Natural Hazards Theme Action Plan 2008

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Overview

Vision: To reduce societal exposure to natural hazards through improved forecasting, integrated risk assessment and scientific advice.

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 trends in urbanisation, land-use, and stressing of ecosystems. Economic losses have increased five-fold in real terms over the last decade and exceed the total losses for the previous four decades. 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. Climate change is leading to a rise in sea level, and the probability is that some hazards, such as severe 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, NERC established Natural Hazards as one of its seven themes. This Theme Action Plan (TAP) provides advice about the initial strategic investments required for implementation of the NERC Natural Hazards Theme Report (http://www.nerc.ac.uk/about/strategy/documents/theme-report-hazards.pdf) - which sits within the overall NERC strategy for 2007–2012 *Next Generation Science for Planet Earth*.

The **scope of the theme** is to develop the science associated with the forecasting and mitigation of earthquakes; volcanoes; flooding; storms; 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. Underpinning the specific hazard-related challenges are the following cross-cutting, generic science challenges: improving monitoring; developing experimental studies; delivering uncertainty-encompassed physical models; enhancing integrated risk assessment; and providing scientific advice. The breadth of the theme will engage much of the NERC community, in particular the atmospheric, freshwater, terrestrial, marine, geological and earth-observation sciences; it will also link to the polar community.

High priority theme challenges

NERC already has a world-leading pedigree in the delivery of high-quality science on natural hazards. Nevertheless, there exists considerable scope to improve upon this by ensuring that in the future it is better focused on enhancing the application of current knowledge and the development of improved tools to minimise the risks that natural hazards pose for society. The NERC strategy thus established three over-riding drivers which should shape future NERC natural hazard science:

- Natural hazards and their consequences need to be ***forecast*** effectively;

- ***Communication*** and application of scientific knowledge and understanding of natural hazards needs to be much improved; and
- Much more emphasis and financial resource need to be invested in ***mitigation*** strategies.

Only the first of these falls almost exclusively within the domain of the natural sciences; the others require significant input from other sectors, for instance the social science and engineering communities. As has been recognised by many commentators, the great jump in losses from natural hazards in recent years has not been matched by increases in the occurrence or intensity of these, but by greater societal vulnerability; the importance of enhancing the uptake of Natural Hazard research into policy through improved communication, including integrated risk assessment, cannot be overstated. The successful development of the Living With Environmental Change (LWEC) Programme, being the main vehicle for delivering excellent cross-sectoral science over the next decade, is vital to this theme.

Being the first in a series, this first TAP necessarily outlines three 'foundation' areas A - C, upon which the science in the theme will be built. These set the direction of the theme, develop capacity and address top-level natural hazard science issues.

A - ***The focus on probability, uncertainty and risk:*** If NERC is to radically improve the impact of relevant natural hazard science it must develop better handling of probability and uncertainty throughout the research community. The science of risk reduction is increasingly concerned with the integration of a broad spectrum of complex, commonly non-linear, hard (physical science) and soft (social science) models. The issues of probability, uncertainty and risk are critical both within, and at the interface between, such models, and several new approaches have been developed in the UK, and international, scientific communities. There is thus a need for advice, research and development of approaches to enable better handling of these issues across NERC natural hazard activities. For this reason, two of the initial actions will provide significant components of a probability, uncertainty and risk 'framework' that will deliver tools and training to researchers so that they use best practice and common standards. These actions, widely called-for by natural hazards scientists consulted, are thus being prioritised in this TAP. It is likely that in the long term, the benefits of early investment on generic approaches for handling of these issues in the theme schedule will greatly outweigh those afforded by other possible actions of similar size. It will increase the value of future hazard-focused research, whether it is observational, analytical, conceptual or predictive, and will apply to all challenges in the theme.

B - *The focus on top-level hydro-meteorological hazards:* Following discussions with the UK community, it has been identified that the key considerations in setting actions and sub-components are: risks for which new research will do most to reduce casualties or economic loss, particularly those that are likely to increase in frequency and magnitude; risks with core UK expertise or datasets; risks inadequately researched by the global natural hazards community; and the capacity of the NERC community to undertake any field of research at a particular time. On this basis, three actions outlined here, relate to top level hydro-meteorological hazards that govern the distribution and impact of many other hazards at a regional or local scale: storms, the impacts of sea-level rise and impacts of the changing water-cycle. All have links with other themes (in the case of those based on sea-level rise and the water cycle, as joint actions that are led by the Earth Systems Science and Climate System themes respectively). They focus on the largest uncertainties in hydro-meteorological science, sitting high in science and model hierarchies; all are critically linked to current climate change questions. Reducing uncertainties in these will substantially lessen those lower in hierarchies and modelling cascades - therefore, they have been prioritised for early action. Prioritizing these will also provide timely advice to policy makers on the likely costs of future hydro-meteorological changes under a range of scenarios. Given the short timescales within which substantial mitigation strategies may be developed, these actions must have a high priority.

C - ***Risk-focused prioritisation of natural hazard research:*** Perhaps the most important foundation area, that will enable NERC to achieve greater natural hazard science impact, is the focus on the strategy drivers (above); a step change is required in the way it prioritises strategic natural hazard research so that it will do most to mitigate against societal risk. The manner in which research is prioritised, on the assessment of its value in prediction, integrated risk assessment and mitigation (see Potential Future Actions, below), will largely define hazard-specific process-based actions in later TAPS.

Action 1: Analysis, propagation and communication of probability, uncertainty and risk

Rationale: As set out above, the impact of NERC natural hazard science will be markedly improved through better handling of the analysis, propagation and communication of probability, uncertainty and risk. Particular challenges faced by natural hazard scientists include: a very broad range in the types, quality and density of data or information to be modelled; the incorporation of assumptions and judgement in models; the diversity of approaches in data assimilation; the modelling of extremes; handling of fluctuations that are far from normal and with long-term memory (that violate many of the common assumptions in risk tools); the computational expense of modelling complex, non-linear systems; the usage of emulators, such as artificial neural networks or group outputs, to parameterize complex systems; the propagation of uncertainty though model cascades (including complications associated with feedbacks); the optimisation of recalibration, or post-processing, approaches to help map model output into real world variables; the handling of ensembles; the integration of contrasting model types (e.g. natural hazard models typically developed within NERC and cat-models within the Insurance industry); and communication of uncertainties and risk to other parties, including end-users. Several NERC natural hazards researchers have recognised, and are attempting to tackle these challenges, or components of them, but many approaches are being used and it is unlikely that only a few will readily fit a wide range of applications. Many of these are common to other areas of science, and it is possible that best practice or solutions (most likely with some adaptation) may thus be readily available, but resources have not been allocated to enable them to explore options, or to thoroughly assess what best tools and methods may be best-suited to the development of natural hazard science. This action will remedy this.

Objective: To undertake a scoping study for a world-class programme to collate and develop tools and methodologies for the analysis, propagation and communication of uncertainty and risk within natural hazard science that will:

1. Collate statistical and non-statistical methodologies that may have applications in Natural Hazards research in the UK, and internationally.
2. Undertake appropriate statistical and non-statistical research to adapt or develop provide greatly enhanced tools for the analysis, propagation and communication of uncertainty and risk
3. Provide best practice guidance and tools for the quantification and analysis of aleatory (natural variability) and epistemic (knowledge) uncertainty, including advice on better

experimentation, measurement, monitoring, conceptualisation of complex multi-component & non-linear systems, assumptions, subjectivity and modelling. This should include advice on the assessment of model performance against observed variations (linking with Action 2, below).

4. Provide best practice guidance and tools for the integration of forecasts, including uncertainty, with vulnerability to develop integrated risk assessments for decision-makers and wider society.
5. Provide best practice guidance and tools for communication of uncertainty and risk to decision makers, and wider society, including use of a common language, better articulation of complexity, joint-working and development of policy advice.
6. Provide training to enhance best practice in analysis, propagation and communication of uncertainty and risk within NERC natural hazards science.

Implementation mechanism: A **scoping study** will be undertaken in 2008/9 with the aim of presenting a detailed plan for consideration by NERC (as part of the second Natural Hazard TAP) on the analysis, propagation and communication of uncertainty and risk. The scoping study will be charged with identifying current and future planned UK and international activity in this area, including a thorough analysis of approaches utilised within NERC, as well as a review of appropriate tools, applications and research in other research councils and with industry. This review may be aided by the development of an international workshop. The study will develop the science case, make recommendations about the focus, structure and outputs of a follow-on world class NERC research programme that will develop appropriate methodologies for use in natural hazard science; the study will also explore the opportunities for co-funding and the need for training.

Links and dependencies: Close links between NERC scientists and statisticians, social scientists, experts in risk perception, valuation, ethics and policy development and public education will be critical, within both the scoping study and succeeding programme. Joint-working and transparency to adapting mathematical techniques from a diverse range of applications, including from the insurance sector, will be essential to the success of this action; much of this is likely to be based on programmes within LWEC. It will incorporate the research in Action 2 (below) and build on programmes based on complexity, uncertainty and risk in the research centres and the work of the EPSRC-ESRC-NERC-DEFRA collaborative centre of excellence on *'Understanding and Managing Natural and Environmental Risks'* and the RCUK *Modelling Uncertainty in Complex Models* (MUCM) project. It is expected that the scoping study will interface with government departments and their agencies, and with initiatives that are developing generic approaches to the transfer of science to policy, such as (USGS-MIT) MUSIC and the Numerical Modelling Policy Interface (NMPI).

Targets addressed: The action directly addresses NERC natural hazard strategy challenges on the recognition, quantification and communication of uncertainty and improvement of integrated risk assessment and scientific advice, but will also provide tools for all hazard specific challenges. The action, being cross-cutting, underpins science addressing all of the LWEC objectives.

Action 2: Quantifying uncertainty in predictions of regional and local climate change and climate impacts

Rationale: Quantitative estimates of uncertainty are a key element of the user requirement for environmental predictions, but the challenge of producing such estimates has received surprisingly little attention until very recently. Thus, for example, many of the predictions presented in the IPCC 4th Assessment simply represent uncertainty in terms of an ensemble of different model predictions, with no indication as to whether some predictions may be more trustworthy than others, or what is the actual likely range within which we should expect future observable quantities to fall. The problem is generic and important, as decision makers are developing policy on the basis of predictions, without any recognition of the significant uncertainties involved; it is not only pertinent to climate prediction, but also to predictions of impacts, for example those of land use change on flood generation, ground stability or ecosystems. This is a joint action with the Climate System Theme.

Objectives:

1. Develop methods to combine observations and models to quantify the uncertainty in predictions of regional and local climate change and climate impacts. Of particular interest to the Natural Hazards theme are predictions of changes in extreme events, the effective incorporation of information from models that may be very different in structure or resolution, and developing generic approaches for handling of climate impacts.
2. Develop strategies and benchmarks to evaluate alternative methods for generating predictions, including decadal predictions for which hindcast sets can be generated.

Implementation mechanism: Following a review of current knowledge to identify challenges and opportunities in respect of the objective, a **sandpit** will be held to define a consortium project to address the detailed content of the programme. A sandpit is considered appropriate because of: a) the highly focused objectives; b) the requirement for different communities (in particular statistical modellers and climate scientists) to work together. The project should have clear deliverables in the form of methods and tools that can be applied to a wide range of prediction applications. The results of this action will have relevance beyond the field of climate, and climate impact prediction, and will feed into the wider programme that is planned under the Action 1 (above).

Links and dependencies: In this action it is critical that experts in statistical modelling and complexity theory should be brought together with experts in climate science. Building on the work already begun at the Hadley Centre and in the UK academic community, there is a real opportunity for continued and strengthening UK leadership in this field.

Targets addressed: The action directly addresses NERC natural hazard strategy challenges on the recognition, quantification and communication of uncertainty, observations and understanding of extreme events and improvement of integrated risk assessment and scientific advice but will also provide tools for all hazard specific challenges. The action, being cross-cutting, underpins the science addressing all of the LWEC objectives, building effective mitigation, adaptation and resilience to climate change.

Action 3: Storm risk mitigation through improved prediction and impact modelling

Rationale: Storms have had an increasing social and economic cost over recent years and are likely to be the main cause of loss of life or assets in the UK over the next few decades. Furthermore, with climate change, the costs associated with storm impacts are likely to substantially increase. This has highlighted the need to improve the quality of forecasting of storm track and intensity - both in the short-term (over several days) through numerical weather prediction (NWP) - and in the long-term with evolving climate change through improved climate prediction. On both timescales there is a need to improve forecasting of impacts. Several research gaps need to be filled with regard to the prediction of mid-latitude storms, particularly extra-tropical cyclones, to inform short-term mitigation strategies against the impacts of hazardous weather such as high winds, and heavy rain. Given the high degree of influence on other natural hazards such as riverine, groundwater, pluvial and coastal flooding, ground stability (including landslides) and coastal erosion, let alone the built environment, ecosystems (e.g. coral reefs) and agriculture, there is a requirement for improved linkage with impact models to better inform policy and enable preventative measures to minimise risks associated with such storms. There is a need to optimise the way in which NWP models and climate models couple from global to regional, and ultimately to impacts models such as those addressing storm surge.

Objectives:

1. To improve the ability to predict hazardous weather associated with mid-latitude cyclonic storms by developing improved representations of the core physical, particularly convective-scale, processes and their interaction suitable for inclusion in high-resolution NWP models - supported by improved observation strategies and technologies.
2. Predict how enhanced greenhouse gas- induced pre-conditioning of the atmosphere will affect the generation and evolution of mid-latitude storms using high-resolution, weather-resolving global coupled climate models that can provide credible boundary conditions to regional and local impacts models.
3. Model vulnerability to storms (arising from precipitation and wind) at catchment/ coastal management unit scale through development of high-resolution (regional) models.

Context: The action is being initiated within the context of widespread, substantial, and growing international funding on storm research. An essential part of the action will be engagement in international activities as almost none of the challenges are specific to the UK, and no country has the resources to tackle the problems alone; in particular it will build upon advances made within the WMO THe Observing system Research and Predictability Experiment (THORPEX) Programme, which will provide significant benefits (including co-funding) for the community being derived from increased collaboration. The action is timely because of recent progress in modelling, data assimilation and observations using in-situ and remote sensing instruments. The action will build upon many of the current strengths of the NERC community; it will build upon research undertaken within the FREE programme and, through its assimilation research, will maximise use of the Global Precipitation Mission (GPM) in 2013. Its modelling component will be designed after, and benefit from, the CASCADE and COPS projects which are focused on tropical systems and cloud microphysical and convective processes respectively. A component of the modelling will support the development of high-resolution global coupled climate models, capable of resolving weather systems, such as those already started in the UK-HiGEM programme. It is expected that the action will improve assimilation techniques, work towards seamless interaction between NWP and climate models and will enhance our understanding of the impact on mid-latitude cyclones of the evolution of those from low- and high-latitudes.

Implementation mechanism: The work will be delivered through a single 5-year **Research Programme**, co-ordinated with related actions in the Climate Systems Theme. NERC will work with LWEC partners to identify shared objectives and opportunities for collaboration to address challenges related to catchment and coastal impacts.. The coupling of a range of impact and NWP and climate models will need to be fully considered, including what is required of global models to provide appropriate boundary conditions to the rest of the model cascade (validated using impacts variables). The challenge of the ***NWP-focused element of the programme*** is to increase the reliability of the useful forecast lead-time for a severe event. This will entail enhancing the physical representation of storms in models through improved understanding of the underlying physics of weather systems, particularly at the convective scale. It will address integration of convective scale processes with those across storm processes at other scales, such as synoptic scale development (including the influence of Rossby-wave dynamics), mesoscale structuring of cyclones (including the development of extreme events within these) and the microphysics of the clouds as influenced by the atmospheric aerosol. The science should aim to enhance the deterministic model forecasts for the 0-3 day forecast period through development of improved (or additional) parameterization schemes, refined observing systems, and the development of data assimilation schemes specifically designed for storm prediction. Furthermore, the programme may address the acquisition of targeted data and / or more intensive and effective use of the available data in specific dynamically determined regions. It should exploit ensemble prediction techniques and multi-model results to assess the probability of an extreme event in the 3-10 day range. This requires developing appropriate perturbation techniques to establish the initial ensemble states, as well as diagnostic analyses and dynamical theories to help pinpoint the occurrence of favourable storm-precursor states of the large-scale flow to frame the statistical analyses of the ensemble predictions. Modelling and field campaigns will provide well studied data sets for testing new techniques, as well as understanding of process and scale interaction that will help to develop the techniques further. The programme should also use operational forecast products, satellite measurements and the meteorological measurements made regularly (e.g. by wind profilers). It is envisaged that there will be an ongoing field programme, tied closely to the modelling effort and international programmes/opportunities. The ***Climatic element of the programme***, addressing how climate change will influence upon the frequency and intensity of mid-latitude storms, will build upon both the NWP component (above) as well as the storm impacts component (below). It will use high-resolution climate models, capable of capturing storms with sufficient detail to feed into regional and local downscaling models required for impacts assessments. The statistics of extreme rainfall, surge and wave prediction, from very fine resolution NWP models need to be tested against observations; model performance in this area is very important for flood frequency predictions. With the focus being on the next few decades, it will also be critical to understand how the incidence of damaging storms is affected by inter-annual and decadal modes of variability, especially the NAO. This will necessitate an ensemble approach to the predictions and require sophisticated statistical techniques, some of which will be developed in Action 2 (above) to characterize hazardous weather and its potential changes in frequency and/or intensity. The ***Impacts element of the programme*** will focus on improved coupling of the high-resolution modelling components, and those addressing storm impacts such as wind damage, flooding, or storm surge. A key element that should be addressed is the assessment of catchment, or coastal vulnerability, particularly during a succession of events (and in longer time frames, sea level rise).

Known links and dependencies: The research programme will be critically dependent on a wide range of NERC facilities, including aircraft, and it clearly overlaps with the interests of a number of other organisations, and partnerships are currently being explored. The programme will involve the development of new meshing strategies, exploitation of massively parallel algorithms and code optimisation. As well as identifying new needs specific to this theme, the plan will be to work closely with, and coordinate with, computational science activities already ongoing in the NERC and other communities.

Targets addressed: The action directly addresses NERC natural hazard strategy challenges on storms (which had the highest priority in the Natural Hazards Theme Strategy Report), floods, coastal erosion, development of physical models, observations and understanding of extreme events and improvement of integrated risk assessment and scientific advice. It will deliver much towards the strategy deliverables aimed at improving: i) predictive capability of extreme wind and precipitation; ii) knowledge about the change in the frequency and intensity of storms under global warming conditions; iii) improved knowledge of the coastal sea surface response to extreme storm conditions and how well the current generation of models deal with it. The action addresses LWEC objectives A - *to build effective mitigation, adaptation and resilience to climate change, including preparedness for changes to the intensity and frequency of extreme events*; and D – *to protect human, plant and animal health by predicting how [..] hazards and other factors will alter under environmental change*.

Action 4: Prediction of risks caused by ice-melt-induced sea level rise

Rationale: Recent observations show that there are major uncertainties in our modelling of ice sheet dynamics and melt processes. The global sea level projections used within the IPCC 4th Assessment do not include the full effects of changes in ice sheet dynamics because a basis in published literature is lacking; the IPCC projections include a contribution due to increased ice flow from Greenland and Antarctica at the rates observed for 1993-2003, but these flux rates could increase or decrease in the future. As the main sources of uncertainty in models are all in the direction of underestimation of the sensitivity of ice sheets to climate change, larger values cannot be excluded. Given the great global societal costs of high rates of sea level rise there is a clear need to produce improved predictions to determine and cost the impacts, not only flooding, but those on other processes (e.g. groundwater and coastal erosion) of revised estimates, and to effectively communicate these, and their uncertainties, to policy makers so that mitigation and adaptation strategies can be developed in a timely fashion. Clearly this will involve coordination of activities with scientists outside NERC, but these linkages are expected to be developed within LWEC and will be explored within the scoping study (see below). This action is also jointly owned by the Earth Systems Science (leading the action) and Climate System themes; details here relate to the sea-level rise elements of the action; other foci will be found in the TAPs of these themes.

Objective: To scope a world-class scientific programme that will:

a) Globally predict rates of sea level rise, based on all contributing drivers, but including rates based on improved modelling of ice sheet melt processes within the programme) under a range of climatic scenarios.
b) Predict impacts (including coastal flooding, estuarine interactions, groundwater interactions, erosion), and uncertainties, at a range of scales (e.g. a highly urbanised industrial catchment, the UK and international).
c) Within LWEC, to establish socio-economic scenarios based on the impacts to enable improved communication and modelling of risk for policy-makers

Context: The research will build on the DTI Foresight Flooding initiative by consideration of sea level scenarios. Within NERC this research will develop that undertaken by the FREE Programme and will deliver some of the research recommend by the Polar Sciences Working Group. Because of its position in global risk markets, this action is of particular relevance to the UK; nevertheless, as the problem of sea level rise is a global issue there is currently considerable international research being undertaken elsewhere on this, such as through the EU FP7 Programme; the relationships between a NERC-funded programme on sea-level rise impacts and those of other funders will need to be fully explored.

Implementation mechanism: A **scoping study** will be undertaken in 2008/9 with the aim of presenting a detailed plan for consideration by NERC (as part of the second Earth System Science TAP) on ice sheet stability and sea level rise. This scoping study, undertaken by leading experts in the area of interest, will be charged with identifying current and future planned UK and international activity on the impacts of sea-level rise, and with identifying a world leading research programme that utilises UK scientific capability most effectively to narrow the current large range of uncertainties on the resultant impacts of sea level rise, on a timescale of decades to the next few hundred years. The study will also identify the opportunities for interdisciplinary working in this area between NERC and other partners in LWEC, particularly economists, social scientists, engineers and policy makers

Targets addressed: The programme expected to succeed the scoping study is likely to address the NERC strategy Coastal Flooding and Erosion challenge and will address LWEC objectives A - *to build effective mitigation, adaptation and resilience to climate change, including preparedness for changes to the intensity and frequency of extreme events*; and D – *to protect human, plant and animal health by predicting how [..] hazards and other factors will alter under environmental change*. All four of ERFF's flooding priority foci are likely to be addressed from a programme resulting from this action, to: a) revisit the assumptions built into current models of flood risk; b) link existing models with higher resolution climate change predictions; c) determine whether existing models and predictions of fluvial and coastal flooding are sufficiently robust; and d) identify priority areas of land that will need to be defended.

Known links and dependencies: The design and operation of monitoring networks will require NERC National Capability resource in the future, most likely in collaboration with key stakeholders. . The programme that is expected to develop from the scoping study will address research needs of a wide range of stakeholders from both the pubic sector and industry.

Action 5: The Changing water cycle

Rationale: Changes in the hydrological cycle are expected to play a central role in governing a vast range of climate impacts, stretching across all NERC's science themes including, under Natural Hazards, the changing frequency of strong winds, floods and droughts. At the same time, predictions of water-related variables show very high uncertainty, as shown in the recent IPCC 4th Assessment report. In order to develop long-term adaptation and mitigation measures to minimise loss, not only of direct hazards, such as floods and droughts, but also indirect hazards, such as wildfires, subsidence and the triggering of landslides, it is essential to improve the prediction of changes in precipitation, and the distribution and nature of future impacts, at a regional scale. As a consequence, this action has been brought-together by the Climate System, Sustainable Use of Natural Resources (see the relevant TAPs for appropriate details) and Natural Hazards Themes.

Objective: To undertake a research programme that will:

1. Develop an integrated, quantitative understanding of the changes taking place in the global water cycle, involving all components of the earth system - the atmosphere, ocean, land surface and geosphere, cryosphere and biosphere.
2. Improve predictions for the next few decades of regional precipitation, evapotranspiration, soil moisture, hydrological storage and fluxes, focusing on the requirement to quantify and narrow the uncertainty in our understanding of future climate.

3. Understand how local to regional scale hydrological and biogeochemical system properties are responding and will respond to changing climate and land use, together with their consequent impacts on the sustainable use of soil and water.
4. Understand the consequences of the changing water cycle for water-related natural hazards, including floods and droughts, and to improve prediction and mitigation of these hazards.

Implementation mechanism: A **research programme** is being developed in this area with global and UK/European dimensions. NERC will work with LWEC partners to identify shared objectives and opportunities for collaboration to address challenges related to the changing water cycle. It is expected that several goals will be developed through actions within appropriate LWEC partnerships. These will: develop and test probabilistic regional models to understand and predict key impacts of changes in water dynamics under a range of climate and land-use scenarios for the next few decades; determine the implications of non-stationarity in climate for the assessment of water-related risks to human and natural systems; and develop appropriate science-based mitigation strategies to respond to and minimise the risks to human and natural systems caused by changes to the water cycle through the development of adaptation options at the river basin scale. To enable better prediction of the distribution and nature of natural hazards, research will be required on complex, non-linear, and multiple-component, interactions with between water and physical and living systems. This will need to address natural variability in physical properties, environmental tolerances, and rates of change (including histories and frequency of wetting and drying cycles). Increased understanding of these will lead to development of improved models of regional precipitation on natural hazards (for instance, groundwater controls on subsidence, landslides, or ecological susceptibility to wildfire). Anticipated outcomes, and potential measures of success may include: improved predictive capability for drought and flood and other water-related natural hazards; development of early warning systems or visualisation of likely future scenarios as a consequence of adaptation or mitigation actions; quantitative assessment of changes in water resource availability with improved confidence and reduced uncertainty; identification of thresholds in terrestrial and freshwater system responses; and advanced capacity for and integrated monitoring of changes in the water cycle. Applied outcomes might include tools for exploring future scenarios of water availability, and related variables, developed with partners, and advice to relevant users.

Known links and dependencies: Existing investments which will contribute to this action were taken account of in the development of this action. These include the current programmes of all the NERC Research Centres, Current NERC Directed Programme activities including FREE, APPRAISE, QUEST, UK-COPS, CASCADE, EHFI and ESPA. There are also important, relevant EU programmes such as WATCH, and international programmes such as the Global Water System Project (GWSP, which is a joint programme of WCRP, IGBP, IHDP and DIVERSITAS.) A QUEST workshop held in April 2008 reviewed some of the science challenges and opportunities associated with the changing water cycle.

Targets addressed: The action will address NERC natural hazard strategy challenges on floods, droughts, subsidence, landslides, wildfires and the development of physical models. The action addresses LWEC objectives A - *to build effective mitigation, adaptation and resilience to climate change, including preparedness for changes to the intensity and frequency of extreme events*; and D – *to protect human, plant and animal health by predicting how [..] hazards and other factors will alter under environmental change*.

Potential future actions

Further activities will be considered once opportunities with LWEC are clearer and following further consultation with research users, providers and other stakeholders. It is envisaged that activities addressing all of the Natural Hazards Theme Strategy challenges will be undertaken over the next 5 years.

To date, much NERC natural hazard science has tended not to be particularly driven by risk reduction, but by a less-specific desire to better understand, or predict natural hazard processes. Whilst research on the latter may happen to have addressed the main areas of uncertainty, or key nodes in risk mitigation frameworks, often this will have been opportune. However, as emphasized under the high priority theme challenges, above, there is a need for strategic NERC natural hazard research to be orientated towards risk-reduction. It must focus on delivery of excellent natural science – rather than social actions which will be governed by end-users, social scientists and policy maker partners - but the selection of which natural science elements to research should be informed by the interests of these partners in managing risk-reduction. To enable future strategic research programmes to be risk-focused, analysis needs to be made both of gaps in the natural hazard science and how outputs are used by decision-makers in managing risk; the value of prospective elements of science should be considered in the light of their potential to reduce risk through forecasting (including the potential for improving the forecasting of hazardous events and crisis management), mitigation and communication to end-users.

It is envisaged that for later, hazard-specific actions (for instance those addressing volcanic, earthquake or heat-stress risks) the analysis will mostly take the form of a scoping study that will highlight the areas in which natural science can contribute most to risk reduction. This in turn will dictate what observations, datasets and models are needed. Collectively these considerations will form the basis for recommending subsequent research programmes. Each scoping study could:

1. Evaluate where new research into a natural hazard will do most to minimise casualties and economic loss in settings that are vulnerable to the hazard.
2. Scope a world-class scientific programme that will develop:
    a. enhanced hazard and risk forecasting capability
    b. probabilistic hazard assessment techniques and, with joint vulnerability assessments, improved risk models.
    c. mitigation options in conjunction with partners
3. Develop the science case and a prioritised inventory of observational requirements, datasets and models to support the research
4. Provide guidance on the prioritisation approach for subsequent natural hazard research initiatives.

Each study will be charged with identifying past, current and future planned UK and international activity in this area. It will initially identify gaps in UK endeavours and will optimise outcomes collectively. It will advise upon specific research areas, including by bringing in expertise from other disciplines, such as statistics, psychology and social science, where needed. The likely contribution to risk mitigation should be the key criterion in choice of processes to be researched. The study may utilise tools such as Bayesian Belief Networks in order to enable prioritisation of research based on knowledge gaps. The study should suggest how hazard assessment advances should be coupled with enhancements to related probabilistic risk assessments, to serve as decision-support to societal needs for appropriate protection measures. The scoping study will develop a plan for a subsequent programme. This needs to detail observational programmes, required resources, including those for computing and for data handling. It should address whether particular sites, should be used as a natural laboratory for natural hazards science, related risk research and training; it should also recommend links with international partnerships, particularly where building on these will be likely to achieve more than working independently. It is likely that the study will require the advice of scientists and policy makers from across a range of sectors; it is expected that LWEC will provide the vehicle for such partnerships. It is envisaged that a research programme following the scoping study will utilise several critical resources in research centres, particularly in setting up and managing relational databases, and for high-performance computing. The scoping study may recommend partnerships between the research programme and other international initiatives.