Natural Environment Research Council's (NERC) Environmental Risks to Infrastructure Innovation Programme

Output from workshop held on July 8 2014, CIRIA offices, London

SUMMARY

This was the second of two workshops to explore how the capabilities in the research base and research programmes (particularly those funded by NERC) could be used and translated into decision making and other aids for infrastructure owners.

The inputs for Workshop 2 were derived from the outputs of workshop 1 – held on 24 June where a group of industry asset owners had discussed their challenges and needs for information / tools. These had been summarised into five Key Areas (KA1-5)

KA1: Understanding variability and chronology in extreme events
KA2: Hazard combinations and impacts
KA3: Incorporating uncertainty in design, operational and investment decisions
KA4: Supply chain resilience
KA5: Flooding, storms and precipitation

Workshop 2 involved a series of industry representatives and research representatives who worked together to identify synergies in industry needs and research capabilities. Summaries of the five principal working sessions are set out below

CONTENT

1. WORKSHOP OVERVIEW

The workshop programme and attendance list are included in Appendix 1. There were four stages:

1. Presentations from industry and research centres Copies of the presentations can be accessed at the following address ***********.
2. Identification of current research capabilities
3. Expansion of previous industry definition of needs in the five Key areas
4. Exploration of links or synergies between industry needs and research capabilities

Items 2 – 4 are discussed in turn below.

2. IDENTIFICATION OF RESEARCH CAPABILITIES

Details of research capabilities and programmes were captured in abbreviated form – principally to convey the general area of capabilities and research.

The information gathered has been transcribed and submitted to NERC. This indicates, in most cases, the institution and contact concerned. However, in an attempt to summarise the nature (as opposed to the detail) of the capabilities identified, they have been characterised as focussing on one or more of the aspects set out in the Table below.

GROUPING OF ON-GOING CAPABILITIES	
DATA AND ANALYSIS (DATA)	Many large / comprehensive data sets existed and/or were still being updated in a number of research institutions. The potential existed to synthesise and customise these to meet any local and/or organisational needs of asset owners and operators
EFFECTS (SINGLULAR OR COMBINED)	A number of research programmes focussed on the effect on infrastructure and/or the natural environment (inasmuch as it can affect infrastructure)
HAZARD CHARACTER (HASCHAR)	For the purpose of this overview, research related to hazards has been sub-divided into that focussing on the general characteristics of the hazard and those focussed more specifically on quantifying the risk and magnitude of that hazard for specific locations.
HAZARD LOCATION (HAZLOC)	A number of studies and models existed that could provide information on particular hazards for specific locations
INTERACTIONS	The interactions between natural hazards and/or between different types of infrastructure were identified as being undertaken in a number of different institutions.
UNCERTAINTY AND DECISIONMAKING	It was suggested in one workgroup that decision-making in the light of uncertainties (and associated risks) was not a mature topic. Organisations' maturity in terms of such decision-making and their appetite for risk was one particular area of research
OPTIONS APPRAISAL	Arguably a sub-set of the preceding topic, the industry needed techniques to help assess between different options
RESOURCES	Resources that are becoming scarce (or present logistical risks by only being available in certain regions or countries) was an area of research considered of interest in the context of supply chain resilience
SOCIAL	This term has been used to cover a variety of current research e.g. the

	study of human behaviour in emergencies, techniques for eliciting knowledge on previous occurrences of hazards
SYSTEMS	This covers a range of network, resource flow, supply chain logistics, interdependencies and other modelling

3. INDUSTRY NEEDS

In parallel with the gathering of information on research capabilities, the industry representatives were invited to review the five proposed discussion areas arising from the previous workshop held on June 24.

These are reproduced for each of the five areas below.

TOPIC	SUB-TOPICS	Associated questions or areas of interest
KEY AREA 1 Understanding variability and chronology in extreme events	Information on extreme events	• Black swan events
	Understanding long-term trends and short-term extremes	• Diurnal changes • Dealing with uncertainty • How is the probability distribution curve shifting (not a bell curve!) • Availability of shared data
	Understanding the chronology of events (e.g. successive pluvial, fluvial and groundwater flooding)	• Spatial extent / coherence
KEY AREA 2 Hazard combinations and impacts	Availability of scientific evidence on joint probabilities	• Improvements in models especially in predicting cause-effect and sequences
	Effects of a combination or succession of hazards	• Resilience to non-environmental hazards in combination with environmental (insurance/financial) • Chain of events
	Identifying inter-dependencies	• Informing decisions on degree of redundancy

KEY AREA 3
 	
Incorporating uncertainty in design, operational and investment decisions
	Tools for informing :
	• Investment decisions
	• Design decisions
	• Operational practice / decisions
		• Consistency of language
		• Information to suit business needs
		• Investments: (rational)
		  ○ timing
		  ○ valuing

	Changes in operational practices re resistance/recovery depending on magnitude of impact	• How understanding future uncertainties - adaptive design

	Maintenance Where and when to take the key decisions	
KEY AREA 4 Supply chain resilience	Tools for identifying environmental hazards within supply chains What techniques, data and tools were available to ensure that contingency arrangements were adequate?	• Identifying critical points/routes/bottlenecks • Anticipating major consequences • Recoverable / unrecoverable (not mecc Insurance) • Contingency arrangements • Diversification / redundancy of supply chain (e.g. New York and Bangkok examples)

KEY AREA 5
 	
Flooding, storms and precipitation
	Signposting existing activities relating to flooding and resilience
	
	Groundwater modelling tools – application at local level
	
	Ecosystem approaches to flood hazard mitigation
	
	Secondary consequences of hazards
		• Signposting
		  ○ digested and re-presented
		  ○ interpretation and synthesis
		
		• Are models applicable at a local scale?
		
		• Evidence base-proof of work
		• Green infrastructure
		
		• Landslides
		• Social Behaviour and Comms (+insurance)
		• Consequences of different operators

Further information can be found in Appendix 2.

Industry representatives were provided with further opportunities during the joint industry – researcher sessions to set out, more specifically, their needs in terms of decision support and other techniques. The industry emphasis was very much on the applicability of the information that resulted from translation of the NERC and other research.

There were generally less examples of specific requirements from the industry participants. These have also been transcribed and submitted to NERC. As above, they have been broadly characterised in the table below.

GROUPING BY INDUSTRY NEEDS	
DATA SYNTHENSIS	Available data sets needed to be processed or combined in such a way that they became useable in various industry contexts i.e. they supported specific industry applications
COMMUNICATION	Data and associated knowledge should be processed and/or presented in a way that made communicating the hazards (their nature, location and extent) and associated risks and uncertainties to different stakeholders

DECISION SUPPORT	This descriptor can be applied to a significant proportion of the industry needs identified. It reinforces the fact that any research translation (whether data synthesis or knowledge summaries) should, ideally, be capable of being applied to support organisational decisions (including options appraisals).
EFFECTS	Industry sought knowledge on the effects of certain hazards (whether singular or in combination) on infrastructure.
HAZARD CHARACTERISTICS	This can be interpreted in the same was as for the research capabilities.
MODELS AND UPDATES	This is interpreted here in the broadest sense and includes both computational and system models. It was noted on many occasions that there appears to be a lag between the latest available datasets being incorporated in models already in use in the industry
PILOT TRIALS	The principle of trialling new techniques arising from research should on live projects was an established approach and one that could be replicated within this programme
SCENARIOS	The robustness of infrastructure systems could be tested against a range of scenarios depicting hazards occurring in isolation, in combination or in succession. Were standard or regional sets feasible?
RESEARCH / KNOWLEDGE TRANSFER	On many occasions, discussions noted that models and techniques to support decision-making or options appraisal had been applied (sometimes routinely) in other sectors e.g. finance, oil and gas etc. While the focus of this programme was on the translation of NERC research, the industry needed to be aware of other sources of other possible sources.

4. SYNERGIES

The purpose of the joint industry / research base discussions was to identify synergies between research capabilities / datasets / programme outputs and the needs identified by industry

Few direct correlations (or perfect matches) were made of research programmes fitting exactly with industry needs. However, there were many instances where research centres possessed data-sets and/or other information that had the potential to be tailored to help address some of the industry challenges identified.

A summary of the discussion of each of the five Key Areas is set out below.

Further information has been tabulated in Appendix 3.

KA1: Understanding variability and chronology in extreme events

A significant challenge is understanding what information is available, some of the data sets are not publicly available.

There was discussion around identifying potential "tipping points" and the need to decide when situations become potentially irreversible. In this context, there is a need to understand trends and the risks and the relevance of frequency. There was discussion around "Black Swan" events and how this may impact how organisations prepare for and manage high impact, low probability events.

There is information available (e.g. Go Science) however it would be useful if this was better synthesised to understand how it can be considered by businesses and the impact on risk management. It was also mentioned that some of the models on climate change impacts may not necessarily include the most recent and robust data sets and that there may be a requirement for more frequent updates which should be widely disseminated.

The importance of chronology, spatial coherence and temporal sequencing was stressed around flood, drought, volcanoes, earthquakes etc.

Gaps:

- There is an opportunity for some quick wins by linking spatially coherent models in ARCC.
- There should be greater use of spatially coherent weather generation models.
- It would be useful to develop a conceptual map of what's known and not understood.

KA2: Hazard combinations and impacts

While a considerable amount of research has been undertaken on a number of hazards the challenge is to make this useful to the business user. It was also suggested there is limited understanding on the risk and impact of joint probabilities. While the discussion focussed on the combination of two or more environmental impacts it was also considered important to also consider the combination of an environmental hazard and a socio-economic, technical or political challenge/hazard (i.e. not an environmental hazard).

Gaps:

- Combining hazards and the need to understand probability and joint probability is not straightforward.
- Industry needs to better understand system, and systems of systems models of how infrastructure works and is inter-dependent
- Possibly need to consider scenario tools, or war gaming as combining probabilities of hazards or challenges is likely to create a black swan event where the probability is exceptionally low but there is a significant impact.
- Understanding interdependencies in terms of hazards and the potential receptors.

KA3: Incorporating uncertainty in design, operational and investment decisions

It was suggested that maintenance of existing assets for many business users is also of growing importance and this should not be overlooked. There is also a need to understand where and when decision making becomes critical and how this can be best managed.

There could be potential translation from other fields/sectors as there are tools/techniques available to support decision making for the management of natural hazards.

Real options, probabilistic management and qualitative approaches to assessing risk can all help with managing uncertainty. Complex systems and models are being developed, there is a requirement to ensure there is adequate computing capacity to help manage the process and utilise big data.

Organisational responses to hazards were discussed as was the role of organisational modelling to assess responses, and how information is created and managed. Reference was made to "maturity modelling" to assess how organisations receive and adapt to information as well as considering how it influences their decision making.

Gaps:

- Agent based models and scenario based models are not yet applied to natural hazards – this could be useful.
- Translation of other learning, processes and practices to natural hazards.
- Might be useful to collate and assess case studies of organisational examples.

KA4: Supply chain resilience

The greatest challenge is that the impact and resilience of a supply chain is not a linear process, it is very much based on how networks work with resultant interdependencies and sequences.

The ongoing research requires integration into required outputs for business users which could be a challenge or a gap in research. It was suggested that often a business case needs to be developed for academics to get involved in the process.

Gaps:

- Transport interoperability.
- Understanding the impact of arctic ice melt on shipping lanes.
- Information on rare earths
- Looking at different logistics.
- Understanding supply chains and ecosystem vulnerability or services may be useful.
- Useful to understand metrics for hazards and vulnerability and understand where the critical elements are.
- Useful to provide a global map of hazards and vulnerabilities.

KA5: Flooding, storms and precipitation

The flooding area was thought to be cross cutting, with some of the other areas also have important synergies with this key area. The flooding area also has a wide range of projects primarily undertaken through EPSRC or the EU. As a result there is considerable information available which needs to be reviewed and filtered to see if it is relevant and useful to different business sectors, over different temporal and spatial parameters. Similarly it might also be useful to see what international research can be usefully applied to the UK situation.

Gaps:

- Consideration of information over different timescales, covering short term operational requirements and longer term strategic needs.
- NERC/BGS has information on groundwater susceptibility, however there is still a requirement for this data to be interpreted and shared with local authorities to assist with managing groundwater flood risk.
- An evidence base on the value of softer approaches to hazard mitigation (green/blue infrastructure) for business would be useful. It needs to be written with the business user (and relevant regulators) to help demonstrate and support a business case.
- There is still a paucity of research on the social impacts of flood hazards
- Summarising / signposting existing research and related activities

5. VOTING

Following discussion of the five Key Areas, participants were given the opportunity to express their interest in the five Key Areas.

This exercise showed that there is a good correlation between industry and academic voting and that the following are the clear preferences:

KEY AREAS	SUBTOPIC
KEY AREA 1 Understanding variability and chronology in extreme events	Understanding long-term trends and short-term extremes
KEY AREA 2 Hazard combinations and impacts	Effects of a combination or succession of hazards
KEY AREA 3 Incorporating uncertainty in design, operational and investment decisions	• Tools for informing : ○ Investment decisions ○ Design decisions ○ Operational practice / decisions
KEY AREA 4 Supply chain resilience	Tools for identifying environmental hazards within supply chains

A full record of the preferences is presented in Table A4.1 in Appendix 4.

APPENDIX 1 – WORKSHOP PROGRAMME AND ATTENDANCE LIST

TABLE A1.1: AGENDA

10:00 – 10:20	Welcome and introductions
10:20 – 10:40	Client's perspectives presentations 1. Shanti Majithia / Damien Culley, National Grid 2. Alison Brown, Shell
10:40 – 11:40	Research centre capabilities presentations 3. Lee Chapman, University of Birmingham 4. Richard Dawson, University of Newcastle 5. Paul Sayers, Sayers and partners 6. Jenny Foster, BGS 7. John Rees, BGS 8. Kevin Forshaw, NOC
12:00 – 12:15	Summary of workshop 1 and input into workshop 2 Overview of afternoon sessions
12.15 – 12.40	Streams • Academics – Room C • Industry – Room A
12.40 – 13.30	Session 1 – Key areas 1 and 2
14:10 – 15:10	Session 2 – Key areas 3, 4 and 5
15.30 – 16.00	Plenary feedback
16.00 – 16.15	Voting
16.15 – 16.30	Next steps and close

ATTENDANCE LIST

Name		Company
Pietro	Bernadara	EDF Energy
Ruth	Boumphrey	Lloyds Register Foundation
Alison	Brown	Shell
Greg	Chant-Hall	Skanska Infrastructure
Lee	Chapman	University of Birmingham
Louise	Clarke	CIRIA
Peter	Cleall	Cardiff University
Brian	Collins	UCL
Damien	Culley	National Grid
Sirio	DAleo	CIRIA
Geoff	Darch	Atkins
Richard	Dawson	University of Newcastle
Kevin	Forshaw	NOC
Jenny	Forster	BGS
Fai	Fung	Environment Agency
John	Gillard	NERC
Ben	Gouldby	HR Wallingford
Steve	Hill	Severn Trent Water
Owen	Jenkins	CIRIA
Ben	Kidd	CIRIA
Shanti	Majithia	National Grid
Richard	Ploszek	Infrastructure UK (HM Treasury)
Nick	Pyatt	Natural Impact
Nicholas	Rawlinson	University of Aberdeen
John	Rees	BGS
Jason	Sadler	University of Southampton
Paul	Sayers	Sayers and partners
Paul	Shaffer	CIRIA
Jonathan	Simm	HR Wallingford
Owen	Tarrant	Environment Agency
Robyn	Thomas	NERC
Alistair	Wyness	BP
Dapeng	Yu	University of Loughborough

APPENDIX 2 – INDUSTRY NEEDS

Tables A2.1 – A2.5 list the types of decision support information and tools identified by the industry. These have been categorised as discussed in Section 3 (Note: only one category has been used).

TABLE A2.1: KEY AREA 1- UNDERSTANDING VARIABILITY AND CHRONOLOGY IN EXTREME EVENTS

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
Information On Extreme Events	BGS skills - volcanic ash					✓				
	UCL - earthquakes					✓				
	Go Science website					✓				
	Extreme event quantification					✓				
	Likelihood of tsunami: - from earthquakes - submarine landslides e.g. historical records indicate run-ups of up to 20m from continental slope events									✓
Understanding Long-Term Trends And Short-Term Extremes	Extremes: - Lancaster - Warick - Cranfield					✓				
Understanding The Chronology Of Events (e.g. successive pluvial, fluvial and groundwater flooding)	ARCC Programme						✓			
Other decision information/tools	Tools on communication risk to senior management		✓							
	Synthesis of information on long/ short term extremes	✓								
	Evidence base - with clear recommendations						✓			
	Tipping points and irreversibilities to shocks					✓				
	Tools to access the risk of non compliance with organisational standards						✓			
	Access to (geo-reference) data set with meta-data	✓								
	New info on frequency of events	✓								
	Periodic synthesis of advanced knowledge and science	✓								

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
	Knowledge understanding atmospheric weather pattern (not yet reflected in climate models)			✓						
	Arctic melting and changes in jet stream not showing variability in current models			✓						
	Wave transformation modelling			✓						

TABLE A2.2: KEY AREA 2 - HAZARD COMBINATIONS AND IMPACTS

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
Availability of scientific evidence on joint probabilities	Translating available information into practice	✓								
	Communicating risk (and appetite for risk)- providing steer to get conversations started - spatial differences in how organisations use/gather data		✓							
	Differences between data + what inferred (interpreted) from data --> understanding limitations and provenance	✓								
	Communicating risk to different groups: operators (tailored information) and public (feedback, influencing risk) --> ESRC		✓							
	Importance of systems model --> then understand granularity of datasets			✓						
Identifying inter-dependencies	Scenario-based research (in conjunction with real world)				✓					
	Scenario-based research: i) operator at national scale ii) interdependencies at particular special scale				✓					
	3Gs: Guidance + Genesis (pilot projects) + Governance (social element)							✓		
	System of system modelling - computational expense great - social aspects (vulnerability, exposure)			✓						
Effects of a combination or succession of hazards	Organisational specific -->effects on businesses, collaborative research, underlying principles					✓				
	Black swan events - hazard combinations - war gaming scenarios				✓					
	Beyond natural hazards: - terrorism - cyber security (combinations, look at whole system)						✓			
	Pilot projects --> then draw out generic lessons							✓		
	Emulus modelling (numerical). Multi-variant modelling (e.g. EA research on coastal flooding) --> link with real-time modelling			✓						

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
	Combined datasets --> localised examples / case studies / pilot studies	✓								
	Assurance + prioritisation --> severity of impact						✓			
Overarching	Decisions (different timescales): - Operational: improving current practice --> add value in short term (0-6 hours) - Maintenance (~5 years) --> health monitoring: GUIDANCE (Assurance Mechanisms) - Investment (10-100 years)				✓		✓			

TABLE A2.3: KEY AREA 3 - INCORPORAING UNCERTAINTY IN DESIGN, OPERATIONAL AND INVESTMENT DECISIONS

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHESIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
Tools for informing : **• Investment decisions** **• Design decisions** **• Operational practice / decisions**	**Consistency in methods/techniques in decision making** **- whether to invest (Paul Sayers, Oxford)** **- need to tie in multiple models**						✓			
	Is tool the right term?	N/A								
	Generating business case for investments						✓			
	Ranking of risks relating to uncertainty and relating to investment decision						✓			
	Mapping of current situation to understand next developmental steps. Gap analysis				✓					
	DEFRA consistent standards source?		✓							
	information to inform designing for multiple events (but not worst-case scenario)						✓			
Changes in operational practices re resistance/recovery depending on magnitude of impact	Justifying additional expense of building in adaptability economic-appraisal techniques						✓			
Maintenance	better valuing maintenance + gap analysis --> two way process (between researchers and users)						✓			
Where and when to take the key decisions	Robust decision making methods. Are there standard "tools" available?						✓			
	non-probabilistic aspects are difficult						✓			
	IBUILD + ICIF, financial modelling + investment decisions capturing uncertainties + opportunities in risk across all infrastructures						✓			
	IBUILD and ICIF valuing direct + indirect social environment						✓			
	recognition of how decisions are made e.g. government vs business especially uncertainty						✓			
Other	**Modelling**									
	Maturity modelling, RD and BC - 'organisational science'			✓						

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
	Statistically driven models			✓						
	Maturity modelling – used extensively in IT			✓						
	General									
	design for range of events (and exceedance)						✓			
	General point Comments about "existing" frameworks need examples of their application. translation cross-science							✓		
	valuing infrastructure against "loss avoided" scenarios - links with probability						✓			
	design levels related to criticality of element						✓			
	"big data" challenge	✓								

TABLE A2.4: KEY AREA 4 - SUPPLY CHAIN RESILIENCE

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
Tools for identifying environmental hazards within supply chains	**Information: - map hazards and vulnerabilities - type of event - probability**	✓								
	Reports	✓								
	Data set is ok	✓								
	Maps (major steps forward!) - Google Foundation	✓								
	Metrics on hazards + vulnerability (standardised?) - risk of failure metrics	✓								
	Understand critical points of failure			✓						
	Advice						✓			
	Techniques for application						✓			
	Methods + Approaches						✓			
	Trend analysis: - new regions in supply chain - vulnerability	✓								
	Things that change without noticing in business as usual									✓
What techniques, data and tools were available to ensure that contingency arrangements were adequate?	**Due diligence on suppliers - Company supply chain (can't ask companies themselves)**						✓			
	Supply networks	✓								
	Vulnerability at specific locations	✓								
	Upstream + downstream analysis	✓								
	Societal impacts should not be forgotten				✓					
	Common weak points - Global hot points					✓				
	Risk of failure - Regulatory finance, etc						✓			
	Critical pathways - understanding business networks + sociology			✓						
Other	Emergency planning and response				✓					
	Leadership required + necessary		✓							
	Translation requires a facilitator / integrator (role of NERC) - challenge		✓							
	Societal good makes it more attractive motive for academic engagement							✓		
	Opportunity: impact of arctic ice melt on shipping lanes									✓
	Supply chain in eco-systems			✓						
	Non probabilistic decision-making						✓			
	Identifying different logics that are applicable - decision making capability						✓			

TABLE A2.5: KEY AREA 5 - FLOODING, STORMS AND PRECIPITATION

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
Signposting Existing Activities Relating To Flooding And Resilience	Signposting: - end-use - type of research - type of flooding - timescale (operation/ strategy)								✓	
	International lesson learned - Bangkok								✓	
	Translation of overseas research								✓	
	Flooding over winter period - disseminate? How much wetter + for how long?		✓							
Groundwater Modelling Tools - Application At Local Level	NaFRA - fluvial + coastal EA - pluvial/ risk? BGS - groundwater/ risk?					✓				
	Datasets + identification of vulnerability to groundwater at national scale	✓								
	Groundwater levels - infrastructure underground (not just overground flooding) - link with mapping/ assessing underworld (EPSRC)	✓								
	Detailed process models exist - apply to infrastructure								✓	
Ecosystems Approaches To Flood Hazard Mitigation										
Secondary Consequences Of Hazards										
Other	Sift + filter + look for relevance to NERC-funded existing	✓								
	Existing-based proofing							✓		
	Operational vs Investments timescales						✓			
	Pluvial planning - land-use - guidance/ research? - TCPA (GI)				✓					
	Linear infrastructure Networks (land-use link with infrastructure) - planning				✓					
	Industry needs data sets	✓								

SUBTOPIC	DECISION SUPPORT INFORMATION/ TOOLS	SYNTHENSIS	COMMS	MODELS AND UPDATES	SCENARIOS	EFFECTS	DECISION SUPPORT	PILOT PROJECTS	RESEARCH / KNOWLEDGE TRANSFER	HAZARD CHARACTERISTICS
	Business case for SuDS/ green infrastructure (GI) - acceptance of approaches by regulators - what data read?				✓					
	Approximately 1/3 National Grid sites 1 in 1000 flood risk - want to avoid water getting onto site - may tend toward ' safer' soils - how demonstrate			✓						
	Operational Decisions How to prioritise? - system criticality - flood alerts from EA - bring data sets together						✓			

APPENDIX 3 – SYNERGIES WITH RESEARCH CAPABILITIES

Although, as documented in Section 4, there were few instances of current research perfectly matching the needs of a specific industry need, a number of projects had relevance. Tables A3.1 – A3.5 below match these on the basis of the information gathered at the meeting. Red text is used below to draw out the key aspect of the item described.

TABLE A3.1: KEY AREA 1- UNDERSTANDING VARIABILITY AND CHRONOLOGY IN EXTREME EVENTS

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
Information On Extreme Events	'Black swan' events, >10^{-4} prob	Chronology + variability of space weather RAL (Mike Hapgood)	*JR*	*BGS*
		UCL research on earthquakes + responses/ precautions - CESE department	*BC*	*UCL*
		ICIF (UCL) impact of governance/ leadership availability - UCL (organisational/ business model resilience)	*BC*	*UCL*
		Where and when do large earthquakes occur? Within UK, in the north sea, continental slope…	*NR*	*University of Aberdeen*
		Internal HR Walligford research, spatial extremes of surges, waves, fluvial flows. Scale of the nation, national flood risk assessment for EA. Data set of extreme waves, winds, water loads around coastline of England	*BG*	*HR Wallingford*
		Hazard dependence modelling done for Willis Research Net by Kilsby + Serinaldi at University of Newcastle	*RD*	*University of Newcastle*
		Variability in earthquakes being investigated by Cambridge, Oxford, Leeds, (internationally - COMET) and in the UK (BGS)	*JR*	*BGS*
Understanding Long-Term Trends And Short-Term Extremes	1. diurnal changes 2. availability of tools and associated uncertainty 3. how is the distribution curve shifting? (not a bell curve!) 4. availability shared data	FROST THAW modelling of soil/ atmosphere interactions for: - snow/ ice management - drying/ wetting - shrinkage/ swelling	*PC*	*Cardiff University*
		Coastal evolution due to extreme events	*PC*	*Cardiff University*
		CONVEX project; high resolution climate models to capture convective storms (led by Met Office with University of Newcasatle)	*RD*	*University of Newcastle*
		Sea level + storm surge chronology - being led by NOC (Kevin Horsburgh/ Phil Woodworth)	*JR*	*BGS*
		Multi hazards - spatial weather generator at University of Newcastle	*RD*	*University of Newcastle*
		Early warning systems (tipping points in complexity science) leading to catastrophic failure of environmental systems e.g. ponds	*JS*	*HR Wallingford*
		CEH - focus on medium term variability (since observations began) in UK precipitation, floods and droughts	*JR*	*BGS*

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
Understanding The Chronology Of Events (e.g. successive pluvial, fluvial and groundwater flooding)	**spatial extent/ coverage**	Combining historic and real time Metocean data, combining sensed data across large, heterogeneous networks	*JS*	*HR Wallingford*
		Chronology (long term) of flood events in the UK Aberystwyth (Mark Macklin)	*JR*	*BGS*
		Impact of extreme weather on slope stability in cold regions: - segregation of permafrost leading to failure of slopes - impact on cold regions infrastructure (pipelines etc)		
		Many large scale projects struggled to take into account the national impact due to a lack of spatially coherent climate change projections - with this limitation overcome, there is a need to revisit these projects	*LC*	*University of Birmingham*
		Chronology of droughts: - currently being investigated in the NERC - led water security research programme	*JR*	*BGS*
		Chronology of variability of volcanic hazards research led by GVM, Sue Loughlin (BGS) and STREVA (Jenni Barclay)	*JR*	*BGS*
		Temporal deterioration process - complete (but only basic!)	*PB*	*EDF Energy*
		Temporal sequencing: - flood memory (NEWC) - beachplan shape changes (HRW - 1995)	*PB*	*EDF Energy*
		Flood memory project looking at persistence in hazard (+social memory). Consortium led by Kinsby at UNIVERSITY OF Newcastle	*RD*	*University of Newcastle*
		Internal HR Walligford research funding: 1. collaboration with IH Cantabria, relationship between large scale meteorological phenomenon and temporal clustering of extremes 2. multi variable extremes in relation to flooding - collaboration with USACE	*BG*	*HR Wallingford*
Other topics		Arctic ice retreat 1/4 degree models from NOC	*KF*	*NOC*
		High resolution Ocean Forecast and models (NEMO) re sea level rise	*KF*	*NOC*
		Climate down scaling spatial and temporal analysis of climate - risks related	*DY*	*University of Loughborough*
		"Project Anytown" - London Resilience/ Interdependencies assessment + cascading effects/ London 2012 work	*BK*	*CIRIA*
		Willis Research Network funded projects (e.g. with Newcastle University) - interdependencies + risk/ uncertainty	*BK*	*CIRIA*
		Assessing current capacity to generate + work with variability + chronology of extreme events. Then identify best next steps + medium + long term + human capacity development pathways, " Natural Impact"		

TABLE A3.2: KEY AREA 2 - HAZARD COMBINATIONS AND IMPACTS

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
Availability of scientific evidence on joint probabilities	improvements in models especially in predicting cause-effect and sequences	University of Newcastle - Cloud + GPU overcoming computational capacity limitations - applied in flood models - can scale up --> large modelling - BIG DATA "smarter + faster modelling"	RD	University of Newcastle
Identifying inter-dependencies	informing decisions on degree of redundancy	ICIF (UCL) - intersectorial interdependencies research and intersystem research	BC	UCL
		Yorkshire Water + United Utilities supported PhD (University of Newcastle) looking at "Swiss Cheese model"	BK	CIRIA
		Yorkshire Water + United Utilities supported PhD (University of Newcastle) looking at "Swiss Cheese model"	RD	University of Newcastle
		3Gs: Guidance + Genesis (pilot projects) + Governance (social element)	JS	HR Wallingford
Effects of a combination or succession of hazards	resilience to non-environmental hazards in combination with environmental (insurance/financial)	**Ground stability and flooding**		
		BGS work on combination of groundwater flooding and other flood sources	JR	BGS
		Natural Hazard information on ground stability - landslides, shrink-swell, dissolution, mining + non coal mining, groundwater, flooding info	JF	BGS
		Combining extreme weather impacts on geothecnical / geoenvironmental (embankments / waste repositories) systems - i.e. Dry-wetting cycles followed by freezing and thawing	PC	Cardiff University
		University of Cranfield research using BGS GeoSure datasets + own datasets --> work on earthwork failure risk for infrastructure (part of ITRC)	PC	Cardiff University
		Rainfall and landslides		
		NHP work on interaction of different hazard in UK (e.g. precipitation and landslides)	JR	BGS
		Natural Hazards Partnership cross government bodies - e.g. landslides + rainfall combination flooding	JF	BGS
		Research on precipitation triggering of slope failure (e.g. Durham, Cambridge, BGS)	JR	BGS
		Wind and other hazards		
		Combined impact of flooding and wind storms	DY	University of Loughborough
		RESNET: wind + other climate impacts on grid	RD	University of Newcastle
		Impacts on cities		
		ARCADIA, EU RAMSES, Tyndall Centre - multihazard city scale impacts	RD	University of Newcastle
		Blue/green cities led by University of Nottingham - Impacts + water sensitive cities	RD	University of Newcastle
		Compounding effect of urban heat and climate change - particular enhanced UHI effect in heat-waves	LC	University of Birmingham
		Social impacts of extreme natural hazard events - generally poorly researched - but some excellent local research (e.g. Tyndall), EA	JR	BGS

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
		Drought		
		NERC Drought programme -e.g. MARIUS led from Oxford University		
		Drought and flood at two extremes	DY	University of Loughborough
		Response to extremes		
		Behaviour response to extreme weather events	DY	University of Loughborough
		Emergency management and response to extreme events	DY	University of Loughborough
		Organisational response project - NERC funded via Sandpit		
		Other areas		
		ITRC - led by Jim Hall at Oxford University	RD	University of Newcastle
		Bristol (ICIF) - learning processes about this topic	BC	UCL
		Existing tidal surge inputs, combined with Met Office to Environment Agency	KF	NOC
		Clearer identification of thresholds - Crucial for CCRA	LC	University of Birmingham
		Understanding current human capacity to assess and work with hazard combinations and impacts. I.D. Best next steps + medium + long-term capacity development pathways	NP	Natural Impact
		INTACT - EU funded research on cascading effects of extreme weather on critical infrastructure	BG	HR Wallingford
		Earthquakes and Tsunami often cause a chain of events - e.g. earthquakes + fires, tsunami + nuclear power station meltdown	NR	University of Aberdeen
		Spatial hazard + network layout topography --> University of Newcastle work (e.g. PhDs)	BC	UCL
		Work with Natural Hazard Partnership + ESSP		

TABLE A3.3: KEY AREA 3 - INCORPORAING UNCERTAINTY IN DESIGN, OPERATIONAL AND INVESTMENT DECISIONS

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
Tools for informing : **• Investment decisions** **• Design decisions** **• Operational practice / decisions**	Consistency of language Information to suit business needs Rationale for investment decisions (timing, value etc.)	Range of projects on designing under uncertainty (including some work for TE2100) + identification of robust options or options that are suitable for multiple criteria	RD	University of Newcastle
		UCL governance systems		
		Geotechnical design parameters	PC	Cardiff University
		Management and visualisation of 'big' high-resolution risk data e.g. 1000s of factors to 10m resolution across UK rail network, RSSB	JS	HR Wallingford
		Work on expert elicitation	JF	BGS
		Communication of confidence	JF	BGS
		Uncertainty + Risk project within BGS looking at defining + communicating uncertainty in geological info	JF	BGS
		PURE - Kate Royse; Environmental information + insurance industry	JF	BGS
Changes in operational practices re resistance/recovery depending on magnitude of impact	How understanding future uncertainties - adaptive design	Understand current human decision making capacity in uncertain environment due to natural hazard - identify best next step to strengthen it - better design, operational + investment decisions + medium + long term capacity development pathways, "Natural Impact"	NP	Natural Impact
		FRMRC 2 research on real options appraisal techniques.	BG	HR Wallingford
Maintenance		Shock - not horror! EPSRC project which looked at evolution and recover after an event i.e. change of state, why put it back!? (Newcastle University)	LC	University of Birmingham
		Improved monitoring and understand the full scale of the problem + tipping points re changes climate	LC	University of Birmingham
Where and when to take the key decisions		Master course in infrastructure finance at UCL being run by Michelle Baddeley		
		FRMRC I and II - various workpackage infrastructure there	PS	Sayers and partners
		ICIF (UCL) - Financial modelling for multisectorial infrastructure investment, including resilience explicitly	BC	UCL
		Investment choices: a) Adaptive capacity - decision tree analysis (practical) b) Real-options analysis (various - Oxford/HRW) (more complex) c) National scale - Long-term investment strategy (LTIS)	PS	Sayers and partners
		How much is it worth investing now for future "certainty" and for flexibility	PS	Sayers and partners
		Design choices, investment and deterioration LWEC - Report Cards Infrastructure performance	PS	Sayers and partners

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
		Handling of uncertainty in decision-making is generally a poorly researched area (partially because it is multi-sectional)	JR	BGS
Modelling		Increasing use of statistical analysis + numerical modelling at BGS	JF	BGS
		Using detailed process models of thermal-hydraulic-mechanical behaviour of soil in large scale catchment models of landscape evolution and land slide risk maps	PC	Cardiff University
Other		Impacts of heterogeneity in geotechnical structures	PC	Cardiff University
		Capabilities easier (in strength) across research councils. Though historically poorly co-ordinated to develop a system-wide perspective	JR	BGS

TABLE A3.4: KEY AREA 4 - SUPPLY CHAIN RESILIENCE

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
Tools for identifying environmental hazards within supply chains	identifying critical points/routes/bottle necks	**Impact of climate change on transport**		
		University of Birmingham (EU funded) Move It project: impact of climate change on european transport	BK	CIRIA
		Impact of climate change on freight operations. Ongoing work at University of Birmingham	LC	University of Birmingham
		Combined impact of extreme rainfall and landslide risks to railway network	DY	University of Loughborough
		Impact of Natural Hazards on Electricity + Water supply onward to Network of Road and Rail	JF	BGS
		Resource flow modelling		
		Resource flow modelling - University of Newcastle	RD	University of Newcastle
		LAYERS of supply of E tech Element--> University of Newcastle project. Catalyst grant funded by NERC	RD	University of Newcastle
		Infrastructure network agent-based modelling		
		Independent infrastructure network modelling: Resilient futures project (IC London led)	RD	University of Newcastle
		Independent infrastructure network modelling: ITRC project (Oxford led)	RD	University of Newcastle
		Independent infrastructure network modelling: IBUILD project (Newcastle led)	RD	University of Newcastle
		ITRC - Oxford University. Network interactions	PS	Sayers and partners
		Understanding supply networks (ICIF)		
		ICIF (Cranfield University) - complexity based modelling of supply chain resilience	BC	UCL
		Cranfield University - Agent-based supply chain hitting with extreme events	RT	NERC
What techniques, data and tools were available to ensure that contingency arrangements were adequate? Other	contingency arrangements diversification / redundancy of supply chain (e.g. New York and Bangkok examples)	Understanding current supply chain resilience management capacity. I.D. Best next steps, medium + long term capacity development pathways (Natural Impact)	NP	Natural Impact
		City University (Robin Bloomfield) - Data resilience in supply chain	BC	UCL
		Transport networks interoperability		
		Institute for Sustainability (EU fundedd): Last Mile Logistics (LaMiLo) Project	BK	CIRIA
		Institute for Sustainability (EU funded): Weastflows project (West and East freight flows)	BK	CIRIA
		Vulnerability of rare earths		
		University of Leeds "Undermining infrastructure" --> mineral/rare earth metal scarcity effect (EPSRC funded via Sandpit)	BK	CIRIA
		Undermining Infrastructure --> University of Leeds project for rare earths	RD	University of Newcastle

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
		General		
		Flood Footprint - University of Leeds. Being developed in "organisational response to flooding" an EPSRC Sandpit Project	PS	Sayers and partners
		ICE State of the Nation Report	PS	Sayers and partners
		Tsunami - subsea geological slump impact prediction	KF	NOC
		Rainfall + Natural ground stability hazards - BGS	JF	BGS

TABLE A3.5: KEY AREA 5 - FLOODING, STORMS AND PRECIPITATION

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
Signposting Existing Activities Relating To Flooding And Resilience	Signposting - digested and re-presented - interpretation and synthesis	NOC tidal prediction models combining all harmonics well into the future	*KF*	*NOC*
		NOC tidal gauge real time inputs for storm surge prediction	*KF*	*NOC*
Groundwater Modelling Tools - Application At Local Level	Are models applicable at a local scale?	IMAP	*PS*	*Sayers and partners*
		Multiple benefits: - ecosystems services - droughts e.g. PS work with WWF - information (Sayers and partners with WWF)	*PS*	*Sayers and partners*
Ecosystems Approaches To Flood Hazard Mitigation	Evidence base- proof of work Green infrastructure	Urbanflood	*BG*	*HR Wallingford*
		Floodsite	*BG*	*HR Wallingford*
Secondary Consequences Of Hazards	Landslides Social Behaviour and Comms (+insurance) Consequences of different operators	Floodprobe	*BG*	*HR Wallingford*
		Flood resilience city (EU- funded) BradfordCC	*BK*	*CIRIA*
		CINCAT	*RD*	*University of Newcastle*
		(Semantic) Discovery and integration of marine, environmental, infrastructure, and real data to predict and manage coastal flooding	*JS*	*HR Wallingford*
		Knowledge + data BGS, susceptible to groundwater flooding groundwater levels info geological indicators of flooding	*JF*	*BGS*
		Groundwater flooding led by BGS, EA		
		NERC consortium on storms (led by Bristol University)	*DY*	*University of Loughborough*
		BGS 1. Susceptibility to ground water flooding national maps, 1 to 50000 scale apply 2. G/W levels characterisation, longer term	*BGS*	
		Assessing current human capacity for assessing + managing flooding, storms + precipitation. Then identifying the best next steps + medium + long term capacity development pathways, "Natural Impact"		
		Defra catchment test project - BGS work		
		Secondary consequences Impacts of drying/ wetting and freezing/ thawing on stability of geotechnical (be it slopes/ foundations/ pipelines) structures	*PC*	*Cardiff University*
		Flood Risk Modelling Flood risk adaptation and resilience	*DY*	*University of Loughborough*
		Catchment scale rainfall/ runoff modelling	*PC*	*Cardiff University*

SUBTOPICS	INDUSTRY QUESTIONS	REASEACH CAPABILITIES	INITIALS	ORGANISATION
		Observational Evidence and Process Understanding to Improve Predictions of Extreme Rainfall Change CONVEX	*RD*	*University of Newcastle*
		Impacts of events of population e.g. where they are on a day-day hour by hour basis (Pop 24/7) Where/who are the vulnerable groups	*JS*	*HR Wallingford*
		Trialling prototypes of sensors for rainfall monitoring at University of Birmingham. Capabilities for high resolution monitoring networks, especially in urban areas.	*LC*	*University of Birmingham*
		(Flash floods) CONVEX - led by Met Office and University of Newcastle High intensity, high impact	*RD*	*University of Newcastle*
		interdisciplinary group investigating the prediction, prevention and mitigation of flooding FRMRC (1 and 2) - EPSRC funded	*BK*	*CIRIA*
		FRMRC (1 and 2) - EPSRC, EA, SERA funded research on wide variety of topics including flood defence reliability analysis	*BG*	*HR Wallingford*
		WWF - promoting and safe guarding eco systems as an active part of FRM	*PS*	*Sayers and partners*
		Coastal flood risks considering land subsistence, storm surge and sea level rise	*DY*	*University of Loughborough*
		ARCoES/ ARIES: coastal flood + storm risk to energy infrastructure (inc. nuclear)	*BK*	*CIRIA*
		iCOAST	*BK*	*CIRIA*
		Storm surges: - ARCoES (coastal infrastructure) - nuclear		
		Flood memory	*RD*	*University of Newcastle*
		EU RAMSES impacts of climate change and the costs and benefits of a wide range of adaptation measures, focusing on cities	*RD*	*University of Newcastle*

APPENDIX 4 – SUBTOPICS VOTING

As discussed in Section 5, participants had the chance to express their preference in the subtopics within each of the five Key Areas. These are captured in Table A4.1 below.

TABLE A4.1 – VOTING EXERCISE RESULTS

KEY AREAS	ACADEMICS	INDUSTRY	VOTES
KEY AREA 1 - UNDERSTANDING VARIABILITY AND CHRONOLOGY IN EXTREME EVENTS			
Information On Extreme Events	4	4	8
Understanding Long-Term Trends And Short-Term Extremes	5	7	**12**
Understanding The Chronology Of Events (e.g. successive pluvial, fluvial and groundwater flooding)	4	5	9
KEY AREA 2 - HAZARD COMBINATIONS AND IMPACTS			
Availability of scientific evidence on joint probabilities	1	0	1
Identifying inter-dependencies	4	3	7
Effects of a combination or succession of hazards	9	7	**16**
KEY AREA 3 - INCORPORAING UNCERTAINTY IN DESIGN, OPERATIONAL AND INVESTMENT DECISIONS			
Tools for informing : • Investment decisions • Design decisions • Operational practice / decisions	10	8	**18**
Changes in operational practices re resistance/recovery depending on magnitude of impact	4	4	8
KEY AREA 4 - SUPPLY CHAIN RESILIENCE			
Tools for identifying environmental hazards within supply chains	4	7	**11**
What techniques, data and tools were available to ensure that contingency arrangements were adequate?	4	0	4
KEY AREA 5 - FLOODING, STORMS AND PRECIPITATION			
Signposting Existing Activities Relating To Flooding And Resilience	0	0	0
Groundwater Modelling Tools - Application At Local Level	1	1	2
Ecosystems Approaches To Flood Hazard Mitigation	0	2	2
Secondary Consequences Of Hazards	4	0	4

Produced for NERC by CIRIA, Griffin Court, 15 Long Lane, London EC1A 9PN