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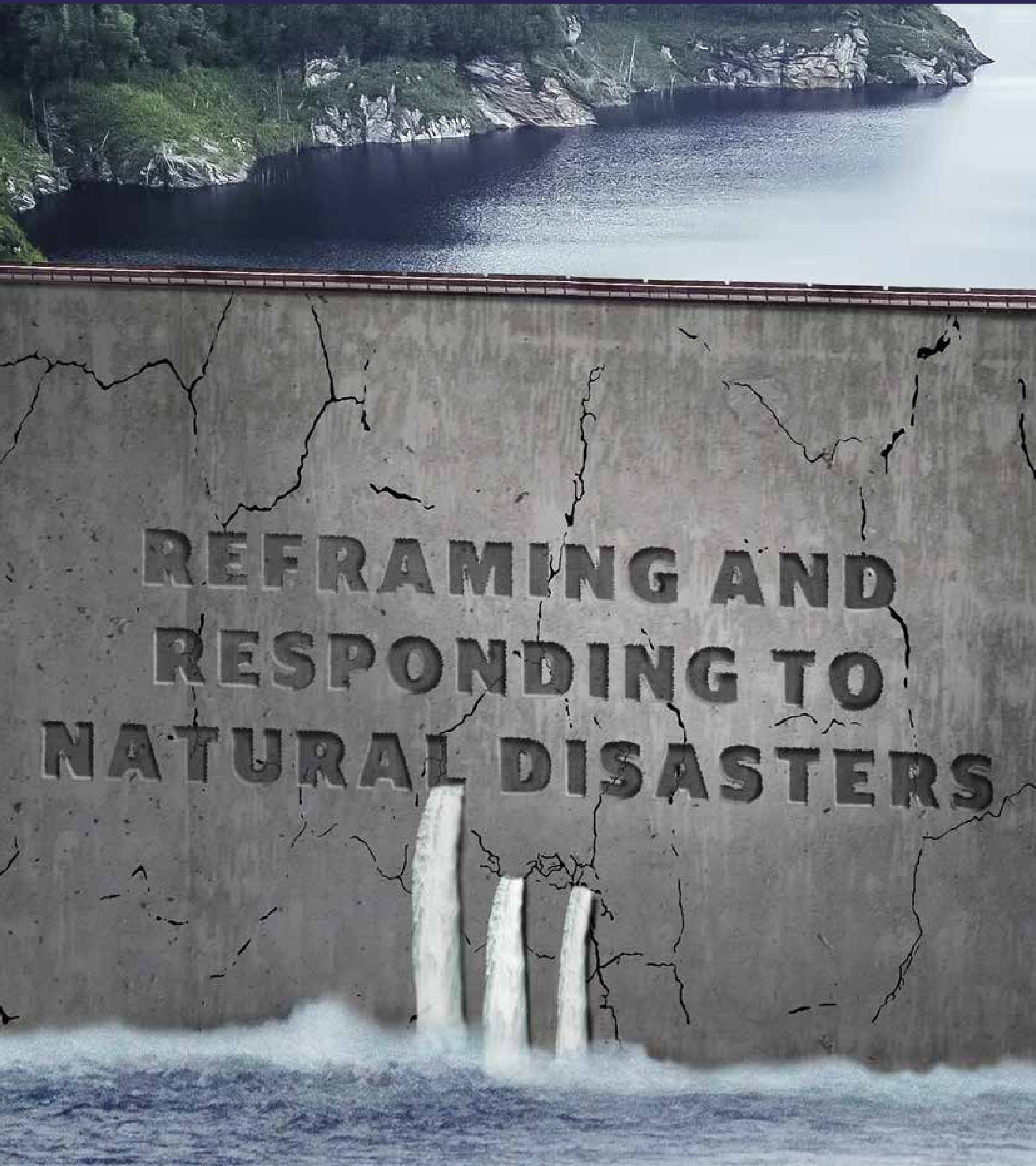

EDITORIAL

No longer natural

Across the globe, news reports highlight the range, diversity and severity of environmental hazards and their impacts. From my perspective these fall into two broad categories: chronic hazards (such as drought and long-term sea-level rise) and acute risks (such as a volcanic eruptions or flash floods). This issue of the environmental SCIENTIST highlights a range of key hazards and our collective societal responses to them. A key issue raised concerns the inequalities that exist across the world and within society – it is the poorest and most disadvantaged that face the greatest risk from the impacts of environmental hazards. From this perspective it is important that the environmental risk is characterised by addressing its component parts:

Risk = hazard x exposure x vulnerability

This will help to keep the focus not only on the physical nature of the hazard and exposure components, but also the societal issues.

Overshadowing all environmental hazards are those associated with climate change. The increasing rate of change and the severity of the associated impacts are pervasive and extremely damaging. The recent public upsurge in activism around environmental issues, from climate change to fracking, plastics, air pollution and species loss, appears to be concentrating the minds of politicians (in most parts of the world). The Greta (Thunberg) effect is galvanising an often-fragmented grassroots collective into more concerted and focused action. The notion of the (un) natural hazard addresses the fact that many of the risks that societies and environments face are the result of anthropogenic influences on what used to be seen as purely natural hazards. However, due to present and future climate change it is becoming increasingly difficult to separate the anthropogenic and natural contributions to heatwaves, floods or droughts. Many of these will have an anthropogenic influence from a number of sources – through changing exposure (more people living on a floodplain) or more vulnerable communities (those who are poorer or disadvantaged in other ways).

The key environmental issues of our time are not discreet and isolated – they are inextricably linked and it will be more efficient to apply solutions that address multiple concerns. For example, tackling plastic production and waste will lead to reduced carbon emissions and resource consumption. And some environmental issues could be completely avoided: for example, if we adhered to the carbon budgets indicated by the Paris agreement would we really need to expose society to seismic shocks from fracking?

I've been working in the climate change arena for nearly 30 years; for most of that time, practitioner and policy-making communities have been slow to react. I now know that the practitioner community is ramping up its work, yet the policy community is still lagging behind and is not reacting quickly enough to our climate and environment emergency. There has never been a more important time for Environmental scientists to raise their profile and set about defining the solutions to solve the climate and environment emergency that we are faced with at present, Greta cannot do this on her own.

Professor David Viner FIEnvSci is the Global Head of Climate Science for Mott MacDonald. He has been involved in climate change work for over 30 years and is currently a Co-ordinating Lead Author for the IPCC's *Sixth Assessment Report*. He is actively involved in both the scientific understanding practitioner response and to climate change risks.

Cover design: Matt Cotterill is a graphic designer based in Hackney. His work includes publication design, branding, and exhibition design. He works at creative content agency SevenC3.

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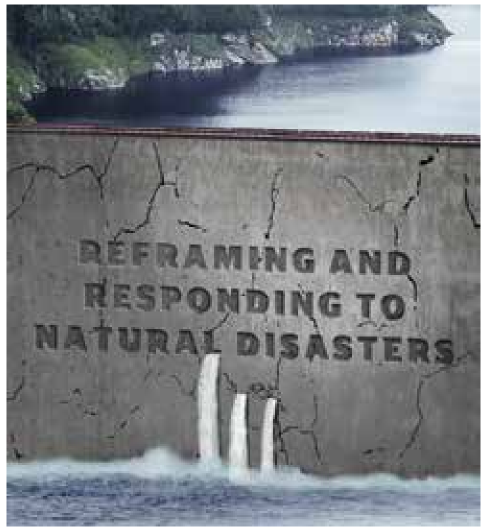

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INTRODUCTION

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Human activities and natural hazards

Louise Bracken and **Julian Williams** review the context of (un)natural disasters.

Disaster Risk Reduction sits at the heart of the world's most pressing concerns: climate change, displacement, urbanisation, pandemics, protracted crises and financial systems collapse.[1]

A substantive body of evidence has established an ever-increasing interaction between anthropogenic activities and natural hazards that societies and ecosystems across the world contend with on a daily basis. The resulting disasters are serious disruptions over a relatively short time that interrupt the functioning of a community or a society. Typically disasters involve widespread human, material, economic and/or environmental loss. We tend to refer to disasters as natural if the observed causal mechanism of impact originates from one or more Earth-surface processes, but disasters are not exclusively natural. Hence, '(un)natural disaster' is an important conceptual paradigm for those responsible for resilience planning, preparedness and post-disaster rehabilitation and reconstruction. Furthermore, through careful observation of cause and effect, research can provide both qualitative and quantitative estimates of the relative contribution of the various components of our global society on the propensity and severity of impact of events.

UNEVEN IMPACTS

Of critical importance is the sobering fact that over 95 per cent of deaths caused by disasters occur in low- and lower-middle-income countries. There are two explanations: first, the vast majority of people exposed to hazards live in low- and lower-middle-income countries; second, high-income societies have processes, infrastructure and mitigation strategies that increase their capacity to absorb adverse events – the complex notion of resilience. But even within a community there is substantial variation in impact, despite geographical proximity: gender, age and health are all significant factors in determining the degree of adversity faced when an event occurs.

Anthropogenic pressures on the environment are related to exposure in two ways. The pressure of growing populations results in an increased tendency for settlements to be located in or near areas prone to hazards (from living near unstable slopes to building on floodplains); and changes in climate can result in regions with very low exposure to hazards suddenly experiencing a rise in the number of disasters, for which populations and public-policy mechanisms may not be well prepared.

MANAGING DISASTERS

The United Nations Office for Disaster Risk Reduction (UNDRR) acts as a steward for the Sendai Framework for managing disasters. This framework has four priorities for action:

- **Priority 1.** Understanding disaster risk.
- **Priority 2.** Strengthening disaster risk governance to manage disaster risk.
- **Priority 3**. Investing in disaster risk reduction for resilience.
- **Priority 4**. Enhancing disaster preparedness for effective response and to 'Build Back Better' in recovery, rehabilitation and reconstruction.

This framework embeds the notion that the mechanisms that expose communities to hazards are a varied and complex interaction of social and physical systems. Moreover, the body of research within this domain is comprehensive and historically has a strong trans-disciplinary element, hence is well set up to support and hone the framework's goals of reducing global mortality from disasters through improved risk management, multilateral coordination and infrastructure.

Whilst the movement towards comprehensive research-driven frameworks is notable, the challenges are substantial and growing. Societies are both increasingly dependent on technology and evolving in terms of co-dependency with the other members of a given community. This change has countervailing effects. Information, advice and planning can be communicated quickly. Coordination and planning can obtain information from remote sensing. When remote-sensing data is used in combination with on-the-ground observations and extensible data-processing tools, powerful tools can be employed that yield effective results in saving lives and reducing economic impacts.

Reliance on technology, unfortunately, does not come without significant risk. The destruction of capital, both human and physical, can be substantially exaggerated if sufficient backstops are not built into an economic system, as is the case with low- and lower-middle-income countries. When economic systems fail, many of the normal aspects of community life fail. As opportunities become sparse, sudden and irreversible declines in population can occur. Compare this situation to the impact of disasters in high-income countries, where the clean-up and rebuilding processes often lead to sudden increases in economic output.

INTRODUCTION

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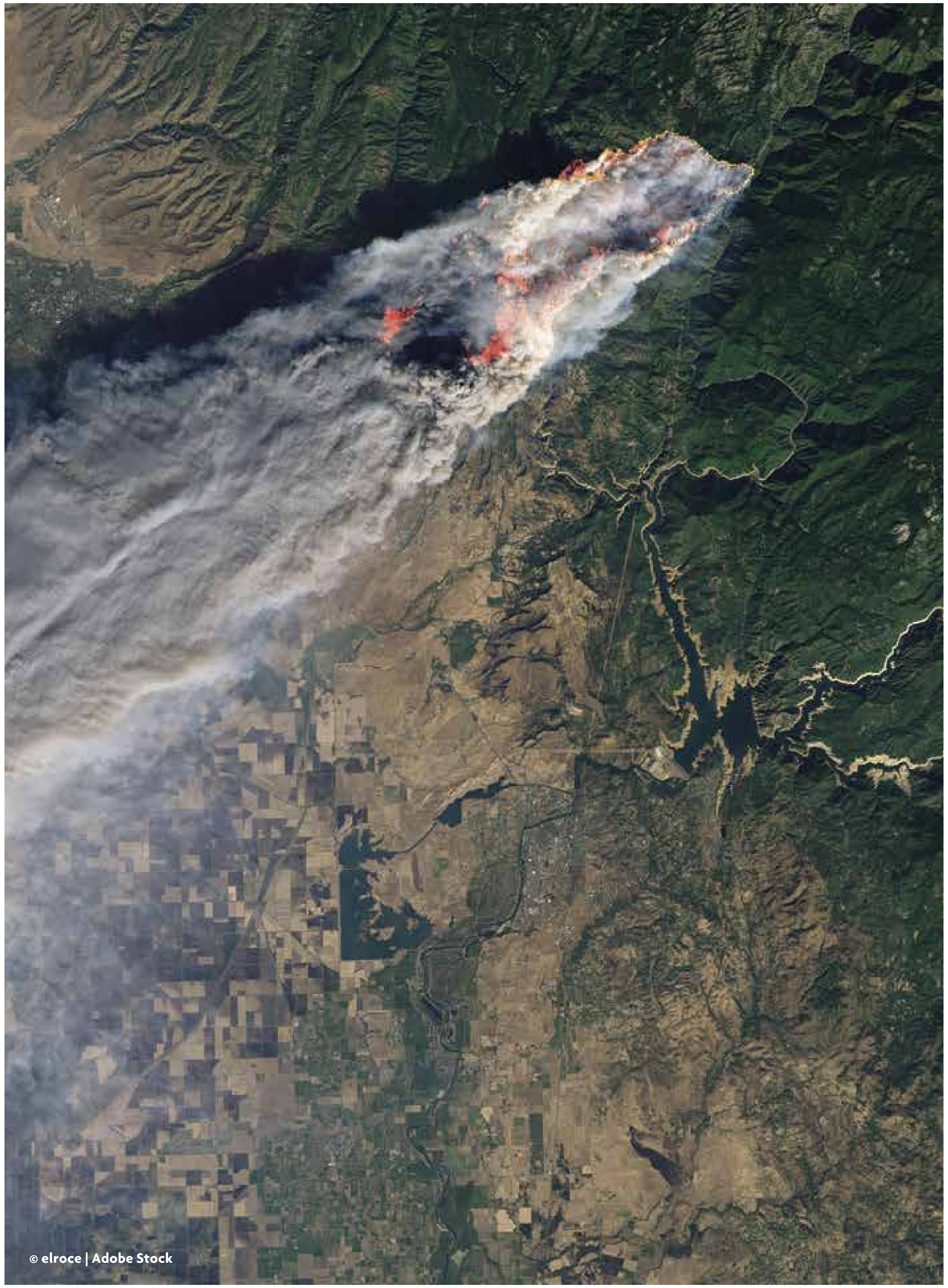

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These divergent responses due to systemic risk only exacerbate inequalities between nations and communities.

Indeed, community information and engagement and the interplay of the social contract between people and government form vital components of managing disasters, particularly in coming to terms with the inherent limits of infrastructure and the capability of policy-makers. Debate about how to intervene in natural hazards continues. The possibility of dropping nuclear weapons into tropical cyclones has been discussed within policy circles since 1959 and has been revisited more recently by the US president. At a local scale, systematic errors in thinking regarding human ability to control hazards has been observed anecdotally in flood management, the redirection of lava flows and in the deliberate manipulation of rainfall. Communicating the limits of human control is one of the great challenges facing researchers. For example, in 2012 six scientists were jailed for manslaughter because their research had not accurately predicted the likelihood of an earthquake in the Italian town of L'Aquila in 2009. The scientists' convictions were overturned, but cases such as this illustrate the way in which the public expect to be protected from disasters, the failure of the government to apply the science to the anticipated threat, and that trust is a fragile commodity when communicating risk to communities.

THE NEED FOR BETTER RESILIENCE

The need for careful measurement of risk and appropriate policies to improve resilience have never been more important. Economically, the impact of hazards can be immense and long lasting, particularly for low- and middle-income countries. The costs of the 2010 earthquake in Haiti, for example, is estimated to have exceeded 15 per cent of GDP (as an event in itself) or 120 per cent of GDP when total damages and losses are included. In larger least-developed countries, such as Bangladesh or Mozambique, the loss of 3–5 per cent of GDP due to disasters every five to ten years has a cumulative impact on development.

Whilst insurance and similar financial tools can provide some protection against economic losses, there are inherent problems. First, the supply and demand of insurance products tilt heavily in favour of those providing protection. Fair actuarial valuations are those that map directly to the underlying likelihood of an event coupled with the event's measured impact in financial terms. When markets are perfectly competitive, the cost of risk management should be identical to the product of the likelihood and the impact. However, whilst some markets have some competitive pressure, most insurance and insurance-like products are bespoke, with very limited numbers of providers. High-income countries can subsidise risk management products directly, thus removing the costly burden of setting aside capital to protect against future losses from hazards. Unfortunately, without impartial evidence on risk and impact, the cost of implementing protection schemes to preserve the assets of communities is often prohibitive and a further driver of inequality of both opportunity and resilience in the long term.

THE IMPORTANCE OF TRUST

Economic impacts after a disaster are common across communities. However, there are impacts that cannot be easily measured. Psychological recovery, both individually and as a group, requires careful direction from an appropriate evidence base. Whilst technology can assist in this process, there are very clear potential avenues for harm, through accidental and deliberate misinformation. An existing lack of trust in public policy can be exacerbated by poorly managed responses to disasters that, especially in a multi-hazard context, can lead to chains of failure in risk resilience and mitigation mechanisms. For instance, strategic management of water resources can be hampered by lack of trust resulting from sudden restrictions in supply caused by extreme weather or another hazard.

Trust is a powerful component of disaster risk management. Fragile trust mechanisms, where communities rely on expert judgement to assist in recovery, can be easily broken when processes are under pressure during a catastrophic event. Thus, through a better understanding of where our actions sit within causal chains, we can be better informed, prepared and directed in the future, but we must remember that we live with natural hazards and we cause un-natural disasters.

ES

Professor Julian Williams is the Executive Director of the Institute of Hazard and Risk (IHRR) at Durham University. He is a professor of Accounting and Finance. Julian has published widely on the topics of financial regulation, risk management and portfolio management.

Professor Louise Bracken is the Deputy Vice Provost (Research) at Durham University and the Wilson Chair in Hazard and Risk Research. Louise's research expertise is in fluvial geomorphology, flooding and how knowledge of water is used to better manage the environment.

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ANALYSIS

Putting climate change in its place

Kimberley Thomas challenges over-simplified approaches that frame climate change as the only relevant stressor on socio-ecological systems.

Sea-level rise is going to displace millions of people in Bangladesh,' a senior security analyst announced matter-of-factly to our group gathered in a small Washington, DC conference room in November 2019. It is, in this moment of heightened climate literacy, a well-worn refrain. However, it obscures a much more complex set of dynamics – one that is not amenable to pithy talking points or tidy policy recommendations.

Commentators hailing from corners as disparate as policy thinktanks, mass-media outlets, academic institutions and government agencies have, despite their many differences, converged on the idea that large river deltas are doomed. This expectation rests on an intuitive logic: coastal deltas such as those in Bangladesh and Vietnam are densely populated, low lying and braided with tidally influenced rivers. Cyclonic storms can quickly erode and redistribute enormous quantities of sediment along the coasts, destroying property and dislocating millions of people in the process. During the dry season, the Ganges–Brahmaputra and Mekong deltas also suffer from seawater intrusion, which is magnified when spring high tides coincide with droughts.

So there appear to be vanishingly few options for such regions in the face of rising sea levels. Indeed, responses tend to take one of three forms: shifting cultivation from rice agriculture to brackish shrimp aquaculture; hardening the landscape through engineered infrastructure; or relocating out of the coastal zone. Delta dynamics, however, assume a very different form when approached from a historical perspective. From this point of view, prevailing responses to climate-change hazards look more like sources of risk than wellsprings of pragmatism.

CLIMATE CHANGE AS A 'MASTER CONCEPT'

The received wisdom that human settlements in low-lying coastal areas are condemned to disappear under climate change exemplifies what geographer Mike Hulme describes as a determinist fallacy. Perhaps the most familiar of these is climate determinism, which elevates climate to 'a – if not *the* – universal predictor (and cause) of individual physiology and psychology and of collective social organization and behavior'.[1] Although this mode of thought has been roundly rejected for nearly a century, some geographers

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and casual observers continue to succumb to its allure. However, while muted versions of traditional climate determinism still circulate, a more recent, and decidedly more strident, iteration has taken shape under the guise of climate reductionism.

Climate reductionism is characterised by simplifying complex systems such that climate is given primacy as the only or most relevant explanatory variable for understanding system behaviour and response. Thus, reductive approaches emphasise climate to the exclusion of a host of other factors that influence socio-ecological change. In large part due to the wide circulation of Intergovernmental Panel on Climate Change (IPCC) reports and heightened media coverage of the topic, climate change has become the 'master concept' for analysing and addressing global environmental change. Alertness to the phenomenon of climate reductionism becomes helpful for interpreting statements such as the one that opens this article. It invites us to consider whether sea-level rise is really the sole, or even the most important, factor driving demographic and environmental change in mega-deltas such as those in Bangladesh and Vietnam.

WATER HAZARDS BY ANY OTHER NAME

The Ganges–Brahmaputra and Mekong deltas are two of the most densely populated regions in the world for good reasons. These river networks convey hundreds of millions of tonnes of sediment along their channels each year, which provide the substrate for highly productive agricultural systems centred on rice cultivation. The rivers are also habitats for diverse aquatic biota that support large, inland fisheries. Rivers make convenient thoroughfares, and large sections of these deltas are served primarily by boat rather than road traffic.

These salubrious features notwithstanding, mega-deltas also face a suite of challenges. Extreme flooding and tropical storms recur with catastrophic impacts, including fatalities, increased disease transmission, crop loss, property damage and associated disruptions to education and livelihoods. Mainstream narratives of water hazards in these deltaic environments stop there. Uncritical audiences thus perceive Bangladesh and Vietnam to be helpless in the face of the inexorable advance of climate change, with sea-level rise being the most conspicuous spectre of them all.

But people living in these environments have not been passive. In Vietnam, the introduction of high dikes in the upper Mekong delta from the 1970s to 1990s revolutionised floodwater management by not only protecting rice fields but also enabling the transition from single cropping to double and triple cropping. As a result, the Mekong Delta reliably produces an agricultural surplus that constitutes 90 per cent of Vietnam's rice exports. In Bangladesh, the construction in the 1960s and 1970s of circular embankments called polders likewise protected people and property from devastating floods and storms. These structures, in conjunction with high-yield rice varieties and other Green Revolution inputs, enabled the country to become food self-sufficient soon after their introduction. However, the Mekong and Ganges–Brahmaputra deltas did not completely get rid of water hazard risks, nor do they exist in isolation of wider dynamics of development and global trade. These factors become central to understanding the *relative* impact of climate change on these complex socio-ecological systems.

Over time, the early successes that water-management schemes generated in the two countries eventually led to widespread problems. The high dikes in the upper Mekong delta deflected flood risk onto unprotected and downstream localities. The polder system in coastal Bangladesh disrupted sediment flows that in turn decimated fish populations, increased risk of inundation and blocked navigation routes. In both countries, groundwater pumping, sand mining for construction, and other activities are driving land subsidence at rates that exceed that of sea-level rise. Upstream water diversions and hydropower development likewise starve deltas of the flows that counteract seawater intrusion and coastal erosion.

RESITUATING CLIMATE CHANGE

One must tread a fine line when challenging climate reductionism. At first it can sound as if situating hazards within a broader political economic and geographical frame is tantamount to disavowing the profound crisis that climate change represents. The intention here is quite the opposite. If we are to take seriously the grave risks of seawater intrusion, flooding, drought and erosion to two of the world's largest deltas, then it bears focusing on their root causes, including climate-change and non-climate change related factors.

Climate reductionism is apparent in government land-use policies that either surrender these deltas to sea-level rise, or attempt to fortify them against the encroaching ocean. The former entails large-scale transformation of the coastal zone to brackish-water shrimp production, which is both environmentally and socially deleterious. While shrimp aquaculture makes economic sense, financial gains come at the cost of soil and groundwater salinisation that denude landscapes of vegetation and impair human health. The low labour inputs needed for shrimp production also translate into significant reductions in employment opportunities, particularly for poor and landless households. Conversely, attempts to protect land and freshwater from sea-level rise entail more of the same hard infrastructural measures (embankments, sluice gates, sea walls, etc.) that perpetuate existing hazards along the lines described above.

▲ **The Ganges-Brahmaputra River delta, the largest in the world, covering parts of Bangladesh and India. ©NASA**

Proponents of these contradictory approaches typically frame them as facilitating adaptation or resilience. However, in making their argument for considering stressors beyond climate change, Sharachchandra Lele and colleagues[2] point out that:

Both concepts [adaptation and resilience], if taken at face value, assume that the condition prior to the predicted change or unpredicted shock was acceptable or desirable. In the context of water, this means assuming that 'these regional ecosystems and human activities are usually reasonably well adapted to the current climate conditions, but may be vulnerable to large or rapid changes'.[3]

The examples from Vietnam and Bangladesh challenge such assumptions, indicating instead that mega-deltas are dynamic and unstable configurations of land-use practices and infrastructures that already generate a host of environmental vulnerabilities for residents. It behoves us to address climate-change impacts alongside these land-use practices and infrastructures, not without them. **ES**

Kimberley Thomas is an Assistant Professor in the Department of Geography and Urban Studies at Temple University. Her research focuses on the socio-political drivers of environmental change at multiple scales to understand how human vulnerability and land-use decisions co-constitute one another. For details and access to research articles:
kimberley.thomasresearch.org
@kimberleyanh

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FEATURE

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Small but mighty

Zehra Zaidi explains the cumulative impact of everyday disasters.

In 2015, in an effort to raise awareness around the frequently unreported disasters that take place around the world every day, the Global Network of Civil Society Organisations for Disaster Reduction (GNDR) ran a Twitter campaign titled #365disasters.[1] For a year, member non-governmental organisations and partners were encouraged to send in information on disasters that might not have received national or global attention but that nonetheless resulted in significant damage and impacted lives and livelihoods at a local level. The reported average was at least two disasters per day, ranging from climate events that caused substantial damage and disruption, to traffic accidents that were considered to be disastrous tragedies by community members.

CUMULATIVE IMPACTS

In a field dominated by headline-making extreme events, research on smaller-scale disasters often gets drowned out by the urgency for preventing, managing and responding to large-scale disasters that cause significant and widespread damage. However, academics in the field of disaster risk reduction have long recognised that localised and recurrent small-scale disasters generate cumulative impacts that are detrimental to development. Small-scale disasters have been interchangeably referred to in the literature as everyday, quotidian, invisible, nuisance, neglected or extensive risk disasters,[2,3,4,5,6] and their occurrence and impact have been largely underestimated until recent times.

FEATURE

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The 2009 UN Global Assessment Report Disaster Risk Reduction (GAR) offered the first systematic analysis of the scale, nature and impact of disasters of a smaller magnitude at a global level.[7] It distinguished between the concepts of intensive and extensive risk as a way of highlighting the broad spectrum of the drivers and multiple configurations of risk factors that can lead to disasters. Using data collected in several Latin American countries, the report demonstrated how the number of people and assets affected by disasters were being consistently underestimated as a result of the exclusion of small-scale disasters.

The United Nations Office for Disaster Risk Reduction (UNDRR) defines intensive risk as the exposure of large concentrations of populations and economic activities to intense hazard events, which can have catastrophic impacts such as high mortality and asset loss.[8,9] By contrast, extensive risk refers to the risk of repeated or persistent hazardous conditions of low or moderate intensity, often highly localised, which can lead to debilitating cumulative impacts in the longer term.[10] While extreme disasters are generally large-scale events such as earthquakes, tsunamis, large volcanic eruptions, flooding in large river basins or tropical cyclones, small-scale disasters are caused by mainly localised hazards such as flash floods, landslides, urban flooding, storms and fires.[9] As such, extreme disasters generate higher levels of mortality and destruction of property, resulting in larger direct losses in monetary terms.

THE MAJORITY OF DISASTERS

However, it has been estimated that in certain contexts there have been more than a hundred extensive disasters recorded for every intensive disaster occurring over the same period of time.[11] On average, databases and insurance statistics indicate that around 80 per cent of disasters recorded for a particular location or time span are classified as moderate or minor. And while small-scale disasters do not generate the high levels of mortality caused by extreme events, they account for a large proportion of losses generated through other forms of impact, including high levels of injury and damage to public assets and critical infrastructure such as houses, schools, hospitals, water supplies, road systems and energy networks. Using data for 85 countries and territories, the GAR[9] estimates that direct losses from extensive risk disasters equalled US$94 billion between 2004 and 2014 alone. These impacts, in turn, produce further indirect losses that affect the long-term quality of lives and livelihoods within local, regional and subsequently national and global contexts.

One of the most comprehensive studies examining the long-term socio-economic impact of small, moderate and extreme disasters was undertaken in Colombia in 2010.[2] Using data for a 32-year period (1971–2002), the authors demonstrated that the cumulative economic costs of small-scale disasters superseded the cost of extreme events in Colombia during this time. Moreover, the impacts of small-scale disasters contributed to the amplification of overall national vulnerabilities and exerted an additional burden on already stretched local development systems.

Similarly, localised and recurrent flooding now occurs with high tides in many coastal locations in the USA due to climate-related sea-level rise, land subsidence and the loss of natural barriers. The National Oceanic and Atmospheric Administration (NOAA) has classified this small-scale disaster as 'nuisance flooding' or 'high-tide flooding' that leads to public inconveniences such as road closures, overwhelmed storm drains and compromised infrastructure. It estimates that nuisance flooding has increased in the country on average by about 50 per cent over the last 20 years and 100 per cent over the last 30 years.[12] In a recent study, Moftakhari *et al*. claim that the cumulative cost of nuisance floods may, over time, exceed the costs of the extreme but infrequent events. Their results suggest that, in response to sea-level rise, nuisance flooding could generate property value exposure comparable to, or larger than, extreme events in the USA.[13]

DISASTERS AND DEVELOPMENT

Extensive risk is also frequently associated with poverty, urbanisation and environmental degradation. It is often characteristic of populations living in rural areas or urban margins, such as informal settlements where communities face greater exposure and vulnerability to weather-related hazard events.[14] Extensive risks

account for the majority of localised disaster losses, and a disproportionate burden of these direct and indirect impacts is borne by vulnerable populations and low-income groups.[15] In spite of this, small-scale disasters remain largely unreported, uninsured and they do not attract sufficient government attention or unlock external financial assistance.[16]

Even today, the majority of global efforts for prevention, preparedness and response for disasters remain focused on extreme events. This is, in part, due to the push for disaster risk reduction originating from national policy structures employing a top–down approach. In many cases the manifestation of extensive risk is viewed through the lens of local development issues, and the management of small-scale events is delegated to municipal authorities or city-level public administrations. Such events are rarely considered within the ambit of disaster-risk-management practices, even though they result in significant local-level damage and disruption, and exceed the capacity of affected communities to respond and recover without external assistance.

DIRECT AND INDIRECT IMPACTS

Yet another explanation for the under-consideration of small-scale disasters is the lack of data on their direct and indirect impacts. Until recently, the majority of global databases for recording the incidence and impacts of disasters only focused on extreme events. Thresholds for inclusion, such as those set by EMDAT or MunichRe's NatCat of more than 10 dead and over 100 injured people, or tens of thousands of US dollars in direct losses, has resulted in the automatic exclusion of many moderate-impact but high-frequency sub-national or regional events with relatively low mortality and morbidity. Moreover, several hazards, such as droughts or heatwaves, cause impacts that do not result in high mortality, are mostly indirect, or occur over a longer time period and across a broader geographical scale.

Relative scale is also an important consideration in the definition of small-scale disasters. If assessed on the basis of traditional loss indicators such as mortality or financial loss, what constitutes an everyday disaster in Beijing will be quite different to an event that causes disruption and losses in a small town in Bangladesh or in Germany. All these factors make the definition of small-scale disasters and the measurement of their impact difficult, resulting in low levels of attention or coverage in loss databases and policy frameworks.

The Sendai Framework for Disaster Risk Reduction 2015–2030 has spurred much-needed progress in highlighting the importance of small and moderate disasters. Specifically, it identifies extensive risk as a critical component in the creation of disaster losses, and promotes its inclusion in disaster loss accounting systems as a means of providing more accurate estimations of global disaster impacts. Understanding the spatial distribution, scale and drivers of extensive disaster risk is considered essential for monitoring progress and creating effective risk-reduction strategies. The Framework Indicators require member states to record disaster impacts at national, regional and local levels; it also requires the inclusion of events that fall below the impact thresholds set by conventional disaster loss databases. In response, several disaster loss databases such as NatCat and EMDAT have adjusted their inclusion criteria to reflect the detrimental effects of small-scale disasters.

OPPORTUNITIES FOR RESILIENCE BUILDING

Despite this renewed attention and the creation of a stronger evidence base, the impact of small-scale disasters continues to be left out of most national risk assessments and future scenario planning. This represents a lost opportunity for improving policy and management responses to disaster risk, since the prevention and resolution of small-scale disasters is closely related to efficient development practices at the local level. Strategies for increasing local resilience to small-scale hazards can create a strong foundation for improved response to more extreme events further down the line. In addition, the inclusion of small and moderate events in disaster risk planning can better link national level policies to local strategies for risk management. It can also highlight the need for improved service provision and infrastructure at the local level.

The type of eruption may also vary, with the most common occurring when magma escapes from vents. The incidence of small-scale disasters is often more closely linked with underlying factors of risk such as poverty or poor urban planning than with the scope or magnitude of the triggering hazard event. The high recurrence rate of these mainly localised events undermines development processes and increases the overall vulnerability of communities. Current trends in population growth, social inequality, urbanisation, land use, environmental degradation and the impact of climate change are all expected to exacerbate the incidence of both extreme and localised disasters in the future. Addressing the drivers of extensive risk offers a critical entry point into identifying and reducing the local-level vulnerabilities that make societies susceptible to harm. It will also strengthen institutional approaches for preparedness, emergency management and resilience at multiple scales. ES

Zehra Zaidi is a Senior Research Fellow at Ca' Foscari University in Venice and a Visiting Lecturer at University College London. Her research focuses on social and institutional responses to climate change, and vulnerability and adaptation for disaster risk reduction.

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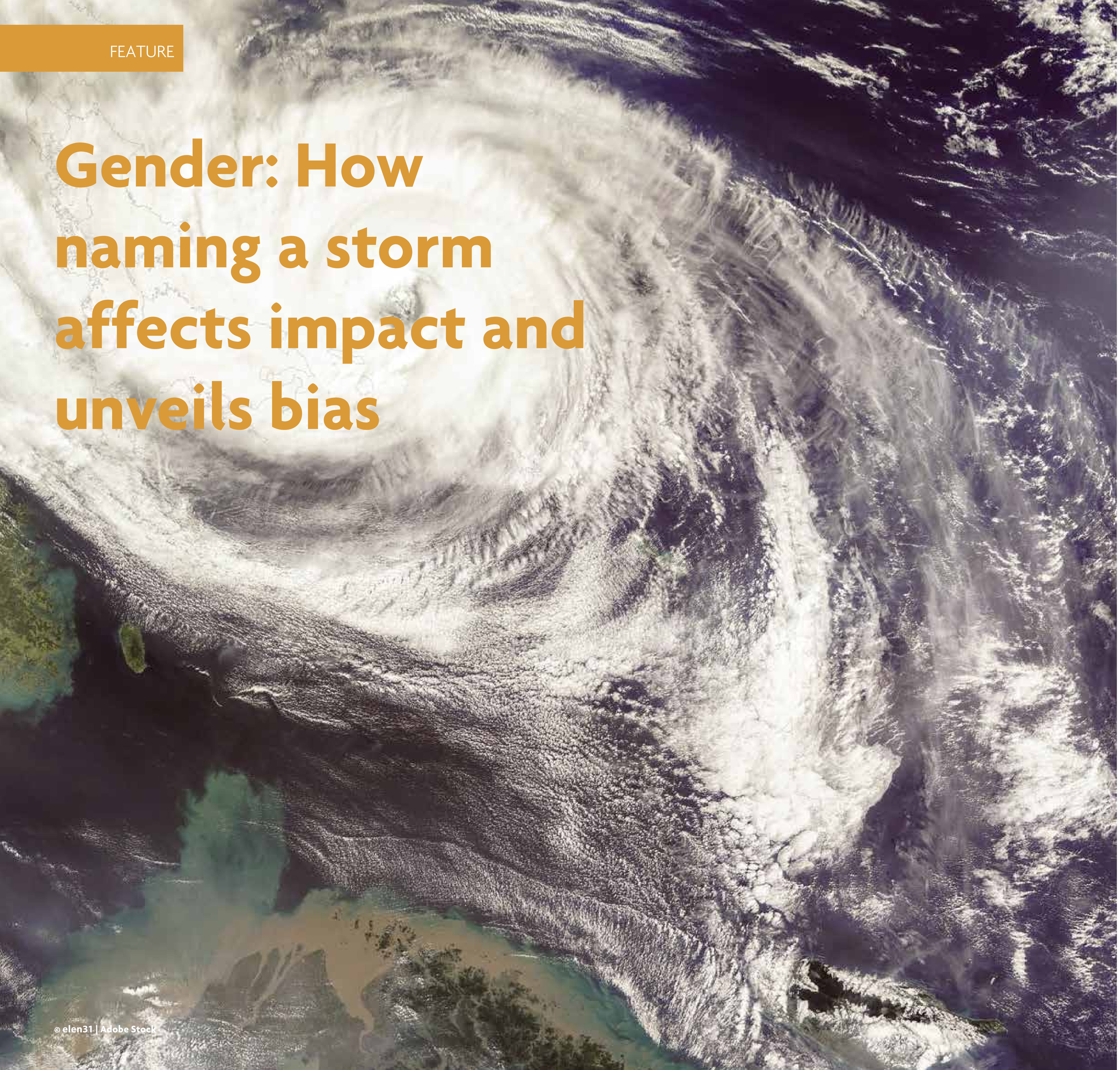

Gender: How naming a storm affects impact and unveils bias

FEATURE

Karen Morrow analyses the contradictions of the visibility of gender in a world of invisible women and underlying prejudice.

I am always on the lookout for gender issues coming to the fore – first because I work in the context of a world where women, albeit often by accident rather than design, are often functionally invisible (in other words 'when we say human, on the whole, we mean man'[1]) and second because I am a scholar concerned with the global law, policy and governance of climate change, where gender issues have only recently begun to gain traction in governing institutions.[2] Jung *et al.*'s controversial 2014 article[3] produced by a cross-disciplinary team,[4] was a case in point. It investigated the psychological impact of the gender of storm names on people's evaluation of hurricane risks and responses. The study in question used archival data analysis and six laboratory-based experiments to look at the potential impact of the gender hurricane names in three areas of public response to hurricanes:

- Subjective predictions of hurricane intensity;
- Delays to an evacuation decision; and
- Intention to follow an evacuation order.[3]

The authors' findings indicated that giving hurricanes gendered names invokes unconscious gender bias which in turn affects individual responses to such events. The implications of this for the efficacy of risk communication strategies are potentially significant. The subsequent coverage in academic literature and popular media proved enlightening in many ways, not least in demonstrating the very different approaches adopted towards the findings by diverse groups of readers.

WHY STORM NAME CHOICE MATTERS

Naming storms and hurricanes is now a globally adopted practice geared towards clarifying, streamlining and facilitating effective risk communication.[5] The practice takes into account the need for us to engage both the rational and emotional parts of the brain when dealing with risk.[6] Broadly speaking, the emotional element of engagement features the use of narrative to help us to process complex information. That the gender of the names given to natural disasters could affect how they are perceived within our construction of reality would be regarded as well-worn ground in many areas

FEATURE

of study. Ecofeminist theory, for example, identifies the designation of the female and natural as inferior to the male and rational as one of the key hallmarks of post-Enlightenment world views. This has important ramifications for the treatment of and attitudes to both women and the environment.[7]

THE RESEARCH AND ITS RECEPTION

Findings based on both desk-based archival analysis and laboratory-based surveys are of course open to criticism on a number of grounds – any experimental approach will be ripe for debate, revision and augmentation. One considered response to Jung *et al.*'s article was an experiment-based MA thesis that specifically sought to parallel the initial research, rather than just critiquing the original article, by changing one contested variable of the original study, namely, the survey participants' familiarity with hurricane threats. The results still found that the gender of the storm name was 'an appropriate consideration in planning hurricane communication'.[8]

Lay commentators appear to have grasped the message of Jung *et al.*'s article in fairly clear terms. *The Week*, for example, summarised the piece thus: 'Gendered names for natural disasters can tap into gender stereotypes, whether we think we hold any or not, and have unintended and potentially dangerous consequences'.[9] Initial responses from academia, however, appeared to be more concerned with contesting the methodology and findings[10] than considering the real-world impact of naming storms and the fact that, whether the impact of gender is statistically significant or not, it poses a risk that, most unusually, could be dealt with at no cost by switching to gender-neutral naming.

APPLYING THE PRECAUTIONARY PRINCIPLE

The precautionary principle is often expressed as follows: 'When human activities may lead to morally unacceptable harm that is scientifically plausible but uncertain, actions shall be taken to avoid or diminish that harm.'[11] A lawyer would be apt to argue that in the circumstances, actions to avoid or diminish harm would be appropriate. As is clear from the original research, the resulting furore in letters to the publishing journal, and various examples of online commentary quoting a variety of sources, the fact that action could be both costless and justified seems to have passed commentators by. Notably, there was a piece on *Live Science* in which no one interviewed thought that a change to gender-neutral naming was a matter of urgency.[12] Somewhat mystifyingly, the interviewees included one of the original authors, who thought it would be enough not to use gendered pronouns in storm reporting, though it is unclear that this would fully address the issue if gender is ascribed in the first place. This is particularly discouraging given the rarity of such a simple option to address a risk. Taken overall, academic commentary, both formal and informal, leaves the reader to conclude that the message and its potential for swift practical application has been lost in the argument.

WHERE GENDER IMPACTS ACTUALLY LIE

While the gender and storm-naming controversy has been interesting and attention grabbing – serving at least to put gender considerations in the frame in both academic and popular discussions of natural disasters – this storm in a teacup largely misses the point about the salience of gender in this context. In a world where global heating will exacerbate both the frequency and severity of natural disasters,[13] the fact that their impacts will be most felt by those who are both the poorest and least implicated in contributing to these problems[14] while at the same time serving to exacerbate existing inequalities, not least those founded on gender,[15] is surely the most pressing issue that arises in this context – though sadly it remains both under-interrogated and ill-addressed. ES

Karen Morrow has been professor of environmental law in the Hillary Rodham Clinton School of Law at Swansea University since 2007. Her research interests focus on theoretical and practical aspects of public participation in environmental law, policy and governance processes and in particular on their application at the interface between gender and the environment.

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FEATURE

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Improving collaboration and coordination in post-disaster response

Belinda Hewitt, Deanesh Ramsewak and **Alan Mills** explain the current and future roles of GIS and mapping.

Geographic information systems (GIS), remote sensing (RS), and mapping are important tools for disaster risk management.[1,2] These technologies support knowledge and awareness during the disaster preparedness phase and time-critical spatial information and analyses during the response phase. Over the period 2008–2017, there were 3,751 recorded disasters caused by natural hazards that affected approximately two billion people and caused an estimated US$1.658 billion in damages across 141 countries.[3] The frequency and severity of storms and extreme rainfall events have increased in previous decades,[4,5] a trend that will continue for decades to come.[6] Collaboration and coordination between governments, international agencies and stakeholder groups during the early phase of disaster response is critical to minimise loss of life, damage and other human impacts.

The 2018 *World Disasters Report* recommends the use of enhanced technologies by humanitarian agencies and supports a community-centred, participatory strategy to address disaster risk.[3] GIS technologies can be used during each phase of the disaster management cycle to support collaboration, coordination and improved response outcomes. Kafi *et al.*[7] have shown how global

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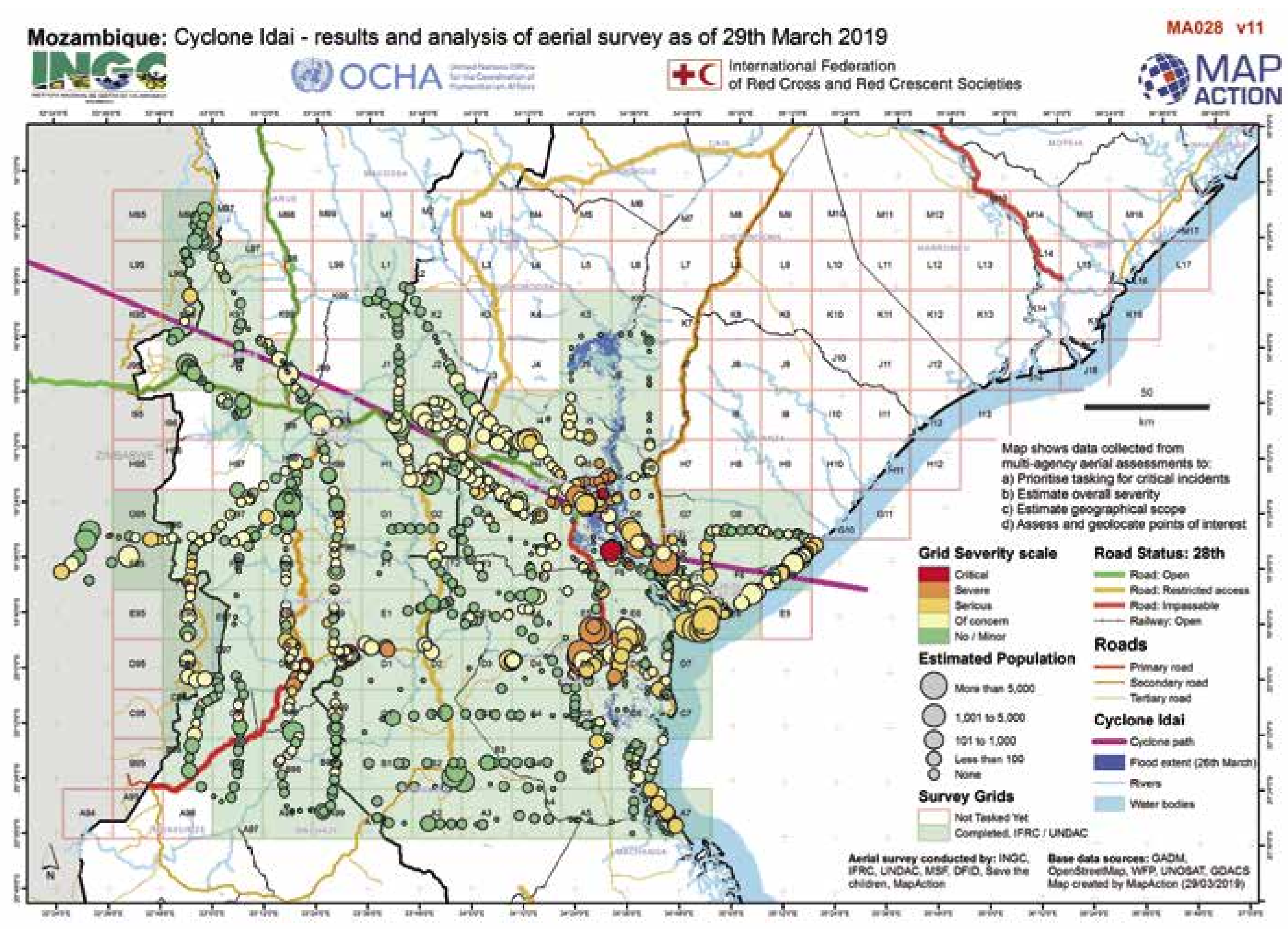


Figure 1. An example of a humanitarian multi-agency aerial impact assessment map; this one was for Cyclone Idai in Mozambique in March 2019.

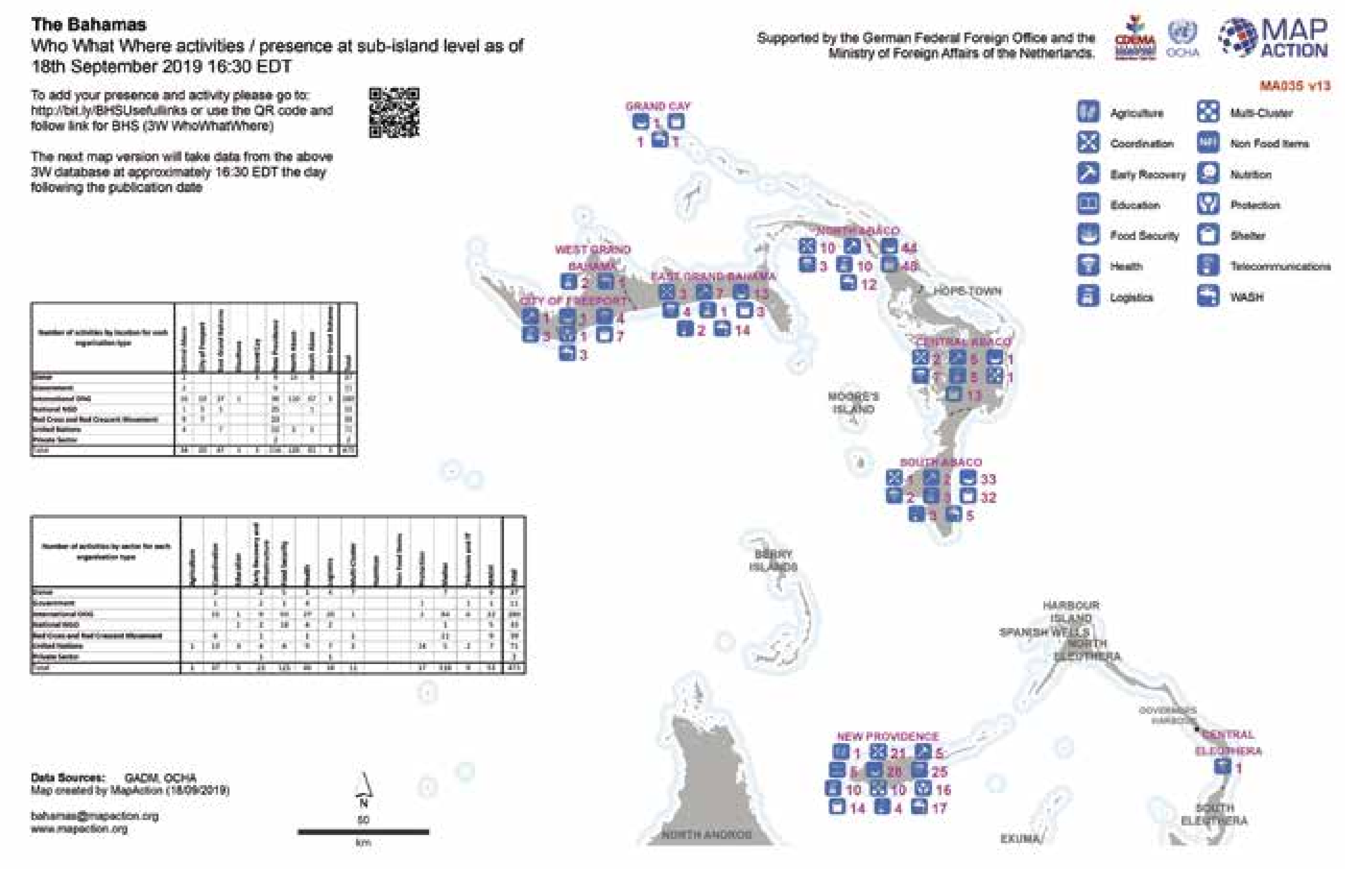


Figure 2. An example of a Who What Where map; this one was generated for Hurricane Dorian in The Bahamas in September 2019.

positioning systems (GPS), an integral part of GIS, have been effectively used in disaster management, and how the merging of GIS, RS and GPS can aid in prediction, detection, monitoring and post-disaster assessment.

THE ROLE OF MAPACTION

MapAction is a UK-based humanitarian mapping organisation that supports international response to emergencies. Launched in 1994, the charity now maintains a membership of around 115 staff, volunteers and trustees. Of these, 91 are professional volunteers based in the UK, Europe and the Caribbean. Over the last 15 years, MapAction has undertaken more than 100 emergency deployments in numerous countries, supporting operational partners such as the United Nations Disaster Assessment and Coordination (UNDAC), United Nations Office for the Coordination of Humanitarian Affairs (OCHA), and regional disaster-management agencies such as the ASEAN Coordinating Centre for Humanitarian Assistance on Disaster Management (AHA Centre) and the Caribbean Disaster Emergency Management Agency (CDEMA). Most recently, MapAction responded to Cyclone Idai in Mozambique in April 2019 and Hurricane Dorian in The Bahamas in September 2019. It has also provided remote support to numerous other emergencies and helped governments and disaster-management agencies around the world use geographic information to prepare for disasters before they occur.

This article offers some context on the functions of geospatial technologies in enhancing collaboration and coordination for more effective post-disaster response based on the experience of MapAction, followed by an overview of some key technology trends in geospatial technologies for post-disaster response.

CURRENT STATE OF PRACTICE

While maps feature in the earliest examples of international post-disaster response, the widespread use of GPS and GIS since the 1990s has transformed the current state of practice.[8] Disasters typically affect large areas and may require international response organisations to respond over unfamiliar geographic environments in coordination with any number of host government agencies, humanitarian actors and other groups.

Spatial data and mapping provides the crucial 'where' dimension of an initial response phase by identifying reference areas, the distribution and severity of disaster impacts, affected populations and infrastructure. Even where response is delivered by an organisation with a long-term host-country presence, the landscape conditions and access may be significantly altered following a disaster. Spatial analysis is also a highly effective means of assessing and visualising collected data on needs, issues and gaps to inform humanitarian decision-making (see **Figure 1**). This has become increasingly important with the emergence of coordinated needs assessment and analysis, where multiple humanitarian agencies and a host government work together to develop a joint strategic plan for the post-disaster response. Thematic or general Who What Where (3W) data and maps capturing the distribution and operations of aid actors have emerged as a key approach to support improved coordination between humanitarian actors. They help to target gaps and avoid overlap in response (see **Figure 2**).

Alongside technological advances in data sources and analysis, simple, low-technology innovations can be among the most impactful in supporting coordination and collaboration in high-pressure, resource-scarce response environments. MapAction's Example Product Catalogue (EPC)[9] has helped to enhance field engagement and map production (see **Figure 3**). The EPC shares examples of products according to response phase and theme, allowing operational partners to visualise potential products and more effectively communicate their needs. MapAction is currently working with partners such as the AHA Centre, CDEMA and various humanitarian clusters to customise the catalogue.

WIDER CONTRIBUTIONS

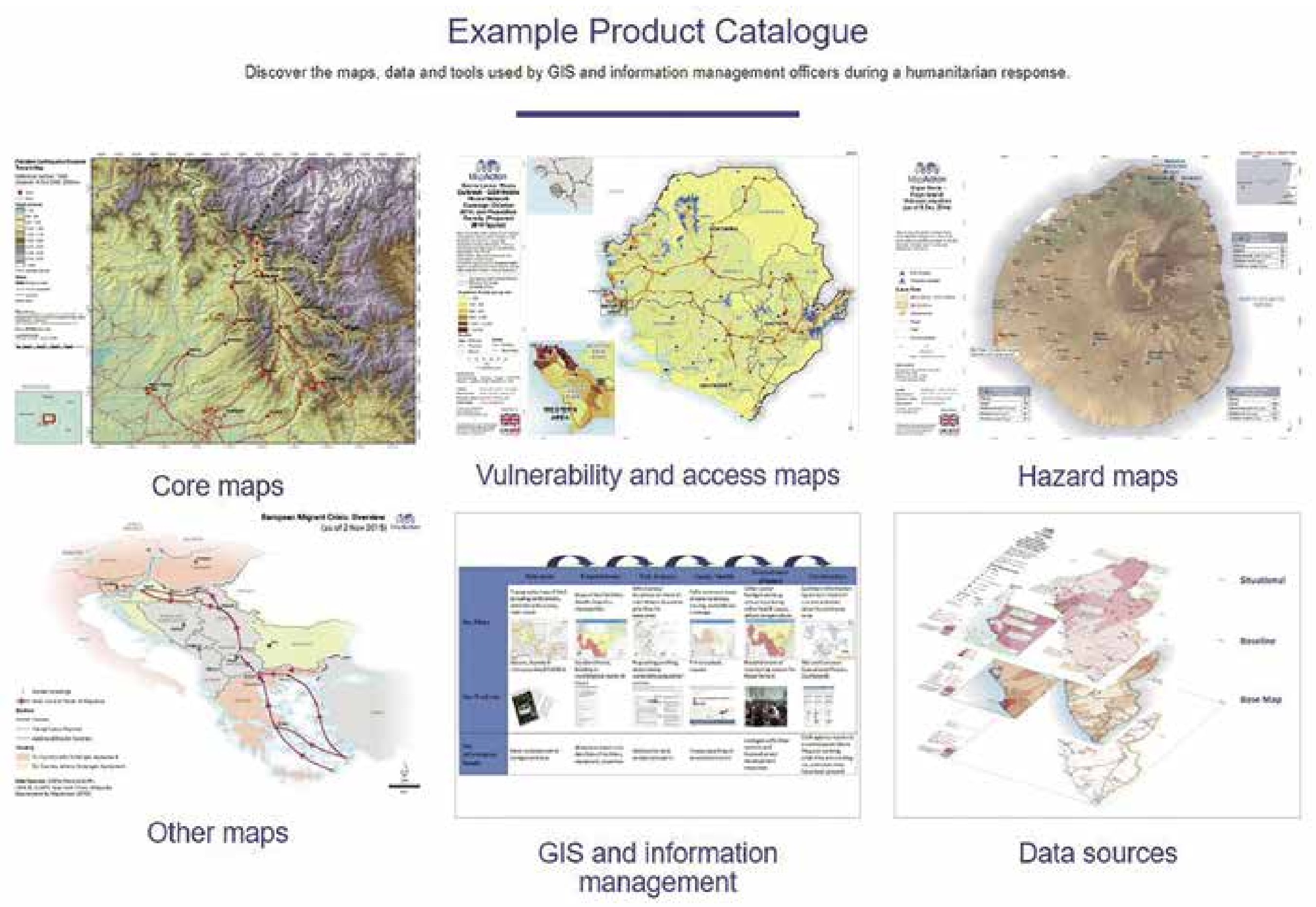
The emergence of crowdsourcing and crisis mapping over the last decade has led to notable successes in humanitarian collaboration. These platforms allow communities to participate in post-disaster response by providing real-time data, supported by online volunteer networks. In 2011, following the collapse of Libya's Gaddafi regime, humanitarian access was limited but the United Nations OCHA Standby Task Force was able to monitor incidents with support from Ushahidi.[10] Humanitarian OpenStreetMap Team (HOT) mobilises 'armchair geographers' to create base maps from imagery and other sources during a crisis, notably including street mapping for Port Au Prince during the critical search-and-rescue phase after the 2010 earthquake in Haiti.[11] Projects such as Missing Maps are contributing to preparedness by ensuring datasets are available before a disaster occurs. These solutions are of great use to humanitarian organisations, although issues of quality assurance can limit their effectiveness.

The proliferation of mobile devices has improved field data collection.[12,13,14] Tools such as GeoODK, Survey123 and UN-ASIGN allow the use of phone GPS to attach assessment data to sufficiently accurate locational information. Once connectivity exists, data can be pooled to a platform to visualise results or integrate with other data. However, robust survey design, understanding of the context of the geographical significance of the data (for example, whether a map point represents a house, village, district or region) and integration of data with decision-making processes are yet to be standardised.

New data sources, methods of manipulation, visualisation and dissemination have increased the complexity of MapAction's operational model. In recent years, MapAction has been working towards automation in areas such as harvesting new data feeds, preparing standard reference and situational maps (drawing from the EPC), sending data and maps to public portals such as HDX, and more efficiently storing and logging metadata to improve searchability.

EMERGING TECHNOLOGY AND TRENDS

Technological advances are continuing rapidly in geospatial science. Humanitarian agencies, particularly service organisations such as MapAction, receive many ideas to improve information management, including new data sources, models, services and portals. The humanitarian community must be selective about which of these to take forward by evaluating each product's utility, viability within harsh field environments and interoperability with existing systems. Increasing volumes of tools and data are not necessarily valuable if they do not improve existing arrangements.



▲ **Figure 3. MapAction Example Product Catalogue, a communication tool that helps operational partners to rapidly identify and request suitable map products in the field.**

Within rapid response environments, responders usually travel light, work in cramped conditions, have variable communications (often sharing very poor internet connections) and manage many issues simultaneously within complex coordination structures (see **Figure 4**). Data is most valuable when it is lightweight, specific, available prior to an emergency where possible to ensure speed of access, and able to be processed quickly. Organisational and procedural development is also essential to complement data improvements.

Remote-sensing sources continue to proliferate. Micro- and nanosatellites launched by national and private agencies, such as the Dove constellation by Planet Labs, complement continuous monitoring by older systems and enrich the range of spectral bands, radiometric precision, and spatial and temporal resolutions available to end users. This range can enhance the availability of data appropriate to specific circumstances, such as radar or thermal bands to cut through atmospheric obscurants (smoke or cloud cover, for example).

Space agencies provide essential early warning and monitoring systems. For example, the European Commission's Copernicus programme provides six services for environmental and climatic monitoring, including a specific service for disaster management that monitors, amongst other things, fires and floods. More specialist products are created from combining multiple remotely sensed sources with other data, such as Columbia University's International Research Institute for Climate and Society monitoring programmes on climatic variability. While web-mapping services allow new issues to be visualised in vivid detail, greater value comes from being able to download information from these portals to combine with other useful response data.

Unpiloted aerial vehicles (UAVs; sometimes referred to as drones) have been actively promoted within the humanitarian sector.[15] Applications in aid delivery, media visualisation and as an alternative source for

▲ **Figure 4. A typical MapAction working environment (© MapAction).**

FEATURE

▲ **Figure 5. A MapAction volunteer delivering humanitarian mapping training to sub-regional team members of the Caribbean Disaster Emergency Management Agency (CDEMA) in Kingston, Jamaica (© Lukasz Gorowiec).**

base mapping have had some impact, but very few examples exist that show UAVs to be a cost-effective and appropriate solution compared to other techniques. UAV operators are working to overcome the current limitations. Some progress has been made to ensure capacity exists *in situ* in disaster-prone countries, and also in working with national authorities to gain flight and airspace clearance for humanitarian purposes. An international network of operators (UAViators) has played a key role in improving the effectiveness of UAVs in the past five years: they have cultivated local operators, established standards and made available a collaborative platform through which the humanitarian community can engage.

Both UAVs and nanosatellites are providing opportunities to explore the use of videography. Having the capacity to obtain data locally, along with the faster repeat cycles possible from constellations of nanosatellites, offers the potential to monitor highly mobile situations. For example, traffic blockages, mass migrations or the speed at which flood water extends.

Enhancing collaboration with groups such as the private sector offers potential to unlock access to further remotely sensed data sources that are not yet fully explored. For example, accurate and updated mapping captured through commercial mobile app data such as Uber's CatchME mapping could supplement national databases. Commercial phone companies are gradually sharing connectivity data with organisations such as NetHope and GSMA, which may provide good proxies for areas of highest impact, particularly where communities have a limited voice. Proprietorial data archives have some applicability but can be prohibitively expensive on a large scale, and open-source information is far more accessible to disaster-affected communities and responders.

BEYOND MAPPING

Whilst the humanitarian community recognises the value of maps and spatial data as fundamental to their operations, the products created by geospatial experts are often underused beyond a quick visualisation. MapAction has come to realise that influencing decisions and coordination, and enhancing collaboration, requires moving beyond preparing cartographically balanced products towards ensuring the right story is told for human audiences. This will require skills-building in the interpretation of maps (see **Figure 5**) alongside technology approaches such as storyboards and dynamic visualisation.

Care must be taken to ensure that the disaster-affected individuals are at the heart of any technology response, and to address ethical questions around publicly available data. For example, identifying migrants crossing borders or the location of vulnerable people in conflict zones could result in their being targeted. Another issue, particularly relevant to crowdsourced information, is the need to comprehend inherent biases and understand social and cultural contexts. While headline figures suggest five billion people had access to mobile phones by 2017,16 the remaining two billion will be harder to reach and yet potentially more vulnerable to the effects of emergencies.

As technology continues to advance, continued dialogue, collaboration and regional cooperation between technologists and humanitarians involving government, civil society, the private sector, communities and affected populations can help to ensure new solutions are fit for purpose within complex post-disaster-response environments, humanitarian coordination systems and local cultural contexts. Establishing guidelines and tools for assessing new technologies will support these objectives. New advances must support and align with the humanitarian principles upon which we all operate to improve the efficiency of aid, reduce disaster impacts and support affected populations. **ES**

Belinda Hewitt is a MapAction volunteer who is currently based in the Philippines to support resilience initiatives in Asia. She has a background in disaster risk management, climate-change adaptation, GIS and engineering.
✉ **bhewitt@mapaction.org**

Deanesh Ramsewak is a GIS Lecturer at the University of Trinidad and Tobago. He has over 15 years' teaching and research service in the geospatial sector in Trinidad and Tobago and the wider Caribbean region. He recently joined MapAction as a volunteer to contribute to the disaster response effort.

Alan Mills has volunteered with MapAction for 15 years and is its Preparedness Coordinator, seeking out better and faster technologies, data and protocols to improve humanitarian information management. He is a professional geographer specialising in use of geoscience for development, particularly in small island states, land, environmental and coastal management.

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Volcanic eruptions

Noel Nelson outlines the dangers of volcanic ash and what is being done to help aircraft avoid them.

Volcanic eruptions are perhaps more common than one might first imagine – some erupt almost continuously, such as Mount Kilauea in Hawaii. Other volcanoes remain inactive for long periods, such as Pinatubo in the Philippines, which had been dormant for 400 years prior to its last eruption in the early 1990s. The type of eruption may also vary, with the most common occurring when magma escapes from vents. Eruptions can be classed as explosive (fragmented magma literally explodes from the vents, accompanied by rock and ash) or effusive (the magma emerges in a thick, viscous lava flow). More specifically, volcanologists tend to classify eruptions according to specific volcanoes that typify a particular eruption characteristic: Hawaiian, Strombolian, Vulcanian, Plinian, Icelandic and Pelean.

HAZARDS

Volcanoes present an immediate hazard on the ground near the eruption, especially from lava flows, pyroclastic flows (fast-moving hot gases and volcanic matter), lahars (violently flowing mud) and avalanches of loose debris. These often result in the displacement of local populations and the destruction of crops, leading to food shortages. Where the ejected ash is deposited on the ground, it may contaminate ground and surface water bodies, and can be resuspended to the atmosphere where it can go on to present further hazards.

In the atmosphere, the ejected ash can reach various heights, depending on the intensity and nature of the eruption and the changing weather conditions, both at the time of the eruption and after it. The prevailing winds will be responsible for transporting the ash many hundreds of kilometres and it is during this phase that the ash can enter the airspace used by domestic and other aircraft. Ash interactions with their high-temperature jet engines may lead to ash melt, causing erosion or blocking parts within the turbine sections of the engine. This

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damage can lead to a reduction in power and, ultimately, total engine failure. Ash particles comprise small, sharp crystals, meaning they are abrasive, so they can also damage the aircraft frame, sensors and windows, leading to a loss of visibility for pilots. Inside the aircraft, high concentrations of volcanic gases that contain sulphate aerosols can also pose a health risk to passengers.

EMERGENCY RESPONSE

In recognition of the potential hazard posed by volcanic ash to aircraft, the International Civil Aviation Organization (ICAO) set up a network of nine Volcanic Ash Advisory Centres (VAACs), which are responsible for issuing guidance information (called 'advisories') about the current and predicted location of atmospheric volcanic ash. Each VAAC is responsible for a defined airspace. The UK Met Office hosts and operates the London VAAC and is responsible for issuing advisories for the airspace over Iceland, the North Atlantic, Great Britain and Scandinavia. Also in Europe, the French meteorological service – Météo-France, runs the Toulouse-based VAAC and covers eruptions in the rest of Europe, Africa and western Asia.

The VAACs issue forecasts of ash location every six hours, offering guidance out to 18 hours ahead. The advisories take the form of text volcanic ash advisories (VAAs) and volcanic ash graphics (VAGs) (see **Figure 1**). They are used by air traffic controllers and the Civil Aviation Authority (CAA) to issue warnings to aviation concerning the presence and location of ash clouds and to support decision-making by the airlines. In Europe, additional information is issued highlighting regions of specified ash concentrations. This is provided in the form of concentration charts and annotated satellite images.

RECENT NOTABLE ERUPTIONS

In 2010 and 2011 the UK was affected by eruptions from two Icelandic volcanoes. On 14th April 2010, Eyjafjallajökull erupted, sending an ash plume several kilometres into the atmosphere that affected European airspace and the North Atlantic. During the initial stages, guidance from the ICAO was for aviation to avoid any contact with the ash plume. Consequently, flights to and from the UK were grounded, leading to major disruption. Following a new consensus about the safe threshold of ash concentrations that could be tolerated by an aircraft, flights were able to resume. The issued forecast graphics evolved during the eruption to include the different concentration thresholds requested by the CAA. Five-day ash concentration forecasts were issued and used by airlines and the UK government to assess the long-term situation and to develop contingency plans.

By the time the eruption had ceased on 23rd May 2010, a new system for assessing the safety of airspace using predicted concentrations of ash had been introduced. The new products were incorporated into the European Volcanic Ash Contingency Plan and used ash concentrations along with annotated satellite images. This was almost immediately tested in May the following year during the eruption of Grímsvötn, another Icelandic volcano. Although this eruption injected a significant quantity of sulphur dioxide 20 km into the atmosphere, the impact on aviation was not so pronounced as it did not last as long as the Eyjafjallajökull eruption (four to five days as opposed to thirty days). In addition, complex processes in the initial eruption column led to much of the ash depositing out to low altitudes over Iceland. This eruption demonstrated the importance of considering uncertainties in observations of the initial stages of the eruption, the need for modelling systems to be flexible, and the challenges in quantifying the amount of ash erupted. Although the economic costs associated with Grímsvötn have not yet been calculated, the impact of Eyjafjallajökull was estimated to have cost in the region of US$5 billion.[1]

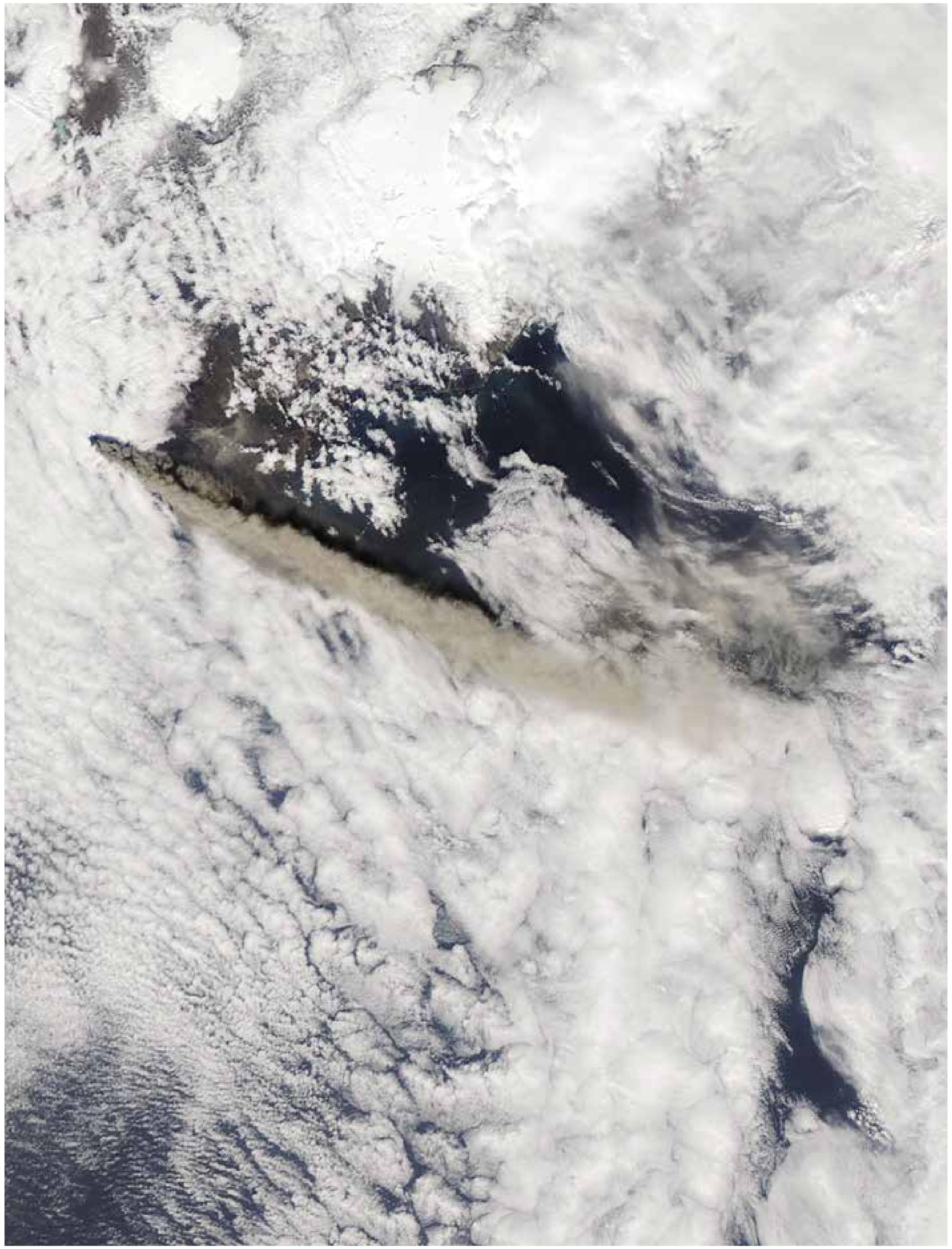
EMERGENCY RESPONSE TOOLS

The eventual fate of volcanic ash ejected into the atmosphere will depend chiefly on the nature and extent of the eruption and the prevailing atmospheric conditions. The movement through the atmosphere of the ejected material can be simulated and predicted using a numerical atmospheric dispersion model (used by all the VAACs). The pre-requisites of these models are that they:

- May be run quickly and on demand;
- Cover regional-to-global spatial scales;
- Can represent the properties of the ash particles; and
- Cover the depth of the atmosphere that includes airline flight (e.g. 11.5 km) and the height of large eruptions.

The quality of the model output will be reliant on the quality of the input data used – essentially all the details concerning the prevailing weather and the eruption. The former is provided by the numerical weather prediction models (used for generating weather forecasts) typically used by national meteorological services; the latter (including volcano location, timing of the eruption, height of the erupted ash and amount of material ejected to the atmosphere) are provided by a range of volcanic observatories and ash observations.

At the London VAAC the dispersion model used is the Met Office's Numerical Atmospheric Modelling Environment (NAME).[2] Volcanic ash is modelled in NAME using a size distribution and density representative of real ash particles. The ash is emitted in the model at the location of the volcano over a height range based on observations of the eruption plume. The transport and dispersion of the ash plume are then calculated using the three-dimensional forecast winds from the Met Office global weather prediction model combined with



Eruptiopn of Eyjafjallajökull volcano, Iceland (© NASA)

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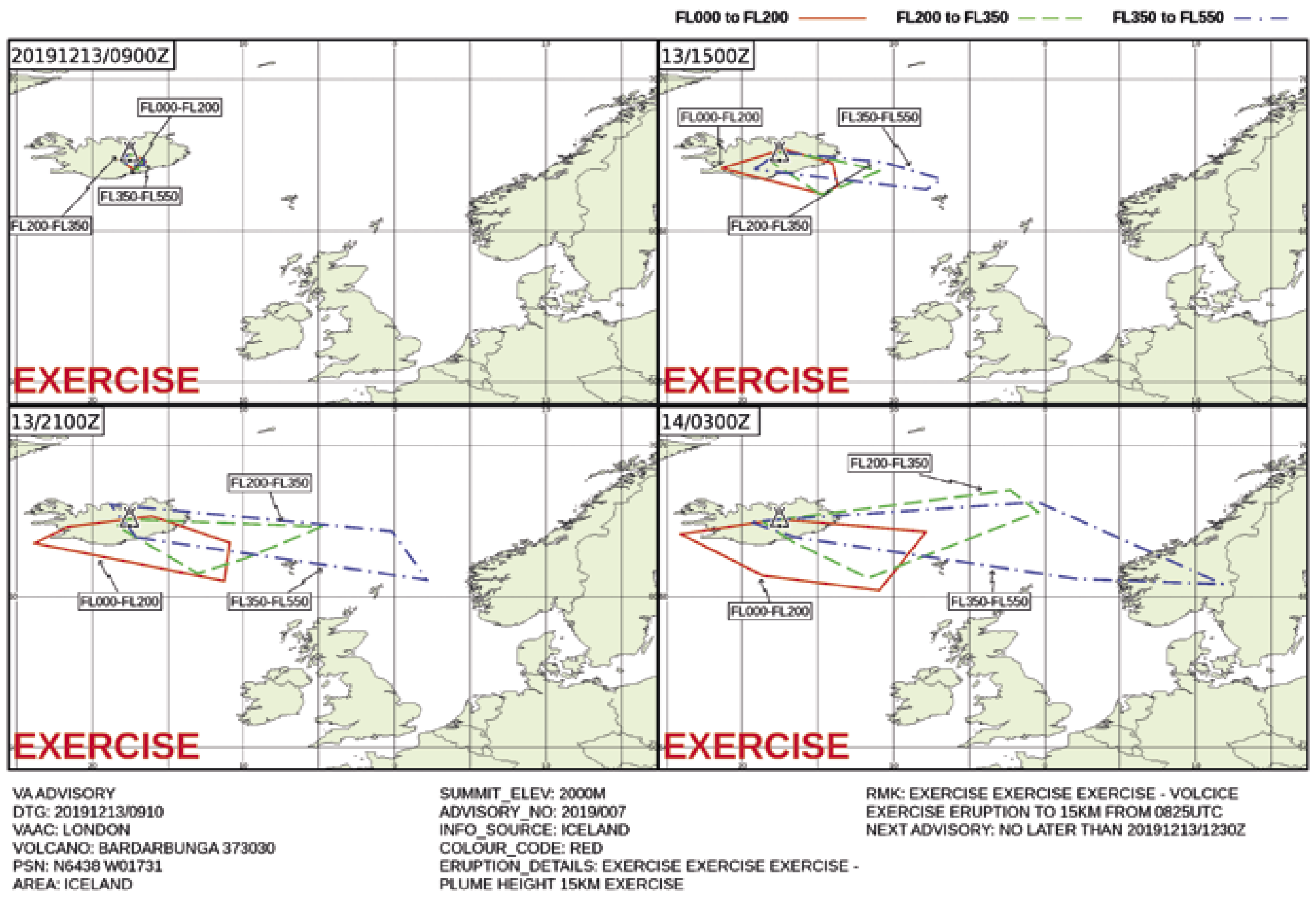

▲ **Figure 1. Volcanic Ash Graphic (VAG) for the London VAAC region (© The Environment Monitoring and Response Centre (EMARC) at the Met Office.)**

smaller-scale turbulence and diffusion applied by NAME parameterisations. Ash is retained in NAME until it is removed by natural physical processes, including sedimentation, deposition and wash-out, all simulated by the model.

The standard VAAC products and supplementary information are developed using a combination of the resulting model output and a wide range of observations including satellite, radar, lidar and research aircraft. These offer valuable real observations with which to routinely validate and verify the NAME output. Good communications with observers in the field are also an essential element in maintaining good-quality input for the model. During the Icelandic eruptions, the Met Office established good communications with the Icelandic Meteorological Office (the volcano observatory for Iceland) and other observers to ensure the best information about the eruption was being used by NAME for the subsequent development of the advisories. Satellite data are another key component in the process: they can be used for detecting plumes, measuring plume size and height, and tracking plume dispersion. The increasing horizontal and temporal resolution of new satellites is leading to better information and more detail.

Although the VAACs are only tasked with forecasting volcanic ash, the sulphur dioxide gas commonly emitted during eruptions is a useful marker for the VAACs because it is detected by many satellites and can be used to identify the presence of volcanic plumes. Sulphur dioxide is also of increasing interest due to the potential for it to cause discomfort to passengers and crew inflight, and long-term degradation to aircraft components. These are both areas of active investigation.

FUTURE DEVELOPMENTS

The 2010 eruption stimulated new work by the VAAC community, the volcanic observatories and academia to advance the underpinning science of volcanic ash forecasting through:

- Developments in dispersion model/satellite data integration;
- Improved understanding of plume buoyancy to better simulate the height and erupted mass in different weather conditions;
- Improved representation of volcanic ash properties in models;
- Exploring how best to represent the spread of ash as it mushrooms out into a bulge that then spreads out laterally (a region known as 'the umbrella cloud') within dispersion models; and
- Ways of incorporating multiple model simulations (known as 'ensembles') to provide probabilistic estimates of the uncertainties.

Within the Met Office, techniques involving an inversion modelling system (a process that links atmospheric measurements, dispersion science and an understanding of the origin of air masses to provide estimates of source emissions) and satellite data are being developed to improve the representation of the eruption source term within the NAME model. It is planned that this system will be able to take advantage of other observations, such as those from lidar and aircraft. Outside the Met Office, the aviation industry (led by Rolls Royce) is pioneering new investigative research to examine the impact of ash on jet engines and their operational sensitivity to ash concentrations.[3] This work has so far demonstrated the merits of adopting a dose-based approach to assess the susceptibility of engines to volcanic ash. The long-term aim is to establish a system of quantitative forecasts to become a standard global aviation product in the 2020s. **ES**

Noel Nelson is a Senior Atmospheric Scientist at the Met Office with a background in atmospheric dispersion, air quality, weather and health relationships, and airborne animal disease transmission. He is currently working on the Clean Air and Climate Resilience Strategic Priority Funded programmes. He has worked for some years on the science/policy interface for air quality at the Department for Environment, Food & Rural Affairs and the Royal Commission on Environmental Pollution. At the Institution of Environmental Sciences, he is currently a Vice President, and has also served as Chair and Vice Chair.

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CASE STUDY

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(Un)natural drought

Lindsey McEwen and **James Blake** make the case for bringing together narrative and environmental science for better drought risk management in the UK.

Although ostensibly a consequence of natural climatic variability, droughts are 'unnatural' in the sense of being highly influenced by human uses of water.[1,2] Traditionally, drought risk decision-making has focused primarily on the supply of specialist science to institutions with statutory responsibility for UK drought risk management – the water companies and environmental regulators. Drivers and stakeholders are considered in isolation. However, the dominance of specialist science in hierarchies of knowledge is a Western paradigm, and there is increasing interest in the role of indigenous knowledges (lay, local, experiential, inter-generational) in local decision-making around environmental risk and climate resilience.[3] More recognition exists that different forms of knowledge can learn from each other,[4] but the science paradigm is culturally and economically embedded in individuals and organisations. So is better UK drought risk management about more science being broadcast more loudly, or are there other ways of framing drought risk communication beyond 'knowledge deficit'?

THE DRY (DROUGHT RISK AND YOU) PROJECT

The DRY project, funded by United Kingdom Research and Innovation (UKRI), adopted a novel interdisciplinary and inter-professional approach to explore how, and by what processes, scientific and narrative evidence might be brought together to support decision-making for drought as an unnatural hazard. This approach reflected the growing recognition of the multi-faceted nature of drought causes and impacts, and the need to develop a better risk agenda and more mitigation options for decision-makers. The basis of DRY's methods was to combine drought risk science (hydrology, ecology and agronomy) with narrative approaches.

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DRY's methods drew creatively on a research team with non-contiguous disciplinary expertise in drought science, sectoral specialisms (health and well-being, business, agriculture, ecosystem services, communities), science communication, media and memory, and storytelling. DRY chose to work at the very specific scale of the river catchment, which is a hydrological entity, but also acknowledged fluidity in how it is experienced by people living, working and undertaking conservation/recreation activities in the catchment. DRY worked over four years in seven UK catchments: the Fowey in Cornwall, the Frome in Bristol, the Ebbw in Blaenau Gwent, the Pang in Berkshire, the Bevills Leam in the Fens, the Don in Sheffield and the Eden in Fife. These catchments were selected to reflect hydro-meteorological, social-cultural and urban-rural gradients across the UK, although hydrological data availability for modelling was a key consideration in choosing potential case studies.[5]

THE POWER OF MODELLING AND SCENARIOING

Within its emergent methodology, DRY evaluated alternative catchment management strategies for the mitigation of water shortages under current and future climates, using UKCP09 projections[6] for the 2020s, 2050s (near future) and 2080s (far future) as a basis for scenarioing. Drought risk modelling was undertaken using DiCaSM (Distributed Catchment Scale hydrological Model[7]) for six of the catchments, with a bespoke pumped drainage water balance model for the Bevills Leam catchment.[8] The modelling involved model calibration/validation for past droughts (1961–2012) and subsequent iterative scenario development, with both elements drawing upon local knowledge. Both the DiCaSM and the Bevills Leam models simulate the terrestrial hydrological cycle, including river flows, groundwater recharge, soil evaporation, plant rainfall interception and transpiration, infiltration, runoff, subsurface flow/base flow, and changes in soil moisture. The models also calculate several drought indices (e.g. wetness index, soil moisture deficit and reconnaissance drought index). Alongside the models, mesocosm (rainfall manipulation) experiments on grassland and food/fodder crops, were used to physically simulate drought, providing an evidence base for engaging stakeholder groups, including farmers and citizen scientists.

NARRATIVE IN REFLECTING AND SCENARIOING

A challenge has been that 'story' and 'narrative' are used interchangeably by non-specialists and across disciplines. A story is the 'text' brought into being by story*telling*, whereas a narrative is the overarching arrangement of a set of events or experiences. In this project, science was used as a stimulus for narrative, while narrative was used as a stimulus for science, as a double mirror. To garner past, present and future drought narratives, DRY adopted a broad definition of 'narrative',[9] to including narrative interviews, digital stories (short audio with images selected by storytellers[10]), micro-narratives (short audio clips or brief written narratives), fragmentary and implied narratives, performed and recited stories, film and song. Themes explored in the storytelling in the seven catchments included:

- Drought-related risk perceptions across different stakeholder groups (by character, age, culture etc.), perceptions of science needs;
- Drought severity: critical thresholds for awareness/action, and the effectiveness of and interactions with mitigation strategies at varying scales;
- History/memory of drought and 'watery sense of place', memories of past water usage, understandings/perceptions of water ownership;
- Specific drought challenges, finding solutions and developing mitigation strategies; and
- Behaviour that results in reaching tipping points – for example, during the 1976 drought, irrigated potatoes became more expensive and people shifted to other staples (rice and pasta), not returning to potatoes to the same extent.

EXPERIMENTS IN SCIENCE AND STORYTELLING

One integral creative experiment, to bring stories and science into the same frame, was the open sharing of drought-risk science processes and outputs with catchment-based groups of diverse local stakeholders, whose scientific knowledge was variable. At the outset, these groups were called DRY Local Advisory Groups (DRY-LAGs), but their role became much more than advisory. The progressive sharing of drought risk science between hydrologists and these local stakeholder groups involved understanding catchment controls, histories of drought and its impacts, calibration and validation of the model, and scenarioing based on different possible futures. This enabled the drought scientists to ensure that the models were correct for the right reasons by incorporating local knowledge, data and understanding to improve hydrological process representation.

Model outputs and visualisations were developed to reflect stakeholder interests, as were locally resonant drought impact indices. Scenario modelling evolved to include potential changes in climate, land use and water management tailored to local concerns, as possible 'what ifs' to fuel discussion about local impacts. Unusually, the modelling process was highly transparent and developmental, exposing stakeholders to a 'warts and all' consideration of issues within modelling and calibration as opposed to just presenting finished results.

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This encouraged stakeholder interest and participation in the modelling processes, raised awareness of issues with modelling and positively challenged drought scientists to improve their communication of complex concepts.

One aspect of creative experimentation involved developing accessible, bite-sized science, layering science within visualisations so that everyone could access a take-home message at different levels of sophistication. DRY experimented with: storying graphs; using intuitive colour schemes; creating narrated animations of the 1976 drought playing out in the catchment with a scientist's commentary; linking climate projections to personal experiences of countries already more droughted than the UK; connecting science to the personal by presenting the scenarioing of the 2020s, 2050s and 2080s in terms of people's ages.

Another creative experiment was to bring this bite-sized science together with storyboarding (visualisation of stages in a story) as a stimulus for stakeholders to envision different possible futures. DRY's methodology culminated in the development of a decision-support 'utility' – a resource that brings science and narrative together to support the management of future droughts by a range of stakeholders, scaling up from the level of the individual.[11] The DRY Utility combines three elements: a searchable Story Bank, Story Maps that triangulate geography, science and stories for the seven case-study catchments, and DRY Resources from DRY's research process.[12]

THE IMPACT ON SKILLS

In these processes, key skills for the scientists went far beyond those of conventional environmental modelling to embrace different ways of communicating science – exchanging knowledge, active listening, displaying empathy – thus building trust and relationships beyond what could be achieved in a traditional one-off intervention. For example, the DRY team encouraged and worked with its scientists to experiment with different forms of bite-sized drought science needed to recognise diverse levels of scientific knowledge in the different target groups for storytelling engagements. This challenge included upskilling *all* the members of the DRY team in the communication of specialist and complex science, independent of their disciplinary and socio-cultural backgrounds.

DRY's research can inform future co-produced interdisciplinary projects. Protected time needs to be built in throughout the project for interdisciplinary dialogue, recognising that team members will have diverse starting points and paces to engagement with both science and stories as data. This involves creative explorations of language and understanding (e.g. around systems thinking and scenarioing). Other skills include reframing understandings of systems thinking, moving out from environmental science to learning for sustainability, media and memory, with more creative understandings of scenarioing and tipping points (for example, in terms of permanent changes in people's behaviour). It also needs to be acknowledged that differences exist in the ability of scientists to engage with more fluid, narrative processes, and some may fall by the wayside, finding such processes intellectually and emotionally challenging to notions of self, science and research.

More practical logistical issues in bringing science and stories into the same frame included the length of time needed for scientists to deliver the sophisticated scenarioing given the iterative co-development process. This had subsequent impacts on the wider DRY team's ability to convert this into meaningful stimuli to engage different publics. Tensions in transdisciplinary working included the need to share research with stakeholders in advance of publication, and churn in scientific processes with staff turnover, a challenge to skill development and relationship building with stakeholders.

BRINGING STORIES AND SCIENCE TOGETHER

In reflecting on its research process, the DRY team found some critical points in working towards integrating science and narrative in co-produced research. These have implications for environmental science and what it brings to the table:

- Different stakeholders have different personal and organisational perceptions of what is understood by 'science' and 'narrative', garnered through their academic, work and personal experiences.
- Differences occurred in the balance of how various knowledges are drawn on, and valued, as evidence bases, along timelines for organisational decision-making in drought risk management. For example, early triggers tend to be scientific and quantitative, whereas later decision-making can be more subjective and ultimately political.
- Science and narrative can be brought together into the same space and time in different ways – from the merging of boundaries between science and narrative, through over-layering to degrees of integration.
- Attention needs to be given to making interdiscipinarity explicit to build the communication skills of scientists, but also the science knowledge of the wider team for information exchange with scientists.

Developing new resources and evidence bases for drought risk management, as applied to the UK, is an area of international challenge. DRY's approach experiments creatively with bringing together new sets of knowledges and knowledge processes not traditionally used together in decision-making about drought triggers and associated communications/actions through the drought-adaptive cycle. Strong potential exists to bring science and narrative together as an evidence base at a range of scales and for diverse stakeholders – statutory agencies and non-statutory organisations, building up from the level of individuals in civil society. This involves reflecting on the knowledge, skills and dispositions of environmental scientists as part of interdisciplinary and inter-professional teams. There is now potential to develop and apply thinking in science–narrative working – as both process and outputs – within other risk domains. ES

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Lindsey McEwen is Professor in Environmental Management and Director for the Centre for Water, Communities and Resilience, UWE Bristol. Her research interests include extreme weather histories/archives, water risk management, knowledge integration to support local risk decision-making, water science communication/education and community-based research/learning. She is Principal Investigator for UKRI DRY.
Lindsey.McEwen@uwe.ac.uk
@Lindsey.McEwen1

James Blake is a Research Hydrologist at the Centre for Ecology & Hydrology, Wallingford, UK and Co-Investigator in UKRI DRY. His interests include soil and catchment hydrology, droughts, floods, integrated catchment management and climate change, alongside improved communication of scientific research and integration of lay and stakeholder knowledge.
jarib@ceh.ac.uk
www.ceh.ac.uk/staff/james-blake

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ANALYSIS

Sinkhole hazards, disaster response and GIS support

Sandy Ebersole summarises the way that geographic information science is used to map landscapes to prevent and deal with disasters.

As populations continue to grow in areas susceptible to natural hazards, there is a growing need to locate these hazards, quantify the risks, and communicate the level of danger to the public. Although simple static maps will always be an important means of communicating these threats, newer digital geographic software and methodology can enhance the accuracy and integration of multiple environmental variables while providing robust platforms for collaboration and communication. Both software and methodology are part of geographic information science (GISci), a growing discipline important in hazard analysis and emergency response.

GISci integrates several disciplines such as cartography, geography, spatial mathematics, statistics and computer science – all in a geographic context, relying heavily on the location and attributes of objects on Earth and their relationships in space and time. Geographic software and data form the geographic information systems (GIS) employed by GISci in analyses and visualisation. These methodologies of GISci and capabilities of GIS are a great asset in analysing complex interdisciplinary problems such as those in which physical and environmental hazards intersect.

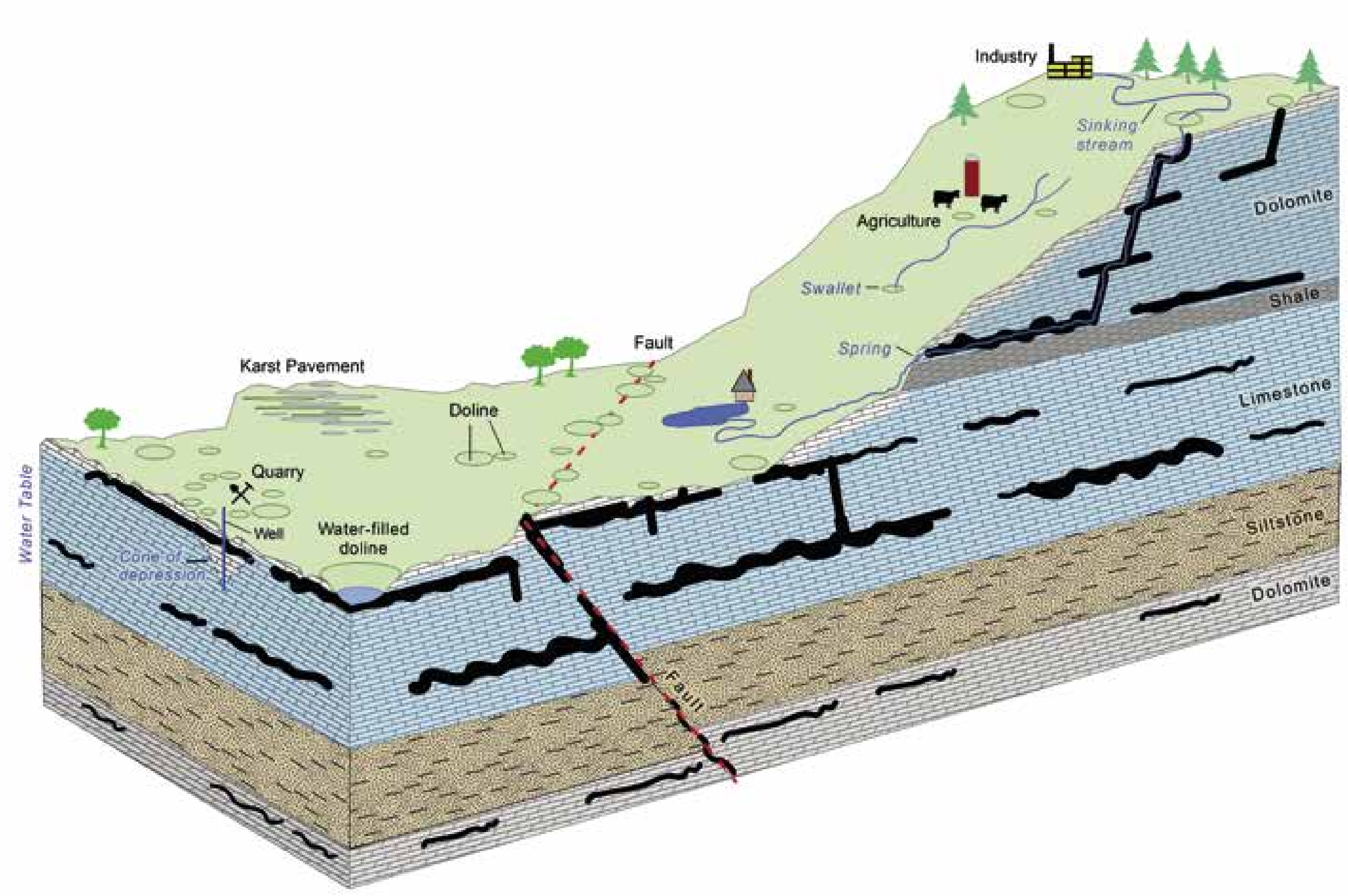
KARST TERRAIN AND ITS FRAGILITY

Some landscapes are more fragile than they appear at the surface, and one example of this is karst terrain, which is land that includes sinkholes (dolines), caves, swallets (openings where a stream goes underground), springs and other unique features (**Figure 1**) that are formed primarily by the dissolution of rock by water. Sinkholes form as the ground surface subsides (slowly or suddenly) into a void or cave below. Natural processes that influence this include the continuous dissolution of the underlying rock, a sudden increase in groundwater or surface water levels, a significant lowering of the water table because of drought, or the dislodging of rock masses during earthquake shaking. Anthropogenic causes of sinkhole growth include water drawdown from well pumping for agriculture, population needs or mining; changes made to natural surface water flow paths in developed areas; and increased surface load from buildings or other structures.

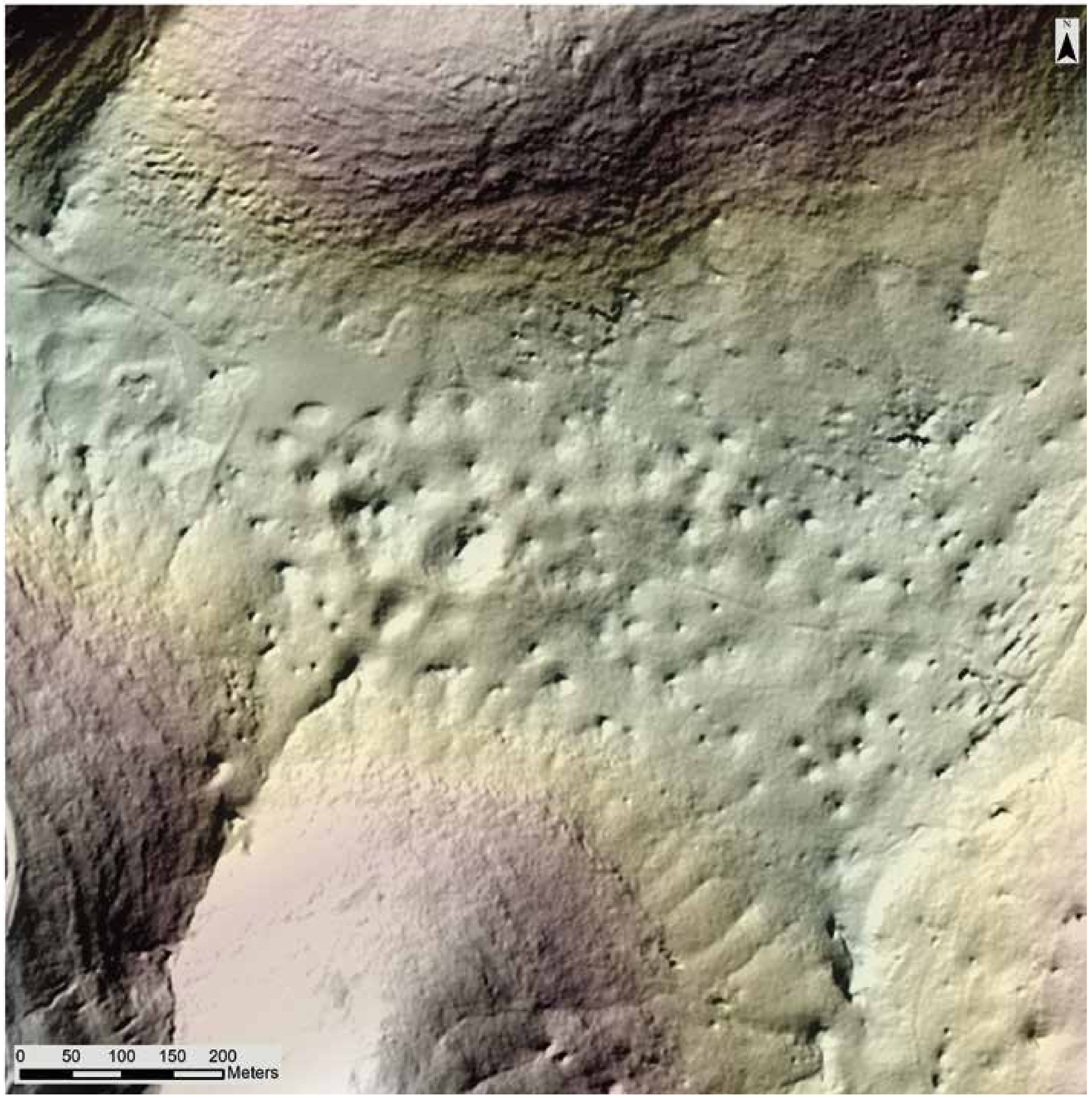
Sinkholes can damage buildings and infrastructure, and can also be a hydrological complication since many karst features are interconnected via surface and groundwater flow paths. This interconnectedness allows contaminants to spread out relatively quickly with little soil filtering.

GISCI FOR KARST MODELLING

Good land-use planning, as well as land and water management, include evaluating the strengths, weaknesses and limitations of land and water before and while land is being built on. Hazard and risk maps are an important part of these evaluations, are essential in karst terrain, and can be generated using GISci methodologies. Although karst hazard and risk categorisation techniques[1] vary, many of them start by mapping the local geology and sinkhole locations, which are often not available through state geological surveys,



▲ **Figure 1. A block diagram of karst terrain and the many karst features, geology and interconnected water paths within the aquifer. (Source: Sandy Ebersole.)**



▲ **Figure 2. A lidar-derived model of a sinkhole basin (green area in the centre); the dark spots are sinkholes accentuated by topographic shadows. The brown areas to the north and south are hills. The shading (called hillshade) on the topography was generated from 2010 lidar. Blount County, Alabama, USA.[11]**

in contrast to other geological data. To map karst features, many karst researchers have successfully applied GISci methods to digital terrain models (DTMs; also called 'bare earth models'). DTMs are derived from lidar (light detection and ranging), a high-resolution elevation data set (**Figure 2**). Feature-recognition models can be coded and run for automated detection, saving time in the analysis of large geographic areas. Models include steps that generate elevation contours, define closed contours, calculate roundedness (or circularity) of the feature,[2,3,4] calculate internal downward slope, and/or identify feature centroids with comparatively low elevations. Additional steps for some models include subtracting features that are linear or elliptical (e.g. roadside ditches) and/or are water filled (e.g. agricultural ponds).[4]

Heads-up digitising (visually identifying features on screen) from lidar is also useful, particularly in areas

where real karst feature morphology varies from model definitions. Heads-up digitising is slower than the automated models, but can provide more accurate final hazard maps, especially when performed in conjunction with the automated techniques. Machine errors that heads-up digitising can help to avoid include errors related to elongate widened joint- or fault-related sinkholes, small artificial reservoirs, quarry pits and other low areas related to construction.

Many factors (natural and anthropogenic) can generate new sinkholes or increase the size of current ones, and because of this, it is important to identify current sinkhole and karst feature locations as well as at-risk zones that are susceptible to future sinkhole development (**Figure 3**). Previously identified sinkhole locations in these zones often share physical attributes such as horizons of voids or caves, geological rock types most susceptible to dissolving, zones of rock weakness, geological structures, water-level horizons, areas with acidic water or areas related to anthropogenic activities. GIS statistical models such as spatial clustering and multivariate statistics can help analyse the aforementioned attributes, clarify patterns and identify risk zones that deserve more careful consideration for land- and water-management planning.

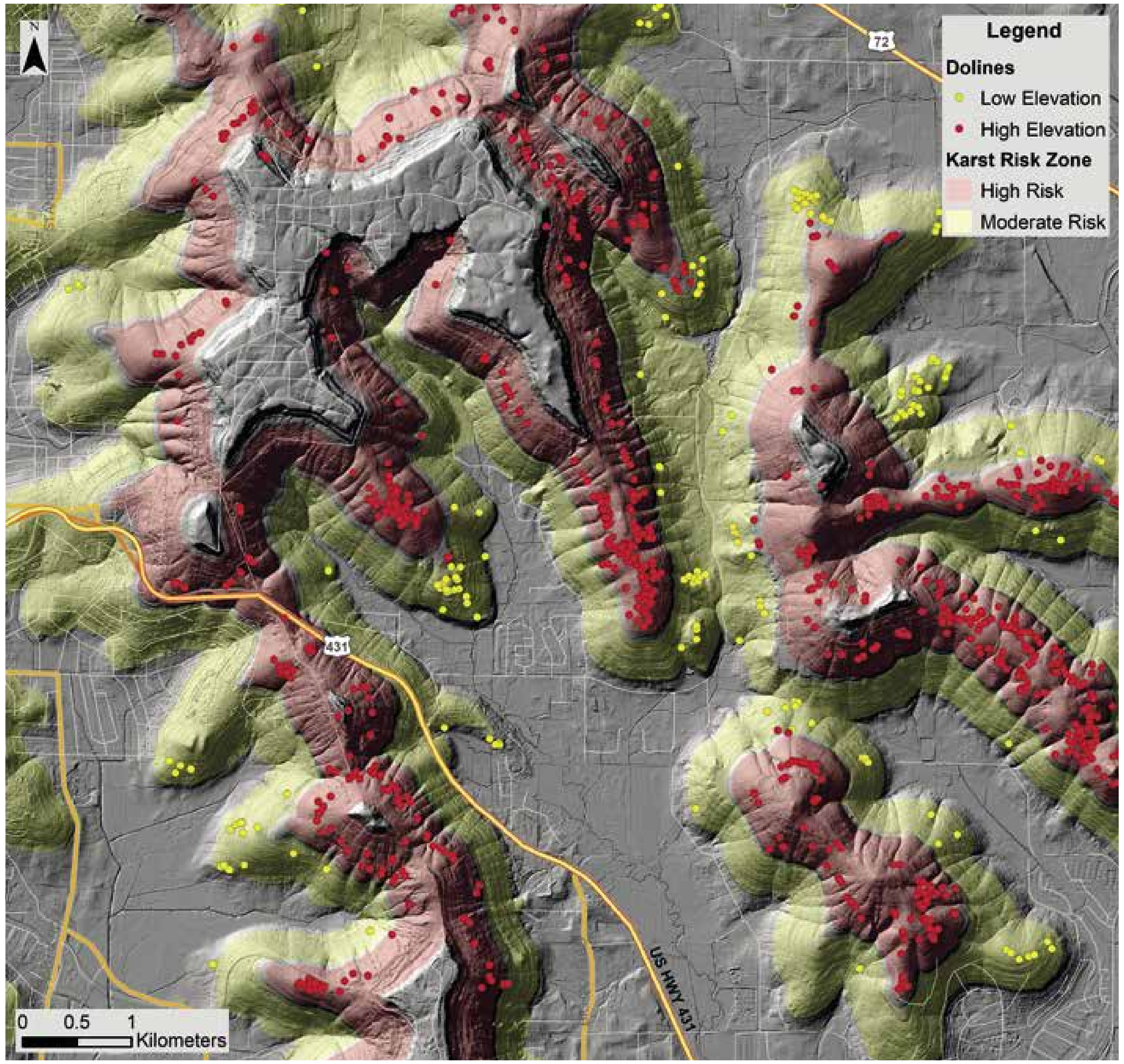
COMMUNICATING HAZARDS AND RISKS

Once karst hazard and risk zone data have been generated, sharing it to benefit planning and mitigation is important. Those who commonly use this data in maps (**Figure 3**) include builders, home owners, regional planners, academic researchers and a number of government agencies.

Beyond static maps, the karst data in GIS format are increasingly requested and relied upon by planners and the public as interactive online maps. Online maps such as Esri's ArcGIS Online[5] provide a simple, easy-to-navigate interactive platform for the public to explore. The online platform allows the author(s) of the data to generate, update, edit and publicly share the GIS data online. These dynamic maps allow users to search for an area, pan around, zoom in/out to view at different scales and click the data points for additional associated information, such as the geological unit or risk level. StoryMaps[6] (**Figure 4**), another product available through ArcGIS Online, allows the hazard data to be displayed along with photographs of sites, written narratives and other associated information. As the name implies, the maps and information guide the user through the area and provide topical information in a story-like fashion that educates users about the area's hazards and risks.

GEOSPATIAL DATA FOR DISASTER RESPONSE

One of the many strengths of online maps is that they allow integration of data from many different sources, including real-time data feeds. This provides a strong platform for emergency managers during disaster



▲ **Figure 3. Map made in Esri ArcGIS software showing sinkhole hazards and risk zones. Sinkhole locations (dots) were interpreted, in part, from topographic models of lidar[13]. Karst risk zones (yellow and pink areas) were modelled using geology,[12] density of sinkhole clusters, and elevation ranges from lidar.[13] Madison County, Alabama, USA.**

response as staff in different divisions or agencies can see the same situational information,[7,8] facilitating collaboration for more efficient, precise responses. Online maps can also be published as apps for smart phones, giving responders in the field access to the same situational information and operational picture (the map on which the situational information is displayed) as those coordinating the response in the emergency operations centre. Additionally, data in the field can be gathered using damage-assessment apps and then uploaded to the online map for further assessment and communication with other field teams and offices.

Another strength of online GIS software is its interoperability with incident management software (for example, WebEOC, a response software used in the USA). This, paired with an environmental hazards GIS software (for example, Computer-Aided Management of Emergency Operations – CAMEO[7,9]), provides a powerful situation-awareness tool during an environmental response. In karst terrain there are many interrelated physical attributes and flow paths, but these complexities may or may not be accounted for in all environmental contamination models. However, an online GIS software can allow the user to integrate previously defined karst risk zone attributes, hydrological data and results from the environmental hazards software for a more complete picture to support early response decisions. Online GIS platforms with analysis and metrics functions (examples: ArcGIS Online and Operations Dashboard for ArcGIS[10]) provide additional support, including quick identification of wells and land ownership for properties anticipated to be affected. All of these GIS capabilities together allow environmental scientists, geologists and emergency managers to more quickly assess and prioritise responses, with better visualisation of karst terrain complexities, contaminant flow direction and people and properties at risk.

LOOKING AHEAD

GISci and GIS can contribute to karst analyses, hazard maps, risk evaluation, planning, communication and incident response. While GIS software and GISci technology and science continue to develop, their contributions and capabilities will continue to grow. Furthermore, as populations continue to expand in hazardous locations, geographic technologies such as these can help to provide a better understanding of the complex settings and a means of coordinating our responses to those situations at times of greatest need. **ES**

Sandy Ebersole is the Director of Geologic Investigations at the Geological Survey of Alabama. She holds an MS in GIS, a PhD in geology, and uses GISci methods in mapping natural hazards, analysing risk, and planning for and responding to disasters.
✉ **sebersole@gsa.state.al.us**

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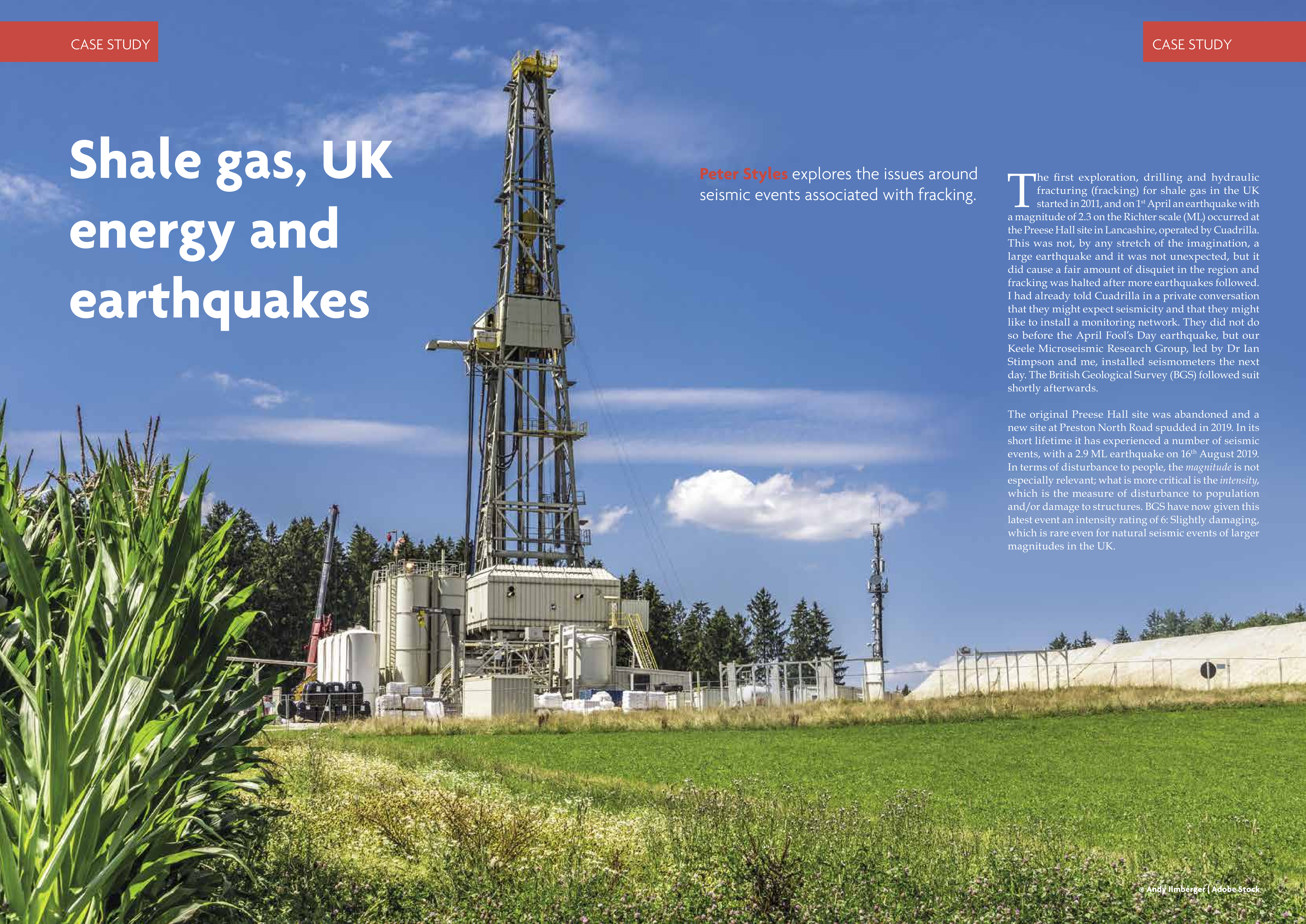
CASE STUDY



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Shale gas, UK energy and earthquakes

Peter Styles explores the issues around seismic events associated with fracking.

The first exploration, drilling and hydraulic fracturing (fracking) for shale gas in the UK started in 2011, and on 1st April an earthquake with a magnitude of 2.3 on the Richter scale (ML) occurred at the Preese Hall site in Lancashire, operated by Cuadrilla. This was not, by any stretch of the imagination, a large earthquake and it was not unexpected, but it did cause a fair amount of disquiet in the region and fracking was halted after more earthquakes followed. I had already told Cuadrilla in a private conversation that they might expect seismicity and that they might like to install a monitoring network. They did not do so before the April Fool's Day earthquake, but our Keele Microseismic Research Group, led by Dr Ian Stimpson and me, installed seismometers the next day. The British Geological Survey (BGS) followed suit shortly afterwards.

The original Preese Hall site was abandoned and a new site at Preston North Road spudded in 2019. In its short lifetime it has experienced a number of seismic events, with a 2.9 ML earthquake on 16th August 2019. In terms of disturbance to people, the *magnitude* is not especially relevant; what is more critical is the *intensity*, which is the measure of disturbance to population and/or damage to structures. BGS have now given this latest event an intensity rating of 6: Slightly damaging, which is rare even for natural seismic events of larger magnitudes in the UK.

WHY FRACK FOR SHALE GAS?

In 2013 BGS estimated that there might be as much as 100 years' worth of UK gas in the Bowland Shale in Lancashire, Yorkshire and Nottinghamshire. This was very welcome news to the UK government because North Sea gas reservoirs are being depleted while gas consumption is rising; some 70 per cent of UK energy is required for heating and cooking and we import more than half our gas.

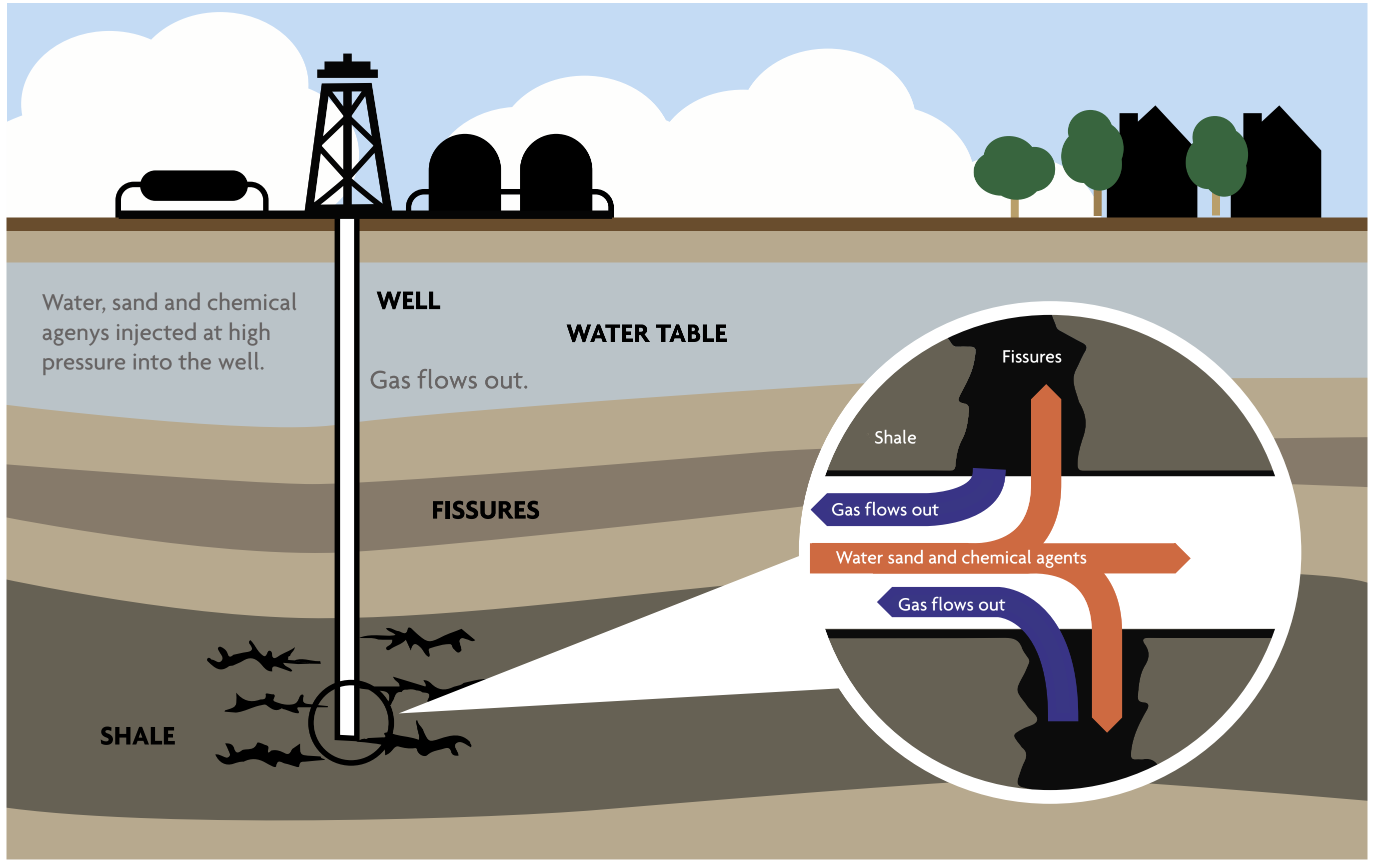
Like North Sea gas, shale gas is natural gas, which is a mixture of methane, ethane and other gases formed by the breakdown of organic material under high temperatures and pressures. Shale gas remains trapped because the permeability of shale (a sedimentary rock) is low – it blocks the flow of fluids and gases. By contrast, North Sea gas, for example, has migrated from the source rocks into a porous reservoir sealed by an impermeable cap. Since the latter is called 'conventional gas', shale gas is often known as 'unconventional gas'.

There are huge quantities of gas in the Bowland Shale, so why did it take so long to be exploited? The reason is that low permeability – it makes the gas hard to extract, so it took the development of the fracking process to enable extraction. Fracking involves drilling a well into shale through which high-pressure fluids (water plus additives) mixed with a proppant (sand or an artificial equivalent) are injected into rock; the purpose is to create a network of small fractures (see **Figure 1**). The proppant holds the fractures open and therefore increases the permeability of the rock, enabling the gas to flow into the well for collection. The earthquakes occur because the water pushes the rocks apart and lubricates them, enabling them to slip past each other.

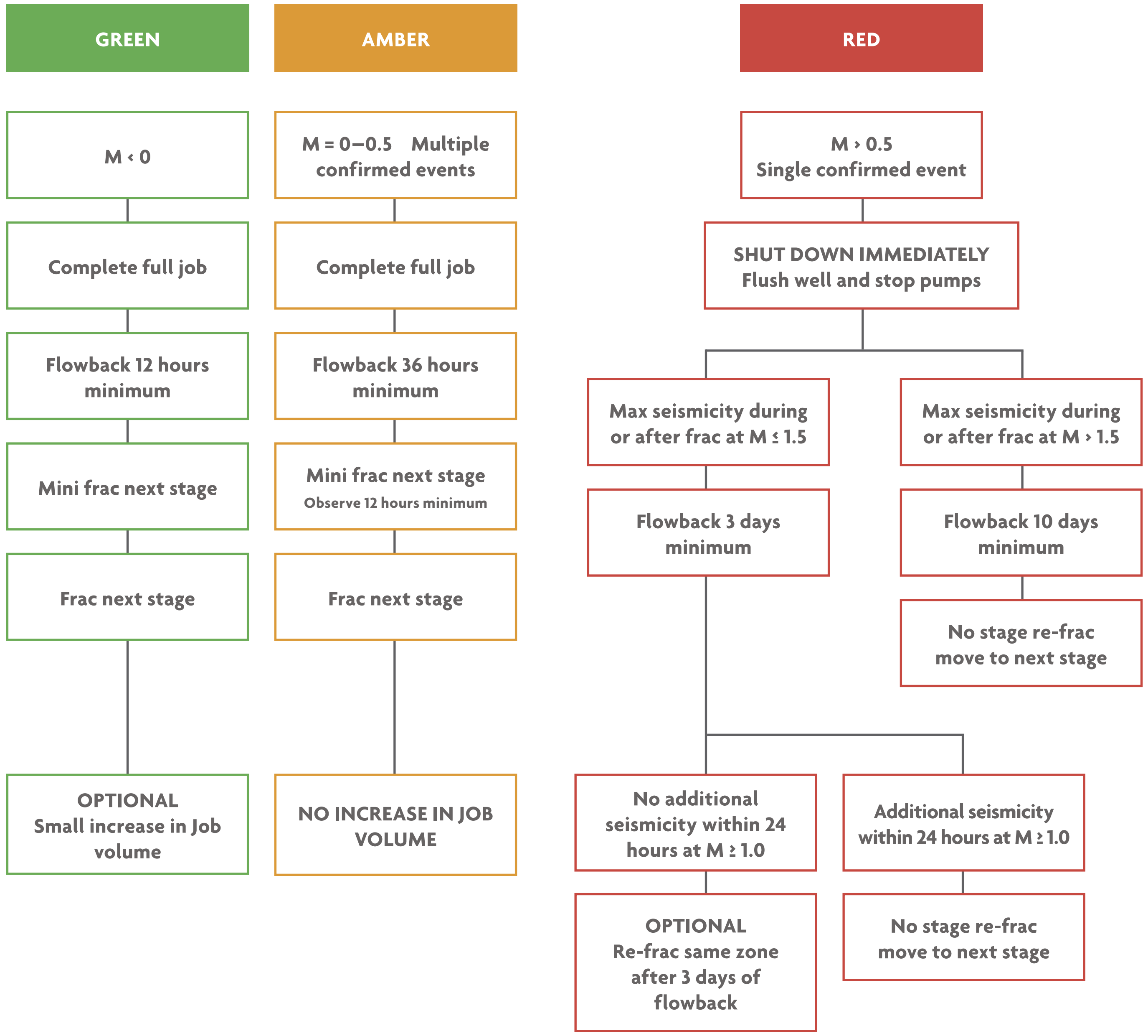
SEISMIC MITIGATION

After a certain amount of analysis of the seismicity and the stimulation parameters, Brian Baptie from BGS, Chris Green, an independent consultant, and I were tasked by the government to come up with some protocols to attempt to mitigate these unwelcome seismic visitors. We suggested a magnitude-based traffic light system (shown in **Figure 2**):

- Earthquakes of less than 0 ML magnitude are classified as green, so work can carry on after 12 hours of withdrawing fluid from the well after the frack;
- Those of 0–0.5 ML magnitude are classified as amber, so work can carry on after 36 hours of withdrawing fluid from the well; and



▲ **Figure 1. The fracking process. A vertical well is drilled until it meets the shale; then it is steered horizontally for significant distances. High-pressure water with some additives fractures the rock by hydraulic pressure. The small fissures are held open by a proppant, usually sand, so that oil and/or gas can flow out and be extracted.**



▲ **Figure 2. The seismic traffic light system. (Source: Christopher Green, Peter Styles and Brian Baptie).**

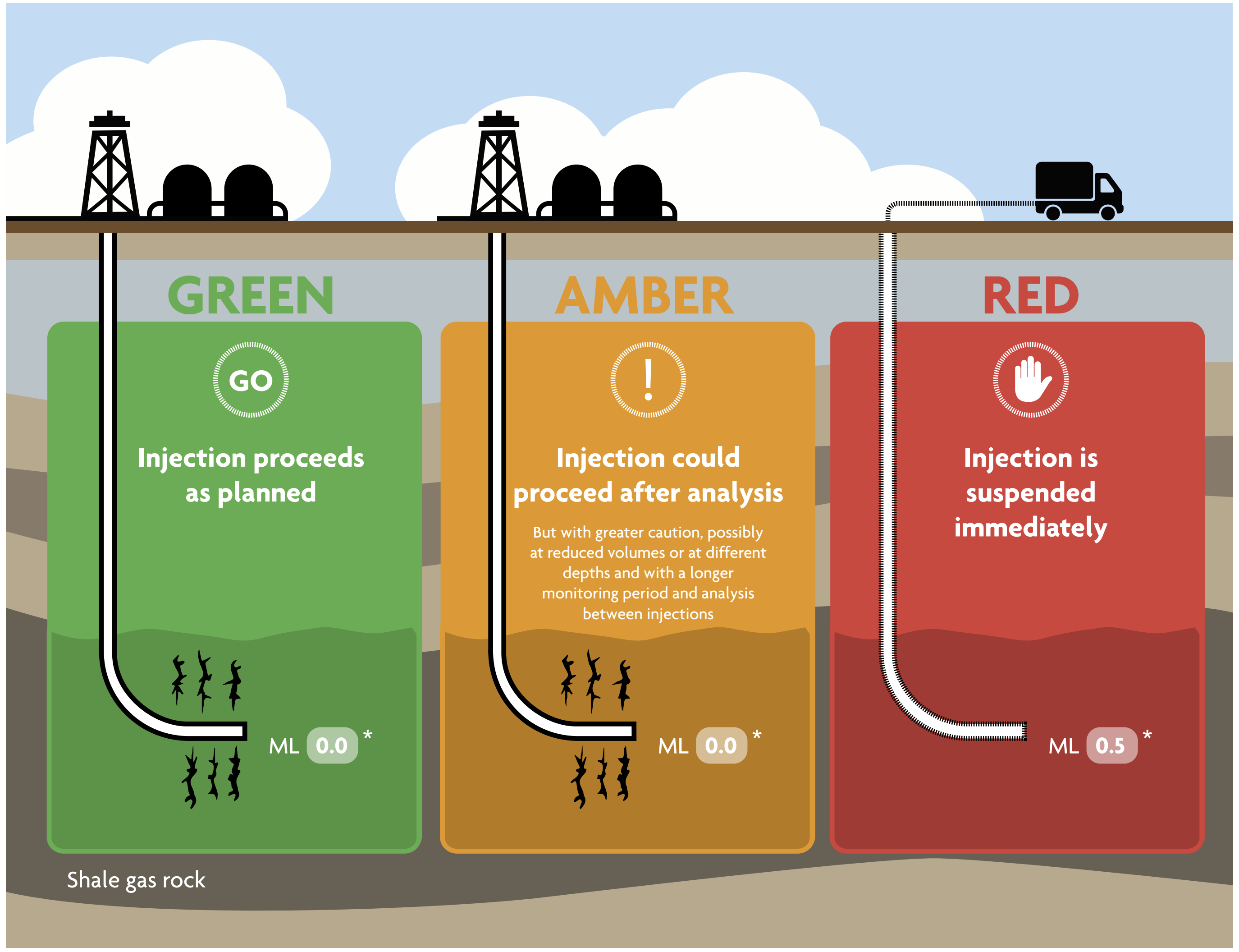
- Those over 0.5 ML are classified as red and work has to stop immediately.

This traffic light system is quite a complex protocol, with a number of decision trees, especially after an initial 0.5 ML event, which may be followed by a sequence of seismic events (known as 'trailing events). Our protocol included trailing events of up to magnitude 1.5 ML, but DECC (the Department of Energy and Climate Change, now merged into the Department of Business, Energy & Industrial Strategy) simplified it to the process shown in **Figure 3**, which mandates that fracking stop after a 0.5 ML earthquake.

SAFE DISTANCES

In addition, with funding from Researching Fracking In Europe (ReFINE), we, at Keele University and subsequently Durham University, attempted to assess how far fracking needed to be from a pre-existing fault in order not to stimulate movement in it. This is a complex question with many variables, not least of which is how much stress is required to trigger movement on a fault that has previously moved in geological time but that currently appears to be stable. The fault can be stimulated either by natural changes in stress, by additional stress imposed by the fracking or by the hydraulic effects of fluid processes, and possibly by mechanisms that we do not currently understand.

We ran 50 different models of a fracking operation based loosely on a site in north-west England and modelled the extent of the expected change in underground stresses. When we combined this with an estimation of the smallest stress change that we consider could trigger an earthquake, it seems that the fracking site needs to be more than 450 m and possibly as much as 850 m away from the fault. An additional and important consideration is that exploratory seismic surveys are unlikely to detect the size of fault that could produce a seismic event that would trigger the traffic light system.



▲ **Figure 3. The traffic light system protocol for implementation when seismic activity occurs during fracking for shale gas in the UK. (Adapted from a diagram by the Department of Energy and Climate Change.)**

The subtleties of what might really happen when a fracking well is operated are dealt with in a hydraulic fracture plan agreed between the Oil and Gas Authority (OGA), the Environment Agency (EA) and the operator, in this case Cuadrilla. After a threshold 0.5 ML seismic event, an 18-hour pause in activity is imposed.

FUTURE FRACKING?

In the same week as the 2.9 ML event (in August 2019), research by Professor Colin Snape at Nottingham University, in conjunction with BGS and using more sophisticated laboratory analysis techniques, reassessed the national potential shale gas reserves at only sufficient to power the UK for 10 years or so, instead of the century that BGS themselves had originally suggested in 2013. So, while there is a convincing case that new sources of preferably British-sourced gas, produced as environmentally as possible, are required, the triangle of truth for UK shale gas must be resolved:

- Long-term economics;
- Societal acceptability; and
- Geological complexity (as expressed through induced seismicity).

Before the General Election took place, Boris Johnson, the UK prime minister, decided that fracking should be halted in the UK. The government's moratorium, announced by Andrea Leadsom, made clear that after the Oil and Gas Authority reported that it was not possible to predict the probability or size of tremors from fracking, shale gas operations in Lancashire- which caused the magnitude 2.9 earthquake – are no longer lawful or at least until the science proves that it can be done safely and without disruption.

The same is true for other fracking sites in earlier stages of development in Yorkshire and Nottinghamshire but a closer look at this moratorium, reveals that similar fossil-fuel activities in south-east England can continue as normal despite the occurrence of recent seismicity in the Weald which is considered, at least by some, perhaps most, to be unrelated to hydrocarbon activity

However, announcements by INEOS that it will continue work at its Woodsetts and Harthill sites in South Yorkshire and that Cuadrilla is seeking new sites to explore, raise the question as to whether they have been given a whisper that the Moratorium may not be as carved in "tablets of shale "as was initially thought! ES

Professor Peter Styles is Emeritus Professor of Applied and Environmental Geophysics at Keele University and has worked for more than 40 years on induced earthquakes from a number of sources, including coal mining and shale-gas fracking.

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Editor Paddy Fowler

Subeditor Caroline Beattie
carolinebeattie.editorial@outlook.com

Designer Kate Saker
katesaker.com

Cover design Matt Cotterill
hi@mattcotterill.com

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6–8 Great Eastern Street
London
EC2A 3NT

Tel +44 (0)20 3862 7484
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