International Journal of Disaster Risk Reduction 27 (2018) 499–511

Contents lists available at ScienceDirect

International Journal of Disaster Risk Reduction

journal homepage: www.elsevier.com/locate/ijdrr

The Natural Hazards Partnership: A public-sector collaboration across the UK for natural hazard disaster risk reduction

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ARTICLE INFO

Keywords:
Natural hazards
Public partnerships
Disaster risk reduction
Hazard impact models
Collaboration
Impacts

ABSTRACT

The Natural Hazards Partnership (NHP) is a collaboration between 17 UK public bodies[1] to provide authoritative, consistent, and useful, hazard, impact and risk assessment information to responder communities and governments. Over the last decade, disasters have affected over 1.5 billion people across the world and damages are estimated to have exceeded $1.5 trillion. To reduce future impacts from natural disasters, the NHP is looking to establish itself as an international model of best practice for delivery of trusted natural hazard advice and services. Development of this impact-focused information and advice is supported by coordinated access to cutting-edge science and natural hazard impact research. This paper presents the NHP as a successful example of a national collaboration of public bodies with a common goal. The partnership's organization and scientific approach is discussed alongside a review of activities and deliverables developed to help realize the NHP's vision: '*To be the UK's trusted voice for natural hazards advice*'. The NHP has overcome collaborative challenges of multi-organizational, geographically dispersed working by building common ground, respect and trust. This has allowed the development of strong leadership and inter-organizational coordination practices and created an agreed common approach to scientific research. These achievements have helped to ensure that the NHP produces valuable products, services and advice, which could translate to other disciplines and other communities.

1. Introduction

Over the last 10 years, disasters have affected more than 1.5 billion people across the world. The total cost of these disasters is estimated to have exceeded $1.5 trillion [98]. Impacts of these events include loss of life, injury, destruction of property and disruption to infrastructure as well as social, economic and environmental damages [23]. Natural hazards and their impacts are complex in nature and do not respect national borders [92]. Consequently, international agreements on disaster risk reduction have become key national and local priorities [91]. The Hyogo Framework for Action (HFA) was the first plan to explain, describe and detail the national and local work required to reduce disaster losses including fatalities [1,94]. The HFA provided motivation for the Global Assessment Reports (GAR) on disaster risk reduction, which understand and analyze global disaster risk today and in the future [95–97,99]. The most recent and potentially most influential agreement is the Sendai Framework for Disaster Risk Reduction 2015–2030 [98] adopted by 193 UN member states. The Sendai Framework's goal is to "Prevent new and reduce existing disaster risk… prevent and reduce hazard exposure and vulnerability to disaster, increase preparedness… and strengthen resilience" ([98], p11). This goal places the State at the heart of disaster risk reduction, but also emphasizes the role of stakeholders such as local government and the private sector. This has encouraged many national governments to consider how they can align their disaster risk reduction activities with Sendai guidance [1].

To better understand the risk to the UK, the UK Government regularly produces a classified assessment of the risks of civil emergencies facing the UK over the next five years known as the National Risk Assessment (NRA). This assessment brings together the key risks that have the potential to cause a significant disruption in the UK. The NRA provides Government and local responders with the means to prioritize and proportionately prepare for a range of eventualities. The public facing version of this assessment, the National Risk Register (NRR), is a resource for individuals and organizations wishing to be better prepared for emergencies. The NRR provides information, advice and

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[1] The Natural Hazards Partnership is comprised of British Geological Survey, Cabinet Office, Centre for Ecology & Hydrology, Department for Environment Food and Rural Affairs, Environment Agency, Government Office for Science, Health & Safety Executive, Met Office, National Centre for Atmospheric Science, National Oceanography Centre, Natural Environment Research Council, Ordnance Survey, Public Health England, Scottish Environment Protection Agency, The Scottish Government, UK Space Agency and Welsh Government.

https://doi.org/10.1016/j.ijdrr.2017.11.014
Received 2 May 2017; Received in revised form 19 November 2017; Accepted 19 November 2017
Available online 21 November 2017

access to resources on natural and anthropogenic hazards that pose a potential civil emergency risk including potential size and scale, likelihood and impact (Fig. 1). Of the 26 civil emergency risks highlighted in NRR, 11 are natural hazards [8].

The Natural Hazards Partnership (NHP) is a collaboration of government departments and bodies from across the UK. The NHP aims to establish a forum for the exchange of natural hazards knowledge, ideas, expertise, intelligence and best practice; provide timely and consistent advice to government and emergency responders for civil emergencies and disaster response; and develop new services to assist in disaster response preparedness. The public body nature status of the NHP means that it is appropriately positioned to provide accessible advice to the UK's resilience community as well as evaluating more sensitive, classified information with UK government and devolved administrations. The NHP is not intended to replace the roles and accountability of existing public bodies, agencies and organizations, but to complement and enhance their current activities through multi-institutional working. The NHP receives advocation and support from the Cabinet Office, which acts as the UK's National Platform for disaster risk reduction [100]. The NHP was presented as evidence in the assessments of the Hyogo Framework for Action's (HFA) Level of Progresses in the United Kingdom [11,12] demonstrating the NHP's relevance and applicability in the field of disaster risk reduction. It has also gained international recognition with initial findings from the United Nations Office for Disaster Risk Reduction (UNISDR) facilitated peer review of the UK's approach to resilience, highlighting the NHP as a model "other nations may wish to adopt" [97,101]. This paper introduces the novel approach taken by the NHP in delivering state-of-the-art, useable, impact and risk-based natural hazard science, services and products. This has revealed key challenges and benefits derived from partnership working, which will be evaluated using underlying themes of communication and sustainability.

1.1. Partnership working for disaster risk reduction

Over the last decade, the UK has experienced a number of severe natural hazard events that have had large economic and human impacts on communities, properties and infrastructure networks. The 2007 summer floods affected 55,000 properties and were estimated to cost £3.2 billion [25], while the 2013–2014 floods cost approximately £1.3 billion in insurance claims [26]. In December 2015, during Storm Desmond, wind gusts of up to 81 mph and record breaking volumes of rainfall were recorded across North West England [53]. The storm, and its associated rainfall, is estimated to have flooded 8900 properties with over 100,000 properties left without power [103], with costs estimated at £1.3 billion [79].

For the UK to better prepare and respond to more challenging and extreme natural hazard events, delivery of efficient, user-oriented advice and services must be rooted in the latest science, and communicated through the most effective channels. This can only be achieved through partnership working. The NHP is a Public-Public Partnership, containing only public sector bodies or public corporations [5], with the broad aim of providing natural hazard scientific advice and information to improve understanding, preparation and planning for natural hazard events. This has direct relevance to the Sendai Framework's Priorities for action of "*Understanding disaster risk*" and "*Investing in disaster risk reduction for resilience*" and "*Enhancing disaster preparedness for effective response*". ([98], p14), and specifically Target (g): "*Substantially increase the availability of and access to multi-hazard early warning systems and disaster risk information and assessments to people by 2030*" ([98], p12).

Development of partnerships is important for integrating disaster risk reduction strategies into national and local government, sustainable development, climate change initiatives, and humanitarian response [81,91]. Partnerships are also key to mainstreaming disaster risk

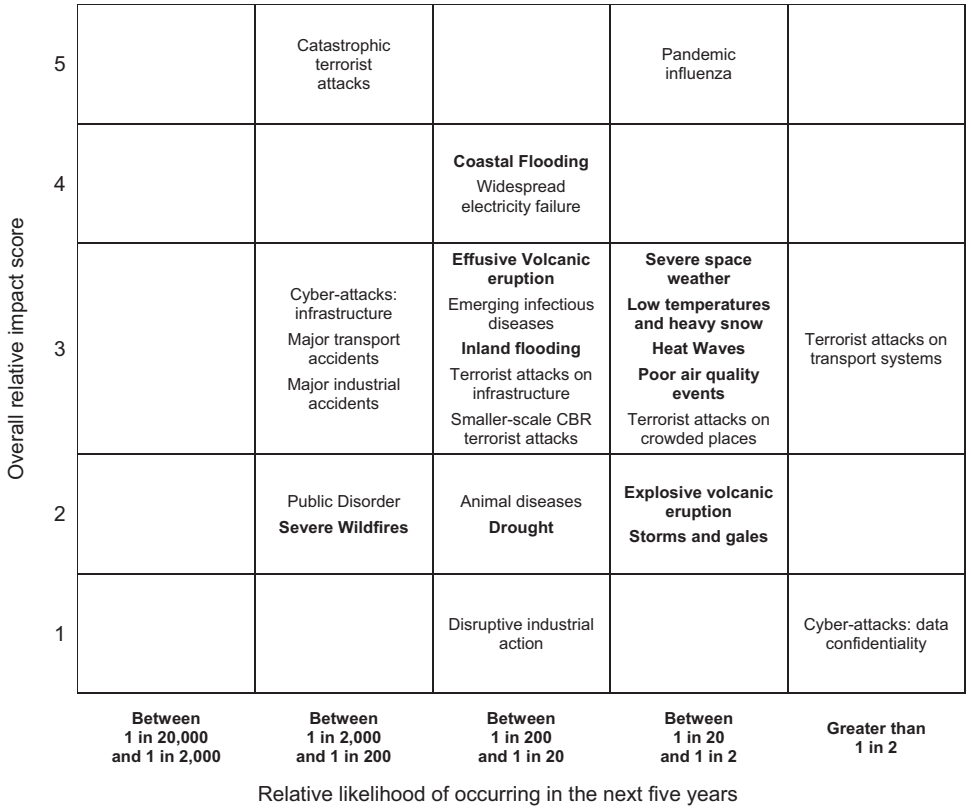

Fig. 1. Key civil emergency risks published in the 2015 National Risk Register (NRR) derived from the 2014 National Risk Assessment. Natural hazards of interest to the Natural Hazards Partnership are highlighted in bold. The position of the civil emergency on the grid indicates risk which is comprised of the relative impact (civil emergencies sited higher are more severe) and the likelihood of occurrence (civil emergencies sited to the right are more likely to occur). Methodology can be found in the NRR [8] (Adapted from UK NRR [8]).

reduction strategies into the policy-making cycle, with a view to improving decision-making and informing spending decisions. Co-operation between stakeholders with different expertise and perspectives has been actively promoted in disaster risk reduction since the 1982 Earth Summit [9]. Consequently, a range of natural hazard-focused, multi-sector collaborations have been established across the world to address the issues written into the HFA and Sendai Framework.

At the international level, the European Commission's (EC) European Civil Protection and Humanitarian Aid Operations have multiple projects focused on disaster risk reduction. These include the Copernicus Emergency Management Service [15], the Disaster Risk Management Knowledge Centre (DRMKC) [19], Joint Research Centre (JRC) [20], Global Disaster Alert and Coordination System (GDACS) [32] (a joint initiative between the United Nations and EC) and the Emergency Response Coordination Centre (ERCC) EC [21], the operational hub of the EU Civil Protection Mechanism [22], into which projects like ARISTOTLE [3] deliver world leading multi-hazard capability. Further, the EC's Horizon 2020 programme [42] funds research and innovation in all areas including disaster risk reduction with projects like I-REACT [43]. Other large international collaborations such as the Pacific Disaster Centre (PDC) [75], the World Meteorological Organization's HIWeather project [102] and the Earth Place Observing System (EPOS) [27] have been developed. All encourage cross-border research in multi-hazard assessment and early warnings.

At a national level, many regions have developed early warning systems through public sector collaborations. These range from hazard-specific warning systems such as the Tropical Cyclone Early Warning System of Cuba [90] and the Bangladesh Cyclone Preparedness Program [4], to more complex multi-hazard platforms developed in New Zealand [66,77], Switzerland [87], Japan [39], France [69], Germany [85], the USA [45], Italy [78] and China [88].

1.2. Communication of impact and risk

Natural hazard assessment and early warning systems are important components of disaster risk reduction. Golnaraghi [34] highlights "Communications systems for dissemination of warnings to the authorities and the population at risk" as one of four key components of an early warning system. Trusted and understandable communication is vital before, during and after natural disasters [51]. Further, the generation and dissemination of poor or ill-informed communications can increase the negative impacts of disasters [58]. Demuth et al., [17] emphasize the need for understandable and relevant communication of natural hazard information and forecasts to emergency managers and the public. Paton and Johnston [74] suggest that if people are warned of, and understand the impacts of a natural hazard, they are more likely to prepare appropriately. This preparation improves their resilience to the hazard. As one member of the media explained: "They [people] want to know three things: what does it mean to them, what does it mean to their family and what do they need to do right now" ([17], p7).

In recent years, various National Meteorological Services have started to address the challenge of producing meaningful advice by moving towards impact-based forecasting. For example, the UK Met Office's National Severe Weather Warning Service (NSWWS) uses meteorological forecasts, impact tables [54] and expert knowledge of impacts to provide color-coded risk warnings based on the likelihood and potential impact of an event [55,62]. This approach combines an understanding of hazard extent and severity with outputs that are more relevant to emergency responders and more meaningful to wider audiences. Meteoalarm [57] is a platform for the presentation of severe weather information from a large number of European National Public Weather Services, including the UK NSWWS, based on principles of improved consistency and the increasing use of impact-based assessments. Further, initiatives like the USA's Weather-Ready Nation (WRN) [67] and WRN Ambassadors™ [68] bring together impact-based decision-support services, science and technology advances, communication and outreach, and information delivery to prepare communities for extreme weather, water and climate events [41]. By engaging closely with government and private organizations, national resilience is better understood and improved, ensuring better preparedness for weather-related disasters [82].

2. The Natural Hazards Partnership

2.1. Origins

The Pitt Review [7] was commissioned in the aftermath of the 2007 UK summer floods. It was found that the UK system of providing advice on potential natural hazards, and ultimately delivering warnings, was too disjointed [7,25], and scientific information was not translated appropriately into actionable and usable information [49]. The Pitt Review recommended improving resource integration between scientific organizations, governmental departments and emergency responders [7,25]. This led to the formation of the Flood Forecasting Centre (FFC) in 2011, a joint undertaking between the Environment Agency (EA) and the Met Office in the UK. The FFC successfully demonstrated the benefits of cross-organizational working and how this leads to improved public services [97,101].

The Pitt Review also highlighted the need for "*a national framework to help reduce the risks to the delivery of essential services resulting from natural hazards*" ([7], pages xxviii-xxix). The success of the FFC led to a desire to explore what further advantages could be gained by creating additional partnerships to provide an 'all hazards' approach to disaster mitigation. During 2010, the British Geological Survey (BGS), the EA, Met Office and Ordnance Survey undertook a feasibility project to assess ways to collaborate on a broader set of hydro-meteorological hazards. This resulted in the formation of the NHP in 2011 [97,101].

2.2. Establishing common ground

The NHP initially consisted of 13 public sector organizations and government departments. It expanded to 17 partners in 2013. NHP partners bring a large range of public sector and scientific expertise to the partnership (Fig. 2; Table 1), with many being responsible for monitoring, forecasting and warning for their specialist areas of natural hazards. Table 2 sets out the current landscape of natural hazard management responsibilities within the UK. The size and scope of the NHP: facilitates the simultaneous undertaking of disaster risk reduction research in a number of scientific disciplines; improves robustness of research via validation and review from a number of different perspectives; and helps to ensure that the output is understandable and relevant to the requirements of the communities served by the NHP.

Building a partnership with so many members can pose challenges for sustainable collaborative success [83]. Establishing common ground is a key factor in promoting a successful collaboration because it aligns partners to common goals and eases the generation of mutual respect and trust [72]. Building trust in a Public-Public Partnership, such as the NHP, is particularly important because there is rarely the security of long-term resource and capital investment, commonly provided by private enterprise in Public-Private Partnerships [5]. The NHP is underpinned by a Memorandum of Understanding between the partners which sets out the basic principles of collaboration and also maintains an operating plan that clearly defines the agreed priorities, activities and structures of the partnership.

At an organizational level, all NHP partners are public bodies from within, or associated with a UK, Scottish or Welsh government department. This ensures that members already operate in a similar organizational environment and all are working primarily to improve public services [5,9]. At the individual level, well-established working relationships have developed into strong personal relationships across the NHP. The strengthening of these relationships helps to build trust, which is critical for successful collaborative work [24].

Fig. 2. Natural Hazards Partnership (NHP) 'wheel' of organizations who are NHP partners.

The NHP has developed common understandings through the promotion of inclusivity in meetings and via the development of a common glossary of terms, which are largely based on established UNISDR definitions. However, agreement of potentially contested terms and processes across 17 partners is not a trivial matter; development of these terms has taken a substantial amount of time and required significant discussion, compromise, and agreement of the scientific principles.

2.3. Organization and structure

Within the NHP, clear leadership and communication are the cornerstones of the successful collaboration because, as Karkkainen [44] highlighted, they allow partners to actively coordinate. This ensures that project tasks are clearly defined and communicated and there is no duplication of effort. Clear definition provides more confidence where a task is split between multiple geographically dispersed partners, because each partner has the same vision of the final outcome. This is more likely to occur in partnerships that practice closer collaboration due to the increased level of communication and interactivity. Close collaboration is particularly important in the NHP, where multiple projects of different scope and scale are underway simultaneously, each with its own focus and subset of project partners. Establishing communication across these projects is important to ensure that no work is duplicated and that the scientific or technical methods used by different partners within a project do not conflict.

With the importance of clarity and communication in mind, the NHP has developed a clear organizational structure. Four sub-groups: Hazard Advice and Science Group (HASG), Hazard Impact Modelling Group (HIMG), Science Strategy Group (SSG) and Communication and Outreach Group (COG), receive overarching steer and governance from the Steering Group and Secretariat (Fig. 3). Each group has a clearly defined remit within the partnership and consists of representatives from multiple NHP partners. This increases confidence among partners and groups and reduces misunderstandings, which can lead to loss of trust [71].

All parts of the NHP organizational structure work in synergy to define direction and priorities. This ensures that work is done efficiently and to a high standard. The Steering Group is made up of senior representatives from each partner organization. The Steering Group is responsible for the NHP's strategic direction including development and delivery of the operating plan. The Secretariat supports the Steering Group and sub-groups by managing governance, funding and supporting the delivery of research and advice. The four subgroups take direction from the Steering Group and support from the Secretariat, to define, prioritize and coordinate activities for the development and delivery of scientific research, natural hazard information, and advice for target audiences. The subgroups are also tasked with raising awareness, reviews and future directions of the NHP.

2.4. Disaster risk reduction products and services

The NHP is unique to many other national disaster risk platforms through its focus on impacts and its ambition to deliver expert, consistent, and coordinated advice, from a single source, across the entire

Table 1
Natural Hazards Partnership member organizations and their official online descriptions.

Organization	Official Description
British Geological Survey (BGS)	A world-leading geological survey. It focuses on public-good science for government, and research to understand earth and environmental processes.
Cabinet Office	Supports the Prime Minister and ensures the effective running of government. It is also the corporate headquarters for government, in partnership with HM Treasury, and it takes the lead in certain critical policy areas.
Centre for Ecology & Hydrology (CEH)	A world-class research organization focusing on land and freshwater ecosystems and their interaction with the atmosphere.
Department for Environment, Food & Rural Affairs (DEFRA)	The UK government department responsible for safeguarding our natural environment, supporting our world-leading food and farming industry, and sustaining a thriving rural economy. Its broad remit means it plays a major role in people's day-to-day life, from the food we eat, and the air we breathe, to the water we drink.
Environment Agency (EA)	Works to create better places for people and wildlife, and support sustainable development.
Government Office for Science (GOScience)	Ensures that government policies and decisions are informed by the best scientific evidence and strategic long-term thinking.
Health and Safety Executive (HSE)	Britain's national regulator for workplace health and safety. It aims to reduce work-related death, injury and ill health. It does so through research, information and advice, promoting training; new or revised regulations and codes of practice, and working with local authority partners by inspection, investigation and enforcement.
Met Office	The UK's National Weather Service. It provides weather and climate-related services to the Armed Forces, government departments, the public, civil aviation, shipping, industry, agriculture and commerce.
National Centre for Atmospheric Science (NCAS)	A world leader in atmospheric science.
National Oceanographic Centre (NOC)	The UK's national centre of excellence for large scale oceanographic research.
Natural Environment Research Council (NERC)	The leading funder of independent research, training and innovation in environmental science in the UK.
Ordnance Survey (OS)	Great Britain's national mapping agency. It carries out the official surveying of GB, providing the most accurate and up-to-date geographic data, relied on by government, business and individuals. It is a government owned company as well as a non-ministerial department.
Public Health England (PHE)	Protect and improve the nation's health and wellbeing, and reduce health inequalities.
Scottish Environment Protection Agency (SEPA)	Scotland's principal environmental regulator, protecting and improving Scotland's environment. Scotland's national flood forecasting, flood warnings and strategic flood risk management authority.
Scottish Government	The devolved government for Scotland has a range of responsibilities which include: health, education, justice, rural affairs, housing and the environment. Some powers are reserved to the UK government and include: immigration, the constitution, foreign policy and defense.
UK Space Agency (UKSA)	Responsible for all strategic decisions on the UK civil space programme and provide a clear, single voice for UK space ambitions.
Welsh Government	The devolved government for Wales. Working to help improve the lives of people in Wales and make the Welsh nation a better place in which to live and work.

UK disaster risk reduction community. The NHP focuses on the preparedness and planning elements and activities of the Disaster Management Cycle (e.g. [46]). In the case of a disaster, the relevant mandated organization(s) (see Table 2) provide warnings and respond as necessary although the NHP does have a role in helping government to identify individual partners and experts to be called upon to provide input both nationally and internationally including at the UK Government's Scientific Advisory Group for Emergencies (SAGE) committee.

The provision of long-term, high-level strategic advice and evidence for national decision-making through to the development of early warning systems and communication strategies for local and regional emergency planners is undertaken and produces:

- The **Daily Hazard Assessment** (DHA): An 'at a glance' overview of potential natural hazards and health implications that could affect the UK over the following 5 days (Fig. 4). It is the primary and most visible service coordinated and delivered by the NHP. NHP partners, responsible for the mandates or legislated warnings for each natural hazard (Table 2), provide expert hazard warning advice and information for inclusion in the DHA to help increase the UK's resilience community's ability to respond to, and be prepared for, multi-hazard events by providing multi-hazard early warnings. It contains links to more detailed information, provided by the responsible authority, about each highlighted hazard. This helps users gain more value from existing services as all the required information is accessible in one location, speeding up decision-making and response. The DHA is available on a daily basis to all UK Category 1 and 2 responders (emergency services and supporting organizations) using the Met Office's Hazard Manager [56] and ResilienceDirect™ [73] web services. At the time of writing, 952 email addresses and 97 phone numbers from 376 individual organizations, including emergency services, government organizations and local authorities are signed up to receive the DHA from Hazard Manager via email or SMS respectively. The DHA uses the NHP Hazard Matrix [63] to assess 12 natural hazards with hazard assessments up to 5-days ahead. The Hazard Matrix colors are consistent across all natural hazards resulting in a consistent message for impact assessment. It also allows for comparison of hazards based on likelihood and potential impact. An internal report found that emergency and resilience professionals regard the DHA to be clear, reliable and useful, valuing the all-hazards approach and summary maps. While those in operational emergency response roles considered the DHA less immediately useful, those in strategic and managerial roles used it to increase their situational awareness and provide a 'heads-up' for the coming week.
- **Science Notes** [64]: A series of publically available short guides that provide additional hazard background information for each natural hazard (Fig. 4). These notes have been produced by the relevant expert NHP partner/s. Each gives a brief introduction to a natural hazard and highlights key aspects that may need to be taken into account in decision-making during an emergency. They are not intended to be a comprehensive analysis or indicate what may happen on a specific occasion. Instead, they provide generic information, signpost issues that are likely to be important, and provide links to more detailed information sources. The NHP Science Notes are published on the NHP website [65] and supported by one-page **Hazard Overviews** providing key information on the natural hazard and their potential impacts.
- Support for disaster risk preparedness: Individual NHP partners have provided expertise and advice to the **UK's NRA and National Security Risk Assessment**, led by the Cabinet Office, which extends the NRA assessment to a 5–20 year timescale. This includes the identification of potential natural hazards for inclusion and assessment, the coordination of NHP partners to support lead government departments in developing robust 'reasonable worst case scenarios' for natural hazards, and provision of experts to independently

Table 2

Natural Hazards Partnership's (NHP) Natural Hazards Landscape highlighting which organizations are involved with which aspects of natural hazards, compiled by the NHP Steering Group. Organizations in bold are current NHP members.

Natural Hazard \ Responsible Organization	British Antarctic Survey	British Atmospheric Data Centre	**British Geological Survey**	**Centre for Ecology & Hydrology**	Department for Regional Development	**Department for Environment, Food and Rural Affairs**	Department of Health	**Environment Agency**	Flood Forecasting Centre / Scottish Flood Forecasting Service	**Met Office**	**National Centre for Atmospheric Science**	**National Oceanographic Centre**	Natural England	Natural Resources Wales	Department of Agriculture, Environment and Rural Affairs (Northern Ireland)	**Public Health England**	River Agency (Northern Ireland)	**Scottish Environment Protection Agency**	**UK Space Agency**	Civil/Military/Research Organizations/Asset Owners
Severe Weather: Rain, Wind, Snow, Ice, Fog								Q		Qⓘ▲[1]				Q				Q		Q
Flooding-River								Qⓘ▲[2]	ⓘ					Qⓘ▲[2]			Qⓘ	Qⓘ▲[2]		Qⓘ[3]
Flooding-Coast								Qⓘ▲[2]	ⓘ			Q		Qⓘ▲[2]			Qⓘ	Qⓘ▲[2]		Qⓘ[3]
Flooding-Surface Water									ⓘ					Qⓘ			Qⓘ	Qⓘ		Qⓘ[3]
Flooding-Groundwater			Q					Qⓘ▲	ⓘ					Qⓘ▲			Qⓘ	Qⓘ		Qⓘ[3]
Ash Rich Volcanic Eruption			Qⓘ	Qⓘ		Qⓘ				Qⓘ	ⓘ							Qⓘ		Q[5,6]
Effusive Volcanic SO_2 Eruption			ⓘ			Qⓘ		Q						Q	Q	ⓘ		Qⓘ		
Space Weather	ⓘ		Qⓘ							Qⓘ[7]										Q[6]
Landslides			Qⓘ																	Q[8]
Wildfires										Qⓘ			Qⓘ	ⓘ						Q[9]
Temperatures (hot or cold)							ⓘ			Qⓘ						Qⓘ				
Air Quality						Qⓘ		Q		ⓘ				Q	Q			Q		
Aero Allergens										Qⓘ										
Earthquakes			Qⓘ																	
Drought/Water resources			Q	Qⓘ	Qⓘ			Qⓘ		Qⓘ				Qⓘ			ⓘ	Qⓘ		Qⓘ[10]
Space Objects and Near Earth Objects		Q[11]																	Qⓘ	
Avalanche			Qⓘ																	Qⓘ[12]
Tsunami												Q								Qⓘ[13]

Q = Monitoring and Detection, ⓘ = Forecasts and advice including information services, ▲ = Mandated or legislated warning (Early Warning Systems). Subscripts provide more information on the associated service, organization or group: [1]*National Severe Weather Warning Service;* [2]*Floodline;* [3]*Local Lead Flood Authorities;* [4]*Provided by Volcanic Ash Advisory Centre;* [5]*Including Iceland Meteorological Office, Smithsonian Institute (USA), Met Office Civil Contingencies Aircraft;* [6]*Universities and Research Institute;.* [7]*Met Office Space Weather Operations Centre;* [8]*Site owners/operators, Infrastructure owners and operators, Local Authority, Public;* [9]*Fire Authorities, National Parks and Forestry Commission;* [10]*Water Companies;* [11]*Including the National Aeronautics and Space Administration;* [12]*Sport Scotland;* [13]*Channel Coastal Observatory.*

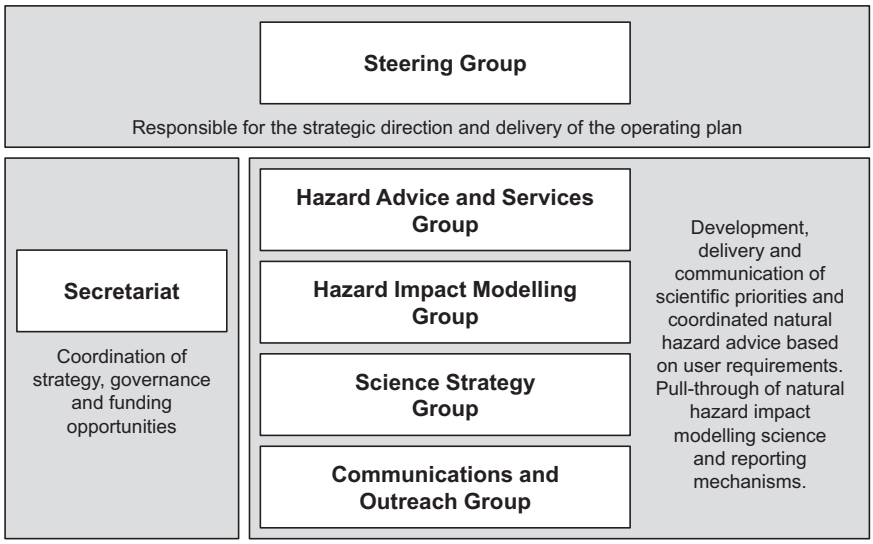

Fig. 3. Natural Hazards Partnership organizational structure with brief role descriptions.

review the natural hazard risks within the NRA. This level of advice is nationally sensitive and is only accessible to a select group of stakeholders.

- The development of a **Hazard Impact Modelling** programme to support impact-based decision-making. The programme is facilitated by the Hazard Impact Modelling Group, with the aim of creating a series of Hazard Impact Models (HIMs) as the basis for establishing a world-class hazard impact forecasting service.

2.4.1. *Hazard Impact Modelling*

The Hazard Impact Modelling programme represents the broadest

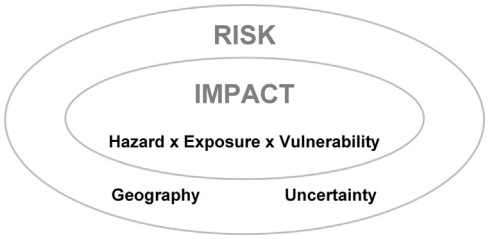

Fig. 5. The relationship between impact and risk as understood by the Natural Hazards Partnership.

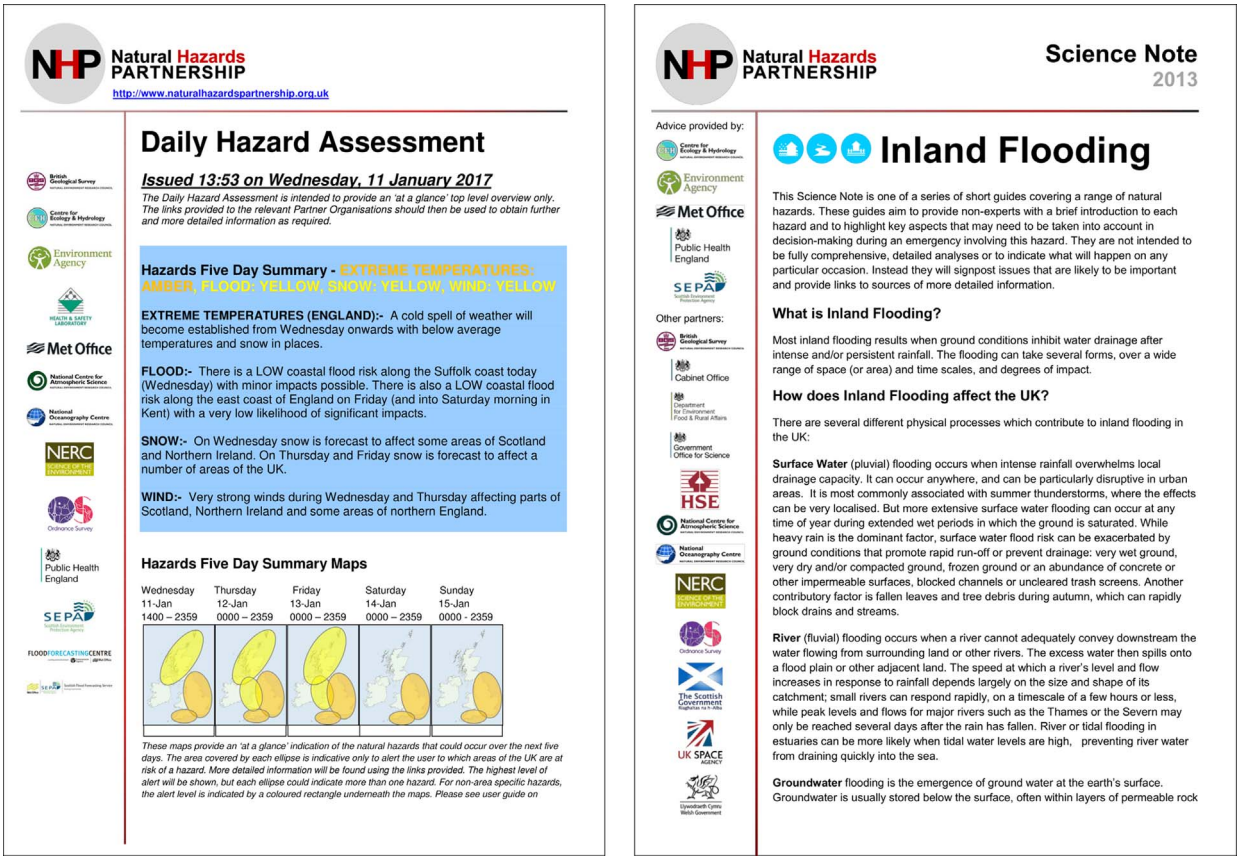

Fig. 4. Examples of NHP services and advice: The Daily Hazard Assessment (Left), and Science Notes (Right).

and most active scientific and technical activity within the NHP. HIMs are built around a set of related concepts (Fig. 5). Risk and impact are calculated as a product of the natural hazard phenomenon; the exposure of people, property and assets - receptors, that may be affected; and vulnerability, which increases a receptor's susceptibility to the hazard. These factors determine how severe the effects are. Impact and risk differ in that impact defines the total effects of a single event, whereas risk incorporates uncertainty via analysis of probabilistic distributions of hazard severities, exposure levels and vulnerability characteristics. This algorithm occurs within geographic space, which includes the hazard footprint and the location and distribution of potentially exposed receptors. Combining the potential impact of an event with its likelihood provides an overall risk assessment, which is interpreted through established risk matrices (e.g. [55]).

The HIM algorithm is similar to that of the (re)insurance industry's catastrophe (CAT) models [36], but there are significant differences. CAT models have been developed since the late 1980s to support risk pricing, portfolio management and capital requirements [47] on a global scale. Consequently, their inputs are large catalogues of computer-simulated catastrophes, high-resolution vulnerability data mainly focused on property, and a financial module to translate physical damage into estimated monetary loss. These components are analysed to provide a probabilistic risk assessment [35]. Due to their commercial nature, most CAT models are inaccessible 'black boxes' [33], however projects like Oasis Loss Modelling Framework are seeking to unlock and change the world around CAT modelling to better understand risk in insurance and beyond [70].

On the other hand, HIMs provide evidence to operational decision-makers by using forecasting data to identify potential impacts before and during natural hazards. Consequently, they are designed to be capable of running multiple times a day in operational settings. Their hazard inputs are forecast meteorological model data with outputs providing an assessment of potential impacts and risk on a UK scale. Financial measurements are not included as these are not critical to the users.

HIMs combine environmental, population and infrastructure data with expertise from NHP partners to identify potential impacts on receptors from a range of natural hazards. Currently, each HIM focuses on a single natural hazard with outputs relating to hazard extent and severity, potential impacts and risk. From the list of hazards identified in Table 2, the NHP identified surface water flooding, high winds and landslides as hazards in which the creation of a HIM was achievable and would be of most benefit to potential users in supporting forecasting and warning services.

The NHP Surface Water Flooding HIM was commissioned by the FFC and Environment Agency. The work is led by the Centre of Ecology & Hydrology (CEH) in collaboration with the Met Office and Health and Safety Executive (HSE) with input from JBA Consulting and King's College London. The Surface Water Flooding HIM takes a pixel-based approach to link probabilistic surface water runoff forecasts produced by the CEH's Grid-to-Grid hydrological model with pre-calculated Impact Library information to generate impact assessments [2,14,60]. These are combined to estimate flood risk as a combination of impact severity and forecast likelihood, at 1 km pixel level, and summarized for counties and local authorities. The second phase of this project has recently drawn to a close with the creation of an end-to-end prototype currently being trialed in an operational environment at the FFC in the Met Office.

The high winds HIM work is led by Met Office with data input from HSE. There are currently three wind HIMs each with a focus on a particular receptor type deemed to be more vulnerable. These include high-sided vehicles, exposed bridges and camping and caravan sites. The Vehicle OverTurning (VOT) model forecasts risk of disruption on the UK road network during a high wind event [40]. It is used by Met Office meteorologists to aid decision-making in the issuing of NSWWS wind warnings to the public and is also currently being trialed by Highways England to provide information and assistance during high winds. The Bridge Model forecasts the probability of bridge restrictions and closures due to high winds; it is currently in development in association with Transport Scotland. The Camping and Caravanning Model forecasts risk of disruption to camping and caravanning activities, it is especially useful during summer months when high winds are uncommon but if they do occur, they can impact upon leisure activities.

The landslides HIM is led by the British Geological Survey (BGS) in collaboration with CEH and HSE. Scientific research at BGS is currently developing an understanding of regional landslide hazard characteristics and developing landslide forecasting methodologies. These methodologies are using landslide domains related to landscape evolution, geology and characteristic landscape process [18] to evolve the landslide hazard assessment. These domains are being evaluated against the National Landslide Database maintained by BGS [31,76]. This is improving understanding of landslide hazards, which will form a key component in the landslides HIM and a landslide forecast in the UK.

The aim of developing HIMs is to provide a consistent approach and method for assessing the potential impacts and risks of natural hazards across the UK. A range of methods, terminologies, modelling structures and output processes have been applied to current HIM development and this is likely to diversify as additional HIMs are created. The diversity of approaches carries the potential to limit analysis when comparing output of multiple HIMs. Consequently, an overarching Hazard Impact Framework (HIF) has been created to provide guidelines and protocols for HIM development ensuring consistency in HIM inputs,

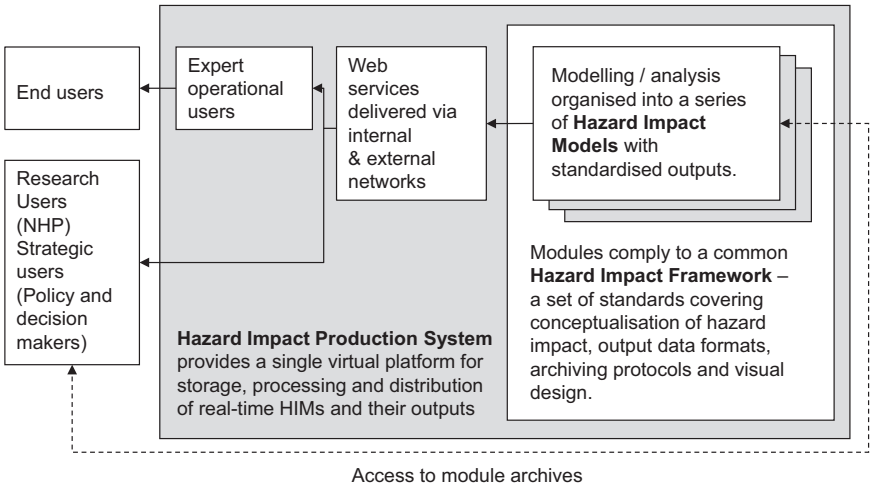

Fig. 6. Structure of the Natural Hazards Partnership's Hazard Impact Modelling programme, which includes the Hazard Impact Model, Hazard Impact Framework (HIF) and Hazard Impact Production System (HIPS).

processes and outputs. The HIF is a key achievement for the NHP as it establishes the standards and framework for future scientific collaboration and scientific project development. The HIF contains definitions of core concepts and processes used in the NHP and details a common, sustainable approach for creating HIMs. This helps to ensure that future NHP research follows robust scientific methods and can be aligned (where possible) with previous and future projects. This means that NHP HIMs will be created to a satisfactory and acknowledged level of quality and accuracy, and outputs across hazards will be comparable and produced in similar formats. In future, this will also allow for HIMs to be combined enabling the creation of multi-hazard HIMs to compliment the HIF development. A virtual environment, the Hazard Impact Processing System (HIPS), is being developed to provide a single digital platform for the storage, processing and distribution of real-time HIMs and their outputs (Fig. 6).

3. Benefits and challenges of multi-organizational collaboration

The multi-organizational partnership working that underpins the NHP was established to realize a number of benefits, both for the partnership organizations and the wider response/resilience community. However, the NHP has also had to overcome a range of challenges raised by collaborative working.

3.1. Communication

Geographical dispersion of members is a major barrier to communication channels within partnerships [38]. Embracing dispersion allows partner organizations to work on their components of a project task in their own specialized environments. However, if project tasks and final goals are not clearly defined, problems can arise when components need to be integrated for testing [59]. NHP groups make a point of conducting face-to-face meetings because partners are located across the extent of Great Britain. These meetings occur at regular intervals throughout the year. As a core feature of the NHP, face-to-face meetings provide familiar environments that enable interactive discussion of complex issues [16,83]. Furthermore, physical meetings assist with development of personal and social interactions, and the reinforcement of project deadlines and common goals that collectively build trust and demonstrate commitment to the partnership [61].

Face-to-face meetings are critical to the working of the NHP and have proven to be productive and valuable. However, this approach often requires extended travel times and overnight stays, which represent considerable time commitments, higher financial cost and significant dedicated effort. This is further complicated when also managing participant availability and finding appropriate locations. Consequently, some subgroups have had to reduce the number of face-to-face meetings that occur in a year in favor of other forms of communication. For example, teleconference facilities are commonly utilized as they are quicker to organize and require less commitment to attend. The partnership is also exploring communication technologies such as video conferencing as an alternative to traditional methods. Notably, the NHP HIMG are engaged in the development of cutting-edge virtual research environments within the EVER-EST Horizon 2020 project [29]. This is exploring enhanced methods of collaborative working; including platforms for model development, and analysis, alongside e-infrastructure for communication, and sharing of information [52]. These approaches are less costly than face-to-face meetings and can provide more interactivity than teleconferences. However, partner organization technology infrastructures may impede the adoption of these approaches [83]. Olsen and Olsen [71] suggest that new technology also introduces new behaviors which users must learn and agree in order to conduct productive conversations. These may include how to take turns in a digital conversation and how to signal intent to speak or contribute. This factor grows more complicated as meeting participation increases.

Establishing secure and efficient channels for sharing data and documents between all NHP groups and members is a challenge that has required continual, dedicated effort from the Secretariat team. Typically, documents are shared via email. However, this presents challenges for large file sizes and the coherent collection of comments or feedback. An online document sharing environment for the NHP is used to overcome this. The environment presents a single repository that allows users to view and securely edit documents and reports. Due to the security of the site a login is required and the interface has limited intuitiveness. This presents obstacles and, along with limited IT capabilities at some partner organizations, has discouraged some members from fully engaging with the system. This means that the full benefits of such an environment cannot be fully realized. Going forward, the NHP recognizes the need to find improved solutions for sustainable support and secure sharing of data and knowledge. It is foreseen that projects such as EVER-EST will allow NHP members to better engage with new technologies and overcome some of the obstacles faced [52].

3.2. Sustainability

A successful collaboration depends on motivation and input from each member [48]. Partners must all contribute towards the collaboration and they must all receive an incentive for being part of the group. Within the NHP, the remit of many of the partners aligns with NHP tasks. Therefore being part of the partnership makes their work more efficient as partners can draw from a diverse pool of experience and knowledge. For others, the incentive lies in the privilege and reputation gained from being part of a large governmental collaboration with a high-priority public focus. All partners contribute resources or time into the partnership at different levels and to different degrees. This is largely dependent on current priorities and available resources.

Financing the NHP is a perennial and significant challenge. The current system of in-kind contributions and funding awards from government departments is not ideal for long-term collaborative sustainability [37]. Without a consistent, reliable stream of sustainable funding, and internal resourcing issues, all NHP partners have found it increasingly difficult to contribute to or attend NHP steering group and sub-group meetings. This has inevitably compromised the effectiveness of the NHP and sometimes results in the partnership missing out on grant opportunities and being unable to meet project deadlines. It has also restricted the ambition of the NHP and the scope of activities that the NHP as a whole has been able to undertake and deliver.

Private enterprises in Public-Private Partnerships generally provide a source of steady capital investment [5]. However, the current NHP construct does not easily allow the involvement of the private sector due to the differing commercial business models of the respective NHP partners. Further, the differing organizational structures of NHP partners means that not all partners are eligible for certain funding opportunities. While this has largely been resolved internally by the NHP through a system of subcontracting, the solution is not ideal and can lead to delays in bidding for funds and project initiation. Additional complications arise through the unique nature of devolved governments in the UK. On the other hand, the NHP does not have the profit-making focus often found in Public-Private Partnerships. This means that all resources and funds can be invested into developing science and related services. This, out of necessity, bases the NHP on stronger foundations of trust and cooperation, improving the chances of stability [50]. This is relevant and useful for public policy applications in general, and disaster risk reduction in particular [9] as solidarity built between NHP organizations is represented as solidarity across the public sector, which instills a greater confidence from the general public. This in turn has been shown to translate into better public services [10].

In other countries, more substantial costs are often financed by a larger sponsor organization such as central government [37]. This

replaces the need for private investment or piecemeal grants and allows partners to plan resources in the long-term. For example, the Pacific Disaster Centre received $30 million from the USA government for its partners to develop tools and services [86]. The Natural Hazards Research Platform in New Zealand receives $14 million from the Ministry of Business, Innovation and Employment. This funding is used to generate grants for long- and short-term external projects [66,77]. Consequently, the NHP is actively investigating sources of sustainable funding to facilitate longer-term strategic planning, which is critical for building resilience to natural hazards, and typically favored by the public sector [30]. Gaining long-term support, particularly from central government, would provide the NHP with a legal mandate, giving the NHP much needed sponsorship, and providing the UK disaster risk community with a clear, unifying focal point.

3.3. Extending the collaboration

The NHP is a guiding example of collaboration across the public sector. However extension of collaboration beyond the NHP, across the wider Civil Service, continues to make extensive demands on already stretched resources. Despite this, the aims of the NHP and reputations of the member organizations have resulted in the engagement of other partnerships, projects and initiatives that want to collaborate. These 'partnerships of partnerships' have helped the NHP to fill gaps in the fulfillment of its vision in supporting the UK's disaster risk management strategies and information dissemination. Non-NHP collaborators have also benefitted from receiving access to world-leading natural hazard science and advice and from the increased reach and recognition of working with the NHP. However, maintaining communication networks between partnerships has added another layer of bureaucracy increasingly restricted by coordinating availability and agendas, and securing necessary resources.

Robust scientific practice underpins the activities of the NHP. To help ensure that the partnership remains at the cutting edge of disaster risk science, the NHP interacts with a number of relevant data providers such as Environmental Science to Services Partnership (ESSP) [28] and Space for Smarter Government Programme (SSGP) [84] who facilitate the use of the latest environmental data across the public sector. The NHP also holds positions on the advisory board of the joint funded Natural Environment Research Council (NERC)/Met Office Flooding From Intense Rainfall (FFIR) programme, which aims to reduce the risks of damage and loss of life caused by surface water and flash floods [13].

To ensure natural hazard information and advice gets to the correct people in a timely and understandable manner, the NHP is also collaborating with a number of initiatives from the UK's environmental services and hazard resilience communities. These initiatives include the UK Alliance for Disaster Research (UKADR) [93], ResilienceDirect™ [73], Business Emergencies Resilience Group (BERG) [6] and Thrivespring [89]. This has been particularly relevant through the collaboration with the National Centre for Resilience (NCR) [80]. The NCR is a multi-agency partnership, working with partners across Scotland and the UK. The NCR aims to support those operating on the ground with practical solutions and by enhancing knowledge of, and preparedness for natural hazards. This collaboration has highlighted the role of the NHP in a knowledge brokering and translational capacity by ensuring that complex scientific and technical natural hazard advice reaches the Scottish resilience community in a timely fashion. This role has been fulfilled thanks to the NHP reaching out to new networks and communities of interest, hence creating a "ripple" effect. These collaborations allow NHP partners to better understand the practical needs and expectations of the wider resilience community. This knowledge feeds into NHP work plans, ensuring products and services are both suitable for, and required by, the users.

4. Conclusions

This paper has presented the Natural Hazards Partnership (NHP) as a relevant, trusted and successful partnership for UK natural hazard disaster risk reduction. The NHP's focus and priorities distinctively position the partnership to assist the UK, Scottish and Welsh governments in aligning with the internationally agreed Sendai Framework. International organizations such as the United Nations Office for Disaster Risk Reduction, European Commission, Organization for Economic Co-operation and Development, World Health Organization, World Meteorological Organization are also acknowledging the role of the NHP and the importance of its work.

As far as the authors are aware, the NHP is unique in the global context. Other initiatives exhibit elements of the NHP; however, none demonstrate such a strong and wide-ranging national inter-organizational natural hazard "research-to-operations-to-responder" focus. This includes a comprehensive range of impact-based natural hazards information and advice aimed at stakeholders including national governments, local responders and the general public. These products and services have been demonstrated to successfully deliver a 'one voice' philosophy ensuring natural hazard advice is coordinated and consistently messaged across multiple communication channels. Working with other communication channels, whilst in close collaboration with other initiatives, has ensured that advice is delivered to those that need it as effectively as possible.

Collaborative scientific research is one of the keystones and benefits of the NHP. The NHP is leading the way in moving from hazard-based to impact-based natural hazard research to better understand and forecast potential impacts. Impact-based forecasts are useful because they provide a 'What does this mean to me?' explanation resulting in improved understanding, preparedness and resilience. The NHP's cutting-edge Hazard Impact Modelling research programme is helping to answer this question. Innovative techniques are being used to assess likelihood and potential impact and the Hazard Impact Framework is helping to ensure consistency between multiple Hazard Impact Models. The diversity of scientific expertise within the NHP enables it to address highly complex situations and helps to ensure that work is completed efficiently to produce scientifically robust and practically relevant forecasting models. This scientific basis underpins and informs the services offered by the NHP and its partner organizations. These are subsequently applied to improve guidance to the government and to the public on mitigation and adaptation strategies for individual natural hazards, and in the future, linked and compounding hazards.

Despite the NHP's success, the partnership faces a number of significant challenges. Central government ownership and an associated source of sustainable funding is needed to maintain and advance current work to fully achieve the aims of the NHP. Maintaining and improving consistent and clear communication is critical in building a successful partnership especially with partners situated in different locations. To this end, face-to-face communication has proved extremely valuable for generating project insights, exploring abstract concepts and building personal and working relationships. The restrictive financial costs and resource demands associated with this form of communication are being addressed by the NHP through a proactive review of new communication technologies, including virtual research environments, to complement established methods and to reduce costs without reducing the benefits. However, the availability of these solutions in the longer term is still uncertain.

The multi-disciplinary response to solving complex scientific problems undertaken by the NHP could be completed by its individual organizations without the partnership. However, the work would take longer, be less efficient, less coordinated and more costly. The value in the work of the NHP is not just in the development of products, services and research but also in the building of organizational and individual relationships and trust within the public sector, providing, among other

things, a catalyst for innovation and growth. This is providing a strengthening basis for the longer-term strategic view necessary for a successful national disaster risk platform.

Acknowledgements and Disclaimer

This paper is supported by the Natural Hazards Partnership and has been jointly funded by the Health and Safety Executive and the Met Office. The authors wish to thank the two anonymous reviewers as well as all individuals involved in the NHP. Specifically, the authors would like to thank Timothy Aldridge, Dr Helen Balmforth, Adam Baylis, Dr Steve Cole, Adam Cook, Dr Rutger Dankers, Paul Davis, David Faichney, Ben Fletcher, Katy Freeborough, Professor Brian Golding, Virginia Hannah, Melanie Harrowsmith, Gavin Iley, Deborah Lee, Ian Lisk, Dr John Mooney, Robert Moore, Alessia Morris, Professor Virginia Murray, Hazel Napier, Dr Helen Reeves and Ian Ridgway for their considered review of previous drafts and their valuable insights and suggestions throughout the course of writing this paper. The Health and Safety Executive contributes specialist hazard impact assessment and population modelling that is also used in support of its own regulatory activities. The contents of this paper including any opinions and/or conclusions expressed, are those of the authors alone and do not necessarily reflect HSE policy.

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