Research Paper

The influence of 4D landscape visualisation on attitudes to reservoir renaturalisation

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HIGHLIGHTS

\begin{itemize}
  \item Cognitive frameworks explain stakeholder attitudes to landscape planning proposals.
  \item 4D landscape visualisation changed beliefs around landscape naturalness.
  \item 4D landscape visualisation changed attitudes towards renaturalisation.
  \item Reconstructing landscape evolution increased support for reservoir renaturalisation.
\end{itemize}

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ABSTRACT

Landscapes change due to natural processes and anthropogenic influences such as farming, forestry, urban development and civil engineering. Sustainable land and water management is needed to meet human needs while responding to the climate and biodiversity crises. Landscape visualisation may facilitate this by improving stakeholder engagement and changing environmental baselines. We developed a 4D landscape visualisation of the Crummock Water catchment in England’s Lake District National Park. It showed 14,000 years of landscape evolution, including 140 years of reservoir engineering and future renaturalisation scenarios (weir removal and river remeandering). We used a cognitive model novel to landscape visualisation research to understand stakeholder values, beliefs, and attitudes. We tested the hypotheses that presenting extended landscape evolution information changes stakeholder beliefs (H\textsubscript{1}) and attitudes (H\textsubscript{2}) towards the renaturalisation proposals. The experiment comprised online visualisation workshops with 45 participants in two treatments (‘long’ extended and ‘short’ control). We analysed pre- and post-workshop surveys using statistical tests and qualitative coding. Results show the workshop changed beliefs around landscape naturalness, and made attitudes towards renaturalisation more supportive. There was no significant difference in belief between treatments, therefore we reject our belief hypothesis (H\textsubscript{1}). However, participants who saw the extended information were more likely to support weir removal, supporting our attitude hypothesis (H\textsubscript{2}). We discuss the validity of the cognitive model and the utility of the extended landscape evolution information. We conclude that 4D landscape visualisation can change beliefs about landscapes and attitudes towards environmental management. This effect may be enhanced by extended landscape evolution information.

1. Introduction

Since the Neolithic, humans have profoundly and extensively modified landscapes. The degradation of terrestrial ecosystems is a key driver of climate change and biodiversity loss (Díaz et al., 2019; Shukla et al., 2019). Sustainable land management can therefore help to address major 21st century challenges. Landscape-scale solutions include: restoration (recovery of ecosystems to pre-degradation states), rehabilitation (recovery of ecosystems to new states), Earth Systems Engineering (rational management of ecosystems), and renaturalisation (defined here

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as reinstatement of natural processes) (Santamarta et al., 2014; Brown et al., 2018; Hewett et al., 2020). However, these can be hindered by political opposition and poor stakeholder engagement (Jørgensen, 2017). Furthermore, people rarely comprehend the extent of anthropogenic modifications to the environment (Leopold, 1949). Societal ignorance of progressive environmental damage over generations has been labelled ‘shifting baseline syndrome’ by Pauly (1995), who posits that this leads to declining ecosystem management targets. Erroneous beliefs about landscape naturalness may also lead to negative attitudes towards more sustainable landscape management. 3D landscape visualisation (LV) is increasingly used to engage stakeholders in landscape planning. 4D LV, using rapidly advancing digital technology to show landscape evolution, has potential for deeper engagement which may change people’s beliefs around landscape naturalness and attitudes towards environmental management, although its effectiveness needs to be assessed.

1.1. Environmental attitudes

Social and environmental psychologists have proposed various cognitive models to explain and predict attitudes towards environmental management (Van Valkengoed et al., 2021). Cognitive models share an assumption that attitudes are a function of underlying values and beliefs. For example, the items in the New Environmental Paradigm reflect ‘prIMITIVE’ ontological beliefs about nature and humanity (Dunlap et al., 2000). Values have been defined as ‘guiding principles of what is moral, desirable or just’ (Kempton et al., 1995). Values are considered to be highly stable and to transcend specific objects and situations. An example is anthropocentric versus biocentric values. Beliefs are ‘associations people establish between the object it refers to and attributes it ascribe to that object’ (Eagly & Chaiken, 1998). Beliefs tend to be stable, although they may be influenced. For example, beliefs pertaining to landscape naturalness might be shifted by evidence that contradicts previous assumptions. Attitudes are psychological tendencies that are ‘expressed by evaluating a particular entity with some degree of favour or disfavour’ (Eagly & Chaiken, 1998). Attitudes, such as those towards river renaturalisation, may shift in response to new information e.g. regarding historic river forms and processes. The Cognitive Hierarchy Framework proposes that values are the most basic cognitions and underpin value orientations, attitudes and norms, intentions and, finally, behaviours (Fulton et al., 1996; Manfredo, 2008). Similarly, Buijs’ (2009) ‘images of nature’ framework proposes that general beliefs and values underlie more specific value orientations. These abstract ‘images of nature’ direct and structure attitudes towards concrete environmental management options.

Values have been measured in different ways, with little consistent methodology (Stern et al., 1995). Rokeach (1973) differentiated between types of values, such as instrumental (concerning conduct) and terminal (concerning goals). Schwartz (1992) developed this further, identifying ten value types, including ‘hedonism’, ‘power’ and ‘universalism’. Schwartz asked respondents to rate each of 56 values as ‘a guiding principle in my life’ using a nine-point scale from ‘supremely important’ (7), through ‘not important’ (0), to ‘opposed to my values’ (-1). Empirical work showed that certain value types tended either complement, or conflict with, each other. De Groot et al. (2008) adapted Schwartz’s survey to establish empirically the concept of ‘biospheric’ – in addition to ‘egoistic’ and ‘altruistic’ – value orientations. The measurement of beliefs and attitudes has been even less structured, with researchers choosing methods appropriate to their research questions (Bizer, 2004). For example, Buijs (2009) ascertained beliefs towards nature and attitudes towards nature conservation by qualitatively coding semi-structured interview transcripts. In contrast, the New Ecological Paradigm measures beliefs and attitudes concerning environmental management on a five-point Likert scale. In summary, attitudes to environmental management schemes are functions of deeper beliefs and values. Although many LV studies have measured audience responses, cognitive frameworks have seldom been used to help explain factors underlying attitudes.

1.2. Landscape visualisation

Landscape visualisation dates back to at least the late 18th century, with Repton’s ‘before’ and ‘after’ Red Book landscape designs (Coffin, 1986). Digital LV has developed rapidly since the 1990s, generating richer and more immersive visualisations (Gobster et al., 2019). 3D LV comprises elements such as terrain, water, vegetation, built structures, atmospheres and animals (Ervin, 2001). Its advantages include: free spatial navigation, replicable creation methods, and highly immersive virtual or augmented reality. On the other hand, 3D LV poses several challenges. For example, landscape modellers must make trade-offs between apparently desirable – yet mutually conflicting – qualities such as realism, generality, and precision (Froo et al., 2015; Lovett et al., 2015). They must also consider ethical issues such as inadvertent modeller bias, and the potential to manipulate planning outcomes (Sheppard, 2001). Furthermore, digital LV is not necessarily better than hand-drawn sketches (Tobias et al., 2016).

4D LV includes 3D space plus time. The time dimension may be implemented using quasi-continuous animations, or discrete time points (Lovett et al., 2015). Users can navigate through time using interfaces such as sliders and buttons. 4D LV ranges in complexity from small/low-resolution spatial and temporal domains, to large/high-resolution domains. Temporal information shows users landscape evolution, facilitating better understanding of landforms and processes. 4D LV can show reconstructed past elements that no longer exist, extant elements, and modelled future projections. It builds on the principle of the ‘baseline’ photographs and ‘proposed’ photomontages used in UK planning. The strength of 4D LV is its ability to allow users to navigate through both space and time and to compare the past, present, and future across a range of spatial scales (e.g. individual plants, to entire landscapes) and temporal scales (e.g. daily hydro-meteorology, to millennia of geology). Several studies have used 4D LV to contextualise planning proposals and elicit landscape preferences to climate change (Schroth et al., 2015; Wang et al., 2016). Challenges posed by 4D LV include uncertainty around past and future landscapes, as well as additional data and labour requirements. In summary, digital LV is developing fast, although it is not yet standard practice in landscape planning and stakeholder engagement. To date, most 4D LV has been temporally simple, showing only present (or recent past) baselines and specific future scenarios.

1.3. Study objectives

This study is designed to provide evidence on how stakeholders’ attitudes towards environmental management (as well as their beliefs) are affected by 4D LVs, using a cognitive model that is novel in landscape visualisation studies. We assess whether presenting extended (‘long’ treatment) landscape evolution information (in relation to a ‘short’ control treatment) changes stakeholder beliefs and attitudes. We investigated beliefs specifically around landscape naturalness, to determine whether 4D LVs can change environmental baselines (Pauly, 1995). We conducted an experiment to test how significant this extended information is using a 4D LV of a reservoir-containing catchment in England’s Lake District National Park that spans 14,000 years from the last Ice Age through the present day and forward to projected future renaturalisation (weir removal and river remaining) in 2030. We ran workshops and analysed participant responses to two levels of 4D LV information (‘short’ control and ‘long’ extended). This article describes the study site, 4D LV, and study design. It presents results to test the two hypotheses that presenting extended landscape evolution information in a 4D LV:

(H1) Changes participant beliefs around landscape naturalness i.e. to more strongly believe that the landscape is modified by human activity;
(H2) Changes participant attitudes towards renaturalisation i.e. to
more strongly support renaturalisation.

2. Methods

2.1. Study site

The 63 km² Upper Cocker catchment is located in the western part of the Lake District National Park in North West England (Fig. 1). The Upland Valley Floors include three natural lakes (Crummock Water, Buttermere and Loweswater), enclosed pasture and small woodlands. The Buttermere-Crummock valley lies within an amphitheatre of steep high fell. To the south is Rugged/Craggy Volcanic High Fell formed by the Borrowdale Volcanic Group (CBA, 2008). To the north is gentler Rugged/Angular Slate High Fell formed by the sedimentary Skiddaw Group. The fells are sheep-grazed acid grassland with some small tarns and peat bogs, and gill-sheltered scrub.

The landscape has been formed by natural – particularly glacial and paraglacial – processes and modified by humans. After the last Ice Age (Devensian) ended c.9,700 BC the ice retreated, leaving cirques and tarns, and the three moraine-dammed lakes in glacial troughs (Pennyington, 1978). Extensive woodland developed, but after 1000 CE was gradually displaced by lowland agriculture and, later, upland pasture (Chiverrell et al., 2007; Shen et al., 2008). The major lowland rivers had been modified and engineered by the 19th century to aid land drainage (Cluer & Thorne, 2014). The First Crummock Reservoir Scheme was built in the 1880s, comprising two timber weirs and abstraction pipes. The Second Scheme, completed in 1904, replaced the timber weirs with a 60 m long masonry weir. This raised Crummock’s water level by ~1.6 m, increased the lake surface area by 2–3%, modified flow regimes, and inhibited migration of anadromous fish such as Atlantic salmon (Salmo salar L.) (Hughes et al., 2021). In 1912, 200 m of the Park Beck tributary was canalised. This has prevented natural hydrogeomorphic processes and reduced habitat diversity. The catchment has been part of the Lake District National Park since 1951, and a UNESCO World Heritage Site since 2017. The reservoir operator, United Utilities, is building the West Cumbria Supplies Project to better integrate the region’s water resources. From 2022, water from Crummock will no longer be needed for public water supply. United Utilities and the Environment Agency are investigating the feasibility of removing Crummock Weir and Park Beck’s concrete walls. We refer to these as the ‘renaturalisation proposals’ since they would reinstate (more) natural processes. Specifically, they would return flow regimes, fish migration and geomorphic processes closer to their pre-engineered state (Hart et al., 2002). Decommissioning, initially costly, would remove reservoir maintenance costs. Other important considerations include flood risk, lakeside farming, and recreation. The downstream towns of Cockermouth and Lorton were severely flooded in 2005, 2009 and 2016. Farms will have to adapt to a receded lakeshore. The local economy relies on tourism and outdoor recreation.

2.2. Landscape visualisation modelling

LV modelling is scientifically-informed and data-constrained. Nonetheless, it requires subjective decisions. We adapted Lovett et al.’s (2015) ‘when, what, how’ 3D LV guide for our implementation of 4D LV for this case study.

1) When (to use them). The purpose was to test whether visualising the Upper Cocker catchment’s landscape evolution changes stakeholder naturalness beliefs and renaturalisation attitudes. The audience included mixed stakeholders, so the LV was kept non-technical. Our resources comprised: a doctoral researcher and workshop facilitator; high performance PC with Nvidia GeForce RTX 2080 Ti 11 GB GPU and 3Dconnexion SpaceMouse; Virtalis Geovisionary 2019, Daylon Graphics Leveller 4.2, and SketchUp software.

Fig. 1. Location of the Upper Cocker catchment within the River Derwent Basin, Cumbria, UK.
2) **What** (to include). The salient **features** were terrain, imagery, water surfaces, vegetation cover, Crummock Weir(s) and Park Beck canal. The time dimension (4D) was implemented by creating 11 discrete time points. This was considered the minimum required to show how the landscape has evolved through pre-historic natural processes, historic anthropogenic modifications, and modern reservoir engineering (Fig. 2). Current 1 m and 5 m DTMs were edited to reconstruct pre-historic and historic terrains; modern roads and hedgerows were removed, and rivers recreated from fluvial geomorphic principles or historic maps. **Realism** (i.e. generally accurate resemblance) was prioritised over detail (i.e. small-scale precision) (Lovett et al., 2015). For example, well-placed simple vegetation models were used, rather than complex individual trees. However, **credibility** demanded that the key engineering structures were modelled in detail. Regarding time, only key points were shown, rather than high resolution changes or animations. This was pragmatic, given limited modelling resources and audience attention. It also maintained credibility, since the scientific data supports only broad landscape reconstructions. We developed a time navigation interface called ‘TimeTraveller’ with buttons such as ‘3000 BC’ and ‘1880s’.

3) **How** (to present them). We originally planned highly **interactive** workshops with participants navigating freely in space and time, to mitigate the effects of modeller bias. This was not possible due to the Covid-19 pandemic and resulting public health restrictions. Instead, the situation provided an opportunity to run online workshops. Consequently, we gave (somewhat less) interactive virtual tours via screen sharing. We ran interactive group workshops, rather than more tightly controlled studies with isolated participants, to simulate real-world stakeholder workshops, and thus potentially increase ecological validity.

The LV was **displayed** on participants’ own devices rather than a large projector. **Supplementary material** such as flow directions and scale bars was minimised, to avoid overwhelming participants. Photographs at key locations, such as Crummock Weir and Park Beck, were included.

### 2.3. Study design

The 4D LV was designed to test the research hypotheses, and to support United Utilities in their engagement with stakeholders over the Crummock Water decommissioning proposals in 2021–2025. Stakeholder mapping identified informal groups in the study area (e.g. farmers, residents, anglers, recreationists), formal groups (e.g. flood activists, i.e. people who campaign to mitigate flood risk), and institutions (e.g. planners and regulators). However, Covid-19 precluded in-person workshops with local stakeholders. Instead, we ran online workshops with ‘representative stakeholders’ recruited through contacts and snowball sampling in northeast England. After a pilot in October 2020, we ran twelve online workshops between 4 December 2020 and 8 February 2021. These involved 45 participants representing five stakeholder types: 22 outdoor recreationists, 11 flood activists, six anglers, three farmers, and three river conservation volunteers. Participants were assigned to mixed stakeholder type workshops as far as practicable.

Participants completed a pre-workshop survey (1), online workshop, and post-workshop survey (2) (Fig. 3). Survey 1 included images of the Upper Cocker catchment’s location, landscape, and current uses (Supplementary data 1). It asked participants to describe their **beliefs** about ‘the catchment’s lakes and rivers at the present day’ on a set of three five-point semantic difference scales: ‘natural’ <> ‘artificial’, ‘tame’ <> ‘wild’, ‘free’ <> ‘controlled’. The first and third items were reversed; this is a commonly-used method to reduce error (Bizer, 2004).

Discussions of ‘nature’ and ‘naturalness’ are semantically and ontologically challenging. Although the dichotomous distinction of nature and culture is questionable (Macnaghten & Urry, 1998), many people still adhere to it. During the surveys and workshops, we allowed participants to use their own notions of ‘nature’, without elaborating further. The survey ascertained **value orientations**, by asking participants to rate twelve values on a nine-point scale (De Groot & Steg, 2008). It showed images of Crummock Weir and Park Beck and asked about their **attitudes** towards the renaturalisation proposals on a five-point Likert-scale (‘strongly oppose’ (1) to ‘strongly support’ (5)), with a brief free text explanation. The workshop included: a video and virtual tour of the 4D LVs, followed by a semi-structured discussion (Supplementary data 1). The video described the evolution of the catchment’s landscape, and provided a consistent basis for workshops. The virtual tour allowed participants to explore the landscape in space and time, and ask questions. During the discussion, the facilitator asked participants to describe their responses to the LV, **beliefs** around landscape naturalness, **values** around land management, and **attitudes** towards renaturalisation. The workshop ended with Survey 2, which repeated Survey 1’s **beliefs** and

![Fig. 2. Visualisations looking upstream over Crummock Water, showing Crummock Weir (foreground) and Park Beck (right) in 3000 BC, 1880s, 2020 and 2030.](image-url)
attitudes questions. Value orientations were not re-measured in Survey 2 since these were assumed, a priori, to be stable (Fulton et al., 1996).

The two hypotheses (H1 and H2) were tested using an experimental manipulation. Participants were assigned to either a ‘long’ (extended) or ‘short’ (control) treatment. The ‘long’ treatment used a LV showing 12,000 BC to 2030, while the ‘short’ treatment’s LV spanned only the 1880s to 2030. The 1880s to 2030 period (covering Crummock Water’s impoundment) was chosen because this corresponds to many stakeholders’ environmental baselines. These baselines may challenge the renaturalisation proposals. Therefore, the effects of presenting pre-impoundment information on beliefs and attitudes were highly relevant. The ‘long’ treatment used a slightly lengthier video (nine rather than seven minutes), due to the additional time points. The difference in video duration added only a minor source of ambiguity in interpreting differences between treatments.

The experiment allowed us to test whether this extended information had an effect on participant beliefs and attitudes i.e. changing environmental baselines. During ‘short’ treatment workshops, the researcher deflected potential discussions about pre-1880s landscape evolution by feigning ignorance. The information given in workshops was standardised to minimise variation. In particular, standard responses were prepared to answer participant questions: 1) removing Crummock Weir would not make much difference to downstream flood risk, and would allow fish to migrate more freely and restore a more natural flow regime; 2) remeandering Park Beck would ‘slow the flow’ of water, but this would have minimal effect on downstream flooding, and would improve local wildlife habitats. Researcher biases in LV design and social science risk influencing results (Lovett et al., 2015; Robson & Steg, 2008) were combined into a single metric, biosphericity, that describes biospheric value orientation relative to altruistic and egoistic value orientations:

\[
\text{Biosphericity} = \frac{2 \times \sum_{n=1}^{3} \text{Val}_{\text{Bio}}}{\sum_{n=1}^{3} \text{Val}_{\text{Al}} + \sum_{n=1}^{3} \text{Val}_{\text{Ego}}}.
\]

Naturalness belief was calculated as a sum of the three naturalness belief scores; Bel\textsubscript{1} (‘natural’<‘artificial’), Bel\textsubscript{2} (‘tame’<‘wild’) and Bel\textsubscript{3} (‘free’<‘controlled’):

\[
\text{Naturalness belief} = -\text{Bel}_1 + \text{Bel}_2 - \text{Bel}_3.
\]

NB Bel\textsubscript{1} and Bel\textsubscript{2} were inverted to take account of their reverse coding. Positive values indicate the belief that the landscape is more modified than natural and vice versa.

Finally, combined attitude to renaturalisation was calculated as the mean of attitudes to Crummock Weir removal and Park Beck remeandering, with ‘don’t know’ (0) converted to ‘neutral’ (3).

The validity of the cognitive model (value orientations, belief and attitude) was assessed using linear regression with categorical variables. Next, the effects of workshops on beliefs and attitudes were assessed. Differences between participants in Surveys 1 and 2 (ordinal, paired data) were tested using Wilcoxon Signed Rank (W). Differences between ‘long’ and ‘short’ treatments (ordinal, unpaired) were tested using Mann-Whitney (U). Verbal responses were qualitatively analysed to gain deeper insights into participant cognitions, triangulate data, and increase the robustness of findings (Bishop et al., 2013). Workshop discussions were automatically transcribed and time/speaker-stamped before being manually edited and coded in Nvivo 1.4. Transcripts were coded to develop themes (Braun & Clarke, 2006). The coding was done in two cycles. In the first cycle ‘structural’ codes (i.e. relating to the workshop itself) and ‘values’ codes (i.e. relating to opinions about the 4D LV and values, beliefs and attitudes about the landscape) were developed by reading transcripts (Saldana, 2009). Codes were then grouped into six categories: (1) workshop-related, (2) information, (3) engagement, (4) belief, (5) values, and (6) attitudes. Insightful and representative responses were annotated. In the second cycle, codes were applied to transcripts, and some large codes were split into smaller codes. Corresponding ‘values’ codes were added to free text attitude explanations in the surveys.

3. Results

3.1. Biospheric values, beliefs and attitudes

We tested whether biospheric value orientations, landscape naturalness belief, and attitudes towards renaturalisation (henceforth referred to simply as biosphericity, belief and attitude) were cognitively linked. Assuming that participants believed renaturalisation would be environmentally beneficial, we expected biosphericity and belief to be positively correlated – or causally linked – with attitude. High biosphericity ought to predict more positive attitudes towards renaturalisation, since it is (assumed to be) environmentally beneficial. Belief ought to predict attitudes towards renaturalisation, since individuals who believe that the present landscape is mostly unnatural may see proposals as restoring a more desirable state. Conversely, individuals who believe that the landscape is mostly unnatural may see proposals as restoring a more desirable state.

Biosphericity was not correlated with attitude in Survey 1 ($R^2 = 0.26, p = 0.52$), but was positively correlated in Survey 2 ($R^2 = 0.46, p = 0.03$) (Fig. 4). This shows that, after learning about the proposals and
their (assumed) ecological benefits, more biospherically-oriented participants were more likely to support renaturalisation than less biospherically-oriented participants. Terry’s attitude, for example, increased from 3.0 to 5.0 after receiving more information. Olivia, on the other hand, simply maintained her supportive attitude (5.0). This supports the validity of the cognitive model and suggests that biosphericity is a moderate predictor of attitude.

Belief and attitude were not significantly correlated in Survey 1 ($R^2 = 0.25, p = 0.19$), but they were positively correlated in Survey 2 ($R^2 = 0.50, p = 0.003$) (Fig. 5). Furthermore, there was evidence that belief may be a causal factor in attitude formation. Many of the participants valued natural forms and processes, either for their inherent value or as providers of ecosystem services. For example, Olivia (‘short’ treatment, outdoor recreationist) appeared to express the belief that natural forms are more desirable than cultural forms when she said:

’It’s a heavily livestock grazed area. You know, a canalised river with no natural floodplain. And, you know, extensive farmland areas with walls and human features. It’s really very different to what it should be.’

Similarly, Terry (‘long’ treatment, flood activist) articulated the belief – common amongst participants who advocated ‘natural flood management’ or ‘nature-based solutions’ – that natural processes can be restored to sustain the landscape, saying:

’It’s really interesting to see how the natural landscape managed itself. And then human intervention caused various issues. And then the suggested way forward seems to go back to the natural landscape.’

Overall, biosphericity, belief and attitude were cognitively linked, as expected based on the work of others (Fulton et al., 1996; Manfredo, 2008). However, correlations were only moderate, with high variation. Other factors such as flood risk, cultural heritage and aesthetics (described in section 3.3) may be more important in explaining attitudes.

3.2. Workshop effects on beliefs

We tested the hypothesis (H1) that presenting extended landscape evolution information in a 4D LV changes participant beliefs around landscape naturalness. We reasoned that, following the workshop, participants in the ‘long’ (extended) treatment would tend to believe that the landscape is modified to a greater extent, in comparison to participants in the ‘short’ (control) treatment.

Beliefs varied widely, ranging from −6 (highly natural) to +5 (highly modified) (Fig. 6). Although there was a small pre-existing difference in beliefs between treatments, this was not significant (Table 1 row 1). Following the workshops, 71% of all participants (N = 32/45) reported increased belief scores. This indicates that they came to believe the catchment was anthropologically modified to a greater extent. The median score in the ‘long’ treatment increased by 2.5 points, from −1.5 to +1. This was slightly more than the ‘short’ treatment’s increase of 2.0 points, from −1 to +1. The change was highly significant in the ‘long’ treatment ($p < 0.01$) and moderately significant in the ‘short’ treatment.
(p < 0.05) (Table 1 rows 3, 4). However, the difference between treatments was too small to be statistically significant (Table 1 row 2).

When asked ‘How natural do you think the Upper Cocker catchment is today?’ most participants referenced the mix of natural and modified elements. Of 58 coded references to belief, seven expressed high naturalness, 17 low, and 34 moderate/mixed. Participants deliberated together, bringing in their own perceptions and knowledge to make often sophisticated judgements. Ben (‘long’ treatment, angler) reflected on the mix of elements, saying:

‘Your perception of how natural it is is just what you’re used to, isn’t it? Compared to wandering around Alaska... To somebody’s perception from the middle of Newcastle, who’s never seen a sheep in a field before... It really is tricky... I didn’t know that we’d had such an impact there (on Crummock Weir and Park Beck). But we’ve had an impact everywhere, haven’t we? What impact have [farmers] had on wild flowers? A lot of that perception is just in your own head.’

Participants in the ‘long’ treatment were more likely to mention landscape modifications than those in the ‘short’ treatment, demonstrating that they had comprehended the extended evolution information. For example, Cameron (‘long’ treatment, flood activist) said:

‘Changes, from the number of different streams running into one of the lakes. And there’s now only one. To the changes in the landscape through farming. Through forestry being reduced and woods being cut down [sic] to allow exploitation by farmers and agriculture... In my head and heart, I probably knew those changes have taken place. But to actually hear it and see it reinforces it. And just makes me think and realize that, you know, don’t accept everything as you see it now.’

In the ‘long’ treatment (N = 22) three participants reported decreased belief scores (mean = -1.7). They argued that, overall, the anthropogenic modifications were quite small compared to the predominance of natural elements such as topography, rainfall, lakes, and powerful rivers. In rare instances the additional landscape evolution information in the ‘long’ treatment appeared to motivate the countervailing belief that the catchment is more natural. Petra (‘long’ treatment, outdoor recreationist) stated that:

‘The fells, corries... the moraines and the gravel beds are all there. And man [sic] has kind of tinkered with it... We haven’t changed the shape of the hills. We haven’t changed what the catchment area is. And all those glacial features are still there.’

Despite this, Petra’s belief score did increase. Participants in the ‘short’ treatment were more likely to express the belief that the landscape as a whole was natural. For example, Ken (‘short’ treatment, flood activist) said:

‘The catchment is essentially natural. And a pretty wild landscape. The only parts that are at all controlled, really, are when you get down to lower levels around the lake.’

Within the ‘short’ treatment (N = 23), Ken was one of five participants who reported decreased belief scores (mean = -2.8). These participants tended to share Ken’s belief that the landscape was highly natural, since the only, or main, human modifications in the catchment had taken place since the 1880s due to the Crummock Reservoir scheme. This suggests that their beliefs may have changed had they received the extended information shown in the ‘long’ treatment.

Overall, the ‘long’ treatment generated marginally higher belief score increases than the ‘short’ treatment. However, the difference was too small to be statistically significant. This finding should be interpreted with the following considerations. Firstly, the ‘short’ treatment did show some historic change (from the 1880s), i.e. the effect of pre-1880s information is being tested, rather than landscape evolution information per se. Secondly, belief referred to the naturalness of the catchment’s lakes and rivers in general. Therefore, specific changes in belief about Crummock Water and Park Beck may have been obscured.

Thirdly, the interactive workshop design of the experiment was loosely controlled, since participants influenced each other. A laboratory study with isolated individuals viewing identical materials may have yielded different results. Fourthly, since sample size was small and variability high, the statistical tests may not have been powerful enough to discover an effect. Finally, the participants were not representative of the general or local population; many were formally educated and had strong environmental interests. Several participants had above-average awareness about historic British landscape modifications, with some citing popular ‘rewilding’ texts (Monbiot, 2014; Tree, 2019). In summary, presenting information in a 4D LV changed participant beliefs around landscape naturalness. However, the extended landscape evolution information did not significantly enhance this effect. The alternative hypothesis (H₃) is therefore rejected.

### 3.3. Workshop effects on attitudes

We tested the hypothesis (H₂) that presenting extended landscape evolution information in a 4D LV changes participant attitudes towards renaturalisation. We reasoned that, following the workshop, participants in the ‘long’ treatment would be more supportive of the proposals than those in the ‘short’ treatment because their environmental baseline would have changed.

Attitudes to the two proposals initially varied widely from ‘slightly oppose’ (2) to ‘strongly support’ (5) (Fig. 7). There were seven ‘don’t knows’ for Crummock Weir and three for Park Beck. There was no

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**Fig. 6. Participant beliefs, before and after the workshop. NB box represents the 25% and 75% percentiles. Whiskers represent the 5th and 95th percentiles. Dots show outliers. ‘Long’ treatment N = 22. ‘Short’ treatment N = 23.**
significant difference in pre-workshop attitudes between the treatments (Table 1 row 5). After the workshop, the variation in attitudes had reduced, and there was only one ‘don’t know’ (for Crummock Weir). Note that participants who strongly supported the proposals (5.0) in Survey 1 could not increase their scores further in Survey 2.

Combined (Crummock Weir and Park Beck) attitude scores increased following both treatments, indicating more support for renaturalisation. The median combined score in the ‘long’ treatment increased by 0.75 points from 4.25 to 5.0. This change was highly significant ($p < 0.01$) (Table 1 row 7). The median combined score in the ‘short’ treatment increased by 0.5 points from 4.0 to 4.5. This change was weakly significant ($p < 0.1$) (Table 1 row 8). The combined attitude change difference between the treatments was weakly significant ($p < 0.1$) (Table 1 row 6). Disaggregating the two proposals, the difference in attitude towards Crummock Weir’s removal between treatments was moderately significant ($p = 0.053$) (Table 1 row 6a). Following the ‘long’ treatment, the number of participants who strongly supported Crummock Weir’s removal increased from eight to 16. In comparison, after the ‘short’ treatment the increase was from six to 11 participants. In contrast, there was no difference between treatments for Park Beck (Table 1 row 6b). This might be expected because both the ‘long’ and ‘short’ treatment LVs showed Park Beck’s pre-canalsation meandering form. Showing the completely unmodified pre-historic planform of Park Beck in the ‘long’ treatment did not therefore have an observable effect on participant attitude.

After the workshop, 12 ‘long’ treatment ($N = 22$) participants were more supportive of Crummock Weir’s removal (mean = 1.25) and two were less supportive (mean = -0.5). In the ‘short’ treatment ($N = 23$) 13 were more supportive (mean = 1.1), and five less (mean = -1.1). Qualitative survey and workshop transcript data explain the reasons for changes in attitudes. These were coded into eight categories (Fig. 8).

‘Naturalness’ was commonly given as a reason for strongly supporting Crummock Weir’s removal. In Survey 1, five ‘long’ and four ‘short’ treatment participants mentioned naturalness, rising in Survey 2 to eight (‘long’) and five (‘short’). For example, Quentin ‘(long) treatment, outdoor recreationist’ was initially neutral (3) about weir removal, writing: ‘I don’t yet know enough about the environmental implications.’ [Coded: environmental, lack of information]. In Survey 2 he strongly supported (5) the proposal, writing: ‘In an intensively managed world, we need to grab any opportunity to allow Nature to take over.’ [Coded: naturalness]. During discussions, participants frequently mentioned ‘naturalness’, with Ivan (‘long’ treatment, outdoor recreationist) making a particularly strong statement: ‘I’m confident that removing [Crummock] weir is a good thing. Just because it would make Crummock Water into something more natural.’ This suggests that ‘naturalness’ is a factor in attitude formation, despite the weak correlation between these cognitions (section 3.1). However, naturalness is not the only important factor. Presumed negative impacts on flood risk, recreation, and development were also reasons for initially opposing Crummock Weir’s removal. The LV showed that recreation and development would be minimally affected. Survey 2 data suggest that the workshop had addressed these concerns. The LV did not deal with flood risk, although participants discussed this. Flood risk remained a concern for some, but fewer participants; four in the ‘long’ treatment and seven in the ‘short’ treatment. As an example, Harry’s (‘short’ treatment, angler) explained his initial slight opposition (2) to weir removal, writing: ‘Possible increase in flooding and loss of amenity resources such as walking. Future outcome on the nature of Crummock Water unclear.’ [Coded: Flood risk, recreation, lack of information]. Yet in Survey 2, Harry strongly supported (4) weir removal, writing ‘Increase biodiversity.

For the Park Beck proposal, ‘naturalness’ was a factor for many participants. In Survey 2, 20 participants (ten in each treatment) strongly supported (5) remembering, citing a desire to return to natural forms and processes. There was occasional direct evidence that the extended information was a factor in attitude formation. For example, in Survey 2 Mark (‘long’ treatment, outdoor recreationist) justified his continued (from Survey 1) strong support (5), writing: ‘From the visualisation, this section of beck has changed greatly over time so it would be great to see it restored to a more natural state’. Other factors important for Park Beck were flood risk, development and heritage. During the workshop,
the researcher stated that the remeandering was unlikely to have a significant effect on downstream flooding, although in theory it would ‘slow the flow’ of flood water. Four participants (three in ‘long’, one in ‘short’ treatment) expressed reservations about loss of Park Beck’s cultural heritage. The three ‘long’ treatment participants had a specific discussion about this. Ulrika (‘long’ treatment, flood activist) wrote: ‘Perhaps could be part removed but some clear history too and perhaps in some ways an attractive view.’

Overall, the workshops changed attitudes towards renaturalisation. Much of the increase in support appears to be due to addressing an information deficit. The extended information caused an additional increase in support for the removal of Crummock Weir in the ‘long’ treatment, which did appear to change the ‘naturalness’ baseline for Crummock Water, if not the whole catchment. Naturalness belief appears to be somewhat important in influencing attitudes, among other factors. Flood risk was very important, although participants held mixed views on whether the proposals would mitigate or exacerbate flooding. Environmental and aesthetic considerations were common reasons for supporting renaturalisation. Improvements to biodiversity and fish populations were seen as important by many participants. These results are caveated by the non-representativeness of the sample population. In summary, presenting extended landscape evolution information caused more supportive attitudes towards renaturalisation. The alternative hypothesis $H_2$ is therefore accepted. However, people’s attitudes were based on sophisticated judgements about many factors, of which belief around landscape naturalness is only one.

4. Discussion

The study was designed to be relevant to a real-world...
renaturalisation initiative and was adapted to take place online during the Covid-19 pandemic. It borrowed a cognitive model from environmental psychology, linking values, beliefs and attitudes. Furthermore, it presented extended landscape evolution information. We discuss the strengths and weaknesses of the study, the validity and utility of the cognitive model, and the effects of extended 4D LV information on beliefs and attitudes.

4.1. Study strengths and weaknesses

Multi-participant workshops simulated real-world stakeholder engagement. While potentially more ecologically valid, this also introduced uncontrolled variables. For example, Quentin shared his concern that remeandering Park Beck would destroy valuable cultural heritage, and clearly influenced co-participants’ attitudes. Workshops were therefore a microcosm of idiosyncratic real-world political discourse around dam removal (Jørgensen, 2017). Free navigation (simulated by the interactive tour) inherently meant that slightly different information was presented. The videos provided consistency, although narration is known to affect participant responses (Chang et al., 2008). Running workshops online caused some technical issues (e.g. lag) and required participants to use their own screens, resulting in a sub-optimal viewing experience. Further, some participants were distracted or browsed additional information. Nonetheless, most participants were comfortable, engaged and discursive. On balance, in-person workshops would have been preferable, although lab-based settings also present issues (Salter et al., 2009). Recruiting ‘representative stakeholders’ was successful insofar as they brought varied interests, beliefs and attitudes. Most participants were empathetic to local concerns, particularly flooding. However, real stakeholders may have reacted differently. Furthermore, participants were self-selecting and not representative of the general population. Most were highly educated, and some had professional environmental interests. Therefore, site- and subject-specific results cannot be easily extrapolated to the wider population. Finally, the small sample size (N = 45), combined with the subtle effects of the extended landscape evolution information, reduced the statistical power to detect significant differences in belief and attitude between the two treatments.

4.2. Validity and utility of cognitive models in landscape visualisation

Based on previous work, we expected to find cognitive links between values, beliefs and attitudes (Fulton et al., 1996; Manfredo, 2008). Biopsychic value orientation somewhat predicted post-workshop attitudes to renaturalisation. However, the link between values and attitudes may have been weakened by the inherent complexity of cognitions, the multifaceted case study, and sampling biases. Firstly, biopsychicity is often associated with altruism (De Groot & Steg, 2008). Pro-environmental participants who believed that renaturalisation would benefit wildlife but exacerbate downstream flooding thus faced a dilemma. Secondly, the link between naturalness belief and attitude is confounded by other factors. For example, many biospherically-oriented participants were recreationists concerned that renaturalisation could reduce public access and aesthetic quality. Thirdly, participants appeared to be more biospherically-oriented than the general population, which could have skewed the data. Similarly, naturalness belief somewhat influenced participants’ attitudes. Several considerations may explain why there was only a moderate link between belief and attitude. Firstly, most participants had nuanced beliefs about the extent to which the landscape was natural. Secondly, most participants deliberated over several different factors to decide their attitudes. Although many participants believed the catchment was quite unnatural (and valued ‘naturalness’), they also considered other factors. For example, some participants believed Park Beck was highly modified, yet also cared about the cultural heritage of its concrete walls.

Although many studies have measured participant responses to LVs, few have used cognitive models to gain deeper insights into how stakeholders form attitudes. Fundamental research, using larger samples and tighter controls, would be required to validate cognitive models in the context of LVs. Nonetheless, this study demonstrates cognitive models can enrich real-world oriented LV research. It offers the following lessons for those wishing to understand attitudes to visualised projects. 1) Values can help to predict attitudes. However, measuring biopsychic value orientations was burdensome for participants, although De Groot & Steg, (2008) 12-item scale is a shortened version of Schwartz’s (1992) scale. Therefore its use may not always be justified. 2) Beliefs also help to predict attitudes. We only measured naturalness belief, but it appeared that other beliefs (e.g. concerning flood risk) were powerful predictors. Belief was less burdensome to measure. Future research may therefore measure multiple beliefs which are held, a priori, to be relevant. 3) Attitude is commonly measured in LV studies (Schroth et al., 2015; Wang et al., 2016). Qualitative coding revealed insights into participant reasons for their attitude. Alternatively, quantitative survey methods may allow easier data analysis, although this requires larger sample sizes than ours (Robson & McCarten, 2016). Carefully chosen variables would allow multiple regression analysis to determine which variables (e.g. beliefs) are the most important in explaining attitudes to management proposals in visualised landscapes.

4.3. Effects of extended landscape evolution information

We expected the extended landscape evolution information to notably change naturalness beliefs and attitudes to renaturalisation, theorising that it would change environmental baselines (Pauly, 1995). However, the difference in belief between treatments was too small to be statistically significant. Nonetheless, there was a significant difference in attitudes to removing Crummock Weir. The extended information changed some participants’ beliefs and influenced their attitudes more than others.

Our findings show that 4D LVs can change environmental baselines. Further research is required to establish whether this can be generalised to other landscapes and different audiences. This study offers some key lessons and directions for future research. 1) LVs and surveys should focus on the most important aspects of environmental modification. For example, we could have focused on Crummock Water and Park Beck rather than the wider lakes, rivers and landscape which, as several participants stated, are rather less modified. 2) Relatively few time points may be needed to change environmental baselines and attitudes. Our ‘long’ treatment LV had nine past time points. Although rich, this required additional modelling effort. Further, some participants found the volume of information overwhelming. 3) Control treatments should cover the shortest possible period to reveal the maximum effect of extended information. Our ‘short’ treatment LV covered the period 1880s to 2030 to compare pre- and post-impoundment treatments. Presenting this much information probably reduced the difference between treatments since, for example, it primed some participants to consider the more distant past. A future study could include a control treatment with a single time point (e.g. 2020). This, together with larger sample sizes, would allow more statistically powerful results to reveal the differences between 3D and 4D LV. 4) We do not know how persistent or general changes in naturalness belief are. We could perform a follow-up study to assess whether the observed changes in belief persist and extend to encompass other modified landscapes. 5) Transparency and free navigation is key. We endeavoured to mitigate bias in our LV (Foo et al., 2015; Sheppard, 2001). However, reconstructing past landscapes (where data is lacking) is particularly vulnerable to modeller bias. Some participants were distrustful of our LV. This could be mitigated by sharing LVs. However, the use of proprietary software limited the ability to distribute the LV to participants. 6) Other media, such as photographs and sketches, may also change environmental baselines. A future study could compare the effects of digital 4D LV with alternative media (Bishop et al., 2013; Salter et al., 2009; Tobias et al., 2016).
5. Conclusions

This study showed, for the first time, that cognitive models can reveal deeper insights into stakeholder responses to landscape visualisation. Biopsychosocial values orientations and beliefs about landscape naturalness somewhat predicted attitudes towards reservoir renaturalisation. In this case, however, flood risk and cultural heritage were more important factors. This study also demonstrated that presenting extended landscape evolution information in a 4D LV can change environmental baselines and thereby change attitudes towards environmental management. The extended information changed stakeholder beliefs about landscape naturalness, although the magnitude of change was small. The extended information also changed stakeholder attitudes towards the removal of a reservoir structure. Future LV research may benefit from using cognitive frameworks to explain stakeholders' attitudes towards environmental management. Further work could establish whether 4D LVs can change beliefs and attitudes in other geographical and social settings. This would further the application of LV to real-world landscape planning initiatives.

CRediT authorship contribution statement

Daryl Hughes: Conceptualisation, Methodology, Formal analysis, Investigation, Data Curation, Writing – Original Draft, Visualization. Geoff Parkin: Conceptualisation, Writing – Reviewing & Editing. Amezaga: Conceptualisation, Funding acquisition. Andy Large: Supervision. Kat Liney: Conceptualisation, Resources, Funding acquisition. Alice Senior: Conceptualisation, Resources, Funding acquisition. Alethea Goddard: Investigation.

Declaration of Competing Interest

The authors declare the following financial interests/personal relationships which may be considered as potential competing interests: The corresponding author’s EngD research is part-funded by a water company, United Utilities plc. The motivation to develop a 3D landscape visualisation for stakeholder engagement over Crummock Water proposals originated with United Utilities at project conception. However, United Utilities had limited influence over the methodology, scope and presentation of this manuscript. Industrial sponsors did suggest recruiting stakeholders with similar interests to local stakeholders. The rest of the study was developed independently by the authors at Newcastle University.

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Appendix A. Supplementary data

Supplementary data to this article can be found online at https://doi.org/10.1016/j.landurbplan.2022.104372.

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