Institution: University of Bristol
Unit of Assessment: 10) Mathematical Sciences
Title of case study: Shaping the delivery of UK resilience policy by improving the National Risk Assessment
Period when the underpinning research was undertaken: 2007 - 2019
Details of staff conducting the underpinning research from the submitting unit:

Name(s): Jonathan Rougier	Role(s) (e.g. job title): Professor of Statistical Science	Period(s) employed by submitting HEI: 01/2007 – 06/2019

Period when the claimed impact occurred: 2016 - present
Is this case study continued from a case study submitted in 2014? No

1. Summary of the impact

The UK National Risk Assessment (NRA) is critical for assessing the UK's capability to respond to disasters. These include pandemics, natural hazards such as floods, industrial accidents such as a failure at a nuclear power plant, and terrorist actions. The NRA is crucial to Government planning, and benefits UK citizens and UK overseas dependencies. Rougier was seconded to the Cabinet Office to help produce the 2016 NRA and to contribute to the design of the 2018 NRA. His work fundamentally improved the assessment of both the impact and the likelihood of disaster scenarios. It has directly shaped the delivery of resilience policy and placed the UK at the forefront of this field.

2. Underpinning research

Rougier has a long track-record of Research Council-funded research and high-quality publications in the area of risk and uncertainty assessment in natural hazards. His funding ranges from work on Antarctica and sea-level rise (PI Prof Jonathan Bamber, School of Geographical Sciences) to volcanic eruptions (PI Prof Sir Stephen Sparks, School of Earth Sciences). In 2009, he was PI of a NERC-funded scoping study on risk and uncertainty assessment for natural hazards (the SAPPUR report). On the basis of the SAPPUR report, NERC decided to fund not one but two consortia on this topic, one of which was based at the University of Bristol (CREDIBLE - Diagnostics, Integration, Benchmarking, Learning and Elicitation for environmental risks, (PI Prof Thorsten Wagener, Rougier was Co-I) [i]). Rougier was lead editor of a Cambridge University Press book following from SAPPUR on *Risk and Uncertainty Assessment for Natural Hazards* (2013) [1].

Rougier's contribution to the National Risk Assessment (NRA) arises from two different aspects of his expertise, both exemplified by his published research. First, Rougier is a leading expert on statistical inference and statistical decision theory. This approach involves applying theory to provide intuitive, transparent and defensible approaches to quantifying uncertainty and risk, and to choosing actions. Two examples of direct relevance to the NRA are extreme weather early-warning systems [2], and volcanic ash detection [6], both funded by the NERC CREDIBLE grant [i]. In both examples, statistical decision theory is used to optimize the action response in the presence of imperfect information.

The paper [5], proposes an operational framework for representing confidence in risk assessments that works across all hazard classes. Within each, a three-dimensional point

process of (time, magnitude, loss) triples is used to model the occurrences of events in that class. Under a natural assumption that loss is a strongly convex function of magnitude, it is shown that expected annual loss is dominated by high-magnitude low-probability events. It is beliefs about the values of these low probabilities (of events with magnitude greater than a defined threshold) that need to be systematised in a logically and numerically coherent way. This is not straightforward since they require eliciting an expert's current beliefs about how her beliefs might be different in the future. Two reasonable modelling simplifications make this framework practical to apply – informally they require threshold-exceeding events to occur completely randomly and rule out paradigm-shifting changes in the underlying processes, which are inherently and necessarily unpredictable.

Second, impact arises from his ability to work with scientists to understand complex datasets, which are very common for high-impact low-probability events. A sequence of papers culminating in Rougier *et al.* (2018) [4] tackled the reliability of the record of large explosive volcanic eruptions. These eruptions pose a direct threat to the UK from Iceland and Italy, a threat to UK dependencies such as Monserrat, and a threat to the many thousands of UK subjects living in Japan and Indonesia, which are all concerns of the UK NRA. Exactly the same techniques can be applied to many other natural hazard records, including floods (e.g. Hawker *et al.* (2018) [3], solar storms, long hot and cold spells, and droughts (all in the NRA), and more widely, to accidents and malicious events. As these techniques become more widely adopted, UK risk assessments are likely to change substantially, as has already happened for large explosive volcanic eruptions.

3. References to the research

[1] **J.C. Rougier**, R.S.J. Sparks, and L.J. Hill (eds), (2013), *Risk and Uncertainty Assessment for Natural Hazards*, Cambridge, UK: Cambridge University Press, 574 pages. Lead Editor, and author/co-author for chapters 1, 2, 3 (pages 1-63).

[2] T. Economou, D. B. Stephenson, **J.C. Rougier**, R. A. Neal and K. R. Mylne (2016), On the use of Bayesian decision theory for issuing natural hazard warnings, *Proceedings of the Royal Society, Series A*, 472, 20160295, 19 pages. doi:10.1098/rspa.2016.0295

[3] L. Hawker, **J.C. Rougier**, J. Neal, P. Bates, L. Archer, and D. Yamazaki (2018), Implications of simulating global digital elevation models for flood inundation studies, *Water Resources Research*, 54 (10), 7910-7928. doi:10.1029/2018WR023279

[4] **J.C. Rougier**, R.S.J. Sparks, K.V. Cashman, and S.K. Brown (2018), The global magnitude-frequency relationship for large explosive volcanic eruptions, *Earth and Planetary Science Letters*, 482, 621-629. doi:10.1016/j.epsl.2017.11.015

[5] **J.C. Rougier** (2019), Confidence in risk assessments, *Journal of the Royal Statistical Society, Series A (Statistics in Society)*, 182 (3), 1081-1095. doi:10.1111/rssa.12445

[6] L.M. Western, **J.C. Rougier**, and I.M. Watson (2018), Decision theory-based detection of atmospheric natural hazards from satellite imagery using the example of volcanic ash. *Quarterly Journal of the Royal Meteorological Society*, 144, 581-587. doi:10.1002/qj.3230

4. Details of the impact

The National Risk Assessment (NRA) is a critical, but very complex, process that spans the whole of Government, and that affects everyone in the UK and its overseas dependencies. The NRA is the UK's primary tool in assessing and managing resilience to high-impact low-probability events, many of which arise from natural hazards. Such hazards can incur harm amounting to hundreds/thousands of lives, and billions of pounds. The 2020 COVID-19 pandemic, with death toll and financial impact still untold, occurred a century after the Spanish flu pandemic; another recent tragic example was the fire at Grenfell Tower in 2017 (72 deaths, total financial impact in excess of GBP100 million, maybe as high as GBP1 billion).

The NRA involves nearly every Government Department and their associated agencies. There are also strong links with similar projects in other countries and with the EU Disaster Risk Management Knowledge Centre (DRMKC). The National Risk Assessment is a restricted report due to its importance pointing out the country's vulnerabilities, and much of the work of the Civil Contingencies Secretariat supporting this activity is therefore also restricted.

Improving the risk assessment process of the NRA

Rougier has a strong commitment to public service. In 2015, he approached NERC, the Government Office for Science, and the Civil Contingencies Secretariat (CCS) of the Cabinet Office, with a proposal to be seconded to the CCS to work on the 2016 NRA and help design the 2018 NRA. This was funded by NERC, amounting to 80% FTE over 5 months in 2016/17 [ii]. The Civil contingences secretariat is tasked with leading cross-department effort to improve the resilience of the UK to emergencies, ranging from floods to terrorism [A].

i) Increased consistency and objectivity in the assessment of impact

Rougier's remit in the secondment was to contribute natural hazard expertise, and more generally as a very experienced statistical scientist, to the risk assessment process of compiling the NRA. His involvement was pervasive, from the elicitation exercises held in Government Departments and agencies, to the compilation of individual hazard assessments into a single combined assessment (represented by a 'risk matrix'). A publicly available and simplified version of this can be found in the National Risk Register for Civil Emergencies [C] (see in particular the methodology section (pp.69-70) and risk matrices (pp.9-10)).

Before Rougier's involvement, the NRA was incoherent; the Home Office Chief Scientific Adviser at the time, says: *"It was always unsatisfactory that the risks had an upper (and lower) limit, and the other big issue was that the approach was always rather focused on a single "reasonable worst case" rather than [a] range of outcomes."* [B]. Such a range of outcomes improves the decision making in government under uncertainty and facilitates actions especially in the case of low frequency extreme events. The Assistant Director, National Risks Team, Civil Contingencies Secretariat, Cabinet Office stated that "*Professor Jonathan Rougier has therefore directly shaped the delivery of resilience policy*" [A].

Rougier reengineered the specification and presentation of impact scales, including creating a fully-automated tool that could be used consistently over many different types of impact; e.g. the loss of different types of service, like health, education, various modes of transport, and finance [A].The Assistant Director of the National Risks Team noted that these changes have enabled the CSS, and specifically the impact assessment, to:

- *"Demonstrate the many ways in which you might cause an equivalent level of harm.*
- *Differentiate between particularly catastrophic risks by showing where risks might go beyond a score of 5.*
- *Make it easier to scale down information relating to national risks, therefore enabling local emergency responders to apply the same principles to their own local risk assessment and understand where they might face resource pressures.*
- *Give officials greater freedom to explain the precise impacts of their scenario and convert this information into a score rather than having to fit within a narrowly defined description of impact that may not be relevant to a particular risk."* [A].

In summary, the former Home Office Chief Scientific Adviser [B] writes *"Ms Clarke's letter …. is a very fair description of Rougier's contribution. Getting some rigour into the whole process is enormously important. You will particularly note her bullet points in the Impact Assessment section".*

Rougier's work also involved auditing and revising guidance documents, including working with scientists, managers, and implementers to clarify meanings, streamline processes, and reduce the possibility of errors. *"Overall, Prof Rougier's work on the impact scales has directly benefitted our ability to consistently, transparently, logically and robustly compare and prioritise very different risk scenarios."* [A].

ii) Improving the assessment of likelihood

Rougier also provided general advice to government Departments on how to assess the likelihood of their 'reasonable worst case' scenario: *"on the basis of Prof. Rougier's advice, we have begun to amend our approach … This will enable us to capture Departmental confidence in risk assessment in a more meaningful way […]"* [A]. This advice informed a discussion about risk and confidence assessments for national-scale risk assessment included in an article published following his secondment [5].

Rougier's involvement has brought clarity and 'usability' to the NRA. As the former Home Office Chief Scientific Adviser writes [B]: *"Rougier's work has had important impact in a crucial area of Government which, of necessity, is not front and centre in the public eye, but it underpins so many things that are."* To exemplify the inadequacy of the NRA before Rougier's involvement, the expression 'reasonable worst case' has become common parlance in the context of the Covid-19 pandemic, but the Cabinet Office did not have a coherent definition of this concept across different risk classes until he helped them to develop one.

Rougier's impact on the NRA has been substantial and wide-ranging. *"[Rougier's] contributions have placed the UK at the forefront of [the field of national risk assessment] and will … raise the quality and consistency of risk information as we embark on the process of updating the NRA."* [A]. *"As we adopt and reflect Prof. Rougier's systems and advice within the new NRA, his work will reach policymakers across HM Government, ranging from permanent secretaries and chief scientists of most Government Departments to specialists and analysts within Executive Agencies such as Natural England and Public Health England."* [A].

Changes to natural hazard risk levels

Rougier's research into extreme weather early-warning systems [2], and volcanic ash detection [6], using statistical decision theory to optimize the action response to imperfect information,

further informed the NRA process. The National Risk Register specifically notes provision of 'early warning on severe weather' as one way of managing risk [C (p.21)].

During his secondment, Rougier liaised with the then Chief Scientific Adviser, and with the UK natural hazards community through the UK Natural Hazards Partnership (NHP), as well as more widely within the UK National Security Secretariat. Since completing his secondment, he continued to work with the CCS, funded by the University of Bristol, and directly with other agencies, including holding a William Penney Fellowship at the Atomic Weapons Establishment (AWE).

Improved public and parliamentarian understanding of NRA

The National Risk Register is the public output from the NRA process [C]. It is an overview of the key risks that have the potential to cause significant disruption in the UK, written for the general public and businesses. Much of Rougier's day-to-day contributions during his secondment concerned the general practice of statistical inference and decision theory including *"providing support to a number of teams within CCS on risk or mathematical queries and presenting a 'lunch and learn' on probability which was very well attended and received"* [A]. One issue which came up repeatedly across the whole community of scientists and risk managers is how to quantify confidence in risk assessment, so that it is accessible and helpful to both scientists and risk managers. Rougier (2019) [5], provides a solution based on the sensitivity of risk assessments to new information, which is now under discussion for incorporation into the 2020 NRA.

Finally, Rougier contributed to a 2019 Parliamentary Office of Science and Technology (POST) brief 'Evaluating UK natural hazards: the national risk assessment' [D]. These briefs are produced as impartial, reactive advice for both the House of Commons and House of Lords Committees and Libraries. Rougier's work [1, 5], is cited in it, and he also acted as an external reviewer.

5. Sources to corroborate the impact

[A] Letter from the Assistant Director, National Risks Team, Civil Contingencies Secretariat, Cabinet Office (2018). *The National Risk Assessment is a restricted report, and much of the work of the Civil Contingencies Secretariat is also restricted.*

[B] Letter from FRS, Former Chief Scientific Adviser, UK Home Office (2020). *Rougier's work with the Cabinet Office took place while he was Chief Scientific Adviser to the Home Office.*

[C] Cabinet Office (2017). National Risk Register of Civil Emergencies – 2017 edition *See in particular; the methodology section (pp.69-70), and risk matrices (pp.9-11).*

[D] Parliamentary Office of Science and Technology (POST). 2019. Research Briefing (POSTbrief 31): Evaluating UK natural hazards: the national risk assessment