

Science Theme Reports  
NERC Strategy 2007 – 2012  
*Next Generation Science for Planet Earth*



# **NATURAL ENVIRONMENT RESEARCH COUNCIL**

Science Theme Reports

## **Natural Hazards**

November 2007

# Natural Hazards

## Reducing casualties and economic losses caused by natural hazards

### 1. Introduction

#### 1.1. This Report

Theme reports are the core of NERC Science and Innovation Strategy, which sits within the overall strategy for 2007 – 2012 *Next Generation Science for Planet Earth*. The reports are the culmination of consultation, advice and decision-making that took place over 2006 and 2007. They are working documents that provide the basis for implementation, informing Theme Action Plans. The NERC strategy document contains a summary of the information in the reports. The overall development process for the Natural Hazards theme report is summarised below:

In November 2005 NERC Council identified seven strategic science themes, and a strategy development panel was set up for each theme. The panels' role was to recommend to NERC's Science and Innovation Strategy Board (SISB) NERC's future research priorities within each theme. The Natural Hazards panel met on 4-5 May 2006.

Each panel prepared a report following a common format that was presented by the panel chair to SISB on 11-12 July 2006. At this meeting SISB provided its initial view on the relative priority of the challenges identified within each theme.

Following the SISB meeting some of the panel reports were updated. The conclusions from the SISB discussion together with a response from the panel chair were appended to the panel reports and presented to Council on 26 - 27 September 2006. The report has been further updated following the discussions at both SISB and Council to reflect the overall priorities agreed at Council for this theme.

A draft NERC Strategy Document was developed from the panel reports and opened to public consultation during February – April 2007. A final version of the Strategy, incorporating recommendations from the consultation, was approved by Council in June 2007 and published in November 2007. Also in November 2007, the theme reports were updated to reflect this evolution of the strategy document.

#### 1.2. Background

Natural hazards are an emerging global issue for humanity. The rate of natural disasters is increasing dramatically as a consequence of population growth and increased vulnerability due to global trends in urbanisation, land-use, and stressing of ecosystems. Global warming is leading to a rise in sea level and the probability is that some hazards, such as severe tropical storms, droughts and floods, are increasing as a consequence of more energy in the atmosphere and oceans.

Science has a central role in the forecasting and mitigation of natural hazards. It is the basis of technological solutions to early warning, providing advice to authorities in areas at risk and during emergencies, designing effective mitigation strategies for communities, and providing critical information for decision-makers and the public to help save lives and avoid economic losses. The UK has a tradition of excellence and international leadership in natural hazards science. With this indigenous scientific know-how and the emerging importance of natural hazards as a global issue this topic is a prominent part of the new NERC strategy.

This report summarises the key scientific challenges and shows that significant progress can be made over the next 5 to 10 years in providing much more robust and confident forecasting and mitigation strategies. Natural hazards are an international and multidisciplinary issue. Solutions require extensive partnerships within the UK and internationally to co-ordinate the different disciplines and institutional efforts

### **1.3 Scope**

The scope of the theme has been agreed as: ‘to identify the science challenges associated with the forecasting and mitigation of the following natural hazards in the geophysical environment: earthquakes; volcanoes; flooding; storms (hurricanes, typhoons, etc); tsunamis; coastal erosion; landslides; subsidence; droughts; wild fires; heat waves; aspects of climate change (for example sea-level rise and changes in frequency and intensity of other hazards); and effects of volcanic emissions on the atmosphere’. In addition, the following topics have been identified, which do not fit this geophysical scope, but which should be considered by other themes: natural pollution (for example radon); dust storms; algal blooms; plagues of insects such as locusts). The scope of this theme also differed from others in that many hazards have short timescales (typically seconds to months). Other themes would focus on events that are more persistent or gradual. Space weather was discussed but, on the advice of SISB, is omitted from this report as not being pertinent to NERC’s mission.

### **1.4 Key drivers**

Global economic losses have increased five-fold in real-terms over the last decade and exceed the total losses for the previous four decades<sup>1</sup>. Similarly, loss of life has been appalling. Since 1990 well over a million people have died, with floods, droughts and earthquakes being the biggest killers. Extreme events make the headlines, raise awareness and bring natural hazards well up the political agenda; however, numerous smaller disasters occurring on an almost daily basis add up to too many unnecessary deaths, economic losses and deprivation.

Natural hazards disproportionately affect the developing world. The same magnitude earthquake in California may kill a couple of people, but in Bam (Iran) it kills 40,000 people due to poor building construction. DFID estimate that natural disasters typically cost poor nations between 5 and 15% of GDP annually. In the developed world, while natural hazards are awful for the affected communities, there are usually few casualties and the disaster does not significantly affect GDP or development. This picture, however, is potentially altered by extreme events, as hurricane Katrina and the Asian tsunami demonstrated, with many deaths of New Orleans citizens and European holidaymakers. At the recent Royal Society Discussion meeting (27 October 2005) on extreme natural hazards there was a pessimistic consensus that the first million fatality natural disaster in a mega-city was merely a matter of time.

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<sup>1</sup> Estimate from Munich Re

Economic consequences are global and significant. For example, US oil installations were out of action and oil prices increased markedly after Katrina, and large amounts of aid were diverted to disaster relief in Asia from much needed aid money elsewhere. In the next decade or so there are likely to be, events in such sensitive places that they either rock the world economy or create political instability; a major earthquake in Tehran or Japan are examples. Natural hazards are also one of the factors that prevent countries escaping from extreme poverty, and their effects contribute to failed states, social deprivation, obstacles to sustainable development, with manifestations such as terrorism, conflicts and economic migration. The UK has taken a lead on many development issues related to extreme poverty and increasingly seen itself as a “force for good”. In this context natural hazards are an important aspect of development as recognised in the recent DfID report.

Planning needs to take account of the risks; examples include housing development in the UK, which is often on flood-plains, and the siting of nuclear facilities near coasts where sea-level rise is likely to increase vulnerability. Direct impacts of hazards in the UK are not confined to hazards taking place in the UK. Large volcanic eruptions in Iceland and tsunamis related to submarine landslides off Norway and West Africa have impacted the UK in the past and would cause disruption, health effects, large economic losses and deaths were they to occur today. UK economic, commercial and political interests are spread globally, so can be affected by natural hazards. Tropical storms regularly lead to rainfall-induced slides which engulf unplanned residential development in the third world. There are societal and cultural possibilities to educate people to recognise potential risky locations and danger signals, and also to understand simple measures that could be adopted to improve slope stability.

The Asian tsunami was a tipping point for international and political concern about natural hazards and led to the Hyogo agreement. This in turn has led to major international efforts to improve the use of science in mitigation and risk assessment (e.g. within UN agencies and programmes, the GEOSS programme and the International Council of Scientific Unions). The July 2005 G8 meeting in St Andrews included a discussion of natural disasters led by the Prime Minister informed by the findings of the Natural Hazards Working Party commissioned by Sir David King.

Some major themes have emerged:

- First, natural hazards and their consequences need to be forecast effectively.
- Second, communication of scientific knowledge and understanding of natural hazards needs to be much improved.
- Third, much more emphasis and financial resources need to be put into mitigation strategies. Almost all financial resources go into disaster relief yet, based on World Bank assessments, for every dollar spent on mitigation three or four dollars are saved on relief (DFID report).

There are commercial reasons for the UK to have a strong science community and to do research in natural hazards. The UK increasingly provides a service economy. There are many opportunities within the natural hazards arena to market skills, new technologies for monitoring and warning systems, engineering strategies, know-how on the hazards and technical aspects of risk assessment; and to provide advice and technical assistance to governments, private enterprise, NGOs and citizens. There are important UK industries (e.g. insurance and energy sectors) where natural hazards expertise is vital. Effective use of development aid is a growing activity with many commercial opportunities and a need for authoritative scientific inputs.

## 2. Key Outcomes

There are grand challenges and tremendous scientific opportunities in natural hazards research. Natural hazards reflect how the Earth system works. A major driver for NERC is to improve predictability of the location, timing and consequences of hazardous natural events. Fundamental scientific investigations and research into the broader issues of the dynamics of the solid Earth, surface environments, the oceans and the atmosphere have a central role in making advances in understanding hazardous natural phenomena. For geophysical hazards the role of geology is essential to almost all natural hazards, as geological studies establish what has happened in the past and provide a major source of evidence. The integration of modelling, data gathering, monitoring and experimental studies provides the core activity of most hazards research.

The science is of no ultimate value unless it is effectively integrated into human actions and decision-making procedures. There is therefore a major challenge in making sure that the scientific knowledge is applied effectively, requiring collaboration with other disciplines in the social and political sciences.

Key outcomes and solutions required from natural hazards science include; better mitigation strategies; more resilient societies; improved risk management; better forecasting to provide timely warnings, influence policy and regulation decisions; more accurate and digestible information to underpin business and policy decisions; assessment of extreme hazards, their risks and likely frequency; comprehensive networks of observations; more robust models; and detailed, accessible databases which can be easily interrogated.

## 3 Science Challenges

Natural hazards are extremely variable in terms of the processes involved and in their spatial and temporal scales. As a consequence it was considered essential to identify hazard-specific scientific challenges and issues. Here the theme distinguishes between hazards related to *hydrometeorological phenomena* (e.g. storms, floods, droughts, heat waves, wild fires, coastal flooding and erosion and landslides<sup>1</sup>) and those related to solid earth processes, referred to here as “*geohazards*” (e.g. volcanoes, earthquakes, subsidence and tsunamis). However, there are strong interconnections: flood hazards, for example, are related to the geological environment through infiltration, whilst volcanic emissions can affect the atmosphere and climate. Landslides and volcanic eruptions can be triggered by intense rainfall. The risks of all hazards are related to increases in vulnerability related to global change, and increasingly a multi-hazards approach is essential in risk assessment in particular places.

**NERC Council concluded that the priorities in this theme are the hazard-specific challenges, and the theme report’s emphasis is on these. However, Council also recognised that in order to meet these challenges, there are a number of underpinning, cross-cutting science challenges, common to each hazard, and these are considered in Section 4.**

### 1. Enable better forecasting and mitigation of hydro-meteorological hazards

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<sup>1</sup> It is recognised that landslides can be triggered by hydro-meteorological or geological forces. They are included under Hydrometeorological Hazards in the theme report, since it is hydrological triggers that are the main drivers in the UK and are likely to change in intensity due to climate change

The highest priority in this challenge is storms, but it also includes floods, droughts, coastal flooding and erosion, landslides, heat waves and wild fires.

## 2. Enable better forecasting and mitigation of geohazards:

The highest priorities in this challenge are:

- Volcanic hazards and the impact of volcanic emissions on the climate;
- Large magnitude earthquakes (and associated tsunamis).

Hydro-meteorological hazards were identified as the highest priority as they have the greatest impact upon the UK and its economy. Nevertheless, it was accepted that the UK has an international role (as a “Force for Good”) in the provision of expertise and informed advice for hazards such as earthquakes and volcanic eruptions, which do not impact the UK landmass (but do affect UK Dependent Territories). In the following sub-sections, more detail is provided on these specific scientific challenges.

## 3.1 Challenge 1: Enable better forecasting and mitigation of hydrometeorological hazards

The hydrometeorological hazards that this challenge will address are outlined below. Storms are the highest priority. In addition to the hazards outlined below, the challenge may also consider wild fires and heat waves, which are interrelated with some of the other hydrometeorological hazards (e.g. Storms, Droughts) and with climate change.

### 3.1.1 Challenge 1(a): Storms

Hazards associated with storms arise from extreme wind speeds and amounts of precipitation. Storms here refer to the dynamically distinct phenomena of extra-tropical and tropical cyclonic storms. The scientific challenge arises from the need to improve the accuracy of, and to extend, the useful forecast range of these storms. In the case of extra-tropical storms there are major challenges related to improving the prediction of their occurrence and the quantitative value of their precipitation, whereas for tropical storms the challenge relates predominantly to improving the prediction of their intensity, and to a lesser extent their track. The ability to extend the lead-time of useful predictions of extreme storm events using concepts such as targeted observations, adaptive grids, ensemble forecasts and improved data assimilation is critical. In addition the change in the frequency and intensity of storms associated with global warming is a key uncertainty that needs to be addressed. A particular issue relates to the factors that would change the frequency of category four and five hurricanes.

Some challenges in storm research include: improved representation of moist processes (clouds and convection); role of model resolution; extending the range of useful predictions beyond a few days ahead; targeted observation strategies; improved data assimilation including dynamically-responsive methods; next generation ensemble prediction techniques; and the role of greenhouse gas increases in pre-conditioning the atmosphere and oceans for storm generation and evolution.

**Specific Deliverables:** increased knowledge leading to improved predictive capability of extreme wind and precipitation; knowledge about the change in the frequency and intensity of storms under global warming conditions; and the role of storms in initiating, and enhancing the risk of, storm surges. These deliverables would enable preventative measures to minimise social and economic costs associated with such storm events.

### 3.1.2 Challenge 1(b): Floods

There are profound impacts of changes in land use on flood risk, which require developments in physically-based modelling and improved process understanding. Fundamental issues of up-scaling arise; how can small scale experiments to evaluate local impacts of land management change be extrapolated to infer catchment scale response? How can physically based hydrological models be parameterised to represent sub-grid heterogeneity? The impacts of climate change on flood risk require improved methods to generate long time series of precipitation for future climate states. In urban areas new methods are needed to simulate flood risk from rainfall runoff, as existing design methods are inadequate. New high-resolution surface elevation data (LIDAR) can now support detailed modelling of urban flooding.

A major challenge concerns the assessment of flood risk at ungauged sites in the absence of local data. Improved regionalisation methods are required to estimate model parameters from catchment characteristics and regional databases. How can spatial dependence of flood statistics be modelled for extreme events? How can multivariate problems, such as the coincidence of fluvial and tidal effects, be represented? How can physical constraints on extreme rainfall be incorporated in extreme value distributions? How does catchment response change for extreme floods? Currently arbitrary assumptions are made. Detailed analysis of large historical floods is required. How will extreme rainfall change with changing climate?

There is an urgent need to improve real-time forecasting using new data sources. New wireless sensor technologies are likely to support dramatic increases in the potential for real-time distributed monitoring of fluvial systems. Remotely sensed data are likely to offer new potential for flood forecasting for developing countries through improved near real-time rainfall estimation (combining meteorological modelling and satellite data) and remotely sensed water surface elevations.

**Specific Deliverables:** Flood research can deliver: a methodology to simulate surface flooding in urban areas, based on high resolution digital elevation data and new process-based models; a methodology to support risk assessment of groundwater flooding for the 400,000 properties at risk on the UK's Chalk aquifers; a global capability for near real-time flood forecasting of the world's major rivers using remotely-sensed surface water levels and global precipitation products. Making available to researchers the information needed in the required formats.

### 3.1.3 Challenge 1(c): Droughts

There are major challenges in modelling the hydrology of droughts. How does catchment response change under drought conditions? Data are limited and particular issues arise for the UK groundwater-dominated rivers. Detailed analysis of historical droughts is required. How will drought frequency change with changing climate? Drought assessment at ungauged sites is particularly difficult. How can drought response be assessed in the absence of local data? Improved regionalisation methods are required to estimate model parameters from catchment characteristics and regional databases. There are challenges for the assessment of the ecological impacts of drought and for water resource management. What is the resilience of ecosystems to drought? What are the implications of climate change, with potential increased drought frequency, for ecosystem quality? How can drought risk under a changing climate be incorporated into risk assessment of water resources? Particular issues arise for the UK for the quantification of reliable yield of groundwater sources under drought. There are important long-

term forecasting issues. To what extent can drought be predicted for different regions of the world from global and regional climate and sea-state indicators?

**Specific Deliverables:** Drought research can deliver: improved understanding of the drought response of UK rivers; a new risk-based method for assessment of groundwater resource yields under drought conditions; and methods to assess the resilience of aquatic ecosystems to drought, including associated impacts of climate change.

### 3.1.4 Challenge 1(d): Coastal Flooding and Erosion

Coastal Flooding and Erosion results from a combination of mean sea level changes (including regional variations) relative to land movement, tides, storm surges and waves driven by atmospheric pressure and especially winds. It is exacerbated by coastal erosion and depends on coastal and estuary morphology. All these factors are subject to climate change. Prediction of future risks or frequency of events of any given severity depends on the extreme statistics of these combined factors, taking account of spatial and temporal patterns. Other challenges, in risk assessment for design and in deterministic forecasts for warning of specific events, are (i) physics-based modelling of scenarios for inundation extent, (ii) coupling of marine models with estuarine, fluvial, catchment and groundwater models – especially for rivers or estuaries “backing up” if sea levels are elevated, (iii) designing monitoring networks synthesising local and national components, (iv) using observed data for initialisation and assimilation in models to improve forecasts of specific events and estimates of uncertainty.

Coastal erosion involves land-slip processes with the added factor of attack from the sea. Wave attack is sensitive to total sea level, including climate-change trends, and to local topography; waves are dissipated by beaches and/or offshore bars. In turn, these features are morphological outcomes of biases in near-shore sediment erosion, transport and deposition, involving detailed processes of multi-phase or granular flow in a combination of waves, currents and turbulence sensitive to topography and overall water depth. These sediment process biases may depend on subtle differences between ebb and flood tide (for example); they may also differ between ongoing processes (e.g. beach build-up through most of the year) and occasional severe events (e.g. beach removal and cliff retreat in one storm). Hence longer-term prediction is a particular challenge. There is scope for investigating the level at which detail is parameterised, i.e. what hybrid of “bottom-up” process basis and “top-down” larger-scale balance and experience is invoked.

**Specific Deliverables:** Coastal flooding research should yield: confident estimates of extreme-level statistics under future climate scenarios; and the ability to predict inundation extent for scenarios of storm surges and waves. Coastal erosion research will gain an understanding of: erosion of mixed-grain-size material under combined waves and currents – and the corresponding bed roughness; large-scale balances controlling overall bedform evolution; and a scientific basis for design of coastal defences (including “soft engineering” and “managed retreat”) with confidence in associated predicted morphology.

### 3.1.5 Challenge 1(e): Landslides

The processes of triggering and emplacement of landslides remain inadequately understood. Consequently, areas at risk may remain unrecognised and the run-out or danger zone cannot be reliably predicted. The dynamic behaviour of the sliding material, often made of multiphase mixtures of soil, rock, water, and air, is not well understood. Landslides commonly involve complex interactions of natural circumstances (e.g. intense rain, geology) and environmental

vulnerabilities (e.g. deforestation, unplanned housing). Mitigation requires local studies that integrate advanced science with local societal conditions.

Massive submarine landslides have occurred in many parts of the world. Slope failures off major deltas (e.g. the Nile) can lead to destruction of offshore oil installations. The triggering mechanisms for failure are not understood and the processes determining the extent of the failure volume, failure rate and run out distance, are inadequately understood. Field evidence reveals extremely long distances of flow with the flowing material entraining soil from the seabed over which it is flowing. Rock avalanches offer a similarly challenging flow problem. These avalanches involve coarse particulate material with particles that tend to break up during the flow. Again, the observations of failure debris indicate distances of run-out that cannot be readily explained. Various linear and non-linear models need to be developed to predict these phenomena more accurately.

**Specific Deliverables:** Landslide research will deliver greatly improved knowledge of the conditions that trigger landslides and of the mechanics of the processes occurring inside the multiphase mass of flowing material, leading to more reliable hazard assessments, predictions and mitigation strategies.

## **3.2 Challenge 2: Enable better forecasting and mitigation of geohazards**

### **3.2.1 Challenge 2(a): Volcanic hazards and the impact of volcanic emissions on the climate**

The scientific challenges involve understanding how magma flows through the crust, erupts, and how volcanic emissions affect surface environments, in particular the atmosphere. Volcanic systems are highly non-linear and some key causative processes cannot be observed directly. The science involves integrating a wide range of geophysical, geochemical and observational data within a framework of conceptual and numerical models and laboratory experiments to measure key material properties and investigate volcanic flows. Assessing hazards, realising hazards and evaluating risks requires understanding the fundamental physics and the many uncertainties. Advances in volcanology develop from systematic long-term monitoring, detailed geological case studies, analytical studies, numerical models of volcanic flows supported by field and experimental data, analysis of time series of multiparameter data, commonly using advanced statistical techniques and laboratory studies of key material properties. There is great prospect for developing comprehensive integrated models of volcanic processes and eruptions.

Worldwide, there are major gaps in basic knowledge; for example only 20% of the World's volcanoes with potential for large magnitude explosive eruptions have an adequate geological and historical record. Baseline studies of high-risk volcanoes in periods of quiescence are vital so that the signs of moving into activity can be recognised well in advance. Case studies conducted by multidisciplinary teams are a key approach; such studies of a handful of eruptions have led to most of the major advances in volcanology. Systematic geological and geochronological studies of high-risk volcanoes are essential for hazard assessment.

Volcanic emissions are a major input into the oceans and atmosphere. Gases and aerosols affect climate, especially after major eruptions, and cause atmospheric pollution and health hazards. Input of reactive volcanic particles into the ocean affects global seawater chemistry and provides nutrients that influence the carbon cycle. A cross-cutting challenge across the Earth System

Science and Climate System themes is to improve understanding and modelling of the role of volcanic emissions in biogeochemical cycles and climate.

**Specific Deliverables:** Volcano research can deliver more complete information to enable robust hazard and risk assessment, improved modelling, more reliable forecasting of eruptions, better management of volcanic crises; better global identification of which volcanoes pose the highest risk; and understanding how volcanic emissions (gas, ash and aerosols) affect climate

### 3.2.2 Challenge 2(b): Large magnitude earthquakes

A wide range of fundamental earthquake science, from fault rupture mechanics to seismic wave propagation, is poorly understood or limited by the resolving power of available data or processing capabilities. Advances in almost all areas will improve understanding of earthquake hazards. Of particular relevance to hazard assessment and mitigation are: (i) characterisation of active faults (i.e. knowledge of slip rates, geometry, earthquake recurrence and history); (ii) identification of active faults through an understanding of active geomorphology; (iii) case studies of individual earthquakes and their seismic cycles (i.e. pre-, co- and post-seismic ground deformation and seismicity); (iv) the tectonic context of earthquake activity (i.e. relations between faulting, velocity fields, and dynamics); (v) relations between earthquakes and the performance of engineering, lifelines and human infrastructure. Such studies should not be limited to urban areas and population centres: the best examples, which will improve understanding and mitigation capability, are not necessarily in the places where that understanding needs to be applied.

**Specific Deliverables:** Earthquake research can achieve: integrated case studies of earthquakes in various places, involving seismology, geodesy, remote sensing, fieldwork and Quaternary geology and geomorphology; advances in seismogram interpretation and synthesis, both for studying the earthquake source and for sound propagation through laterally varying media, which controls local ground motions and shaking; and improved modelling of pre-, co- and post-seismic ground deformation using radar (InSAR) and other space-based geodesy (such as GPS).

### 3.2.3 Challenge 2(c): Tsunamis

The scientific challenge is to advance the modelling of the relation between submarine ground movement (for example, earthquake faulting, oceanic island collapse, or slope failure) and tsunami generation. Modelling the nature of a tsunami and its potential effects, and development of mitigation strategies, requires detailed knowledge of bathymetry and topography in coastal regions, which is not available everywhere.

The link between earthquake faulting and tsunami generation depends on the time history of fault slip as well as on its geometry. A particular challenge is to be able to tell rapidly (i.e. within seconds) from the observed seismograms whether or not a tsunami will be generated. A further challenge is to integrate models of the effects of tsunamis into near-real-time seismological analysis, to provide warnings of trans-oceanic tsunamis. Proper understanding of fault locations, geometries and rupture characteristics in subduction zones, which are known to vary considerably, is essential for identifying areas at risk, particularly from local tsunamis. These areas of science will all advance through case studies, the surveying and characterisation of subduction zones and their earthquake-related behaviour, improved theoretical and analytical techniques, and through better and faster modelling capability. An understanding of the relations between oceanic-island collapse and possible tsunami generation will advance through forensic case studies of submarine slides and improved knowledge of multiphase phase flows.

**Specific Deliverables:** Tsunami research should have made progress on: characterization of the modes of faulting and rupture propagation in the subduction zones that are major tsunami source areas; modelling of near-source coastal effects from major subduction zone earthquakes including co-seismic vertical ground motions and possible tsunami run-up areas and heights and forensic studies on submarine slides from collapsed flanks of ocean-island volcanoes.

## 4 Underpinning, cross-cutting challenges

Underpinning the specific hazard-related challenges are several generic science challenges common to all of the hazards. Making progress in these areas will be essential to meeting the hazard-specific challenges.

### 4.1 Developing physically-based models (multiple challenges)

Natural hazards involve stochastic and non-linear systems that need to be understood in terms of physically-based models. A variety of complementary modelling strategies need to be developed to address forecasting and understanding. These include: forward analytical and numerical models of process, data routing and assimilation into models for real-time forecasting; statistical models looking at time series or spatial distributions; and probabilistic and ensemble modelling approaches. Integration of evidence, data and models together requires innovative research for hazard and risk assessment, such as the development of Bayesian Belief Networks. The overall deliverable is to have, in ten years time, the modelling capacity to forecast the location, timing and consequences of hazardous events and assess the associated risks in order to protect life and minimise loss.

### 4.2 Utilising experimental studies

Many natural hazards processes depend on material properties and dynamic processes that are poorly characterised or understood. These can be best addressed through laboratory measurements and experiments on natural or analogue materials. Major challenges arise because many hazardous processes involve complex multiphase mixtures (gas, solid, liquid) whose properties are either poorly characterised or understood.

### 4.3 Distinguishing, quantifying and communicating uncertainty

A key challenge is the understanding of uncertainty, which is essential for providing reliable forecasts and risk assessments. Distinguishing and quantifying aleatory uncertainty (natural variability) from epistemic uncertainty (lack of knowledge) is a formidable challenge that can be addressed by advances in theory, improvements in modelling, experimental measurements and better monitoring. Uncertainties may increase as well as reduce as a consequence of research and better data. There is a particular challenge in communicating the uncertainty in forecasts and risk assessments to decision-makers and the public; here collaboration between natural sciences and social scientists, expert in risk perception, policy development and public education is essential.

### 4.4 Improving methods for monitoring and survey

Monitoring of natural hazards within the natural laboratory of the Earth provides large quantities of data of different types and qualities. There is a generic challenge to handle these large datasets efficiently and to be able to extract information and patterns. Innovation in techniques of monitoring and in handling of metadata are challenges, but they can be met through the ever-increasing computer power. Earth Observation systems provide great opportunities for more comprehensive and robust monitoring of the Earth on many scales from global to individual volcanoes, faults, storm systems and catchments.

## **4.5 Observing and understanding extreme events**

Extreme events present great challenges because of their rarity and as a consequence the paucity of data. It is vital to collect observations and data when such events happen. Advances in extreme value theory are needed to analyse non-stationary time series; a problem of particular importance in hydrometeorological hazards in view of climate change. The definition of extreme events is not just dependent on the natural hazard itself, because increasing vulnerability means that events of a particular magnitude can have more extreme consequences.

## **4.6 Improving integrated risk assessment and scientific advice**

Risk assessment and provision of evidence-based scientific advice requires natural scientists to collaborate in multidisciplinary research involving expertise from many other disciplines. Effective collaboration involves challenges of understanding and common language between disciplines, as well as funding mechanisms for allowing the multidisciplinary research to flourish. Research might involve, for example, issues of social and cultural factors affecting vulnerability, risk perception, science communication and effective ways of providing advice on the basis of complex scientific ideas and data. Novel methods of integrated risk assessment (e.g. Bayesian Belief Networks) need to be developed that combine hard and soft data. Research projects might also involve working closely with local communities and authorities so that hazards science is integrated into the societal dimensions and concerns.

# **5 Meeting the Challenges**

The published NERC Strategy highlights some of the ways in which the NERC will be “Meeting the Challenges” for each Theme. These are essentially some of the potential key deliverables. They often cut across several of the Theme’s challenges. For consistency, we have included those for Natural Hazards below, against the challenges that they most strongly relate to. They are not exclusive and may evolve during the Strategy’s lifetime.

“Meeting the Challenges” (from the NERC Strategy)	Natural Hazards Challenges								
	1(a)	1(b)	1(c)	1(d)	1(e)	2(a)	2(b)	2(c)	Underpinning cross-cutting challenges (*)
Improve predictions of extreme hydrometeorological events, such as high winds, heavy rainfall, high river flows, storm surges and their impact	X	X	X	X	X				X
Enable better predictions of flooding in urban areas to assess the risk posed to people and buildings	X	X		X					X
Make confident estimates of worst-case coastal flooding, corresponding to future climate scenarios	X	X		X					X
Enable better forecasting of volcanic eruptions and management of volcanic crises by providing the necessary observations and developing more robust tools for statistical risk-analysis					X	X			X
Quantify the effect of volcanic emissions and forest fires on the climate by investigating their effects on atmospheric chemistry and integrating the data with climate change models			X		X	X			X
Increase knowledge of geological processes that are responsible for earthquakes and tsunamis, and the conditions that trigger landslides. This will enable better predictions of risk and will help to identify the most vulnerable regions on the planet					X		X	X	X

(\*) All six underpinning challenges relate to all of the deliverables under “Meeting the Challenges”.

## 6 Links and interfaces to other science themes

The hazards theme has the following links to other science themes:

- Environmental Pollution and Human Health – natural hazards such as radon, arsenic in groundwater, toxic elements in soils, etc.
- Climate systems – climate models and decision support systems

- Earth System Science (ESS) – strong links as natural hazards are a consequence of how the Earth system works, including the dynamics of the Earth’s interior and interactions between surface environments, the atmosphere and hydrosphere. In particular with ESS challenges: forewarning of abrupt changes in the Earth system, records of past environments, dynamics of the Earth’s interior, methane hydrates.
- Technologies – novel instrumentation and telemetric methods.
- A cross cutting challenge has been identified within the Biodiversity and Sustainable Use of Natural Resources themes relating to tools to value the environment. Such tools could be applicable in assessing the potential impact of natural hazards.

## 7 Implications for the Science Base

The outcome of implementing the theme would have the following implications on the science base:

- There would be more and better-trained scientists, if the right people could be attracted. However, training scientists to PhD level within three years would be challenging – a four-year period may become necessary. It may be necessary to find routes for support for European or other foreign nationals;
- Greater computing power would be required. Technology is moving rapidly; computing facilities must be maintained at the cutting edge;
- Capacity building of a UK hazards community, this is an opportunity for NERC to ensure links are made with relevant activities in other research councils; there is a particular need to build links with the social sciences; and to sustain UK strengths in geophysics and volcanoes;
- There is a requirement for improved management, interrogation and archiving of data, as well as the necessity for it to be held in common, accessible formats – especially internationally;
- There is a requirement for funding experimental research in natural laboratories, both at long-term sites such as Plynlimon and those funded under the LOCAR programme, and also for the study of natural laboratories, such as Montserrat;
- NERC needs the flexibility to support urgent forensic studies of sudden short-lived natural events.

## 8 Synergies and Partnerships

NERC should take advantage of the opportunities for national and international collaboration with other bodies and scientific disciplines relevant to natural hazards mitigation (e.g. sociology, economics, psychology). The following synergies and partnerships would be required to deliver the science:

- With organisations such as: DfID, European Union; National Science Foundation; UN agencies (UNESCO, ISDR); Intergovernmental Oceanographic Commission; Defra; Environment Agency.
- Partnerships with developing world scientists and institutions: NERC should be supportive to such partners and recognise their lack of resources.
- With industry, to facilitate the use and development of technology.

- Stronger partnerships between NERC's Centres and the university sector to improve capabilities, data management, and logistics.
- Enhanced links with other Research Councils to develop and support truly interdisciplinary research themes.

## 9 Knowledge

The following are the requirements and opportunities for the exchange of knowledge:

- Influencing politicians and their advisors;
- Providing the public with accessible information, i.e. with a web-based knowledge portal;
- Disseminating knowledge to resource-poor institutions and scientists in the developing world;
- A range of outlets for data from directed programmes;
- An emphasis on knowledge exchange by government;
- Branding of NERC (important for government, not for the public);
- Glossy publications aimed at schools;
- Using money in grants flexibly to communicate science in education;
- Commercial opportunities for the use of NERC science, such as scientific services (to aid organisations, NGOs, and the insurance industry);
- Demonstrating the economic benefit of NERC science to bodies such as the World Bank, insurance companies, ESA;
- NERC to solicit specialist/professional assistance in producing 'glossies'.

## 10 Links and interfaces with organisational themes

Sections 8 and 9 above set out specific opportunities for partnerships and knowledge exchange within the Natural Hazards theme. At a strategic level, these have been incorporated into the corresponding organisational themes of the NERC Strategy