GLOBAL RISK FORUM GRF DAVOS GRF planet @risk



http://www.planet-risk.org

# Novel Indicators for Identifying Critical INFRAstructure at RISK from Natural Hazards

TUCKER, M.[a], NÍ CHOINE, M.[b], O'BRIEN, E.[c], O'CONNOR, A.[d], GAVIN, K.[e], D'AYALA, D.[f], ADEY, B.[g], CHENG, T.[h], VAN GELDER, P.[i], SABEUR, Z.[k], and JIMENÉZ, M. J.[l]

[a] Roughan & O'Donovan Innovative Solutions, Dublin, Ireland. E-mail: mark.tucker@rod.ie
[b] Roughan & O'Donovan Innovative Solutions, Dublin, Ireland. E-mail: Mairead.NiChoine@rod.ie
[c] Roughan & O'Donovan Innovative Solutions, Dublin, Ireland. E-mail: eugene.obrien@rod.ie
[d] Roughan & O'Donovan Innovative Solutions, Dublin, Ireland. E-mail: alan.oconnor@rod.ie
[e] Gavin & Doherty Geo Solutions, Dublin, Ireland. E-mail: kgavin@gdgeo.com
[f] University College London, London, United Kingdom. E-mail: d.dayala@ucl.ac.uk
[g] Eidgenössische Technische Hochschule, Zurich, Switzerland E-mail: adey@ibi.baug.ethz.ch
[h] University College London, London, United Kingdom. E-mail: tao.cheng@ucl.ac.uk
[i] Probabilistic Solutions Consult and Training, The Hague, Netherlands. E-mail: pvangelder@bureaupsct.nl
[k] IT Innovation, Southampton, United Kingdom. E-mail: zas@it-innovation.soton.ac.uk
[l] Institute of Geosciences (CSIC-UCM), Madrid, Spain. E-mail: mj.jimenez@csic.es

***Abstract*** – The achievements of the European Union targets regarding energy and socio-economic sustainability are highly dependent on the way risks and vulnerabilities of European operating infrastructure networks and critical assets are minimised against natural extreme events. The INFRARISK project is developing reliable stress tests for European critical infrastructure using integrated modelling tools for decision-support. As a result it is possible to obtain higher infrastructure networks resilience to rare and low probability extreme events. INFRARISK advances decision making approaches and leads to better protection of existing infrastructure whilst achieving more robust strategies for the development of new ones. INFRARISK expands existing stress test procedures and adapts them to critical land-based infrastructure, which may be exposed to or threatened by natural hazards. Integrated risk mitigation scenarios and strategies are employed, using local, national and pan-European infrastructure risk analysis methodologies. These take into consideration multiple hazards and risks with cascading impact assessments. The INFRARISK approach robustly models spatio-temporal processes with propagated dynamic uncertainties in multiple risk complexity scenarios. An operational framework with cascading hazards, impacts and dependent geospatial vulnerabilities is developed. This framework is a central driver to practical software tools and guidelines that provide greater support to the next generation of European infrastructure managers to analyse and handle scenarios of extreme events. The minimisation of the impact of such events by the supporting tools establishes optimum mitigation measures and rapid response. INFRARISK delivers a collaborative integrated platform where risk management professionals access and share data, information and risk scenario results efficiently and intuitively.

***Keywords*** – *Critical Infrastructure, Resilience, Risk Assessment, Stress Test, Natural Hazards, Decision Support Tool*

## 1. Introduction

Natural hazards are regularly occurring destructive phenomena, the severity of which is largely dependent on the level of preparedness and resilience of society for such events. Protection against natural hazards must be guaranteed for people to work and live in a secure and resilient environment. No activity (including emergencies and rescue operations) can be carried out with the loss of key buildings and facilities, transport networks and an interruption to essential supplies.

In Europe the occurrence of natural hazards, and in particular hydro-meteorological hazards due to climate change, is expected to increase over the next 50 years (EEA 2010, EEA 2012). Coupled with increased land occupation, eastwards expansion of the EU, human activity in hazard zones, an ageing infrastructure, reduced spending, the existence of interdependent cross cutting Pan European Networks and critical infrastructure along these networks, the potential for greater damage costs and fatalities is increased.

The trend of rising economic losses continues to challenge sustainability and economic growth and there is a drive to build a culture of resilience in Europe. Based on Europe's recent 10-year average of disaster losses of €10 billion, it is the third most affected region in the world after the Americas and Asia. As stated in the ECTP Implementation Action Plan (ECTP 2007), during the first decade of the 21st century, the average cost of natural and man-made hazards was estimated at €7.35 billion/year, which demonstrates the large economic lever effect of adopting rational protection and prevention measures. This lever effect is even more pronounced when only the most vulnerable areas are considered, particularly if we only consider necessary protection against rare low frequency extreme events. Moreover, potential loss of life is not incorporated in these figures.

Although extreme events are not relatively frequent in many parts of Europe (EEA Technical report No 13/2010), due to the complex interdependent, and cross cutting networks that extend throughout the continent (roads, railways, gas lines, electricity, etc.), and the significant amount of critical facilities along these networks, a disruption in one node or link of that network may have negative impacts at a European level. Moreover, this disruption can constitute a source of political and social unrest within society in addition to functional and operation disruption.

In recent years, the complex interdependencies of the European infrastructure network have been highlighted through cascading, escalating and common types of failures during extreme events. These failures have been the driver for this project concept and the aim of INFRARISK is to better predict the sensitivity of European infrastructure to widespread disruption so that mitigation measures can be planned.

The INFRARISK project brings together a well balanced, experienced multi-disciplinary, multi-national consortium combining a strong academic and industry presence, consisting of research institutes, higher education institutes, SMEs and large enterprise. The project is funded under the European Union Seventh Framework Programme (FP7), under the call topic Env.2013.6.4-4 towards stress tests for critical infrastructure against natural hazards. While the focus of the project is aligned to road and rail transport infrastructure, it is envisaged that the framework developed will be transferrable to any critical infrastructure system or systems of systems for interdependent networks.

## 2. The INFRARISK Concept

Extreme, low probability natural hazard events, whilst being extremely rare, can have a devastating impact on critical infrastructure systems. The INFRARISK vision is to develop reliable stress tests to establish the resilience of European critical infrastructure to rare low frequency extreme events and to aid decision making in the long term regarding robust infrastructure development and protection of existing infrastructure. The project considers seismic, flood and landslide hazard events and looks in particular at the resilience of road and rail bridges, tunnels, embankments and the networks of which they are a part.

In pursuit of resilient infrastructure, the goal of INFRARISK is two-fold, namely to:

a) Develop reliable stress tests to establish the resilience of Critical European Infrastructures to rare low frequency extreme natural hazard events.
   In this regard it is our aim to identify rare low-frequency natural hazard events and develop a stress test framework for linear infrastructure systems with many nodal points. We plan to develop an integrated approach to hazard assessment that will consider the complicated interdependencies of infrastructure networks and their response to one or more hazards, cascading hazards and cascading effects and spatial and temporal vulnerability.
b) Aid decision making in the long term regarding robust infrastructure development and protection of existing infrastructure.
   In this regard we aim to: 1) facilitate implementation in practice through GIS based and web based tools; 2) test the framework developed through simulation of case studies and 3) develop exploitation strategies aimed at disseminating the 'knowledge' and not just the results, to ensure the framework developed can be utilised by infrastructure managers.

## 3. The Methodology

The methodological core of the project is based on the establishment of an ''Overarching Methodology'' (Harmonisation Process) to evaluate the risks associated with multiple infrastructure networks for various hazards with spatial and temporal correlation. Interdependency will be formalised and damage will be defined in terms of capacity decrements. This will be the basis for the development of stress tests for multi-risk scenarios and will define the general framework, providing a tool for decision making based on the outcome of the stress test. The overarching methodology will capture and incorporate, into a GIS platform, outputs from an extensive profiling of natural hazards and infrastructure, and analysis of single event risk for multiple hazards and space-time variability of a critical infrastructure network. An INFRARISK strategic decision support tool will be developed to ensure network models and stress test procedures are integrated and used under specific process workflows and modules. Further application to selected case studies to demonstrate the modelling techniques and procedures developed in INFRARISK will be carried out. A schematic of the technical work flow is illustrated in Figure 1.

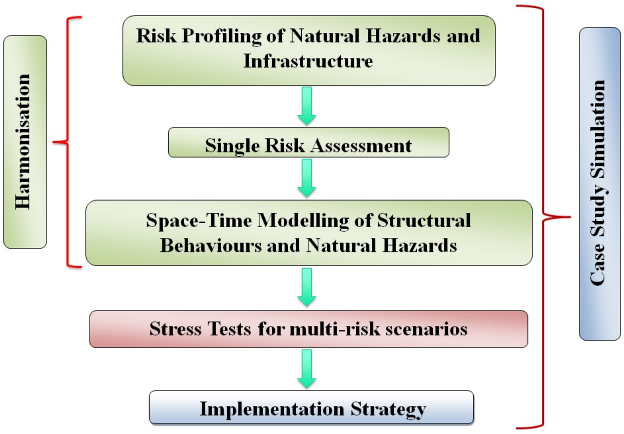


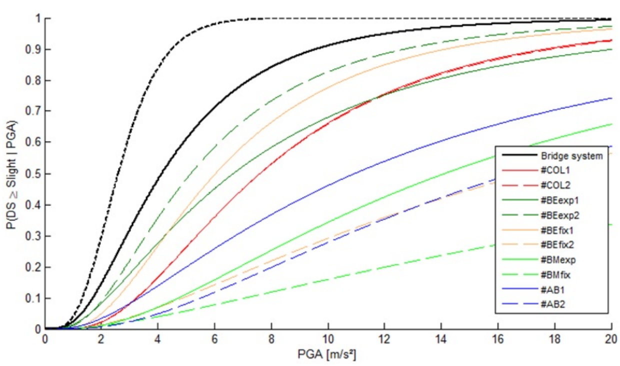

**Figure 1**: Methodology

### *3.1. Risk Profiling of Natural Hazards and Infrastructure*

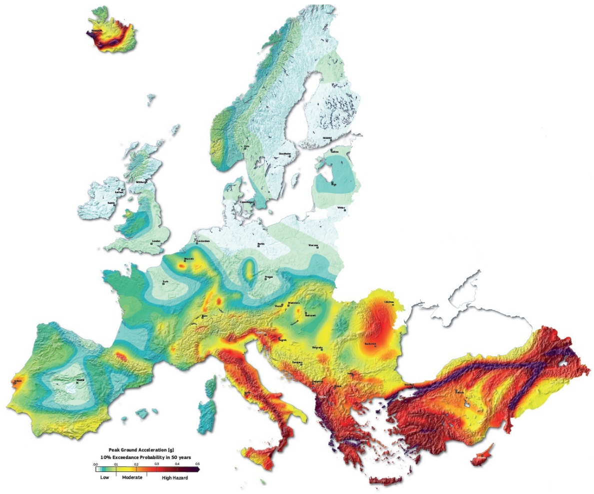
A database of critical infrastructure in Europe is being developed to identify the risks posed by natural hazard events considering the geographical correlation between elements of critical infrastructure and extreme natural hazard events. Furthermore methods are to be developed to estimate the effects of climate change on the occurrence of natural hazards.

### *3.2. Single Risk Assessment*

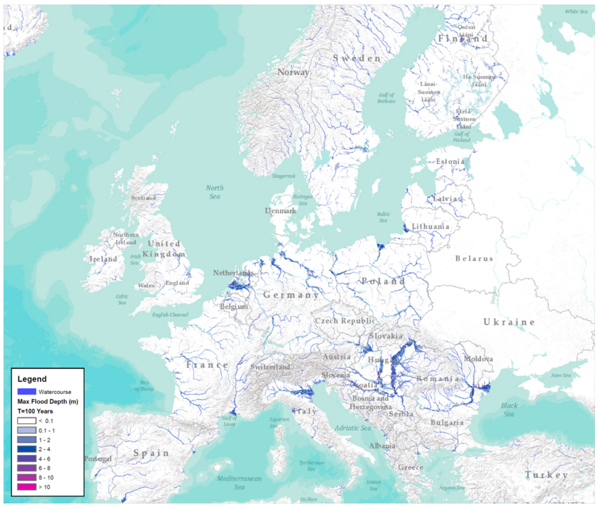
Single event risk analysis methodologies are developed for the hazards of interest (Figure 2b, 2c, 2d) incorporating the methodologies into geo-referenced spatial models, ultimately used to evaluate the probability of occurrence of actions on infrastructure elements/networks and of resulting physical consequences to the elements/networks. The objective is to develop generalised analytical vulnerability functions (e.g fragility curves, Figure 2a) within a single framework which can be seamlessly interfaced to be compared and cumulated in multi risk analysis scenarios.



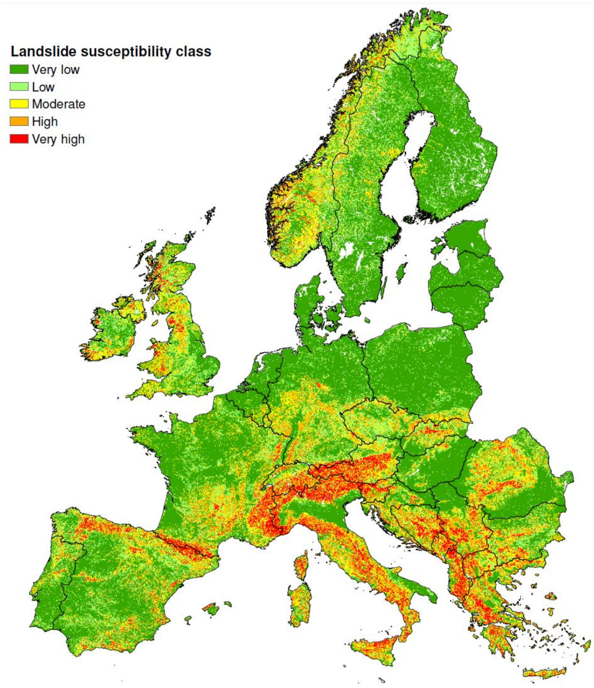

**(a)**



**(b)**




**(c)**




**(d)**

**Figure 2**: a Fragility Curves (INFRARISK); b Seismic Hazard Map (Giardini et al. 2013); c Flood Hazard Map (Alfieri et al. 2013); and, d Landslide Hazard Map (Panagos et al. 2012)

### 3.3. *Space Time Modelling of Structural Behaviours and Natural Hazards*

Space-time models are being developed to analyse the impact of natural hazards on structural behaviours of critical infrastructures that may be location (space) or/time dependent. Given the impacts of natural hazards on structural behaviour might be nonlinear, interconnected and scale-variant, three approaches will be explored here in order to fully tackle these challenges, namely, Support Vector Matching (SVM), Network Complexity Theory and Wavelet Analysis.

### 3.4. *Harmonisation*

An overarching methodology or harmonised risk process will be established to evaluate the risks associated with multiple infrastructure networks for various hazards with spatial and temporal correlation. It will capture and incorporate, into a GIS platform, outputs from the extensive profiling of natural hazards and infrastructure, the analysis of single event risk for multiple hazards and the space time variability of a Critical Infrastructure network. The overarching process established will enable infrastructure managers to identify the risk related to critical infrastructure.

### 3.5. *Stress Tests for Multi-Risk Scenarios*

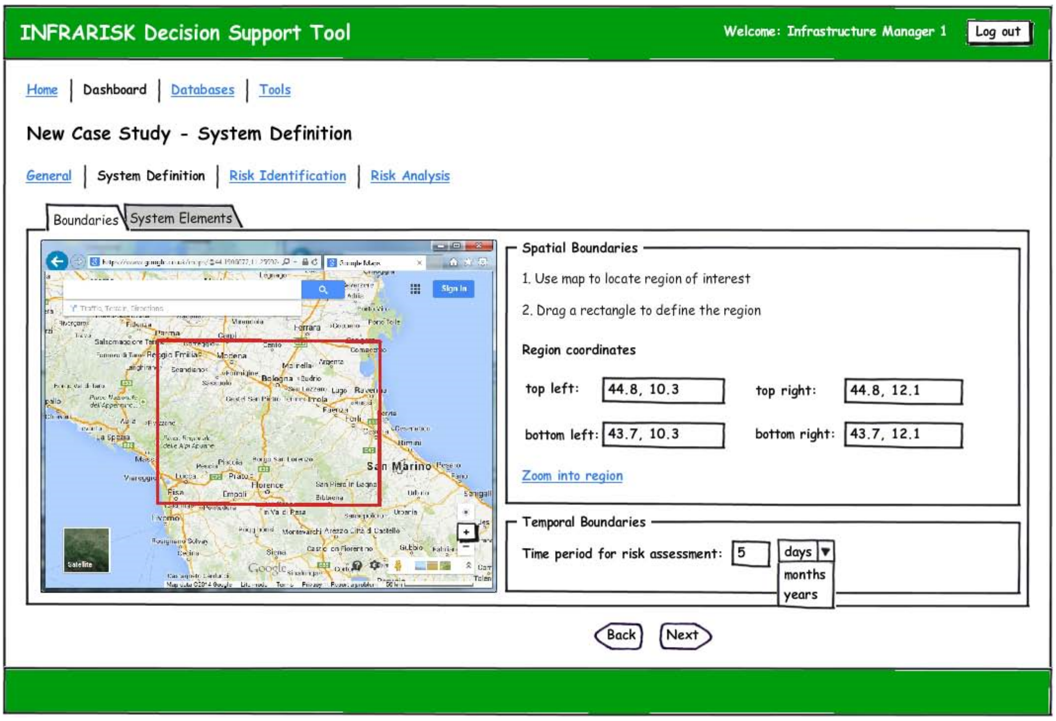
The purpose of the stress test is to be able to quantify the probability of failure more accurately i.e. reduce uncertainty. A Stress test framework is to be developed for the evaluation of the consequences that would be incurred if the critical scenarios identified in previous work streams are realised. Probabilistic models will be utilised since the response will be inherently stochastic. These stress tests will include optimum physical test scenarios and management support systems and will build on experiences within other sectors.

### 3.6. *Implementation Strategy*

A strategic INFRARISK Decision Support Tool (IDST), Figure 3, will be specified, designed and developed to ensure that the INFRARISK stress tests and the harmonized risks management methods are practically integrated and used under specific process workflows and modules. In other words, the IDST will provide computational support to the risk assessment process. See IDST Mock Ups on page 6.

### 3.7. *Case Study Simulation*

In this work stream case studies will be simulated to test the applicability and validate the effectiveness of the tools and methodologies developed in INFRARISK. The case studies will focus on road and rail transport infrastructure systems on the European TEN-T network and will be characterised by the simulation of the response of the individual and interdependent systems when subjected to a variety of rare high consequence natural hazards.



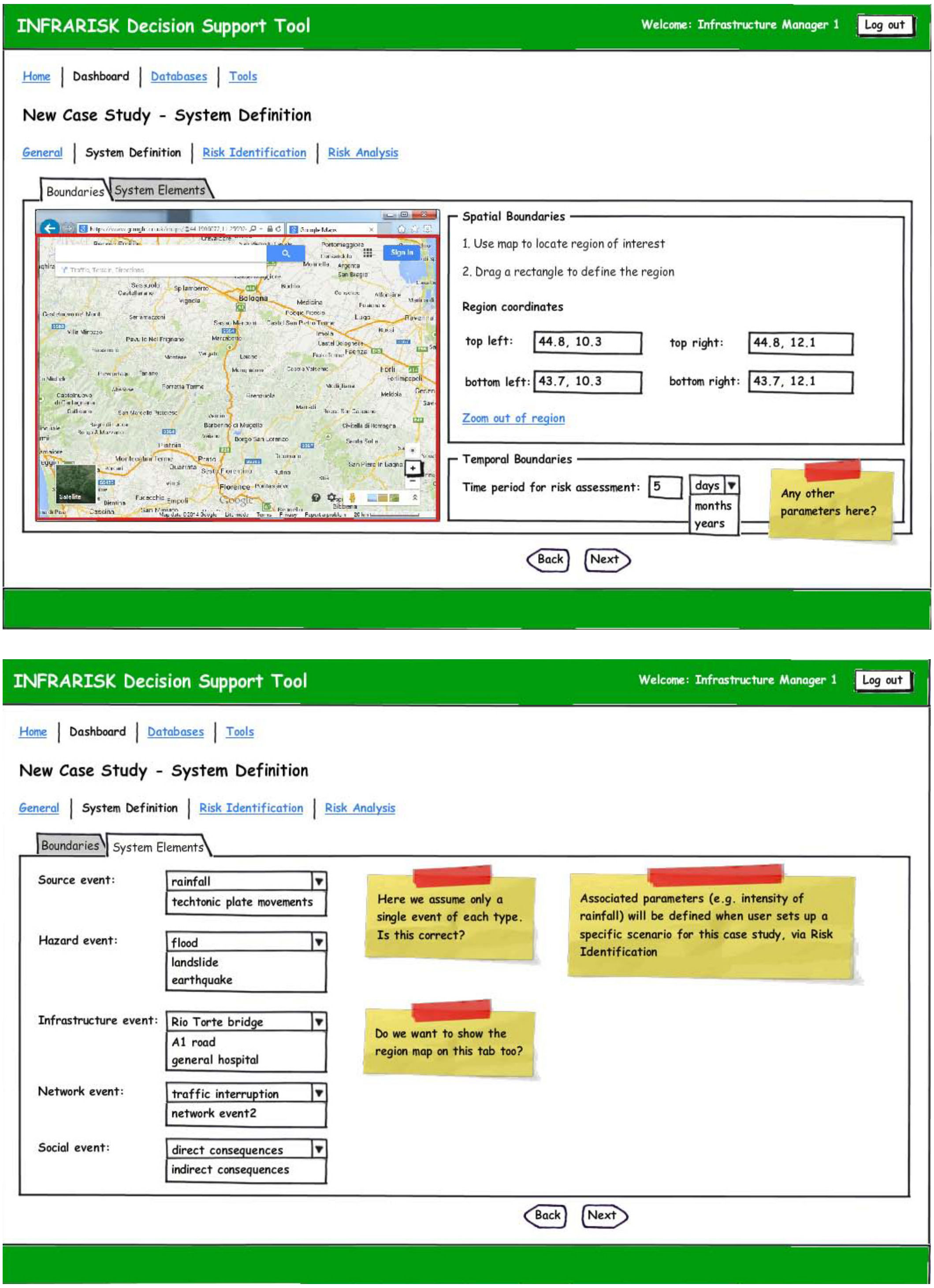



**Figure 3:** IDST Mock Ups

## 4. Expected Impact

The INFRARISK project is expected to deliver the following:

- Improved and more reliable stress tests for Critical Infrastructure;
- Support for decision making and prioritisation in the field of mitigation options and support to preparedness;
- Pan European and Optimised risk assessment process;
- Optimised operational risk assessment for maintenance and management;
- Resilience to climate risks;
- Decoupling of economic growth & energy use.

Dissemination activities will also form a crucial aspect of the project and will involve several target levels, developing focused materials and products to reach the widest audience possible including the formulation of specialised training courses.

## 5. Added Value for the Post 2015 Framework for Disaster Risk Reduction

The methodology adopted in INFRARISK will be based on a harmonised risk approach which considers single and multi-risk events and analysis. This will lead to improved decision making as decisions can be taken based on a more accurate assessment of risk. Equally, stress testing of critical infrastructure, the purpose of which is to reduce uncertainty, will result in an improved understanding of the resilience of CI elements and networks. This will enable infrastructure managers, owners and operators to have a more realistic estimation of how their infrastructure will behave when subjected to natural hazards, effectively reducing the risks, which is an essential component of governance. Furthermore, the consortium consists of partners from a number of organisation types (SME's, Research Institutes, Universities and Large Enterprise) with expertise in a wide range of fields. This facilitates knowledge sharing and training within the consortium and will facilitate extending the reach of the project results across various disciplines.

## 6. Conclusions

INFRARISK seeks to minimise the impact of natural hazards on critical infrastructure elements and networks. It will establish a means of cross-European collaboration, supported by the necessary tools and methodologies, where relevant stakeholders can share data, results of model simulations and environmental services in a seamless, efficient, and effective way. The objectives of INFRARISK will be achieved through the carefully selected consortium made up of experts in hazard identification, complex risk analysis and uncertainty modelling, operational analysis, implementation strategies, infrastructure management and engineering design and assessment. Concrete results are expected to be produced within the 12 to 18 months.

## 7. Acknowledgements

This project has received funding from the European Union's Seventh Programme for research, technological development and demonstration under grant agreement No 603960. For further information please see `http://www.infrarisk-fp7.eu/`.

## References

Alfieri, L., Salamon, P., Bianchi, A., Neal, J., Bates, P. and Feyen, L. (2013). Advances in pan-European flood hazard mapping, Hydrol. Process., doi: 10.1002/hyp.9947

Giardini, D., Woessner, J., Danciu, L., Crowley, H., Cotton, F., Grünthal, G., Pinho R., Valensise G. and the SHARE consortium. (2013). SHARE European Seismic Hazard Map for Peak Ground Acceleration, 10% Exceedance Probabilities in 50 years, doi: 10.2777/30345, ISBN-13, 978-92-79-25148-1

EEA (2012) Climate change, Impacts and Vulnerability in Europe 2012 an Indicator-Based Report, EEA Report No 12/2012, 304 pp., European Environment Agency, Copenhagen.

EEA (2010a) Mapping the Impacts of Natural Hazards and Technological Accidents in Europe an Overview of the Last Decade, EEA Technical report No 13/2010, 146 pp., European Environment Agency, Copenhagen.

Panagos, P., Van Liedekerke, M., Jones, A. and Montanarella, L., (2012). European Soil Data Centre: Response to European policy support and public data requirements, Land Use Policy, 29, 329-338

EEA (2010b) The European Environment — State and Outlook 2010: Synthesis, 228 pp. European Environment Agency, Copenhagen.

ECTP European Construction Technology Platform (2007) Strategic Research Agenda for the European Construction Sector Implementation Action Plan Version 1, July 20th. `http://www.ectp.org`.

## Citation

Tucker, M., Ní Choine, M., O' Brien, E., O'Connor, A., Gavin, K., D'Ayala, D., Adey, B., Cheng, T., Van Gelder, P., Sabeur, Z. and Jimenéz, M. J. (2015): Novel Indicators for Identifying Critical INFRAstructure at RISK from Natural Hazards. In: Planet@Risk, 3(2): 300-305, Davos: Global Risk Forum GRF Davos.