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Does interactive visualisation increase stakeholders' understanding?

A case study of Te Waihora/Lake Ellesmere, Canterbury, New Zealand

B. Otinpong[1], S. Charters[1], A. McKinnon[1] and B. Gidlow[2]

[1]Department of Applied Computing ;[2]Department of Social Science, Parks, Recreation, Tourism and Sport Lincoln University;PO Box 85084, Lincoln 7647, New Zealand

Email: bernard.otinpong@lincolnuni.ac.nz

Abstract: Visualisation has been used in a number of natural resource management applications with the aim of enhancing people's personal understanding of issues but little evaluation of the effectiveness of the tools developed has been undertaken. The purpose of this study was to investigate whether interactive visualisation increase stakeholders' personal understanding of lake values using a case study of Te Waihora/Lake Ellesmere, in the South Island of New Zealand.

Te Waihora/Lake Ellesmere is a broad, shallow lake. It is separated from the Pacific Ocean by the long narrow sandy Kaitorete Spit. Its unique position allows for it to be opened to the sea periodically to provide drainage and prevent flooding of surrounding farmlands. There is a lack of agreement among the diverse stakeholders regarding the appropriate levels at which the lake level should be maintained throughout the year.

We describe an interactive visualisation tool (ElleVis) which shows the effects of different lake opening regimes on lake values at Te Waihora/Lake Ellesmere. The tool allows users to input different opening scenarios and visualise the resulting impact on water levels around the lake at various times. It incorporates historical rainfall data from New Zealand's National Institute of Water and Atmospheric Research to deliver a graphical map display, including a summary table with a 'traffic light' status for lake values - birds, fish, farming and other stakeholder interests at different locations around the lake. The interactive nature of the ElleVis tool allows the stakeholders to compare Te Waihora/Lake Ellesmere under different opening scenarios using one interactive tool.

A quasi-experimental design was adopted to measure the knowledge of the participants before and after using the ElleVis tool. Overall, participants' scores were significantly higher (M = 34.5, SD = 6.549) after using the ElleVis visualisation tool than before (M=22.5, SD = 7.408) t (13) =5.842, p = .005. Post-study comments from the participants were analysed to see if there were any patterns or differences with participants' experiences or impressions with the use of ElleVis. The results revealed that interactive visualisation can increase the personal understanding of stakeholders with diverse interests. More widely, the findings of this study inform discussions about whether visualisation tools might contribute to the management of "disagreements" in environmental management in situations that involve contested resources or a multiplicity of interests.

Keywords: *Personal understanding, interactive visualisation, simulation, evaluation, visual simulation*

1. INTRODUCTION

Issues relating to the manipulation of bodies of water are widely recognized to be a major concern to stakeholders (Lehman, 1986). Challenges also exist in communicating these issues and management options to stakeholders and it has been suggested that visualisation techniques could facilitate stakeholder engagement, increase understanding and improve the quality of decision making (Orland, Budthimedhee, & Uusitalo, 2001; Sheppard, 2005).

Visualisation can be used to structure information in ways which highlight interests of users/stakeholders, rather than simply providing raw data. In seeking to manage natural environments, it is desirable to model and understand complex interactions in order to compare the outcomes when different management scenarios are applied. To achieve this, simulations linked to the visualisation are critical.

Visualisation is often treated as an endpoint for communicating observations (Zudilova-Seinstra, Adriaansen, & van Liere, 2009). However, with the inclusion of interactivity the visualisation changes from being a passive communication medium to being an integral component of a dialogue with stakeholders (Lange & Hehl-Lange, 2006). The way people perceive and interact with visualisations can influence their understanding of issues and the usefulness of the visualisation systems (Zudilova-Seinstra, et al., 2009). It is on this basis that an interactive visualisation tool (ElleVis) was developed as a medium to communicate to Te Waihora/Lake Ellesmere stakeholders with diverse opinions/interest. The research question we are exploring is:

"Does applying the use of interactive visualisation to a specific natural resource management site - Te Waihora/Lake Ellesmere - increase stakeholders' personal understanding of the impact of opening regimes on lake values?"

"Personal understanding" refers to stakeholders' understanding of wider interests relating to the lake as well as their own areas of expertise". For the purposes of this study, the term "lake values" refers to farming, nature conservation and other stakeholder interests, which are affected by the different opening regimes at Te Waihora/Lake Ellesmere. These values have been identified by the various stakeholders as being of significance to them (Hearnshaw & Hughey, 2010).

2. CASE STUDY SITE

Te Waihora/Lake Ellesmere in the Canterbury region of the South Island of New Zealand is a broad, brackish, shallow lagoon separated from the Pacific Ocean by the long narrow sandy Kaitorete Spit. Its unique position allows for it to be opened to the sea periodically to provide drainage and prevent surrounding farmlands from flooding. There is a lack of agreement between the various stakeholders as to the levels at which the lake should be maintained and how that level should be manipulated. Different lake levels are perceived to advantage/disadvantage competing lake values. For example, a high lake level will inundate surrounding farmlands but is good for recreational fishing and duck shooting.

3. ELLeVIS

To explore the research question an interactive visualisation tool (ElleVis) was developed. The tool is designed to provide information which a range of stakeholders would need to aid their decision making about the lake.

The primary source of stakeholder requirements was the lake opening consent (CRC 042860) from the local Regional Council (Environment Canterbury). This identified the need for the visualisation to show:

- The level of the lake at different lake levels
- The area of the lake at different lake levels
- The shoreline and farmlands covered at different lake levels
- The impact on birdlife
- The impact on native fisheries at different lake levels
- The impact on livestock along the surrounding farmlands at different lake levels

The design of ElleVis shown below in Figure 1 has three main components: a "traffic light" summary table; a map showing lake extent; and a lake level time series graph. The tool allows users to configure lake opening scenarios and select the conditions under which they are viewed. The data for the visualisation are generated by the Plover model (Raffensperger, 2009) which simulates the behaviour of the lake. The "traffic light"

summary table shown in Figure 1 represents an overview of information on the impact of the opening regimes on lake values. The cells are colour coded to help stakeholders to distinguish which lake values are good (green), tolerable (amber) and unacceptable (red). The summary table view provides stakeholders with overview information on lake values at a glance for the opening regime entered. Each row in the table represents one lake value with each colour representing the month of the year. The concept of the "traffic light" was applied to the choice of colours used in the summary table. Research (Kristensen & Gabrielsen, 2000) has suggested that, for thousands of years, the colour red has represented danger, stop or "suffer the consequences" in most western cultures. Red was chosen to show the lake level caused by unacceptable conditions for that lake value. The "good" ranges in which the lake values thrive the most are denoted by the colour green. The colour amber denoted the ranges between "good" and "unacceptable", which are "tolerable" conditions. The use of shaded cells to indicate the best and worst results has been used previously by (Lorie, 2006) in his design of decision support tables to solve water resources management issues.

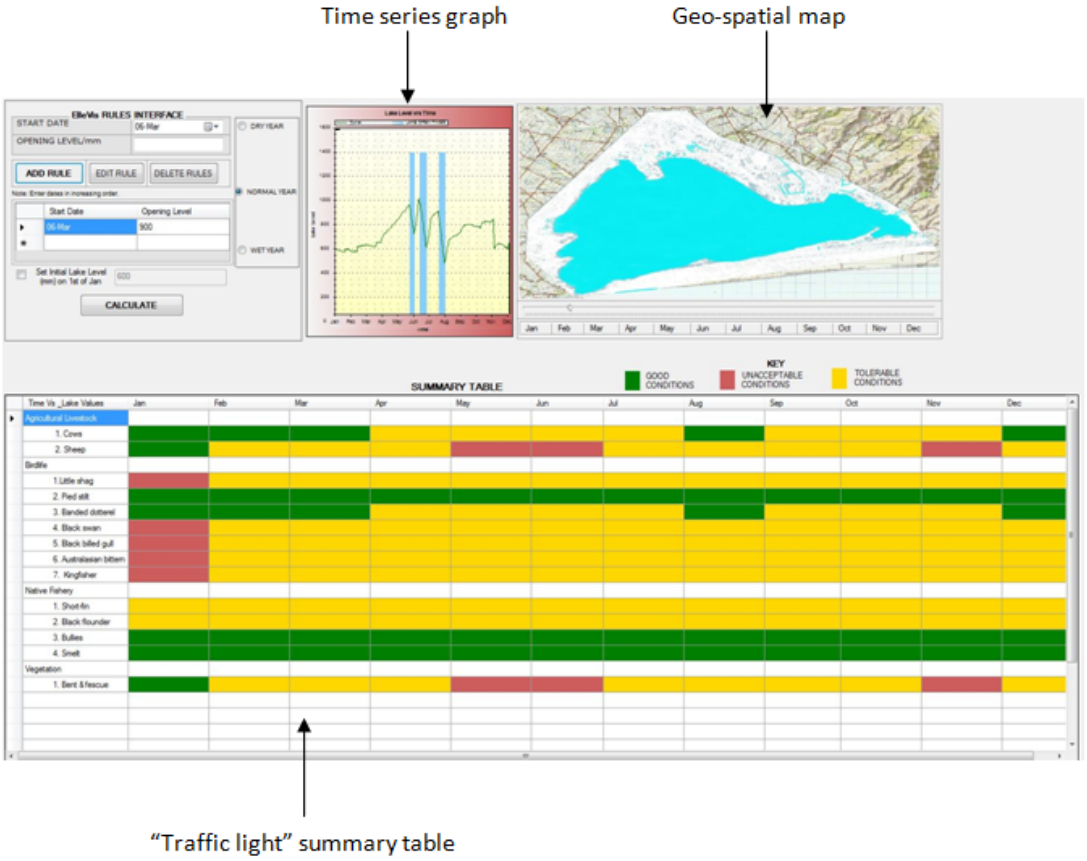

Figure 1. ElleVis visualisation interface

The interactive map shown in Figure 1 allows stakeholders to see the consequences of different opening regimes on the extent of the lake. The image is a topographic map with the lake superimposed. A slider beneath the image allows the extent of the lake during the year to be explored on a day by day basis.

The time series graph shown in Figure 1 shows the level above mean sea level (amsl) of the lake over the year. The graph is augmented with blue shaded areas that show when the lake has been opened to the sea. The shading gives a visual indication of the frequency and duration of lake openings.

4. STUDY DESIGN

In order to measure the effectiveness of the ElleVis tool at improving stakeholders' understanding, the participants' knowledge of the impact of different opening regimes was measured before and after using the ElleVis tool to examine different lake scenarios. Figure 2 shows an overview of the process involved in measuring the change in participants' understanding. The study uses a pre-test and post-test design involving

a treatment group but without a control group (Dimitrov & Rumrill, 2003). Using this design, participants are pretested, exposed to the intervention (ElleVis in this case), and then post-tested.

For this study, the target population is individuals working in stakeholder organisations which have an interest in Te Waihora/Lake Ellesmere and which are consulted as directed by the local Regional Council (Environment Canterbury) with regard to the opening and closing of the lake. Given that it would be impossible to test every individual stakeholder in the population, samples were drawn from this target population representing each Te Waihora/Lake Ellesmere stakeholder group.

Employing purposive rather than probability sampling, fourteen participants were recruited either through direct contact or by being nominated by their stakeholder organisation.

The stakeholder groups were comprised of farmers, fishers, employees of governmental and non-governmental organisations, and Ngài Tahu (the major South Island Maori iwi (tribe).

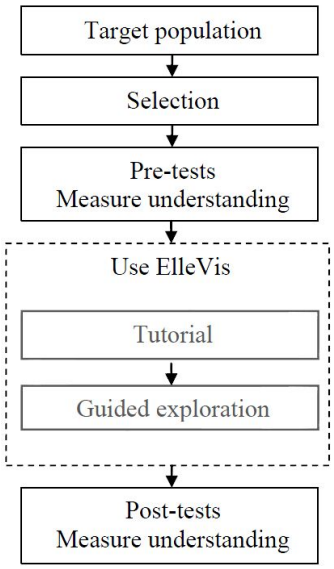

Figure 2. Overview of study design

4.1. Conducting the study

Five instruments were developed for the study: a pre-test and post-test; tutorial tasks; guided exploration tasks; and a post-study questionnaire. Between the pre-test and post-test, a tutorial and a guided exploration task were conducted. After the pre-test and post-test, a post-study questionnaire were used to gather information on participants' impressions and experiences with the ElleVis visualisation tool.

To test the instruments a usability study was conducted using 12 postgraduate and staff at Lincoln University. The pilot highlighted some minor wording changes that needed to be made. Ethics approval was obtained from the Lincoln University Human Ethics Committee to conduct the study.

The pre-test and post-test were designed to assess the participants' knowledge about Te Waihora/Lake Ellesmere. The test was structured in four sections with twenty two options. A grading schedule was used to score all responses provided by the participants so that any change in score provided a measure of change in understanding. The tutorial provided a familiarisation with the detailed features of the ElleVis tool and the test procedures. The tasks centred on participants exploring features of the visualisation. The purpose of the guided exploration was to ensure the participants used the ElleVis tool fully to explore the effects of the various opening regimes on lake values at Te Waihora/Lake Ellesmere. The guided-exploration tasks required participants to run the ElleVis program under various opening scenarios that were provided to them and in a variety of rainfall conditions (wet, normal and dry years) and observe the changes to the visualisation in order to answer a set of multiple-choice questions. The purpose of the post-study questionnaire was to obtain participants' impressions of the visualisation tool (ElleVis).

Letters seeking participants for the study were sent to all stakeholder organisations. The study was conducted at a time and place most convenient to participants, and was conducted individually with each stakeholder group representative.

4.2. Data Analysis

Participants' responses in the pre-test and post-test were scored using a grading schedule. The mean, median and standard deviation were calculated to determine if there were any changes in the level of personal understanding following participants' use of ElleVis. To determine whether differences in scores between the pre-test and post-test were statistically significant, a paired sample t-test and a Wilcoxon signed ranks test were used. Post-study comments were analysed to see if there were any patterns or differences with participants' experiences or impressions with the use of ElleVis.

The pre-test and post-test consisted of 22 questions. Therefore, a score of -22 would be obtained if a participant gave wrong answers to all questions, while a score of 44 would be obtained where a participant gave fully correct answers to all questions. The maximum possible change is 66 (-22 to +44), which would be the case if a participant gave all wrong answers in the pre-test and then all fully correct answers in the post-test or vice versa. The scores achieved on each participant in the pre-test and post-test are shown in Table 1.

The highest pre-test score of 32 was recorded by participant P7 and the lowest score of 9 was recorded by participant P13. The highest post-test score of 43 was recorded by two participants (P5, P6), while one participant (P10) scored 24, which was the lowest score. The largest change in understanding between the pre-test and post-test was 29 and the smallest change, 1. The data in Table 1 suggest that each participant increased their understanding about lake values after using the ElleVis tool.

Table 1. Participants' scores in the pre-test and post-test

Participants	P1	P2	P3	P4	P5	P6	P7	P8	P9	P10	P11	P12	P13	P14
Pre-test scores *(x)*	18	25	29	16	31	14	32	14	27	20	30	28	9	22
Post-test scores *(y)*	31	31	30	30	43	43	38	32	30	24	42	40	27	42
Change in understanding *(y) - (x)*	13	6	1	14	12	29	6	18	3	4	12	12	18	20

Overall, participants' scores were significantly higher after using the ElleVis visualisation tool than before. The mean scores (all participants) increased from 22.5 in the pre-test to 34.5 in the post-test. The standard deviation (all participants) decreased from 7.4 in the pre-test to 6.5 in the post-test. The higher post-test scores means that all participants increased their understanding of lake values after using the ElleVis tool.

A paired sample t-test (Bakan, 1966) was undertaken to test the statistical significance of the participants' understanding following their use of ElleVis. The test was undertaken to assess whether the group means of the pre-test and post-test were statistically different from each other. This was determined using a two tailed '*t*' test with an alpha of .005 and using a null hypothesis that the group means of the pre-test and post-test are equal to zero.

The results in Table 2 and Table 3 show that overall, participants' scores were significantly higher (M = 34.5, SD = 6.549) after using the ElleVis visualisation tool than before (M=22.5, SD = 7.408), *t* (13) =5.842, *P* = .005.)

Table 2. Descriptive statistics

Tests	Mean	N	Std. Deviation	Std. Error Mean
Post-test	34.50	14	6.549	1.750
Pre-test	22.50	14	7.408	1.980

Table 3. Paired *t* test statistics

	Paired Differences					*t*	d*f*	Sig. (2-tailed)
	Mean	Std. Deviation	Std. Error Mean	95% Confidence Interval of the Difference				
				Lower	Upper			
Post-test Score ─ Pre-test Score	12.000	7.686	2.054	7.562	16.438	5.842	13	.000

To test whether the group median between the pre-test and post-test were statistically different from each other, an additional test ─ a Wilcoxon signed-ranks test ─ was conducted. It involved a null hypothesis that the median differences between the pre-test and the post-test scores are equal to zero, with an alpha of .005.

The Wilcoxon signed-ranks test indicated that overall, participants scores were significantly higher (Median =31.50) after using the ElleVis visualisation tool than before (Median = 23.50), Z= -3.301, p = .001, r = .88. These results further support the conclusion that participants' personal understanding of the impact of Te Waihora/Lake Ellesmere opening regimes on lake values significantly increased after use of ElleVis.

5. DISCUSSION

This study assessed whether an interactive visualisation tool - ElleVis - helped increase stakeholders' personal understanding of the impact of opening regimes on lake values in the case of Te Waihora/Lake Ellesmere.

The differences between the pre-test and post-test show that use of ElleVis significantly increased participants' personal understanding of the impact of the different opening regimes on lake values. The layout of the ElleVis visualisation, coupled with appropriate methods to view each type of data set (either graphically, spatially or tabular) and the responsiveness of the visualisation, allowed the participants to explore how Te Waihora/Lake Ellesmere behaves under different opening regimes. In the post-study questionnaire, where all participants rated themselves as having learnt "a lot" or "a little" following use of ElleVis, over 70% stated they had learnt "a lot". These results are consistent with the findings of other research (Bishop & Stock, 2010), (Lewis & Sheppard, 2006) and (Weiner, Harris, & Craig, 2002) which found that the use of visualisation as an intervention method increased participants' knowledge of a natural resource. Further, 9 of the 14 participants (64%) indicated that ElleVis presents an accurate picture of lake behaviour under different conditions. The remaining participants, particularly those representing government interests, responded they were "not sure" whether or not ElleVis presented an accurate representation of lake values. The following comments from two of these respondents is indicative:

"In general it does, but it is too difficult to be able to say so. If my interest has been included I should have been able to answer this" and "Not sure, more data required on birds".

Such participants felt that their specific interest areas – other types of vegetative plants around the lake and other bird species – were not canvassed in the visualisation tool. This weakness could be addressed in future studies by expanding the lake values reported in the ElleVis summary table.

In the case of 5 participants – P2, P3, P7, P9 and P10 – the changes in understanding between the pre-test and post-test were minor. These participants had maximum scores in their pre-test and post-test regarding their areas of interest and as such can be considered as "experts" but their scores in the other areas did not change by more than a point or two between pre-test and post-test. For such participants, ElleVis had little impact in helping them to understand other stakeholders' interest. The implication for this is discussed in a further study.

6. CONCLUSION AND FUTURE WORK

The design and implementation of ElleVis provides the opportunity to assess the value of an interactive visualisation in the area of natural resource management applications. The strength of the interactive ElleVis visualisation tool is that participants were able to manipulate and explore the lake opening scenarios which, according to the post-study questionnaire results, strongly influenced the personal understanding of majority of the participants with regard to the impacts of different opening regimes on lake values of Te Waihora/Lake Ellesmere.

The findings that ElleVis increases stakeholder' personal understanding suggest that visualisation can assist users holding different opinions to improve their understanding. This supports suggestions from the visualisation literature by (Carver, A. Evans., R. Kingston., & Turton, 2000), (Lange & Hehl-Lange, 2006) and (Wissen, Schroth, Lange, & Schmid, 2008). A more significant finding is that encountering ElleVis helped participants to appreciate key issues from other stakeholders' interests.

The findings of the study reveal that visualisation can increase stakeholders' personal understanding. An extension to this study would be to assess whether gains in personal understanding are permanent and, most significantly, whether they lead in practice to the resolution of environmental management conflicts. Future

research should take a longitudinal approach in order to assess the longevity of these gains in understanding made as a result of using a visualisation tool like ElleVis.

Visualisation has been used for a number of natural resource issues but little evaluation of the effectiveness of this type of tool has been conducted. This study goes some way to addressing this issue, but the authors acknowledge that further research is required.

The results of the study show that the use of ElleVis was readily accepted by most stakeholders of Te Waihora/Lake Ellesmere participating in this study. It was easily comprehended and found to be meaningful and useful. When the participants encountered ElleVis, issues regarding lake levels became clearer and they began to appreciate the dynamics behind the opening regimes. Certain controversies surrounding the opening regimes have the potential to be reduced or eliminated when stakeholders view a pictorial representation of competing factors at play. Further, the results show that stakeholders' improved their personal understanding in areas outside their main interest. This suggests that the use of ElleVis could facilitate future discussions concerning lake opening regimes and the impact these have on lake values.

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