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The Use of Experts' Judgements to Assess Agri-Environmental Policies in the Venice Lagoon Watershed: a Bayesian Network Approach

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Abstract: Expert elicitation processes are increasingly applied in environmental management, to deal with complex phenomena characterised by lack or scarcity of data. Information obtained from carefully defined elicitation protocols can overcome uncertainty limits and support decision-making processes. The work illustrates the potentials of an innovative methodological framework, built upon the integrated use of specific tools, such as cognitive maps and Bayesian networks (BNs). The methodology was applied to the Venice Lagoon Watershed (VLW) case study, to assess agri-environmental measures, adopted to reduce nitrogen diffuse pollution of water. The framework consisted of two main phases, both built upon processes eliciting judgments from experts. The first phase aimed at gaining a clear understanding of the problem, categorising the main factors of the system into a shared cognitive map, built during an interactive group elicitation exercise. The second phase focused on the construction of a BN, representing the probabilities of relationships between the variables of the system and assessing the effects of different measures on the environment. The Conditional Probability Tables (CPTs) underlying each node of the BN was populated with probabilities elicited through specific questionnaires. To minimize the elements of bias in the estimation of the experts, both processes of engagement of the experts were formalised, choosing the most indicated tools and procedures, into carefully designed protocols.
The results of the research highlighted the potential of the methodology to incorporate the uncertainty in multidisciplinary and participatory contexts, for *ex-ante* and *ex-post* policy assessments. This methodology allows the integration of the available knowledge and of the uncertainty that characterise it, giving the possibility of knowledge updating whenever new information become available.

***Keywords**:* cognitive maps; measures assessment; uncertainty; nitrogen diffuse pollution; agriculture.

1. INTRODUCTION

Nowadays, the careful management of water resource has become relevant as a global issue considering the scarcity of fresh and clean water. In many developed countries, the main threat for water resources is the elevated level of nutrient loads (nitrogen and phosphorus) coming from agricultural runoff [Heathwaite, 2003]. This means that intensive agriculture determines diffuse water pollution or non-point sources pollution, i.e. a pollution where sources are not plenty detectable [EEA glossary].
In Europe, water management is regulated by the Water Framework Directive (WFD, 2000/60/EC). This directive points to the recommendations of the Nitrate Directive (1991/676/EEC) whose objectives are the reduction and prevention of further nitrate pollution. Nitrates derived from agricultural activity are the main cause of diffuse water pollution in EU [EC, 2002], therefore acting on agricultural management seems an effective way to limit water depletion [D'Arcy and Frost, 2001; Pieterse et al., 2003; Ripa

et al., 2006]. Policy instruments and mitigation programs affecting agricultural management were introduced by the WFD and need to be evaluated both before (*ex-ante*) and after (*ex-post*) their implementation. *Ex-ante* evaluation is useful to plan new strategies for the future while *ex-post* evaluation becomes relevant to assess the effectiveness of investments. To assess the policies is necessary to study their influence on both water cycle and agriculture. Therefore, the complexity of the problems requires the integration of model outcomes with other sources of information, such as statistics, qualitative data, and expert knowledge. Experts' judgements are deemed useful to minimise and characterise the uncertainty particularly in a context where there is a lack of information and substantial uncertainty [O'Hagan et al., 2006]. Uncertainty characterise water management, as most of environmental management issues [Ricci et al., 2003], mainly due to lack or scarcity of data (*epistemic* uncertainty), but also because of the inherent variability of the system (*aleatory* uncertainty). The first type of uncertainty can be reduced with further studies but the second is irreducible.

The probabilistic approach provided by the Bayesian network (BN) model takes into account and characterise *aleatroy* uncertainty while *epistemic* uncertainty is managed through the integration of different kinds of knowledge, among which experts' judgments. Expert knowledge, elicited through a careful definition and implementation of elicitation protocols, allows to overcome limits of analytic modelling, and to support decision-making processes.

The objective of the present work is to present the potentials of a methodology that integrates experts' judgments, through structured elicitation protocols, in a model that could perform *ex-ante* and *ex-post* policy analysis.

At the roots of the methodology there is the belief, based on multiple experiences at the international level, that the direct involvement of different experts in the management of environmental issues can overcome the usual problems related to different visions and interests in the scientific community and can enhance the analysis of complex cause-effect relationships among the factors of the system.

1.1 Case study

The new methodology developed was subsequently tested on a specific case study. The aim is to assess the effectiveness of agri-environmental measures implemented in the Venice Lagoon Watershed (VLW) to limit diffuse nitrogen pollution. The selected watershed is part of the Northern Italy alluvial plan that flows into the Venice Lagoon. This area is vulnerable and densely populated; the predominant land use is agriculture (75%), characterized by a high level of fertilization and intensive breeding. Nutrient loads from agriculture and breeding activities represent the main source of water pollution; therefore, the Regional Government has planned interventions and actions, on voluntary basis, to reduce nutrient loads, especially nitrogen (Master Plan 2000, [DGR 2000]). The measures included:

- promotion of low-input agriculture (e.g. changes in crop rotation, rationalisation of agronomic techniques and meadows surfaces);
- introduction of buffer-strips and set-aside to take advantage of the phytoremediation potential of wastewaters;
- support of irrigation management (e.g. reduction of water input, recycle of meteoric waters for irrigation purposes);
- interventions in breeding (e.g. manure and sludge management, structural investments).

A brief description of the financed measures was presented in Carpani [2009].

Preliminary data on farmer's participation indicated that 550 farms were involved i.e. around 1% of the farms of the VLW.

2. MATERIAL AND METHODS

An *ex-post* evaluation of policy measures was necessary to assess the effectiveness of investments, in order to define new strategies for the future, within the local implementation of the WFD. The complexity of the issue required to integrate model

outcomes derived from the QUAL2E/SWAT models' combination, applied at the watershed scale [Salvetti et al. 2008], with other sources of information, such as statistics, qualitative data, and expert knowledge.
The innovative methodological framework was built upon integration of already existing tools, such as cognitive maps and BNs, and upon the implementation of structured processes of elicitation of experts' judgments (Figure 1).

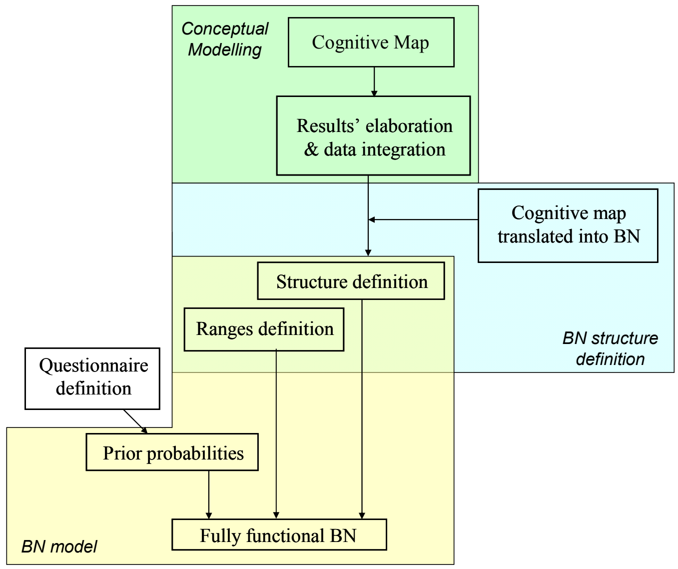

Figure 1 – The methodological framework built to assess agri-environmental policy measures.

The integrated methodological flow was defined to provide policy makers with an informative and transparent decision support tool, which could quantify and characterise the uncertainty, incorporate it into the BN model and finally effectively communicate it, as suggested by Morgan [2008]. The rigorous and comprehensive framework was composed by several subsequent steps (Figure 1) that were subdivided in two main phases, both built upon the elicitation of experts' judgments. The conceptual modelling phase, aimed at gaining a clear understanding of the problem through the categorisation of the main factors of the system into a shared cognitive map built during an interactive group elicitation exercise. The second phase focused on the creation of a BN model, representing the probabilistic relationships between the variables of the systems and assessing the effects of the implementation of different measures to reduce nitrogen, such as imposing diverse fertilizations rates. This second phase was composed by two different parts: BN structure definition and model population. The Conditional Probability Tables (CPTs), underlying each node of the BN model, were filled-in with subjective probabilities elicited from the experts through a series of face-to-face interviews.
According to the literature the validity of expert judgments depends on the completeness of the experts' mental model of the phenomena, and on the way in which the expert data are elicited, modelled, analysed and interpreted. An expert's assessment may not be properly calibrated or may reflect several cognitive or motivational biases [Clemen and Ulu 2008], therefore, to minimize and possibly eliminate the elements of bias, prejudice and irrationality, both processes of engagement of the experts, and of elicitation of their judgments were formalised into carefully designed protocols. Those protocols were built choosing the most indicated tools and procedures suggested by reviewing specific literature and successful applications, thus justifying the entire framework.
The two protocols were composed by four steps: (1) the introductory assessment of the issue, (2) the selection of the elicitation components, (3) the definition of the elicitation process and (4) the choice of the analysis procedures. Each phase of the protocol contained a series of actions and choices (Figure 2), which aimed at ensuring the robustness of the elicitation process and the validity of the outputs.

The most important stage of the elicitation process was the choice of experts [O'Hagan et al., 2006]. For both phases of experts' involvement, the conceptual model definition and the prior probability elicitation, experts were selected through the snowball sampling technique developed by Salganik and Heckathorn [2004]. This technique starts with a small group of person, generally 4 or 5, who identify all the main actors through an iterative selection procedure.

2.1. The Conceptual Model Protocol

A group elicitation situation was chosen to benefit from the synergies and the interaction among experts from distinct disciplines, in order to obtain qualitative information defining a shared conceptual model of the system. At the end of this process, the experts provided a cognitive map, i.e. a diagrammatic representation of the relationships among the elements of the analysed system. The analysis of the cognitive map allowed the definition of the BN model structure by identifying meaningful variables of the system and relationships among them. Once obtained an effective model structure, available data were analysed to describe and quantify the selected variables through the ranges definition.

2.2. The Prior Probabilities Protocol

A specific questionnaire was defined to elicit quantitative information, i.e. prior probabilities, from domain experts; obtained probabilities were subsequently used to define a fully functional BN.
To ensure the robustness and reliability of the results it was necessary to carefully tailor the elicitation process through a structured procedure. As stated by Morgan and Henrion [1990] there is no "cookbook" generally applicable in every elicitation situation; but the main attributes of a "good" protocol can be highlighted: a careful planning, attention to the different problems and training the experts. Therefore the *ad hoc* protocol presented in Figure 2 was defined studying the basic methods presented in the literature and selecting the most suitable approaches to conduct a structured elicitation tailored on the VLW case study.

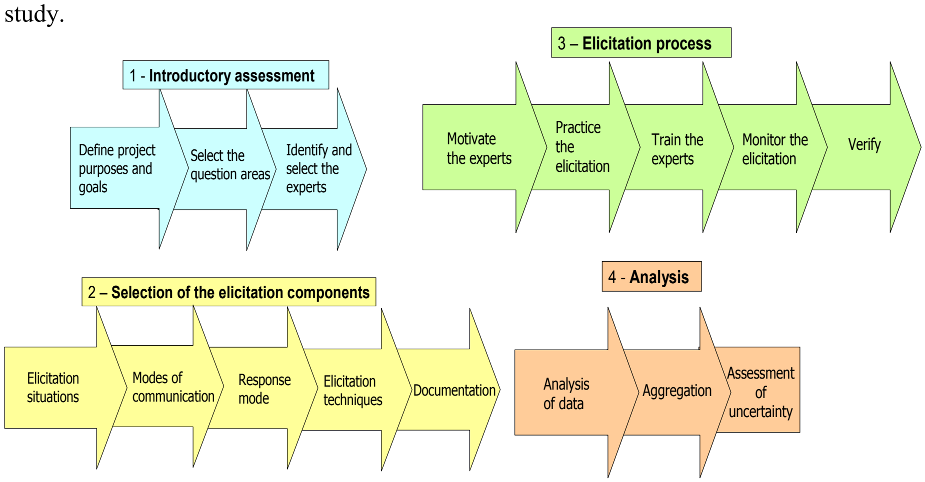

Figure 2 – The flow diagram of the elicitation protocol.

The most important steps of the protocol were the definition of techniques for selection, engagement and motivation of the experts, and for elicitation of probabilities. Another important part was training the experts, because they have to have a clear understanding of: the subject matter, the quantity elicited, the concepts of probability, and biases in probability assessment. The training helped them to familiarise with the elicitation methods and with specific approaches to limit the occurrence of biases [Meyer and Booker, 1991; O'Hagan et al., 2006], moreover, in order to minimize errors in the final results, the analyst monitored the elicitation process carefully, adjusting biases in real time.

3. RESULTS

The main results of the experts' judgments elicitation derived from two different protocols and corresponded to the conceptual model definition and the elicitation of prior probabilities. Once obtained those information the assessment of agri-environmental measures could be performed through a fully functional BN model.

3.1. The Conceptual Model

A former workshop [Giupponi et al., 2008] collected the environmental meaning and mechanisms of the agri-environmental measures settled in the VLW, allowing the definition of a useful shared scheme to frame experimental evidences and monitoring data. Results obtained were organised according to the DPSIR approach (Driving forces, Pressures, States, Impacts and Responses) proposed by EEA [1999]. In the obtained cognitive map agricultural and breeding activities, were grouped as drivers and pressures, influencing the state of the environment affecting air, soil, landscape and water (quality and quantity), generating environmental impacts that agri-environmental measures (i.e. responses) try to mitigate.
The map was transformed, through a semi-structured procedure proposed by Nadkarni and Shenoy [2004], in a preliminary BN structure. The obtained structure was simplified to avoid non meaningful variables and links inclusion, as suggested by Borsuk et al. [2004], and thus allow to obtain a causal BN structure, subsequently validated by the experts interviewed.

3.2. The Prior Probabilities

The objective of the second elicitation process was to collect input parameters to populate the BN model. Considering that the framework definition and its test were part of a PhD research project, the main constraints, that influenced every subsequent choice, were time and resources availability.
Experts' selection combined with selection criteria guarantee that the selected experts represent different domains: academia, field research, government and environmental institution; that they know the study area at the watershed level and the agri-environmental measures implemented.
Because the aim of the elicitation was to obtain conditional probabilities, as suggested by O'Hagan et al. [2006], individual face-to-face interview was the selected method of communication. That, furthermore, better performs with questions related to the field of expertise [Brockhoff, 1975 cited by Morgan and Henrion, 1990], such as in the VLW case study, where three main field of expertise were detected (i.e. administrative, agronomic and hydrologic – Figure 3).
To avoid misinterpretation or elaboration of expressed judgments used in the BN, the selected elicitation technique was the probability estimate. Moreover, probability results the best choice to express uncertainty when knowledge is scarce [Meyer and Booker, 1991]. For those reasons the selected response mode was the direct elicitation of probabilities. Thus required anyway the training of the experts to fill them confident and to reduce biases that direct probability estimation can determine [Meyer and Booker, 1991 and reference therein].
Developed questionnaires collect the quantitative information, but also ancillary information were collected taking notes during the interviews; thus providing a complete documentation to gather experts' judgments.
The importance of their contribution motivated the experts to participate to the elicitation; the motivation phase was performed by phone calls and e-mails, also used to send information materials (i.e. the introductory documentation and the questionnaire). The introductory document allows to present the project and the aim of the questionnaire, while the questionnaire allows the experts to get acquired with the questions before the interview. Thus allow the experts to contact the interviewer for any explanations.

A couple of researchers already familiar with the case study, working on a parallel project, tested the elicitation allowing the refinement of both, the introductory documentation and the questionnaire.
The questionnaire is composed by three parts, one for each field of expertise, sharing a common structure with two main parts, introduction and questions. The introductive part has an image highlighting the variables of interest and their parents that help the experts to better contextualise their answers, and a table describing the analysed variables indicating their unit of measures and ranges of variation. In the questions part, a reference-frame scenario highlights every influence that the parents nodes have on the analysed variable, to better contextualise the probability assessment.
To verify if the obtained results reflect experts' beliefs follow-up interviews were conducted, by e-mail and telephone.
To contextualise the responses of multiple experts, ancillary information collected were combined with a correlation analysis for each node, and for field of expertise. The correlation analysis highlight that with the exception of the agronomic field no strong correlation (i.e. greater then 0.5) exist among experts.
Aggregate experts' judgments allowed to obtain a prior distribution for each node of the BN model. Different aggregation techniques exist; behavioural or mathematical, but the most suitable in face-to-face interviews results the mathematical aggregation. Among different mathematical aggregation methods Clemen and Winkler [1999] suggested the equal-weighted average, applied in the VLW case study. Results from the aggregation allow populating the CPTs of each variable, obtaining a fully functional stochastic model.

3.3. The methodological test

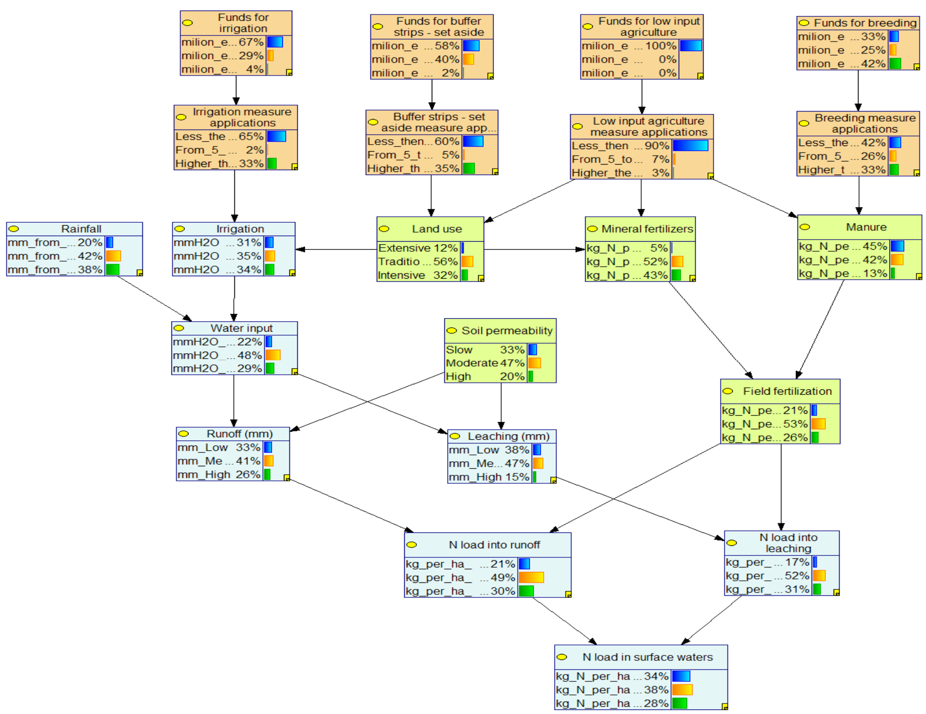

Figure 3 – The fully functional BN model for the VLW case study; three main field of expertise are highlighted: administrative (orange), agronomic (green) and hydrologic (light blue).

The fully functional BN model obtained throughout experts' judgments (Figure 3) highlights that agri-environmental policies seems not to have a meaningful influence on the *N load in surface waters* node, i.e. the target node. Thus because the maximum regional threshold level for agricultural nitrogen load is enclosed in the lower range of the target node, while its probability distribution results nearly uniform.

An updating scenario built elaborating preliminary outputs of a field model (not published data) was inserted into the BN model as evidence that selected the higher range for both, *N load into runoff* and *N load into leaching* nodes. This evidence affects the probability distribution of the target node, indicating an higher probability (63%) to obtain an higher level (more then 22 kg N ha^{-1}) of nitrogen in surface waters.

4. DISCUSSION AND CONCLUSIONS

Considering a future in depth assessment of the agri-environmental policies performed in the VLW, the methodological test, even if non-comprehensive, will became useful to consider the general trends of the results and to think about data availability. The test shows the ease of results updating when new information from model simulations, became available.

The use of experts' judgments was crucial to fill the lack of data and the inadequate or incomplete measurements from models and empirical studies concerning. Considering the broad results, therefore, the methodological framework emerges as an innovative, flexible and powerful tool able to perform *ex-post* or *ex-ante* analyses of policy measures. Thus because the framework allows the assessment of agri-environmental measures overcoming the limits of consolidated approaches (e.g. indicators and simulation models), handling missing data through the integration of different kinds of information, having different sources, with experts' judgments.

Moreover, BN provides a support for adaptive management, in an effort to structure an informed and transparent decision making process for the choice of agri-environmental measures, following a precautionary approach that overcame the uncertainty of models' estimates. Handle explicitly uncertainty makes the developed framework an easier and comprehensive way to represent the analysed system, and the effects of policy measures and for this reason extremely useful in participatory approaches. It worth to be noticed that participatory approach is broadly considered the best way to handle decision-making processes; so the instrument flexibility makes the framework useful for diverse disciplines.

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REFERENCES

Borsuk, M.E., Craig, A.E., Reckhow, K.H., A Bayesian network of eutrophication models for synthesis, prediction, and uncertainty analysis. *Ecological Modelling, 173,* 219-239, 2004.

Carpani, M., Alternative methods for the assessment of agri-environmental measures. The Venice Lagoon Waterhed case study, PhD thesis, University of Milan, Italy, 2009.

Clemen, R.T., Ulu, C., Interior Additivity and Subjective Probability Assessment of Countinuous Variables, *Management Science, 54*(4), 835 – 851, 2008.

DGR (Decreto del Consiglio Regionale) n. 24, 2000. http://www.serviziregionali.org/direttore2000/

D'Arcy, B., Frost, A., The role of best management practices in alleviating water quality problems associated with diffuse pollution. *The Science of The Total Environment, 265,* 359-367, 2001.

EC (European Commission), Implementation of Council Directive 91/676/EEC concerning the protection of waters against pollution caused by nitrates from agricultural sources. Office for Official Publications of the European Communities, Luxembourg. ISBN 92-

894-4103-8, 2002.

EEA (European Environment Agency), Environmental signals 2000. Environmental Assessment Report No. 6. Office for official publication of the European Communities, 1999.

EEA (European Environment Agency) Glossary, http://glossary.eea.europa.eu/EEAGlossary/.

Giupponi, C., Fassio, A., Sgobbi, A., Evaluation of Agri-Environmental Measures in the Venice Lagoon Watershed. Expert Knowledge Elicitation and Multi-Criteria Analysis. *Italian Journal of Agronomy, 3,* 147-165, 2008.

Heathwaite, A.L, Making process-based knowledge useable at the operational level: a framework for modelling diffuse pollution from agricultural land. *Environmental Modelling & Software, 18,* 753-760, 2003.

Meyer, M.A., Booker, J.M., Eliciting and Analysing Expert Judgment: A Practical Guide. Academic Press Ldt., London, 1991.

Morgan, M.G., Best Practice Approaches for Characterising, Communicating and Incorporating Scientific Uncertainty in Climate Decision making, U.S. Climate Change Science Program, Synthesis and Assessment Product 5.2, Under public review, 2008.

Morgan, M.G., Henrion, M., Uncertainty. In: A guide to dealing with uncertainty in quantitative risk and policy analysis. Cambridge University Press, ISBN 0-521-36542-2, 1990.

Nadkarni, S., Shenoy, P.P., A causal mapping approach to constructing Bayesian networks, *Decision Support Systems, 38,* 259-281, 2004.

O'Hagan, A., Caitlin, E., Buck, C.E., Daneshkhah, A., Eiser, J.R., Garthwaite, P.H., Jenkinson, D.J., Oakley, J.E., Rakow, T., Uncertainty judgements: Eliciting Experts' Probabilities. Jhon Wiley & Sons, Ltd, ISBN 0-470-02999-4, 2006.

Pieterse, N.M., Bleuten, W., Jorgensen, S.E., Contribution of point sources and diffuse sources to nitrogen and phosphorus loads in lowland river tributaries. *Journal of Hydrology, 271*, 213-225, 2003.

Ripa, M.N., Leone, A., Garnier, M., Lo Porto, A., Agricultural land use and best management practices to control nonpoint water pollution. *Environmental Management, 38*, 253-266, 2006.

Ricci, P.F., Rice, D., Ziagos, J., Cox, L.A., Precaution, uncertainty and causation in environmental decisions. *Environment International 29,* 1-19, 2003.

Salganik, M.J., Heckathorn, D.D., Sampling and Estimation in Hidden Populations Using Respondent-Driven Sampling, *Sociological Methodology, 34,*193-239, 2004.

Salvetti, R., Acutis, M., Azzellino, A., Carpani, M., Gipponi, C., Parati, P., Vale, M., Vismara, R., Modelling the point and non-point nitrogen loads to the Venice Lagoon (Italy): the application of water quality models to the Dese-Zero basin. *Desaination*, *266*, 81-88, 2008.