TRANSLATING THE COMPLEXITIES OF FLOOD RISK SCIENCE USING KEEPER – A KNOWLEDGE EXCHANGE EXPLORATORY TOOL FOR PROFESSIONALS IN EMERGENCY RESPONSE

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ABSTRACT

Within Flood Risk Management (FRM) decision making, there is a growing interest in participatory approaches to engage and integrate stakeholder expertise. Decision support tools are becoming common features in the FRM 'toolkit', yet there is a limited application of participatory methodologies in the construction of such tools. This paper reports on completed FRMRC research (Flood Risk Management Research Consortium, UK *www.floodrisk.org.uk/*) and the construction of a GIS-based flood risk assessment tool, KEEPER - a Knowledge Exchange Exploratory tool for Professionals in Emergency Response. An iterative methodology was used to engage emergency professionals throughout the research process, allowing a mixing of scientific and professional expertise in the co-production of KEEPER. KEEPER was both instrumental in facilitating participation and knowledge exchange, and informing recommendations for future tools in practice. This paper argues that participation is both essential for supporting pragmatic flood research and as a means of enhancing communication across traditionally divided communities.

KEY WORDS

Flood risk - Social vulnerability - GIS - Knowledge exchange - Stakeholder participation - Mapping

INTRODUCTION

There is a need for pragmatic flood research to translate the complexities of flood science into *useful* and *useable* tools for practitioner end-users and mediate knowledge gaps between scientific and practitioner communities. Research has highlighted the ineffectiveness of traditional education-based communication, and with this, there has been a shift in communication theory towards participatory models for stakeholder engagement and knowledge exchange (Callon, 1999). Technological advances in visualisation and GIS offer an opportunity to facilitate dialogue at the scientific-practitioner interface, bridging the gap between traditionally divided communities and breaking down communication barriers. Therefore, such tools can be conceived as more than just an end product, but as a means of engaging the desired end-user to become an active participant within the research process (Morss et al., 2005).

This paper explores this further in the context of constructing a GIS-based tool for UK Flood Incident Management (FIM), KEEPER - a Knowledge Exchange Exploratory tool for Professionals in Emergency Response, namely Category One Responders (Civil Contingencies Act, 2004). KEEPER is an interactive mapping tool that enables end-users to adapt the calculation and presentation of risk information. This tool was principally designed as a participatory method for facilitating scientific-practitioner knowledge exchange, but also raises a number of practical recommendations for future tool development. Although this research is focused in the UK, the findings presented may also be relevant to non-UK emergency services and other agencies with a professional responsibility to flooding. More broadly, the methodology has implications for improving practitioner engagement with complex flood science, facilitating understanding, ownership and co-knowledge production. These goals are desirable given current policy shifts in the UK, namely the Flood and Water Management Act 2010, which extends the responsibility of FRM onto a broader base of practitioners, with potentially less formal training in flood science.

FLOOD RISK COMMUNICATION IN THEORY

Recent research describes a shift in communication theory, advocating a move away from traditional *monologic* models for communication based on transference and consultation, towards *dialogic* models and knowledge exchange (Tufte and Mefalopulos, 2009). As illustrated in Figure 1, the top-down diffusion of scientific knowledge has increasingly been replaced with participatory approaches to actively engage stakeholders, inform co-knowledge production and enhance ownership and empowerment (Vogel et al., 2007). The participatory model arguably presents a more democratic approach, appreciating different types of knowledge (i.e. multiple experts) and the contexts in which knowledge is embedded.

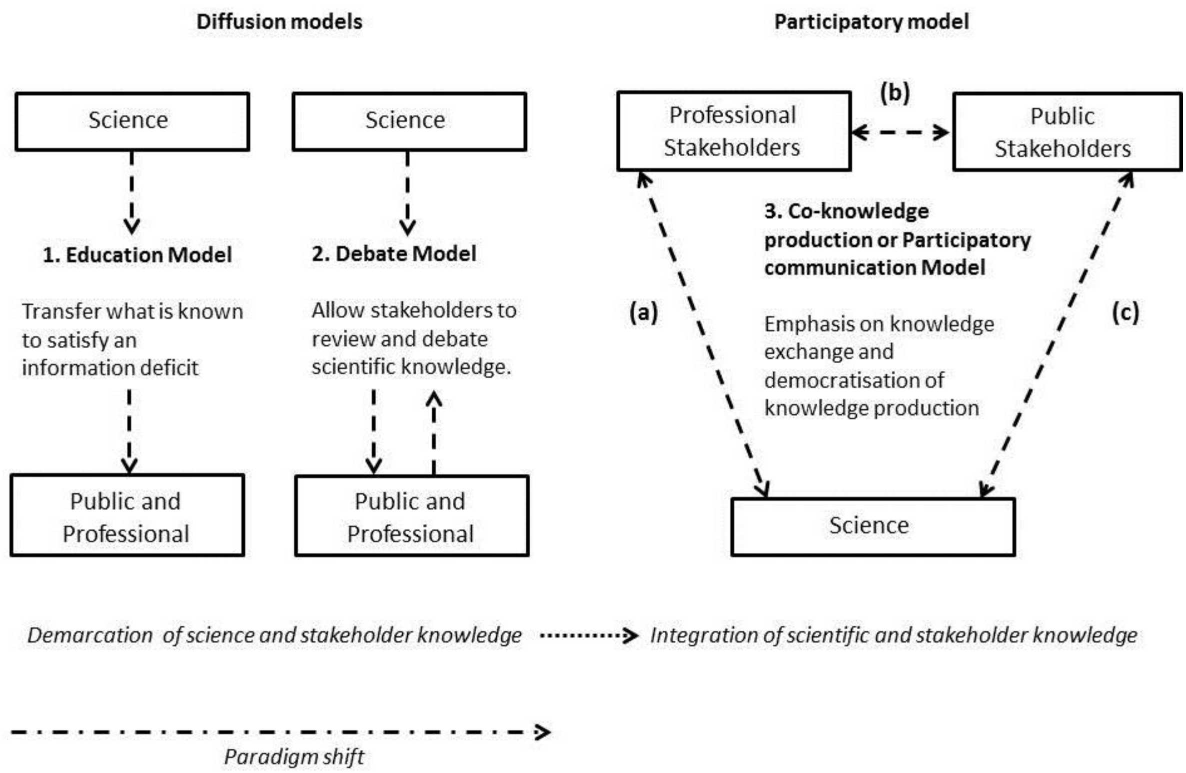

Figure 1: Paradigm shifts in stakeholder communication (built upon review by Callon, 1999). Although an *inclusive* participatory model accounts for all potential stakeholders, (a), (b) and (c) indicate different factions where participatory communication may also occur.

Successful communication requires a sensitised space, whereby communicators appreciate the context in which meaning is constructed, interpreted, assimilated and ultimately applied (Faulkner et al., 2013; McCarthy et al., 2007). At the *science-practitioner* interface specifically (pathway (a), Figure 1), a diversity of knowledge and professional domains collide and can be thought off as a complex web of multiple and multi-layered interactions between a range of actors that requires navigation (Morss et al., 2005).

FACILITATING COMMUNICATION WITH INFORMATION TECHNOLOGY

There has been a growing interest in utilising information and communication technology, Geographic Information Systems (GIS) and Decision Support Systems (DSS) to facilitate knowledge exchange and stakeholder participation. Research has explored communication issues at public (e.g. White et al., 2010) and professional interfaces (e.g. McCarthy et al., 2007), outlining the distinct and varied expertise, requirements and expectations which alter both between and within these groups, and shape the stakeholder's response to the tool at hand. In terms of professional stakeholders (the main focus of this paper), web-based interfaces for instance, have facilitated interaction with potentially unwelcomed information on scientific uncertainty (Leedal et al., 2010). Balica and Wright (2009) also utilise a web management interface to support the calculation of vulnerability (according to the Flood Vulnerability Index), whilst simultaneously cultivating a knowledge network. In the current FIM "toolkit" in the UK, web-based portals centralise incoming, up-to-date information and facilitate multi-agency working through shared knowledge; such as the Met Office's Hazard Manager (http://www.metoffice.gov.uk/publicsector/hazardmanager) or the National Resilience Extranet (http://www.cabinetoffice.gov.uk/content/national-resilience-extranet). Emergency management has also benefitted from GIS, serving to minimise the *information demand-provision gap* by supporting the transformation of data into *fit for purpose* information (MacFarlane, 2005).

Visualisation can be viewed as a useful tool for supporting *visual communication* (i.e. communicating what is known) and prompting *visual thinking,* i.e. stimulating the *unknowns* and exciting creativity (MacEachren, 2001). Just as the paradigm shift in communication theory blurs the distinction between knowledge-producer and knowledge-user, this shifting paradigm in cartography similarly recognises the active contribution of the map-user. GIS applications support end-user engagement with spatial data analysis and mapping in ways that conventional static maps could not. *FloodViewer©* for instance, was trialled in the UK EA-led, national Exercise Watermark 2011 and enables users to navigate flood information, to zoom, animate and view a given water level using a slider control bar (Halcrow, 2011).

Technology can have an instrumental role in stakeholder participation. Indeed, Meyer et al. (2011) demonstrate how participatory flood mapping can function both a means to an end (i.e. inform improved mapping) and a desired end in itself (i.e. improve stakeholder communication). Other research has demonstrated the importance of *interaction* between tool-developer and end-user to ensure products are tailored according to professional cultures and encouraging uptake in practice (Nobert et al., 2010).

Although hazard communication has benefitted from technological advances in flood modelling and visualisation, arguably vulnerability has been somewhat side-lined (Priest et al., 2007), yet both are recognised as partners in risk. There are multiple reasons as to why this might be the case. From a technical perspective, the physical processes driving flooding are arguably easier to define and dynamically capture, than the temporally-variable, multi-layered facets of social vulnerability; thus vulnerability remains statically mapped. Furthermore, there has been little research that has examined whether there is a professional want for more engagement with vulnerability. This research sought to address this and trial interactive methods for assessing and mapping *both* hazard and vulnerability; whilst acknowledging that the perceived value of each will be underscored by professional responsibilities and potentially varied understandings. By emphasising user-control, KEEPER reflects the broader shifts in communication and cartography thinking and the move away from the passive connotations of the end user, towards active participation.

THE TARGET GROUP: EMERGENCY PROFESSIONALS

Emergency management in the UK is organised through the statutory framework of the Civil Contingencies Act (HM Government, 2004) and operates according to Integrated Emergency Management (IEM), promoting joined-up, multi-agency response. Category One Responders are central to emergency response and are supported by Category Two Responders (including utility companies, transport operators, Health and Safety Executive and Strategic Health Authority). IEM is coordinated through a tiered command structure, from broad scale events requiring a strategic response, through to the tactical and operational command required on the ground.

While risk is acknowledged as a function of the hazard and vulnerability of receptors (e.g. people) exposed to this hazard, this information is negotiated and balanced differently throughout the emergency management cycle, and between different emergency professionals (Figure 2). Hazard information is normally sourced solely from the Environment Agency (EA), whereas vulnerability information is sourced from multiple agencies (e.g. health services, utility companies), with data sharing coordinated by the Local Authority (HM Government, 2008). Therefore, FIM represents a complex space, where multiple professional stakeholders with diverse responsibilities, needs and understandings, collide. In light of this diversity, KEEPER was initially designed to present the user with a range of options for manipulating risk information to enable the research to clarify unique professional interests and inform future tailoring, both in terms of the tool's *design and purpose*.

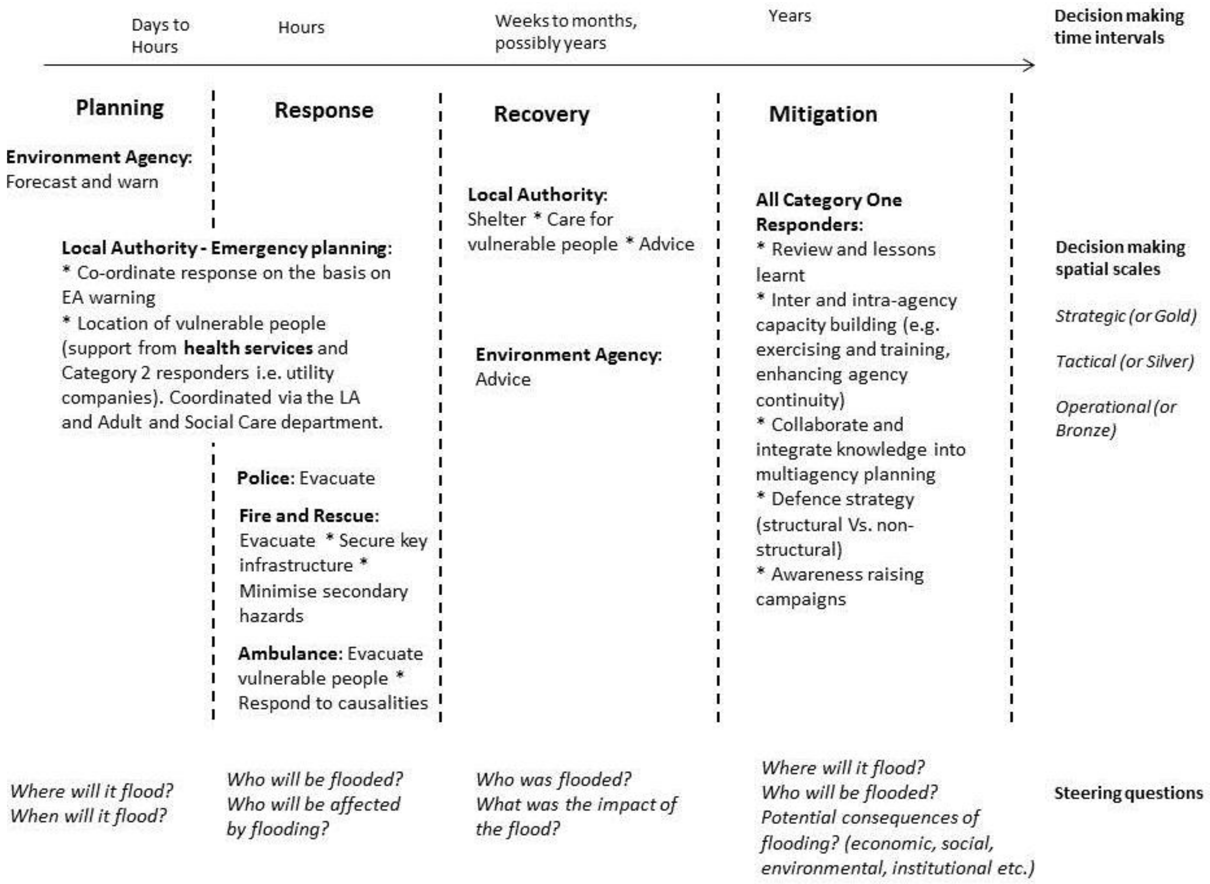

Figure 2: Locating the principal roles of Category One Responders within the emergency management cycle

METHODS

This paper outlines the construction of KEEPER; a Knowledge Exchange Exploratory tool for Professionals in Emergency Response. KEEPER was constructed to facilitate participation with emergency professionals (i.e. striving towards pathway (a) in Figure 1) and in turn, inform recommendations for future tools in practice. Methodological stages are illustrated in Figure 3. While Figure 3 recognises that multiple iterations are required between tool developer and end-user to tailor the tool accordingly and uphold a participatory framework, this paper reflects on the first stage of iteration only. This includes the construction and evaluation of KEEPER with a select sample of emergency professionals.

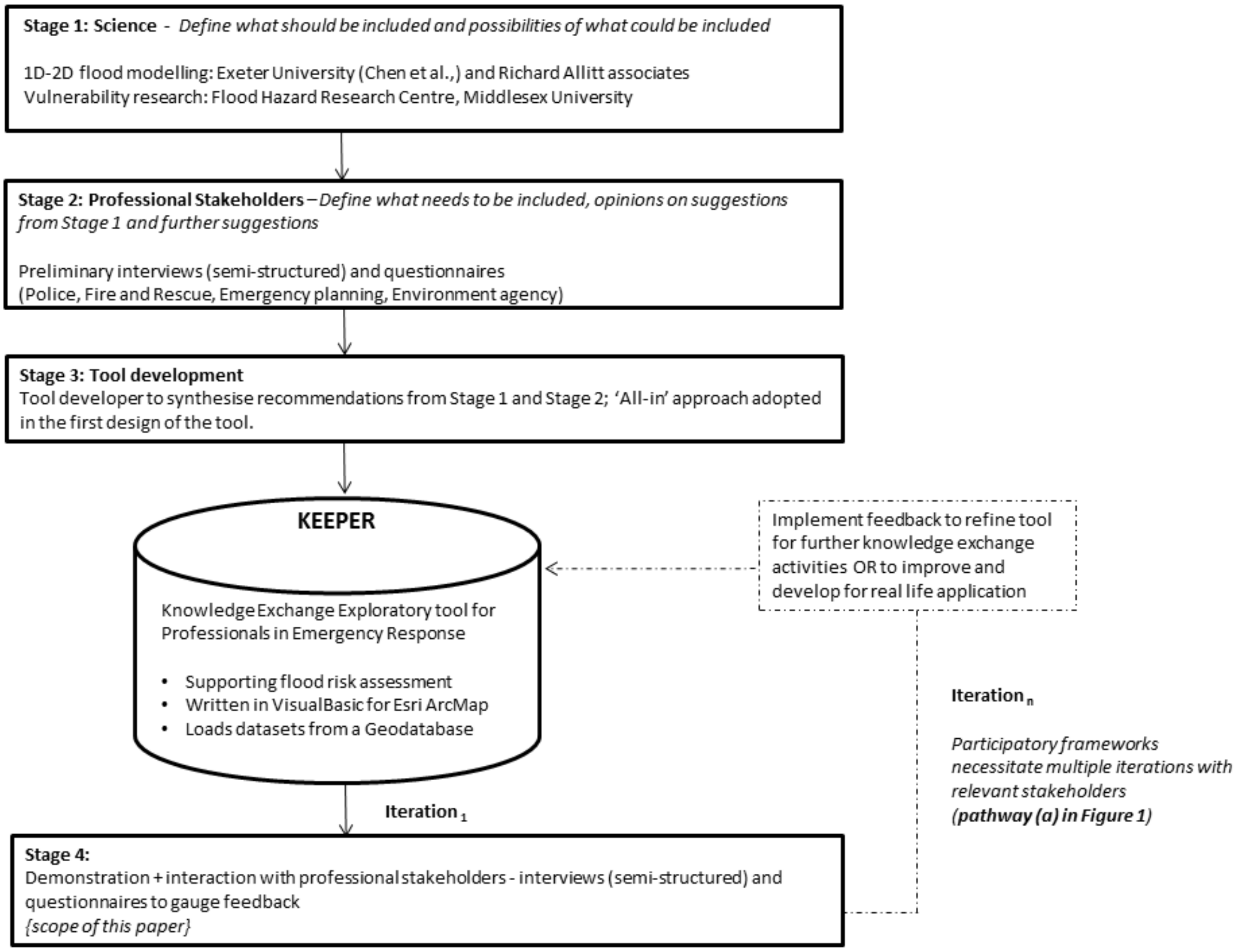

Figure 3: Applying a participatory communication model to construct KEEPER: a Knowledge Exchange Exploratory tool for Professionals in Emergency Response

STAGE 1 utilised existing scientific knowledge to infer what *should* be included, whilst equally framing the possibilities for what *could* be included in KEEPER. The scientific input derived from the interdisciplinary contributions from physical and social sciences to represent the hazard and vulnerability dimensions of the risk equation respectively. Available to this study were detailed, local-scale flood inundation visualisations, produced from previous 1D-2D inundation modelling developed under the auspices of the Flood Risk Management Consortium's research (FRMRC Phase1). These model outputs were developed for two UK locations; Keighley, West Yorkshire (Chen et al., 2010) and Cowes on the Isle of Wight (IOW), Hampshire (Allitt et al., 2009). Expert consultations and literature review (e.g. Wilson, 2008) informed the vulnerability interface of the tool, including options to manipulate and map the Social Flood Vulnerability Index (Tapsell et al., 2002).

STAGE 2 involved preliminary engagement with Category One responders, with responsibilities for the study locations in Hampshire and West Yorkshire. Semi-structured interviews were administered to elicit professional viewpoints on flood risk assessment and how a decision support tool might aid current practice. These interviews also helped contextualise the roles and responsibilities of emergency professionals (Figure 2). A total of 18 professionals participated, representing the Police, Fire and Rescue, Ambulance service, Environment Agency, Emergency Planning (county and district council), Health Protection Agency and a utility company. Interviews were complemented by structured questionnaires, which asked respondents to rate suggestions (functionality and presentation) proposed in Stage 1.

STAGE 3 concerned the tool's construction, which was designed to be exploratory in this first stage (i.e. not a final product). KEEPERs aim was to act as an intermediary between science and emergency professionals; therefore its initial design merges the respective 'wish lists' revealed in Stage 1 and 2. The tool was written in Visual Basic for Esri and constructed as an interface to the GIS application, ArcMap (9.3). Datasets included inundation model outputs, spatially-referenced census data and critical infrastructure (e.g. location of emergency service stations), and these are organised in a geodatabase, which acts as a central repository for storing and managing spatial data. As KEEPER is launched, data are automatically organised into relevant interfaces for hazard, vulnerability and risk assessment (e.g. all flood inundation outputs are available through the hazard interface). This 'GIS-interface' approach, aimed to facilitate user-friendliness, whilst maintaining the GIS interactive capabilities. As the user interacts with KEEPER, both the global map in ArcMap and a corresponding 'summary window' on the interface itself are updated.

STAGE 4 is essentially the 'tailoring stage'. KEEPER was demonstrated to a sample of Category One Responders (n=8), with opportunities for interaction. Throughout this process, responders were invited to give their views concerning the tool and its application potential for supporting decision making. Given the diversity of professional responsibilities and user requirements, these open-interviews also addressed the extent to which a 'one stop' flood risk mapping tool is valued. Finally, professionals completed a short questionnaire to rate each feature. All interviews were transcribed and analysed in the qualitative data software NVivo to locate key themes and identify different and convergent opinions (Saldaña, 2009).

RESULTS FROM PRELIMINARY ENGAGEMENT WITH EMERGENCY PROFESSIONALS

A questionnaire was used to elicit professionals' perspectives on the suggestions proposed during the expert consultations (Stage 1). These included:

- Visualisations of hydraulic 1D-2D modelling for pluvial event matrices, plus fluvial levee breach and overtopping scenarios for Keighley (Chen et al., 2010: Allitt et al., 2009).
- Expert-declared versus user-declared hazard thresholds
- Interactive animation
- Vulnerability metrics based on the Social Flood Vulnerability Index (Tapsell et al., 2002). Option for user to select indicators and adjust weighting criteria.
- Combine and weight hazard and vulnerability metrics to calculate local-scale risk.

- Background pages to describe 'the science' (model assumptions and uncertainty).

From the interviews with emergency professionals it was apparent that the questions steering decision making shifted from the primary concern of *where* will flood and *when* (i.e. hazard orientated), to *who* will be flooded (i.e. vulnerability-orientated); and finally onto the broader implications for affected communities (i.e. risk-orientated: Figure 2). There was a strong convergence between the expert suggestions for the hazard features in KEEPER and professional's views. The questionnaire findings reflect this, as the top three rated items included the ability to interact with inundation mapping (100%), map a range of scenarios (100%), and interactive flood animation (79%). However, opinions diverged in terms of vulnerability assessment (scale, indicator selection), where 75% considered this useful information, 16% were indifferent and 8% consider it not useful.

It was not however the case that vulnerability information was considered less important. The seeming lack of interest expressed amongst the police and fire and rescue particularly, arose from assurances that this information is stored and accessible via other agencies (e.g. LA Adult and Social Care) and not within their remit; and also from the need to assume that *all* people within a flooded area are potentially vulnerable. However, representatives from emergency planning and the Environment Agency could see the potential for indicator-based vulnerability assessments to support *strategic* decision making. Whilst all responders acknowledged the highly variable nature of vulnerability, it was commonly defined by any characteristic which will limit a person's ability to save themselves (i.e. elderly, ill or disabled populations) and at the very least these indicators would need to be included in the tool. Emergency planning departments in particular stressed the value of this form of assessment in overviewing an area, if complemented by existing data-sharing practice for locating specific vulnerable households. Interest in additional indicators (e.g. ethnicity and language) was expressed amongst the professionals for West Yorkshire, which given its multi-cultural towns is not surprising, but reveals the need for flexible, 'place appropriate' assessments. This finding supports recent literature which highlights the influential nature of *place* in characterising social vulnerability and advocates a retreat from the traditional 'one size fits all' approach when downscaling vulnerability assessments at local scales (Cutter and Finch, 2007).

Although most responders acknowledged the hazard generic nature of vulnerability indicators, the phase-relevance of indicators was also noted, from primary concerns for risk to life to the recognition that vulnerability can manifest post-event. This observation suggests that it is inappropriate to apply a universal vulnerability index, but instead requires a flexible system for selecting and weighting vulnerability indicators. Moreover, responders concerned with strategic FIM emphasised the importance of mapping critical infrastructure, recognising that the vulnerability of communities can dramatically change with the loss of key utilities, or from secondary hazards.

There is a wide scope for flood risk mapping in FIM to support different scales of decision making, varied activities and multiple stakeholders. This presents a particular challenge in the design of a 'one stop' tool. Furthermore, the apparent challenges in vulnerability data management (accessibility and accuracy) seriously limit the extent to which vulnerability can be mapped and utilised in response-orientated decision making, and this was widely acknowledged and accepted. Despite these challenges, there was an interest amongst certain stakeholders for interactive vulnerability mapping and this was examined further in KEEPER.

TAILORING KEEPER

KEEPER was designed with three separate interfaces, isolating hazard, vulnerability and a combined-risk assessment, to support professionals' requirement for simplicity. Secondly, the research sought to intentionally draw the user's attention to these components individually to evaluate different forms of presentation (Table 1).

Table 1: Features in KEEPER (Alexander et al., 2011)

<table>
<tr><th>The Hazard Interface</th><th>The Vulnerability Interface</th></tr>
<tr><td rowspan="3">1) User can map the flood extent from a range of scenarios based on pluvial event matrices developed within FRMRC. Additional fluvial scenarios were included in the Keighley version of this tool (levee breach and overbanking).

2) User can recolor map according to depth-velocity interaction, based on expert-declared thresholds (based on Risk to Life; Priest et al., 2007). The user can manipulate these thresholds and adjust the hazard classification. Recoloring was set to a RAG (red, amber, green) scheme, based on interviews.

3) 'Clean' the map to view flood hazard posed to the road network (based on depth-velocity thresholds from Risk to Life modelling) and/or property only (based on risk to life or depth-damage thresholds (Penning-Rowsell et al., 2010). User can further base this reading on the min/max/mean flood statistics.

4) Interactive flood animation.</td><td>1) User can adapt the original Social Flood Vulnerability Index methodology (Tapsell et al., 2002) to view relative vulnerability according to the nation, region/district or local town.

2) View indicators in isolation with accompanying explanations.

3) Construct a vulnerability index, from user-defined indicator selection and weighting.</td></tr>
<tr><td>The Risk interface</td></tr>
<tr><td>Collates hazard and vulnerability models at the property scale. User can define the weighting between hazard and vulnerability and automated property and people count to summarise risk categories.</td></tr>
</table>

Options for 'cleaning' the map were trialled in the Hazard interface, enabling the user to recolor the flood map according to various hazard thresholds and visualise where flooding intersects the road network or individual properties only. This latter option trialled two different hazard models; the thresholds for Hazard Model 1 (HM1) were based on Risk to Life modelling (according to depth-velocity interactions: Priest et al., 2007), whereas Hazard model 2 (HM2) was based on depth-damage thresholds (inferred from the Multi-Coloured Manual: Penning-Rowsell et al., 2010). These two hazard models were provided to reflect the different interests of emergency response and recovery. While risk to life is the predominant concern, vulnerability can manifest post-event; therefore, this option allows professionals concerned with the recovery phase, to identify properties that are particularly susceptible towards damage, or may seek/require support in the aftermath of flooding. Additionally, users can base hazard classification according to the minimum, maximum or average flood statistics and thereby engage with the inherent uncertainty in flood modelling. Finally, users were able to launch an interactive flood animation.

The Vulnerability Interface addresses ways of integrating census-derived data for vulnerability mapping (according to UK census Output Area). The Social Flood Vulnerability Index (SFVI, Tapsell et al., 2002) was used to represent a ‘vulnerability product’, i.e. packaged together by expert academics. The disadvantage of such a product is that its assumptions may not be apparent to end-users, such as the equal treatment of indicators. The SFVI is based on an additive model of four indicators; the Townsend index of deprivation, elderly, lone parent households and long-term illness. Users can view the original SFVI scores (standardised to national measures of central tendency) or can adjust the SFVI scoring system to reflect the *relative* vulnerability according to different geographical scales. These indicators can also be viewed in isolation, with accompanying expert-declared rationales. Finally, users can construct their own vulnerability index by simply weighting each indicator according to the relative importance in decision making (Figure 4).

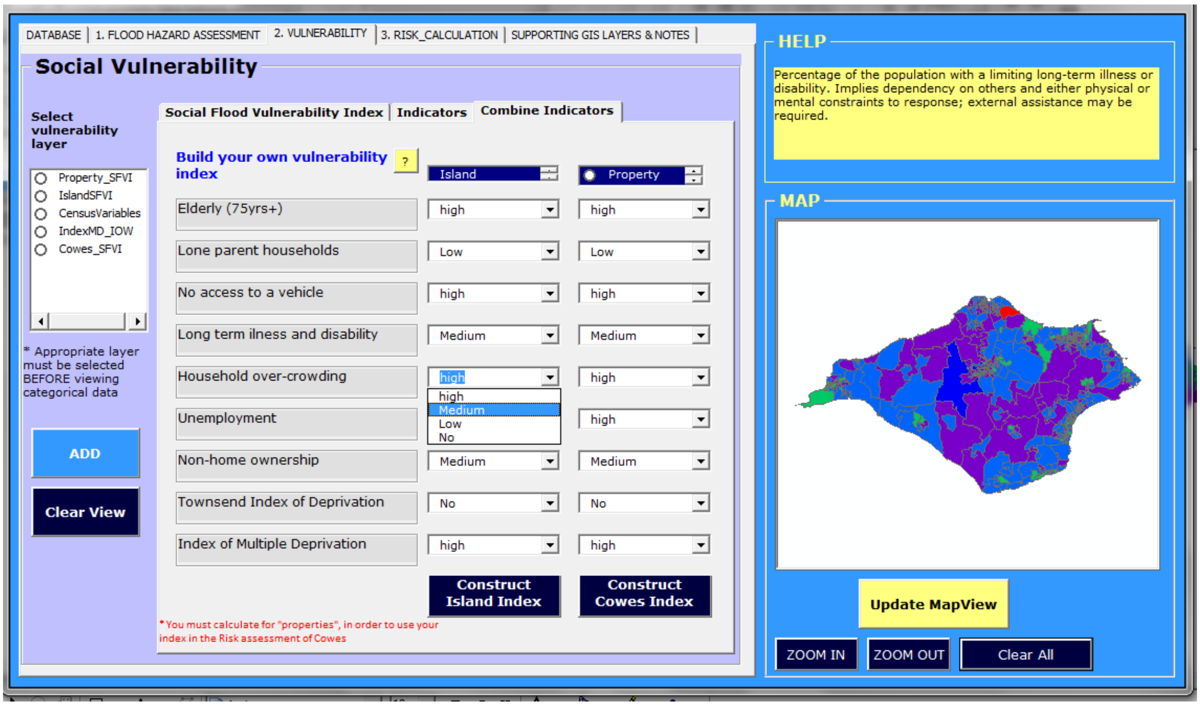

Figure 4: Building a vulnerability index according to user-declared relevance of each indicator (based on a sample of indicators only at this stage)

The Risk interface collates hazard and vulnerability details at the *property level*. This part of the tool examines how responders negotiate this risk equation (weighting hazard and vulnerability) and provides users with five aggregation models for equal weighting or applying a minor or major weight to hazard or vulnerability. An automatic property and people count is calculated according to the selected risk model.

KEEPER'S EVALUATION BY EMERGENCY PROFESSIONALS

This section reports on the responses of the emergency professionals re-interviewed following a demonstration of KEEPER (n=8).

Professional perspectives on flood hazard

Responders valued the repository of design flood scenarios (different flood drivers and return periods) for the planning phase of emergency management and training and exercising. Visualising different sources of flooding was considered by the EA and LA representatives as important for gauging scale, likely impacts and clarifying responsibility. This was notably less important amongst police and Fire and Rescue representatives; *"It is either a flood or it isn't."* (Police, WY)

All responders valued complementary depth-velocity details when recolored according to Risk to Life. However, many expressed their concerns at being able to adjust these thresholds; *"I go with what the experts tell me"* (Emergency Planning, WY). In fact, it was commented that this feature would be better placed for clarifying the hazard posed to the road network, to allow the user to adjust a specific depth or depth-velocity to suit the vehicle, or view a binary *Yes/No* for safe routes, facilitating quick access to information (as found by Meyer et al., 2011). Faulkner et al. (2013) question the use of 'traffic light' presentation for its oversimplification of complex situations and in masking undeclared boundaries of scientific uncertainty. However, this form of presentation was highly rated for its compatibility with existing systems (e.g. Flood Forecast Centre and Met Office mapping) and for the "*quick judgement"* it affords (Emergency Planning, WY).
Depth-velocity information was widely regarded as *useful*, but as this latter statement highlights, responders also emphasised the importance of *usable* information. Most responders acknowledged the complexity and uncertainty of flood science and conceived RAG (red, amber, green) presentation as a valuable means of translating this complexity into information that can be easily understood and integrated into decision making.

The simplicity criterion was explored further with options for 'cleaning' the map to depict flooded roads or properties only. However, many responders still felt they would overlay the flood extent rather than view these as stand-alone layers; somewhat undermining the intended purpose of these options. From the interviews it seems that this finding reflects professionals' training to assume the 'worst case event' and responsibly assume that all properties within the defined area may be flooded. Similarly, most responders remarked that in practice they would base the hazard calculation according to the maximum flood value modelled. This property-scale presentation of two different hazard models rated highly, although given the low risk to life posed by UK flooding it was argued that a depth-damage hazard model would be more appropriate.

Visualisation was viewed as a tool for prompting the *proactive* thinking required for effective emergency management. Animation was unanimously welcomed as an invaluable means of depicting spatial-temporal flood patterning, although it was suggested that summary tables should complement this to provide rapid, digestible information of the display. There is however a question of the certainty that visualisation portrays; "W*hen you show an animation you get caught up in it and you forget this is plus or minus depth…I think it's good because animation engages people better…But it's that uncertainty that gets forgotten"* (EA, Hampshire). Conversely, it was noted that any flood visualisation is in fact a way of reducing uncertainty during response and a useful tool for directing resources; "[it's better] *than nothing"* (Fire & Rescue, WY). Although design scenarios offer some indication and could be useful in planning evacuation routes for example, responders were eager to know whether the visualisation could be informed by real-time data during operational response; providing further support for recently developed tools, such as FloodViewer© (Halcrow, 2011).

While some responders commented that they would like "*certain or uncertain information to be discussed in more detail"* (EA, Hampshire), there were mixed views on how this could achieved. Although a written caveat could be difficult to understand (EA, Hampshire), several responders expressed caution in uncertainty visualisation, which could otherwise cloud the overall picture and map message – "[and] *may end up becoming a larger element than it actually proportionally needs to be"* (Emergency Planning, IOW). Uncertainty is already accommodated within the professional culture to plan for and respond to the worst-case scenario. For example, if a 1 in 50 year event was forecast, some professionals said they would be inclined to view a 1 in 75 year event and knowingly over-estimate flood extent to ensure public safety. Therefore additional information on uncertainty was deemed to have little effect on decision making or its outcome, mirroring the findings of previous research (Morss et al., 2005). An exception was voiced by Fire and Rescue in the context of managing critical infrastructure, where the potential for far-reaching impacts exerts a greater weight on uncertainty within decision making.

Professional perspectives on vulnerability

Some stakeholders described the use of vulnerability indices in practice, but equally could not explain the make-up or aggregation of these indicators. Arguably this creates a 'blind user', which KEEPER sought to avoid. Some responders valued the option to adjust the spatial scale at which relative vulnerability is calculated and felt that this added to the usefulness of this 'product', particularly given the variable scales of flooding and decision making. The option to isolate indicators was valued as a means of understanding the SFVI, visualising the social 'make-up' rather than relying on pre-conceived assumptions (Emergency Planning, IOW) and could help tailor FIM activities such as awareness-raising campaigns (EA, WY).

Although vulnerability indices have traditionally applied equal-weighted models, arguably academic objectivity is less meaningful than the subjectivity of emergency professionals (based on their experience and professional obligations). However, there was mixed feedback on the user-constructed index; *"I think that's really good… e.g. unemployment that's not really important to responding to a flood event, but some of them like elderly really are"* (EA, Hampshire). It was also noted that this feature could prove useful when comparing between locations or assessing other hazards (Emergency Planning, IOW). A concern voiced by Emergency Planning and the Police for Hampshire was that individual responders may deduce vulnerability differently. While KEEPER satisfies a need for flexibility, multi-agency working would still be required in vulnerability calculations to satisfy the integrated emergency management framework. In this context, KEEPER could function as a support system to help professional groups articulate and visualise their concerns, and facilitate a consensus.

There was a degree of negativity surrounding the indicator/index approach. Ultimately it seems that professional's feedback reflected a mismatch in scale between the property-scale flood hazard assessment and community-wide vulnerability assessment. For true local scale appraisal, responders require the identification of specific vulnerable households (e.g. dialysis patients). Given the decadal nature of the census, many responders commented on the danger of relying on out-dated information for informing response; *"It gives you that general picture…we'd still have our normal links into the health service, adult and social care"* (Emergency Planning, WY). However, it was suggested that this could change in the context of wide spread flooding, requiring strategic decision making and priority-setting.

KEEPER was not designed to address these bigger challenges facing local-scale vulnerability mapping; indeed, matters of data protection (HM Government, 1998) and the transient nature of vulnerability discussed by professionals, limit the extent to which it is both *possible* and *advisable* to plot vulnerability at this scale. This finding suggests that vulnerability mapping may be justifiably 'side-lined' at this local scale, where lists of vulnerable households exist and detailed flood modelling can highlight those potentially at-risk. However, this research demonstrates the want and value for interactive vulnerability mapping that enables professionals to examine the 'make-up' of social vulnerability across their districts of responsibility and in locations exposed to particular hazards; here, vulnerability should not be side-lined and is essential for holistic decision making.

Professional perspectives on 'playing' with risk

KEEPER's risk feature created some confusion amongst responders and in some cases this led to 'risk' being treated as synonymous to vulnerability. Responders widely agreed that they would continue to overlay the flood map: *"I think it's interesting to see the risk calculation shown as a map but I would always like to break it back down into hazard and vulnerability"* (EA, Hampshire). In light of the concerns surrounding census-derived vulnerability indicators, and incompatible spatio-temporal resolutions, some felt it was inappropriate to integrate information in this way. However, several responders acknowledged its potential as an exploratory tool in professional training to examine how property and people estimates shift between different combinations of hazard and vulnerability.

Additionally, it was commented that this feature could be applied at times of interacting hazards; *"…If we were in a situation of pandemic flu already and then went into a period of flooding, perhaps we would weight vulnerability higher"* (Emergency Planning, IOW). This paper has thus far advocated flexibility in vulnerability indicator-selection and weighting between different phases of FIM, but this latter finding also suggests the potential need for flexible systems in a *multi-hazard context*. The spatial and temporal shape (or 'etiology') of the hazard can influence social vulnerability (Tapsell et al., 2010). Although emergency professionals commented on the generic nature of vulnerability in terms of responding to rapid onset and short duration hazard events (e.g. flooding, snow storm), vulnerability could manifest differently for other hazard etiologies and vulnerability criteria, and hazard-vulnerability weighting, could conceivably change. Further research is required to examine this further.

Presenting KEEPER

Keep It Simple Stupid (K.I.S.S) was a recurring theme and an essential requirement in the end-users' 'wish list'. The requisite for simplistic tools is tied to a contentious debate concerning the dualistic meaning of simplicity: Do practitioners require *simplistic-user-friendly* tools or *simplistic-information* tools? It is apparent from the professional interviews that simplistic-user-friendly tools are essential. Firstly, due to the varied demands placed on professionals, any tool needs to be '*like riding a bike*'; and secondly, due to inexperience or lack of confidence in using new software. The simplicity criterion did not seemingly reflect a want for simplistic-information; indeed, responders did not underestimate scientific complexity or uncertainty, and appreciated the nuances underlying vulnerability. Instead, the necessity to simplify data seems to mirror the overarching goal for *operational feasibility* and requirement for *useable* science (Morss et al., 2005). Moreover, several responders noted that, while planning and longer-term mitigation strategies could benefit from an interrogative and interactive tool, the time constraints during emergency response necessitate the need for rapid retrieval of information: *"Our day job in planning [and] training...is measured and calm. Everything changes with response; you don't have time to play with a system"* (Emergency Planning, Hampshire). These findings reiterate existing research that highlights the importance of sensitising decision support tools to the needs of the end user and professional setting (e.g. Nobert et al., 2010).

To-date, KEEPER has been trialled with select professionals and further research is required to examine the generalizability of these findings across the UK, as well as its relevance to non-UK frameworks. Nonetheless, a number of practical recommendations and suggestions for further tailoring are presented at this stage (Figure 5). The majority remarked that an inclusive flood risk assessment tool would need to distinguish between the phases of FIM and possibly differentiate between operational/tactical and strategic tiers of decision making. There was also some debate regarding a flood-centric tool, versus an all-in hazard assessment tool. From these discussions it is clear that there are a number of challenges in a 'one stop' tool design, not least in accommodating multiple stakeholders, different spatial and temporal scales of decision making, and various activities in FIM. This was noted as one of the failings of the National Resilience Extranet and professionals interviewed discussed how a focused tool, supporting a small number of tasks, is better than a tool that tries to be "*everything to everyone and hence nothing to no one*" (WY Fire and Rescue).

Discussions with professionals revealed the need for multi-user accessibility, allowing users to create and share a Commonly Recognised Information Picture (CRIP: HM Government, 2010). This requirement for CRIP is somewhat at odds with the desire for tailored tools. By enabling user-controlled mapping and options to integrate subjectivity into vulnerability calculation, KEEPER sought to accommodate professional variability but inadvertently threatens this requirement for common information. Ultimately, a successful tool needs to achieve both; it needs to be tailored to the end user and deliver outputs that contribute to, and facilitate the creation of CRIP. While discussions with emergency professionals highlight the practical challenges of a 'one stop' tool and suggest that a suite of complementary (and tailored) tools may be more welcomed, these would still need to bolt onto a shared interface in order to support IEM.

KEEPER was not designed for practical application at this stage and a number of factors would need to be addressed to develop it into a commercial tool. Firstly, architectural changes are required to the underlying database and launch platform itself, to address the need for multi-user accessibility and inexpensive software. Given the lead role of Local Authorities in coordinating vulnerability information (HM Government, 2008) and responsibilities for local FRM (Flood and Water Management Act, 2010), the LA would be the obvious candidate for database management. However, critical decisions need to be made in delineating spatial boundaries; indeed, while a national tool may be too cumbersome, incidents have the potential to transcend boundaries of decision making and further research is required to examine this. Finally, whereas KEEPER's current treatment of vulnerability could support area-wide, multi-hazard assessment from freely available data; detailed hazard mapping and animation would require existing or commissioned research for 'hotspot' areas of interest.

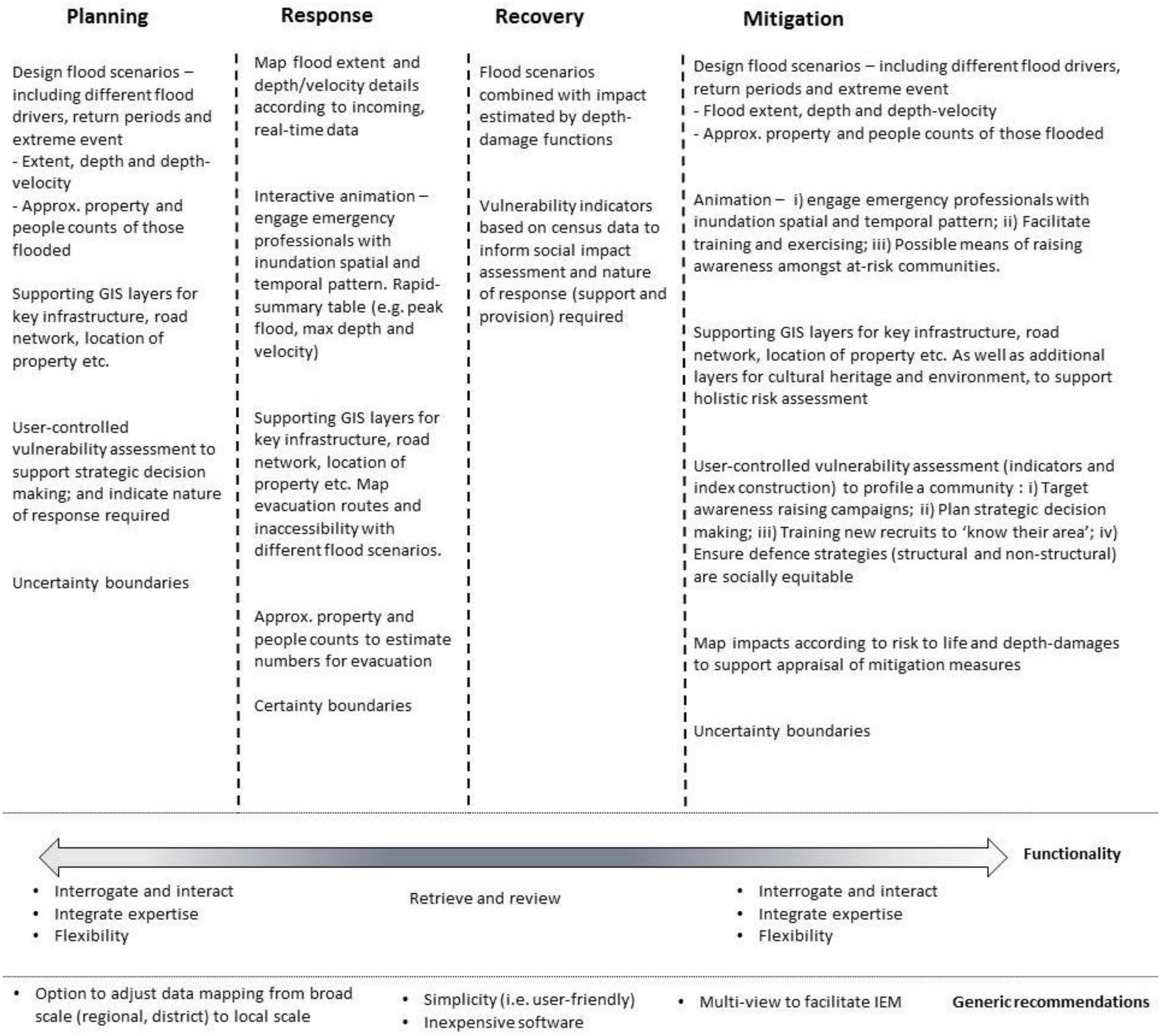

Figure 5: The 'ingredients' for developing future decision support tools in flood incident management

CONCLUSION

Flood risk mapping is a cornerstone of FIM decision making, but its formulation notably varies depending on the decision at hand (steering questions, temporal and spatial scale). KEEPER can assist by enabling the end user to actively construct the risk map to suit the decision, as well as acting as a support system to help professionals explore, articulate and visualise their concerns. Although further iterations are required to inform continued tailoring of KEEPER, this research revealed a want for user-controlled and active engagement with flood risk mapping amongst FIM practitioners. However, the context in which this information is interpreted, assimilated and acted upon must be understood, and is emphasised in this paper and echoed in existing literature (Faulkner et al., 2013: McCarthy et al., 2007). For instance, an overarching theme that emerged from professional discussions was the request for *simplicity*, which arises not from the desire for 'dummied down' science, but from the need for user-friendly science.

Participatory methodologies can reveal the qualities of *useful and usable* information to facilitate the translation of science and its inclusion in decision making. However, professional constructions of usefulness and usability are not static and multiple iterations and sustained collaborations are required to capture how these conceptions evolve from further engagement with new knowledge and technologies (Morss et al., 2005). More generally, scientific-practitioner interaction could benefit from the formation of a *learning alliance* to enable knowledge exchange, stimulate debate and opportunities for experiment with scientific developments. Such an alliance could help cultivate and sustain multidirectional communication, the co-production (and tailoring) of decision support tools and in turn, facilitate the diffusion of ideas and tools in practice.

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