RELU Workshop On Expert Systems For Natural Resources Management – Summary

Wednesday 14th January 2009. London International Development Centre, 36 Gordon Square, London
Prepared by Tobias Krueger, Laurence Smith and Kevin Hiscock

Programme

9:45 **Arrival and coffee.**

1. **Welcome, introductions and review of agenda.**
2. **Project introductions** (see attached PDFs of presentations)**.**
   a. Paulette Posen: Catchment Hydrology, Resources, Economics and Management (ChREAM): Integrated Modelling of WFD Impacts on Rural Land Use and Farm Incomes (http://www.relu.ac.uk/research/projects/SecondCall/Bateman.htm)
   b. Klaus Hubacek: Sustainable Uplands: Combining participatory research and integrated socio-biophysical models (http://www.relu.ac.uk/research/projects/SecondCall/Hubacek.htm)
   c. Kevin Hiscock: Developing a Catchment Management Template for the Protection of Water Resources: Exploiting Experience from the UK, Eastern USA and Nearby Europe (http://www.relu.ac.uk/research/projects/Third%20Call/Smith.htm)
   d. Lisa Norton: Understanding and acting within Loweswater: a community approach to catchment management (http://www.relu.ac.uk/research/projects/Third%20Call/Waterton.htm)
   e. Rob Fish: Strategies for containing livestock diseases: Conceptualising & eliciting uncertainties (http://www.relu.ac.uk/research/projects/Third%20Call/Wynne.htm)
3. **Discussion.**
   a. What is an expert?
   b. What is an expert system or a model?
   c. How do we collect expert information?
   d. How do we communicate model results?
4. **Next steps.**

17:00 **Close and departure.**

Summary of discussions

As a general message of encouragement from RELU, Jeremy Phillipson welcomed the workshop; such activities are timely with respect to RELU's final phase of reporting science outcomes and translating these into policy recommendations and decision making.

2a. Catchment Hydrology, Resources, Economics and Management (ChREAM): Integrated Modelling of WFD Impacts on Rural Land Use and Farm Incomes

(http://www.relu.ac.uk/research/projects/SecondCall/Bateman.htm)
The overall aim is to model the bio-physical and economic impacts of achieving WFD targets for good ecological status in the Humber catchment. However, there is much uncertainty in modelling ecological outcomes. With regard to the surveys conducted by the project, the issue of how much significance to assign to 'expert' responses was raised, as well as, in the context of farmer surveys, the importance of building a long-term relationship with informants so that they "do not tell you want you want to hear". At the farm level, data sources include the FBS, Agcensus (EDINA) and a farm survey to identify the variety of farm management techniques used within each one of a number of discrete farm types. The farm survey is a one-off but time is invested in engagement and trust-building during interviews. Following on from 'stakeholder engagement issues' discussed at this workshop, ways of communicating feedback to participating farmers in the ChREAM farm survey are being investigated. While the project's approach aims to predict a range of outcomes under a number of different policy and economic scenarios, it may be difficult to update the knowledge base and corresponding models in the light of change (e.g. the recent economic down-turn). Another "1000 interviews" will be very costly, although there may be ways to model such unanticipated changes. Benefit estimation for improved water quality will be based on a choice modelling experiment and travel cost study. Is there a need to consider negative environmental impacts from increased tourist activity/recreational use which may also generate unforeseen costs?

Tools potentially useful to other projects:

- Land use modelling methods
- Hydrological & water quality models (CEH)
- Farm economic model
- Benefit estimates for WFD implementation based on willingness to pay values derived from choice modelling for recreational use of water bodies and a travel cost study (to be made available on the ChREAM website)
- Farm survey to test assumptions of farm economic model (results to be made available on the ChREAM website).

2b. Sustainable Uplands: Combining participatory research and integrated socio-biophysical models

(http://www.relu.ac.uk/research/projects/SecondCall/Hubacek.htm)
The project is using a large networked model for upland management that links and integrates a number of specific models. This is employed in an iterative adaptive management approach with stakeholders. This can achieve more than simple models and does build stakeholder "buy-in". However, the process is costly and time consuming, and there is limited ability to respond to the unexpected. The issues of model uncertainty and communication of uncertainty were discussed. Uncertainty is mainly addressed at the end of the modelling chain when single value model outputs will be communicated to stakeholders as being indications or scenarios. The project team prefers this

approach because of the short time they have to simulate an adaptive management process and also because explaining, for example, uncertainties in model calibration might be too much for the stakeholders. This raised the question of how much stakeholders can be involved in the modelling. The project tries to establish a fundamental understanding of the models and the modelled environment based on, for example, maps. They want to get across how people interact with their environment. Also, stakeholder knowledge is used to test model outcomes.

Another discussion developed around the project's social network analysis. Discussing initial network analysis results iteratively with stakeholders had developed understanding of the reality of nodes, communication links and relationships. The importance of relationships and trust were highlighted once more, both in the working of real world networks and for the use of analytical tools. It took the project years to establish the stakeholder group although they could build on previous work in the area. Domino effects were important too.

Tools potentially useful to other projects:

- Social network analysis
- Agent-based model of land use based on a survey of choices and what-if responses
- Ecological models (e.g. vegetation and grouse dynamics)
- Soil erosion model PESERA
- Carbon balance model.

2c. Developing a Catchment Management Template for the Protection of Water Resources: Exploiting Experience from the UK, Eastern USA and Nearby Europe

(http://www.relu.ac.uk/research/projects/Third%20Call/Smith.htm)
The project is exploring the use of Bayesian Belief Networks (BBNs) as a flexible and robust modelling tool that can be developed with stakeholders and can integrate existing knowledge and issue specific models. In discussion, the importance of in-stream/in-lake processes in controlling sediment/phosphorus dynamics was highlighted which are currently absent from the project's conceptual network. Response times for improvements in lakes and groundwater can be very long, and this reality must be communicated to stakeholders. There is a long history of failure in communicating models to stakeholders; will the use of BBNs prove more effective? Evaluation of the experience and possible social learning legacies should be part of the research agenda. In general, communication of models and their refinement and iterative use with stakeholders in adaptive management needs to be better understood and experiences documented.

The project's link with the New York City watershed prompted a discussion about the US approach of investing money on farm land to pre-empt water treatment. Is it fair that water suppliers rather than farmers pick up the pollution bill? Comparison was made to Scotland where some whiskey distillers have bought land in upper catchments to be able to control their water quality.

Tools potentially useful to other projects:

- Bayesian Belief Network as an integrating modelling tool.

2d. Understanding and acting within Loweswater: a community approach to catchment management

(http://www.relu.ac.uk/research/projects/Third%20Call/Waterton.htm)
The project is using a process-based lake phytoplankton model (PROTECH) and a nutrient export model (GWLF + export coefficient type model) to estimate phosphorus loads from land use and relate

this to the ecological quality of Loweswater. This is being integrated with detailed land use and feature mapping, a survey of farm practices by an agricultural management consultant, and potentially the PLANET (ADAS) farm nutrient model. The aim is an integrated understanding of lake ecology, hydrology and farm practice, and the ability to explore land use scenarios.

The discussion considered social networks, stakeholder engagement in modelling and the difficulty of measuring empowerment and social learning. The Loweswater team benefits from a small community and the relationships and trust they can build. However, one downside in this respect is that the Loweswater community does not currently benefit from the Catchment Sensitive Farming initiative. The need to raise awareness is one of the CSF selection criteria and the Loweswater community is already considered "aware". The project will also investigate the nature of expertise and the "ownership" of knowledge.

Tools potentially useful to other projects:
- Landscape mapping approach
- Hydrological & pollutant export models (GWLF & export coefficient types of models)
- Lake model PROTECH
- PLANET farm nutrient model (ADAS).

2e. Strategies for containing livestock diseases: Conceptualising & eliciting uncertainties

(http://www.relu.ac.uk/research/projects/Third%20Call/Wynne.htm)
The project is examining the effectiveness of strategies of containing livestock diseases; strategies being assemblages of principles and practices. There are a range of strategies and forms of uncertainty for each, comprised of incomplete knowledge, ignorance and indeterminacy. Understanding of both strategies and uncertainties will be gained from elicitation of expert knowledge from key informants, primarily from government agencies, industry and the research community. This will be combined with investigation of uncertainties embedded within key datasets linked to the three disease areas.

There was wide ranging discussion of the nature of expert knowledge and expert systems. There is now a spectrum of tools and approaches that can be termed expert systems. It was deemed interesting to analyse how different scientific disciplines understand and categorise expert systems.

Tools potentially useful to other projects:
- Expert consultation/elicitation approaches.
- Account of farmer and Defra experience from the 2001 Foot-and-Mouth disease outbreak.

3a. What is an expert?

> The *Concise Oxford English Dictionary* defines an *expert* as a "person having special skill or knowledge" (Cowell et al. 2007, p. 5).

Discussion points:
- Conventionally, an expert is a person that uses technical training, knowledge and experience to interpret information.
- The term *expert* implies the notion of *authority*; i.e. authority to comment, to use information and to take action. This may be a barrier to communication when scientists and non-scientists talk to each other. Use of less "authoritarian" intermediaries may be important, but lead scientists in a project may also need to fulfil the role of experts.
- Other loaded terms (e.g. *anecdotal* observation or evidence) are best avoided in stakeholder

meetings. Even the term *local expert* might be misleading as it is not only the citizen of an area or an otherwise connected stakeholder that can be a local expert; scientists are also "localised" in their field of expertise. Everyone is an expert but the spatial, temporal and subject matter boundaries of their knowledge define their expertise.

- Both scientists and non-scientists can be wrong in their perceptions and determinations.
- Generalisations may be dangerous but it is expected that the knowledge of scientists will typically be more abstract and generic, whereas the knowledge of local people may be more applied, detailed and location specific.
- In seeking to achieve interaction and communication in stakeholder meetings the boundaries of expertise should not be over emphasised.
- Experts are people; can a model also be classed as an expert?

3b. What is an expert system or a model?

> Expert systems are attempts to crystallize and codify the knowledge and skills of one or more experts into a tool that can be used by non-specialists. […] An expert system consists of two parts, summed up in the equation: Expert System = Knowledge Base + Inference Engine (Cowell et al. 2007, p. 6).

Discussion points:

- An expert system does not have to be mathematical, it could consist of a list of options and instructions. While our projects are concerned with mathematical (or quantitative) approaches, our general definition of expert systems should not alienate people coming from a qualitative background. The group acknowledged that a spectrum exists from purely quantitative to purely qualitative expert systems; neither extreme is inherently superior.
- An expert system was seen as a model and it was discussed whether expert system as a term is really necessary, defining a model sub-class or category might be better.
- The term *Decision Support Tool* is an option but, in the way commonly used, may imply a separation between science and decision making which we would like to bridge with expert systems. This is particularly important in the context of adaptive management.
- Even the most complicated physically-based mathematical model incorporates expert knowledge in the way that equations are derived and combined.
- Models may evolve through iteration as expert opinions or judgements are replaced with observed data.
- Semantics should not become a constraint, but terminological distinctions between model sub-classes are potentially useful.
- Models are simplifications of reality that can only present scenarios. The challenge of unexpected events will always remain.
- Expert systems often seem to arise from particular situations for a specific purpose, perhaps after traditional modelling approaches have failed. Hence the definition of the boundary of the system to be modelled becomes important.
- Referring to the definition above, both the knowledge base and the inference engine depend on expert knowledge for their construction and their utilisation/interpretation.

3c. How do we collect expert information?

A number of expert elicitation approaches were mentioned but there was not enough time for an in-depth discussion. Experience with expert elicitation, however, existed in the group, the RELU project Sustainable and Safe Recycling of Livestock Waste, for example, used electronic and email approaches to collect expert information (see Fish et al., in press). There seems to be scope for a future workshop on expert elicitation methods. The following approaches were outlined briefly:

- Consulting a number of people to elicit a probability distribution of opinions (excluding uncertainty in each opinion) in a frequentist way (i.e. the probability of an event is defined as the limiting proportion in an infinite sequence of experiments). The resulting data is just like any other repeatable observation with the associated benefits of a large number of cases, although such surveys are time demanding. Concerns about representativeness, "are we asking the right question", and divergence of cases were raised. As a response to the latter it was argued that if divergence occurs this is part of the nature of the variable in question and should be accounted for in the analysis, e.g. in the form of scenarios.
- Consulting a single person to elicit their judgment (including uncertainty) as a probability in a frequentist way. An example question was "If you observed a stream 100 times, how many times would the stream be out of its bank?" with the example answer "20". This example led to the probabilities p(out of bank) = 20/100 = 0.2 and p(not out of bank) = 1-0.2 = 0.8. More events could be considered too.
- Consulting a single person to elicit a probability distribution of their belief in a Bayesian way (i.e. probability is defined as a person's subjective degree of belief). No expertise as to how this is done in practice was available within the group.
- Consulting a single person to elicit their judgment (including uncertainty) in the form of a fuzzy number. This appears to be commonly achieved through structured interviews where the interviewee is asked to locate boundaries for the variable in question that separate those values that are "certainly out" and those that are "certainly in".

It was further discussed which format the expert information should take to be useful for modelling. As a general answer, it was deemed possible to combine qualitative and quantitative information in certain types of models.

3d. How do we communicate model results?

Model results (including those of expert systems) are necessarily uncertain. Two approaches to dealing with this uncertainty were clear from the presentations: (1) either the uncertainties of individual model components are explicitly quantified and retained in the modelling process resulting in model outputs specified with a measure of uncertainty; or (2) single value model outputs are generated and an assessment of uncertainty, perhaps of a more qualitative nature, is made and communicated at the end of the modelling exercise. Time was limited, and the techniques involved in each approach and their respective advantages and difficulties could be a topic for a future workshop. It was pointed out, however, that the communication of uncertainty to stakeholders such as farmers has proven difficult, especially if a change of behaviour is sought whilst at the same time economic security is at stake. As a theoretical example of reasoning based on an uncertain model output, Figure 1 was discussed. See the original publication for details.

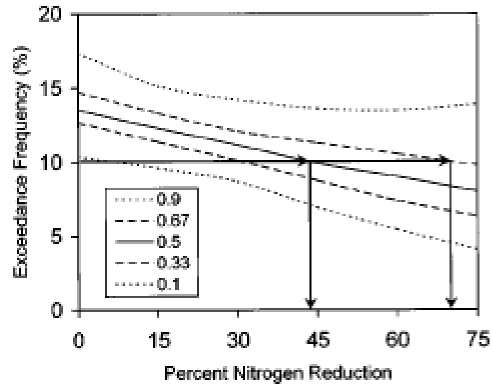

Figure 1: Example of reasoning based on an uncertain model output, here a probability distribution of the exceedance frequency of a water quality standard. The predicted change in frequency of exceedance of the state chlorophyll standard is shown as a function of percent reduction in nitrogen inputs. Lines represent percentiles of predictive distributions as is indicated in the legend. Bold arrows correspond to the graphical method of selecting target reduction (from Borsuk et al. 2003).

4. Next steps

- Tobi to circulate a workshop summary with PDFs of project presentations attached for comments.
- Judith to transcribe her recording of the workshop and make this available.
- Tobi to keep email list of group; all to suggest further members for inclusion.
- All to explore the possibility of a follow-up meeting on how the modelling components of each project proceeded, specifically the success with stakeholder engagement in this respect, and also scale issues in catchment modelling.
- All to explore if a knowledge transfer group could be established (e.g. under NERC's new Living With Environmental Change programme). David has experience with setting up a NERC working group.
- All to explore the possibility for a conference session on Expert Systems (e.g. at the European Geosciences Union General Assembly in spring 2010).
- All to explore the scope for an ESRC seminar series or ESRC/NERC joint seminar series. Rob has experience with setting those up.
- All to explore the scope for an Expert Systems for Natural Resources Management Special Issue of a journal and/or joint papers. Possible topics for joint 'review' papers include:
  - Conceptual review and definition of *expert* & *expert system* (Judith to lead)
  - Approaches for eliciting expert knowledge (Rob to lead based initially on past work on FIOs; see Fish et al., in press)
  - Comparison of catchment modelling approaches: quantitative vs. qualitative, problem – data – model – purpose, model selection criteria (Trevor & Tobi to lead)
  - Stakeholder engagement: iterative modelling and communication of results.

References

Borsuk, M. E., Stow, C. A. and Reckhow, K. H. (2003). Integrated approach to total maximum daily load development for Neuse River Estuary using Bayesian probability network model (Neu-BERN). Journal of Water Resources Planning and Management-Asce 129(4): 271-282.

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Fish, R., Winter, M., Oliver D. M., Chadwick, D., Selfa, T., Heathwaite, L., Hodgson, C. (in press) Unruly pathogens? Eliciting values for environmental risk in the context of heterogeneous expert knowledge. Environmental Science and Policy, in press.

Attendees

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