COMMENTS FROM THE NATURAL ENVIRONMENT RESEARCH COUNCIL ON THE ECONOMICS OF CLIMATE CHANGE, FOR THE REVIEW BY NICK STERN FOR HM TREASURY AND THE CABINET OFFICE

1. The Natural Environment Research Council (NERC) welcomes the opportunity to comment.

2. NERC is one of the UK's eight Research Councils. It funds and carries out impartial scientific research in the sciences of the environment. NERC trains the next generation of independent environmental scientists. Its priority research areas are: Earth's life-support systems, climate change, and sustainable economies.

3. NERC's research centres are: the British Antarctic Survey (BAS), the British Geological Survey (BGS), the Centre for Ecology and Hydrology (CEH) and the Proudman Oceanographic Laboratory (POL). Details of these and of NERC's collaborative centres are available at www.nerc.ac.uk.

4. NERC's comments draw on inputs from BGS, CEH, the National Oceanography Centre, Southampton (NOCS), the Plymouth Marine Laboratory (PML), the Scottish Association for Marine Science (SAMS) and Swindon Office staff.

General comments

5. NERC welcomes the Government's decision to review the economics of climate change. Evidence suggests that humans have already contributed to climate change and that further warming is inevitable, even if we take significant action now to limit greenhouse-gas emissions. The challenge is to avoid a dangerous level of warming.

6. In 2004-05, NERC invested 28% of its science budget income in projects investigating climate change. This research was carried out in NERC's research and collaborative centres and in university departments. Our expenditure demonstrates our recognition of the need to improve our understanding of climate change in order to tackle it effectively, both to mitigate its extent by reducing greenhouse-gas emissions and to adapt to it. Details of the research programmes funded by NERC which are of greatest relevance are given in Annex 1. The work referred to in more detail this submission forms only a small part of NERC's portfolio of research relevant to assessing the economic impacts of climate change.

7. The review is tasked with examining four areas of evidence. In this input we comment mainly on areas two and three. We emphasise that considerable research is still needed to reduce the uncertainties associated with predicting the consequences of climate change. Reducing those uncertainties will improve our ability to recommend how we should adapt, and our ability to estimate the costs of adaptation. For example, the recent finding by scientists at NOCS (published in Nature on 1 December 2005: Bryden et al. 2005) that the North Atlantic Conveyor Belt has slowed by approximately 30% in the past decade requires follow-up monitoring, and NERC's RAPID programme will continue to investigate the currents in the Atlantic Ocean in order to provide us with greater certainty about the likely climate in the UK and Europe. As The Sunday Times (4 December 2005) asks, "So, are we going to freeze or fry?" Ongoing research is vital in this and other climate-change-related areas.

8. The Tyndall Centre for Climate Change Research, which was established in 2000 with funding from NERC (50%), EPSRC and ESRC, has recently had its funding from the research councils renewed for a further three years. The Tyndall Centre intends to provide its own input to the review. It provided input in March 2005 to the House of Lords Economic Affairs Committee Inquiry into "Aspects of the Economics of Climate Change". It made the point that " damage valuation and cost-benefit exercises for climate-change policy are fraught with methodological difficulties which are difficult to resolve", and "two critical issues make the use of conventional cost-benefit analysis inappropriate for use as a decision support tool when dealing with climate change; these are the uncertainties and the time frame".

9. NERC is conscious that the Government is anxious to use the Stern Review to respond to the House of Lords Economic Affairs Committee's call for "significantly greater effort to clarify and estimate (those) costs". We would make the point that in such an economic assessment there are at least three components: (i) to estimate the costs of the damage from the increased environmental hazards (such as storms and flooding) that will result from human input of greenhouse gases, if no action were to be taken, (ii) to estimate by what proportion these costs can be reduced if action of various sorts is taken (of course such action will incur a cost that needs to be taken into account) and (iii) to estimate the economic benefit that accrues to the UK from it leading the world in creating and selling solutions to these increased environmental risks. The third component is the opportunity side of the economic consequences of climate change. All three aspects of this economic analysis cannot be done without an improved level of scientific knowledge as to the precise nature and consequences for the UK of climate change. Whilst we currently have a reasonable understanding of the global picture, the local and regional impacts are currently hugely uncertain. NERC's contribution is to invest part of its share of the science budget in answering these scientific questions to allow economic benefit to flow.

10. The science that needs to be done, some highlights of which are given in this submission, will provide a predictive tool whereby policy-makers can assess the climate impacts, including economic, of various actions in the short, medium and long-term. Such predictions – scenarios or early warnings – are key to effective and efficient action.

11. Prediction will allow us to plan not only for the threats but also for the opportunities created by climate change. For example, prediction on a 20- to 50-year timescale of the scope for the Arctic Ocean to support major trading routes in summer as a result of ice-thinning might have implications for developments in the transportation market (e.g. ship design) and the planning of European transport infrastructure (location of key ports, rail links etc.).

12. We regret that we are not in a position to provide detailed economic analysis. However, in the text below, BGS makes reference to a likely increase in the cost of damage resulting from climate-change-aggravated effects on shrink-swell clays, and provides estimates of the cost of Carbon Capture and Storage Technology. PML draws attention to the possible cost implications of an often-overlooked consequence of the increase in atmospheric carbon-dioxide concentrations, namely ocean acidification. And SAMS makes reference to direct effects of climate change on marine resources.

13. NERC is currently undertaking a study of the economic benefits of a selection of its research. The study will look at the direct economic benefits (e.g. technology) and indirect benefits (e.g. policy development) to the UK economy, including where research findings have led to savings such as those resulting from improved flood prediction. One of the areas

of focus will be the "Prediction and Consequences of Climate Change in Europe – RAPID". A report of the study will be prepared in February 2006 and made widely available.

14. The text below mainly examines the environmental consequences of climate change. These range from effects on ecology and biodiversity, hydrology (including groundwater), onshore slope stability (including the increased likelihood of landslips affecting transport infrastructure, for example), offshore slope stability (including the possible generation of tsunamis as a result of methane release), soil quantity and quality, coastal erosion, and marine ecosystems and bioresources (in response to climate change and ocean acidification).

15. Further information on the input from the contributing research centres may be obtained from the contacts listed in Annex 2. We appreciate Nick Stern's decision to interview CEH scientist Chris Huntingford in November and are ready to offer further such help.

<u>The implications for energy demand and emissions of the prospects for economic growth over the coming decades, including the composition and energy intensity of growth in developed and developing countries</u>

16. NERC, with the Engineering and Physical Sciences Research Council (EPSRC) and the Economic and Social Research Council (ESRC), in collaboration with the Biotechnology and Biological Research Council (BBSRC) and Council for the Central Laboratory of the Research Council (CCLRC) is co-funding the UK Energy Research Centre, part of the Towards a Sustainable Energy Economy (TSEC) Programme.

17. One of UKERC's key themes is 'Energy Systems and Modelling', which aims to integrate previous top-down and bottom-up energy-modelling approaches to develop whole-systems energy-environment-engineering-economy ("E4") modelling. The work will draw on research under UKERC's demand reduction, future sources of energy, infrastructure and supply and environmental sustainability themes, and is being conducted in close collaboration with the Tyndall Centre. Other work on energy markets and the economics of energy is under consideration as part of the TSEC Programme's 'Managing Uncertainties' Theme. Outputs from both may be able to contribute to this area of the Stern Review.

<u>The economic, social and environmental consequences of climate change in both developed and developing countries, taking into account the risks of increased climate volatility and major irreversible impacts, and the climatic interaction with other air pollutants, as well as possible actions to adapt to the changing climate and the costs associated with them</u>

Taking an interdisciplinary approach

18. The consequences of climate change will be many, and it is important to take an interdisciplinary approach to researching climate change and developing an effective response. Many of NERC's programmes take such an interdisciplinary approach. One is described here, others in Annex 1.

19. NERC's QUEST programme takes a co-ordinated 'Earth-system' approach to finding solutions to the world's pressing environmental problems, i.e. it considers the complexity of interactions and feedbacks between different components of the Earth system, including human society, in order to identify solutions. QUEST aims to improve quantification to

allow better prediction of changes to the Earth system, including risk evaluations required by industry, government and other decision-makers. Carbon budgets and dynamics are one focus of the programme, but QUEST aims to accelerate the development of environmental-change models generally.

20. Theme 3 of NERC's QUEST Programme aims to understand and quantify the implications of global environmental change for the sustainable use of resources. Collaborative projects will be funded in two areas: (i) quantitative mapping of the risks associated with different degrees of climate change for ecosystem services related to water supply, food and fibre production, biodiversity and human health and well-being; (ii) quantitative analysis of the potential for biosphere management in a broad sense, including measures such as agroforestry, biofuel production and increased use of long-lived wood products, to mitigate climate change.

Hydrology

21. Climate change is inextricably linked with hydrological change. Such change may include altered rainfall patterns, river flows and groundwater levels, and increased flood risk. CEH has expertise in hydrology, and comments on the links with agriculture and ecology are given below. BGS's account of geological hazards also demonstrates hydrological links. The Proudman Oceanographic Laboratory (POL) is particularly concerned with coastal flooding.

22. NERC provided input to the House of Commons Environment, Food and Rural Affairs Committee inquiry into Climate Change, Water Security and Flooding in April 2004, incorporating comments from BGS, CEH and the Tyndall Centre (see www.publications.parliament.uk/pa/cm200304/cmselect/cmenvfru/558/558.pdf). Some additional points about flooding and groundwater resources appear below.

23. Anthropogenic climate change is likely to cause an increase in the frequency and intensity of storms and thus more frequent flooding. Flooding is a major and costly environmental hazard with annual damage from floods of around £1000 million in the UK at present levels of protection. The implication is that this will increase. NERC has just launched a research programme (FREE) aimed at improving the UK's ability to forecast, quantify and manage flood risks – see Annex 1. FREE will bring together researchers from the hydrological, meteorological, terrestrial and coastal oceanography communities. A central feature is to bridge the interfaces between the various water environments and users of flood forecasts and to properly quantify uncertainty.

24. Changes in groundwater levels have a major impact upon ground stability issues, as illustrated below, but are also vulnerable to climate change either directly (though decreased total precipitation and infiltration under some scenarios) or indirectly through increased extraction caused by pressures on water systems.

Agriculture, ecology and biodiversity

25. CEH's proposed Climate Change Programme (see Annex 1) aims to integrate long-term environmental datasets to help improve climate models and reduce uncertainty. Models will cover the interactions between climate change, ecology and hydrology. In particular, the Programme will take account of land-surface feedbacks, which many scientists suspect will cause warming to accelerate. CEH's Sustainable Economies Programme includes research into water policy and management issues, ecological risk, and biosystems management,

areas which also cover climate-change-related research and consider the interaction of climate change and human activities.

26. CEH emphasises the importance of effects of climate change on agriculture and ecology, including biodiversity. Many of the effects will result not just from temperature changes but also from changes in soil moisture and river flows as a result of changes in evaporation and the incidence of extreme rainfall events.

27. As results emerge, the CEH programmes should be able to contribute reliable guidance on the potential impacts of future climate change to help to inform, at national and international levels, policy decisions on mitigation and adaptation, and to contribute to estimates of the cost of mitigation and adaptation measures.

Geological resources and hazards

28. BGS is active in the research of geological resources and hazards in relation to climate change, using expertise and data holdings to provide advice on where and when impact will occur, and the extent of this. The climatic scenarios used have mainly been taken from the Intergovernmental Panel on Climate Change Special Report on Emissions Scenarios (IPCC SRES) (2000), which developed a range of projections for possible future emissions. In 2002, the UK Climate Impacts Programme (UKCIP) published a scientific report (Hulme et al., 2002) describing four of these possible climate futures for the United Kingdom until the year 2100.

29. It is currently extremely difficult to assess the economic social and environmental consequences of climate change on regional (strategic) geological and geomorphological systems as the state of understanding and state of modelling of physical geological and geomorphological change is immature. Many models are site-specific, conceptual or empirical and are mostly deterministic rather than stochastic. More work is needed on groundwater interactions, soils and submarine slope stability and those impacts that may cause major climatic feedbacks.

30. As a generalisation, the soils and rocks formed from the smallest particle sizes, such as clays and mudstones, are more vulnerable to the effects of climatic change. Water level or pressure changes can, however, affect the engineering behaviour of all types of soil and rock (Gammon, 1993). Paragraphs 31-36 illustrate the immaturity of the modelling of change, and focus on major direct changes. Indirect, or relatively minor changes such as those resulting from the growth of vegetation or impacts of temperature on evaporation, evapotranspiration, water-ice balances (in tundra), the water demand for human consumption, irrigation, and air-conditioning systems etc. and the weakening of rock masses due to expansion and contraction are given little consideration here.

31. Slope stability (onshore) is likely to be influenced by changes in precipitation patterns. However, despite some advances (Collison et al. 2000; Dehn & Buma 1999), whilst it is possible to predict when a slope may be prone to instability at a site level, prediction at a regional level is generally not possible. To enable this we need to have a good understanding of the geotechnical characteristics of rock and soil formations as well as a good understanding of their saturation. Currently groundwater models may reasonably describe aquifers, but are not generally so effective in impervious, impermeable or heterolithic formations. Models of the interaction between surface water and groundwater in terms of infiltration also need to be developed. Where a permeable material overlies a relatively impermeable material, infiltrating water may ‘perch’ on the boundary between the

two; the rise and fall in the perched water table can be rapid and related to the duration of storms if these are responsible for the infiltration on an intermittent basis. The significance of this is that if the boundary is sloping and is reflected by the topography then conditions leading to slope failure can occur. Where a potential problem of this kind is identified, continuous monitoring of the groundwater regime will be necessary. Intermittent readings may miss the time when the perched water table is at its highest and a false indication of the amount of fluctuation may be gained. As an example, in Hong Kong, transient rises in the water table of the order of 2 m to 5 m above normal water levels are observed in association with storm events and significant antecedent rainfall.

32. Many tens of thousands of people live with continuing slope instability or the threat of instability. Many of them live in population centres on actively eroding coasts (e.g. Ventnor, Lyme Regis, Holderness) or on inland slopes (e.g. London, Edinburgh, South Wales Coalfield). Thousands of kilometres of transport links and numerous utilities are located in areas susceptible to failure of natural slopes. In addition, construction often involves the formation of cut and fill slopes that can also become unstable. Slope instability can have a major detrimental effect on the UK's infrastructure as demonstrated by the disruption of the road and rail networks resulting from the many slope failures that occurred during the period of high precipitation in winter 2000/2001 (Dixon et al. 2006).

33. Similarly in offshore settings, the factor of safety of marine slopes can be assessed with reasonable accuracy, given access to appropriate data. However, fluid movement in slopes, particularly in the presence of free gas, or gas hydrate is poorly understood. Certainly some of the larger submarine landslides, such as that at Storegga in the North Sea, or that which caused the Papua New Guinea tsunami are likely to have been associated with the occurrence of gas hydrates in the submarine slopes. The release of methane from such hydrates may well have been a major cause of (geological) past global warming (for instance at the Palaeoeocene- Eocene boundary).

34. Shrink-swell soils have a high capacity to take-up and displace water in the clay lattice of minerals (commonly smectites), thus causing them to swell when saturated and to shrink when dehydrated. Given that the seasonal distribution of precipitation will change with winters becoming wetter and summers perhaps drier across the UK and with the biggest relative changes in the south and east (precipitation in the High Emissions scenario may also decrease in summer by 50% in the 2080s in the southeast and increase in winter by up to 30 per cent (Hulme et al. 2002) shrink-swell cycles may be accentuated. Soils above specific formations, such as the London Clay in the UK cause major problems for engineers and the insurance industry. The costs of such clays to the UK insurance industry has been over £3 billion over the last decade.

35. Soil distributions, composition and function will change over time. Many soils will become more susceptible to erosion (e.g. wind erosion, commonly in lowland settings) or gullying, partly because of changes in the seasonal distribution of precipitation. Winters are predicted to become wetter; extreme winter precipitation will become more frequent - by the 2080s, winter daily precipitation intensities that are experienced once every two years on average may become up to 20 per cent heavier (Hulme et al. 2002). Currently our ability to predict windiness prevents the development of accurate wind erosion models. There is considerable uncertainty about future changes in wind speed and direction, and we have little confidence about the regional changes in average or extreme wind speeds (Hulme et al. 2002). Organic soils are common in lowland settings, commonly fluvial belts and estuaries, as well as in upland settings. They are particularly vulnerable to change through desiccation and oxidation, in which case they may change volumetrically. Chemical changes in soils due to

leaching out of salts from marine clays can dramatically reduce the strength of the clay when disturbed (Bjerrum, 1955; Gammon, 1993). Higher temperatures can lead to higher evaporation loss and this can draw concentrations of chemicals towards the ground surface. Climate-induced chemical change can therefore be very significant (Gammon, 1993; Hawkins, 1992).

36. Coastal erosion in coastal systems covers a range of processes in environments ranging from cliffs and beach systems to littoral and sub-littoral. Regionally it is likely to be accentuated by extreme sea levels, occurring through combinations of high tides, sea-level rise and changes in winds. Extreme sea levels will be experienced more frequently in many coastal locations. For some east-coast locations, for example, a water level that at present has a 2 per cent probability of occurring in any given year may have an annual occurrence probability of 33 per cent by the 2080s under the IPCC's Medium-High Emissions scenario. Sea-level rise may also lead to deeper water in the near-shore zone allowing waves with greater energy to reach the shoreline (Hulme et al., 2002). With increased storminess, more coastal erosion may be expected, with more expense on defences. In many settings the dominant erosive process is through wave action which controls the rate of scour in littoral and sublittoral environments and largely governs the transport of sediment away from sites of erosion. It is this removal of material by coastal processes that commonly controls the rate of recession of coastal systems.

Effect of climate change on marine bioresources

37. The following paragraphs on marine bioresources have been contributed by SAMS.

38. *Changes in plankton and fish productivity*
Climate change has a region-specific effect on ocean productivity (as expressed by phytoplankton abundance). For example, warming of sea surface temperatures across the Northeast Atlantic is accompanied by increasing phytoplankton abundances in cooler regions and decreasing phytoplankton abundances in warmer regions. This impact on phytoplankton propagates up the food web (bottom-up control) through zooplankton herbivores to zooplankton carnivores because of tight trophic coupling (Richardson and Schoeman 2004). Future warming is therefore likely to alter the spatial distribution of primary and secondary pelagic production. Moreover, emerging evidence (Ware and Thomson 2005) suggests that the regional carrying capacity of the ocean, in terms of commercial catches of planktivorous and piscivorous fish species, is directly dependent on productivity at lower trophic levels. Therefore changing plankton productivity is likely to translate into changing fish productivity. This in turn will directly impact the costs of fishing, especially in warmer areas, where boats might have to make longer runs to reach productive grounds.

39. *Range-shifts of fisheries and aquaculture species*
As the global oceans warm, the ranges of both fish and their planktonic prey are shifting polewards (Beaugrand et al. 2002; Perry et al. 2005). There is no reason to suspect that aquaculture species will not be similarly affected. Some of the consequences of changing spatial distributions for capture fisheries have already been briefly addressed, but the impacts on aquaculture could be more severe. For this industry, the establishment of species-specific culture facilities and markets are crucial economic factors. Climate-driven impacts on cultured species will therefore have important economic ramifications.

40. *Temporal mismatches in trophic elements of marine food chains*
Exacerbating the effects of altering spatial patterns of plankton productivity are temporal

changes in plankton ecology. In particular, phenological (the timing of seasonal events) responses of temperate plankton species to climate change seems to be taxon specific (Edwards and Richardson 2004). This might be leading to a temporal mismatch between planktonic trophic levels and functional groups, which in turn could have severe consequences for higher trophic levels, such as commercial fish species (Beaugrand et al. 2003).

41. *Fisheries collapses*
The act of fishing undoubtedly has severe repercussions for marine ecosystems (Jackson et al. 2001), but cutting fishing pressure has not always resulted in the anticipated levels of recovery among heavily depleted stocks. Although there is speculation that such phenomena might have resulted from trophic cascades (Frank et al. 2005, Scheffer et al. 2005), evidence is far from conclusive and it is highly likely that climate change has plays an important, if not dominant role (Schiermeier 2002). In this sense, the economic costs of climate change can be significant.

42. *Novel transport routes and invasive species*
Climate warming alters both spatial and temporal patterns of Arctic sea-ice formation and melt. These changes result in navigation routes, which have until recently been limited by ice, becoming increasingly accessible (ACIA 2005). This increases the potential for species, which otherwise would be less motile, to move between what are now biologically discrete ocean basins, with unpredictable consequences for receiving communities and the ecosystem services they provide.

Ocean acidification

43. NERC supports PML's request that the Stern Review recognises "the other half of the CO_2 problem", i.e. not just climate change itself, but also ocean acidification. As described below, the latter could have serious implications for marine resources, and there is also concern that damaging synergistic impacts (of climate change and ocean acidification together) will be seen.

44. The oceans have already taken up nearly 50% of the CO_2 produced by human activities over the past 200 years, effectively buffering climate change. However, this is already affecting ocean carbonate chemistry and lowering the pH of the oceans and will continue to do so, at a level not seen by the marine organisms and ecosystems for millions of years. The carbonate ion concentration will decrease by 50%. Critically the rate of change is about 100 times faster than at any time over this period. By 2100 the pH of the oceans will decrease by 0.5 pH units (as pH is measured on a log scale – this equates to around a 3-fold increase in hydrogen ion concentration).

45. The chemistry of these changes is certain, but the impact on organisms and ecosystems is uncertain, partly because research in this area is in its infancy. However, work over the past few years on marine organisms that require calcium carbonate to make shells and other skeletal structures indicates that these may be at high risk within this century because of the decrease in carbonate ion concentration. Organisms that require calcium carbonate include microscopic algae (coccolithophores), microscopic animals (zooplankton but also the larvae of larger organisms such as shellfish) and larger organisms, such as shellfish and both warm- and cold-water coral. Many of these organisms form either key habitats for other species (e.g. corals) or are important parts of the marine foodweb and global biogeochemical cycles (microscopic plants and animals) and provide food resources for human consumption (shellfish).

46. Loss of habitats and ecosystems will have a profound effect on the substantial goods (valued at $100 billion) and services (valued at $billions of dollars per year) provided by the marine environment for developed and developing nations alike.

47. The Royal Society formed a working group on ocean acidification and they published their report on 30 June 2005. See: www.**royal**soc.ac.uk/displaypagedoc.asp?id=13314. The report addresses the science as well as some of the socio-economic impacts. It concluded that reducing emissions of CO_2 to the atmosphere was the only practical way to minimise the risk of large-scale and long-term changes to the oceans. PML presented a paper reviewing ocean acidification at the Avoiding Dangerous Climate Change Symposium in Exeter in February 2005 and at the Twenty-second session of the Subsidiary Bodies of the UN Framework Convention on Climate Change in Bonn in May 2005. The paper produced for the Proceedings of the Exeter meeting accompanies this submission.

48. Thus, chemical effects of CO_2 on the marine environment may be as great a cause for concern as the radiative effects of CO_2 on the Earth's climate (Caldeira and Wickett 2005). Acidification of freshwaters may also have significant implications, not least because freshwater is less well buffered than seawater against changes in pH.

The costs and benefits of actions to reduce the net global balance of greenhouse gas emissions from energy use and other sources, including the role of land-use changes and forestry, taking into account the potential impact of technological advances on future costs

Carbon Capture and Storage (CCS)

49. BGS is a world leader in underground CO_2 storage, one of the main options available for reducing anthropogenic CO2 emissions. BGS co-ordinates the European Research Network of Excellence (CO_2GeoNet) and is involved in the bulk of EC Framework projects on geological storage. It is also closely involved with the DTI which recently launched the DTI/DEFRA Carbon Abatement Technology (CAT) Strategy.

50. There are few published details of storage costs. They will vary from site to site and depending on the technology for removal and transfer of CO_2 from point of source to underground reservoir. Some details are available for Sleipner (Torpe & Brown 2004), which refer to the incremental cost of storage only. The capital costs were approximately US$96m (based on a projected total storage of 25 MtCO_2 = US$3.8/t$CO_2$ stored) and the operating costs are approximately US$7 million/year (7US$/t stored) respectively. Therefore, total storage costs are about US$11/t (£6/t) CO_2 stored.

51. Storage integrity will be required for many thousands of years. Methods and best practice for site selection, characterisation, risk assessment, monitoring and verification of the CO_2 in the subsurface are required. Leakage tolerance thresholds need to be defined for different fluxes and modes of leakage for the purposes of carbon trading, environmental protection, health and safety, and intervention/remediation strategies. Identifying these thresholds will require deliberate release experiments and study of natural CO_2 seeps.

52. Monitoring costs are minor and have been estimated (Benson et al 2004) at 0.05-0.10US$/t of CO_2 stored (discounted at 10% per year), 0.16-0.31US$/t of CO_2 stored (undiscounted), 2.7-5.4p and 8.7-17p per tonne CO_2 respectively.

53. In many oil-field conditions, CO_2 is miscible with oil and can be injected to enhance oil recovery (EOR). There are over 70 CO_2 EOR projects in N. America. CO_2 storage is a passive bi-product of these operations. Offshore EOR using CO_2 has not yet been deployed and costs and risks would be higher. Economic viability is field specific, dependent on the oil price, supply of CO_2, re-engineering costs of existing infrastructure and tax regime. Costs will be higher offshore because of the larger capital and operational investment needed.

Other

54. We are unable to provide specific information about the costs of other actions to reduce greenhouses gas emissions. However, we believe that when costs are considered in relation to benefits they should take into account wider issues such as the potential impact of ocean acidification on fisheries, and the possibility that coastal-related tourism could be affected.

The impact and effectiveness of national and international policies and arrangements in reducing net emissions in a cost-effective way and promoting a dynamic, equitable and sustainable global economy, including distributional effects and impacts on incentives for investment in cleaner technologies

55. NERC and its research and collaborative centres expect to be able to contribute to assessments of the impact and effectiveness of measures taken to reduce greenhouse-gas emissions by continuing to monitor emissions and environmental change.

Natural Environment Research Council
December 2005

Annex 1

A selection of climate-change-related research programmes

NERC's directed research programmes address areas of present or anticipated national need, in particular environmental issues where sustained national capability or major critical mass is required. NERC hopes that the UK and international governments will be able to use the outputs from the listed research programmes in their policymaking to mitigate and adapt to climate change and develop a low-carbon global economy.

Flood Risk from Extreme Events (FREE) www.nerc.ac.uk/funding/thematics/free

The aim of NERC's recently-announced FREE programme is to improve the prediction of river and coastal floods occurring from extreme events, and quantitative measures of uncertainty associated with the predictions. The broad objectives are:

- to improve the estimation and prediction of flood risk from extreme events occurring with return periods exceeding 1 in 50 years including very rare events, addressing aspects of how to improve the estimation and prediction of fluvial, pluvial, estuarine and coastal flooding from such severe events;
- to reduce uncertainty and improve the quantification of flood risk;
- to identify and articulate critical guidance on how flood risk is changing.

The emphasis will be upon research targeted at an integrated modelling approach within which different environmental systems interact with each other to achieve a "clouds-to-catchment-to-coast" approach to flood forecasting and frequency estimation.

Quantifying and Understanding the Earth System (QUEST)
www.nerc.ac.uk/funding/thematics/quest/

As described in the main text, this programme takes a co-ordinated 'Earth-system' approach to finding solutions to the world's pressing environmental problems. Its emphasis is on improving quantification to allow better prediction of changes in the Earth system.

UK SOLAS

The overall aim of the UK SOLAS programme, which will work closely with the QUEST programme, is to advance understanding of environmentally significant interactions between the atmosphere and ocean, focusing on material exchanges that involve ocean productivity, atmospheric composition and climate. The knowledge obtained will not only improve the predictability of climate change but will also give insights into the distribution and fate of persistent pollutants and other future environmental conditions - thereby helping to develop appropriate policy responses.

Rapid Climate Change (RAPID) www.noc.soton.ac.uk/rapid/rapid.php

The major objective of this programme is to improve our ability to quantify the probability and magnitude of future rapid change in climate, with a main (but not exclusive) focus on the role of the Atlantic Ocean's thermohaline circulation.

The programme is conducting measurements to better understand the strength and structure of the overturning circulation, and to quantify the atmospheric and other drivers behind water, heat, salt and ice transport in the Atlantic. It is also constructing palaeo data records of past climate change, with particular emphasis on periods of rapid change. And it is trying to understand, using model experimentation and data, the relationship between heat transport in the Atlantic and the atmospheric response, including changes in storm frequency and strength.

The CEH Climate Change Programme www.ceh.ac.uk/sci_programmes/climate_change.html

There are three main themes in the proposed CEH Climate Change Programme:

- Detection and attribution of change in UK and European ecosystems
- Ecohydrological impacts of climate change
- Land Surface feedbacks in the climate system

The programme includes projects contributing to the detection, attribution and prediction of climate impacts in both developed (Environmental Change Network - ECN - project) and developing (African Monsoon Multidisciplinary Analyses - AMMA - project) countries.

The CEH Climate Change Programme aims to build on existing collaborations (e.g. with the Met Office, Tyndall Centre and the Climate and Land Surface Interactions Centre, CLASSIC) and on NERC programmes such as QUEST and FREE, as well as on projects such as AMMA.

Climateprediction.net www.climateprediction.net

Climate*prediction*.net is the largest experiment to try to produce a forecast of the climate in the 21st century. It asks people around the world to donate time on their computers - time when they have their computers switched on, but are not using them to their full capacity.

Marine Laboratory Research Programmes

NERC supports strategic research in 7 marine centres:

Marine Biological Association (MBA), NOCS, PML, POL, SAMS, Sir Alistair Hardy Foundation for Ocean Science (SAHFOS), Sea Mammal Research Unit (SMRU).

These centres are currently jointly developing their next five-year research programme: Oceans 2025. An overview of the programme has been published for consultation (see www.soc.soton.ac.uk/oceans2025.php or www.pml.ac.uk/pml/Oceans2025/oceans_2025_consultation.htm), and detailed proposals for each of the ten Oceans 2025 themes are now being developed. The programme will examine many of the most pressing problems affecting the marine environment in the face of climate change and ocean acidification.

Coupled Ocean-Atmosphere Processes and European Climate (COAPEC)
www.nerc.ac.uk/funding/programmes/progsummaries/coapec.shtml and www.noc.soton.ac.uk/coapec/coapec.php

COAPEC's goal was to determine how the coupling between the Atlantic Ocean and the atmosphere affects the climate, especially in Europe. COAPEC focused on natural changes in the system that occur over seasons to decades, including how events in other oceans, such as El Niño in the Pacific, influence the interaction between Atlantic Ocean and atmosphere.

COAPEC aimed to answer five key questions:

1. What are the characteristics of seasonal-to-decadal climate variability in the Atlantic?
2. How do these characteristics differ from those simulated in coupled general circulation models? How do we correct the models?
3. What are the physical mechanisms that determine the mean climate and seasonal-to decadal climate variability in and around the Atlantic?
4. What processes determine the predictability of climate fluctuations in the Atlantic/European region?
5. How do we make sure our scientific output is useful to society?

The results of the programme have been reported, and an event for users of the scientific outputs will be held in the spring of 2006.

Rural Economy and Land Use (RELU)
www.nerc.ac.uk/funding/programmes/progsummaries/relu.shtml

Rural economy and land use scientists are collaborating on wide-ranging interdisciplinary research projects grouped around four key themes:
Integration of land and water use
Environmental basis of rural development
Sustainable food chains
Economic and social interactions with the rural environment

The objectives of the programme cover science, capacity-building and knowledge transfer, i.e.

To deliver integrative, interdisciplinary research of high quality that will advance understanding of the social, economic, environmental and technological challenges faced by rural areas, and of the relationships between them.

To enhance and expand capabilities for integrative, interdisciplinary research on rural issues.

To enhance the impact of research on rural policy and practice by involving stakeholders in all stages of RELU, including programme development, research activities and communication of outcomes.

Lowland Catchment Research (LOCAR)
www.nerc.ac.uk/funding/programmes/progsummaries/locar.shtml

The major objective of LOCAR is to undertake detailed, interdisciplinary programmes of integrated hydro-environmental research relating to the input-storage-discharge cycle and in-stream, riparian and wetland habitats within groundwater-dominated systems.

Catchment Hydrology and Sustainable Management (CHASM)
www.nerc.ac.uk/funding/grants/jif/round1.shtml

The objectives are closely linked with those of LOCAR but address upland as well as lowland catchments.

Earth Observation

Satellite-borne measurement systems have a central role to play in understanding the Earth system as a whole. They overcome the historical difficulty of obtaining accurate, continuous, synoptic and simultaneous measurements of the Earth's atmosphere, oceans, ice sheets, land surface and interior.

NERC maintains a wide-ranging Earth Observation programme. Its Earth Observation Strategy (2004-2009) is available at: www.nerc.ac.uk/funding/earthobs/eostrategynew.shtml

NERC supports several Earth Observation Centres of Excellence which conduct research using earth observation data and models, and act as focal points for collaboration and training.

Towards a Sustainable Energy Economy (TSEC)
www.nerc.ac.uk/funding/programmes/sustenergy//
www.epsrc.ac.uk/ResearchFunding/Programmes/Energy/Funding/TSEC/default.htm

- The UK Energy Research Centre – providing a focus for energy research in the UK and for international collaboration.
- Keeping the nuclear option open – addressing some of the key issues in nuclear fission power.
- Managing uncertainties - the socio-economic challenges and implications of moving towards a sustainable energy economy.
- Carbon management and renewables – research taking a whole systems approach and complementing the SUPERGEN programme.

UK Energy Research Centre (UKERC) www.ukerc.ac.uk/

The UK Energy Research Centre is charged with drawing together energy research in the UK, while establishing itself as a centre of research excellence in its own right.

By taking a co-ordinated and collaborative approach to national and international energy research, and through its own interdisciplinary research activities, it aims to provide the knowledge needed to work towards a sustainable energy system and realise UK energy policy goals.

Annex 2

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Annex 3

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