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Communicating risks to infrastructure due to soil erosion: A bottom-up approach

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Abstract

Soil erosion is a major problem worldwide, affecting natural, agricultural, and urban environments through its impact on flood risk, water quality, loss of topsoil, eutrophication of water bodies, sedimentation of waterways, and damage to infrastructure such as roads, buildings, and utility supply networks. Thus, there is a need to identify risks to infrastructure associated with erosion and interventions needed to reduce those risks. Further, inclusive ways of communicating about mitigation strategies with stakeholders such as farmers, land managers, and policymakers are essential if interventions are to be implemented. Applying the Decision-Support Matrix approach, which combines hydrologic and geomorphic principles with participatory action research, a tool for Communicating and Visualising Erosion-associated Risks to Infrastructure (CAVERTI) was developed in collaboration with a variety of stakeholders including farmers, private landowners, asset owners, and environmental organisations, focusing on a case-study area in northern England. The CAVERTI tool synthesises process understanding gained from modelling with knowledge and experience of stakeholders to address the sediment transport problem. Tool development was collaborative, ensuring that the problems and solutions presented are easily recognised by practitioners and decision-makers. The tool helps to assess, manage, and improve understanding of risk from a multistakeholder perspective and presents mitigation options. We argue that visualisation and communication tools codeveloped by researchers and stakeholders are the best means of influencing decision-makers to invest in mitigation. The CAVERTI tool is designed to encourage farmers, land, and asset owners to act to reduce erosion, providing multiple benefits from protecting local infrastructure to reducing pollution of waterways.

KEYWORDS

communication, decision support matrix, participatory action research, risks to infrastructure, soil erosion

1 | INTRODUCTION

Soil erosion is a major problem in both the developed and developing world, affecting agriculture and the natural environment through the loss of land and nutrient-rich soil for crop production; and contributing to deterioration of water quality through sedimentation and eutrophication of water bodies (Ananda & Herath, 2003; Lal, 2001; Shi & Shao, 2000). The cost of soil degradation in England and Wales alone has been estimated at around £1.2 billion per year, 98% of which is attributed to the loss of organic soil content, erosion, and compaction (Graves et al., 2015). Sediment-related impacts are also linked with increased flood risk and damage to infrastructure such as buildings, roads, and utility networks. There is thus a need for interventions to reduce erosion at catchment scale. Such interventions require understanding better which parts of the landscape are most susceptible to erosion and which measures are most effective in reducing it. There are opportunities here to capitalise on experiential knowledge of practitioners such as farmers combined with understanding gained through research. However, understanding is not enough: there are real difficulties in translating knowledge gained from scientific research into practical measures to reduce risk (Eshuis & Stuiver, 2005). Effective ways of communicating about mitigation strategies with stakeholders such as farmers, land managers, and policymakers are also essential if interventions are to be implemented.

Existing approaches to assessing erosion risk include qualitative methods based on risk assessment of sediment production and transfer and quantitative approaches based on models such as Phosphorus and Sediment Yield Characterisation in Catchments (PSYCHIC) (Davison, Withers, Lord, Betson, & Strömqvist, 2008), Water Erosion Prediction Project (WEPP) (Laflen, Lane, & Foster, 1991), Limburg Soil Erosion Model (LISEM) (De Roo, Wesseling, Cremers, & Offermans, 1994), European Soil Erosion Model (EUROSEM) (Morgan et al., 1998), Griffith University Erosion System Template (GUEST) (Rose, Parlange, Sander, Campbell, & Barry, 1983; Rose, Williams, Sander, & Barry, 1983), and Model for Assessing Hillslope-Landscape Erosion Runoff and Nutrients (MAHLERAN) (Wainwright et al., 2008). However, these models are complex to set up, require expert input, and provide little or no advice on how to reduce erosion. Thus, although they increase our research understanding, they are of limited use in promoting mitigation.

In recent years, there has been a move towards more democratic approaches to research in which co-production of knowledge is employed as a means to successful intervention (Wakeford, 2010). This is in part driven by the recognition that uptake of decision support systems in the past by stakeholders such as farmers has been poor and that it can be greatly improved by involving stakeholders in tool production (McCown, 2002). Oliver et al. (2012) argue for the need to integrate farmer participation throughout the research process from project inception through to qualitative validation and legitimation, and Whitman, Pain, & Milledge (2015, p2) make the case for “a more radical participatory approach” to environmental research. Such approaches have collaboration at their heart. They go beyond “shallow” participation driven by the desire to build trust in research and encourage participants to shape research questions and consequent outcomes (Whitman et al., 2015).

The Decision-Support Matrix (DSM) approach reflects these considerations (Hewett, Quinn, & Wilkinson, 2016). It developed in response to the drive to solve environmental issues and has been applied successfully to problems such as nutrient export from farming (Hewett et al., 2009; Hewett, Doyle, & Quinn, 2010; Hewett, Quinn, Whitehead, Heathwaite, & Flynn, 2004) and flooding in farmed landscapes (Posthumus, Hewett, Morris, & Quinn, 2008; Wilkinson, Quinn, & Hewett, 2013). The approach rests on a set of hydrological principles underpinned by participatory action research (PAR; Brydon-Miller, Greenwood, & McIntyre, 2003; Chambers, 1994; Hall, 2005). Participative approaches have been shown to increase the adoption and success of environmental projects (Arnalds, 1999). The approach is supported by measurement, mapping, mathematical modelling, and the production of risk-indicator maps generated within an iterative decision support framework, an essential element of which is the generation of simple communication and visualisation tools codeveloped by researchers and stakeholders (Hewett et al., 2010). Shared knowledge generation and codesign of tools are of central importance as it engenders a sense of common ownership of, and trust in, the tools produced (Wakeford, 2010; Whitman et al., 2015). DSMs allow specific fields and practices to be assessed and provide advice on interventions to improve outcomes. The mitigation measures proposed, while directed at specific problems, offer multiple benefits. For example, erosion-reduction measures can reduce flood risk and export of nutrients and pesticides to waterways. Making tool development a collaborative venture ensures that the problems and solutions presented are easily recognised by practitioners and decision-makers, which helps to ensure that the tools get used. DSMs have been taken up widely in the UK by bodies such as the Environment Agency (EA) and Defra and have been employed successfully within wider decision-support frameworks alongside modelling at multiple scales (Hewett et al., 2009; Hewett et al., 2010; Hewett et al., 2016; Quinn, Hewett, Muste, & Popescu, 2010).

The aim of the research described in this paper was to develop a stakeholder-friendly decision support tool for Communicating and Visualising Erosion-Associated Risks to Infrastructure (CAVERTI) and interventions to mitigate those risks. The structure of the paper reflects the bottom-up PAR approach taken, with an emphasis on partnerships and knowledge co-produced by all participants. 'The CAVERTI project team' thus refers throughout this paper to Durham University researchers working in partnership with the Wear Rivers Trust (WRT), a charity dedicated to conserving and protecting the River Wear, its tributaries and the surrounding countryside, and a number of local farmers in the North East of England. The project addressed directly the problem of sediment transport in a case-study catchment by developing a new DSM for use by WRT and its stakeholders. A web-based tool was developed that helps to assess, manage, and improve understanding of risk from a multistakeholder perspective and proposes mitigation measures drawing on knowledge from practitioners, policymakers, and researchers from multiple disciplines. The resulting tool is used by WRT in their work with local farmers, landowners, land managers, and business operators.

2 | THE CAVERTI PROJECT

Engagement with numerous stakeholders in the UK including the EA, water companies, environmental consultancies, Durham Wildlife Trust, English Beef and Lamb Executive, Natural England, Home-Grown Cereals Authority, and Rivers Trusts indicated significant interest in soil erosion with specific reference to the protection of infrastructure. This emerged from discussions held during the Dynamics of Runoff and Erosion Modelling project which resulted in advances in the understanding and modelling of particle-based erosion models (Cooper et al., 2012; Long et al., 2014) and gave rise to a project to develop a communication and visualisation tool aimed at reducing risks to infrastructure associated with soil erosion (The CAVERTI project). Figure 1 shows a flow diagram representing the stages of the CAVERTI project.

2.1 | Methodology—The DSM approach

The DSM approach was employed, meaning that partnerships between stakeholders and researchers were central to the project and that tools and knowledge were co-produced within a participatory framework (Hewett et al., 2016). This approach did not constrain the form of the tools produced but provided a solid foundation and well-defined

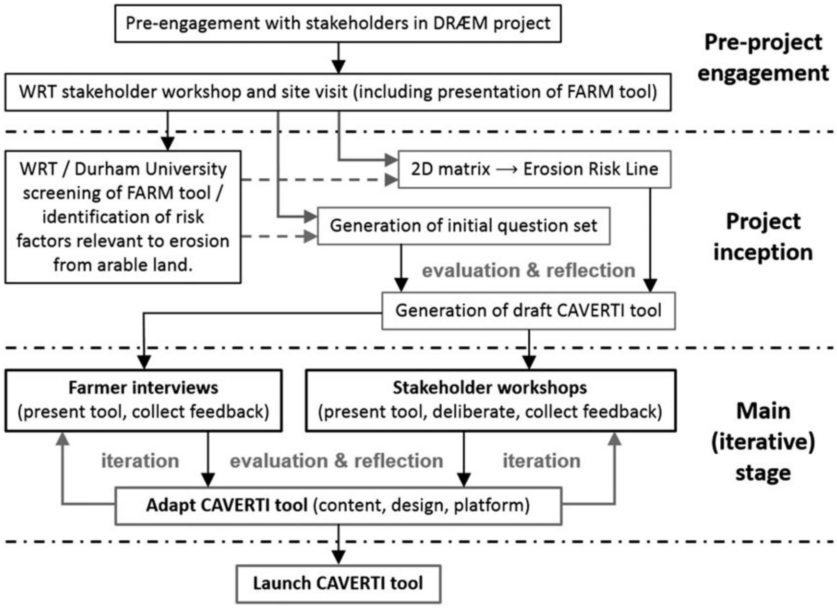

FIGURE 1 Flow diagram showing the stages of the Communicating and Visualising Erosion-associated Risks to Infrastructure (CAVERTI) project. DRÆM = Dynamics of Runoff and Erosion Modelling; FARM = Floods and Agriculture Risk Matrix; WRT = Wear Rivers Trust

methodology for the project. Developed over many years, the DSM approach draws on interdisciplinary methods from the natural and social sciences to synthesise research expertise and the knowledge and experience of practitioners in tools that are accessible to end users (Hewett et al., 2016). The aim is to develop tools that are shaped by and relevant to stakeholders. Previous applications of the DSM approach have resulted in a variety of tools including illustrations of good and bad practice, interactive tools for assessing specific fields and practices, and advice on mitigation measures (Hewett et al., 2004; Hewett et al., 2009; Hewett et al., 2016; Wilkinson et al., 2013). It should be noted that, although such tools can be used in isolation, they are best applied within a decision-making framework involving multiscale modelling of processes, demonstration farms, stakeholder engagement, and tool development in an iterative cycle (Hewett et al., 2010).

Boardman, Bateman, and Seymour (2017) point to the variety and complexity of motivations farmers have for changing their practice. Thus, gaining an understanding of what influences individual farmers has to be embedded in the approach. In the CAVERTI project, a PAR approach was adopted and was used with a view to ensuring that knowledge and tools were cogenerated by stakeholders and researchers (Brydon-Miller et al., 2003; Wakeford, 2010). In contrast to traditional approaches to research, PAR promotes collaboration between researchers, practitioners, and decision-makers, resulting in “rich, high quality research that circumvents the dangers of ‘shallow’ participation and enhances environmental outcomes” (Whitman et al., 2015, p2). Any participatory method can be employed from citizen juries, focus groups, role-playing and public discussions to cognitive maps, multicriteria analysis, questionnaires, participatory mapping, and scenario analyses (Rowe & Frewer, 2000; Luyet et al., 2012). Stakeholder workshops have been favoured as the primary means to conduct the PAR within the DSM approach in the past as they provide opportunities for extensive deliberation between participants and lend themselves well to co-production of knowledge (Hewett et al., 2016). However, project timing and work priorities of project partners and the farming community made it more practical to arrange to visit individual farmers and to limit the number of stakeholder workshops. Consequently, only three workshops were held, and these were supplemented by semistructured interviews carried out on farm premises on a one-to-one basis. This limited the deliberative element of the project (which took place only in the workshops), in turn limiting the co-production of knowledge. However, it did provide the opportunity for individuals to share their knowledge and ideas unconstrained by peer pressure and allowed rich data to be drawn from each participant for thematic analysis, including data on farmers' motivations for reducing erosion. The benefits of this technique are well established in ethnographic research, for example, where farmers' narratives on their experience and understanding of the landscape produce a depth of knowledge and afford a more detailed understanding of participants' interests (Lewis, 2012).

Experience of producing previous DSMs has shown that, although the tools produced are applicable generally to the risk under scrutiny (in this case, soil erosion), the use of specific case-study sites is a powerful tool in engaging stakeholders' interest in the research (Hewett et al., 2004; Hewett et al., 2009; Hewett et al., 2010; Posthumus et al., 2008). Thus, a specific catchment was selected as a case-study area to boost the level of engagement of farmers involved in the project. One-to-one engagement with farmers provided opportunities to collate images of the local landscape which were highly meaningful in the context of the study and became integral to the tool, helping to engender a sense of ownership. However, it should be noted that, because the tools produced were intended to be of general use, case-study sites had to be chosen carefully to ensure that they exhibit problems and practices found elsewhere.

CAVERTI tool development involved an iterative cycle in which demonstration versions were created and evaluated during stakeholder workshops and semistructured interviews with farmers. Participants were advised that the researchers would seek to exchange knowledge with them in order to build on existing tools, producing a tool specifically for CAVERTI; that is, communicating and visualising risk factors and potential mitigation measures, with a focus on erosion-associated risks to infrastructure. This exchange included research-derived knowledge (results of soil erosion modelling, decision support tools, and damage to infrastructure), farmers' knowledge (where erosion takes place, what/where mitigation methods have been employed, why farmers would benefit from reduced erosion, and what infrastructure it impacts), and stakeholders such as asset owners' experience of damage to infrastructure. Factors considered throughout included identification of the potential sources of sediment from arable land; the key risk factors for soil erosion occurring during storm events; the infrastructure placed at risk by erosion and sedimentation; and the interventions that could be made to reduce erosion.

The start point for the iterative cycle was an existing DSM: the Floods and Agriculture Risk Matrix (FARM; Wilkinson et al., 2013). In the FARM, a ranking methodology is combined with a simple mapping of information onto a two-dimensional matrix with axes; *soil management* and *flow connectivity*. The axes are intended to capture the underlying factors controlling runoff: the soil management axis relates to the soil infiltration, storage, and the tillage regime, whereas the flow connectivity axis relates to runoff that has been mobilised and how efficiently it flows into and through the local drainage network. The risk associated with runoff generation is represented by a position plotted on the matrix. A low risk (corresponding to good soil management and low flow connectivity) appears in the bottom left hand corner of the matrix and a high risk (poor soil management and high flow connectivity) in the top right hand corner (Wilkinson et al., 2013). The FARM suite of tools includes an interactive spreadsheet-based tool containing questions associated with each axis. This allows the user to answer the questions according to the current or proposed management of a particular field or farm and generates a plot of the risk level on the 2D matrix. The position plotted on the matrix depends on the answers to all of the questions.

As has been discussed at length in previous work, interactive DSMs employ a simple scoring system to rank the level of risk, whereby an equal weighting is applied to each risk factor (Hewett et al., 2004, 2016). Thus, what is plotted on the matrices is a *relative* risk, that is, the only way in which the results of monitoring and modelling are transposed onto the DSMs is through the understanding of the trajectory of increased or decreased risk (Hewett et al., 2016). This simplification is made in response to the problems associated with getting agreement on what weighting to assign to each risk factor, something on which it can prove impossible to agree (Kim & Lee, 2014).

Initially, WRT and a Durham University researcher screened the interactive FARM tool and identified a set of risk factors relevant to erosion from arable land. Notably, at this early stage, the 2D matrix representation of risk was rejected in favour of a simple Erosion Risk Line on which to plot the risk level, with high risk at one end and low risk at the other (Figure 2). A set of initial questions were generated for use in the semistructured interviews. The interviews involved collecting feedback on, reviewing, and refining (a) the questions; (b) the way in which they were plotted on the matrix; and (c) the form of the interactive tool itself.

During tool development, a stakeholder workshop was held at which a demonstration version implemented on a tablet was presented. The proposed features and function of the tool were evaluated with reference to clarity of information, quick reference capability, and performance, whether in the field using a tablet or at a work station. Changes were made to tool design based on feedback collected at this event.

Although initial thoughts regarding tool design were that the CAVERTI tool would be similar to interactive DSMs produced in previous work, it was important to be receptive to alternatives. The key point to take away from this outcome is to stay open-minded throughout the design process.

2.2 | Stakeholders

A selection of stakeholders across the Wear catchment were invited to participate in the research including WRT (the primary stakeholder); statutory and environmental organisations with interests in the area; and key land and asset owners. They were identified through WRT's established contacts with the farming community; identifying asset owners in the catchment using 'Line Search Before You Dig', an online search service that can be used to find the location of utility assets such as pipelines and cables in the electricity, gas, high pressure fuel/oil, heating, water, and fibre optic networks (LinesearchbeforeUdig, 2016); identifying land ownership in the catchment; and carrying out a desk-based scoping exercise to establish how agricultural land, natural, and built infrastructures could be affected by erosion-associated risks and who would be the relevant contact. Stakeholders showed a strong interest in reducing the risk of erosion associated with heavy rainfall events and in participating in co-producing and sharing knowledge. Initially, all stakeholders were invited to participate in the project through telephone and email conversations plus, in some cases, visits to the case study site. Subsequently, to optimise participation, a variety of engagement methods were used because some stakeholders declined to attend workshops. Table 1 lists the stakeholders identified and involved in the research and indicates how they were engaged.

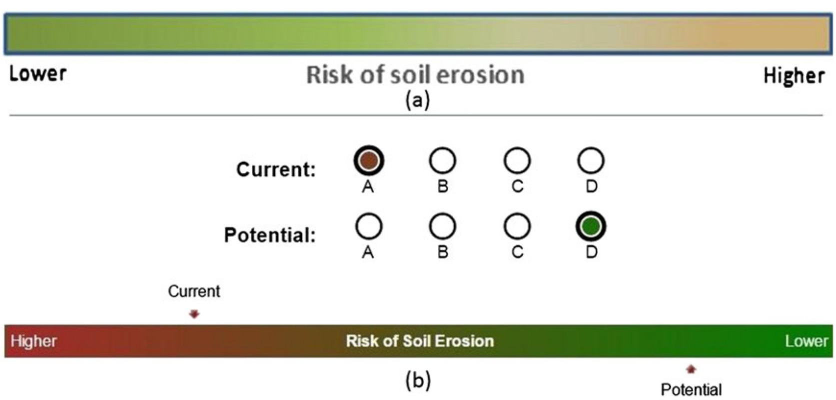

FIGURE 2 (a) Draft Erosion Risk Line used in semistructured interviews (above); (b) final version with check boxes showing current and potential risk levels (below) [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 1 Stakeholders in the Wear catchment

Key land and asset owners		
Stakeholder	**Land / assets owned or managed**	**Engaged via**
Farmers	Farms in study area and arable farms in adjacent subcatchments of the River Wear	I, W, S, P, E
Brancepeth Castle Golf Club	Golf course through which Brancepeth Beck flows	S, C, P, E
National Grid (Northern Gas)	Gas main at Page Bank, Brancepeth Beck	C, P, E
National Grid Electricity Transmission	Pylons in fields in study area	C, P, E
Northumbrian Water Ltd.	Sewage treatment works situated in grounds of Brancepeth Castle Golf Club and owner of public water supply networks	C, P, E
Highways/roads, Durham County Council	Bridges in study area	P, E
Public rights of way, Durham County Council	Public footpaths in study area	P, E
Sabic UK Petrochemicals North East	Buried assets in fields in study area	P, E
Other stakeholders identified and engaged in the research		
Stakeholder	**Description/interest**	**Engaged via**
The Wear Rivers Trust	Charity dedicated to conserving and protecting the River Wear, its tributaries and surrounding countryside/ project partners (primary stakeholder)	W, S, P, E
Durham University Geography Department	Researchers in soil erosion/evidencing impacts	W, S, P, E
Campaign for the Farmed Environment	Farmers and agricultural advisors	W, P, E
Frontier	Agricultural advisors and seed supplier for cover crops	W, P, E
Environment Agency	Statutory agency responsible for fisheries, freshwater biology, flood risk, and environmental regulation	C, P, E
Elvet Striders/Maiden Castle	Leisure activities on land adjacent to River Wear, downstream of Brancepeth Beck	S, E
Country Land and Business Association	Land agents with regional newsletter	P, E
Soil Association	Facts and figures on soil losses in UK	P, E
Woodland Trust	Tree planting initiatives and suppliers	P, E
Butterfly Conservation Trust	Conservation of wildlife habitat (riverbanks) for butterflies/moths	E
Durham Wildlife Trust	Ecological interests (riverbanks)	E

Note. Engagement via I = interview; W = workshops; S = site meetings; C = case study; P = phone; E = email.

2.3 | Participatory action research

The bottom-up, participatory approach taken was intended to ensure that the values, interests, and needs of end-users were embedded in the project output and to create opportunities for stakeholders to build working relations, increasing the likely impact. The PAR approach employed followed that outlined by the Centre for Social Justice and Community Action (2016), involving five key features of PAR: (a) focus on change; (b) context-specificity; (c) collaboration; (d) process; and (e) participant competency.

The *focus on change* related to reducing rapid surface-water runoff and soil erosion from arable landscapes during heavy rainfall. This focus was expected to bring multiple benefits to multiple stakeholders through reducing risk to infrastructure, loss of topsoil, flood risk, and export of nutrients and pesticides. The *specific context* was the requirement to meet the needs of the primary stakeholder (WRT) in working with landowners and land managers and the needs of the agricultural sector (predominantly arable farmers) in the Brancepeth Beck catchment and lowland areas of the River Wear. *Collaboration* between research staff, WRT, and local farmers was intrinsic to the project: DSM development depended on engagement with stakeholders with experience of erosion or sediment impacts, and site visits to farms examining areas where erosion/land loss had been problematic and where mitigation measures had been introduced. The *process* was “an iterative cycle of research, action and reflection” (Kindon, Pain, & Kesby, 2007). First, problems were identified by all participants, partnerships formed, and reflections shared in stakeholder workshops. The formal project involved gaining site-based knowledge of the landscape, rainfall history, and soil type and an understanding of the values, interests, and needs of stakeholders. Reflection on these led to proposals for action and development of a demonstration DSM. The iterative cycle involved demonstrating drafts of the DSM to stakeholders, collecting, analysing, and reflecting on feedback, and adapting the DSM (revising the content and design as discussed in Section 4 below). *Participant competency* was taken to consist of any level of interest or knowledge in erosion and its associated risks to infrastructure. For example, experience of the consequences of erosion; knowledge of the arable landscape, its prior and current land management; local knowledge of where erosion takes place and where land management changes have increased or reduced erosion rates; and specialist knowledge about storm events and associated runoff, erosion rates, or risks to infrastructure.

From project inception, participants were asked to share their experiences of erosion-associated risks to infrastructure for which they might share responsibility and to express views on how communicating and visualising this information could benefit them and others. It was clear that significant costs are involved in responding to soil-erosion issues, from cleaning up soil washed on to roads to replacing or protecting structures placed at risk by erosion of land, particularly in the vicinity of rivers. Thus, participants agreed that collating case studies from stakeholders including images and outline costs would be valuable.

2.3.1 | Case studies

The use of specific case study sites (usually individual fields or farms) can be a useful aid to visualising interventions and communicating with stakeholders (Heathwaite, Quinn, & Hewett, 2005; Hewett et al., 2009; Wilkinson et al., 2013). The catchment of Brancepeth Beck, a tributary of the River Wear in County Durham, was selected as a case-study area (Figure 3) owing to its landscape and susceptibility to erosion, and the identification of arable land at which fieldwork could be carried out. The catchment was considered a valuable case study, because it provided examples of erosion relevant to areas with similar issues which are common elsewhere in the UK and internationally (Ananda & Herath, 2003; Fullen, 2003). In addition, a case-study farm in the area was identified at which the farmer was highly receptive to involvement in the project having already introduced interventions to manage runoff risks which the CAVERTI project team considered exemplars of good practice (Figure 4). The farmer is well respected in the area and was keen to share ideas on good practice with the team and other stakeholders, which made a welcome contribution to the stakeholder workshops.

2.3.2 | Stakeholder workshops

WRT identified the problem that silt moving from land into Brancepeth Beck presents a direct threat to a range of infrastructure both natural

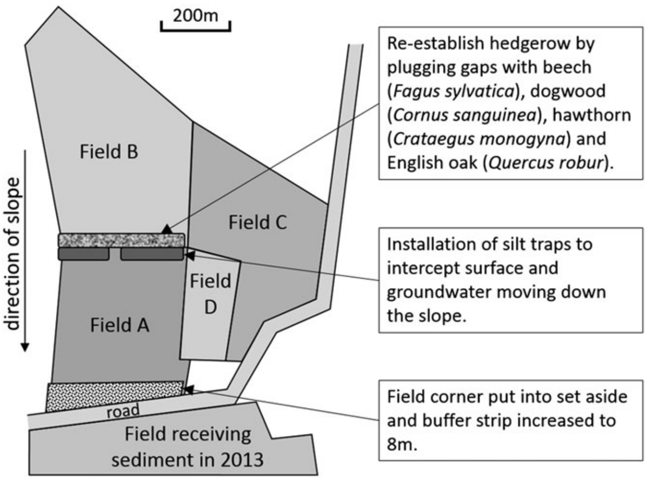

FIGURE 4 Schematic of field survey areas at case-study farm

and built. In the light of this, WRT organised a workshop in advance of the project which involved stakeholders in discussions about erosion risks and impacts in the area and helped to establish an informed network of contacts for research on the CAVERTI project. Workshop participants were introduced to the FARM tool as an example DSM, and a tour of the case-study farm was undertaken.

A second workshop was held at project inception which introduced participants to the project and explored the issues through deliberation. Participants highlighted numerous costly cumulative effects of runoff and sedimentation occurring following storms including flooding of public roads preventing residential access; blockage of bridge culverts leading to flooding and collapse; erosion of river embankments resulting in loss of farm and amenity land; and

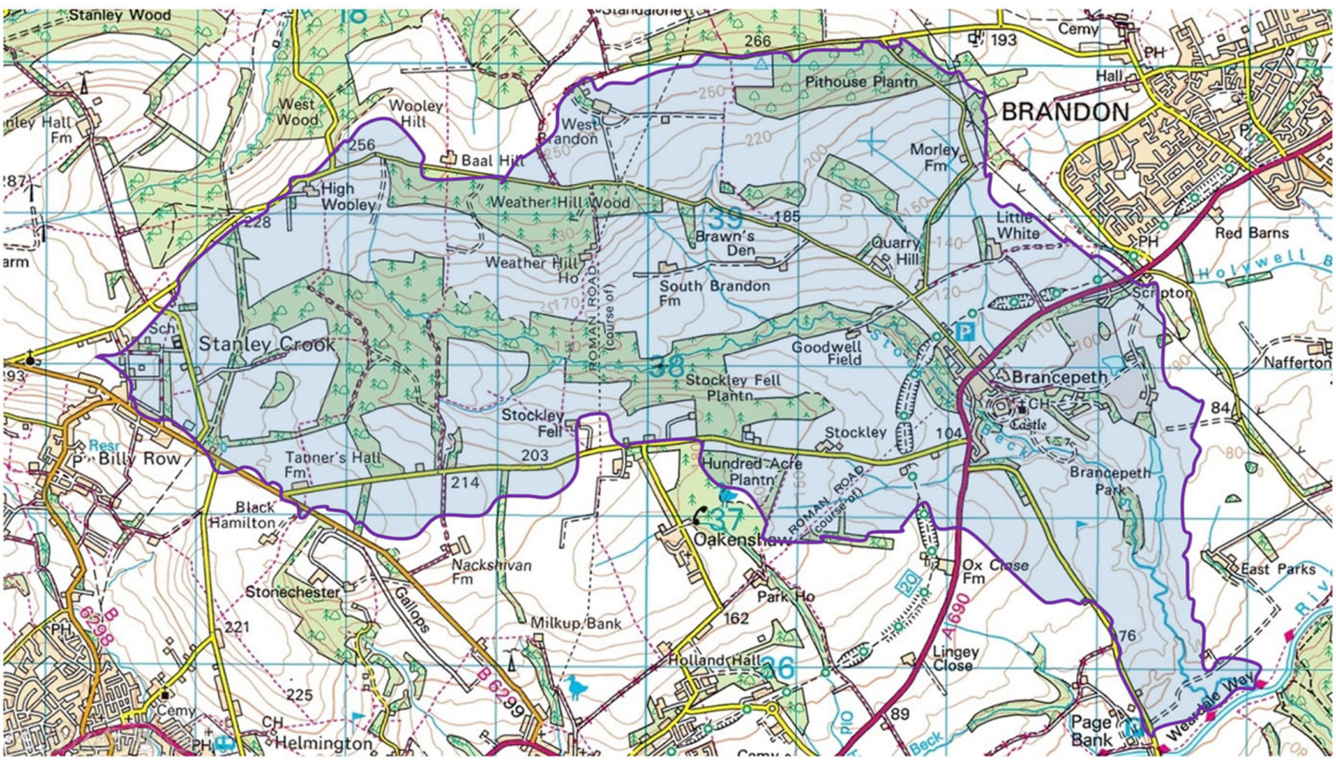

FIGURE 3 Location of the Brancepeth Beck catchment in County Durham showing the predominantly rural nature of the study site. © *Crown Copyright and Database Right 21/6/17. Ordnance Survey (Digimap Licence)* [Colour figure can be viewed at wileyonlinelibrary.com]

the gradual exposure of a gas mains pipe supplying major suburbs of Durham (Case Study 2 in Figure 5). There was considerable interest in raising awareness of the environmental and socio-economic pressures arising from these impacts and in encouraging the introduction of mitigation measures on farms to reduce the risk of silt movement during heavy rainfall. In addition to risks to infrastructure, the introduction and deposition of sediment into watercourses pose a risk to invertebrates (e.g., riverfly species) owing to their sensitivity to sediment, and to fish populations, owing to the blanketing of spawning gravels.

Participants also recognised that rapid runoff to and sedimentation of tributaries contribute to wider erosion-associated risks to infrastructure downstream of their catchments. For example, in the River Wear catchment, WRT identified impacts on power generation facilities, sewerage, drainage, and communications networks, the undermining of pylons, and disruption to business and recreational activities owing to erosion of riverside paths.

Two further workshops were held during tool development at which demonstration versions of the CAVERTI tool were presented. Deliberation at these events informed the next stage of evaluation and reflection, leading to changes to tool content and design.

2.3.3 | Semistructured interviews

The interviews contained the following elements: explanation of the purpose of the research; obtaining formal agreement to participate; discussion of what sort of tool would be useful and why; discussion of where soil erosion is an issue on participant's land; discussion of the impact of specific storm events on participant's farming activity; introduction of draft tool and eliciting comments; and discussion of specific risk factors and questions related to each risk factor. However, it should be noted that the semistructured nature of the interviews allowed for flexibility in the order and manner in which they were presented and encouraged dialogue, providing richer data than that allowed by a structured format.

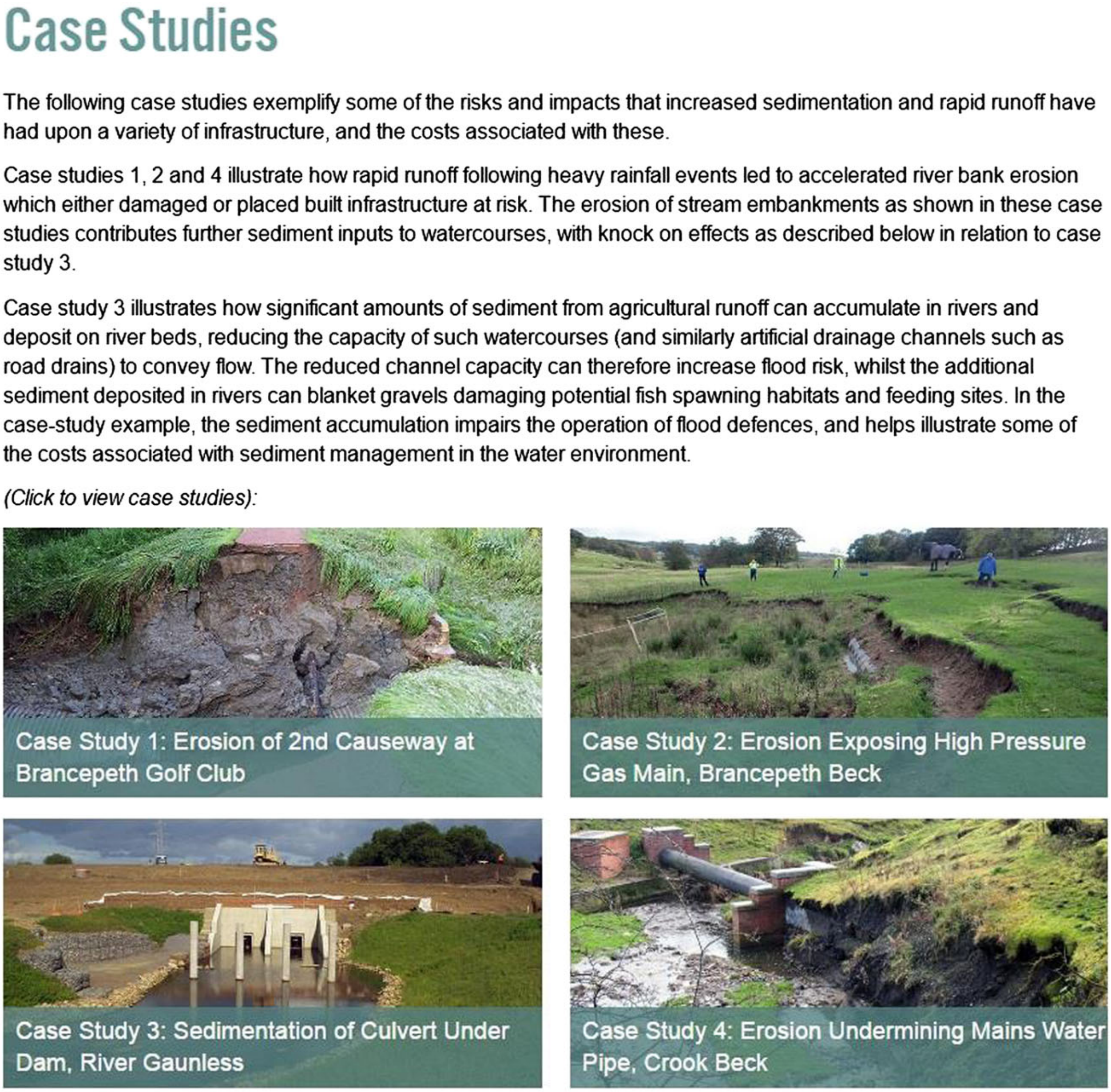

FIGURE 5 Case-studies page illustrating risks to infrastructure [Colour figure can be viewed at wileyonlinelibrary.com]

Discussion of what sort of tool would be useful opened with the use of FARM, first by establishing whether participants were familiar with the interactive FARM tool, either through involvement in the workshop held before project inception or otherwise. They were asked whether they had used, or had knowledge of, similar tools. Their opinion was elicited on what scope there was for developing a similar DSM, and their likely interest in using a DSM, specifically for the CAVERTI aim. Comments were sought on what aspects of the FARM were more or less helpful, for example, question layout, diagrams, weighting of risk factors, and time required to go through the questions. These comments helped the team gain an understanding of what farmers would find most useful in the CAVERTI tool.

A key element of each interview was to elicit specific suggestions on the form and content of the tool. Printed visual materials such as photographs, a draft introductory page (Figure 6), and the Erosion Risk Line (Figure 2) were used to facilitate this process. The participant was encouraged to share knowledge of impacts to infrastructure, consider categories for tool content, and suggest and evaluate ways to visualise and communicate them. This involved inviting comment on the components, the tool might include, and suggestions for useful supporting materials. It was explained that there would be interactive questions to help visualise links between a range of arable landscape features and land use/practices and the effect they might have on erosion risk during rainfall (see Step '1' in Figure 6), and suggestions for questions were elicited. The interviewer also discussed whether case studies illustrating erosion-associated risks to infrastructure should be included in the tool. An example was shown of loss of embankments revealing a water-main pipe, resulting in the need for costly remedial works (Case Study 4 in Figure 5).

3 | DESCRIPTION OF THE CAVERTI TOOL

The tool produced consists of a set of 10 web pages (tabs). The first eight cover the following categories of risk factor: 'Slope,' 'Soil Type,' 'Soil Structure,' 'Crop Cover,' 'Tramlines,' 'Drainage,' 'Gateways,' and 'Boundaries'. These categories were selected during the design process as priority factors to assess soil-erosion risk. Each tab contains a question with four potential answers from which to choose, labelled A to D, with accompanying images. These are ranked highest to lowest in terms of their contribution to soil-erosion risk. As an example, Figure 7b shows the Gateways risk factor in the CAVERTI tool.

There are four check boxes for 'Current' and 'Potential' scenarios on each risk-factor tab (the circles labelled A to D in Figure 2b). Initially,

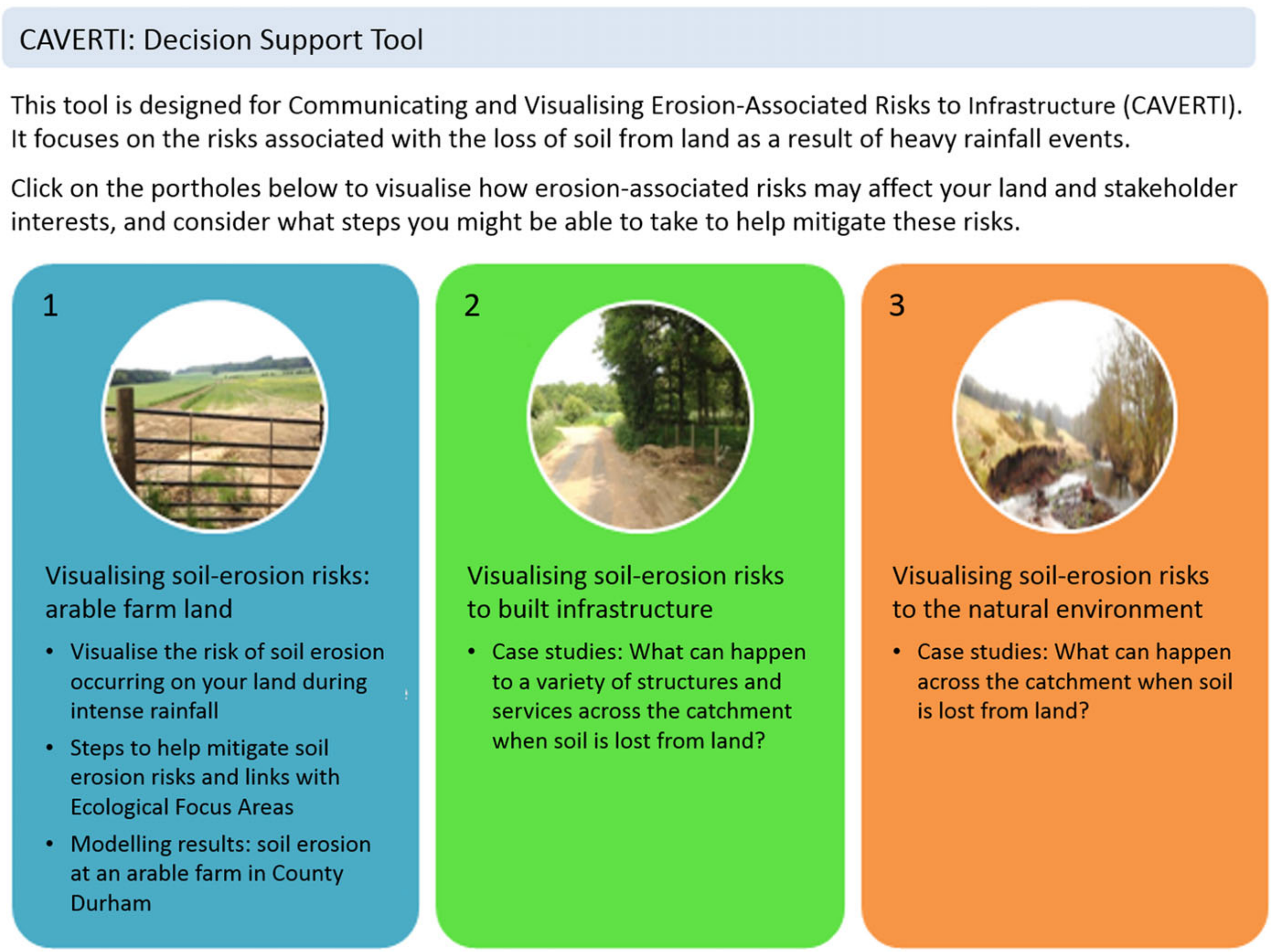

FIGURE 6 Image of draft introductory page of the CAVERTI tool shown in semistructured interviews [Colour figure can be viewed at wileyonlinelibrary.com]

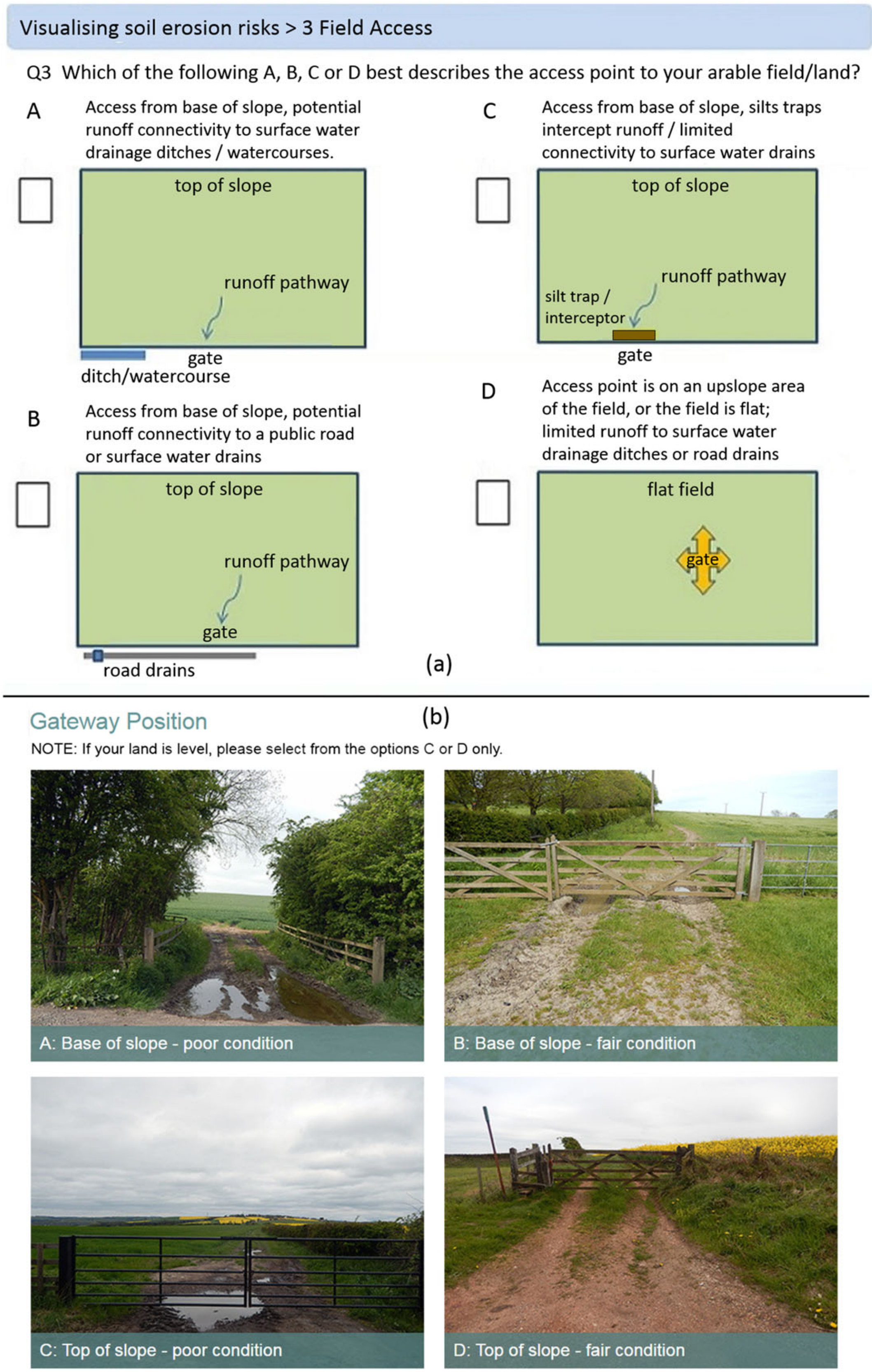

FIGURE 7 (a) Draft field access question used in semistructured interviews (above); (b) gateway position question (below) that replaced it in final version of the Communicating and Visualising Erosion-associated Risks to Infrastructure tool [Colour figure can be viewed at wileyonlinelibrary.com]

the user selects the option they feel currently represents the land unit to be assessed. Once a selection has been made, a marker indicating the current level of risk appears above the Erosion Risk Line. If there is potential to move to a lower risk for the land unit of interest, then the user selects a lower risk option as the potential scenario, and a marker indicating the potential risk level appears below the Erosion

Risk Line. The resulting risk plot for the category thus shows a relative difference in risk of soil erosion as shown in Figure 2b.

Two additional tabs provide a summary of the responses made (the *Risk Summary* tab) and advice on mitigation options that could be employed (the *Interventions* tab). The *Risk Summary* tab displays the responses made in table form to indicate the risk of soil erosion for each factor (e.g., Figure 8). This helps the user identify which risk factors could potentially be lower and for which interventions could be considered. An overall risk level based on all of the responses is also given. The *Interventions* tab contains advice and links to options to help mitigate erosion risk under the categories explored in the tool. These are drawn from research and from stakeholder engagement (workshops and interviews), incorporating knowledge of all participants. Table 2 shows an example of the advice provided for three risk factors.

It is worth noting that, although a 'finished' tool was generated during the research reported, we consider that the tool should continue to evolve on the basis of ongoing feedback from end users.

A critical component to the development, quality, and interactive functionality of the tool was the involvement of Durham University computer technicians who became collaborators in the PAR process and the output of the project.

4 | RESULTS AND DISCUSSION

The design and content of the tool were developed through an iterative process of trial, reflection, evaluation, and adaptation. This allowed participants' input to shape the tool, embedding meaningful presentation, terminology, and considerations of farming practice in its output, including the practicalities of interventions. This process resulted in a tool that is significantly different from DSMs produced in previous work, which is a good indication that the approach taken was successful. The key differences are discussed below.

Existing DSMs were conceptualized first with three dimensions and later with two dimensions; examples of good and bad practices were presented in the form of diagrams of example fields, and interactive spreadsheet-based tools were produced in which the user is presented with a series of questions intended to apply to a particular land unit. On answering the questions either in accordance with current practice or potential future practice, these interactive DSMs present the user with a risk level plotted on a 2D matrix (Hewett et al., 2016).

Initial thoughts regarding the CAVERTI tool design were that the risk level would be plotted on a 2D matrix as with DSMs produced in

Risk Factor	Current	Potential
Slope	High	High
Soil Type	Medium	Medium
Soil Structure	Very high	Low
Crop Cover	High	Medium
Tramlines	Very high	Low
Gateways	Very high	Low
Drainage	Very high	Low
Boundaries	High	Medium
Overall Risk	**High**	**Medium**

FIGURE 8 Risk summary table for a particular answer set [Colour figure can be viewed at wileyonlinelibrary.com]

TABLE 2 Interventions advice in the Communicating and Visualising Erosion-associated Risks to Infrastructure tool for the first three risk factors

Risk factor	Interventions to help mitigate risk of soil erosion and erosion-associated risks to infrastructure
Slope	As you can not alter slope, manage other risks factors where possible, especially where your baseline risk of erosion is high owing to a relatively steep or long slope.Break up slopes with across slope buffer features that will help slow runoff and intercept soil whilst offering benefits for wildlife: for example, beetle banks, in-field grass strips (minimum 3 m wide). • http://www.cfeonline.org.uk/campaign-themes/arable/(also see boundaries options below).
Soil type	As you can not alter soil type, manage other risk factors where possible, especially where your baseline risk of erosion is high owing to a heavy clay or very light sandy and loamy soils. Check the optimum cropping regime for your soil type: • http://www.landis.org.uk/soilscapes/
Soil structure	Avoid soil compaction by using dual or flotation tyres on farm vehicles to help spread the load over a large area. To encourage topsoil stability apply organic manures; avoid over-deep working of the land and over-deep cultivation. Use minimal cultivation techniques for susceptible soils, for example, by ploughing and rolling in one operation with the crop sown at right-angles to the direction of rolling. A variety of manuals are available to help assess your soil structure and optimise soil organic matter which can improve drainage and crop yields. For guidance and links to other information see: • https://www.gov.uk/soil-management-standards-for-farmers • http://www.soilassociation.org/whatisorganic/organicfarming/organicmatter • https://www.gov.uk/managing-soil-types

previous work. However, unlike coresearchers in previous projects, CAVERTI participants felt that the 2D matrix was unnecessarily complex, obscuring understanding of how runoff and connectivity are related. It was agreed that this might put off users seeking a quick reference tool, in particular one intended for use in the field as per the aims of WRT. Thus, it was agreed that the risk level in the CAVERTI tool would be plotted on a risk *line*. This resulted in the draft Erosion Risk Line shown in Figure 2a, which is colour-coded running from green on the left (low risk) through amber to red on the right (high risk). Further, participants felt that the trajectory of *improvement*, that is, moving from higher to lower risk, should go from left to right, and thus, the risk line in the final tool runs in the opposite direction to the draft version, as does the colour coding (see Figure 2b).

Participants felt that a web-based tool would be preferable to the spreadsheet format used in existing DSMs. This was based on three main factors: ease of access; the feeling that this was more practical and stakeholder-friendly than the spreadsheet format; and the finished tool could be used online by anyone anywhere. They also expressed a preference for photographs over diagrams such as those used in DSMs produced in previous work. Decisions over which photographs to use were made in conversation with participants, a process which required multiple iterations before final choices were made.

Figure 7a shows the first draft of a question about 'Field Access' along with four options from which to select and illustrations alongside each option to aid clarity. This question was replaced in the final tool by the 'Gateway Position' question shown in Figure 7b, and it is noteworthy how different it is from the draft question. The contrast between the two illustrates how, drawing on a conceptual design, feedback from participants helped evolve the detail, functionality, and presentation of the tool content. A similar iterative process was applied to each risk factor, although they are not presented here for purposes of brevity. The final questions for the other seven risk factors can be viewed in the online tool.

Participants indicated that 10 min is the approximate period they would like to spend familiarizing themselves with the tool and gaining some initial results. This influenced the number of risk factors and format of the questions and required considerably simplifying the tool. They were also keen on the tool providing a summary of responses, an overall erosion risk plot, and signposting the user to interventions. This resulted in the Risk Summary and Interventions tabs described above.

Changes were made to tool design based on feedback collected at the stakeholder workshop at which the tablet-based demonstration version was presented. For example, one participant from the arable farming community commented that the option selection boxes were too small on the tablet display for tapping by most farmers' fingertips, and hence, these boxes were enlarged for the final version (shown in Figure 2) to make the tool more user-friendly.

Participants felt that case studies to illustrate impacts of soil erosion and rapid runoff, particularly within the study area, would be useful and that gaining an appreciation of the potential costs of erosion-related impacts on infrastructure would be likely to influence users to consider investing in interventions. Thus, four case studies were compiled from stakeholder responses and incorporated in the CAVERTI website (see Figure 5). Each case study indicates the cost of remedial and/or maintenance works involved in the example given, thereby illustrating the relatively low cost of mitigation measures, and the typically high socio-economic costs of the cumulative impacts of widespread rapid runoff and sedimentation on infrastructure across a catchment. Their inclusion increases the versatility of the tool in communicating land and asset management costs, sustainability, and opportunities for catchment-based initiatives.

The CAVERTI tool is used by WRT as a quick reference tool to facilitate discussions with volunteer groups and farmers engaged in projects to help reduce diffuse pollution and to illustrate erosion risk factors, potential impacts, and interventions that could be undertaken. The tool is used in WRT project feasibility studies as a means to engage rural landowners in mitigating erosion-associated risks to river invertebrates and spawning gravels and has been used to identify and illustrate project synergies such as the potential to protect built infrastructure from flooding by reducing and managing sources of sediment.

The case studies page of the website (Figure 5) is referenced by WRT staff in nonagriculture specific discussions, for example, with riparian owners in industrial areas, to help illustrate sedimentation and erosion-associated risks to infrastructure and to influence alternative approaches to hard engineering, frequent maintenance, and sediment management which may otherwise impact upon the river habitat and natural river processes. The case studies are thus a highly valued element of the tool for WRT. There are indications that the CAVERTI tool is also being used remotely. The website has been accessed frequently resulting in 204 unique page views between January and July 2017. However, it is not possible, nor is it appropriate ethically, to identify who is accessing the tool.

The CAVERTI project has resulted in interventions being installed. For example, as a result of engagement in the project, one farmer worked with WRT and volunteers from Durham University Conservation Society to plant a hedge between adjoining fields to break up a moderately steep, long slope, greatly reducing the runoff and erosion risk. However, the CAVERTI tool was only part of the story, and it is not possible to attribute the intervention directly to the tool itself. This example highlights the difficulty associated with quantifying the impact of the CAVERTI tool. First, it is designed primarily as an engagement tool and thus sits within direct engagement with farmers as one of many tools, including, for example, detailed modelling of individual sites, workshops, discussions, and sharing of good practice. Second, farmers who do access the tool remotely may or may not communicate their use of the tool. Thus, even if they subsequently implement interventions, it may not be clear that the CAVERTI tool has played a part.

However, there is a great deal of interest in the type of measures proposed by the CAVERTI team in the Wear catchment. Notably, the EA are investing £2.1 million into a project which will target an area of ≈100 km^2 in the Wear catchment to assess the impact of interventions on erosion, flood risk, and water quality. This project will include instrumentation, engagement, design, build, and evaluation of interventions, providing invaluable data regarding the efficiency and effectiveness of a variety of mitigation measures. However, as discussed above, although we are certain that CAVERTI played a part in exciting this interest and attracting this investment, it would not be reasonable to attribute it directly to the CAVERTI project or tool.

Participants indicated that they would have liked additional functionality to allow CAVERTI tool results to be saved to file and/or sent via email for future reference. Owing to time limitations, this functionality was not provided and remains a potential avenue for further development of the tool. However, in light of participant interest, a print function was added to the *Risk Summary* tab, which enables users to print the erosion risk summary table produced for a given set of answers.

The geographical focus of the research is a limitation of the tool produced, resulting directly from the local focus of the project. However, we would argue that the content of the main tabs is applicable to many intense agricultural landscapes both in the UK and internationally. One obvious extension of the tool we would like to explore is the inclusion of a wider set of international case studies including implementation costs to further broaden the appeal and influence of the CAVERTI tool.

5 | CONCLUSIONS

Risks to infrastructure due to soil erosion are a major problem worldwide, and there is a real need for interventions to reduce those risks. We argue that visualisation and communication tools codeveloped by researchers and stakeholders are the best means of ensuring that mitigation measures are undertaken across the landscape to reduce erosion. A simple web-based tool developed in collaboration with a variety of stakeholders using a bottom-up PAR approach has been created as a means of encouraging farmers and land owners to act to reduce erosion and provide multiple benefits, from protecting local infrastructure to reducing pollution of waterways.

The CAVERTI project took place in the context of the UK and a particular catchment. However, the CAVERTI tool itself can be adapted easily to include a wider set of risk factors and to incorporate examples relevant to conditions elsewhere. We argue that the problems highlighted and mitigation measures proposed are relevant to a wide set of circumstances in the UK and internationally. Further, we argue that the collaborative approach taken in developing the CAVERTI tool is a useful model that can be applied anywhere to a wide range of environmental issues. The approach encourages common understanding of risks associated with particular land management decisions and can help to drive creative problem-solving leading to action.

The CAVERTI tool is freely accessible and is available at https://www.dur.ac.uk/geography/research/caverti/. The link was circulated to contacts collated from the PAR process including the North East Rural Sector Group, receiving positive comments from a number of stakeholders and from other research institutions such as the Centre for Agri-ecology, Water and Resilience, and University of Coventry; advocation by the EA's National and Northumbria River Basin District Catchment Coordinator group; and afforded publication on the River Restoration Centre's River Wiki board (http://www.therrc.co.uk/news/caverti-new-erosion-risk-management-tool).

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REFERENCES

Ananda, J., & Herath, G. (2003). Soil erosion in developing countries: A socio-economic appraisal. *Journal of Environmental Management*, *68*(4), 343–353. https://doi.org/10.1016/S0301-4797(03)00082-3

Arnalds, A. (1999). Incentives for soil conservation in Iceland. In D. W. Sanders, P. C. Huzar, S. Sombatbanit, & T. Enters (Eds.), *Incentives for soil conservation* (pp. 135–150). Oxford: Oxford & IBH Publishers.

Boardman, J., Bateman, S., & Seymour, S. (2017). Understanding the influence of farmer motivations on changes to soil erosion risk on sites of former serious erosion in the South Downs National Park, UK. *Land Use Policy*, *60*, 298–312. https://doi.org/10.1016/j.landusepol.2016.10.043

Brydon-Miller, M., Greenwood, D., & McIntyre, A. (2003). Why action research? *Action Research*, *1*(9), 1–28. https://doi.org/10.1177/14767503030011002

Centre for Social Justice and Community Action, Durham University. 2016. Participatory action research & organizational change: Defining PAR, https://participation.wordpress.com/whatpar/defining-par/ (accessed 19/1/2016)

Chambers, R. (1994). The origins and practice of participatory rural appraisal. *World Development*, *22*(7), 953–969. https://doi.org/10.1016/0305-750X(94)90141-4

Cooper, J. R., Wainwright, J., Parsons, A. J., Onda, Y., Fukuwara, T., Obana, E., … Hargrave, G. H. (2012). A new approach for simulating the redistribution of soil particles by water erosion: A marker-in-cell model. *Journal of Geophysical Research - Earth Surface*, *117*, F04027. https://doi.org/10.1029/2012JF002499

Davison, P. S., Withers, P. J. A., Lord, E. I., Betson, M. J., & Strömqvist, J. (2008). PSYCHIC – A process-based model of phosphorus and sediment mobilisation and delivery within agricultural catchments. Part 1: Model description and parameterisation. *Journal of Hydrology*, *350*, 290–302. https://doi.org/10.1016/j.jhydrol.2007.10.036

De Roo, A. P. J., Wesseling, C. G. N., Cremers, H. D. T., & Offermans, R. J. E. (1994). LISEM: A new physical-based hydrological and soil erosion model in a GIS-environment, theory and implementation. *IAHS Publication*, *224*, 439–448.

Eshuis, J., & Stuiver, M. (2005). Learning in context through conflict and alignment: Farmers and scientist in search of sustainable agriculture. *Agriculture and Human Values*, *22*(2), 137–148. https://doi.org/10.1007/s10460-004-8274-0

Fullen, M. A. (2003). Soil erosion and conservation in northern Europe. *Progress in Physical Geography*, *27*(3), 331–358. https://doi.org/10.1191/0309133303pp385ra

Graves, A. R., Morris, J., Deeks, L. K., Rickson, R. J., Kibblewhite, M. G., Harris, J. A., … Truckle, I. (2015). The total costs of soil degradation in England and Wales. *Ecological Economics*, *119*, 399–413. https://doi.org/10.1016/j.ecolecon.2015.07.026

Hall, B. (2005). In from the cold? Reflections on participatory research from 1970–2005. *Convergence*, *38*(1), 5–24.

Heathwaite, A. L., Quinn, P., & Hewett, C. J. M. (2005). Modelling and managing critical source areas of diffuse pollution from agricultural land by simulating hillslope flow connectivity. *Journal of Hydrology*, *304*, 446–461. https://doi.org/10.1016/j.jhydrol.2004.07.043

Hewett, C. J. M., Doyle, A., & Quinn, P. F. (2010). Towards a hydroinformatics framework to aid decision making. *Journal of Hydroinformatics*, *12*(2), 119–138. https://doi.org/10.2166/hydro.2009.022

Hewett, C. J. M., Quinn, P. F., Heathwaite, A. L., Whitehead, P. G., Lerner, D. N., & Doyle, A. (2009). A multi-scale framework for strategic management of diffuse pollution. *Environmental Modelling & Software*, *24*(1), 74–85. https://doi.org/10.1016/j.envsoft.2008.05.006

Hewett, C. J. M., Quinn, P. F., Whitehead, P., Heathwaite, A. L., & Flynn, N. (2004). Towards a nutrient export risk matrix approach to managing agricultural pollution at source. *Hydrology and Earth System Sciences*, *8*(4), 834–845. https://doi.org/10.5194/hess-8-834-2004

Hewett, C. J. M., Quinn, P. F., & Wilkinson, M. E. (2016). The decision support matrix (DSM) approach to reducing environmental risk in farmed landscapes. *Agricultural Water Management*, *172*, 74–82. https://doi.org/10.1016/j.agwat.2016.03.008

Kim, H. Y., & Lee, H. K. (2014). Enhanced validity and reliability of spatial decision support systems (SDSS) for sustainable transportation decision-making. *Applied Geography*, *51*, 65–71. https://doi.org/10.1016/j.apgeog.2014.03.009

Kindon, S., Pain, R., & Kesby, M. (2007). *Participatory action research approaches and methods: Connecting people, participation and place*. London: Routledge.

Laflen, J. M., Lane, L. J., & Foster, G. R. (1991). WEPP—A next generation of erosion prediction technology. *Journal of Soil and Water Conservation*, *46*(1), 34–38.

Lal, R. (2001). Soil degradation by erosion. *Land Degradation and Development*, *12*, 519–539. https://doi.org/10.1002/ldr.472

Lewis, S. (2012). Thalloo my Vea: Narrating the landscapes of life in the Isle of Man. In A. Arnason, N. Ellison, J. Vergunst, & A. Whitehouse (Eds.), *A landscapes beyond land: Routes, aesthetics, narratives (EASA Series)* (pp. 98–115).

Long, E. J., Hargrave, G. K., Cooper, J. R., Kitchener, B. G. B., Parsons, A. J., Hewett, C. J. M., & Wainwright, J. (2014). Experimental investigation of a liquid droplet onto a granular bed using 3D, time-resolved, particle tracking. *Physical Review E*, *89*, 032201. https://doi.org/10.1103/PhysRevE.89.032201

LinesearchbeforeUdig. 2016. Line Search Before You Dig. http://www.linesearchbeforeudig.co.uk/ (accessed 19/1/2016)

Luyet, V., Schlaepfer, R., Parlange, M., & Buttler, A. (2012). A framework to implement Stakeholder participation in environmental projects. *Journal of Environmental Management*, *111*, 213–219. https://doi.org/10.1016/j.jenvman.2012.06.026

McCown, R. L. (2002). Changing systems for supporting farmers' decisions: Problems, paradigms, and prospects. *Agricultural Systems*, *74*(1), 179–220.

Morgan, R. P. C., Quinton, J. N., Smith, R. E., Govers, G., Poesen, J. W. A., Auerswald, K., … Styczen, M. E. (1998). The European soil erosion model (EUROSEM): A dynamic approach for predicting sediment transport from fields and small catchments. *Earth Surface Processes and Landforms*, *23*, 527–544. https://doi.org/10.1002/(SICI)1096-9837(199806)23:6<527::AID-ESP868>3.0.CO;2-5

Oliver, D. M., Fish, R. D., Winter, M., Hodgson, C. J., Heathwaite, A. L., & Chadwick, D. R. (2012). Valuing local knowledge as a source of expert data: Farmer engagement and the design of decision support systems. *Environmental Modelling and Software*, *36*, 76–85. https://doi.org/10.1016/j.envsoft.2011.09.013

Posthumus, H., Hewett, C. J. M., Morris, J., & Quinn, P. F. (2008). Agricultural land use and flood risk management: Engaging with stakeholders in North Yorkshire. *Agricultural Water Management*, *95*(7), 787–798. https://doi.org/10.1016/j.agwat.2008.02.001

Quinn, P. F., Hewett, C. J. M., Muste, M., & Popescu, I. (2010). Towards new types of water-centric collaboration. *Proceedings of the Institution of Civil Engineers - Water Management*, *163*(1), 39–51. https://doi.org/10.1680/wama.2010.163.1.39

Rose, C. W., Parlange, J. Y., Sander, G. C., Campbell, S. Y., & Barry, D. A. (1983). Kinematic flow approximation to runoff on a plane: An approximate analytic solution. *Journal of Hydrology*, *62*, 363–369. https://doi.org/10.1016/0022-1694(83)90113-0

Rose, C. W., Williams, J. R., Sander, G. C., & Barry, D. A. (1983). A mathematical model of soil erosion and deposition processes: I. Theory for a plane land element. *Soil Science Society of America Journal*, *47*, 991–995. https://doi.org/10.2136/sssaj1983.03615995004700050030x

Rowe, G., & Frewer, L. J. (2000). Public participation methods: A framework for evaluation. *Science, Technology, & Human Values*, *25*(1), 3–29.

Shi, H., & Shao, M. (2000). Soil and water loss from the Loess Plateau in China. *Journal of Arid Environments*, *45*(1), 9–20. https://doi.org/10.1006/jare.1999.0618

Wainwright, J., Parsons, A. J., Muller, E. N., Brazier, R. E., Powell, D. M., & Fenti, B. (2008). A transport-distance approach to scaling erosion rates: 1. Background and model development. *Earth Surface Processes and Landforms*, *33*(5), 813–826. https://doi.org/10.1002/esp.1624

Wakeford, T. (2010). From transmission to co-inquiry: Future trends in science communication. *Japanese Journal of Science Communication*, *7*, 87–93.

Whitman, G. P., Pain, R., & Milledge, D. G. (2015). Going with the flow? Using participatory action research in physical geography. *Progress in Physical Geography*, *39*(5), 1–18. https://doi.org/10.1177/0309133315589707

Wilkinson, M. E., Quinn, P. F., & Hewett, C. J. M. (2013). The Floods and Agriculture Risk Matrix (FARM): A decision support tool for effectively communicating flood risk from farmed landscape. *International Journal of River Basin Management*, *11*(3), 237–252. https://doi.org/10.1080/15715124.2013.794145

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