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Customising virtual globe tours to enhance community awareness of local landscape benefits

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RESEARCH HIGHLIGHTS

- Virtual globes can help raise public awareness of local landscape benefits
- Virtual globe applications can be customised to describe landscape features better
- Collaboration with many stakeholders from project outset brings significant benefit
- Schoolchildren are confident users of virtual globe visualisations
- Compartmentalisation aids modification and transferability of visualisation tools

ABSTRACT

Our wellbeing depends upon the services provided by ecosystems and their components. Despite recent advances in academic understanding of ecosystem services, and consideration in UK national environmental policy, a greater awareness is needed at community and individual levels. Dynamic features of virtual globe applications have considerable potential for helping convey the multi-dimensional context of ecosystem services and promoting general awareness. In a case study targeting residents in a small urban fringe river catchment in Norfolk, UK, representatives from local authorities and responsible agencies collaborated with scientists to produce extensive customisation of virtual globes in this context. By implementing a virtual flight over the catchment, different views and scales are traversed to set the context for landscape features and ecosystem services. Characteristic sites, e.g. supplying cultural services, are displayed and relationships with the natural environment are explained using linked on-screen text. Implementation is cost-effective and described for practitioners in ecosystem and landscape management, who may be inexperienced in landscape visualisation. Supplied as three pre-packaged virtual tours, products are made available for download and are publicised at a variety of engagement events, including teaching events with schoolchildren. The tours have attracted public interest and generated positive feedback about improving knowledge of local natural assets. Schoolchildren show confidence with the interface, but supplementary problem-based activities can improve learning opportunities. The capacity of virtual globes to support more participatory involvement of the public in local ecosystem management may increase in the future, but such visualisations can already help promote community awareness of local landscape benefits.

Keywords: Visualisation; Virtual globes; Virtual tours; Ecosystem services; Landscape management

1. Introduction

1.1 Individual and community awareness of landscape benefits

Human well-being is inescapably tied to the natural environment. A landscape unit, such as a river catchment, can regulate the flow of water, provide crops and livestock, support nutrient cycling and supply landscape features for aesthetic enjoyment (e.g. Maltby et al., 2011). The benefits that humans obtain from the natural environment have been formalised in academic publications and government documents as ‘ecosystem services’ (e.g. Fisher, Turner & Morling, 2009; Millennium Ecosystem Assessment, 2005) and this approach and nomenclature is gaining traction with decision makers and stakeholders (e.g. Potschin, Haines-Young, & Fish, 2011).

As natural and anthropogenic stresses continue to threaten the ability of the natural environment to maintain ecosystem services, a greater societal consciousness about human dependencies on terrestrial, freshwater and marine ecosystems is desperately needed. There have been great advances in academic understanding of the state of the natural environment and its value to society, for example through the pioneering work of the United Kingdom National Ecosystem Assessment (UK-NEA, 2011). Other countries – including Spain, Germany, Israel and the United States – are at different stages of developing similar ecosystem assessments. Adopting an ecosystem service approach to policy and decision making is a pragmatic way to examine the links between ecosystems and human well-being and to promote sustainable use in an equitable way. A range of actors, however, from national governments to individuals and communities, need to play roles in the initiation and implementation of responses to secure and improve the future delivery of ecosystem services.

An individual can act as a participant in the landscape, a processor of information from the landscape and a performer of biological and physical change (Zube, 1987). Such an individual, however, may be unaware of these roles and their potential to conflict with, or enhance, underpinning landscape structures and processes. While society has some appreciation of the benefits that the natural environment provides through the supply of food and clean water, environmental settings which deliver recreational opportunities (Brown, Montag, & Lyon, 2012), and even sequestration of carbon to mitigate climate change (Wild & McCarthy, 2010), a greater awareness at individual and community levels is needed to raise understanding of environmental assets and their value (UK-NEA, 2011). In a UK-government commissioned qualitative study, a stratified socio-demographic sample of respondents understood the concept of ‘ecosystem services’ but did not find the terminology useful without new evidence and reasons to listen (Defra, 2007). While the UK-NEA improved the evidence base at a national level, particularly with reference to ascribing value, this new knowledge has not filtered to public documents and vocabulary. Whether formal terminology is used or not, it is important for individuals to recognise that the natural environment delivers a flow of societal benefits that can be both tangible (e.g. drinking water) and intangible (e.g. aesthetic enjoyment).

1.2 Potential for promoting awareness through visualisation

Raising environmental awareness is an important first step towards increasing voluntary actions and community participation in decision-making. Digital landscape visualisation is a device with considerable potential in this context. As noted by Sheppard (2012, p.403), visualisations can “help people to know, see and recognise what was previously vague, abstract or hidden” which makes them particularly relevant for increasing public appreciation of ecosystem services. One of many remaining challenges in integrating the concept of ecosystem services in everyday landscape planning, management and decision-making, is the definition of appropriate visualisation techniques (de Groot, Alkemade, Braat, Hein & Willemen, 2010).

Visual representations (maps, images and computer graphics) are powerful means of conveying landscape characteristics and can provide a common language in discussions on planning issues between technical and non-technical participants (e.g. MacEachren & Brewer, 2004; Sheppard, 2012; Van den Brink, Van Lammeren, Van de Velde & Däne, 2007). In particular, spatial referencing can be an effective and intuitive shared framework in which to synthesise data (Wood, Dykes, Slingsby & Clarke, 2007). Geographic-based visualisations have demonstrated benefits in improving communication, understanding and ultimately action, for example in the landscape planning process (Pettit, Bishop, Sposito, Aurambout & Sheth, 2012) and improving foresight and action with respect to climate change (Sheppard, 2012).

Traditional visual media include, for example, physical models, diagrams, charts and maps, and these have been used as communication tools for centuries. More recently, technological and scientific advances have enabled representation of increasingly complex information in multiple dimensions (Lange & Bishop, 2005). The use of photomontages, two- and three-dimensional visualisations to ascertain public landscape preference have been widely discussed in the urban and rural planning literature (e.g. Laing, Davies, & Scott, 2005; Dramstad, Tveit, Fjellstad, & Fry, 2006; Lange, Hehl-Lange & Brewer, 2008; Ode, Fry, Tveit, Messager, & Miller, 2009; Mell, Henneberry, Hehl-Lange & Keskin, 2013; Todorova, Asakwa, & Aikoh, 2004). Three-dimensional visualisation of a place on Earth using a virtual globe offers more interactive possibilities than traditional static two-dimensional mapping, such as permitting direct manipulation of the interface for real-time browsing of satellite imagery and aerial photographs. Several studies have demonstrated that virtual globes can increase the level of engagement with scientific data, transferring ‘known’ information to the public domain in formats that permit a high level of user interaction with the data (e.g. Aurambout, Pettit & Lewis, 2008; Pettit et al., 2012; Sheppard & Cizek, 2009). Four-dimensional representation offers further possibilities for greater uptake and understanding. For example, virtual globes can depict past environments through geological modelling (De Paor & Whitmeyer, 2011), display scientific datasets e.g. of snow and ice cover (Ballagh et al., 2011), or show how events unfold using time sequencing of spatial content (e.g. Polczynski & Polczynski, 2013; Schroth, Pond, Muir-Owen, Campbell & Sheppard, 2009). As such, virtual globes have been used to help users interpret their past and present environment and plan for the future (e.g. Pettit, Raymond, Bryan, & Lewis, 2011; Schroth et al., 2011). Virtual globes are also used by NGOs and activist groups to disseminate information about their activities and concerns, e.g. through Google Earth’s ‘global awareness layers’ (Elwood, 2010; Parks, 2009). Such dynamic alternatives could have significant advantages over traditional 2-D maps for representing and communicating changing bundles of ecosystem services in space and time (de Groot et al., 2010).

Visualisations are now a typical component of landscape research and practice (Lange, 2011); they are standard mechanisms to communicate activities concerned with the natural and urban environments of the past and present, and the creation of future environments. In practice, however, landscape visualisation for public information and community involvement requires a grasp of a range of disciplines including cartography, computer science, and cognitive science (MacFarlane, Stagg, Turner, & Lievesley 2005). Aspiring landscape visualisers will also have to manage possible public unfamiliarity with geospatial technology (Ball, 2002) and consult specialised texts on usability engineering and human-computer interaction (e.g. Haklay, 2010; Haklay & Tobon, 2003; Neilson 1993). Visualisation developers should also have a wider appreciation of the cultural, social and political implications of contemporary visualisation methods (Elwood, 2010) and reference to specialised sub-disciplines, such as critical geographic information systems (GIS) and public participatory GIS, PPGIS (Ball, 2002; Elwood & Ghose, 2001; Sieber, 2006), may be relevant. While this plethora of literature correspondingly provides substantial support for the novice, landscape practitioners may also face various additional challenges such as limited budgets, time and personnel, and organisational restrictions such as access to sources of assistance and collaborative networks and the ‘fit’ with organisational mission or priorities (Elwood & Ghose, 2001; MacFarlane et al., 2005; Paar, 2006).

1.3 Aims and scope

The aim of this study was to design visualisations to enhance community awareness of the tangible and intangible benefits which they obtain from a local river catchment. In practice this involved developing a set of communication tools for a virtual globe environment and then disseminating these products through community engagement and education opportunities. Implementation details are presented here for researchers and non-experts in visualisation software, such as planning practitioners from local authorities and representatives from wildlife charities and civil society organisations. These tools are particularly suitable for engagement with small or less well-resourced, communities.

The methodology outlined below begins by establishing user needs and introducing the study area: a small calcareous river system draining a catchment within an urban fringe area of Norfolk, UK. Consultation between scientists, local authorities and other responsible agencies helped establish themes for the visualisations and provided a regular and frequent source of solicited feedback. This collaboration was central to the research design. The ultimate effectiveness of the visualisations will only be apparent over several years, but the approach is evaluated in terms of the utility of the tools, their initial uptake and participant feedback. Based on this research experience, challenges for similar endeavours are identified and recommendations for customisation of landscape visualisations are offered.

2. Study context and users

The Sustainable Urban Fringes (SURF) Project is an EU Initiative to realise the value of landscapes which link urban and rural environments. Urban fringes face specific challenges due to environmental pressures and changing demographics; these include conflicts between planning and sustainable development, fragmented habitats, declining biodiversity and deteriorating water quality. Furthermore, the use of the natural environment for outdoor recreation is potentially inhibited due to poor access to the countryside and a lack of engagement from socio-economically deprived local communities. Under the auspices of SURF, the Gaywood Valley Project adopted an ecosystem approach and sought to unlock the potential of the River Gaywood and its catchment as a multifunctional landscape for local people (see Potschin et al. 2011). The visualisation tools presented here were a fundamental part of a public engagement programme with a remit to raise awareness of the local landscape and its value to society. The project team, consisting of practitioners in the catchment from local authorities and civil society organisations, sought the assistance of academic researchers in the design and implementation of the visualisation tools.

The Gaywood catchment has a total area of just under 60 km^2 and a main river length of approximately 12 km (Fig. 1, boundary as defined by the project team). This relatively small lowland catchment supports valuable riparian and aquatic ecosystems through a rolling chalk landscape. Downstream, the river runs through (and under) the urban centre of King's Lynn, Norfolk, where it joins the Great Ouse and the North Sea through The Wash embayment.

<Fig. 1>

Within the upper and middle catchment there are important wildlife habitats, including heathland, woodland and wetland, with national and international designations such as Site of Special Scientific Interest, County Wildlife Site, National Nature Reserve, Special Area of Conservation and RAMSAR wetland. Other locations are nationally important from a geodiversity perspective, e.g. outcrops that have contributed stage names to UK stratigraphy (Lower Cretaceous Dersingham Formation, for example) and landforms that provide evidence for past climates (Holt-Wilson, 2010). Management of surface water flows is important in the context of drainage and as part of the flood defence system. The majority of the town of King's Lynn is within the hydrological boundary of the Gaywood catchment and the river runs through a park which is a significant urban green space for recreational use. Rural villages and sites of historical importance, e.g. monuments, earthworks and ruins, are dotted throughout the catchment. Outside of King's Lynn, the landscape is predominantly agricultural land, with a range of arable crops and grazing of livestock. The Gaywood catchment thus contributes to the delivery of cultural, provisioning, regulating and supporting ecosystem services as defined by the Millennium Ecosystem Assessment (2005).

Many of the settlements close to the river, particularly housing estates on the eastern side of King's Lynn, are among the most socially deprived parts of England (source: Index of Multiple Deprivation 2007). Initial consultation with the project team revealed that there is generally little connection with, or use of, the nearby countryside by urban residents. Moreover, the general public did not identify with Gaywood Valley as a place or landscape. This presented an immediate challenge as place-names provide the basis of geographic referencing in normal human discourse (Goodchild, 2007). Place attachment, past experiences, and knowledge of historic uses, influence individual preferences towards present values and landscape change (Ball, 2002; Brown & Raymond, 2007; Hanley et al., 2009; Zube, 1987). Visualisation tools were required to respond first to this need by generating an identifiable landscape unit and a foundation from which to build increased engagement by nearby residents. Tools would also explain the various pathways of benefits from the natural environment to people (ecosystem services) and finally encourage more active involvement in the catchment.

The early plan had been to create static photorealistic images (e.g. Lovett, Appleton, & Jones, 2009) of current and potential future views from a series of vantage points around the Gaywood catchment. Following the initial discussions, however, it was decided that providing a greater degree of user interactivity through virtual touring would have benefits for orientation and establishing the requisite local context for the consideration of ecosystem services (e.g. see Defra, 2007). Collaboratively, the decision was also made not to use the visualisation tools for presentation of potential and uncertain landscape change, although tools would ultimately maintain the functionality to be adapted to incorporate such issues.

Visualisations responded to two coinciding user needs: (a) the agenda of practitioners in the catchment, who would take primary responsibility for dissemination of the final tools; and (b) the perceived learning needs of the public. Education, at all ages, is essential for increasing public awareness of the importance of nature conservation and stimulating action by civic and voluntary groups (UK-NEA, 2011). Visualisation tools were designed to permit guided and exploratory visual analysis of ecosystem services in the catchment. The tools assumed a default single user environment, namely individual use of the tools (at home) by the general public and for teachers to direct learning with schoolchildren in the classroom.

3. Materials and methods

3.1 Data and visualisation content

Based on early discussions with the practitioners in the catchment, content for the visualisations was organised in three themes: (i) Introduction to Gaywood Valley; (ii) Geology and Past Climates; and (iii) Green Infrastructure. Descriptive examples linking local catchment services to the community were integrated into the themes. The Introduction theme served to orientate users, identify the Gaywood Valley catchment and present a few tangible locally-relevant examples of ecosystem services (e.g. the Gaywood catchment provides drinking water). The second theme was created to illustrate the link between the types of rocks that outcrop at the surface, their changes with depth and conditions under which they formed. Geodiversity underpins and delivers many vital ecosystem services (Gray, Gordon & Brown, 2103), and this theme was essential for providing context (e.g. porous Norfolk chalk delivers groundwater storage). The temporal range was defined by the age of the rocks and sediments in Gaywood Valley (i.e. Jurassic to Quaternary) (see Holt-Wilson, 2010). This encapsulated a variety of events and significant environmental changes, e.g. widespread global volcanism during the Cretaceous, the extinction of the dinosaurs at the Cretaceous-Tertiary boundary, ice sheets moving across Norfolk in the Quaternary with associated changes in sea-level and recent climate change. Finally, the green infrastructure theme sought to encourage physical exploration of the landscape by displaying public rights of way, cycle routes, health walks and accessible green space.

The ability to digitally represent the natural environment is highly dependent on data availability and quality. Integrating data of diverse types holistically to make a coherent picture is one of the core advantages of visualisation (Sheppard, 2012) and information from a variety of literary, photographic or scientific sources was collated and spatially referenced where appropriate (see also Schroth et al., 2009, for further information on data gathering and preparation for virtual globes). As far as practical, data were open access to ease redistribution.

Photographs depicting features of the contemporary Gaywood Valley landscape were sourced from the Geograph Britain and Ireland Project (Editor, in press b). Paper maps from the British Geological Survey (1999) and Norfolk Geodiversity Partnership (e.g. Holt-Wilson, 2010) were used to support interpretation for a cross-section and stratigraphic section (vertical changes of bedrock with depth). Geospatial data were obtained from project partners at Norfolk County Council e.g. boundaries for land designations, areas of green infrastructure and public rights of way. Details were also extracted from published public documents, e.g. health, heritage and biodiversity walks for King’s Lynn (Editor, in press c). Practitioner knowledge was used to identify further locations of local cultural value.

3.2 Software

Virtual globes allow a graphical user interface for exploration of high-resolution satellite imagery and aerial photography through spatial and temporal navigation tools. Access to ancillary geographic information such as geographic borders, places, roads and terrain (digital elevation) is also standard. Client-side architecture resides in an application downloaded and installed on the user’s computer, which interacts with a server over the Internet for requesting data. Data are typically streamed from servers in response to user interaction but virtual globes can also cache imagery on the user’s computer, thereby not only providing a very smooth experience once the data have loaded on to the computer but also permitting offline viewing. Google Earth was selected as the platform for visualisation tool development from a number of available virtual globes e.g. NASA World Wind, Microsoft Bing Maps, ESRI Arc Explorer (see reviews in Aurambout et al., 2008; Schroth et al., 2011; Tuttle, Anderson & Huff, 2008). An important factor was that the basic version of this platform is free to download and this was beneficial for the dissemination of the products. Additionally, Google Earth has a considerable archive of associated online information, an established support system with developer forums, and is compatible with tools to help with customisation, such as (free) Trimble SketchUp.

Custom visualisations developed for Google Earth sit on top of the native imagery. Such content is in the form of files (not software modifications, plug-ins nor add-ons) which are automatically recognised by a host system with Google Earth software installed. Tailored geographic content is supplied to Google Earth via Keyhole Markup Language (KML) which is a simple human-readable scripting language (see Wernecke, 2009). Visualisation tools for the Gaywood Valley Project were produced by extensive manual KML scripting undertaken in a simple text editing program (Notepad++; http://notepad-plus-plus.org/). Current versions of the tools were developed using KML version 2.2 scripting and optimised for the standard (free) Google Earth version 6.0 running on a Windows Operating System. Final output was packaged into a single KMZ archive, a compressed folder, which can be hosted publicly on a web server and shared.

3.3 Design decisions

Non-expert users must navigate an interface with a computer system that embeds a language, world view and concepts that may be different to their own work or home view (Haklay & Tobon, 2003). Creation of any worthwhile visualisation tool requires adequate understanding of the end users (Andrienko et al., 2010). Understanding user characteristics, their requirements and goals is central to the design process and can improve usability (Haklay, 2010). Here, specific additional content was developed to run within the stand-alone Google Earth application; this consequently inherited the default usability and functionality of this web-mapping application. Within the custom scripting, additional signposting and progressive disclosure of information attempted to cater for users of all experiences and abilities, and ensure that the tools were efficient, effective, engaging, error tolerant, and easy to learn (Haklay & Zafiri, 2008). Döllner (2005) also provided specific guidance on improving usability of the virtual environment by employing spatial (e.g. camera position, orientation and movement) and structural constraints (e.g. addition or removal of thematic layers).

Tool functionalities and format were the result of design decisions that were sympathetic to the framework for good visualisation presentation established by Sheppard and Cizek (2009). These guidelines for good practice pertain to access to visual information, interest, representativeness, accuracy, visual clarity, framing and presentation, and legitimacy of virtual globes (Table 1). Additionally, tool appearance was influenced by recommendations from published research on visualisation representativeness and scale (e.g. Appleton & Lovett, 2003; Pettit et al., 2012), use of colour and symbology (e.g. Brewer, 2005; British Cartographic Society, 2008; Robinson, Morrison, Muehrcke, Kimberling, & Guptill, 1995), and subjectivity of developer perspectives on the input data, content and display format (e.g. MacFarlane et al., 2005; Monmonier, 1996; Wood & Fels, 2008).

Human short-term memory can only maintain a maximum of seven information units or facts simultaneously and repetition or elaboration is needed to transfer these units to long-term memory (see e.g. Ball, 2002). Auxiliary text was needed to provide a visual commentary or a ‘virtual chauffeur’. Drawing on recommendations from surveys on public perception of ecosystem services (Defra, 2007; UK-NEA, 2011), specific academic terms were avoided and significant consideration was given to the appropriate level of detail for these specific audiences.

<Table 1>

Effective customisation of the Google Earth interface begins with an appreciation that KML is based on a nested set of elements. A parent element contains several child elements that establish the initial field of view and styles for cartography that are inherited by all descendants. Subsequent elements in a KML script associate data with positional geometries e.g. pop-up balloons for sites of interest (called placemark elements) and images superimposed on the screen or ground (called overlay elements). KML scripting is used to customise the basic characteristics of these elements, for example name, description, and view. The hierarchy of elements in the KML scripting controls overlap of elements in the field of view, therefore this should be carefully considered. Branches to the lineage can be introduced, such as ‘network links’ as a mechanism for connecting multiple KML files and auxiliary data, e.g. illustrations and photographs (see Wernecke, 2009; Wood et al. 2007). Once a structure for organising files is established, further revisions are straightforward. A simplification of the data file hierarchy used in the visualisation tools is shown in Fig. 2. Three-dimensional models were added for educational benefit and interest. These were drawn in SketchUp and exported to COLLADA files which were then packaged within the KMZ (Fig. 2) and encoded as placemarks in the main

KML. The touring-related KML element ‘animated update’ allowed the altitude of the model to be altered by the developer as part of the tour sequence, thereby creating motion.

<Fig. 2>

Customisable elements within Google Earth enabled locally-relevant pathways for the delivery of ecosystem services (and derived goods) to be emphasised within the three tools. Pathways were a descriptive mechanism to connect the services of the catchment to beneficiaries without using technical terminology. Table 2 outlines the design of elements for the main local pathways incorporated within the visualisations (adopting the Millennium Ecosystem Assessment, 2005, definition for ecosystem services). Supporting services (e.g. soil formation, water cycling, and nutrient cycling) are not considered final ecosystem services as they are necessary for the production of all other ecosystem services (UK-NEA, 2011). Other final ecosystem services, such as climate regulation, have global-scale pathways to the community that were communicated more implicitly through the tools. Equable climate in Gaywood Valley, for example, is a benefit that was introduced with reference to past average temperature, sedimentary rock formation (e.g. chalk in warm shallow seas), movement of glaciers, sea level change, and present day anthropogenic climate change.

<Table 2>

3.4 In-development review

Talking to users during the implementation stage can help improve usability (Haklay, 2010). A cycle of discussions to identify relevant features and test visualisation styles is a common approach for visualisation development and tools often develop iteratively (e.g. Steinitz, 2012;

Williams, Ford, Bishop, Loiterton & Hickey, 2007). Two particular consultation sessions were integral to tool development.

A prototype virtual fly-through-the-valley tour was discussed with the practitioners. Following a practical demonstration, the group was asked for feedback e.g. regarding individual thematic layers of data, proposed sites typifying the catchment and general visualisation format. Participants responded favourably to the dynamic tour (and had been involved in the initial decision to use a virtual globe format). However, they also identified features for improvement: the prototype tour gave insufficient time to read text in placemarks; there were too few sites of interest; some photographs were outdated and not representative of the current landscape; and there was too much overt use of technical terminology in site descriptions. Edits were subsequently made to the duration of pauses, further placemarks were added, photographs were updated and nomenclature was revised.

The first public consultation exercise evaluated pilot tools with the general public attending the official launch of the SURF Gaywood Valley Project at Green Quay, King's Lynn (May 2011). A portable visualisation display was used to facilitate individual and small group discussion at this general open-day event. Constructive criticism was provided on the speed of the tour (again, too fast to allow all information to be absorbed) and terminology (again, too technical). Following further design modifications, the tools were officially released to the public.

4. Final visualisation tools

A visualisation tool under each theme is available for download as an independent KMZ archive less than 4 MB in size. All accompanying data are provided within the KMZ (e.g. photographs and 3D models, see Fig. 2) and they can be saved, distributed and used offline (download files from: http://tinyurl.com/GE-Opener; http://tinyurl.com/GE-Geol; and http://tinyurl.com/GE-Green - save to computer hard drive to run). By unzipping the archive, the KML scripting can also be interrogated by aspiring visualisers (see Wernecke, 2009).

Google Earth will launch after the user double-clicks the KMZ archive called ‘Introduction to Gaywood Valley’. The user then sees a screen overlay displaying a welcome message and basic operating instructions. After doubling-clicking on the ‘TOUR’ (network-) link the user encounters another screen overlay with a short description of the catchment. The user then follows instructions to start the tour and the camera angle rotates and zooms to frame the catchment (see discussion in Döllner, 2005). The tour continues without user interaction, automatically opening a series of text balloons and waiting to allow the user to read. This highlights areas of interest and gives a general overview of catchment features. The viewing angle then changes as the camera zooms to the Gaywood River source and the user is taken on a virtual fly-through down the catchment towards the river mouth. All these elements were designed to describe synergistically the pathway pertaining to water provision (Table 2). At specific sites (placemarks depicted by custom arrow icons), the tour pauses and a balloon opens providing further information (e.g. Fig.3). Photographs and text within the balloons are referenced so that the user can access the information source. The user can also navigate to further information by clicking on hyperlinks, which will open in a web browser. Some sites include 3D models (Fig. 3). A screen overlay allows the user to see where they are in the catchment (e.g. top-right of Fig. 3). The tour progresses downstream (changing camera angle and altitude) following input from the user (i.e. play button, bottom of Fig. 3). For instance, the tour pauses at selected sites of interest and so forth. Finally, a screen overlay informs the user that the tour is over and provides acknowledgements. However, the user can override the tour at any time to explore the virtual environment independently. The tour will resume from its last position when the play button is pressed.

<Fig. 3>

Fig. 4 provides screen-shots of the viewing window from the ‘Geology and Past Climates’ tool. This tool operates in a similar way to the Introduction tool (described above). Due to the complexity of some of the concepts under this theme, however, the Phanerozoic and Quaternary eras were provided as separate tours within the tool. Screen overlays in both tours were used to provide an extensive visual commentary for the user. A key functionality of this tool was the interest and educational benefit provided by a geological cross-section (3D model) appearing from the ground (after De Paor & Whitmeyer, 2011; Walsh, 2009). Fig. 4 (part a through c) shows the movement of the cross-section, update of screen overlays (including vertical section) and rotation of camera angle. A 3D model and screen overlays describe the movement and action of glaciers across Norfolk. All these customised Google Earth elements work together to describe how Norfolk’s geodiversity underpins provisioning, cultural and regulating ecosystem services in the Gaywood catchment (Table 2).

<Fig. 4>

Independent exploration was the emphasis of the ‘Green Infrastructure’ tool and as such it did not include a touring component. An initial screen overlay encouraged the user to interrogate a suite of placemarks (describing recreational sites, Table 2) and multiple thematic layers were placed entirely under user control.

5. Engagement activities

To enable enhancement of community awareness of ecosystem services it was imperative to provide equal access to data and information for all sectors of the community (Table 1). The tools were made available to the general public by way of a university-hosted website in October 2011 (http://tinyurl.com/GE-UEA-blog) and a dedicated Gaywood Valley Project website. Public release was advertised by general exposure, e.g. website newsfeeds and social media, and targeted activities, e.g. a project newsletter to subscribers and oral presentations with live demonstrations of the tools at public open day and local planning practitioner events. Visits to the university-hosted website were monitored (anonymous counts of unique visitors only). By the end of June 2012, the website had received 447 unique views with particular peaks following advertisements (Fig. 5). There were also repeat visits from some IP addresses suggesting visitors returned to further investigate the tools.

<Fig. 5>

Activities were also conducted at two primary schools in the Gaywood Valley. Accompanied by teachers and classroom assistants, the researchers ran 1-1.5 h sessions with two classes of Key Stage 2 children (8-11 year olds). The visualisation tools were augmented with a custom quiz, and supplemented with two extra activities: a Global Positioning System exercise in the playground and a geology activity using rock samples and microscopes. Links between the Google Earth content and the supplementary activities were emphasised and the theme of the day was investigating the Gaywood Valley. Multiple presentation formats were chosen following research that different media styles can complement virtual globes by suiting different learning styles (Schroth et al., 2011). Engaging problem-based activities sought to maximise learning potential (Johnson, Lang & Zophy, 2011; Schultz, Kerski & Patterson, 2008), thereby avoiding insufficient analysis in typical virtual globe-based lessons (Allen, 2007).

Children used the visualisation tools to derive answers for the Google Earth quiz. The quiz aimed to enforce benefit pathways, such as chalk providing an aquifer for drinking water and providing construction materials (Table 2). Despite no prior experience with the virtual globe visualisations, the children used the mouse competently to navigate the system and were able to interact effectively with the content i.e. pausing, rewinding or stopping the tour entirely to explore the virtual world to search for answers or clues. Neither children nor teachers required intervention or special instructions to use the tools or drive the software (Haklay & Tobon, 2003). Perhaps in response to teachers' pedagogic style (Bodzin, Anastasio & Kulo, 2014), or available resources, it was apparent that use of the instructional materials and tools varied between teachers. Researchers acted as observers or facilitators in different classrooms dependent on the role taken by the teacher, i.e. as leader or participant. In one classroom, the students used the visualisation tools in small groups (7 or 8 children) and answered the quiz collaboratively. In the second classroom, the students sat and worked quietly in pairs. Although the children's answers to the quiz were not graded, they were used to facilitate one-on-one and small-group discussion about the benefit pathways.

Teachers and children were asked to complete questionnaires at the end of the events. The feedback sheet for children consisted of simple ranking exercises (three-level Likert) and dichotomous questions on the usability of the tools and learning outcomes. There was also space to write a sentence summarising what they had learnt. Teachers and classroom assistants were prompted to give lengthier, qualitative replies via a different questionnaire. As there were only a limited number of child participants ($n \approx 60$) and responses received by return ($n = 21$), formal quantitative analysis of questionnaires from schoolchildren is not especially meaningful.

Some qualitative findings, however, are provided. The children were asked to answer the question: *“Thinking about all activities today, what did you learn?”* by completing the sentence: *“Today I learnt…”;* eight children wrote about the physical appearance of rocks, their age (five correctly recalling 90 million years old for chalk) or composition (e.g. “*Today I learnt…* that one bit of [chalk] is made out of little [skeletons]”). Five (different) children wrote about the size, location or history of the Gaywood Valley (e.g. “*Today I learnt…* about what the town looked like a long time ago”; “*Today I learnt…* that our classroom used to be water”).

Most children delivered feedback that they had leant “lots” or “quite a bit” about the Gaywood Valley. These learning outcomes were echoed in the comments provided by the teachers, e.g. “They [now] know where it [Gaywood Valley] is!” and “their [the children’s] interest has been started and they would like to share their knowledge and to learn more”. The teacher’s thought that the diversity of activities worked well, e.g. “each activity proved to be inspiring for different children” but observed that the mode of delivery relied too heavily on independent reading (difficult for this age group). Collectively, children gave feedback that although they had enjoyed the event, they would have liked more time to complete the Google Earth quiz.

These initial findings from activities with Gaywood Valley schoolchildren suggest that Google Earth tools have considerable potential for enhancing children’s knowledge about the catchment and its history. These children were able to use the tools to answers direct questions about benefits pathways (e.g. *“What can chalk be used for?”*) and retained some knowledge about abiotic diversity in the catchment.

6. Discussion and an agenda for future research

6.1 Capacity for promoting community awareness of landscape benefits using virtual globes

A recent survey suggests that many children in England are losing connection with local natural environments, particularly those who live in urban areas (Dillon & Dickie, 2012). While there is no direct reflection of the influence of having children in the household on concern for the environment, children can be a strong motivator for adults to take outdoor recreational visits and appreciate the natural environment (Stewart & Costley, 2013). Locally-relevant problems have shown to be motivating contexts to provide students with reasons to learn more about an environmental issue (Bodzin et al., 2014). Thus, the Gaywood Valley Project may provide a personally relevant and meaningful setting for wider discussion of ecosystem services. Precedent for using virtual globes as teaching tools has been established in the disciplines of geography (Schultz et al., 2008; Tate, 2012), geomorphology (e.g. Allen, 2007) and geosciences (e.g. Johnson et al., 2011). This project demonstrates that these visualisation tools have the potential to be included in formal learning about ecosystem services. The design benefits of Google Earth activities for learning could be improved by designing curriculum materials to align directly with classroom contexts and providing instructional materials for teachers which permit customisation (see Bodzin et al. 2014). For example, learning activities could have greater relevancy if tailored to reading age.

An ecosystem approach is a way to frame and unite interdisciplinary research under a common agenda. This research shows that virtual globes have characteristic functionalities that make them particularly suited for the communication of the spatio-temporal, multi-faceted principles of ecosystem services (Table 2). For example, the touring capability in Google Earth allows different spatial and temporal scales to be traversed to set appropriate detail or wider context. Narrated fly-through tours can be exploited to describe the pathways between capabilities and benefits, and descriptions of stocks and flows of services (albeit the terminology may not be explicit). Additionally, KML is based on a hierarchy of nested elements which, when understood by the visualisation developer, can allow a single file to express spatial relationships through description and overlay or, conversely, reduce overlap to improve visual clarity; again, this functionality suits the multiple spatio-temporal concepts of ecosystem services. Other useful virtual globe traits include access to spatial contextual information (i.e. the backdrop of aerial imagery and ancillary geographic information), placemarks for interrogation and hyperlinks to other information. Three-dimensional models and animation provide an additional means of capturing interest. These traits can also be tailored to explain ecosystem characteristics.

Initial meetings with the project team revealed that there was little knowledge of the study area. It was therefore fundamental to provide orientation and establish a location that was recognisable by the local population; these visualisations have provided that georeferencing for ‘Gaywood Valley’. To build a collective understanding of the importance of ecosystem services in the catchment, visualisations may be best placed in a physical space to facilitate collective discussion (e.g. a meeting hall) (Sieber, 2006). Consultations and engagement activities provided descriptive feedback that the public, schoolchildren in particular, began to identify with Gaywood Valley catchment and its benefits to society. It is difficult, however, to separate the effect of the visualisations from the other activities of the SURF Gaywood Valley Project and outcomes will inevitably be long-term.

6.2 Audience accessibility and usability

In Great Britain, 22 million households (84%) now have Internet access and 38 million adults (76%) access the Internet every day (ONS, 2014). Personal computers are now ubiquitous in the developed world and users are accustomed to fast download speeds and near-instant transmission or receipt of information. In-vehicle satellite navigation systems and digital maps with drapes of aerial photography are familiar media for geographical exploration (e.g. Google Maps and Microsoft Bing Maps). Spatio-temporal analysis is no longer restricted to specialists (Goodchild, 2007; Unwin, 2005) and is performed routinely for journey planning (Andrienko et al., 2010). The general public has become familiar with the concept of ‘zoom’ and simple navigation to a place or street address, and this is also shown by this research. Further, in 2014 computer programming became part of the national curriculum in primary and secondary schools in England. By the time they reach the age of 11, schoolchildren will be taught how to design and write programs. All child participants in this study had a computer at home (although Internet speeds are still limited in some rural areas of Norfolk). Teachers interested in these technologies, could also direct the pedagogic focus inward, to teach about scripting and visualisation.

Accessibility and interest are two key benefits of using virtual globes to provide landscape visualisations (e.g. Pettit et al., 2011; Sheppard & Cizek, 2009). An indication of public interest in these visualisations is demonstrated by visits to the website hosting the tools and participation in engagement events. This research could be extended to improve understanding of participation rates to see, for example, if uptake (downloads) varied with publicity or different visualisation media. This has been identified as a research priority for PPGIS (see Brown & Kytta, 2014). In a survey ranking different visualisation media for communicating the impact of climate change, Schroth et al. (2009) found that respondents who preferred posters had a non-interactive learning style and strongly rejected the virtual globe. Anti-technology prejudice and misconceptions has been a considerable barrier to overcome in using visualisations to engage the public about local issues (Ball, 2002), but such cynicism was not observed among participants in this study. Augmentation of the visual tools with sound, to avoid overload of the visual sense (e.g. Ball, 2002), and (embedded) videos were considered in the implementation stage but there were concerns about minimising the file size.

There is a general paucity of evaluations of visualisation effectiveness (e.g. Pettit et al., 2011) perhaps due to logistic problems of evaluating long-term use of tools (e.g. Bishop et al., 2013) and knowledge transfer (e.g. Cash et al., 2003). In this study, researchers made observations of behaviour in classroom and performed a simple usability evaluation, i.e. an objective assessment of the user's ability to answer questions and perform tasks (Bishop et al., 2013). Formal testing of the design, implementation and usability of the Google Earth tools could be performed, such as use of additional software to record interactions between users and the system (Bishop et al., 2013; Haklay & Tobon, 2003; Neilson, 1993) and before/ after tests of beliefs and attitudes towards ecosystem services. Despite difficulties quantifying competence of the visualisations, this research provides case study experience of responding to tangible social needs with virtual globes. Visualisations were tailored to a particular local study area, and described local benefit pathways, but such tools have great potential for application to other landscapes and scales.

6.3 Longevity, adaptability and transferability

The Internet is changing not only from day to day, but from second to second (Crampton, 2010). Virtual globe software and their applications are changing so rapidly that some of the more technical or methodological details discussed in this paper undoubtedly will be outdated by the time it is published. There is also a wider evolution of the state of the art for GIS-based landscape visualisation. For example, the increasingly pervasive use of smart phones and tablet computers signals a new era in digital communication and provides a new arena for landscape visualisation. Current research is investigating the use of augmented reality to communicate information about ecosystem services in the Gaywood Valley and other river catchments (Taigel, Lovett, & Appleton, 2014). However, customising a virtual globe is very cost effective compared to more sophisticated techniques of landscape visualisation (Lovett et al., 2009) and the techniques for best practice discussed here (e.g. Table 1; Fig. 2) can be readily adapted to other locations. Inequalities in Internet access, and lack of technology and knowledge, however, may prove prohibitive for use of this approach outside the developed world. For more information on the persistent digital divide, see Crampton (2010).

Virtual globe customisations, such as the visualisation tools here, have a practical longevity due to automatic update of aerial imagery and ancillary geographical information. Furthermore, if required, the framework illustrated in Fig. 2 permits further modification or extension of individual KML elements. During this research, this compartmentalisation and adaptability was especially relevant during review phases and in facilitating the maintenance of full functionality across major software upgrades (in particular the transition from Google Earth version 5 to version 6). In general, however, changes in technology during the period of development tended to be backwards compatible and resulted in increased functionality (see also Wood et al., 2007). While customisation of KML elements involves writing bespoke code, some level of KML scripting is accessible to most non-experts (see Wernecke, 2009) and semi-automated creation of KML code is possible through proprietary and non-proprietary software (e.g. Ballagh et al., 2011; Polczynski & Polczynski, 2013).

Based on this experience, general recommendations for effective customisation of virtual globes are: (i) collaboration with a range of stakeholders from an early stage; (ii) adherence to guidelines (Table 1) to ensure general validity appropriate to purpose; (iii) organisation of tour elements to permit easy modifications in response to feedback.

7. Agendas, framing, empowerment and further research

7.1 An agenda for promoting community awareness of ecosystem services

The right of the public to participate in environmental decision-making and the inherently political nature of planning are now taken for granted (Cullingworth & Nadin, 2006). In Europe, for instance, the Aarhus Convention, EU INSPIRE and EU Water Framework Directive have given substantial impetus to moving from an 'inform and consult' form of public involvement, typically at the end of the decision-making process, towards higher levels of public interaction (e.g. Benson, Jordon, & Huitema, 2012; Hillman, 2009; Van den Brink et al., 2007). Several integrated catchment management programmes document local values and empower local knowledge and expertise (e.g. Morris & Morris, 2005; Raymond et al., 2009) and the use of spatial technologies in this process has been recognised (e.g. Goodchild, 2007; Macleod et al., 2007). Despite investment in pilot catchment projects and increasing activity by river trusts (e.g. Catchment Change Management Hub, see Editor, in press a) progress towards such integration and engagement has been quite uneven across the UK. These issues have implications for the way ecosystem services are measured and integrated into planning and environmental management.

Despite the growing body of literature on ecosystem services (Fisher et al., 2009), challenges remain to integrate the concept of ecosystem services and associated values in landscape planning, management and decision making (Daily et al., 2009; de Groot et al., 2010). To foster sustainable development improved effectiveness in the transfer of scientific information is needed to bridge interfaces between science and policy, knowledge and action (Cash et al., 2003). Notwithstanding the challenges of embedding an ecosystem approach in policy making, the UK-NEA generated a substantial research impact at a national level, including a major and explicitly acknowledged influence upon the UK Government's agenda for the natural environment. Policy objectives set in the 2011 Natural Environment White Paper support a move towards a landscape-scale approach to conservation and raising local awareness of, and the value placed on, the services provided by the natural environment. Government and its agencies, local authorities, wildlife charities, landowners, and communities have a crucial role to play in effecting these changes.

Going forward, the best use of the ecosystem services framework and enabling conditions will be through a holistic and integrated approach to the natural environment. One example is the move to integrated catchment management which seeks to increase the dialogue between scientists, policy-makers and stakeholders in order to ameliorate pressures and help sustain multiple services for both society and nature (e.g. Falkenmark, Gottschalk, Lundqvist & Wouters, 2004; Macleod et al., 2007). While these are global-scale issues involving a range of actors, ecosystem services are inherently spatially sensitive and their maintenance often requires some engagement with communities at more local levels. Undoubtedly, geographical visualisation is a powerful and established medium for conveying information to the general public, but virtual globes also have potential to support more participatory involvement.

The use of geospatial technologies to participate in civic processes such as mapping and decision making has been referred to as 'public participation GIS' or PPGIS. Modes of public participation GIS differ markedly, however, depending on who defines it and their agenda (Sieber, 2006). Applying a loose definition, evidence of public involvement in this project could be classed as mere tokenism PPGIS (e.g. number of hits on a website) (Sieber, 2006), two-way conversations during tool implementation, and observations of tool usability by children. Broadly, however, the goal was consistent with that of PPGIS, namely to include and empower marginalised populations (see Brown et al., 2012), such as those living in the urban fringe, by involving them in early discussions about their landscape and ecosystem services. The goals of different actors in this collaborative effort may have been competing, contradictory or less than altruistic (Sieber, 2006) and their (our) framing of issues ultimately effected which actors were empowered (Dunn, 2007; White et al., 2010). Specific groups, such as those with potential to influence land use planning and action, could have been targeted as ‘communities of interest’ (Fish, 2011).

Another way of involving the public is to engage them with visualisations during ecosystem service assessment. As positioned by Goodchild, “citizens possess one important advantage over experts: knowledge of, and access to, local ground truth” (2009, p.8). Surveys of public preference and attitudes have been used for mapping social and cultural values for landscapes and ecosystem services (e.g. Alessa et al., 2008; Plieninger, Dijks, Oteros-Rozas & Bieling, 2013; Raymond et al. 2009; Sherrouse et al., 2011). Such research, however, faces challenges from public unfamiliarity with the ecosystem services framework; terminology is typically translated into a less technical, easier to understand format and then reframed for analysis (Plieninger et al., 2013; Raymond et al., 2009).

7.2 Visualising the future

There is scope for using virtual globes for wider topic exploration in the field of ecosystem research. Changes to landscapes are inevitable due to policy, market and natural environment drivers. Land use change has far-reaching consequences for biodiversity, the delivery of ecosystem services and, accordingly, human well-being. The use of scenario based studies to assess future land use and consequences for ecosystem services is correspondingly growing (e.g. Haines-Young, Paterson & Potschin, 2011; UK NEA, 2011). Economic valuation is one way to standardise how these impacts are captured and has become essential for decision-makers faced with weighing up the consequences of different policy options or future scenarios (e.g. Bateman et al., 2013). Three- and four-dimensional visualisations, and in particular virtual reality simulations, move away from the abstracted environment of typical economic experiments and have shown to provide options to participants that are easier to evaluate (e.g. Bateman, Day, Jones & Jude 2009; Fiore, Harrison, Huges & Rustrom, 2009). Dynamic visualisation methods, in particular, may hold advantages for representing changing ecosystem services over time (de Groot et al., 2010). To be truly useful, however, visualised scenarios should be developed in real-time while participants are exploring options (Barndt, 2002). Integrating visualisations with underlying models has been identified as one of the next steps for landscape and urban planning research (Schroth et al. 2009; Lange, 2011).

Combining the representation of space, environmental processes and time has the potential to provide new insights to aid the understanding of changes in the location-specific environmental functions of ecosystem services (Aspinall, 2009). It is becoming increasingly possible to link sources of spatial data (e.g. environmental models), technology for handling such data (e.g. a GIS) and visualisation media (e.g. virtual globes). At a basic level, further research could focus on improved coupling of scientific model output and visualisations e.g. to allow visual analytics (see Andrienko et al., 2010) or verification of model outcomes (Schroth et al., 2009). The degree of integration will likely vary by project (Brimicombe, 2010), for example, from simple file exchange to fully-integrated spatially distributed environmental models (see Fedra, 1996). While possessing some basic functionality for spatial analysis, such as distance measurement, a virtual globe is not a GIS. Text within a template KML for Google Earth, however, could be updated with real-time outputs from a GIS or environmental model. Scripting could be autonomously updated with a readable coding language, such as Python. Coupling environmental models with GIS and other spatial data technologies may also have benefits for the translation of science to practice and policy (Aspinall, 2009).

8. Conclusions

The importance of an ecosystem approach is becoming more widely recognised in landscape and urban planning. There is considerable interest from new or existing landscape scale partnerships for guidance on how the approach can be integrated into existing activities and future work (Porter et al., 2014).

An ecosystem approach challenges society to be interested and accountable for the environment we live in. Society has a responsibility to respect inextricable ties between human well-being and ecosystem health. An individual has a responsibility to recognise their local landscape and their role within it. A landscape visualisation has a capability to raise awareness of the present and future ecosystem values and in doing so the aspiring visualiser has a responsibility to provide appropriate and effective communication tools.

Effectiveness of virtual globes for promoting awareness of ecosystem services is inevitably linked to an adequate understanding of end users. A framework for tool development has been outlined in this paper, centred on collaboration with a range of actors. Visualisation tools were designed with a view to fitness for purpose, while observing criteria for ensuring general validity, and content was structured so that it was easy to modify and update. Once created, such existing templates can be readily adapted as a cost-effective solution to increasing awareness of relevant issues in other locations.

Customising a virtual globe such as Google Earth in the manner described establishes a baseline from which a more aware (and active) role of the public can be fostered. Virtual globe visualisations can equip society to rise to a call for greater public involvement in realising the value of nature’s assets and societal reliance on these, and ultimately recognising the necessity for a sustainable form of development.

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LIST OF TABLES

Table 1. Designing landscape visualisation tools using guidelines for good practice (criteria from Sheppard & Cizek, 2009)

Criteria (and description)	Functions implemented in the visualisation tools
Access to visual information (provide easy access in a range of forms)	- Provide freely downloadable tools - Plan engagement activities and a range of publicity
Interest (engage the audience)	- Use dynamic display such as virtual tours - Use three-dimensional models - Allow user interrogation and interactivity
Accuracy and representativeness (simulate actual or expected appearance of the landscape at appropriate level of detail)	- Traverse different views and scales - Establish sites typifying the landscape (through consultation with local experts) - Combine realistic landscape elements with more abstract components for a synergistic mix of detail and context - Relate to ground photographs
Visual clarity (communicate content clearly)	- Partition information into three themes to reduce overlap and clutter - Use changes in hue to represent categorical differences in data - Avoid colours similar to aerial imagery - Use transparency if appropriate - Permit overlap of data and information where this may be useful for the user
Legitimacy (provide defensible information)	- Avoid controversial or emotive information, or subjective interpretation - Provide data sources and metadata where appropriate
Framing and presentation (include neutral contextual information)	- Provide foreground information - Avoid technical terminology or explain in simple language

Table 2. Google Earth elements used to explain the pathway of benefits from ecosystems to people. (Visualisation tool theme: IGV = Introduction to Gaywood Valley; GPC = Geology and Past Climates; GI = Green Infrastructure).

Final ecosystem services (*and derived goods*)	Locally-relevant pathways to individuals and communities	Google Earth elements used
PROVISIONING		
Water supply *(drinking water)*	Norfolk's chalk aquifer provides groundwater storage and River Gaywood arises from freshwater springs at Grimston.	- Multi-geometry placemarks (line and polygon) delineate the river and the draining area of the catchment (IGV). - A placemark balloon provides an explicit description of pathway (IGV). - A tour links placemarks as a low-level flight from river source to mouth (IGV).
Crops and livestock *(food)*	Well-drained and fertile soils support Norfolk agriculture (dominantly arable crops).	- A screen overlay provides an explicit description of pathway (GPC). - A ground overlay shows the distribution of fertile quaternary deposits (GPC). - A tour (with placemark balloons and screen overlays) highlights the formation and role of alluvium in the catchment (GPC).
Abiotic diversity *(construction materials, fossils)*	Local Norfolk sands, iron-rich sandstone (carstone) and white chalk are used as building materials. St Mary Magdalen's Church, Sandringham, is mostly made from local carstone.	- Placemarks locate quarries, describe extraction of bedrock and provide photographs (IGV; GPC). - A placemark with photograph of building made from local stone (GPC). - A tour links a ground overlay of outcrops, a screen overlay of a vertical section and an animated 3D cross-section and placemarks (GPC).
CULTURAL		
Wild species diversity and environmental settings *(aesthetic value and recreation)*	Glaciations shaped the chalk into the rolling landscape typical of Norfolk. Heathland, woodland and wetland now combine to provide important habitats. At several sites (e.g. Roydon Common), these habitats are protected, but remain accessible.	- Animated 3D models and screen overlays describe the role of glaciers (GPC). - Placemarks locate access points for designated areas, describe the habitat and provide photographs (IGV). - Placemarks locate the start of health walks and river access points (GI).
REGULATING		
Hazard regulation *(flood control)*	Surface water infiltrates through grassland and well-drained soils. River flow (discharge) can be managed through meander restoration and controlled flooding.	- A placemark describes channel changes using historical aerial imagery (IGV). - Sea-level changes are depicted by ground overlays of elevation and accompanying screen overlays (GPC).

LIST OF FIGURES

Fig. 1

A traditional-style two-dimensional map of the Gaywood Valley catchment using an Ordnance Survey 1:250 000 raster product. © Crown Copyright/database right 2012. An Ordnance Survey/EDINA supplied service.

Fig. 2

The file structure used in the Google Earth visualisation tool (after Wernecke, 2009).

Fig. 3

Typical components of the tools. (Photo of ruins, inset, taken by Richard Humphrey as part of the 'Geograph' project © Copyright Richard Humphrey and licensed for reuse under Creative Commons Licence).

Fig. 4

The Geology and Past Climates Tool links outcrops, stratigraphy and a 3D cross-section through a series of screen overlays which serve as a narrative during a tour (sequence a through c). Ground overlay of geological outcrops and screen overlay for a stratigraphic section based upon DiGMapGB-625 data and 1:50 000 Provisional Series data, with the permission of the British Geological Survey.

Fig. 5

Summary of engagement activities: left-hand panel shows publicity activities for the tools; right-hand panel shows corresponding monthly visitors to the website (*from website launch on Oct 24 to Oct 31).

Fig. 1

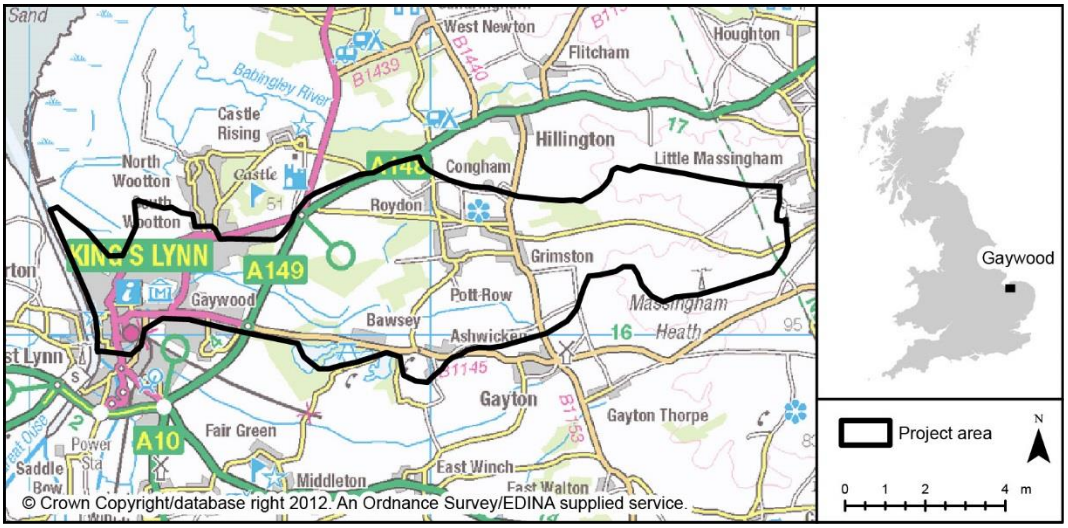

KING'S LYNN
Gaywood
Castle Rising
North Wootton
South Wootton
Roydon
Congham
Hillington
Little Massingham
Grimston
Pott Row
Bawsey
Ashwicken
Massingham Heath
Gayton
Gayton Thorpe
Fair Green
Middleton
East Winch
East Walton
West Newton
Flitcham
Houghton
A148
A149
A10
B1145
B1153
B1439
B1440
Babingley River
Project area
N
0 1 2 4 m

Fig. 2

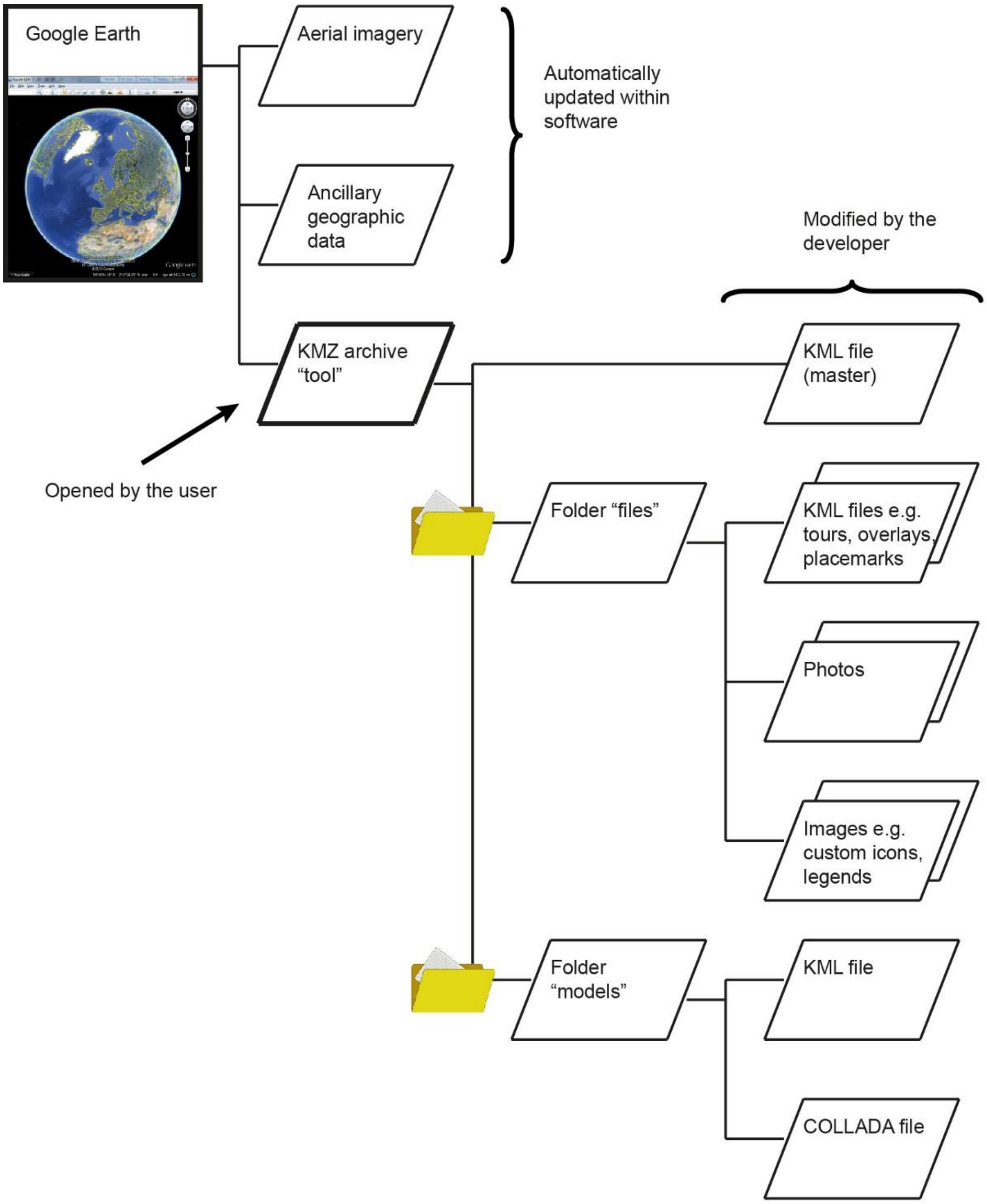
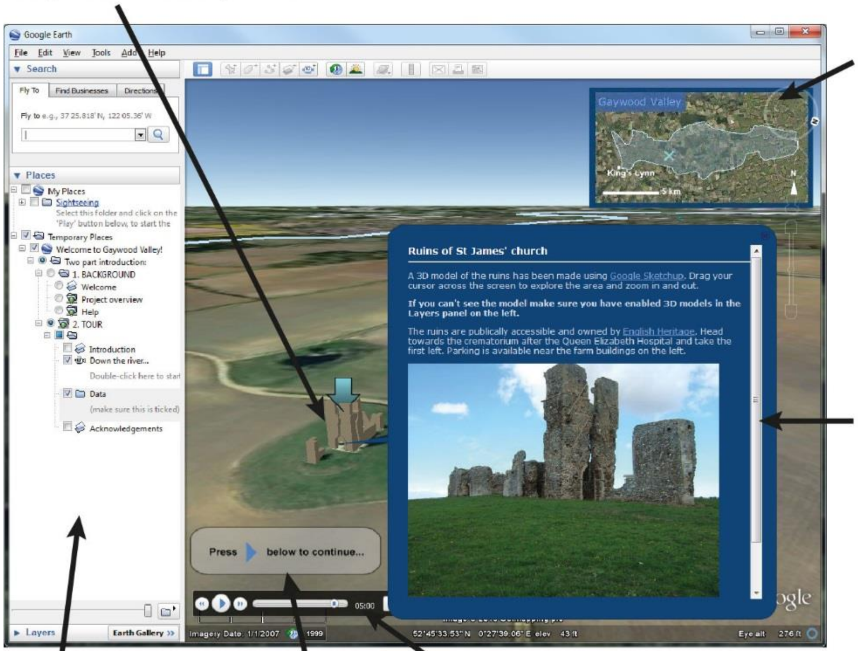

Google Earth
Aerial imagery
Ancillary geographic data
Automatically updated within software
Modified by the developer
KMZ archive "tool"
KML file (master)
Opened by the user
Folder "files"
KML files e.g. tours, overlays, placemarks
Photos
Images e.g. custom icons, legends
Folder "models"
KML file
COLLADA file

Fig. 3

3D model provides
recognisable landscape feature



Ruins of St James' church

A 3D model of the ruins has been made using Google Sketchup. Drag your cursor across the screen to explore the area and zoom in and out.

If you can't see the model make sure you have enabled 3D models in the Layers panel on the left.

The ruins are publically accessible and owned by English Heritage. Head towards the crematorium after the Queen Elizabeth Hospital and take the first left. Parking is available near the farm buildings on the left.

Miniature map
(screen overlay)
to orientate user

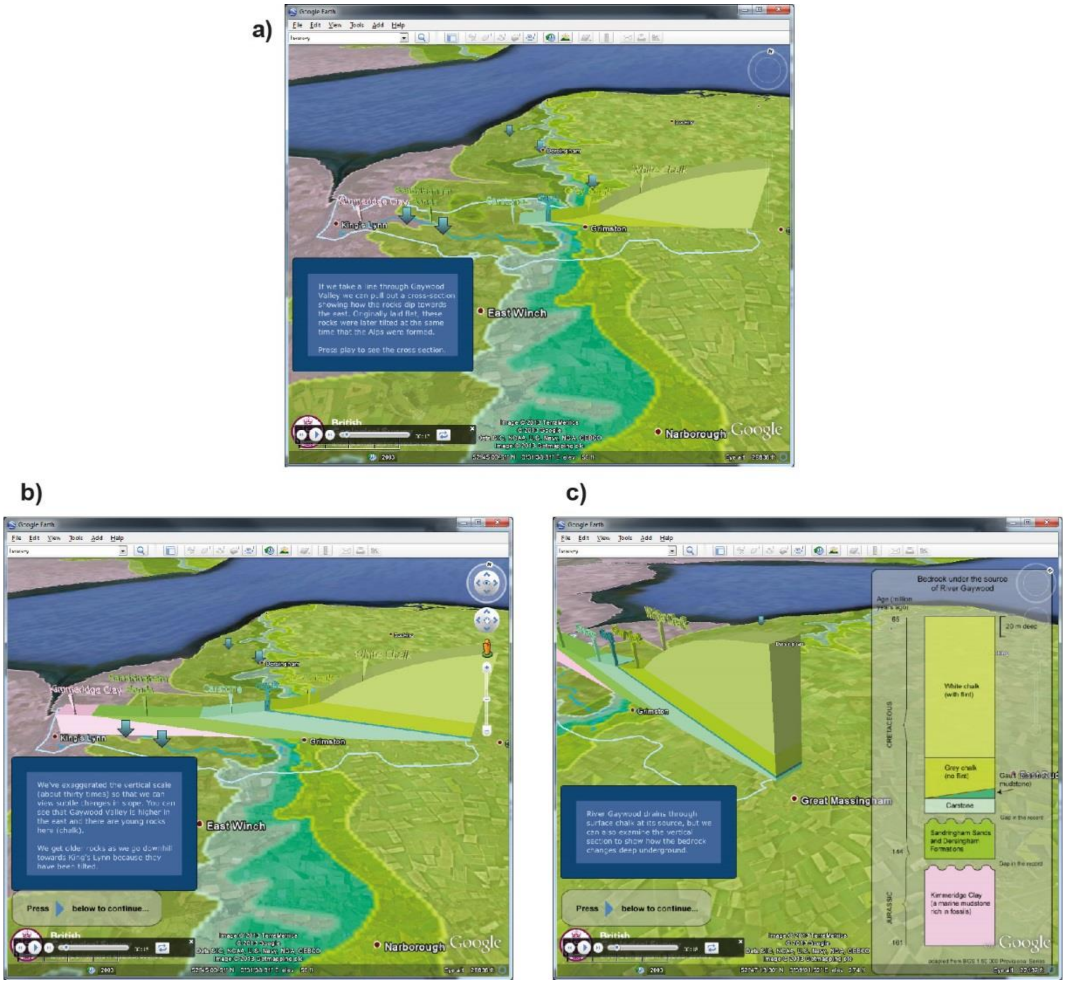
Placemark
contains text,
hyperlinks and
photos

Places panel allows
user cotrol of elements
but developer-coded
radioFolders prevents
visual clutter

Screen overlay
provides instructions

Tour bar allows user control

Fig. 4



a)

If we take a line through Gaywood Valley we can pull out a cross-section showing how the rocks dip towards the east. Originally laid flat, these rocks were later tilted at the same time that the Alps were formed.

Press play to see the cross section.

b)

We've exaggerated the vertical scale (about thirty times) so that we can view subtle changes in slope. You can see that Gaywood Valley is higher in the east and there are young rocks here (chalk).

We get older rocks as we go downhill towards King's Lynn because they have been tilted.

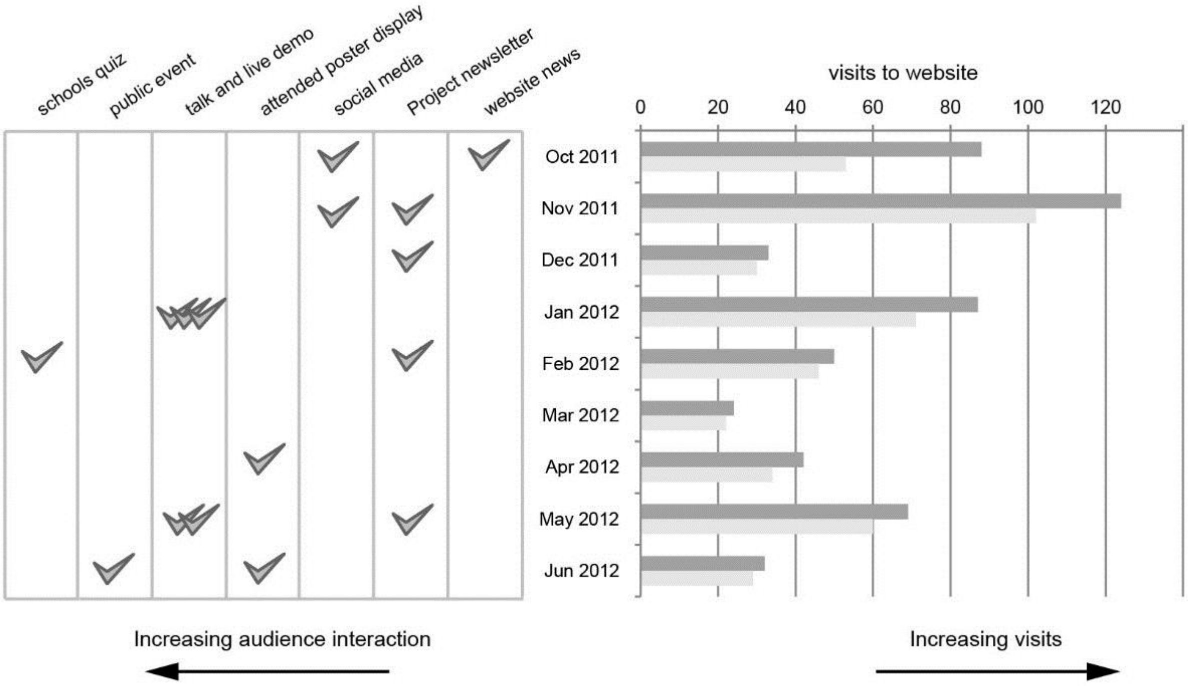
Press ▶ below to continue...

c)

River Gaywood drains through surface chalk at its source, but we can also examine the vertical section to show how the bedrock changes deep underground.

Press ▶ below to continue...

Fig. 5


schools quiz
public event
talk and live demo
attended poster display
social media
Project newsletter
website news
visits to website
0
20
40
60
80
100
120
Oct 2011
Nov 2011
Dec 2011
Jan 2012
Feb 2012
Mar 2012
Apr 2012
May 2012
Jun 2012
Increasing audience interaction
Increasing visits