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Does it help? Testing the usefulness of a tool to aid Integrated Catchment Management

E.A. Shaw[a,*], V. Kumar[a], L. Gill[b], E. Lange[c], D.N. Lerner[a]

[a]Catchment Science Centre, Kroto Research Institute, Broad Lane, Sheffield, S3 7HQ, UK
[b]Department of Computer Science, Regent Court, 211 Portobello, Sheffield, S1 4DP, UK
[c]Department of Landscape, Crookesmoor Building, Conduit Road, Sheffield, S10 1FL, UK

Abstract

Integrated Catchment Management (ICM) advocates the consideration of multiple management objectives together in the decision making process rather than as unconnected separate issues. To deliver ICM, many integrated models are being created to be used as tools that predict how catchment interventions affect multiple management objectives. It is generally assumed that if applied, these tools will improve decision making. In this paper we discuss how this assumption can be tested, and then present preliminary work to do just that.
A tool was created to predict how weir modifications such as fish passes affect multiple river ecosystem services in the Don Catchment, UK. These ecosystem services included eel productivity, conservation of an endangered and spread of an invasive crayfish, hydroelectricity generation and river quality for canoeing. In an experiment this tool was used to make hypothetical management decisions, and the quality of the decision making was compared to a control decision making process representative of current practice in the catchment. The experiment was designed to evaluate decision quality by gauging efficiency and moderateness of decisions made, and by measuring the confidence and knowledge gained by participating decision makers. Preliminary results indicate that users of the tool learnt less information about the environmental issue of weir impoundment compared to the more conventional approach. If this effect is common when decision support tools are used to support ICM, then it has implications for how they are designed and utilised in the future.

Keywords: Decision support system; weirs; ecosystem services; decision making; decision quality; integrated modelling

* Corresponding author. Tel.: +44-114-222-6283.
E-mail address: ed.shaw@shef.ac.uk

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1. Introduction

The management paradigm of Integrated Catchment Management (ICM) proposes a holistic approach to catchment management, advocating the treatment of the full range of stakeholder interests as management objectives in the decision making process [1]. These are used together as a framework with which to evaluate and compare different potential catchment interventions. One of the key benefits of this approach is that it makes explicit the conflicts and synergies between different management objectives, which is thought to improve the effectiveness of decision making [2]. While it is largely recognised that ICM is the right approach to catchment management, actually implementing it is highly challenging; requiring that decision makers are able to predict the response of environmental, social and economic systems to catchment interventions. Given that responses to management interventions are commonly spatially and temporally interacting, and often non linear, clearly ICM decision making poses a huge analytical burden, one that the human mind struggles to cope with, even when they come highly trained and in teams.

It is therefore not surprising that since the advent of the digital age, researches have sought to exploit the analytic ability of computing systems to run models that provide the predictive capability required by ICM [3]. As time has progressed, the models built to aid decision making, termed Decision Support Systems (DSSs), have become increasingly sophisticated. However, this has not been reflected in the application of DSSs, which have a poor rate of uptake for use in catchment management [4]. Barriers to utilisation include a lack of confidence in the predictive ability of DSSs and the high level of technical support required for operationalisation [5]. Several papers in the literature suggest ways of overcoming these hurdles, and seem to unquestioningly assume that if these are surmounted, improved catchment decision making will follow [e.g. 6].

However, this need not necessarily be the case. There are numerous mechanisms by which DSSs could plausibly reduce the effectiveness of decision making. For example, the use of a computer screen as a channel of information exchange may be less stimulating for decision makers than more social collaborative approaches, or users may not be able to process and make use of the large quantity of information provided by a DSS.

To test whether a DSS improved ICM decision making, we ran an experiment to compare hypothetical catchment management decisions made by a group using a DSS to a control group that took a more conventional map and rule based approach to decision making. The DSS was one developed to help address the environmental management problem of weir impoundment in the Don Catchment.

The objectives of this paper are to:

- discuss how a DSS can be tested to see if it improves decision making
- introduce the design of the experiment set up to test a DSS
- describe the DSS and the environmental issue of weir impoundment that the tool addresses
- present the initial results, and plans for further analysis
- discuss the results and the implications for design and usage of DSSs

2. Method

2.1. How do you test whether a DSS improves decision making?

Some decisions made in decision making processes have a higher quality than others, that is to say they produce a more desirable outcome. To test whether one approach results in a higher quality of decisions than another, we must first have an idea of what decision quality is and how it can be measured. For the purposes of this study we identified four interrelated aspects of a decision that form components of decision quality. These are presented in the left column of Table 1. In the right column are the ways a DSS could potentially aid the user so that these components of decision quality are improved.

Table 1. What is decision quality and how might a DSS improve it?

Components of decision quality	How might a DSS improve decision quality in ICM?
the degree to which stakeholder interests are maximised	by teaching the user about the catchment management issue
the extent to which environmental, social and economic processes underlying stakeholder interests are sustainable	by encouraging the user to do further learning e.g. after noticing knowledge gaps
how fair and equitable a decision is	by allowing the user to simulate the impact of interventions that are mentally difficult or impossible to estimate
how satisfied stakeholders are with a decision	by reducing error in the thinking of stakeholders
	by reducing the time taken for the user to understand the impact of an intervention
	by improving communication between stakeholders
	by increasing creativity in solving environmental management problems
	by increasing engagement and interest in an environmental issue

Table 1 shows that evidence that a DSS improves decision making can be looked for in both decision making process and the decisions that result from it, so we can make observations of both. Based on the above table we derived four hypotheses that we thought we could feasibly test in an experimental setting:

- Hypothesis 1- A decision maker's knowledge of an environmental issue is enhanced

One of the primary purposes of a DSS is to communicate information to a user that they did not already know, especially information that is unfeasible to easily obtain during conventional decision making methods. Therefore we predict that the users of a DSS will gain a greater knowledge of an environmental issue than decision makers using more conventional approaches.

- Hypothesis 2 - The effectiveness of decision making is increased

By effectiveness of decision making we mean how close it is to maximising the decision's management objectives. When there are multiple management objectives and numerous options in terms of management interventions, many potential decisions are suboptimal in that another potential decision exists that can improve at least one objective without causing a decline in any other objective. However, for some decisions, there is no way to improve on it with regards to one objective without causing a subsequent decrease in another objective i.e. causing a trade off. Such decisions are said on lie on the Pareto frontier [7]. Therefore we predict that if a DSS results in more effective decision making then we would observe that decisions lay closer to the Pareto frontier.

- Hypothesis 3- Decisions are more moderate

By making the tradeoffs between different management options explicit, a user of a DSS will be more aware of potential inequalities and conflicts between stakeholders. Even when a decision maker is neutral, such as when making hypothetical decisions in an experimental context, we predict that a heightened awareness of tradeoffs will result in a more balanced set of weightings between objectives. We expect that this will be evident as decision making with less extremes i.e. objectives with particularly high weightings.

- Hypothesis 4 –Decision makers are more confident in their decisions

If a decision maker has a good ability to find the most effective decisions, we would expect them to be more secure about them. Therefore we predict that if a DSS has been successful in aiding its user, they are more likely to feel confident about their decisions.

2.2. Experimental design

To test these hypotheses, an experiment was designed to compare two groups; a control group and a group using a DSS. Individuals of both groups were asked to independently develop two catchment management strategies to address the environmental issue of weir impoundment in the Don Catchment (see section 2.3).

The decision making process in the control group was arranged to be representative of how catchment management decision making has been conventionally done. Each member of the group was provided with paper documentation that included an introduction to the weir impoundment environmental problem, maps of the catchment, and the intervention options they had at their disposal. They were also supplied with a set of rules that described how at a local level weir modification affected the management objectives. These rules were also the basis upon which the models in the DSS used by the experimental group were built on, and were representative of the knowledge actual decision makers in the catchment could be expected to have. The individuals in the experimental group were also provided with the same paper documentation as the control group, but also had the use of a DSS called the Weir tool (see section 2.3).

Participants in the experiment were recruited from students of biological sciences, landscape architecture, and civil and structural engineering at the University of Sheffield, and were offered £15 to take part. Students with these academic backgrounds were selected as they could be expected to have some knowledge of environmental management, and be computer literate, so would require minimal training to participate in the experiment. In total nineteen volunteers were found to take part, and while best efforts were taken to distribute an equal number of each academic background between both the control and experimental groups, logistic issues and rearrangements meant that the numbers were not exactly equal (Table 2).

Table 2. Academic background of participants across the experimental and control groups

Group	Academic background			
	Biological sciences	Landscape architecture	Civil and structural engineering	Total number of participants
Experimental	4	3	3	10
Control	5	0	4	9

2.3. The weir impoundment management issue and the weir tool

The hypothetical management scenarios used in the experiment were based on the real issue of river impoundment weirs; a major environmental problem facing decision makers across the UK. In the Don Catchment, the setting of the experiment, weirs can be found in particularly high number as the region was a historically important centre of water powered metal working. Despite most now being obsolete, weirs are still a common sight in the Don Catchment (Fig. 1).

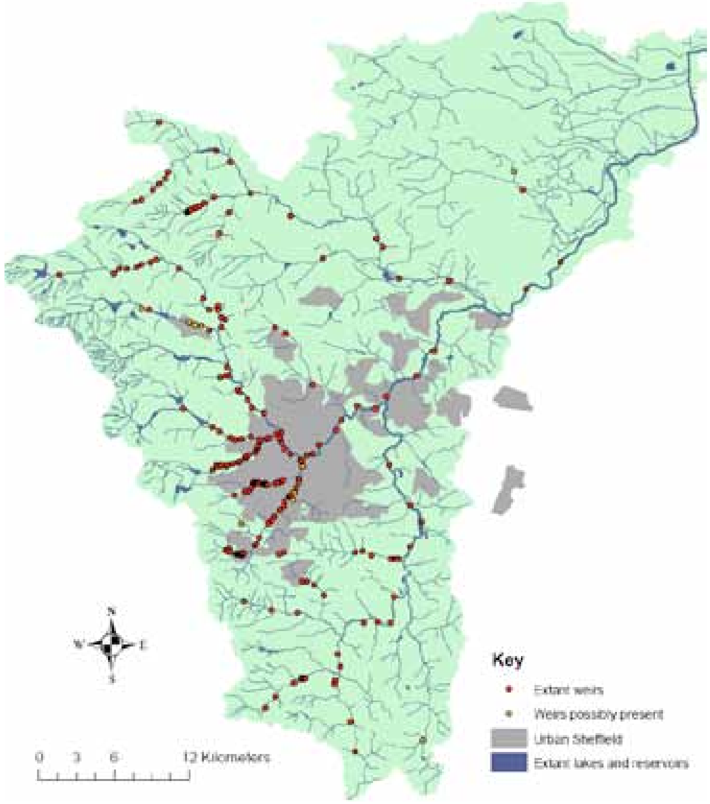

Fig. 1. Distribution of weirs in the Don Catchment

Many stakeholder groups would like to modify the weirs. These include anglers wanting to install fish passes; potential victims of flooding interested in removing weirs; proponents of hydro-electricity wishing to install micro-hydro schemes; enthusiasts of natural history aspiring to restore the river to a more natural state and enthusiasts of the river's heritage want to conserve weirs for their historic value. The various aspirations represent the multiple ecosystem services the rivers in the catchment can provide.

A DSS informally named the Weir tool has been developed that can predict a subset of these ecosystem services as management objectives:

- the quantity of hydroelectricity produced by microhydro schemes installed on weirs
- how much habitat is potentially accessible to European Eel (*Anguilla anguilla*)
- how much of the catchment has been colonised by the invasive Signal Crayfish (*Pacifastacus leniusculus*)
- how much habitat belonging to the native White-clawed Crayfish (*Austropotamobius pallipes*) has been lost to Signal Crayfish
- the quality of the catchment's weirs as a fun resource for canoeists
- the danger the catchment's weirs pose to canoeists
- the cumulative cost of all weir modifications specified by the user

Multiple modelling approaches were adopted to predict these management objectives. A Bayesian Network was developed using expert judgement elicited from canoeists to predict how weir modification affected the fun weirs provided canoeists, as well as the danger they posed [see 8]. To assess the impact of weir modification on eel and crayfish distributions, a spatially explicit habitat quality model was used to predict how habitat connectivity altered by weir modification affected species distributions. To calculate hydropower a simple physical model was used following the method outlined by Sheffield Renewables [9]. Cost is simply the sum of all weir modifications across all weirs in the catchment based on a mean cost for each modification type.

To make the Weir tool as user friendly as possible, minimising the amount of time required to learn how to use it, a web based graphical user interface (GUI) was developed that displayed an interactive map of the catchment and the value of the management objectives in a radar graph and a table (Fig 2. (a)). When the user selected a weir on the catchment map, a page loaded that presented a web form that allowed the selection of weir modification options (Fig 2. (b)). Once a modification is selected the models update the values of the management objectives in the radar graph and table.

The exercises completed by the participants in both groups were to develop weir modification strategies for the following two hypothetical scenarios:

- maximise hydroelectric output and eel habitat accessibility with a budget of £3m.
- maximise all management objectives with a budget of £1.5m (this budget was initially 6m, but it came apparent during the first session that they were not going to be able to spend all this money).

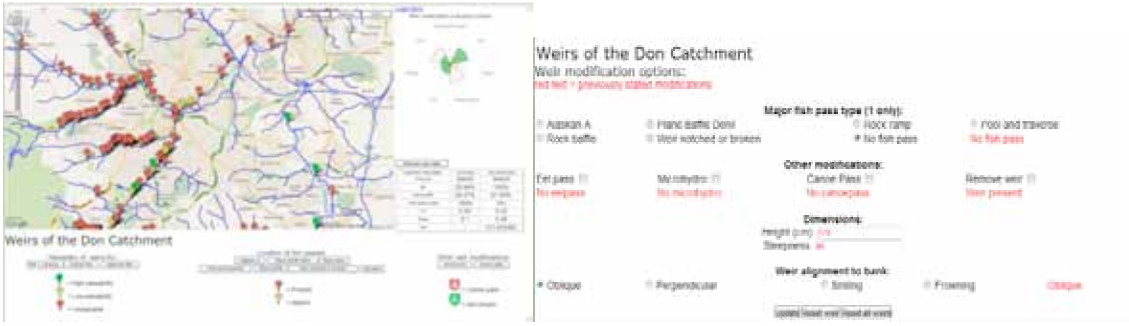

Fig. 2. (a) web based graphical user interface of the Weir tool; (b) web form of weir modification options

0	1	2	3	4	null
None	Little	Intermediate	Reasonable amount	Lots	Don't know

Fig. 3.numericisation of the Likert item used when participants were questioned about the depth of knowledge they had about the environmental issue of weir impoundment, and how much confidence they had in the decisions they had made during the experiment. No respondents selected the null category

3. Results

Differences between the experiences of the individuals in the control and experimental group were observed during the course of the experiments. Participants in the experimental group seemed to enjoy themselves more than the control group, who were often heard to sigh. The control group scrutinised the paper documentation they were provided with, often made extensive notes, whereas the experimental group tended to ignore theirs.

3.1. Knowledge gain

To analyse how the knowledge participants believed themselves to have about the environmental issue of weirs changed over the course of the experiment, the Likert item questions that asked how much knowledge the participant had was numericised (see Fig. 3). The results are shown in Table 3. Both groups started with a very similar belief that they had a low level of knowledge, typically around ‘little’. Both groups perceived a gain in knowledge which was to the same degree, believing by the end that they had an ‘intermediate’ or ‘reasonable amount’.

In the case of the multiple choice questionnaire that tested for an actual increase of knowledge about the issue of weir impoundment over the course of the experiment, results are presented in Table 4. Pre-experiment the Weir tool group performed slightly better than the control group but the difference was not significant (Two sample $t(28)=1.25$, P = n.s.). The post-experiment questionnaire revealed both groups were much more successful in answering the questions, indicating they had gained knowledge, but when the proportion of correct answers per question was compared between groups, the control group showed a significantly bigger increase in knowledge (Paired two sample $t(14)=-2.98$, $P<0.001$).

Table 3. Change over the course of the experiment in knowledge participants believed they had about the environmental management issue of weir impoundment.

	Perceived knowledge at start		Perceived knowledge at end	
Group	Mean	Median	Mean	Median
Experimental	0.9	1	2.5	3
Control	0.77	1	2.5	3

Table 4. Change in the proportion of questions answered correctly in a multiple choice questionnaire about the environmental issue of weir impoundment over the course of the experiment

Group	Mean proportion of correct answers at start	Mean proportion of correct answers at end
Experimental	0.4	0.69
Control	0.31	0.82

3.2. Confidence in decision making

As with perceptions of knowledge, the Likert item participants were asked to fill in to measure confidence in the decisions they made during the experiment was numericised. The confidence of the participants was typically between ‘intermediate’ and a ‘reasonable amount’, across both groups and exercises. There was not a significant difference between the groups for either of the exercises (exercise 1: Two sample $t(13)= -1.67$, P=n.s.; exercise 2: Two sample $t(13)= -1.73$, P=n.s.).

3.3. Further analysis

To test the hypothesis that an ICM DSS results in more effective decision making, we plan next to compare the decisions made by the participants in the control and experimental groups. To measure how effective they are, we will calculate the Pareto frontier for the decision space of the Weir tool. As the frontier demarks the most effective catchment management interventions, it will serve as a frame of reference to judge the performance of both groups. The closer a decision, the more effective it is. As the number of possible catchment interventions is far greater than it is feasible to compute performance for, we will use a genetic algorithm to optimise the decision space of catchment intervention scenarios that are Pareto efficient (i.e. lying on the Pareto frontier). As the rules used to guide decision making in the control group are the same rules that underlie the models in the Weir tool, this means that while the Pareto frontier may not be faithful to reality, it is consistent between the two groups.

The genetic algorithm will also map the extent of the Weir tool's decision space i.e. the range of values for the management objectives within which all possible catchment intervention scenarios lie. As one of our hypotheses is that the use of an ICM DSS would result in more equitable and fair decision making, then we predict that decisions made using the Weir tool would tend to lie in more central positions in the decision space rather than outlying locations. We therefore also plan to compare the distribution of decisions made by the control and experimental groups to measure the degree of clustering and the areas they occupy within the decision space.

4. Discussion

Contrary to our expectations, in our experiment we found that the group using the DSS to plan catchment intervention strategies learnt significantly less information about the environmental issue of weir impoundment than the control group. There could be many reasons to explain why this occurred. Some that we have considered are that the Weir tool could be too complex so that users do not fully absorb what it presented to them, that the Weir tool was a less effective way of communicating information, and that the Weir tool was less successful at stimulating learning. As the participants had little trouble using the Weir tool, and the information it presented to them was no more complex than the information provided in the documentation used by the control group, then the first reason is unlikely. Information was also easy to access on the Weir tool which only has two web pages on its GUI. Information is more conveniently at hand than in the the documentation which had multiple pages. Therefore the second reason is also improbable. Instead, we believe that the most likely reason for our results is that the Weir tool is not effective at stimulating learning. As mentioned earlier, members of the control group were observed to carefully scrutinise the maps and documentation provided, and many made extensive notes. They seemed to find the process mentally taxing (hence the sighing) as opposed to the experimental group who used the Weir tool in a casual manner. The situation could be a parallel to that of the advent of the calculator, which by providing mathematical calculations on demand without the need of mental effort, has resulted in a decline in standards of mental arithmetic. It was also noted that the group using the Weir tool rarely used the maps and other documentation provided to them. This may be because they viewed them as redundant in the same way someone with a calculator might view notes explaining how to do long division.

It is interesting that individuals in the control group did not perceive themselves as learning any more than the experimental group. This may be due to a limitation with the use of Likert items which have a central tendency bias [10], making it more likely that participants would only use moderate inner categories to describe their knowledge. The consequence of this is that it may be insensitive to differences in perceived knowledge between the two groups. The same issue applies to the Likert item used to test whether there was a difference in confidence in the decisions made between the two groups.

It is important to point out that while the Weir tool may inhibit learning about the system, this does not necessarily mean that the quality of decisions made whilst using the tool is reduced. An individual armed with a calculator can outperform those with the greatest mental arithmetic skills when it comes to hard sums. Worth noting is that the users of the Weir tool appeared to enjoy themselves more than the control group, and so an advantage of the tool may be to make ICM more appealing, and get stakeholders involved whom might otherwise be reluctant due to the mental effort involved. A better picture of how decision quality is affected by the use of the Weir tool will come out when the Pareto frontier analysis is finished.

Whatever the final outcome of the analysis of the results of the experiment, it also must be acknowledged that they may not hold general relevance to other DSSs. The experimental conditions are contrived and artificial, and differ in many respects to the diverse ways ICM decision making can be implemented, with or without a DSS. For example, the experiment was conservative in that the participants used weren't experts, and therefore might not know how to utilise the Weir tool to its full potential. The reverse also applies; that by not being experts they were more likely to learn from the weir tool, and therefore find it useful. The participants also worked independently when drawing up their plans, which are contrary to how ICM is supposed to be done; a collaborative effort that draws on a wide range of pooled expertise. Nevertheless, the mechanism we put forward for the way the Weir tool might lower the rate of learning by reducing mental effort logically applies to most DSS, and if correct, must therefore be widespread.

5. Conclusions

The experiment we ran found that the use of the ICM DSS the Weir tool resulted in less knowledge being gained by its users relative to those using more conventional map and rule based approaches to catchment management decision making. We suggest that this may be a widespread effect resulting from less mental effort being required of the users of DSSs as compared to those using more basic tools to aid decision making. This has implications for the design and utilisation of DSSs, especially as one of the proposed advantages of such systems is sometimes to facilitate learning [11].

The experimental design we have used looks for evidence of different aspects of decision making quality, and we suggest that this will provide a relatively robust way of assessing whether an approach to deliver ICM improves decision quality. Our unexpected initial findings show that it shouldn't be assumed that after usability, trust and institutional barriers to the uptake of DSSs are resolved, that the technology will necessarily improve decision making in all its aspects. More evidence must be gathered to understand the advantages and disadvantages of DSSs, so that their potential can be fully utilised.

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