wetlands at single farm scale.

Alternative 0 (do nothing) has also been considered in the evaluation phase.

Prediction of the impacts

During EIA, through the scoping analysis, the main significant impacts (both positive and negative) were identified: a quick review of methods used to predict the impacts is presented in the next points. Importance of each impact have been expressed through appropriate indicators of "satisfaction": orientation defines if satisfaction grows with growing of numeric value of the indicator (positive) or with its decreasing (negative).

Flooding risk

It is not possible to present here the details of the hydrological-hydraulic simulation (Consorzio Dese Sile 2001) as the model is too detailed (it considers 258 nodes and 276 reaches). Surface referred to each node could be partitioned in three subsurfaces to simulate the hydrologic response of different existing land use; hydrologic behavior related to Antecedent Moisture Conditions was also considered by the model.

The final indicator chosen to compare alternatives has been defined as: “Flooding volume for a given return time (30) [1000 m^3/year] (orientation negative; range: [0, ∞])”.

Nitrogen removal

To predict nitrogen removal of off-stream CW we used Kadlec and Knight (1996) equation (area based, first-order k-C*). Since the concentration of N in our system is very low compared to wastewater, we adopted “K” value derived from a similar situation: the Des Plains wetland system in Illinois (Kadlec and Knight 1996). For the on stream wetland, to simulate a dynamic behavior, we had to develop an *ad hoc* dynamic model based on a first order kynetics. The indicator chosen is the annual amount of nitrogen removed [Kg/year] (orientation positive; range [0, 5000]).
(To define the upper end of the scale an assumption was introduced: we assumed that, given the low concentrations of N, the maximum possible removal is around 25% of the total N generated. Being then the estimated load or the hole watershed approx. 20,000 Kg, , the upper bound results in 5000 Kg/y approx.).

Damage to farmers

The assessment of this impact has been made on the basis of several “qualitative” criteria amalgamated into an index, to allow comparison with other indicators. The index has negative orientation and ranges between [0, 3], where ‘0’ means “no damage” and ‘3’ maximun damage with the following meaning:

- Surface subject to expropriation: 150.000 m^2
- Number of land properties to be expropriated: 17
- Number of land properties located on the border of large working place, during construction phase (flooding areas or CW): 14
- Land use: vineyards 5%; poplar plantation 7%; crops 88%
- Economic value of expropriation: 9 millions of Italian lire (460.000 €)

Management cost

Only the increased cost due to the management of wetlands that is not included in the “ordinary” activity of the Drainage Autority has been considered. The indicator [1000 €/year] has negative orientation and ranges between: [0, ∞].

Landscape degradation or improvement

The assessment of the impact on landscapehas been done with a complex original procedure developed on the basis of previous Italian experiences (Malcevschi 1986) that allows a quantification of the “landscape value” of different “objects” (both “natural”, as trees lines, water bodies, etc. and “manmade” as typical bridges, houses, etc.). the result is and index which is a sum of different impacts. The index have negative orientation with a scale ranging between: [0, ∞], with the following meaning: 0-25= low impact; 25-50= significant impact; 50-75= medium impact; 75-100=high impact; oltre100= very high impact.

Biodiversity and Nature conservation

The impact has been assessed through an analysis of the present situation of existing water bodies from the “ecological” point of view, and the construction of an index conceptually similar to the one developed for the landscape. The index has positive orientation and ranges between: [0, 4], where “0” means that the resulting environment (after the project realization) is very poor, without any typical aquatic vegetation and fauna, while “4” means a “natural like” aquatic environment.

Damage for inhabitants
This impact has been assessed considering the nuisance deriving by two factors occurring during the realization phase:

- truck traffic (estimated in 10000-15000 trips in different alternatives);
- problems to free access to roads or properties due to working places

The resulting index has positive orientation with a scale ranging between: [0, 10] where 10 is the worst possible situation

Possibility to have additional water for irrigation
Since only some alternatives envisage the creation of an hydraulic connection of the system with the Zero river that would allow the use of water for irrigation, the resulting indicator is a very simple binary (yes/no) one, with positive orientation [0, 1]

Criteria for prediction and indicators for measuring the impacts, have been discussed with a set of stakeholders during meetings organized by the municipalities and Drainage Authority. The investment cost has not been considered among the criteria of analysis because it has already been set by the financing authority of the project (Regione Veneto).

RESULTS AND DISCUSSION

The "performance" of different alternatives is summarized in the following table.

Table 1. The Effect Matrix

	Unit [range]	Alt.0	Alt.A	Alt.B	Alt.C	Alt.D	Alt.E
N removal	N Kg/year [0, 5000]	0	3783.5	0	1715.8	2156.2	2086.9
Flooding volume	1000 m^3/year [0, 282.6]	282.6	190.0	115.2	135.7	138.4	135.6
Damage to farmers	Index [0, 3]	0	2	2	2	2,25	2,25
Management cost	1000 €/year [0, ∞]	0	27,7	0	23,7	23,5	23,5
Landscape	Index [0, ∞]	0	22	71	68	68	68
Nature conservation	Index [0, 4]	6	16	11	15	15	14
Damage to people	Index [0, 10]	0	5,75	3,8	4	4,45	4,45
Irrigation	Index [0, 1]	0	1	0	0	1	1

It is important to notice that for both the indicators related to the main objectives of the project (N removal and flooding volume reduction) none of the alternative is able to reach the corresponding maximum (5000 N Kg/year and 0 flooding volume). This is due to budget restriction: each alternative, in fact assumes the same fixed budget that is not sufficient to reach the maximum value of the objective.

To allow a comparison of the alternatives, each indicator should be a measure of the (relative) *satisfaction* that a given stakeholder associates with a given *impact* (Beinat 1997). Hence, the indicators have to be "translated" into an index through a Value Function (or Utility Function when uncertainty is explicitly considered) in the sense specified by Keeney and Raiffa (1976), i.e. a mathematical representation of human preferences. As a consequence, any index becomes positively oriented, i.e. the larger its numerical value, the higher is the *satisfaction*.
Very simple linear Value Functions, were adopted, except for N removal for which we assumed a "saturating" Value Function.

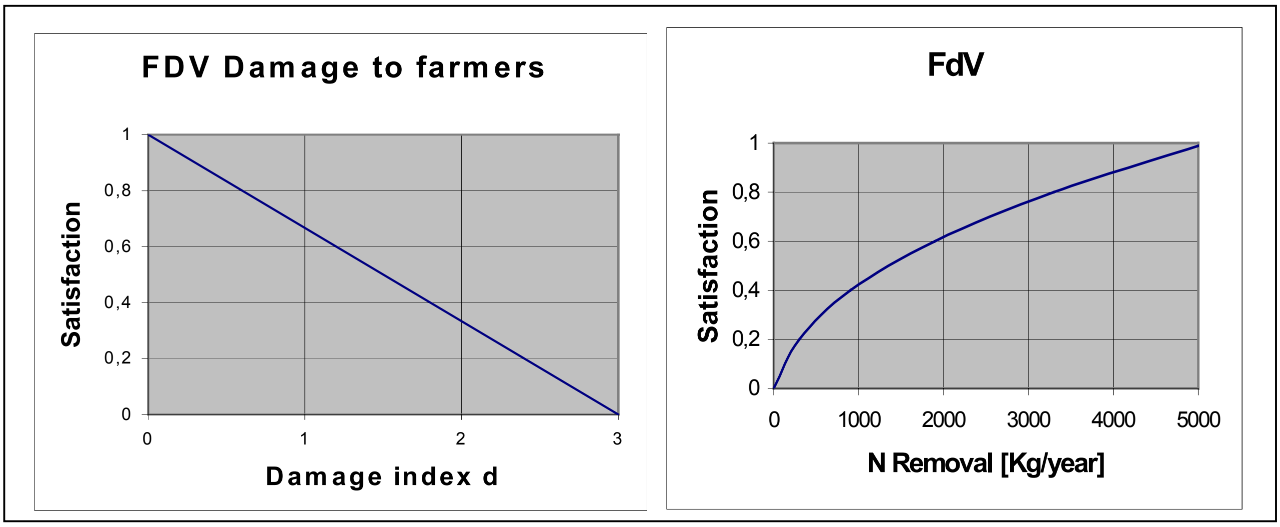

Figure 1 Example of Value functions: linear negative oriented, saturating positive oriented

After conversion through the normalized Value Functions, the different criteria become comparable, assuming that 0 corresponds to the "worst performance" , while 1 corresponds to the "best possible performance" (that, as already pointed out, owing to existing budget constraints, could be lower than the higher extreme of the range scale).

Table 2. The e Evaluation matrix

	Alt.0	Alt.A	Alt.B	Alt.C	Alt.D	Alt.E
N removal	0,00	0,57	1,00	0,88	0,85	0,88
Flooding volume	0,30	1,00	0,52	0,86	0,90	0,90
Damage to farmers	1,00	0,33	0,33	0,33	0,25	0,25
Management cost	1,00	0,00	1,00	0,15	0,13	0,13
Landscape	1,00	0,78	0,29	0,29	0,32	0,32
Nature conservation	0,19	0,50	0,35	0,47	0,47	0,44
Damage to people	1,00	0,43	0,62	0,60	0,56	0,56
Irrigation	0,00	1,00	0,00	0,00	1,00	1,00

The following step of Multicriteria Analysis is a critical one. The different evaluation criteria have different importance: definitely the main objectives of the project were nutrient removal and hydraulic risk reduction, while the other impacts are relatively less important. So there is the need to "weight" criteria, according to their importance. Consorzio Dese Sile managed this project phase by meeting the most important stakeholders of the area (municipalities, citizens and environmental associations, farmer organizations, etc.) and, through public meetings, defined the importance of each aspect by a 0 to 10 score.
During this phase it turned out very useful to rely on both the matrix shown in tables 1 and 2. In fact, the first one reminds the physical meaning of the impacts, while the second one makes clear the preferential ordering (for a deeper discussion on this issue see Nardini, 2004).

The following table reports the scores of each criteria and the relative normalized weight.

Table 3. Importance of criteria

	Score	Weight
N removal	10	0,213
Flooding volume	10	0,213
Damage to farmers	5	0,106
Management cost	7	0,149
Landscape	3	0,064
Nature conservation	3	0,064
Damage to people	5	0,106
Irrigation	4	0,085

The main aspects arisen during the discussion sessions that, somehow, led to assign weight to the different criteria, are the following:

- *Nutrient removal*: is the main objective of the project (the financial resources come from a fund for environmental recovery of the lagoon);
- *Hydraulic risk*: is considered at the same level of the first aspect, since it is the main problem for the local population (that have no direct interest in the recovery of the lagoon);
- *Management cost*: is the most important after the main objectives
- *Damage to farmers and to people*: both are very important but the highest negative extreme is not so high;
- *Landscape, nature*: the low value attributed to these aspects is linked to the scarce presence of "environmentalist" between the stakeholders, however we have also to consider that the area have not a particular landscape value and most of the project alternatives have positive impact on ecosystems;
- *Irrigation*: the low value attributed depend on the fact that most of the farmers already use private wells for irrigation.

In table 4 is summarized the final ranking of the 6 alternatives

Table 4. The final evaluation

	Alt.0	Alt.A	Alt.B	Alt.C	Alt.D	Alt.E
Performance	0,50	0,58	0,61	0,54	0,61	0,62
Ranking	0	0	0	0	0	1

From Table 4 it can be observed that Alt.0 has a performance far lower than the others, confirming the need for the project realisation. It is also evident that three alternatives (B,D,E) have very similar performance, that could rise the suspect that slight changes in weight assignment could bring to a different result in terms of ranking. However, a sensitivity analysis showed that the ranking showed in table 4 is robust enough: in fact only a change of at least 35% of a weight brings to a different ranking (and the following alternative is B).

CONCLUSIONS

In many densely populated areas constructed wetlands are not well accepted by local population, specially in large floodplain areas where classic land reclamation practices have been implemented till a few decades ago. In such areas the design and realisation of CW require particular care in public involvement. However public partecipation processes still suffer a lack of tools able, on the one side, to reliably predict the effects of project realisation, and, on the other side, to correctly communicate to the public such effects, and incorporate their preferences into the project design and realisation.

Multicriteria Analysis used in the present case, showed to be a powerful tool, not only to inform the public on the effect of an envisaged project, but to involve the public in the design phase. In fact the best alternative (E) has been identified through the MCA, once it appeared that the most interesting alternatives by the point of view of the financing agency (A and D that have the highest performances in terms of nutrient removal) would not be accepted by the population.

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